

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

LONG-TERM TRENDS OF METEOROLOGICAL DROUGHT
OVER TURKIYE

SEVDA MERVE ALYAGUT

A THESIS OF MASTER OF SCIENCE
DEPARTMENT of EARTH and MARINE SCIENCES

ADVISOR: ASSOC. PROF. DR. HAKKI BALTACI

JULY 2024

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

**LONG-TERM TRENDS OF METEOROLOGICAL
DROUGHT OVER TURKIYE**

SEVDA MERVE ALYAGUT

A THESIS OF MASTER OF SCIENCE
DEPARTMENT of EARTH and MARINE SCIENCES

ADVISOR: ASSOC. PROF. DR. HAKKI BALTACI

JULY 2024

T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

TÜRKİYE'DE UZUN VADELİ METEOROLOJİK
KURAKLIK EĞİLİMLERİ

SEVDA MERVE ALYAGUT

YÜKSEK LİSANS TEZİ
YER ve DENİZ BİLİMLERİ ANABİLİM DALI

DANIŞMANI: Doç. Dr. HAKKI BALTACI

TEMMUZ 2024



MASTER of SCIENCE JURY APPROVAL FORM

A thesis submitted by Sevda Merve, ALYAGUT, defended on 04/07/2024 before the jury formed with the 24/06/2024 date and 2024/32 numbered decision of the GTU Graduate Administration Board, has been accepted as a MASTER of SCIENCE thesis in the Department of Earth and Marine Sciences.

JURY

MEMBER

(THESIS ADVISOR) : Assoc. Prof. Dr. Hakkı BALTACI

MEMBER

: Assist. Prof. Dr. Diğdem ACAREL

MEMBER

: Assist. Prof. Dr. Hilal ARSLAN

APPROVAL

Gebze Technical University Graduate Administration Board

...../...../..... date and/..... numbered decision.

SIGNATURE/SEAL

ABSTRACT

In this study, long-term variations of dry and wet events of Türkiye, their relationship with surface environment and background large-scale atmospheric circulation mechanisms triggering drought conditions are investigated for Türkiye. For this purpose, surface based monthly mean- temperature, relative humidity, and monthly total precipitation data of homogenously distributed 92 meteorological stations in Türkiye are used for the period 1965-2020. For drought conditions, 0.5°X0.5° monthly gridded values of Standardized Precipitation Evapotranspiration Index (SPEI-1 month) are used for the period 1903-2022. Station and regional based correlations between seasonal drought conditions and in-situ observations and the role of teleconnection patterns (TPs) on regional dry/wet seasons are investigated by using the monthly index values of North Atlantic Oscillation (NAO) and East Atlantic/West Russia (EA/WR) patterns. Synoptic mechanisms causing the occurrence of extreme dry/wet events in Aegean Region (AR) of Türkiye are also investigated using NCEP/NCAR Reanalysis data. According to the main results, statistically significant negative trends of SPEI-1-month values are especially observed in the western (AR) and southern (Mediterranean: MeR and Southeastern Anatolia: SEAR) regions of Türkiye during winter and summer seasons. In addition to highest statistically significant ($p<0.05$) positive correlations between winter SPEI-1 and precipitation values in AR ($r=0.62$), MeR ($r=0.67$), and SEAR ($r=0.48$), we have found that temperature increments enable to occurrence of more frequent summertime drought events in these regions, especially during July temperatures (r values are -0.58, -0.60, and -0.61 for AR, MeR, and SEAR regions, respectively). The impact of NAO on drought events is more meaningful during winter and summer months. During positive phases of winter NAO conditions, Azores surface high is located over Eastern Mediterranean Basin and causes atmospheric blockage which is resulted severe drought conditions in western of Türkiye (precipitation in AR is 60% less than its normal and 1.5 °C below-normal regional temperature). On the other side, during summer NAO (-) phases, northerly light winds transfer dry air from northern terrestrial regions to the AR as a consequence of the interaction between expanded Azores surface high and surface Asiatic monsoon low. Prolonged above-normal temperature isotherm at low level of the atmosphere and dry air at the surface resulted in more frequent and intense drought conditions over western of Türkiye (1.2 °C above-normal AR temperature).

Key words: Drought, SPEI, Teleconnection Patterns, NCEP/NCAR, Türkiye

ÖZET

Bu çalışmada, Türkiye'deki uzun vadeli kurak ve yağışlı dönemlerin değişimleri, bunların yüzey ortamı ile ilişkisi ve kuraklık koşullarını tetikleyen büyük ölçekli atmosferik dolaşım mekanizmaları incelenmiştir. Bu amaçla, Türkiye'de homojen bir şekilde dağıtılmış 92 meteoroloji istasyonunun yüzey tabanlı aylık ortalama sıcaklık, bağıl nem ve aylık toplam yağış verileri 1965-2020 dönemi için kullanılmıştır. Kuraklık koşulları için, 1903-2022 dönemi için $0.5^{\circ}\text{X}0.5^{\circ}$ aylık ızgaralı Standartlaştırılmış Yağış Evapotranspirasyon İndeksi (SPEI-1 ay) değerleri kullanılmıştır. Mevsimsel kuraklık koşulları ile yerinde gözlemler arasındaki istasyon ve bölgesel bazlı korelasyonlar ve uzak etkileşim paternlerinin (TP'ler) bölgesel kuru/nemli mevsimler üzerindeki rolü, Kuzey Atlantik Salınımı (NAO) ve Doğu Atlantik/Batı Rusya (EA/WR) desenlerinin aylık indeks değerleri kullanılarak incelenmiştir. Türkiye'nin Ege Bölgesi'nde (AR) aşırı kuru/nemli olayların meydana gelmesine neden olan sinoptik mekanizmalar, NCEP/NCAR Reanaliz verileri kullanılarak araştırılmıştır. Ana sonuçlara göre, SPEI-1 ay değerlerinde istatistiksel olarak anlamlı negatif eğilimler, özellikle kış ve yaz mevsimlerinde Türkiye'nin batı (AR) ve güney (Akdeniz: MeR ve Güneydoğu Anadolu: SEAR) bölgelerinde gözlemlenmiştir. AR ($r=0.62$), MeR ($r=0.67$) ve SEAR ($r=0.48$) bölgelerinde kış SPEI-1 ve yağış değerleri arasındaki en yüksek istatistiksel olarak anlamlı ($p<0.05$) pozitif korelasyonlara ek olarak, sıcaklık artışlarının bu bölgelerde daha sık yaz kuraklığı olaylarının meydana gelmesine neden olduğu belirlenmiştir. Özellikle Temmuz sıcaklıklarında AR, MeR ve SEAR bölgeleri için r değerleri sırasıyla -0.58, -0.60 ve -0.61 olarak bulunmuştur. NAO'nun kuraklık olayları üzerindeki etkisi, kış ve yaz aylarında daha anlamlıdır. Pozitif kış NAO koşulları sırasında, Azorlar yüzey yüksek basıncı Doğu Akdeniz Havzası üzerinde yer almakta ve atmosferik blokaj oluşturarak Türkiye'nin batısında şiddetli kuraklık koşullarına neden olmaktadır (AR'daki yağışlar normalin %60 altında ve bölgesel sıcaklık normalin 1.5°C altında). Diğer taraftan, yaz NAO (-) evreleri sırasında, kuzeyden gelen hafif rüzgarlar, genişlemiş Azorlar yüzey yüksek basıncı ve Asya muson düşük basıncı arasındaki etkileşim sonucunda AR'ye kuru hava taşımaktadır. Atmosferin düşük seviyelerinde uzayan normalin üzerinde sıcaklık izotermi ve yüzeydeki kuru hava, Türkiye'nin batısında daha sık ve yoğun kuraklık koşullarına neden olmaktadır (AR sıcaklığı normalin 1.2°C üzerinde).

Anahtar kelimeler: Kuraklık, SPEI, Uzak etkileşim paternleri, NCEP/NCAR, Türkiye

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my esteemed mentor and advisor, Assoc. Prof. Hakkı Baltacı. His profound expertise, generous assistance, and unwavering guidance have been instrumental throughout the intense process of completing this thesis. I am deeply grateful for his kind support and insightful advice.

I would also like to extend my heartfelt thanks to my dear spouse, my family, and my friends. Their unwavering support and encouragement have been a source of strength and motivation for me. Their patience, understanding, and constant love have helped me overcome numerous challenges and stay focused on my goals.

In addition, I am thankful to Gebze Technical University for supporting this thesis. Your resources and opportunities have significantly contributed to the completion of my research.

Lastly, I am grateful to all the individuals who have directly or indirectly contributed to this work. Your support, guidance, and encouragement have been invaluable, and I thank you all from the bottom of my heart.

TABLE OF CONTENTS

ABSTRACT	v
ÖZET	vi
ACKNOWLEDGEMENTS	vii
TABLE OF CONTENTS	viii
LIST OF ABBREVIATIONS AND ACRONYMS	ix
LIST OF FIGURES	x
LIST OF TABLES	ii
1. INTRODUCTION	1
2. DATA AND METHODS	6
2.1. Meteorological Drought Indices	6
2.1.1. Palmer Drought Severity Index (PDSI)	6
2.1.2. Standardized Precipitation Index (SPI)	8
2.1.3. Standardized Precipitation Evapotranspiration Index (SPEI)	10
2.2. Standardized Precipitation Evapotranspiration Index (SPEI) and Meteorological Data	12
2.3. Mann-Kendall rank statistic	13
2.4. Statistical Analysis	14
3. RESULTS AND DISCUSSION	18
3.1. Precipitation, temperature, and relative humidity climate of Türkiye	18
3.2. Long-term trends of drought conditions over Türkiye and their relationship with local scale atmospheric parameters	21
3.3. The impacts of teleconnection patterns on drought events	30
3.4. Synoptic reasons causing drought condition under TPs	35
4. SUMMARY and CONCLUSIONS	40
REFERENCES	42
BIOGRAPHY	47
APPENDICES	48

LIST OF ABBREVIATIONS AND ACRONYMS

AR	: Aegean Region
BSR	: Black Sea Region
CAFEC	: Climatically Appropriate for Existing Conditions
DM	: Drought Magnitude
EAR	: Eastern Anatolia Region
ENSO	: El Niño-Southern Oscillation
HD	: Hydrological Drought
MB	: Mediterranean Basin
MD	: Meteorological Drought
MeR	: Mediterranean Region
NAO	: North Atlantic Oscillation
NCP	: North Sea-Caspian Oscillation
PDSI	: Palmer Drought Severity Index
PET	: Potential Evapotranspiration
SEAR	: Southeastern Anatolia Region
SPEI	: Standardized Precipitation Evapotranspiration Index
SPI	: Standardized Precipitation Index
SO	: Southern Oscillation
TSMS	: Turkish State Meteorological Service

LIST OF FIGURES

	<u>Page</u>
Figure 1.1: The distribution of 92 meteorological stations in Türkiye. The borders indicate the seven geographical regions of the country.	5
Figure 2.1: Mapping of Palmer Drought Severity Index values for U.S.A during September 2023.	6
Figure 2.2: Mapping of Standardized Precipitation Index (SPI)-3 month values (July-September 2023) for Türkiye.	10
Figure 2.3: Mapping of SPEI)-1 month values (December 2022) for Türkiye.	12
Figure 3.1: The distribution of 92 meteorological stations in Türkiye. The borders indicate the seven geographical regions of the country.	20
Figure 3.2: Percentage seasonal mean frequencies (%) of wet (left panel), normal (middle panel), and dry (right panel) events (SPEI-1 month records) of each station in Türkiye for the period 1903-2022.	22
Figure 3.3: The correlation coefficient results between temperature values of the stations and SPEI-1 index values for each month of the year for the period 1965-2020.	26
Figure 3.4: The correlation coefficient results between relative humidity values of the stations and SPEI-1 index values for each month of the year for the period 1965-2020.	28
Figure 3.5: The correlation coefficient results between precipitation amounts of the stations and SPEI-1 index values for each month of the year for the period 1965-2020.	29
Figure 3.6: The correlation coefficient results of the NAO index and gridded SPEI-1 month values, which are close to the station locations, (a) winter, (b) spring, (c) summer, and (d) fall seasons for the period 1965-2020.	32
Figure 3.7: The correlation coefficient results of the EA/WR index and gridded SPEI-1 month values, which are close to the station locations, for (a) winter, (b) spring, (c) summer, and (d) fall seasons for the period 1965-2020.	34
Figure 3.8: (a) Composite maps of the sea level pressure (black lines, hPa), wind speed and direction at 1000 hPa (arrows, m/s), and air temperature (red lines, °C) at 850-hPa level for the winter drought years of the Aegean Region (AR) of Türkiye (brown rectangle). (b) average precipitation- (mm) and (c) temperature- anomalies (°C) of the stations inside AR during winter drought years when compared to their long-term means. (d) same as (a), (e) same as (b), (f) same as (c) but for wet winter years of AR.	37

Figure 3.9: (a) Composite maps of the sea level pressure (black lines, hPa), wind speed and direction at 1000 hPa (arrows, m/s), and air temperature (red lines, °C) at 850-hPa level for the summer drought years of the Aegean Region (AR) of Türkiye (brown rectangle). (b) average precipitation- (mm) and (c) temperature- anomalies (°C) of the stations inside AR during summer drought years when compared to their long-term means. (d) same as (a), (e) same as (b), (f) same as (c) but for wet summer years of AR.

LIST OF TABLES

	<u>Page</u>
Table 2.1: Classification of the Palmer Drought Severity Index (PDSI).	8
Table 2.2: Categorization of the Standardized Precipitation Index (SPI).	9
Table 2.3: Classification of the Standardized Precipitation Evaporation Index (SPEI).	11
Table 2.4: Descriptions of Meteorological Stations (i.e., Latitude, Longitude, Altitude, Regions) used in the study.	15
Table 3.1: Seasonal mean percentage (%) frequencies of dry, normal, and wet events (according to the SPEI-1 month index values) in each region (areal average index values of the stations inside in the region) of Türkiye for the period 1903-2022	23
Table 3.2: Seasonal dry (≤ -1.0) and wet (≥ 1.0) years and Mann-Kendall (M-K) trend results of SPEI-1 month index values in each region of Türkiye for the period 1903-2022. The bold values indicate the statistically significant negative trend according to 95% confidence level of M-K.	24
Table 3.3: The correlation coefficient results of monthly SPEI-1 index values and monthly temperature, relative humidity, and precipitation values in each region of Türkiye for the period 1965-2020. The bold values indicate the statistically significant positive/negative trends at 95% according to Student's t test.	27
Table 3.4: Seasonal dry (≤ -1.0) and wet (≥ 1.0) years and Mann-Kendall (M-K) trend results of SPEI-1 month index values in each region of Türkiye for the period 1903-2022. The bold values indicate the statistically significant negative trend according to 95% confidence level of M-K.	30

1. INTRODUCTION

Drought has attracted the attention of many scientists as an environmental disaster. It occurs in all climatic regions having high or low annual/seasonal precipitation amounts. It is known that many factors such as precipitation deficit, temperature, wind strength and low relative humidity play significant role in its formation. In recent years, the major factors such as high-density population and the demand to the fresh water for energy and industrial sectors have affected the limited water basins. Among these interactions, precipitation climate has primary role on water resources [Mishra and Singh, 2010].

From the general identification, drought is primarily defined as a prolonged period without precipitation and is one of the adverse climatic events with detrimental effects on both the environment and society. As a result, drought events are classified as meteorological- (precipitation), hydrological- (streamflow), and agricultural- (soil moisture) based [Dabanli et al., 2017]. In these classifications, meteorological drought, which usually occurs in the absence of precipitation, is considered to be the forerunner of other types [Tosunoglu et al., 2018]. Therefore, understanding the formation of the meteorological drought mechanism is vital not only for atmospheric conditions but also for the other sectors. The transition from meteorological drought to hydrological drought is called as drought propagation. Decreases in soil moisture and the problems in agricultural production are observed as agricultural drought. Finally, socio-economic droughts may occur when the water demands of the society are not met with hydrological drought [Apurv et al., 2017]. To monitor drought events and to mitigate the potential risks caused by droughts, drought indices were developed. From the meteorological point of view, numerous meteorological drought indices such as Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI), and Standardized Precipitation Evapotranspiration Index (SPEI) were defined and started to use by researchers. Among all of indices; PDSI, SPI, and SPEI have received more attention by the users and researchers due to their ease of application and ability to capture the variability of drought [Afshar et al., 2022].

Due to the global context of the climate change, the risk of severe drought is increasing in the Mediterranean Basin (MB hereafter). This basin is known as a “hot

spot” for climate change and under the risk of climate change related natural hazards such as extreme precipitation, flash-floods, droughts, severe storms, heat waves etc. For this purpose, numerous researchers have been focused on drought monitoring and predictions for the MB [e.g., **Merino et al., 2015; Gouveia et al., 2017; Habibi et al., 2018; Villani et al., 2022; Acharki et al., 2023**]. For example, **Merino et al. [2015]** examined the meteorological drought of the Iberian Peninsula located on the Western Mediterranean Basin between 1901 and 2010. They evaluated the spatiotemporal variability of drought by using the SPI. The causes of observed drought were calculated using rainfall trends and anomalies. The results indicated that droughts were longer and more intense in the central to northeastern interior of the Iberian Peninsula. It was observed that the drought was short and weak in the western and Mediterranean coastal areas. Severe droughts are expected to occur in the inner parts of the Iberian Peninsula due to its lack of humidity in the following years. **Gouveia et al. [2017]** used the SPEI while examining the effects of drought on vegetation in the Mediterranean Region. Major drought periods were determined and the effects of these periods on the region were examined. The risk of land degradation and desertification, resulting from increasing water stress, stands out in the region. According to the results, the hot spot status of the Mediterranean Region in climate change scenarios has been confirmed. The increase in the frequency of drought events in the basin is compatible with future scenarios of climate change. **Habibi et al. [2018]** investigated meteorological drought conditions by using SPI in the semi-arid and arid Chéiff-Zahrez basin of Algeria. SPI drought index was calculated by using the daily precipitation data for the period 1960-2010. As a result, below-normal precipitation values were found in the central and northern parts of the basin. Specifically, the highest probability of drought was found in the western and southwestern parts of the basin. The data of the study supported the improvement of drought management and agricultural irrigation problems for the Cheliff-Zahrez basin. **Acharki et al. [2023]** investigated the spatiotemporal analysis and prediction methods for agricultural and meteorological drought in the Mediterranean coastal basin. For this reason, SPI-3 and SPI-6 monthly index values were used. The study discusses the effects of climate circulation indices such as the North Atlantic Oscillation (NAO) and El Niño-Southern Oscillation (ENSO) on drought events in the MB. It was emphasized that the SPI drought index, which is based only on precipitation, is insufficient for risk assessment, and the importance of using

temperature and evapotranspiration-based indices (e.g. SPEI) was explained in detail. Finally, it has been stated that the results obtained through the combined use of SPI and SPEI datasets will contribute to the anticipation of potential droughts.

Türkiye, which is located in the MB, is one of the countries significantly affected by climate change. Some factors such as the expansion of semi-arid regions of the country and transition to arid climatic conditions, increasing desertification, unstable atmospheric conditions and inhomogeneous precipitation distribution in places where land-sea interactions are some of the obvious effects of climate change in the country. The increase in drought conditions in Türkiye not only changes the socio-economic balance within the country, but also increases the water demand of surrounding countries (e.g. Iraq, Syria etc.) due to transboundary waters. Therefore, numerous drought-monitoring studies have been carried out for Türkiye. These studies mainly have been focused on the variation of meteorological, hydrological and agricultural drought events in large- or regional-scale [**Dabanlı et al., 2017; Gumus and Algin, 2017; Tosunoglu et al., 2018; Mehr et al., 2020; Kumanlioglu, 2023; Pekpostalci et al., 2023**]. From the latest basic studies, **Gumus and Algin, [2017]** studied the meteorological and hydrological drought analyzes of the Seyhan and Ceyhan River Basins (S of Türkiye). Totally, 14 meteorological station and 12 streamflow station data were used. According to the results, one-year lag time was found between meteorological and hydrological drought. It has been determined that drought analysis is of great importance in the effective use of water resources, as drought that may occur in these regions can affect many sectors such as agriculture, tourism and energy production. **Dabanlı et al. [2017]** investigated spatiotemporal changes of drought over Türkiye. In the study, long-term (1931-2010) station-based precipitation data were examined by using the Standard Precipitation Index (SPI) methodology. Four sensitive homogeneous drought zones have been found on the Turkish mainland. Based on the drought classification, the percentages were found for extreme, severe and moderate drought events. As a result, while southeast and western regions of Türkiye are more stable, the central and northern regions are less stable due to the low correlation variance scores on the fronts. **Tosunoglu et al. [2018]** examined the relationship between atmospheric oscillation (North Atlantic Oscillation: NAO, Southern Oscillation: SO and North Sea-Caspian Oscillation: NCP) and meteorological drought indices in Türkiye. SPI index values were used to

determine meteorological drought indicators. According to the correlation results between NCPI and SPI; NCP has a significant impact on the northeastern and eastern Black Sea parts of Turkey. Later, **Mehr et al. [2020]** analyzed the effects of climate change on meteorological drought of Ankara using SPI and SPEI index values for 3, 6, 12 month time scales. It was found that the most severe drought events in the region took place between 1993-1995 and from the simulation results, the occurrence of the next severe drought events are predicted in the years between 2031-2033 and 2036-2038. Finally, **Pekpostalci et al. [2023]** systematically examined the drought studies for Türkiye between 2010-2022. They emphasized that drought events have frequently occur in the country and the numbers and severity of meteorological (MD) and hydrological (HD) drought will be increase in the coming years.

Apart from previous studies, it is necessary to analyze long-term drought conditions for Türkiye, including times when station data are not sufficient, and to examine in detail the local and large-scale atmospheric factors that cause this situation. In the study to be carried out, both spatial and temporal resolution should be high and evaporation along with precipitation should be taken into account. For this purpose, in our study, long-term changes (1903-2022) of station and regional based drought conditions were analyzed by using SPEI-1 month index values. In the second part, the relationship between surface-based meteorological observations (i.e. precipitation and temperature values of 92 meteorological stations in Türkiye, as shown in **Fig. 1.1**) and drought conditions were investigated for the 50-yr period (1973-2022). Finally, the effects of large-scale atmospheric circulation mechanisms on drought conditions were examined in detail.

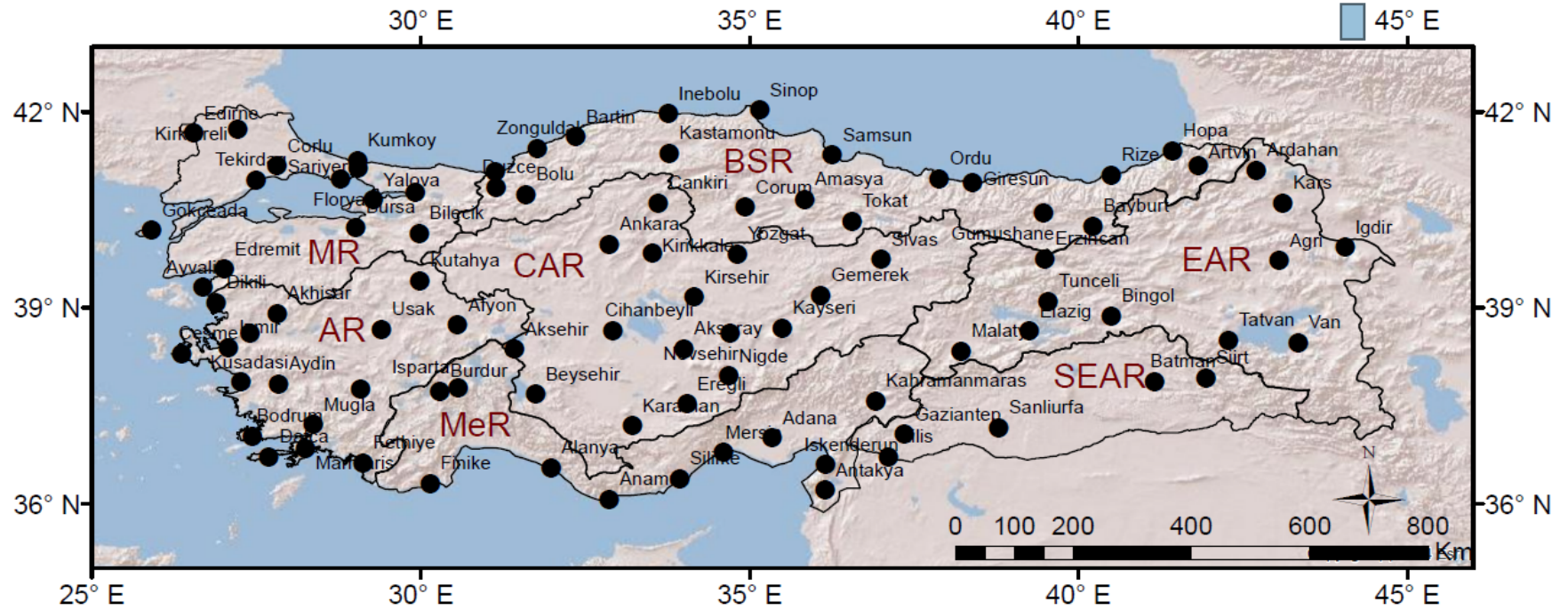


Figure 1.1: The distribution of 92 meteorological stations in Türkiye. The borders indicate the seven geographical regions of the country.¹

¹ The abbreviations of the regions are as follows: MR: Marmara Region, AR: Aegean Region, CAR: Central Anatolia Region, BSR: Black Sea Region, MeR: Mediterranean Region, SEAR: Southeastern Anatolia Region, EAR: Eastern Anatolia Region.

2. DATA AND METHODS

2.1. Meteorological Drought Indices

2.1.1. Palmer Drought Severity Index (PDSI)

The Palmer Drought Severity Index (PDSI) is frequently preferred to examine hydrological drought and climate change impacts [Wang et al., 2022]. This standardized index is based on a simplified soil water balance and associated soil moisture estimations. The magnitude of the PDSI changes from very wet conditions (>4) to extreme drought (<-4), as shown in Table 2.1. From the literature, PDSI studies frequently have been carried up for the U.S. and monthly mapping of PDSI is routinely performed (Figure 2.1).

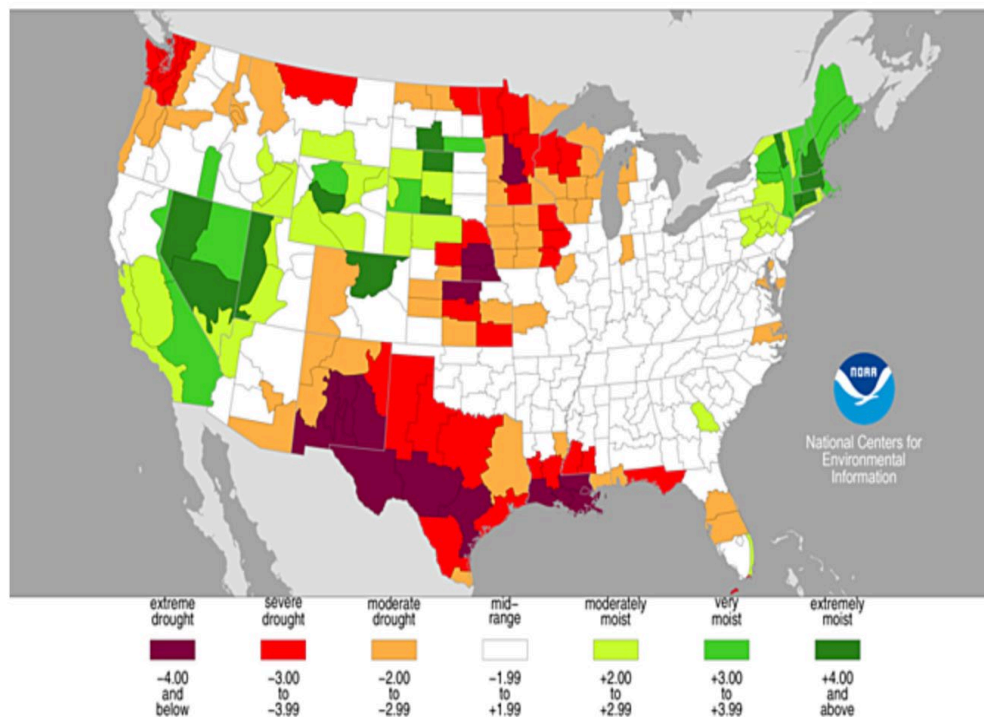


Figure 2.1: Mapping of Palmer Drought Severity Index values for U.S.A during September 2023 (source:<https://www.ncei.noaa.gov/access/monitoring/historical-palmers/>).

Among the PDSI studies conducted for Türkiye, **Beyaztas et al. [2018]** created prediction intervals for PDSI with the Bootstrap method. The effects of the North Atlantic (NAO) and Arctic Oscillation (AO) indices on drought forecasting have been observed. In the study, Konya closed basin in Turkey was examined using the PDSI method. As a result of the study, reliable results were found for the short-term prediction of drought prediction (for example, 3 months), however, uncertainty of the results increased during the long term. Additionally, there is no obvious impacts of NAO and AO oscillations on drought.

PDSI methodology was developed firstly by Palmer (1965). This index was calculated by assigning values of -4.0 and +4.0 to represent extremely dry and extremely wet conditions. Totally 11 classification categories (**Table 2.1**) related to wetness and dryness were determined [**Heddinghaus et al., 1991**].

The following index equations are used for PDSI as follow:

$$X_i = .897 X_{i-1} + Z_i/3 \quad (2.1)$$

where X_i = current PDSI

X_{i-1} = previous month's PDSI

Z_i = z index (current moisture anomaly).

The X_{i-1} term accounts for the effect of the duration of the drought or wet spell while the value of Z is given by:

$$Z = k (P - P^*)$$

where k = climatic weighing factor

and P = monthly precipitation

P^* = the Climatically Appropriate For Existing conditions (CAFEC) precipitation

$$\text{where } P^* = ET^* + R^* + RO^* - L^*$$

and $E(T)^*$ = CAFEC evapotranspiration

R^* = CAFEC recharge of soil moisture

RO^* = CAFEC runoff

L^* = CAFEC loss of soil moisture.

Table 2.1: Classification of the Palmer Drought Severity Index (PDSI)

Palmer values	Class
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

2.1.2. Standardized Precipitation Index (SPI)

Among the drought indices, SPI is widely used for the analysis of drought conditions. It provides significant benefits if precipitation is examined as a water source while examining drought conditions. Since calculations can be made using only precipitation data, it can shorten the data collection time, which increases the preferability of SPI. The fact that it can be classified in different time scales such as monthly, seasonal and annual enables the examination of short and long term drought. It provides detailed data on the analysis of drought by region and time. While additional meteorological data are needed for other drought indices, SPI seems to be more suitable due to its simple flexibility and more reliable [Tsesmelis et al., 2023]. In brief, the SPI represents the difference in precipitation on a time scale divided by the standard deviation relative to the mean and standard deviation determined by historical records. The lack of precipitation is linearly proportional to the standardized precipitation calculation and indicates the probability, average percentage and lack of accumulated precipitation. The main approach is to use standardized precipitation for a range of time scales representing various water sources. When calculating the SPI, a monthly precipitation data set covering at least 30 years is ideally prepared. Average periods corresponding to 3, 6, 12 and 48 months are selected to determine the time range [Mckee et al., 1993].

Based on the Standard Precipitation Index, Drought Magnitude (DM) is defined as:

$$DM = -\sum_{j=1}^n (j-1)^x SPI_j \quad (2.2)$$

The data used in the calculation of SPI are evaluated in the range of +2.0 and -2.0 (**Table 2.2**). To calculate SPI, the data have at least 30 years long. It is seen as a suitable model in the analysis of precipitation data. While calculating SPI within the data, time periods such as 1, 2, 3 months can be customized according to the suitability of the study. While 3 or 6 month SPI is preferred in agricultural sector studies, hydrologists may consider longer SPI data such as 24 months. One of the strengths of SPI is that it can be adjusted according to user needs [Wu et al., 2022].

SPI is often preferred in drought studies in the MB. Hertig and Trambly, [2017] analyzed the data from 114 different stations using the SPI method while examining Mediterranean droughts in the past and future. The results showed that the severity and frequency of droughts will increase in the entire Mediterranean Region for the period of 2070-2100. Later, Achite et al. [2023] studied meteorological and hydrological drought over the Wadi Ouahrani basin (Algeria). For this purpose, they used 6-month SPI data to analyze 1972-2018 drought period. After identifying the driest years during the period, they focused on the temporal evolution of drought.

Table 2.2: Categorization of the Standardized Precipitation Index (SPI).

Category	SPI Values
Mild drought	0 to -0.99
Moderate drought	-1.00 to -1.49
Severe drought	1.50 to -1.99
Extreme drought	≤ -2.00

In Türkiye, numerous studies have been conducted up by using SPI index values for the particular region or the whole country. In Turkish State Meteorological Service (TSMS), SPI-3 month mapping is routinely achieved and shared with the public and public authorities (**Figure 2.2**).

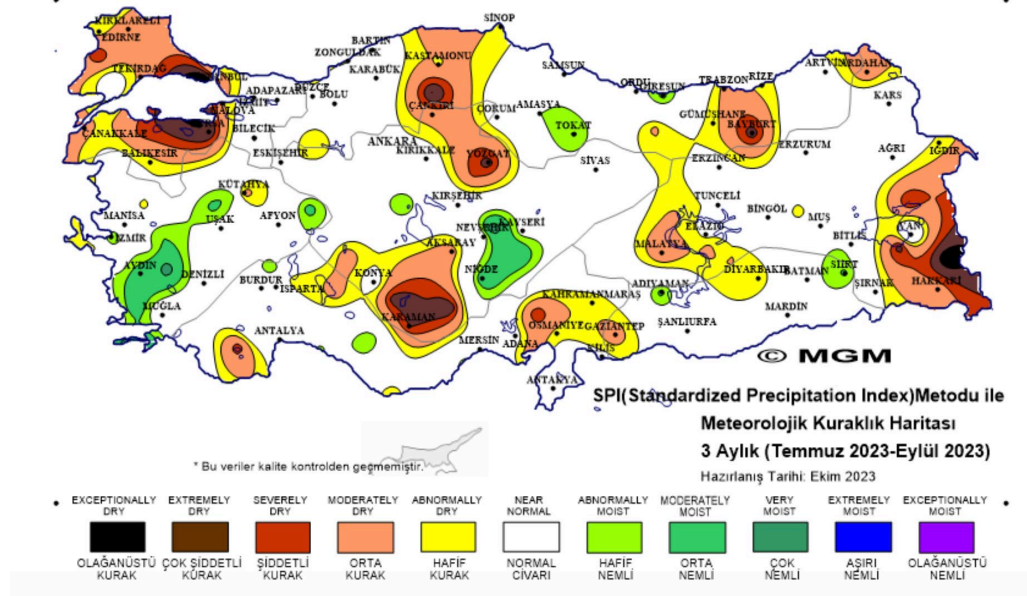


Figure 2.2: Mapping of Standardized Precipitation Index (SPI)-3-month values (July-September 2023) for Türkiye (<https://www.mgm.gov.tr/veridegerlendirme/kuraklik-analizi.aspx>).

2.1.3. Standardized Precipitation Evapotranspiration Index (SPEI)

SPEI can be calculated in different climates, allowing comparison of drought severity over time and space. SPEI is used for the detection and monitoring of scientific interdisciplinary drought events. The difference between monthly and weekly precipitation and potential evaporation (PET) is calculated, and different time scales can be used in climatic water balance calculations.

The first step is to calculate the PET value. Among the calculation methods, the Thornthwaite equation was preferred due to its ease.

$$PET = 16K \left(\frac{10T}{I} \right)^m \quad (2.3)$$

where K is a function calculated by the correction coefficient of the latitude and month, T is the monthly mean temperature (C), I is a heat index, which is calculated as the sum of 12 monthly index values i, and m is a coefficient depending upon I. PET and monthly precipitation values are used in units of millimeters.

With a value for PET, the difference between the precipitation (P) and PET for the month i is calculated using,

$$D_i = P_i - PET_i. \quad (2.4)$$

This equation provides a simple measure of the water excess or deficit for the month analysed,

$$D_k^n = \sum_{i=0}^{k-1} (P_{n-i} - PET_{n-i}), n \geq k. \quad (2.5)$$

For the different D series, k (month) is the time scale of the cluster and n is the calculation number. The D values are undefined for $k > n$ [Baltaci et al., 2023]. As a consequence, the classification of SPEI related drought conditions are shown in **Table 2.3**.

Table 2.3: Classification of the Standardized Precipitation Evaporation Index (SPEI).

Categories	SPEI values
Extremely wet (EW)	More than 2.00
Severely wet (SW)	1.50–1.99
Moderately wet (MW)	1.00–1.49
Near-normal (NN)	−0.99 to 0.99
Moderate drought (MD)	−1.49 to −1.00
Severe drought (SD)	−1.99 to −1.50
Extreme drought (ED)	Less than −2.00

Apart from the previous two indices, the usage and application of SPEI for monitoring, detection and prediction of drought conditions give better results. For example, temporal scale and autoregressive characteristic problems of PDSI are shown as the main limitations. For SPI, the methodology is only dependent to the precipitation. However, other atmospheric factors such as evaporation-transpiration, wind speed, temperature etc. also play significant role in determining drought conditions. To overcome these limitations, SPEI methodology developed **Vicente Serrano et al. [2010]** and precipitation and potential evapotranspiration calculations were defined to differentiate the surface wetness/dryness properties. Additionally, easily understandable definition and statistically strong and easy calculation procedures enable the usage of this index for different sectors.

In this study, 0.5X0.5 gridded long-term (1903-2022) SPEI-1 month values were extracted for Türkiye. For this purpose, the closest grid point to meteorological station locations were taken into account. The 1 month SPEI values were chosen

because its representation to meteorological drought events and relation to atmospheric factors, which is shown an example of SPEI-1 month in Figure 2.3. (https://spei.csic.es/spei_database/#map_name=spei01#map_position=1463)

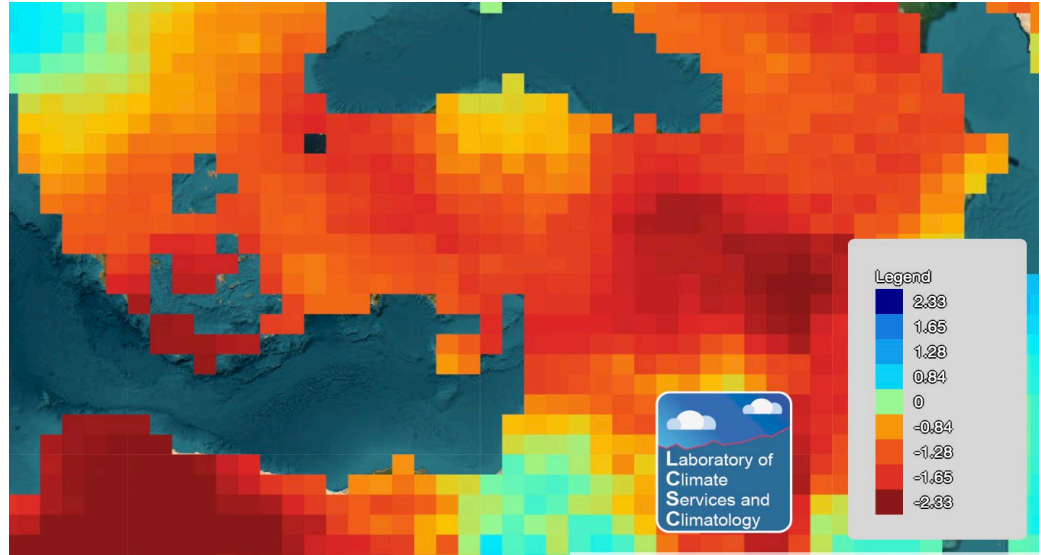


Figure 2.3: Mapping of SPEI-1 month values (December 2022) for Türkiye (source: https://spei.csic.es/spei_database/#map_name=spei01#map_position=1463).

2.2. Standardized Precipitation Evapotranspiration Index (SPEI) and Meteorological Data

In order to analyze the long-term trends of drought conditions, we used gridded SPEI-1 month index values for Türkiye (https://spei.csic.es/spei_database). For the long-term evaluation, grid values of SPEI-1 month index values between 1903-2022 (120-yr) were used. The SPEI data was chosen by considering the location of the closest meteorological station. To compare the relationship between drought conditions and meteorological parameters, the SPEI and meteorological data for the period 1973-2022 (50-yr) were extracted. This selected period was preferred because the availability of the surface-based observations. Later, the relationship between drought conditions and meteorological parameters (e.g. precipitation and temperature) were analyzed in detail. For SPEI calculation, the classification methods indicating the wet, normal, and dry conditions, as shown in **Table 2.3**) were used for the analysis. Decadal frequencies of wet, normal and dry conditions were taken into account. In the study, while $SPEI \leq -1$ demonstrates drought conditions, -

$0.99 \leq \text{SPEI} \leq 0.99$, and $\text{SPEI} \geq 1$ index values illustrates normal and wet conditions, respectively, as shown in **Table 2.3**.

In regard to the meteorological data, 1-month precipitation total amounts, and monthly mean temperature values (mean, minimum and maximum) were used. For this purpose, totally 92 meteorological station data, which are homogenously distributed over Türkiye, were provided by Turkish State Meteorological Service (TSMS, in **Fig. 1.1**). The period was chosen between 1973 and 2022. For the regional perspective, areal average values of meteorological parameters and SPEI index values were implemented. With this aim, meteorological data of totally 16, 19, 16, 11, 14, 11, 5 stations inside Aegean (AR), Black Sea (BSR), Central Anatolia (CAR), Eastern Anatolia (EAR), Marmara (MR), Mediterranean (MeR), Southeastern (SEAR) region of Türkiye were selected, respectively (which is shown in **Fig. 1.1** and **Table 2.4**). In terms of meteorological data, daily precipitation totals and daily mean, minimum and maximum temperature records were obtained from TSMS and converted to monthly values.

2.3. Mann-Kendall rank statistic

The Mann-Kendall rank statistic test was initially introduced by Sneyers [1990] and has found application in studies aimed at pinpointing the commencement year of a notable trend. “The practical execution of this methodology encompasses the following ordered steps:

- a. The original values of the series (x_i) are substituted with their corresponding ranks (y_i), organized in ascending order.
- b. The magnitudes of y_i ($i = 1, \dots, N$) are juxtaposed with y_j ($j = 1, \dots, i - 1$). For each comparison, the count of instances where $y_i > y_j$ is tabulated and labeled as n_i .
- c. Subsequently, a statistic t_i is computed as the summation of n_i for each i :

$$t_i = \sum_1^i \Pi_i \quad (2.6)$$

- d. The distribution of the test statistic t_i displays mean ($E(t)$) and variance ($\text{var}(t)$), characterized as:

$$E(t_i) = \frac{i(i-1)}{4} \quad (2.7)$$

and

$$\text{var } t_i = \frac{i(i-1)(2i+5)}{72} \quad (2.8)$$

e. The sequential values of the standardized variable $u(t_i)$ are then calculated using the formula:

$$u(t_i) = \frac{[t_i - E(t_i)]}{\sqrt{\text{var } t_i}} \quad (2.9)$$

In this context, $u(t_i)$ represents a standardized variable featuring a zero mean and unit standard deviation, showcasing sequential fluctuations around the zero level. It is important to note that $u(t_i)$ adheres to a Gaussian normal distribution.

f. Similarly, the values of $u'(t)$ are computed in reverse, commencing from the end of the series". According to the test, a trend is deemed statistically significant at the 5% level if it surpasses or falls below 1.96 [Baltaci, 2019].

2.4. Statistical Analysis

In this study, the correlation coefficient was applied to analyze the relationship between drought events and local-meteorological conditions. The calculation technique is as follows:

$$R_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} \quad (2.10)$$

"In the equation, x_i and $\bar{x}$ demonstrate the i -th value and average value of the variable X , respectively; y_i and $\bar{y}$ demonstrate the i -th value and average value of the variable Y , respectively and n is the total number of data. The mightier correlation is observed when the $|R|$ is closer to 1. The two sets of variables show a great positive (negative) correlation when R is equal to ± 1 . In addition, the two sets of variables show a positive correlation when R exists between 0 and 1 while a negative correlation observed if R exists between -1 and 0.

For trend analysis, fitted ordinary least squares regression method was implemented to index values and precipitation/temperature for the each station location". Then,

statistically significances of the trends were calculated by using Mann-Kendall rank test (the methodology was explained in detail in **Baltaci et al. 2023**].

Table 2.4: Descriptions of Meteorological Stations (i.e., Latitude, Longitude, Altitude, Regions) used in the study.

Region	Station No:	Station Name	Latitude (°N)	Longitude (°E)	Altitude (m)
Marmara	17050	Edirne	41,6767	26,5508	51
	17052	Kirklareli	41,7382	27,2178	232
	17056	Tekirdag	40,9585	27,4965	4
	17054	Corlu	41,1798	27,8160	145
	17636	Florya	40,9758	28,7865	37
	17061	Sariyer	41,1464	29,0502	59
	17059	Kumkoy	41,2505	29,0384	38
	17119	Yalova	40,6589	29,2796	4
	17116	Bursa	40,2308	29,0133	100
	17066	Kocaeli	40,7663	29,9173	74
	17120	Bilecik	40,1414	29,9772	539
	17110	Gokceada	40,1910	25,9075	79
	17145	Edremit	39,5895	27,0192	21
	17175	Ayvalik	39,3113	26,6861	4
Aegean	17184	Akhisar	38,9118	27,8233	92
	17180	Dikili	39,0737	26,8880	3
	17221	Cesme	38,3036	26,3724	5
	17220	Izmir	38,3949	27,0819	29
	17232	Kusadasi	37,8597	27,2652	25
	17234	Aydin	37,8402	27,8379	56
	17290	Bodrum	37,0328	27,4398	26
	17297	Datca	36,7083	27,6919	28
	17298	Marmaris	36,8395	28,2452	16
	17292	Mugla	37,2095	28,3668	646
	17237	Denizli	37,7620	29,0921	425
	17188	Usak	38,6712	29,4040	919
	17190	Afyon	38,7380	30,5604	1034
	17155	Kutahya	39,4171	29,9891	969

Table 2.4: (Continued)

	17296	Fethiye	36,6266	29,1238	3
	17186	Manisa	38,6153	27,4049	71
Mediterranean	17375	Finike	36,3024	30,1458	2
	17238	Burdur	37,7220	30,2940	957
	17240	Isparta	37,7848	30,5679	997
	17310	Alanya	36,5507	31,9803	6
	17320	Anamur	36,0686	32,8649	2
	17330	Silifke	36,3824	33,9373	10
	17340	Mersin	36,7808	34,6031	7
	17351	Adana	37,0041	35,3443	23
	17255	Kahramanmaras	37,5760	36,9150	572
	17370	Iskenderun	36,5924	36,1582	4
	17372	Antakya	36,2048	36,1513	104
Central Anatolia	17239	Aksehir	38,3688	31,4297	1002
	17242	Beysehir	37,6777	31,7463	1141
	17246	Karaman	37,1932	33,2202	1018
	17248	Eregli	37,5255	34,0485	1046
	17250	Nigde	37,9587	34,6795	1211
	17192	Aksaray	38,3705	33,9987	970
	17191	Cihanbeyli	38,6505	32,9218	973
	17196	Kayseri	38,6870	35,5000	1094
	17160	Kirsehir	39,1639	34,1561	1007
	17162	Gemerek	39,1850	36,0805	1182
	17090	Sivas	39,7437	37,0020	1294
	17140	Yozgat	39,8243	34,8159	1301
	17135	Kirikkale	39,8433	33,5181	751
	17130	Ankara	39,9727	32,8637	891
	17080	Cankiri	40,6082	33,6102	755
	17193	Nevsehir	38,6163	34,7025	1260
Black Sea	17072	Duzce	40,8437	31,1488	146
	17070	Bolu	40,7329	31,6022	743
	17022	Zonguldak	41,4492	31,7779	135
	17020	Bartın	41,6248	32,3569	33
	17024	Inebolu	41,9789	33,7636	64
	17074	Kastamonu	41,3710	33,7756	800
	17026	Sinop	42,0299	35,1545	32
	17030	Samsun	41,3441	36,2563	4
	17084	Corum	40,5461	34,9362	776
	17085	Amasya	40,6668	35,8353	409
	17086	Tokat	40,3312	36,5577	611

Table 2.4: (Continued)

	17033	Ordu	40,9838	37,8858	5
	17034	Giresun	40,9227	38,3878	38
	17088	Gumushane	40,4598	39,4653	1216
	17089	Bayburt	40,2547	40,2207	1584
	17040	Rize	41,0400	40,5013	3
	17042	Hopa	41,4065	41,4330	33
	17045	Artvin	41,1752	41,8187	613
	17015	Akcakoca	41,0895	31,1374	10
Eastern Anatolia	17199	Malatya	38,3367	38,2173	950
	17201	Elazig	38,6443	39,2561	989
	17165	Tunceli	39,1058	39,5408	981
	17094	Erzincan	39,7523	39,4868	1216
	17203	Bingol	38,8847	40,5007	1139
	17205	Tatvan	38,5033	42,2808	1665
	17172	Van	38,4693	43,3460	1675
	17099	Agri	39,7253	43,0522	1646
	17100	Igdir	39,9227	44,0523	856
	17097	Kars	40,6042	43,1073	1777
	17046	Ardahan	41,1061	42,7055	1827
	17261	Gaziantep	37,0585	37,3510	854
Southeastern Anatolia	17262	Kilis	36,7085	37,1123	640
	17270	Sanliurfa	37,1608	38,7863	550
	17282	Batman	37,8636	41,1562	610
	17210	Siirt	37,9319	41,9354	895

3. RESULTS AND DISCUSSION

3.1. Precipitation, temperature, and relative humidity climate of Türkiye

As a first step, seasonal climate of Türkiye was extracted by using the meteorological data of 92 meteorological stations throughout the period 1965-2020. IDW (Inverse Distance Weighted) methodology was applied to temperature, relative humidity, and precipitation values. We have been focused on the use of three primary meteorological parameters because these measurements have been recorded routinely in TSMS together with quality control procedures. According to the wintertime temperature climate, lowest temperature values are observed in the Eastern Anatolia (EAR), especially in the northeastern parts with -10°C (upper panel in **Fig. 3.1**). This region has high mountainous terrain and the average elevation is over 1500m. There are some volcano cones in the EAR with an altitude exceeding 5000m. Snowfall events occur frequently in this region during winter months due to very low temperature values.

During spring, summer and fall seasons, highest temperature records are observed in the southern and western regions of Türkiye. The closest of these regions to the eastern Mediterranean Basin (EMB) and the desert areas (e.g. Syria, Iraq etc.) and the transferring of warm air from the surrounding environment under the suitable atmospheric conditions enable having high temperature records. Already, heatwave events and associated atmospheric blocking conditions cause breaking temperature records in MeR and AR, especially in the extended summer months (From 1 May to 30 September, **Baltaci et al., 2024**). In the recent years, obvious increases in the frequency and severity of heat waves stands out as the main atmospheric factor in the occurrence of forest fires in these regions.

As a consequence, Turkish temperate climate roughly shows us that there are three different climate zones as: Eastern Anatolia, southern and western portions of the country, and the remaining terrestrial regions.

When we analyze in terms of relative humidity, highest rates (between 70% and 80%) are shown in the northern regions of Türkiye (i.e. Marmara and Black Sea) in all seasons (middle panel in **Fig. 3.1**). We can explain this situation as the fact that

northern winds are generally dominant throughout the year, and hence, significant amount of moisture is carried to the northern parts of the country via northerly types of the winds (i.e. NW, N, and NE directions) over the Black Sea. As a result of the mountains extending parallel to the sea along the Black Sea, highest moisture content is shown in the coastal areas of the northern Türkiye, and relatively dry air prevails in the inland areas due to the rain shadow effect.

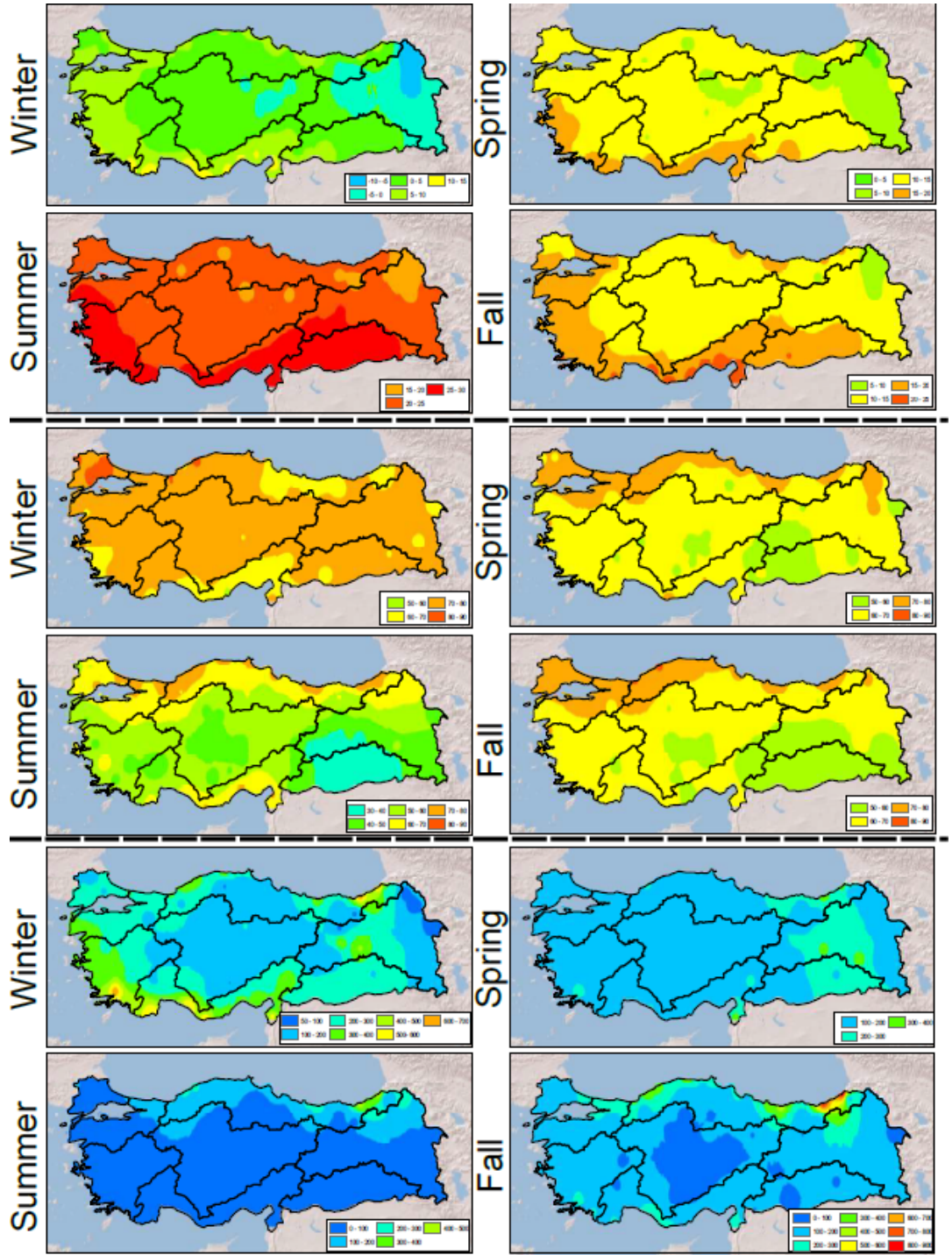


Figure 3.1: Seasonal mean temperature ($^{\circ}\text{C}$, upper panel), relative humidity (% , middle panel), and seasonal total precipitation values (mm, lower panel) of Türkiye for the period 1965-2020. Surface-based meteorological data of 92 meteorological stations were calculated and interpolated for the study.

In regard to winter precipitation climate, highest precipitation values are recorded in the limited areas of the Mediterranean Basin and northeastern part of Türkiye. While the frequency of the cyclones, their movements to the EMB together with

transferring precipitation to the limited areas of the MeR, where air-sea interactions, play significant role in precipitation characteristic of the southern MeR [Karaca et al., 2000]. On the other side, the precipitation climate of the northeastern BSR is significantly differs from the other regions. The mean annual precipitation (MAP) is almost 2200 mm in this limited portion of the BSR. Separated or concurrent convective, orographic and cyclonic originated atmospheric mechanisms over this region enable to have high precipitation records throughout the year. If cut-off cyclone is located over the eastern Black Sea during the late summer or fall months, warm sea surface temperature and unstable atmospheric conditions between surface and upper levels enable rapid development of convective cells and associated extreme precipitation events [e.g. Baltaci, 2017]. When we examine carefully, highest fall seasonal precipitation amounts occur in the northeastern of BLS and it also appears to be higher than wintertime precipitation totals. The main reason for this situation can be explained as the above-normal sea surface temperature of the eastern Black Sea reaching up 25-26 °C in normal, and as a consequence, formation of convective cell and associated releasing a large amount of precipitation to the region occurs in a short time.

3.2. Long-term trends of drought conditions over Türkiye and their relationship with local scale atmospheric parameters

To easily understand the long-term variations of SPEI-1 values; we firstly investigated the percentage seasonal frequencies of wet, normal, and dry events for each station and region. The frequency of wet conditions in each region and season varies between 16% and 18%, with the lowest in the SEAR (Fig. 3.2 and Table 3.1). Normal SPEI conditions generally vary between 60% and 65% in all regions and seasons throughout the year. The frequency of dry conditions varies regionally between 17% and 20% and is shown as similar to the occurrence frequency of wet conditions.

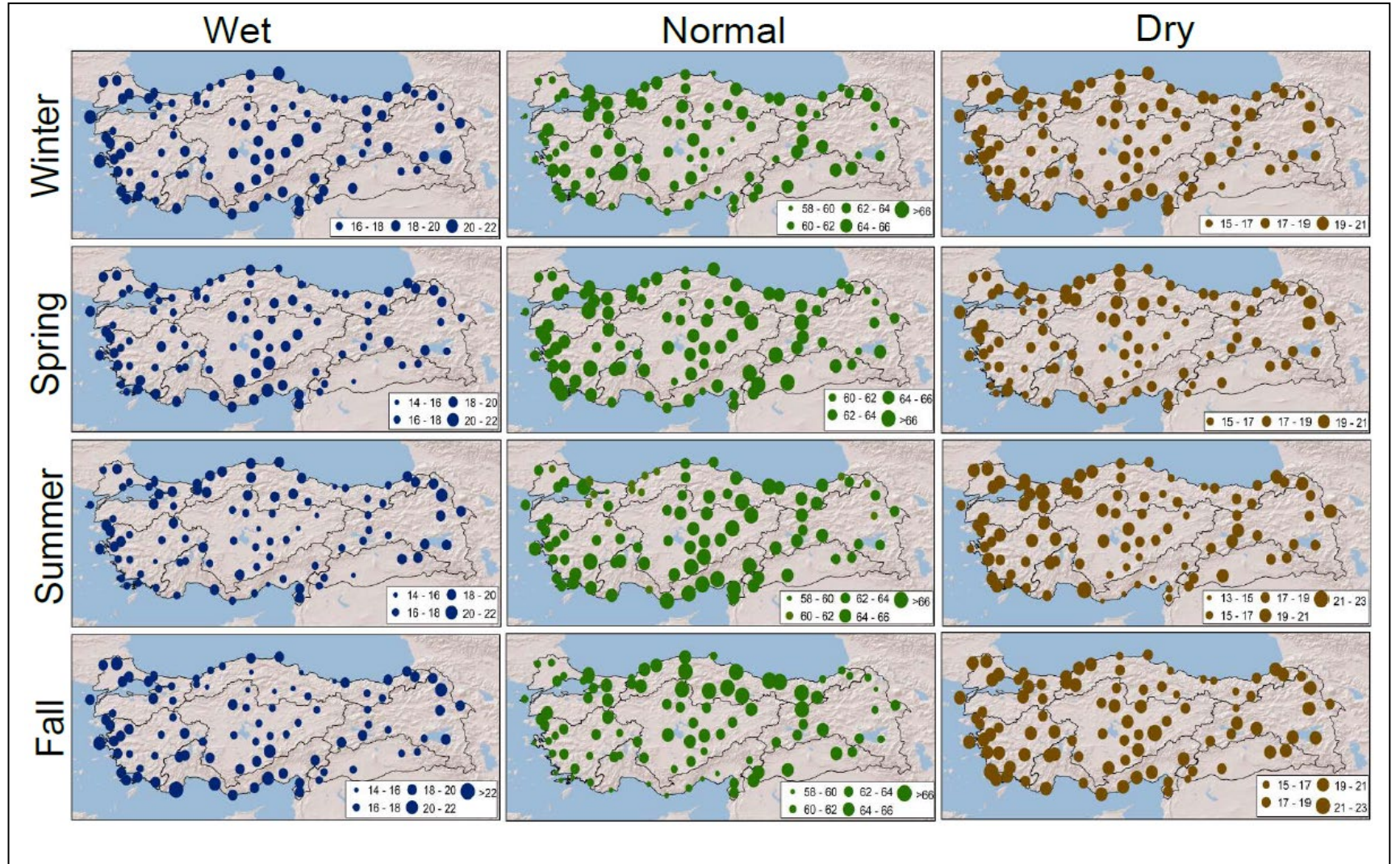


Figure 3.2: Percentage seasonal mean frequencies (%) of wet (left panel), normal (middle panel), and dry (right panel) events (SPEI-1 month records) of each station in Türkiye for the period 1903-2022.

In addition to these average meteorological drought conditions, it is very important to analyze long-term seasonal variations and trends of region-based dry and wet conditions for regional early warning systems and risk reduction strategies (**Table 3.1**). During winter, SPEI-1 month index values are decreasing trend in all regions, with statistically significant decreasing trends occur in the AR and MeR regions of Türkiye. Winter precipitation constitutes more than half of the annual precipitation total and has an important role in determining drought conditions. In these two regions, which are close to the Mediterranean Basin (MB), as long as the negative trend continues, drought risks will be more evident in the next years. Considering the last two decades in AR and MeR; 2008 and 2017 winters are shown as dry years while 2009 and 2012 are wet years. This implies that extreme climatic events such as drought and extreme precipitation have been observed more frequently in recent years [e.g. Akkoyunlu et al., 2019] and our results are consistent with climate model simulations [Gumus et al., 2023].

Table 3.1: Seasonal mean percentage (%) frequencies of dry, normal, and wet events (according to the SPEI-1 month index values) in each region (areal average index values of the stations inside in the region) of Türkiye for the period 1903-2022.

Season	Winter			Spring			Summer			Fall		
Region	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet
MR	18,63	63,05	18,31	17,94	64,43	17,64	19,88	62,50	17,62	18,83	62,94	18,23
AR	18,50	63,00	18,51	17,54	64,41	18,06	18,99	63,61	17,40	19,79	61,65	18,56
MeR	18,86	62,80	18,33	17,55	63,74	18,71	17,02	65,83	17,15	19,65	60,73	19,62
CAR	18,18	63,28	18,54	17,67	63,96	18,37	17,95	62,28	16,77	18,92	63,37	17,71
BSR	18,79	63,38	17,84	18,63	63,67	17,70	18,29	63,52	18,19	18,14	64,90	16,96
EAR	18,23	63,21	18,56	18,19	63,89	17,93	18,41	63,18	18,41	18,91	62,70	18,38
SEAR	17,61	64,50	17,89	17,50	65,61	16,89	18,11	64,28	17,61	18,33	64,83	16,83

During spring, there is a decreasing trend in all regions (except for BSR and EAR) and statistically significant decreasing trend is more obvious in semi-arid region of Türkiye. In addition to role of precipitation in winter, excessive temperature and evapotranspiration plays significant role during summer for the occurrence of dry/wet conditions. During summer, statistically significant negative trends of SPEI-

1 month values (1903-2022 period) are found in all regions, except Central Anatolia and Black Sea regions. The most pronounced drought conditions are shown in the Ar and MeR regions, as in winter. We know that there has been a significant increase in the number and magnitude of heatwaves (HWs) in recent years in Türkiye. **Baltaci et al. [2024]** explained the atmospheric reasons such as cloudless conditions and atmospheric blocking mechanisms for the occurrence of HWs in the Aegean region of the country. As can be seen from Table 3.2, dry years have occurred frequently in the AR region in the last two decades. The expansion of the summer season (from 1 May to the end of 30 September, as mentioned in **Baltaci et al. [2024]** and the shortening of the transition seasons (spring and fall) periods cause drought conditions to be felt in more obvious, along with the increase in temperature, and the transport of significant amount of moisture from the surrounding seas due to evaporation cause us to see more hailstorm occurrences [**Baltaci et al., 2018b**], sea-effect precipitation mechanisms [**Baltaci et al., 2015, 2017**] and flash-flood events [**Baltaci, 2017, 2020**]. During fall, significant decreasing trends of SPEI-1 index values are found in all regions of Türkiye.

Table 3.2: Seasonal dry (≤ -1.0) and wet (≥ 1.0) years and Mann-Kendall (M-K) trend results of SPEI-1 month index values in each region of Türkiye for the period 1903-2022. The bold values indicate the statistically significant negative trend according to 95% confidence level of M-K.

Season	Winter			Spring			Summer			Fall		
Region	Dry years	Wet years	M-K trend	Dry years	Wet years	M-K trend	Dry years	Wet years	M-K trend	Dry years	Wet years	M-K trend
MR	1972, 1989	1940, 1963, 1981, 2010, 2012	-1,25	1934, 1947, 1986	1940	-1,37	1946, 1950, 2003, 2007, 2008, 2012, 2016	1933, 1936, 1949, 1972, 1975, 1976, 1983, 1997, 2014	-2,07	1948, 1969, 2019, 2020, 2022	1998	-1,08
AR	1957, 1972, 1989, 1992, 2008	1940, 1969, 1981, 2009, 2012	-2,67	1945, 1947, 1986	1965	-1,10	1993, 1998, 2000, 2003, 2007, 2008, 2012	1936, 1972, 1976, 1983	-3,63	1969, 2022	1955, 2002	-1,70
MeR	1932, 1972, 1989, 2017	1940, 1981, 2012	-2,57	1947, 1989	1967	-1,30	1932, 1962, 1978, 1998, 2000, 2001	1921, 1939, 1959, 1972, 1982, 1992	-3,15	2020	1942, 1968, 1997, 2006	-1,36
CAR	1955, 1973, 1982, 1989, 1995, 2017	1940, 1954, 1969, 2009, 2010, 2012	-1,03	1928, 1947, 1970, 1989, 1994	1946, 1963, 1967, 1980, 2011	-0,19	1928, 1956, 1962, 1980, 2003	1972, 1982, 1992, 1997, 1999, 2015, 2019	-0,63	1931, 1973, 1984, 2019, 2020	1942, 2006, 2014	-1,22

Table 3.2: (Continued)

BSR	1984, 1995	2012	- 0,53	1947	-	0,44	1957, 1962, 2003	1972, 1983, 2002	-0,34	1966, 2019, 2020	1942, 1989	-0,54
EAR	1972, 1989, 1999, 2017	1940, 1987	- 0,64	1970, 1989, 2008, 2021	1963	0,22	1980, 2000, 2006, 2017	1931, 1939, 1946, 1963, 1967, 1972, 1988, 2009	-2,99	1952, 1962, 2020	1920, 1967, 1989	-1,36
SEAR	1972, 1984, 1989, 1995, 1999, 2014, 2017	1940, 1954, 1968, 2012	- 1,28	1947, 1970, 1989, 2008, 2021	1946, 1950, 1963, 1967, 1972, 1976, 1988	-2,33	1954, 1962, 1966, 1998, 2000, 2001, 2017	1919, 1939, 1946, 1959, 1967, 1972, 1982, 1983, 1988, 1992	-5,24	1952, 1962, 1998, 2017, 2020	1942, 1967, 1989, 1997, 2009	-1,39

Later, we have investigated the role of meteorological parameters on drought conditions. This is important because local and topographical differences influence the climate properties of a region. For example, if a region is located in a rain shadow area, the climate properties of that region significantly differ from its surrounding environment. Due to Türkiye's complex topography, there are many climatologically different regions. For example, while the mean annual precipitation in Rize province is about 2200 mm, which is the region with the highest precipitation record in Türkiye, we have observed almost 400 mm in the Bayburt province, approximately 90 km south of the Rize. Kaçkar mountains prevent the rainy air masses from penetrating the interior areas. As a first step, we analyzed the temperature influence on drought conditions in for each station and region (**Fig. 3.3** and **Table 3.3**).

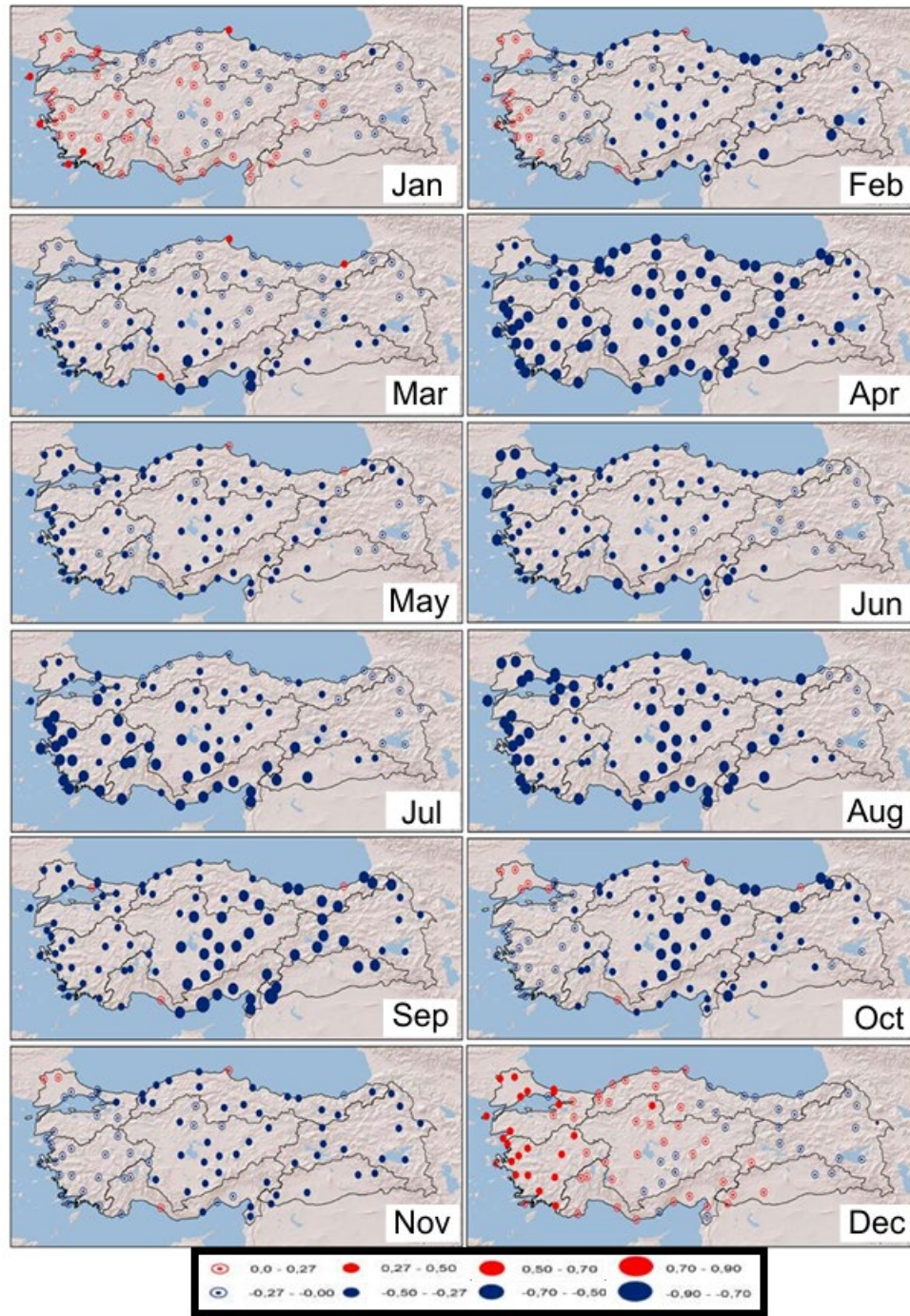


Figure 3.3: The correlation coefficient results between temperature values of the stations and SPEI-1 index values for each month of the year for the period 1965-2020. Regional correlation results are shown in Table 3.3.

Unlike the winter months in general, temperature has a significant effect on drought during the extended summer months (between May and September). This situation shows that as temperature values increase, SPEI index values decrease and severe drought conditions occur. From a regional perspective, the temperature values recorded in July, August and September pose a great risk of drought in the south and

west of Türkiye (i.e. AR, MeR, and SEAR). This condition can be explained by the movement of Asiatic monsoon from its origin to the south and interior parts of Türkiye for a long time, especially in the last two decades.

Table 3.3: The correlation coefficient results of monthly SPEI-1 index values and monthly temperature, relative humidity, and precipitation values in each region of Türkiye for the period 1965-2020. The bold values indicate the statistically significant positive/negative trends at 95% according to Student's t test.

Temperature (C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MR	0.13	-0.04	-0.17	-0.45	-0.35	-0.48	-0.43	-0.61	-0.28	-0.07	-0.10	0.28
AR	0.23	0.01	-0.28	-0.59	-0.31	-0.44	-0.58	-0.57	-0.34	-0.19	-0.09	0.29
MeR	0.10	-0.25	-0.40	-0.61	-0.33	-0.39	-0.60	-0.55	-0.52	-0.34	-0.22	0.08
CAR	0.00	-0.38	-0.33	-0.63	-0.34	-0.31	-0.48	-0.50	-0.57	-0.46	-0.29	0.08
BSR	-0.12	-0.34	-0.17	-0.53	-0.30	-0.29	-0.24	-0.37	-0.40	-0.39	-0.37	0.00
EAR	-0.08	-0.36	-0.23	-0.52	-0.26	-0.15	-0.19	-0.26	-0.49	-0.34	-0.34	-0.10
SEAR	-0.02	-0.54	-0.36	-0.55	-0.29	-0.38	-0.61	-0.57	-0.65	-0.37	-0.39	-0.02
Relative Humidity (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MR	0.45	0.34	0.25	0.21	0.01	0.16	0.02	0.03	0.32	0.08	0.33	0.49
AR	0.54	0.31	0.24	0.42	0.12	0.19	-0.02	-0.03	0.35	0.26	0.44	0.47
MeR	0.57	0.29	0.24	0.54	0.21	0.21	-0.02	0.04	0.26	0.38	0.46	0.46
CAR	0.56	0.26	0.33	0.52	0.13	0.25	-0.12	-0.04	0.28	0.41	0.45	0.45
BSR	0.27	0.15	0.26	0.30	0.07	0.15	-0.11	-0.08	0.17	0.29	0.22	0.32
EAR	0.18	0.08	0.32	0.33	0.26	0.15	-0.07	-0.16	-0.06	0.29	0.13	0.29
SEAR	0.38	0.11	0.31	0.40	0.27	0.10	-0.11	-0.06	0.05	0.32	0.19	0.42
Precipitation (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MR	0.56	0.36	0.22	0.12	-0.02	0.10	0.28	0.19	0.38	0.18	0.24	0.50
AR	0.62	0.38	0.34	0.33	0.22	0.15	0.31	0.20	0.36	0.34	0.30	0.49
MeR	0.67	0.59	0.60	0.61	0.49	0.42	0.40	0.20	0.29	0.59	0.64	0.71
CAR	0.65	0.51	0.60	0.59	0.47	0.34	0.41	0.20	0.29	0.55	0.57	0.73
BSR	0.32	0.29	0.37	0.26	0.19	0.22	0.28	0.20	0.26	0.30	0.37	0.44
EAR	0.25	0.30	0.43	0.29	0.45	0.40	0.31	0.29	0.16	0.40	0.46	0.46
SEAR	0.48	0.51	0.58	0.50	0.61	0.51	0.43	0.19	0.11	0.50	0.60	0.65

As shown in **Figs. 3.4 and 3.5**, the influences of relative humidity and precipitation on drought events are more remarkable during the extended winter months (Nov-Mar). The increase in winter precipitation causes us to see wet atmospheric conditions and hence, the SPEI index values can be seen at high values. The positive correlation between winter precipitation amounts and winter SPEI index values is obviously high in all regions, except the Black Sea and Eastern Anatolia (**Table 3.3**).

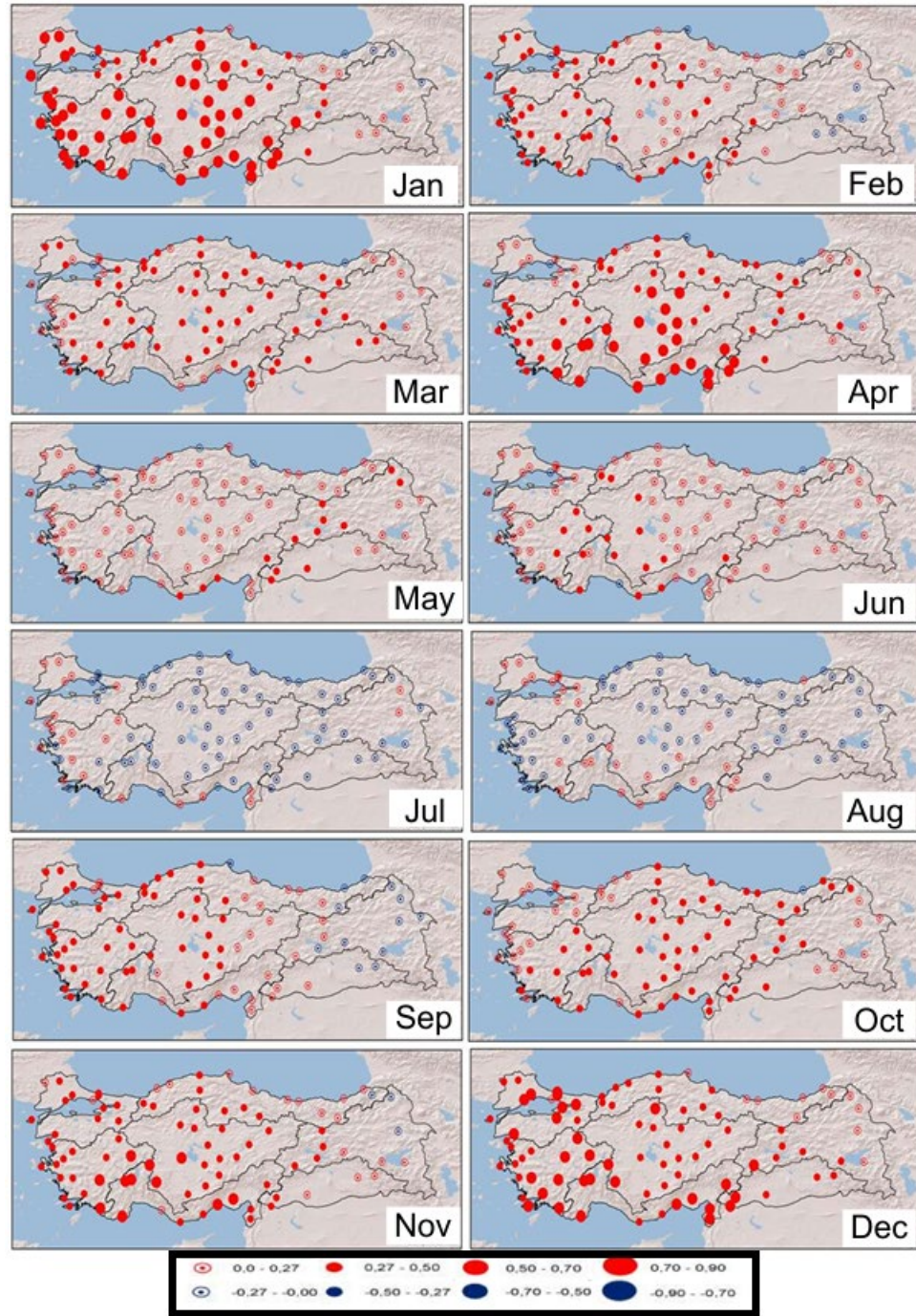


Figure 3.4: The correlation coefficient results between relative humidity values of the stations and SPEI-1 index values for each month of the year for the period 1965-2020. The values inside each region indicates regional correlation results.

In these two regions, reasons such as continuity of precipitation throughout the year and snow formation mechanisms, keeping the soil as moist for long periods of time, cloudy atmospheric conditions, and minimum evaporation do not significantly allow occurrence of drought. As a result, transferring of the hot/cold and rainy/ air masses

over the country and the change in their frequency and duration effect large-scale drought conditions and many sectors such as agricultural production, hydrological drought and tourism may be negatively damaged. For this reason, in the next section, we have investigated the role of teleconnection patterns on drought occurrence mechanism.

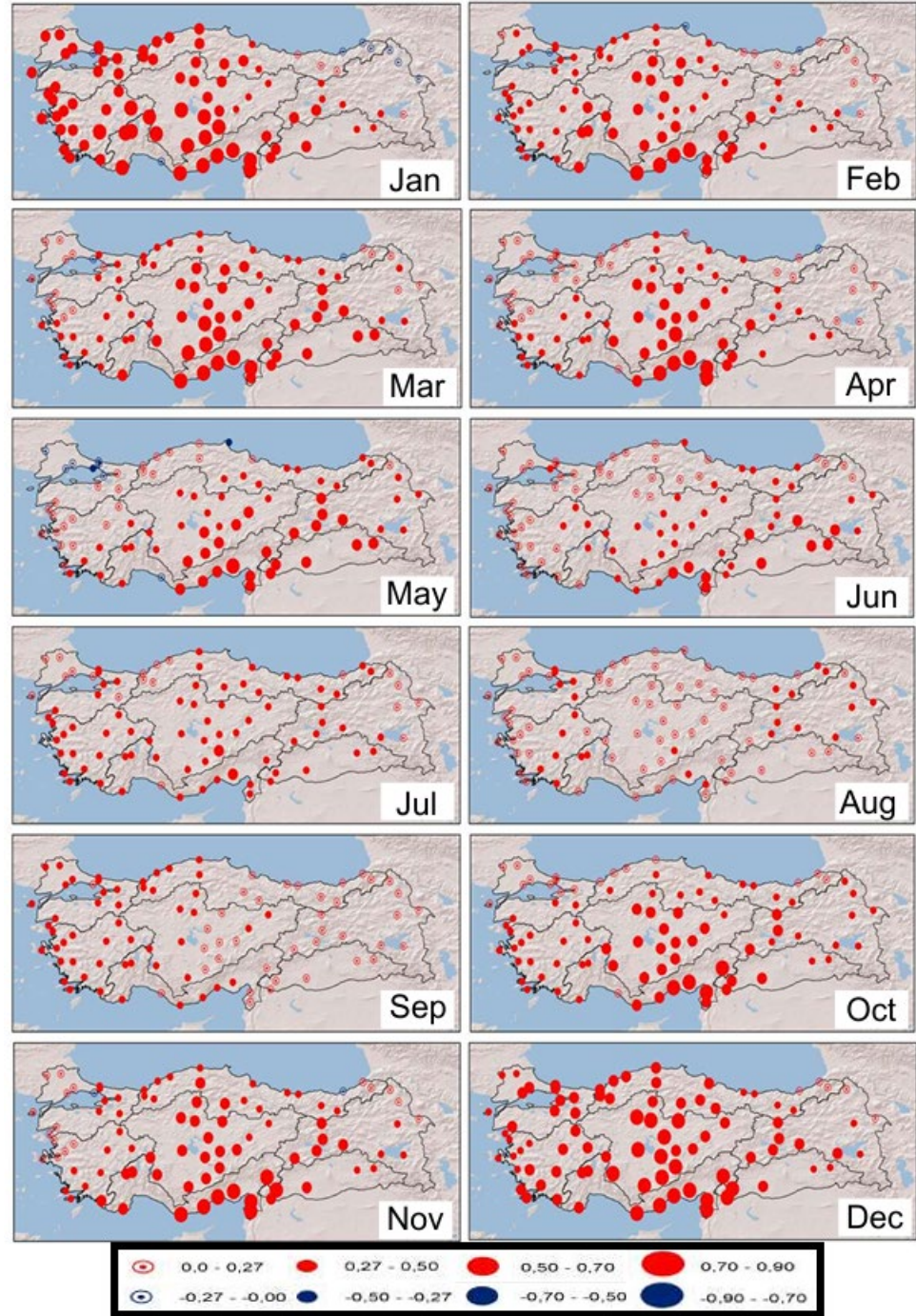


Figure 3.5: The correlation coefficient results between precipitation amounts of the stations and SPEI-1 index values for each month of the year for the period 1965-2020. Regional correlation results are shown in Table 3.3

3.3. The impacts of teleconnection patterns on drought events

In literature, there are numerous studies investigating the role of teleconnection patterns on precipitation/temperature variability for Türkiye [Kutiel et al., 2002; Türkeş and Erlat, 2003, 2005; Ünal et al., 2012; Baltacı et al., 2018a]. To evaluate the role of long-range atmospheric circulation on prolonged dry/wet events, researchers generally have been focused on SPI as a drought index [e.g. Sönmez et al., 2005; Tosunoglu et al., 2018; He et al., 2022]. However, since SPI contains only precipitation terms in its formulation, it does not fully represent drought events. In recent years, SPEI has started to be used frequently in determining meteorological drought conditions due to the including terms based on precipitation and evapotranspiration. From the latest study, the impact of drought events on particulate matter concentrations was investigated by using SPEI values [Baltacı et al., 2023]. In this study, we examined the role of NAO and EA/WR patterns on station- and regional- based drought conditions for each season (Figs. 3.6 and 3.7 and Table 3.4). In regard to NAO, it is obvious that winter and summer atmospheric conditions play significant role to determine dry/wet events of Türkiye (Fig. 3.6).

Table 3.4: Seasonal correlation coefficient results between teleconnection patterns (NAO and EA/WR; EA/WR-SPEI correlation results are shown in parenthesis) and SPEI index values for each region of Türkiye for the period 1950-2022. The bold values indicate the statistically significant at %95-confidence level according to Student's t test.

Region/Season	Winter	Spring	Summer	Fall
MR	-0.24 (-0.16)	-0.10 (0.03)	0.27 (-0.04)	-0.09 (0.05)
AR	-0.22 (-0.21)	0.00 (-0.03)	0.28 (0.05)	-0.08 (0.11)
MeR	-0.14 (-0.02)	0.08 (-0.03)	0.20 (0.09)	0.05 (0.21)
CAR	-0.17 (0.02)	-0.02 (0.05)	0.16 (0.03)	0.04 (0.17)
BSR	-0.15 (0.16)	-0.06 (0.10)	0.13 (-0.02)	0.04 (0.16)
EAR	-0.14 (0.21)	0.04 (0.03)	0.07 (0.18)	0.15 (0.24)
SEAR	-0.12 (0.16)	0.06 (-0.07)	0.19 (0.27)	0.14 (0.29)

During winter, the western parts of Türkiye are more influenced from the westerly circulation patterns, as previously mentioned by Türkeş and Erlat [2003]. As a result, the MR and AR regions show negative correlations between NAO and SPEI conditions (Table 3.4). This means that when negative phase of NAO (-) active, above-normal precipitation records and associated wet days are more frequently occur in these regions (Fig. 3.6a). The main reason having above-normal

precipitation values is known as the mid-latitude cyclonic activity passing over the Mediterranean Basin. In winter, it transfers moist and relatively warm air to the western of Türkiye via westerly/southwesterly winds. During spring, statistically non-significant negative and positive relations are shown in the stations (**Fig. 3.6b**). Instead of dominance of frontal systems, convective cloud formation and geographical properties of the region are the main factors to determine precipitation/temperature climate. During summer, statistically significant positive correlations are found between NAO and SPEI values in the stations located over western of Türkiye (**Fig. 3.6c**). This indicates that when NAO is in positive trend, positive SPEI values are observed or vice versa. Summer precipitation is the season that contributes the least to the MAP. Instead, temperature changes have more importance to determine its effect on drought conditions. Unlike the effects of mid-latitude cyclones in winter, during NAO (+), it is known that Azores high-pressure center extends from its origin to the Balkan Peninsula and restricts the movement of rainy systems into the western of Türkiye. Additionally, summer Asiatic monsoon low is also active in summer months [e.g. Baltaci et al., 2015].

Similar to the spring conditions, statistically non-significant correlations are shown between NAO and drought conditions during fall season (**Fig. 3.6d**). Only, significant positive relationships were found at the limited stations in the eastern of Türkiye. Some atmospheric factors such as cooling process in November, the saturation of the soil in terms of moisture content and the early snowfall formation due to highest mountainous area can be the underlying atmospheric mechanisms to explain this event.

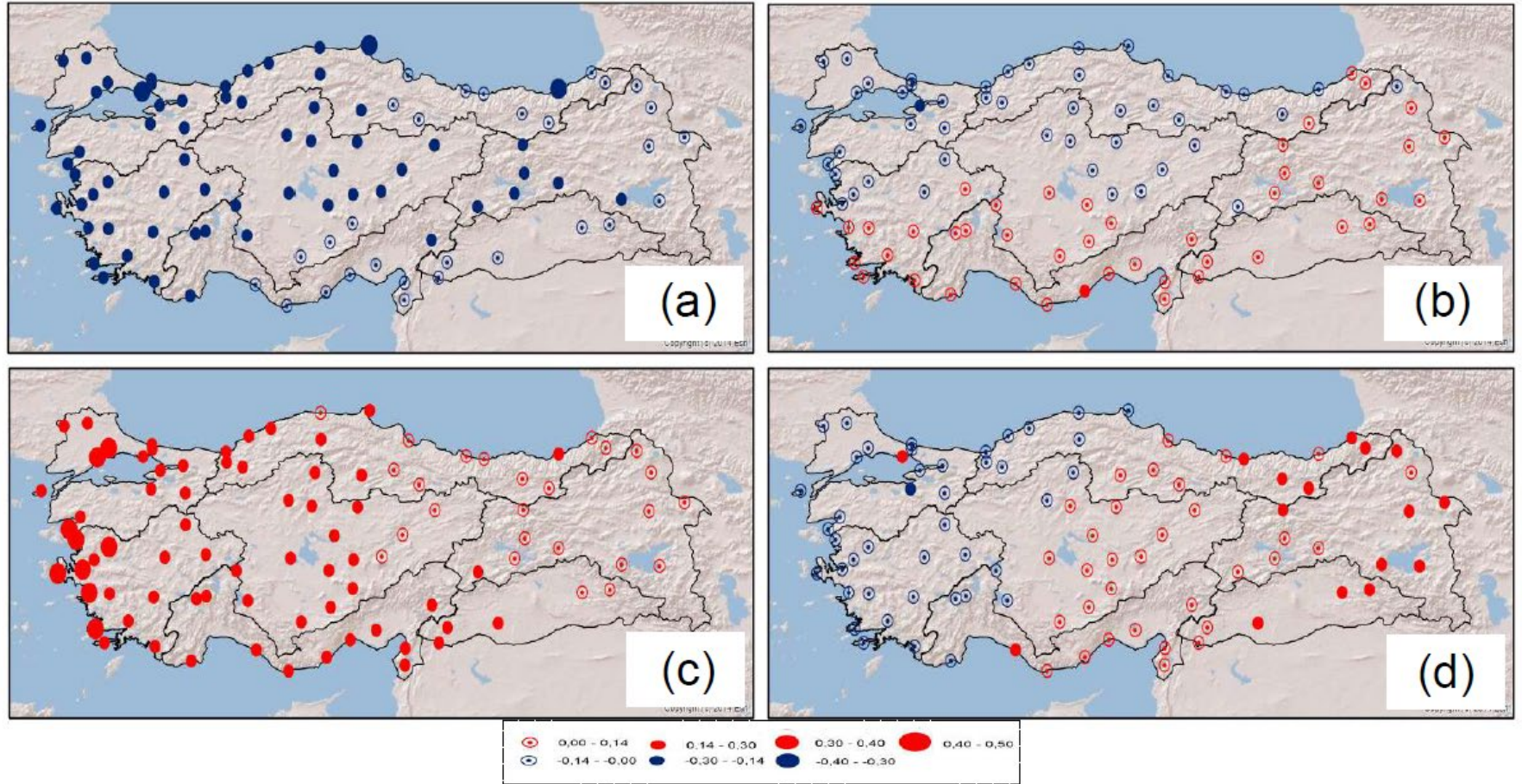


Figure 3.6: The correlation coefficient results of the NAO index and gridded SPEI-1 month values, which are close to the station locations, for (a) winter, (b) spring, (c) summer, and (d) fall seasons for the period 1965-2020.

EA/WR is known as the other important TP affecting Turkish climate characteristics. During winter, while some limited area of the eastern BLS stations show statistically significant positive correlations with SPEI values, western stations show statistically significant negative correlations (**Fig. 3.7a**). In regional perspective, this relationship is not very meaningful (**Table 3.4**). However, precipitation mechanism in the eastern BLS is originated by convective activity, land-sea interaction, orography and frontal systems, and in the positive phase of EA/WR (+), above-normal precipitation records occur under cloudy atmospheric conditions. As mentioned by **Baltacı et al. [2018]**, during EA/WR (+), northwesterly winds are dominant in the eastern BLS and transfer humid and warm air to the coastal places, which resulted in extreme precipitation events. During spring, there is no remarkable relationship between EA/WR and SPEI events (**Fig. 3.7b**). During summer and fall months, the positive relation between EA/WR and SPEI indicates that positive EA/WR (+) cause wet days in the SEAR region or vice versa (**Figs. 8c, d**). As mentioned by **Baltacı et al. [2018]**, during active EA/WR (+) phases, moisture transport to the SEAR by southwesterly winds from the Eastern Mediterranean can be the main atmospheric factor because overheated Eastern Mediterranean Sea surface, evaporation and associated significant amount of moisture is transported to the SEAR region via southeasterly flows. Here, the location strength, and persistency of the Cyprus Low (CL) center is also important in determining the intensity of the precipitation and the area it affects. **Hochman et al. [2020]** found that there will be decrease in CL frequency (-35%) and persistence (-8%) at the end of the century (2081-2100). In this case, the SEAR, which receives the least MAP in Türkiye, will change from semi-arid to arid climate and will face more drought related threats (erosion, air pollution, health diseases, water crisis etc.) in the coming years.

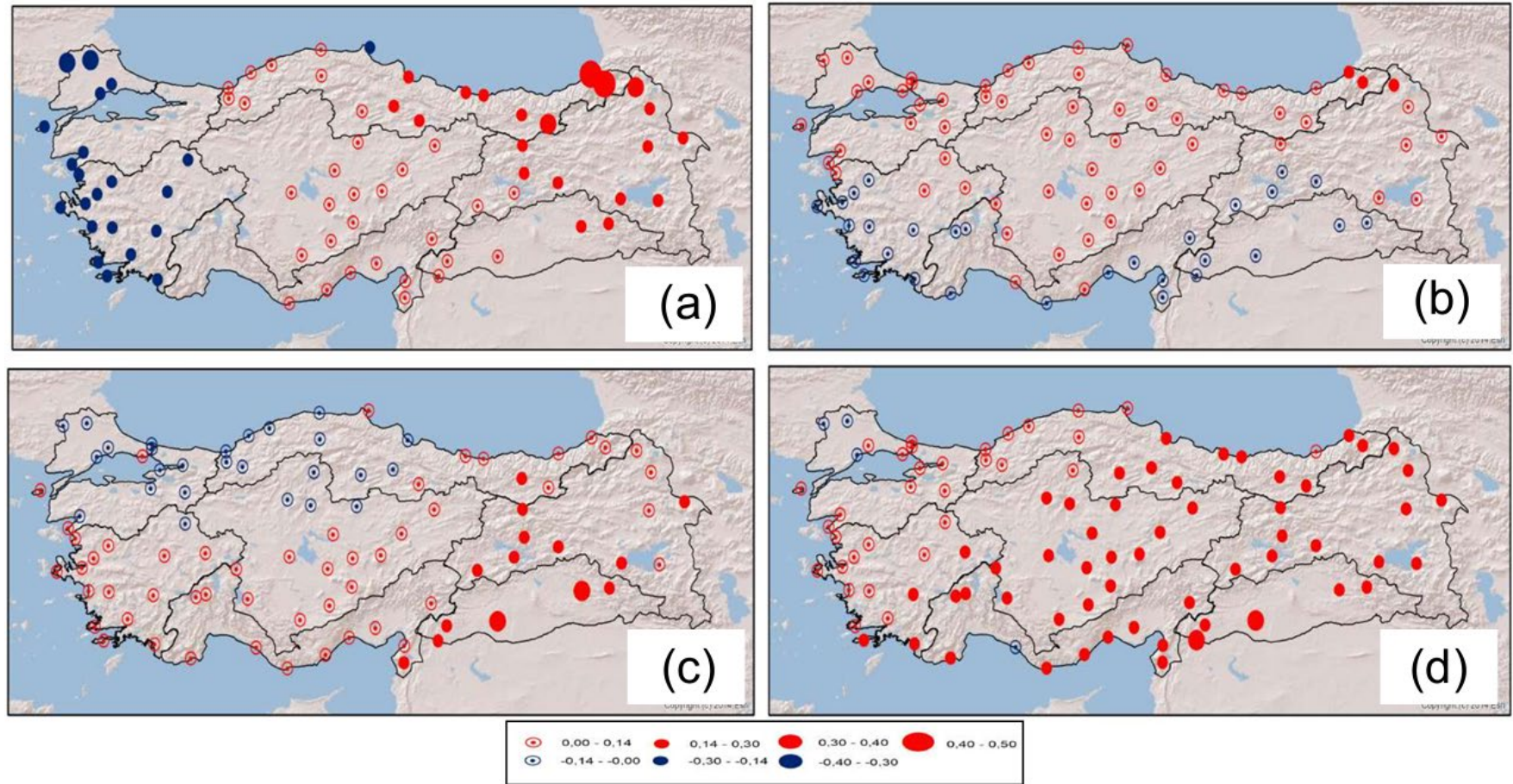


Figure 3.7: The correlation coefficient results of the EA/WR index and gridded SPEI-1 month values, which are close to the station locations, for (a) winter, (b) spring, (c) summer, and (d) fall seasons for the period 1965-2020.

3.4. Synoptic reasons causing drought condition under TPs

From the results, negative trends of SPEI-1 month values show more drought conditions over the Türkiye. While most statistically significant negative trends are shown in the western and southern regions during winter; western, southern, eastern and southeastern regions are also under the risk of drought events during summer (**Table 3.2**). From the regional perspective, AR is more influenced from the extreme hydrometeorological events such as flash floods, droughts, storms etc. In regard to drought of Aegean, **Serkendeniz et al. [2024]** found a remarkable increase in the occurrence of drought periods over time. They also declared a gradual north-to-south intensity in Türkiye, similar findings to our results. **Sen et al. [2012]** found that drought effects will be strongest in the Aegean and Mediterranean regions according to the simulation results. This situation shows that AR is at high risk of drought in both trend results and future scenarios. For this purpose, in addition to the role of teleconnection patterns on the variability of meteorological parameters [e.g. **Türkeş and Erlat, 2003, 2005; Baltacı et al., 2018**], we investigated the main synoptic conditions during dry and wet conditions of Aegean in winter and summer seasons.

During dry winters, Azores high-pressure system extends from its origin to eastern Mediterranean Basin and prevents the penetration of Genoa cyclone to Türkiye. As a consequence, more northeasterly light winds transfer dry air from the northern regions to Aegean (**Fig. 3.8a**). This situation generally consistent with the positive phase of NAO (+) conditions as large-scale atmospheric effect. The 0° isotherm at 850-hPa level is generally dominant over the region. When we compared to long-term means, it is seen that precipitation is recorded at values much lower than the average values (**Fig. 3.8b**). While the negative winter precipitation anomaly is in the range of 100-200 mm in the inner parts of the AR, it was measured 300-400 mm less than average values in the coastal stations. When we examine in terms of temperature, negative temperature anomalies are observed at all stations, with the highest decreases occurring in the inner regions with 2.5-3.0 °C less than normal (**Fig. 3.8c**).

During wet winters, surface Genoa cyclone is more active, and hence, westerly/southwesterly strong winds transfer humid and relatively warm air to

western of Türkiye (**Fig. 3.8d**). The 2.5 °C isotherm at 850-hPa level passes over the region. This synoptic image is generally more meaningful with the active NAO (-) phases. As a result of this situation, while an above-normal 100-200 mm precipitation is observed in terrestrial stations, the positive precipitation anomaly can reach up to 300-400 mm in the coastal stations (**Fig. 3.8e**). In terms of temperature, above-normal values are recorded at all stations, and positive temperature anomaly reaching up to 2.0 °C in the inner parts of AR (**Fig. 3.8f**). The main reason for this situation is that the 2.5 °C isotherm at 850-hPa level is located in the region and warm air advection from the Northern Africa (7.5 °C isotherm) is transferred to the region by southerly wind flows.

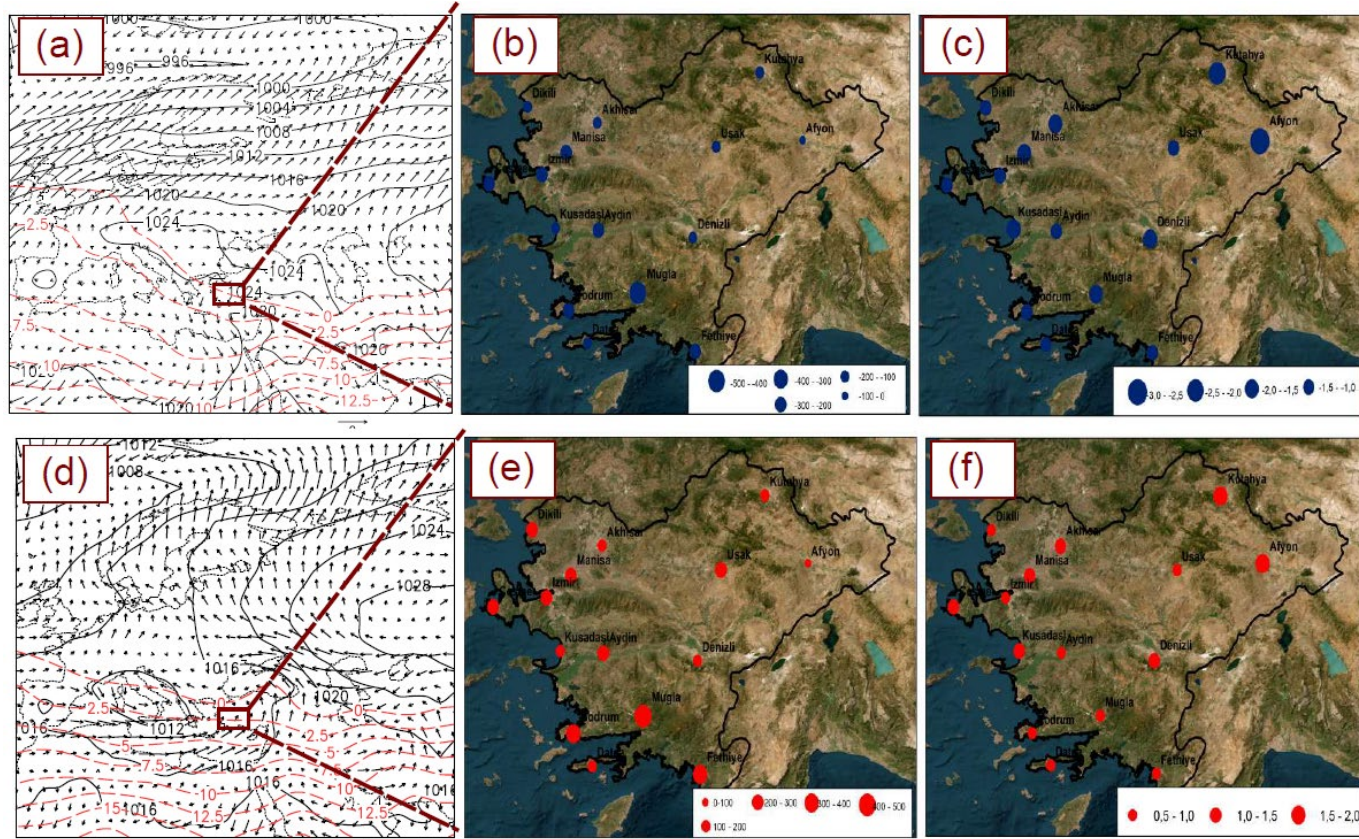


Figure 3.8: (a) Composite maps of the sea level pressure (black lines, hPa), wind speed and direction at 1000 hPa (arrows, m/s), and air temperature (red lines, °C) at 850-hPa level for the winter drought years of the Aegean Region (AR) of Türkiye (brown rectangle). (b) average precipitation- (mm) and (c) temperature- anomalies (°C) of the stations inside AR during winter drought years when compared to their long-term means. (d) same as (a), (e) same as (b), (f) same as (c) but for wet winter years of AR.

During dry summers, Azores surface high is located in the source region; however, it has expanded significantly and covers all of Europe (**Fig. 3.9a**). On the other hand, the surface summer Asiatic monsoon has penetrated into the inner parts of Türkiye. As a result, dry air from the northern regions is carried to the Aegean by northern winds and summer precipitation totals, which are low in quantity, are observed to be 0-100 mm below the average (**Fig. 3.9b**). The 18°C temperature isotherm over the region causes above-normal temperature values at the Aegean stations (**Fig. 3.9c**). The continuity of these atmospheric blockage conditions increases the frequency and severity of heat waves, as previously mentioned in the previous studies [Demirtaş, 2018; Baltaci et al., 2024].

During wet summer months, the influence of Azores surface high is limited to Western Europe, and thus, northwesterly light winds are dominant over the region (**Fig. 3.9d**). As a result, moisture is transported from the northern Aegean Sea to the region, especially to the northern coastal stations, and positive summertime precipitation anomalies occur with 0-100 mm above from its average in the stations of the AR (**Fig. 3.9e**). In this precipitation mechanism, land-sea interaction and related convective activity become stronger and the total summertime precipitation increases due to extreme precipitation events occurring in a short period of time. As a consequence of the dominance of the 15 °C isotherm over the region and the 12.5 °C cold air advection from the north, below-normal temperature values are observed at the stations of AR (**Fig. 3.9f**).

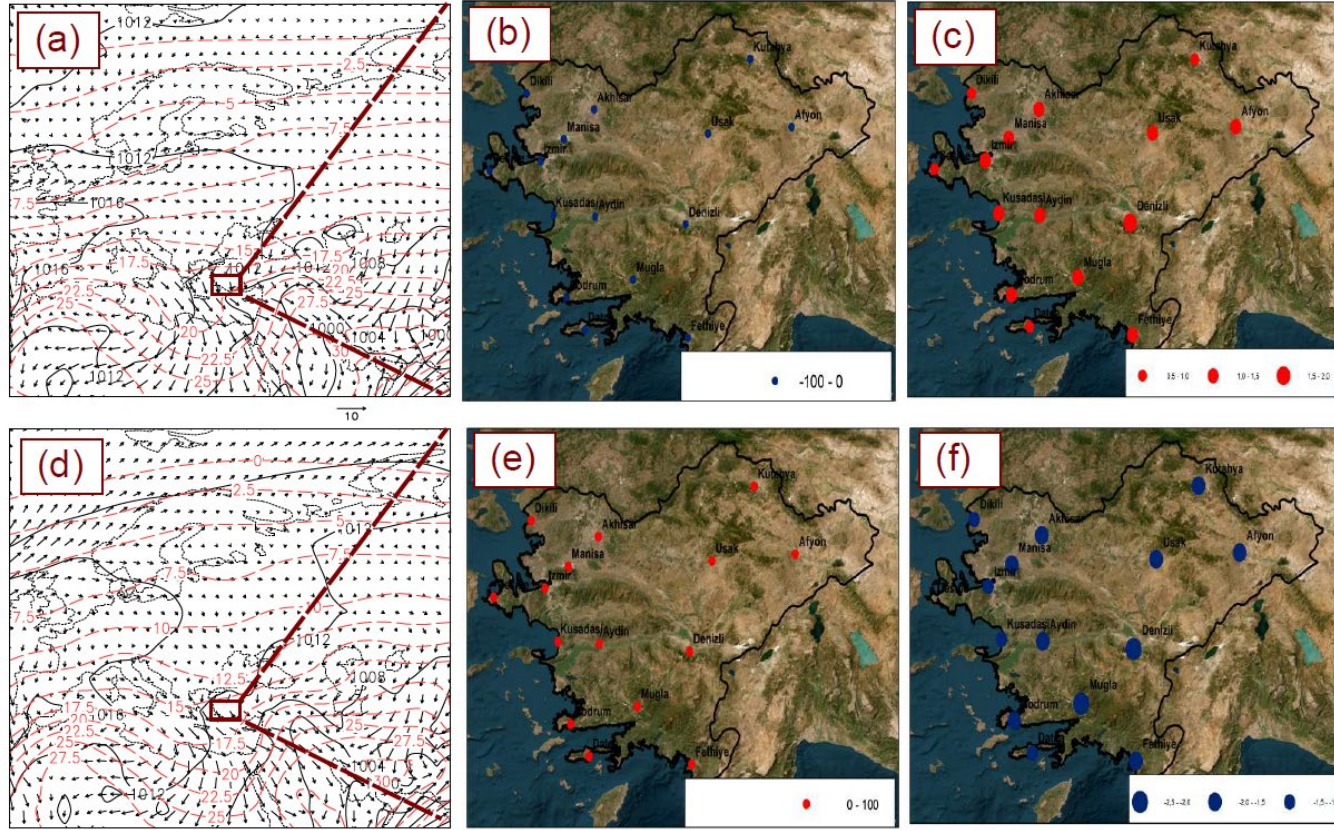


Figure 3.9: (a) Composite maps of the sea level pressure (black lines, hPa), wind speed and direction at 1000 hPa (arrows, m/s), and air temperature (red lines, °C) at 850-hPa level for the summer drought years of the Aegean Region (AR) of Türkiye (brown rectangle). (b) average precipitation- (mm) and (c) temperature- anomalies (°C) of the stations inside AR during summer drought years when compared to their long-term means. (d) same as (a), (e) same as (b), (f) same as (c) but for wet summer years of AR.

4. SUMMARY and CONCLUSIONS

In this paper, we first investigate the seasonal long-term changes of drought conditions over the regions of Türkiye. For this purpose, we have used gridded SPEI-1 month index values for the period 1903-2022. In order to evaluate trends, linear regression and Mann-Kendall significance tests were applied to the SPEI values. Later, the relationship between local meteorological conditions and drought events and underlying large-scale atmospheric effect were investigated in detail. With this aim; daily mean temperature, relative humidity, and daily total precipitation records of 92 meteorological stations over Türkiye were used throughout the 1965-2020 period. Later, we have been focused on NAO and EA/WR patterns of their impact on drought. In the last stage, the synoptic situation and precipitation/temperature anomalies of dry and wet conditions in the Aegean Region were examined using the sea level pressure, wind speed and direction at 1000-hPa and temperature isotherm values at 850-hPa level of NCEP/NCAR reanalysis data. The salient results are as follows:

It was found decreasing trends in all seasons in the regions of Türkiye. It was concluded that these decreasing trends are statistically significant during winter and summer months. While statistically significant decreases are found in the western and southern of Türkiye (AR and MeR) during winter months, a significant downward trend in SPEI is observed in all regions (except CAR and BSR) during the summer months.

It was found important contribution of precipitation in the occurrence of dry and wet periods in the western/southern of Türkiye during the extended winters (Nov-Mar). Also, temperature increase in the extended summer months (May-Sep) triggers the formation of dry events in all regions, and this relationship is especially more evident in the western regions of Türkiye.

We have been observed that NAO significantly affects the wintertime and summertime drought conditions in western Türkiye. Drier winter events are shown under the positive phase of NAO. In this case, the location of the surface Azores high over the eastern Mediterranean Basin creates an atmospheric blockage, transfer of dry and relatively cold air from the north to the region, and cause below-normal

winter precipitation and temperature values in the AR. During the NAO (-), Genoa cyclone is more active and westerly/southwesterly winds transfer relatively warm and humid air to the western of Türkiye, which result in positive precipitation and temperature anomalies at the stations in AR.

During dry summer, the interaction between expanded Azores high and summer Asiatic monsoon low enable transferring of warm air advection at low levels to the AR, which result in above-normal temperature and below-normal precipitation records. On the other hand, as a consequence of the penetration of Asiatic monsoon low to the inner parts of Türkiye, significant amount of moisture is transported from the northern Aegean Sea to the AR by northwesterly winds and positive precipitation anomalies and below-normal temperature measurements occur in the stations of AR during wet summer episodic events.

REFERENCES

- Acharki, S., Singh, S. K., do Couto, E. V., Arjdal, Y., Elbeltagi, A. (2023). Spatio-temporal distribution and prediction of agricultural and meteorological drought in a Mediterranean coastal watershed via GIS and machine learning. *Physics and Chemistry of the Earth, Parts A/B/C*, 131, 103425. <https://doi.org/10.1016/j.pce.2023.103425>
- Achite, M., Simsek, O., Adarsh, S., Hartani, T., Caloiero, T. (2023). Assessment and monitoring of meteorological and hydrological drought in semiarid regions: The Wadi Ouahrane basin case study (Algeria). *Physics and Chemistry of the Earth, Parts A/B/C*, 130, 103386. <https://doi.org/10.1016/j.pce.2023.103386>
- Afshar, M. H., Bulut, B., Duzenli, E., Amjad, M., Yilmaz, M. T. (2022). Global spatiotemporal consistency between meteorological and soil moisture drought indices. *Agricultural and Forest Meteorology*, 316, 108848. <https://doi.org/10.1016/j.agrformet.2022.108848>
- Apurv, T., Sivapalan, M., Cai, X. (2017). Understanding the role of climate characteristics in drought propagation. *Water Resources Research*, 53(11), 9304–9329. <https://doi.org/10.1002/2017WR021445>
- Akkoyunlu, B. O., Baltaci, H., Tayanc, M. (2019). Atmospheric conditions of extreme precipitation events in western Turkey for the period 2006-2015. *Natural Hazards and Earth System Sciences*, 19, 107-119.
- Baltaci, H. (2017). Meteorological analysis of flash floods in Artvin (NE Turkey) on 24 August 2015. *Natural Hazards and Earth System Sciences*, 17, 1221-1230.
- Baltaci, H. (2019). Spatiotemporal variability of climate extremes in the Marmara Region (NW Turkey). *International Journal of Global Warming*, 18, 239–259.
- Baltaci, H. (2020). The role of atmospheric processes associated with a flash-flood event over northwestern Turkey. *Pure and Applied Geophysics*, 177, 3513-3526.
- Baltaci, H. (2021). Temporal evolution of surface humidity in Turkey: Recent trends and the role of sea surface temperatures. *Theoretical and Applied Climatology*, 146, 1277-1296.
- Baltacı, H., Göktürk, O. M., Kindap, T., Karaca, M. (2015). Atmospheric circulation types in Marmara Region (NW Turkey) and their influence on precipitation. *International Journal of Climatology*, 35, 1810-1820.
- Baltaci, H., Tumay, G., Labban, A. H. (2023). Impact of drought conditions on air pollution over Turkey. *International Journal of Climatology*, 43(8), 3647–3663. <https://doi.org/10.1002/joc.8050>

- Baltacı, H., Kındap, T., Ünal, A., Karaca, M. (2017). The influence of atmospheric circulation types on regional patterns of precipitation in Marmara (NW Turkey). *Theoretical and Applied Climatology*, 127, 563-572.
- Baltacı, H., Akkoyunlu, B. O., Tayanc, M. (2018a). Relationships between teleconnection patterns and Turkish climatic extremes. *Theoretical and Applied Climatology*, 134, 1365-1386.
- Baltacı, H., Akkoyunlu, B. O., Tayanc, M. (2018b). An extreme hailstorm on 27 July 2017 in Istanbul, Turkey: Synoptic scale circulation and thermodynamic evaluation. *Pure and Applied Geophysics*, 175, 3727-3740.
- Baltacı, H., Arslan, H. (2022). Seasonal and regional variability of wet and dry spell characteristics over Turkey. *Atmospheric Research*, 270, 106083.
- Baltacı, H., Ozturk, Y., Akkoyunlu, Y. (2024). Long-term variations and synoptic features of heat waves in Türkiye. *International Journal of Global Warming*, 33(1), 51-68.
- Beyaztas, U., Bickici Arikan, B., Beyaztas, B. H., Kahya, E. (2018). Construction of prediction intervals for Palmer Drought Severity Index using bootstrap. *Journal of Hydrology*, 559, 461–470. <https://doi.org/10.1016/j.jhydrol.2018.02.021>
- Dabanlı, I., Mishra, A. K., Şen, Z. (2017). Long-term spatio-temporal drought variability in Turkey. *Journal of Hydrology*, 552, 779–792. <https://doi.org/10.1016/j.jhydrol.2017.07.038>
- Dabanlı, I. (2019). Temperature difference relationship among precipitation, dry days, and spells in Turkey. *Theoretical and Applied Climatology*, 135, 765-772.
- Demirtaş, M. (2016). The October 2011 devastating flash flood event of Antalya: triggering mechanisms and quantitative precipitation forecasting. *Quarterly Journal of the Royal Meteorological Society*, 142(699), 2336-2346.
- Demirtaş, M. (2018). The high-impact 2007 hot summer over Turkey: atmospheric blocking and heat-wave episodes. *Meteorological Applications*, 25(8), 406-413.
- Duzenli, E., Tabari, H., Willems, P., Yilmaz, M. T. (2018). Decadal variability analysis of extreme precipitation in Turkey and its relationship with teleconnection patterns. *Hydrological Processes*, 32, 3513-3528.
- Gouveia, C. M., Trigo, R. M., Beguería, S., Vicente-Serrano, S. M. (2017). Drought impacts on vegetation activity in the Mediterranean region: An assessment using remote sensing data and multi-scale drought indicators. *Global and Planetary Change*, 151, 15–27. <https://doi.org/10.1016/j.gloplacha.2016.06.011>
- Gumus, V. (2023). Evaluating the effect of the SPI and SPEI methods on drought monitoring over Turkey. *Journal of Hydrology*, 626, 130386.

Gumus, V., Algin, H. M. (2017). Meteorological and hydrological drought analysis of the Seyhan–Ceyhan River Basins, Turkey. *Meteorological Applications*, 24(1), 62–73. <https://doi.org/10.1002/met.1605>

Gumus, B., Oruc, S., Yucel, I., Yilmaz, M. T. (2023). Impacts of climate change on extreme climate indices in Türkiye driven by high-resolution downscaled CMIP6 climate models. *Sustainability*, 15, 7202.

Habibi, B., Meddi, M., Torfs, P. J. J. F., Remaoun, M., Van Lanen, H. A. J. (2018). Characterisation and prediction of meteorological drought using stochastic models in the semi-arid Chélif–Zahrez basin (Algeria). *Journal of Hydrology: Regional Studies*, 16, 15–31. <https://doi.org/10.1016/j.ejrh.2018.02.005>

He, Q., Xu, B., Dieppois, B., Yetemen, O., Sen, O. L., Klaus, J., Schoppach, R., Çağlar, F., Fan, P. Y., Chen, L., Danaila, L., Massei, N., Chun, K. P. (2022). Impact of the North Sea-Caspian pattern on meteorological drought and vegetation response over diverging environmental systems in western Eurasia. *Ecohydrology*, 15, e2446.

Heddinghaus, T. R., Sabol, P. (1991). A review of the Palmer Drought Severity Index and where do we go from here? 242–246.

Hertig, E., Trambly, Y. (2017). Regional downscaling of Mediterranean droughts under past and future climatic conditions. *Global and Planetary Change*, 151, 36–48. <https://doi.org/10.1016/j.gloplacha.2016.10.015>

Hochman, A., Alpert, P., Kunin, P., Rostkier-Edelstein, D., Harpaz, T., Saaroni, H., Messori, G. (2020). The dynamics of cyclones in the twenty-first century: The Eastern Mediterranean as an example. *Climate Dynamics*, 54, 561–574.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Wollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., Joseph, D. (1996). The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society*, 77, 437–471.

Karaca, M., Deniz, A., Tayanç, M. (2000). Cyclone track variability over Turkey in association with regional climate. *International Journal of Climatology*, 20, 1225–1236.

Kumanlioglu, A. A. (2023). A new approach for characterization of meteorological and hydrological droughts: Cumulative standardized drought index (CSDI). *Physics and Chemistry of the Earth*, 131. <https://doi.org/10.1016/j.pce.2023.103420>

Kutiel, H., Maheras, P., Türkeş, M., Paz, S. (2002). North Sea-Caspian Pattern (NCP) an upper level atmospheric teleconnection affecting the eastern Mediterranean: Implications on the regional climate. *Theoretical and Applied Climatology*, 72(3-4), 173–192.

Lolis, C. J., Türkeş, M. (2016). Atmospheric circulation characteristics favouring extreme precipitation in Turkey. *Climate Research*, 71, 139–153.

- McKee, T. B., Doesken, N. J., Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In *Eighth Conference on Applied Climatology*.
- Mehr, A. D., Sorman, A. U., Kahya, E., Afshar, M. H. (2020). Climate change impacts on meteorological drought using SPI and SPEI: case study of Ankara, Turkey. *Hydrological Sciences Journal*, 65(2), 254–268. <https://doi.org/10.1080/02626667.2019.1691218>
- Mehr, A. D., Sorman, A. U., Kahya, E., Afshar, M. H. (2020). Climate change impacts on meteorological drought using SPI and SPEI: case study of Ankara, Turkey. *Hydrological Sciences Journal*, 65(2), 254–268. <https://doi.org/10.1080/02626667.2019.1691218>
- Merino, A., López, L., Hermida, L., Sánchez, J. L., García-Ortega, E., Gascón, E., Fernández-González, S. (2015). Identification of drought phases in a 110-year record from Western Mediterranean basin: Trends, anomalies and periodicity analysis for Iberian Peninsula. *Global and Planetary Change*, 133, 96–108. <https://doi.org/10.1016/j.gloplacha.2015.08.007>
- Mishra, A. K., Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, 391(1–2), 202–216. <https://doi.org/10.1016/j.jhydrol.2010.07.012>
- Palmer, W. C. (1965). Meteorological drought. Vol. 30. *US Department of Commerce, Weather Bureau*.
- Pekpostalci, D. S., Tur, R., Mehr, A. D., Ghaffari, M. A. V., Dąbrowska, D., Nourani, V. (2023). Drought monitoring and forecasting across Turkey: A contemporary review. *Sustainability*, 15(7), 6080.
- Sen, B., Topcu, S., Türkeş, M., Sen, B., Warner, J. F. (2012). Projecting climate change, drought conditions and crop productivity in Turkey. *Climate Research*, 52, 175–191.
- Serkendiz, H., Tatli, H., Kılıç, A., Çetin, M., Sungur, A. (2024). Analysis of drought intensity, frequency and trends using the SPEI in Turkey. *Theoretical and Applied Climatology*, 155, 2997–3012.
- Sheffield, J., Wood, E. F., Roderick, M. L. (2012). Little change in global drought over the past 60 years. *Nature*, 491(7424), 435–438.
- Sneyers, R. (1990). On the statistical analysis of series of observations. *WMO Technical Note 143, World Meteorological Organization*, Geneva, 192pp.
- Sönmez, F. K., Kömüscü, A. Ü., Erkan, A., Turgu, E. (2005). An analysis of spatial and temporal dimension of drought vulnerability in Turkey using the Standardized Precipitation Index. *Natural Hazards*, 35, 243–264.
- Toker, E., Ezber, Y., Sen, O. L. (2021). Numerical simulation and sensitivity study of a severe hailstorm over Istanbul. *Atmospheric Research*, 250, 105373..

Tosunoglu, F., Can, I., Kahya, E. (2018). Evaluation of spatial and temporal relationships between large-scale atmospheric oscillations and meteorological drought indexes in Turkey. *International Journal of Climatology*, 38(12), 4579–4596. <https://doi.org/10.1002/joc.5698>

Tsesmelis, D. E., Leveidioti, I., Karavitis, C. A., Kalogeropoulos, K., Vasilakou, C. G., Tsatsaris, A., Zervas, E. (2023). Spatiotemporal Application of the Standardized Precipitation Index (SPI) in the Eastern Mediterranean. *Climate*, 11(5), 95. <https://doi.org/10.3390/cli11050095>

Türkeş, M., Erlat, E. (2003). Precipitation changes and variability in Turkey linked to the North Atlantic Oscillation during the period 1930-2000. *International Journal of Climatology*, 23(14), 1771-1796.

Türkeş, M., Erlat, E. (2005). Climatological responses of winter precipitation in Turkey to variability of the North Atlantic Oscillation. *Theoretical and Applied Climatology*, 81(1-2), 45-69.

Türkeş, M., Erlat, E. (2018). Variability and trends in record air temperature events of Turkey and their associations with atmospheric oscillations and anomalous circulation patterns. *International Journal of Climatology*, 38(14), 5182-5204.

Unal, Y. S., Tan, E., Montes, S. (2013). Summer heat waves over western Turkey between 1965 and 2006. *Theoretical and Applied Climatology*, 112, 339-350.

Unal, Y. S., Deniz, A., Toros, H., Incecik, S. (2012). Temporal and spatial patterns of precipitation variability for annual, wet, and dry seasons in Turkey. *International Journal of Climatology*, 32(3), 392-405.

Vicente-Serrano, S. M., Beguería, S., López-Moreno, J. I. (2010). A multiscale drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate*, 23(7), 1696–1718. <https://doi.org/10.1175/2009JCLI2909.1>

Villani, L., Castelli, G., Piemontese, L., Penna, D., Bresci, E. (2022). Drought risk assessment in Mediterranean agricultural watersheds: A case study in Central Italy. *Agricultural Water Management*, 271, 107748. <https://doi.org/10.1016/j.agwat.2022.107748>

Wang, Z., Yang, Y., Zhang, C., Guo, H., Hou, Y. (2022). Historical and future Palmer Drought Severity Index with improved hydrological modeling. *Journal of Hydrology*, 610, 127941. <https://doi.org/10.1016/j.jhydrol.2022.127941>

Wu, G., Chen, J., Kim, J.-S., Gu, L., Lee, J.-H., Zhang, L. (2022). Impacts of climate change on global meteorological multi-year droughts using the last millennium simulation as a baseline. *Journal of Hydrology*, 610, 127937. <https://doi.org/10.1016/j.jhydrol.2022.127937>

BIOGRAPHY

Sevda Merve ALYAGUT completed her undergraduate studies in the Department of Geography at Sakarya University Faculty of Science and Letters between 2013 and 2017. Following her undergraduate studies, she served as a Geography Teacher at Güzeller Education Institutions. During 2022, she started master programme in the Institute of Earth & Marines Sciences at Gebze Technical University (GTU-IEMS), Türkiye.

APPENDICES

Appendices A: Publishments produced by the thesis study.

ALYAGUT M. S., BALTACI H., (2024). Long-Term Trends of Meteorological Drought Over Türkiye. Lisansüstü Araştırmalar Sempozyumu. 30/05-31/05/2024. Kocaeli.