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Evaluation of Drought Using Meteorological Drought Indices, a Case Study: Alanya (Türkiye)

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Abstract

Drought is one of the most important challenges that many countries, especially countries in the Middle East region, are struggling with. Based on this, the study and monitoring of hydrological and drought factors is an important issue that can have a significant impact on management decisions in the field of water resources, especially in crisis management. Therefore, investigating the drought parameters is very important to understand the drought situation of a region. In this study, Alanya region, which is located on the southern coast of Turkey, was selected as a case study for drought analysis. Four drought indices for the selected region including: China Z-Index (CZI), Standardized Precipitation Index (SPI), Modified China Z-Index (MCZI) and Z-Score Index (ZSI) have been investigated. All these indicators have been investigated and evaluated using time scales of 1, 6, 12 and 24 months, the coefficient of determination (R^2) has been calculated for each drought index with a different time scale and their results have been compared. The findings of the research showed that SPI and CZI drought indices performed better than other selected drought indices in identifying and effectively tracking drought severity. In addition to the study of dry events, wet events were also investigated, which indicates the presence of consecutive floods in the last years of the studied period in the region. The results indicated similar very dry events for the selected indicators in the 6-month period. Also, the rainfall trend for the period of 2015-2022 was taken into consideration to examine the rainfall of the last eight years. The results show that precipitation has decreased in recent years and has a downward trend in most months of the period in question, and the possibility of flood events due to sudden showers in the region has increased due to the continuation of droughts experienced in the years before 2015. Investigating soil moisture and vegetation for the selected period in the study area is also important for the evaluation of the drought level. Evaluation of the available land (vegetation) cover maps of the years 1975, 1985, 2000, 2010, 2020 and 2022 show that the vegetation cover has weakened over the years, and it has been evaluated as an indicator that the danger of drought in the region has increased.

Keywords
Drought, Z-Score Index (ZSI), Modified China Z Index (MCZI), Standardized Precipitation Index (SPI), China Z Index (CZI)

Meteorolojik Kuraklık İndeksleri Kullanarak Kuraklık Değerlendirmesi: Alanya (Türkiye) Vaka Çalışması

Özet

Kuraklık, başta Orta Doğu bölgesi ülkeleri olmak üzere pek çok ülkenin mücadele ettiği en önemli sorunlardan biridir. Buradan yola çıkarak hidrolojik ve kuraklık faktörlerinin incelenmesi ve izlenmesi, su kaynakları alanında, özellikle kriz yönetiminde yönetim kararlarını önemli ölçüde etkileyebilecek önemli bir konudur. Bu nedenle kuraklık parametrelerinin araştırılması bir bölgenin kuraklık durumunun anlaşılması açısından oldukça önemlidir. Bu çalışmada Türkiye'nin güney kıyısında yer alan Alanya bölgesi kuraklık analizi için örnek vaka çalışması olarak seçilmiştir. Seçilen bölge için Çin Z-İndeksi (CZI), Standart Yağış İndeksi (SPI), Modifiye Çin Z-İndeksi (MCZI) ve Z-Score İndeksi (ZSI) dahil olmak üzere dört kuraklık indeksi araştırılmıştır. Tüm bu göstergeler 1, 6, 12 ve 24 aylık zaman ölçekleri kullanılarak incelenmiş ve değerlendirilmiş olup, her bir kuraklık indeksi için farklı zaman ölçeği için R^2 hesaplanmış ve sonuçları karşılaştırılmıştır. Araştırmanın bulguları, SPI ve CZI kuraklık endekslerinin, kuraklık şiddetini belirleme ve etkili bir şekilde izleme konusunda seçilen diğer kuraklık endekslerinden daha iyi performans gösterdiğini göstermiştir. Kurak olayların incelenmesinin yanı sıra, bölgede incelenen dönemin son yıllarında art arda taşkınların varlığına işaret eden ıslak olaylar da araştırılmıştır. Sonuçlar, seçilen göstergeler için 6 aylık dönemde benzer çok kuru olayların yaşandığını gösterdi. Ayrıca son sekiz yılın yağışlarının incelenmesinde 2015-2022 dönemi yağış eğilimi de dikkate alınmıştır. Sonuçlar, son yıllarda yağışların azaldığı ve söz konusu dönemin çoğu ayında düşüş eğiliminde olduğunu, 2015 yılı öncesi yıllarda yaşanan kuraklıkların devam ettiği nedeniyle bölgede ani sağanaklardan dolayı taşkın olaylarının yaşanma olasılığının arttığını göstermektedir. Çalışma alanında seçilen döneme ait toprak nemi ve bitki örtüsünün araştırılması kuraklık düzeyinin değerlendirilmesi açısından da önemlidir. 1975, 1985, 2000, 2010, 2020 ve 2022 yıllarına ait bitki örtüsü haritalarının incelenmesi sonucu, bitki örtüsünün yıllar geçtikçe zayıfladığı görülmekte olup, bölgedeki kuraklık tehlikesinin arttığının bir göstergesi olarak değerlendirilmiştir.

Anahtar Sözcükler
Kuraklık, Z-Skor İndisi (ZSI), Modifiye Çin Z Indisi (MCZI), Standart Yağış İndisi (SPI), Çin Z İndisi (CZI)

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1. Introduction

Natural disasters are one of the main obstacles to sustainable development. Global warming has a major impact on climate of the special region (Angelidis et al., 2012). Therefore, most of extreme events need got attention. In the case of drought evaluation, trend analysis on precipitation and flow data is one of the most important methods in order to understand the magnitude of the drought. Drought is one of the major challenges relevant to weather in all around the world (Shah et al., 2015), and governments and international organizations are trying to identify and manage it. In the past few decades, lots of examples are available for devastating drought events. The concept of aridity is quite different from drought. The aridity is only confined to areas with low rainfall and is a permanent state of the climate. While, drought can usually occur in any climate, even humid. Drought has four types including: i) hydrological, ii) meteorological, iii) agricultural and iv) socio-economic (Shah et al., 2015; Zarch et al., 2015). Drought monitoring has an important role to predicting and analyzing drought impacts (Guttman, 1988; Bonaccorso et al., 2003). The main manifestation of meteorological drought is a decrease in rainfall below normal (long-term average). A decrease in rainfall is expected to lead to reduced soil moisture, runoffs, and groundwater levels in the future. A large-scale analyzed comparison of dry and moist summers in the midwest USA was done by Weaver et al. (2023). A comprehensive statistical assessment of SPI and SPEI drought indices using was done to monitor drought status in Bangladesh by Uddin et al. (2020). In another research, CZI and SPI drought indices were compared for evaluation of the drought in the Hirfanli Dam basin of Turkey by Zeybekoğlu and Aktürk (2021). A case study was done 52 years data using five drought indices including the Standardized Precipitation Index (SPI), Statistical Z-Score Index (ZSI), Rainfall Anomaly Index (RAI), Standardized Precipitation Evapotranspiration Index (SPEI), and Reconnaissance Drought Index (RDI) on the Euphrates basin by Katipoğlu et al. (2020).

In a study conducted in a Semi-Arid River Basin of India, Wable et al. (2019) determined that the most appropriate time frame for comparing drought indices is the 9-month scale, with the SPEI-9 being the most suitable drought index for monitoring drought conditions in their chosen study area. They assessed five meteorological drought indices, which included Percent Departure from Normal (PDN), Effective Drought Index (EDI), Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), and Standardized Precipitation Evapotranspiration Index (SPEI) (Wable et al., 2019). Salehnia et al. (2017) conducted an evaluation of eight precipitation-based drought indices, which included SPI (Standardized Precipitation Index), PNI (Percent of Normal Index), DI (Deciles index), EDI (Effective Drought Index), CZI (China-Z index), MCZI (Modified CZI), RAI (Rainfall Anomaly Index), and ZSI (Z-score Index). These indices were calculated using both observed precipitation data and AgMERRA gridded precipitation data. The purpose of their study was to assess historical drought events that occurred in the Kashafrood Basin of Iran during the period 1987- 2010 (Salehnia et al., 2017). Guttman (1988) made a comparison between SPI and PDSI in 1998, using spectral analysis. Wu et al. (2001) designate China-z Index (CZI), SPI and statistical Z-Score indices four, 1, 3-, 6-, 9- and 12-month time scales for four states in China from January 1951 to December 1998 for presenting dry and wet climates, flood and earthquake events. Bonaccorso et al. (2003) worked on spatial variability of drought. They evaluated on the analysis of the SPI in Sicily, Italy. Loukas et al. (2008) compared three drought indices in Greece. The using data were collected from 28 stations for 40 years (1960-2000). The Standardized Precipitation Index (SPI) was applied to 3 month and 12-month time scales using monthly mean precipitation data for the time series of over 60 years by Rahmat et al. (2012).

The main purpose of this study is to evaluate and compare the performance of multiple drought indices using different time-scales for indicating the number and magnitude of drought events and indicating the level of drought danger. Considering that drought has started to show its effects in Turkey in recent years, it shows the importance of researching drought throughout Turkey. In this study, the Alanya region in Türkiye, a touristic region that has not been examined in terms of drought before, was investigated.

2. Study area

Alanya is situated along the southern coast of Turkey, at an elevation of approximately 14 meters above sea level. This coastal region encompasses a total area of 175,658 hectares, spanning between 36° 30' 07" and 36° 36' 31" north latitudes and 31° 38' 40" and 32° 32' 02" east longitudes (Figure 1).

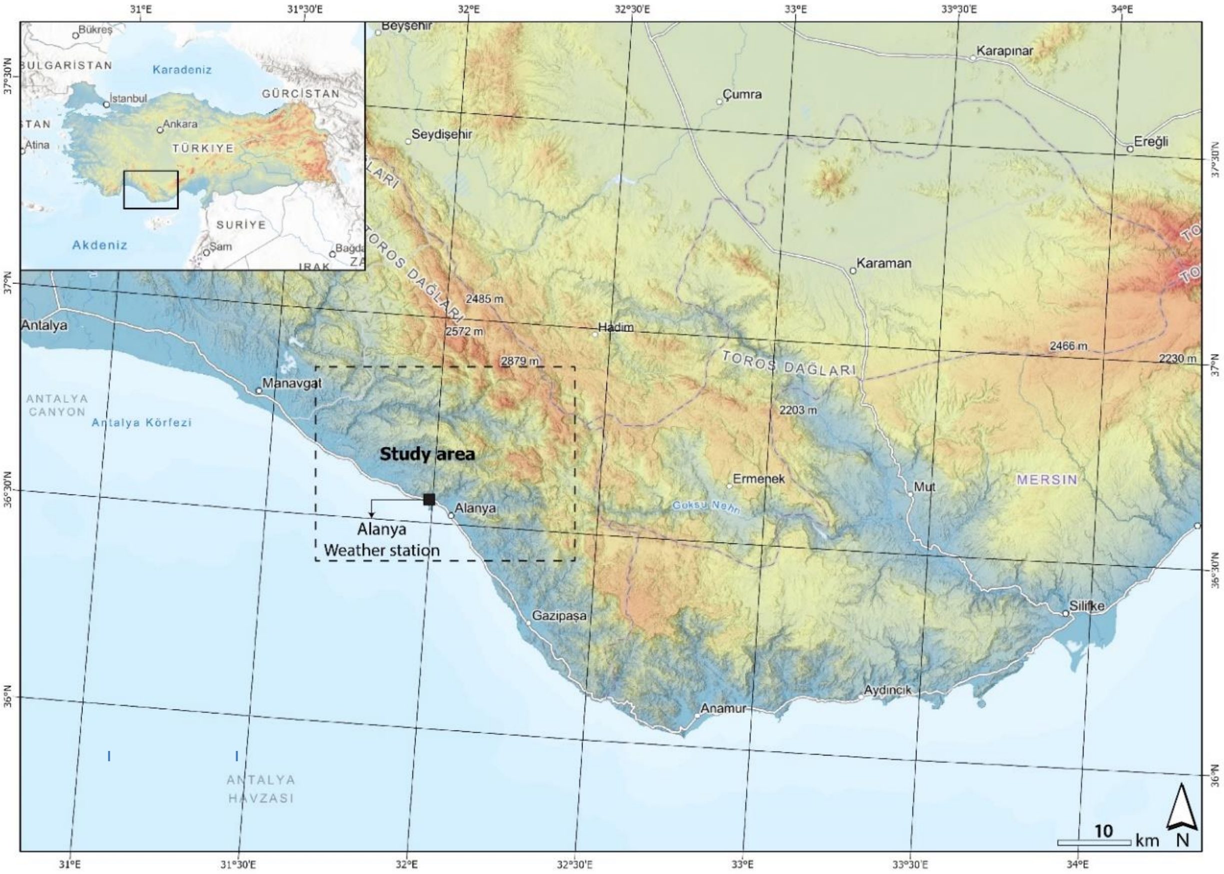


Figure 1: Location of the study area

Alanya is located in the Mediterranean thermal climate zone, characterized by specific weather patterns. This area experiences mild and rainy winters, while summers tend to be hot and dry. The region has a warm and temperate climate overall, with significantly more rainfall during the winter months compared to the relatively dry summers. During the summer, the streams in the region often see reduced flow rates, and in some cases, some rivers may even completely run dry. However, in autumn, water levels gradually rise. The warmest and coldest months in Alanya are August and January, with average temperatures around 26.4°C and 11.8°C, respectively. The approximate average annual temperature is around 18.7°C. The highest recorded temperature reached 41.9°C, while the lowest recorded temperature dipped to -3.1°C. Average temperature (ºC) and total annual precipitation (mm) maps for the study area are shown in Figure 2.

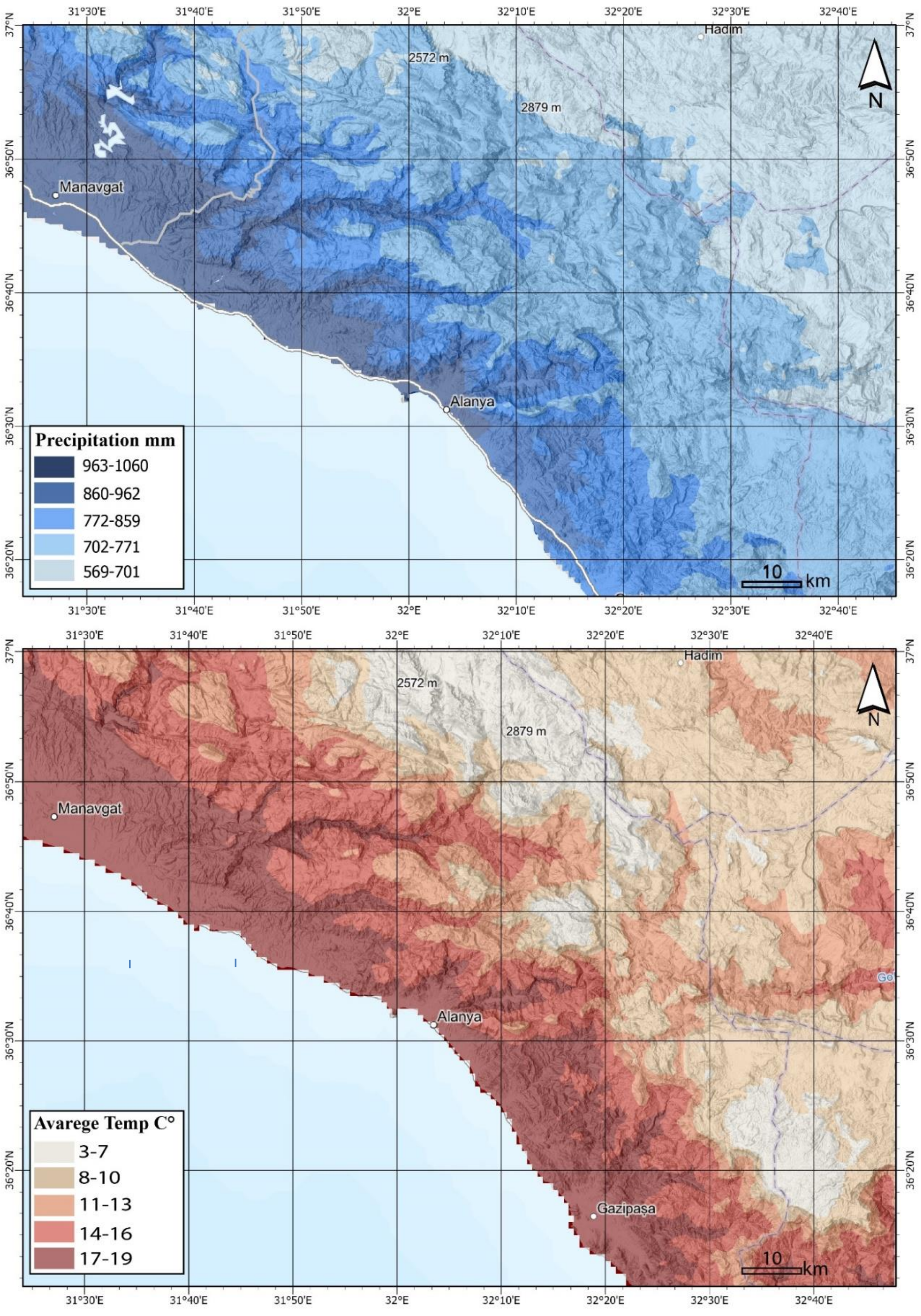


Figure 2: Average temperature (ºC) and total annual precipitation (mm) in study area (Fick & Hijmans, 2017)

3. Material and Methods

In Antalya, annual rainfall per square meter is approximately 946 kg/m^2. The maximum rainfall is 237 kg (in December), the lowest precipitation is 0.2 kg (in August). Minimum and maximum values for yearly average flows are 13.9 m^3/sec and 55.6 m^3/sec, respectively.

In addition, the measured minimum and maximum values for daily precipitation in the selected area are 0 and 205.7 mm. These measurments about the precipitation show that the selected area experienced the annual average precipitation equal to 1081.7 mm, approximately. 16.9% of annual precipitation occurs in spring (March-May), 1.2% in summer (June-August), 24.4% in fall (September-November) and 57.5% in winter (December-February) (General Directorate of Water Management, 2016). Measurments show that the Alanya has dry periods in June, July, August and September, mostly. The measured yearly average precipitation (mm) and monthly mean total precipitation for the period 1954-2022 is presented in Figure 3a and 3b, respectively.

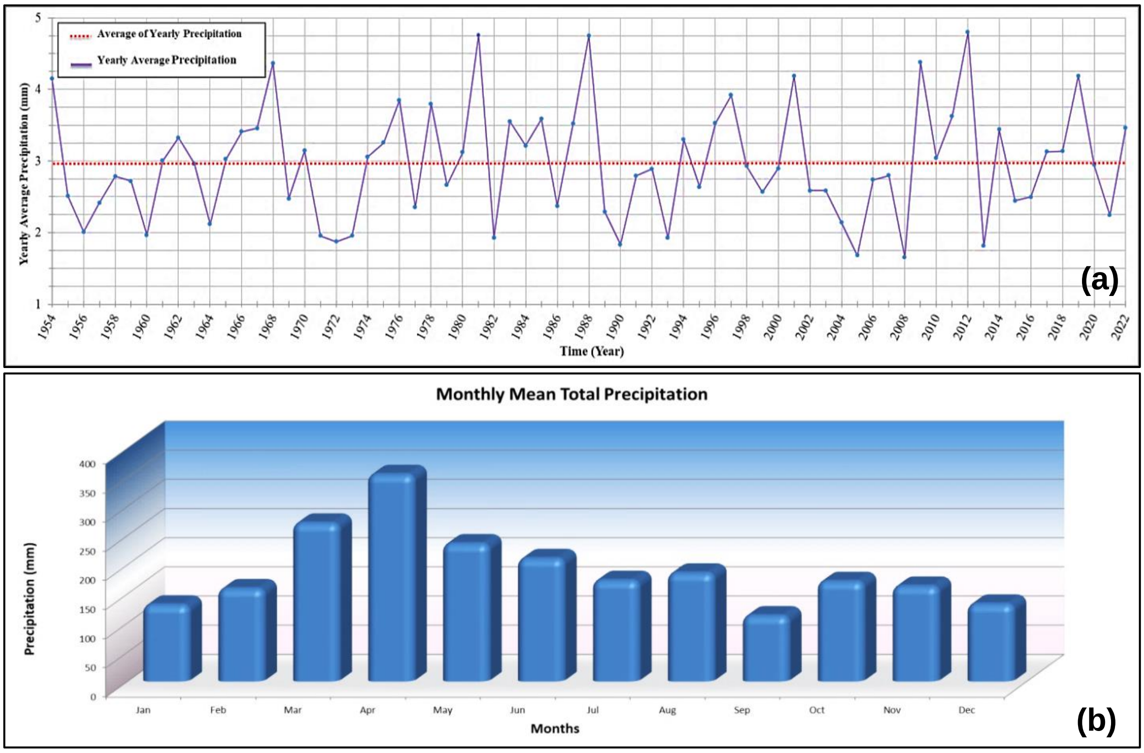


Figure 3: a) Yearly average precipitation (mm) for the period 1954-2022, and b) Monthly mean total precipitation in the study area

Type of data used for obtaining of the drought indices are monthly average precipitations, which were calculated from the total daily precipitations. The selected data are the recorded data from the selected station (Alanya Station presented in Figure 1) between 1954-2022, which covers 69 years (828 months), totally. The recorded data show that the 78% (19967 days) of the days of the 69-year period had no rainfall. By examining the available data for the selected station, some calculated statistical descriptions are given in the Table 1.

Table 1: Observed statistics from Alanya station

No. of years	No. of months	No. of data	Type of data	Min.	Max.	Avg.	Median	SD	σ^2	Skewness	Kurtosis
69	828	25613	Daily	0	205.7	2.96	0	10.38	107.84	6.03	53.61

Selected data must follow the normal distribution to be able to perform any parametric test on the data. In this regard, to understanding that the data used in the this study is normally distributed or not, the Kolmogorov-Smirnov Normality test was used. The result of this test is given in Table 2a. Based on the results of this test, as it is clear, the calculated Asymp. Sig value is greater than 0.05 (Asymp. Sig. > 0.05). It shows that the data used in this study is normally distributed. In addition to the Kolmodorov-Smirnov normality test, Shapiro-Wilk, Anderson-Darling, Lilliefors, and Jarque-Bera Normality tests were done for the data (Table 2b). Based on the calculated p-value for these tests, it can be seen that the p-value was greater than 0.05 for all four tests, which means that the data is normal distributed. The Mann-Kendall trend test is used for the used data of the study area to determine whether the data value is increasing over time or decreasing, and whether the trend in either direction is statistically significant. Test statistic value is important parameter, in which the positive Mann-Kendall statistic value means that the trend is increasing. While, the negative values of this parameter show that the trend is decreasing. By evaluating the results of Mann-Kendall test given in Table 3, it is obvious that the trend is positive for the used data of this study, which presents an increasing trend.

Table 2: Normality tests based on a) Kolmogorov-Smirnov Test, and b) Shapiro-Wilk, Anderson-Darling, Lilliefors, and Jarque-Bera Normality tests

(a)		**Normal Parameters**		**Most Extreme Differences**				
No. of data	**Type of data**	**Mean**	**Std. D.**	**Absolute**	**Positive**	**Negative**	**Test Statistics**	**Asymp. Sig.**
69	Yearly	2.96	0.79	0.061	0.061	-0.05	0.061	0.2

(b)	p-value			
Variable\Test	Shapiro-Wilk	Anderson-Darling	Lilliefors	Jarque-Bara
Rainfall	0.075	0.285	0.758	0.266

Table 3: Mann-Kendall Test

Statistics							
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Rainfall	69	0	69	1.658	4.800	2.963	0.787

Mann-Kendall trend test					**Sen's Slope**	
Kendall's tau	S	Var(S)	p-value	Alpha	Slope	Intercept
0.046	108	37275.33	0.576	0.05	0.003	-2.72

In scientific literature, droughts are commonly classified into four main categories: meteorological, hydrological, agricultural, and socio-economic (Wilhite & Glantz, 1985; Mishra & Singh, 2010; Tallaksen & Lanen, 2004). For this particular study, meteorological drought was the focus, with an emphasis on analyzing drought using rainfall data. In this research, four distinct drought indices were chosen for the initial 61 years of the study, spanning 732 months. These indices included the Standard Precipitation Index (SPI), China Z-Index (CZI), Modified China Z-Index (MCZI), and Z-Score Index (ZSI). These selected indices each assessed various aspects of drought solely based on precipitation data. Furthermore, data from 96 monthly total precipitation measurements (in millimeters) and 8 yearly total precipitation measurements (in millimeters) covering the period from 2015 to 2022 were incorporated to evaluate trends in precipitation over the last eight years, focusing on short-term trends. All calculations related to drought indices and statistical analysis were done using Microsoft Excel and SPSS software.

3.1. Standard Precipitation Index (SPI)

Standardized Precipitation Index (SPI) was developed by McKee et al. (1993), which is based on the probability of precipitation for any time scale. The only required input parameter in calculation of SPI is precipitation, that made it the powerful, practical and flexible index. In this method, the statistical distribution of the recorded rainfall data is converted to the normal distribution, and then the normalized data are used with relation (Wable et al., 2019). The SPI is calculated by Equation 1.

$$SPI = \frac{P_i - \bar{P}}{\delta} \quad (1)$$

Where in, P_i and $\bar{P}$ are amount of precipitation and the average long-term precipitation for the intended period, respectively. δ is the standard deviation of precipitation. The calculated value of this index varies between -2 and +2, and the smaller value of SPI indicates the more severe of drought in the study area. Figure 4 shows this state.

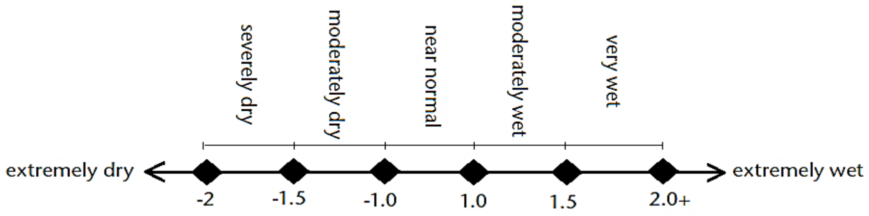


Figure 4: Values and classification of SPI

Accordingly, SPI with calculated values equal to or less than -1 indicates the start of the drought and, in contrast, the drought ends with positive values of the SPI. On the other hand, calculated values less than -2 and more than +2 for this index, indicate extreme drought and extreme wet conditions, respectively.

3.2. China Z-Index (CZI)

The CZI is based on the Wilson-Hilferty cube-root transformation (Kendall & Stuart, 1977). This index is calculated using Equation 2 with assuming that the precipitation data follow the Pearson Type III distribution.

$$CZ_{ij} = \frac{6}{C_{si}}\left[\frac{C_{si}}{2}\varphi_{ij} + 1\right]^{1/3} - \frac{6}{C_{si}} + \frac{C_{si}}{6} \qquad (2)$$

In which, CZ_{ij} is the China Z-Index, j is the current month, C_{si} and φ_{ij} are the skewness coefficient and standart variation, which could calculated using Equations 3 and 4, respectively.

$$C_{si} = \frac{\sum_{j=1}^{n}(x_j - \bar{x})^3}{n\,\sigma_i^3} \qquad (3)$$

$$\varphi_{ij} = \frac{x_{ij} - \overline{x_i}}{\sigma_i} \qquad (4)$$

Where, n is the total number of recorded months and x_{ij} is precipitation in month j. The same SPI classification is used to classify this index.

3.3. Modified China Z-Index (MCZI)

To calculate the MCZI, the median of precipitation is used instead of the mean of precipitation in the calculation of the CZI (Mahmoudi et al., 2019).

3.4. Z Score Index (ZSI)

The Z-score index was suggested by Heim & Kotil (Morid et al., 2006). It is calculated by subtracting the long-term mean from an individual precipitation value and then divided the difference by standard deviation (S). In addition, when rainfall data is incomplete, use of CZI index can be preferred over SPI index ZSI is calculated using Equation 5. In this equation, P_i is the precipitation in a specific month, S is the standard deviation, and P is the mean monthly precipitation.

$$ZSI = \frac{P_i - \bar{P}}{S} \qquad (5)$$

4. Results and Discussion

In this research, considering the importance of the subject, drought analysis was carried out in the area using four indices including SPI, ZSI, CZI and MCZI. Beside using of these indices, the use of different time scales were be useful, because it allows the effects of a precipitation deficit on different water resource components such as reservoir storage, groundwater, stream flow and soil moisture to be assessed (Morid et al., 2006).

Drought characteristics including duration, severity, and intensity were analyzed at selected station for period of 1954-2014. The number of drought months with different magnitude classes at short and long timescales such as 1-,6-,12- and 24-months for the mentiond defined indices are shown as Figure 5.

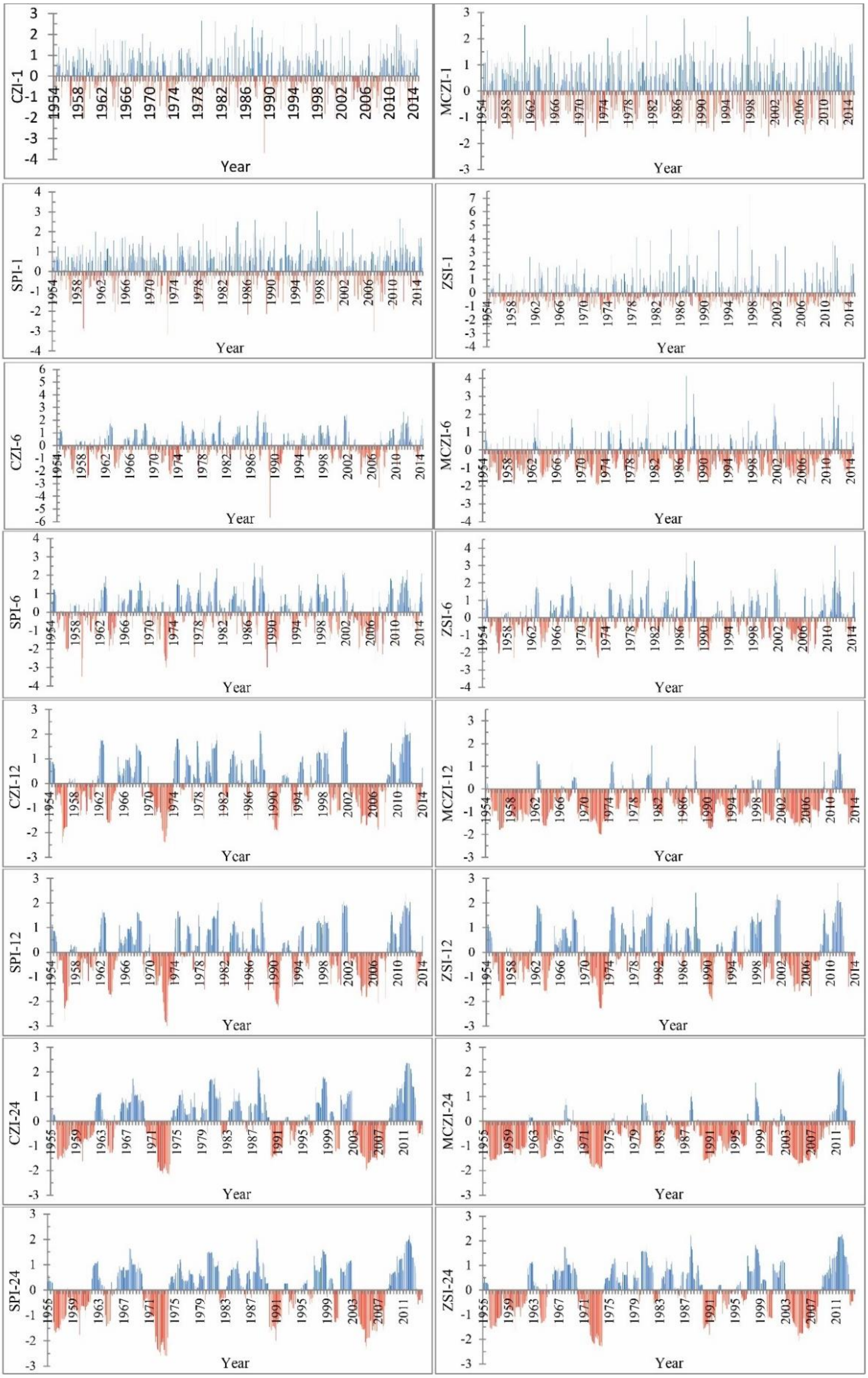


Figure 5: Calculated drought indices (1955-2014)

With evaluating Figure 5, it is clear that major extreme drought events occured during the periods 1956-1958, 1972-1974, 1989-1992 and 2005-2008, in the selected time period. Whereas, major extreme wet events occured during the period 1988-1990, 2001-2002 and 2011-2013. From Figure 1, Tables 6 and 7 in years between 2005 and 2008 the region experienced one of the longest drought events. For 1-, 6-, 12- and 24-months time scales, selected stations showed statistically significant upward trend for whole the period.

Table 4: Slope of trend lines for different indices and time-scales for the period of 1955-2014.

	Time Scale (1954-2014)			
	1-	6-	12-	24-
SPI	+0.0001	+0.0003	+0.0004	+0.0006
ZSI	+0.0002	+0.0004	+0.0004	+0.0007
CZI	+0.0001	+0.0004	+0.0004	+0.0007
MCZI	+0.0006	+0.0004	+0.0004	+0.0006

From the Table 4 it is obviouse that the slopes are positive. Investigating Table 3 shows that the CZI and ZSI have the highest slope of trendline in the term of 24-months time scale, which is equal to 0.0007 for these calculated drought indices. While the SPI and CZI have the lowest slope of trend line in the term of 1-month time scale with a slope value equal to 0.0001. It is also clear from this table that all calculated drought indices have a same slope of trend line for 12-months time scale, which are equal to 0.0004 for the selected time period.

Pearson correlation coefficient (R^2) between each calculated drought index versus the others were estimated for selected station. The results showed that the SPI and CZI have a better relationship in terms of the time scale for one month than other calculated indices (R^2=0.97). Obtained results also showed the CZI and ZSI, for one-month time scale, have a good relationship, in which the correlation coefficient has a value equal to 0.80. The results for the terms of time scale for six months showed that the SPI have a good relationship versus CZI and ZSI, respectively. In this time scale, MCZI has a weak relationship versus SPI and CZI. Totally, comparison of obtained results shows that the MCZI drought index indicated the weakest correlation with comparing all indices for all time scales (Table 5).

Table 5: Correlation coefficient (R^2) between calculated drought indices

	SPI-1	**ZSI-1**	**CZI-1**	**MCZI-1**		**SPI-6**	**ZSI-6**	**CZI-6**	**MCZI-6**
SPI-1	1.00	0.75	0.97	0.39	**SPI-6**	1.00	0.96	0.98	0.69
ZSI-1	0.75	1.00	0.80	0.37	**ZSI-6**	0.96	1.00	0.95	0.75
CZI-1	0.97	0.80	1.00	0.42	**CZI-6**	0.98	0.95	1.00	0.69
MCZI-1	0.39	0.37	0.42	1.00	**MCZI-6**	0.69	0.75	0.69	1.00
	SPI-12	**ZSI-12**	**CZI-12**	**MCZI-12**		**SPI-24**	**ZSI-24**	**CZI-24**	**MCZI-24**
SPI-12	1.00	0.99	0.99	0.89	**SPI-24**	1.00	0.99	0.99	0.90
ZSI-12	0.99	1.00	1.00	0.94	**ZSI-24**	0.99	1.00	1.00	0.94
CZI-12	0.99	1.00	1.00	0.93	**CZI-24**	0.99	1.00	1.00	0.95
MCZI-12	0.89	0.94	0.93	1.00	**MCZI-24**	0.90	0.94	0.95	1.00

Scatter Diagram of SPI, ZSI, CZI and MCZI for 1-, 6-, 12- and 24-months Time scales are presented in Figure 6 for the period of 1955-2014.

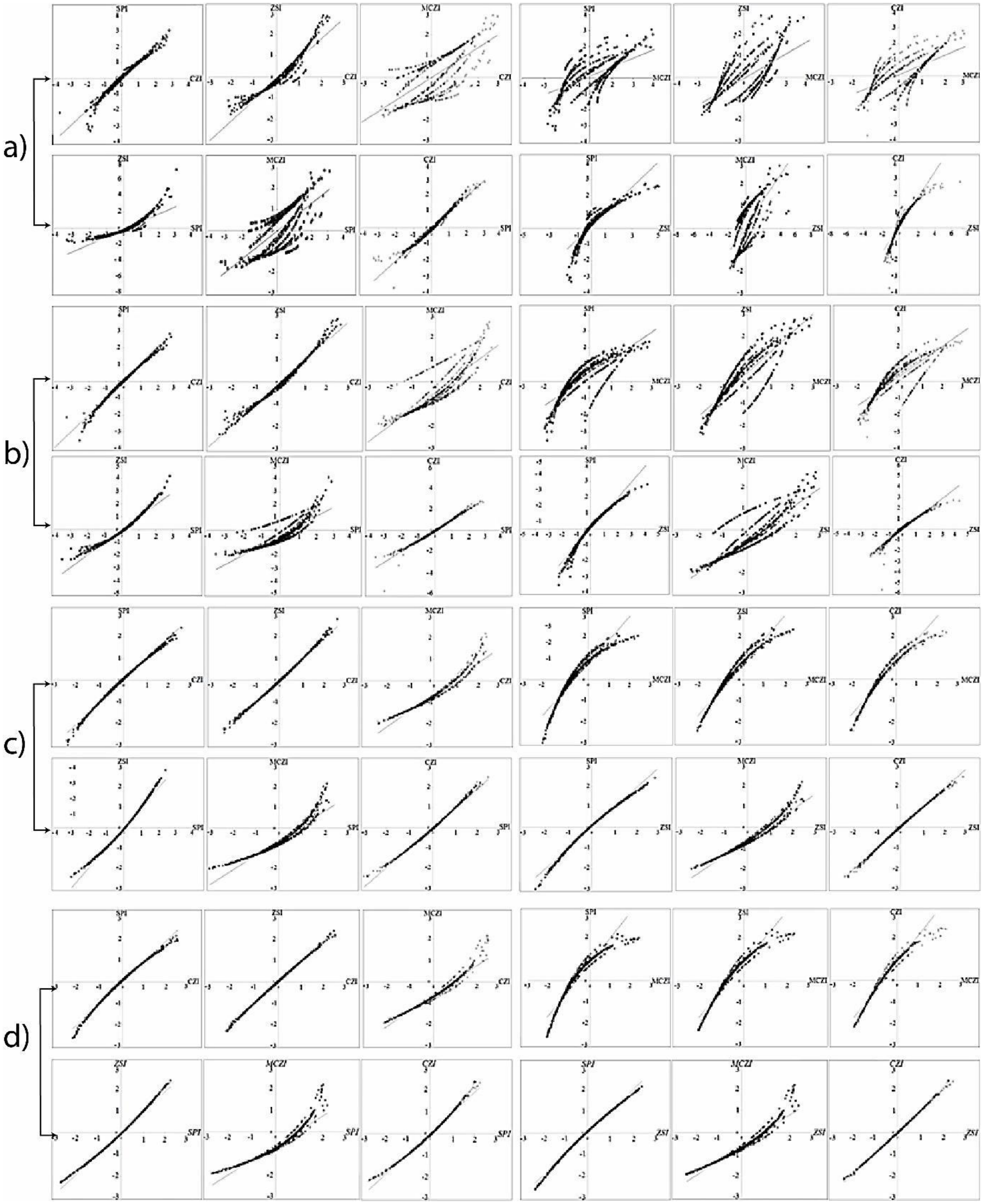


Figure 6: Scatter Diagram of SPI, ZSI, CZI and MCZI for a) 1-, b) 6-, c) 12- and d) 24-monthsTimescales from 1954 to 2014.

With comparing the obtained results for different selected drought indices and time scales, it was clear that total number of events for selected period were approximately equal for SPI and CZI indices. This state is presented in Figure 7. Based on this figure, selected station mostly had normal or near normal drought classes with the total percentage of between 62% and 79% for all time scales for the period 1955-2014, approximately. The obtained MCZI showed different results in comparison with other drought indices. CZI and ZSI drought indices gave closer results in terms of total percentage of each event in comparison of other indices.

From Figure 7, all calculated drought indices estimated the similar values for severe wet events for all time scales in the study period, exceed MCZI, which estimated different values for severely wet event. MCZI for any time scale conditions estimated an inappropriate value for drought classes in comparison other indices. With analyzing Figure 7, it also turns out that the trends indicated that with increasing in time scale the ZSI tend to be more severe dry events. The trends also indicated that with decreasing in time scale the MCZI, ZSI, SPI and CZI tend to be more extreme dry events. Also, as the time scale increases, the normal events in all indicators, except for the MCZI index, decrease.

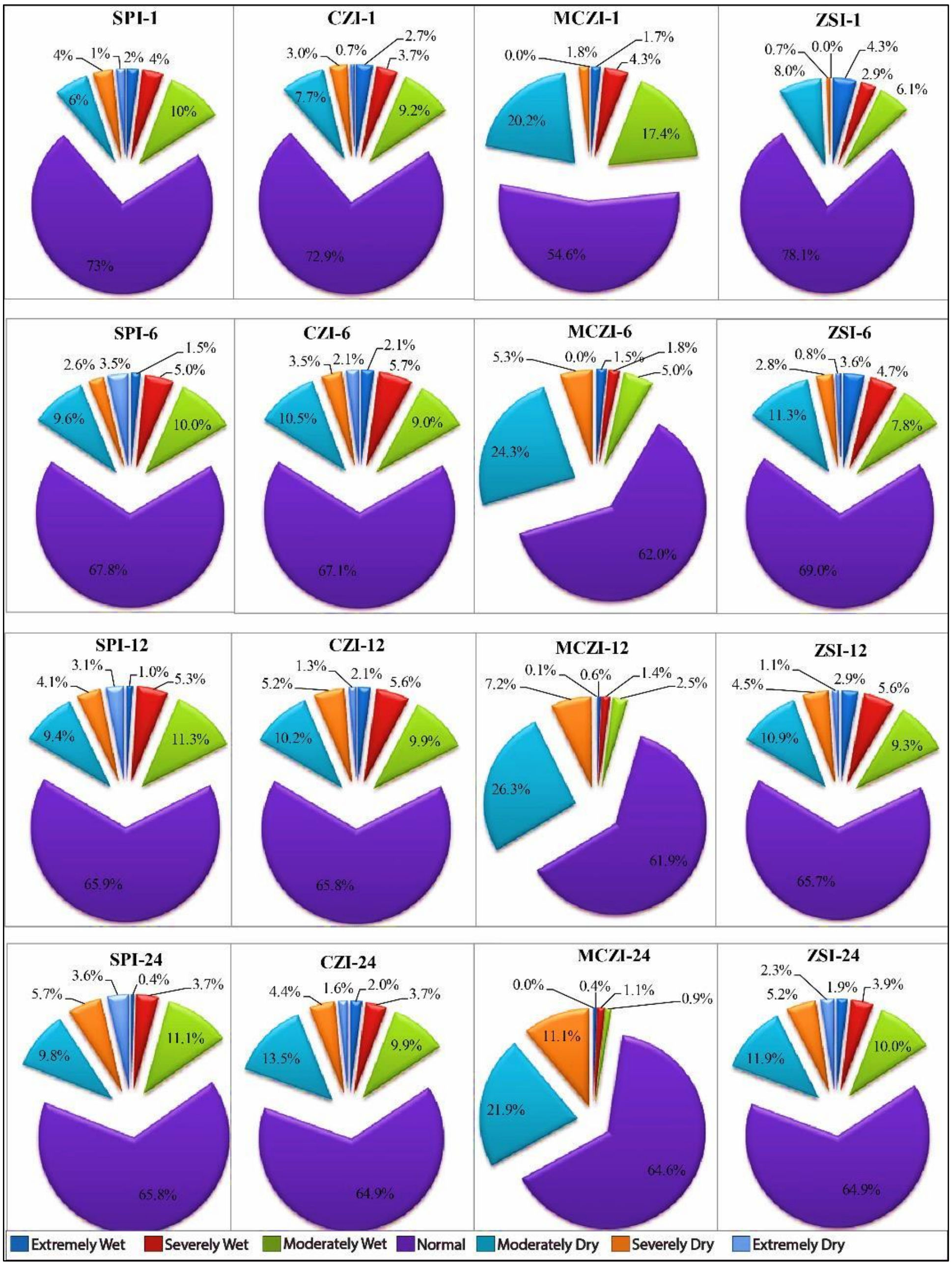


Figure 7: Total Number of Drought Classes for years 1954 to 2014

Based on the results show in Table 7, the number of severe wet months has increased in recent years and after 2010, specially. The total severe dry months for years were increases between years 2005 and 2008. After 2012, increasing in number of extreme wet months were obvious from Table 6. Evaluation of historical recorded flood events show that flood occurred in year 1999 at the Manavgat station, which located near Alanya. All the calculated drought indices show the high number of severe wet months for 1999. It seems 1999 was a wet year for this area. All calculated indices show the extreme wet months happened for 2002, in which flood was occurred in Antalya region. From recorded measurements, it is also seen that the momentary maximum current with a discharge equal to 620 cubic meter per second was occurred in 1981 at Dim cay Stream, a stream that located near Alanya (General Directorate of State Hydraulic Works, 2014).

All drought indices for all different time scales show numerous severely and extreme wet events in this year (except the indices with 24-month time scale for extreme events). All indices with 6-month time scales estimated the December in 1997 as an extremely wet month. According to recorded observations, the significant increase in flow of the Obaçay stream with a discharge of 186 cubic meters per second indicates excessive rainfall in this area in this date. It is important to mentioned that the streams Obaçay and Dim are located near Alanya. From Table 6, all drought indices with 6-month time scale estimated same years for extremely wet events, approximately. It is also seen that the region has experienced the driest year in 1973 in the chosen period, because of number of extremely dry months in a year.

Table 6: Extremely dry and wet events occurred in the selected period for all indices

Extreme Events

Time Scale	SPI			ZSI			CZI			MCZI		
	Year	No. of Dry month(s)	No. of Wet month(s)	Year	No. of Dry month(s)	No. of Wet month(s)	Year	No. of Dry month(s)	No. of Wet month(s)	Year	No. of Dry month(s)	No. of Wet month(s)
6-month	1956	1	-	1957	1	-	1957	1	-	1978	-	1
	1957	3	-	1959	1	-	1959	2	-	1981	-	2
	1959	2	-	1963	-	1	1963	-	1	1987	-	1
	1964	1	-	1968	-	1	1973	5	-	1988	-	1
	1972	1	-	1973	3	-	1977	1	-	1997	-	1
	1973	5	-	1975	-	1	1978	-	1	2001	-	1
	1977	2	-	1978	-	1	1981	-	1	2002	-	1
	1978	-	1	1981	-	2	1987	-	2	2011	-	1
	1981	-	1	1987	-	3	1988	-	2	2012	-	1
	1987	-	1	1988	-	5	1989	2	-			
	1988	-	1	1997	-	1	1997	-	1			
	1989	3	-	2001	-	1	2001	-	1			
	1991	2	-	2002	-	4	2002	-	3			
	1997	-	1	2007	-	1	2004	1	-			
	2001	-	1	2009	-	1	2007	2	-			
	2002	-	2	2011	-	3	2008	1	-			
	2004	2	-	2012	-	1	2011	-	1			
	2007	2	-	2014	-	1	2012	-	1			
	2008	1	-				2014	-	1			
	2011	-	1									
	2012	-	1									
	2014	-	1									
12-month	1957	5	-	1957	1	-	1957	2	-	1973	1	-
	1973	9	-	1973	7	-	1973	7	-	2002	-	2
	1981	-	1	1981	-	1	1981	-	1	2012	-	2
	1988	-	1	1988	-	2	1988	-	2			
	1989	-	1	1989	-	1	1989	-	1			
	1991	6	-	2002	-	8	2002	-	7			
	2002	-	1	2012	-	9	2012	-	4			
	2007	2	-									
	2012	-	3									
24-month	1972	1	-	1973	7	-	1973	5	-	2012	-	3
	1973	11	-	1974	7	-	1974	5	-			
	1974	9	-	1988	-	2	1988	-	2			
	1988	-	1	2006	2	-	2006	-	1			
	1991	1	-	2012	-	9	2012	-	10			
	2005	1	-	2013	-	2	2013	-	2			
	2006	2	-									
	2012	-	2									

Table 7: Severely dry and wet events occurred in the selected period for all indices

Severe Events

Time Scale	SPI			ZSI			CZI			MCZI		
	Year	No. of Dry month(s)	No. of Wet month(s)	Year	No. of Dry month(s)	No. of Wet month(s)	Year	No. of Dry month(s)	No. of Wet month(s)	Year	No. of Dry month(s)	No. of Wet month(s)
6-month	1956	1	-	1956	1	-	1956	2	-	1956	2	-
	1957	1	-	1957	3	-	1957	3	-	1957	4	-
	1963	-	3	1959	1	-	1959	1	-	1959	2	-
	1964	1	-	1963	-	3	1963	1	3	1963	1	-
	1968	-	1	1964	1	-	1964	2	-	1964	3	-
	1969	-	1	1968	-	1	1968	-	2	1968	-	2
	1971	1	-	1969	-	2	1969	1	2	1969	1	-
	1973	1	-	1972	1	-	1972	1	-	1972	2	-
	1975	-	2	1973	2	-	1973	1	-	1973	6	-
	1981	-	4	1975	-	3	1975	-	4	1975	-	1
	1984	-	1	1977	1	-	1977	1	-	1977	1	-
	1985	-	1	1981	-	3	1981	-	3	1988	-	2
	1987	-	3	1984	-	3	1984	-	2	1989	4	-
	1988	-	4	1985	-	1	1985	-	1	1991	4	-
	1989	1	-	1987	-	2	1987	-	3	1997	-	1
	1991	2	-	1989	2	1	1988	-	3	2002	-	3
	1993	1	-	1991	3	-	1989	2	1	2004	2	-
	1997	-	1	1994	-	1	1991	3	-	2005	1	-
	1998	-	1	1997	-	1	1997	-	1	2007	4	-
	1999	1	-	1998	-	1	1998	-	1	2008	3	-
	2001	-	1	1999	-	2	1999	-	2	2009	-	1
	2002	-	2	2001	-	1	2001	-	1	2011	-	1
	2004	1	-	2004	1	-	2002	-	1	2012	-	1
	2005	1	-	2006	3	1	2004	2	-	2014	-	1
	2006	-	1	2007	2	-	2006	-	1			
	2007	2	-	2008	2	-	2007	2	-			
	2008	2		2009	-	1	2008	3	-			
	2009	-	2	2011	-	2	2009	-	2			
	2010	1	-	2012	-	4	2010	1	-			
	2011	-	4	2014	-	1	2011	-	4			
	2012	-	3				2012	-	3			
	2014	-	1				2014	-	1			
12-month	1957	5	-	1957	8	-	1957	8	-	1957	10	-
	1963	-	6	1963	-	8	1963	-	8	1964	8	-
	1964	8	-	1964	6	-	1964	7	-	1973	10	-
	1968	-	1	1968	-	2	1968	-	2	1979	1	-
	1969	-	2	1969	-	3	1969	-	2	1981	-	1
	1973	2	-	1973	3	-	1973	4	-	1986	1	-
	1975	-	4	1975	-	7	1975	-	6	1988	-	1
	1978	-	1	1978	-	2	1978	-	2	1990	1	-
	1979	1	-	1981	-	6	1981	-	5	1991	9	-
	1981	-	2	1989	-	1	1989	-	1	2002	-	4
	1986	1	-	1991	8	-	1991	9	-	2005	5	-
	1989	-	1	1999	-	1	1999	-	1	2006	3	-
	1990	1	-	2001	-	1	2002	-	3	2007	2	-
	1991	3	-	2002	-	2	2005	4	-	2008	1	-
	2002	-	9	2005	3	-	2006	3	-	2012	-	4
	2005	5	-	2006	1	-	2007	2	-	2013	1	-
	2006	1	-	2007	2	-	2009	-	1			
	2009	-	1	2008	1	-	2010	-	1			
	2010	-	1	2009	-	1	2011	-	3			
	2011	-	3	2010	-	1	2012	-	5			
	2012	-	8	2011	-	3						
	2013	1	-	2012	-	2						
24-month	1957	8	-	1957	5	-	1957	4	-	1957	11	-
	1958	1	-	1958	1	-	1961	1	-	1958	1	-
	1961	1	-	1961	1	-	1968	-	2	1961	1	-
	1968	-	2	1968	-	2	1969	-	1	1972	2	-
	1969	-	1	1969	-	1	1972	1	-	1974	11	-
	1973	1	-	1972	1	-	1973	7	-	1990	1	-
	1974	2	-	1973	5	-	1974	6	-	1991	11	-
	1981	-	4	1974	4	-	1981	-	10	1999	-	1
	1988	-	1	1981	-	11	1989	-	2	2005	8	-
	1989	-	2	1989	-	2	1990	1	-	2006	9	-
	1990	1	-	1990	1	-	1991	2	-	2007	9	-
	1991	4	-	1991	3	-	1999	-	8	2008	2	-
	1999	-	6	1999	-	8	2005	1	-	2012	-	5
	2005	6	-	2005	3	-	2006	8	-	2013	-	2
	2006	7	-	2006	7	-	2007	1	-			
	2007	9	-	2007	7	-	2011	-	1			
	2008	1	-	2012	-	2	2012	-	1			
	2012	-	8	2013	-	1	2013	-	1			
	2013	-	3									

4.1. Trend Analysis of the precipitation during 2015-2022

With evaluating the trend of the yearly precipitation of the last eight years (2015-2022) shows that the precipitation in the last eight years have increasing trends in total (Figure 8).On the other hand, trend analysis of the total monthly precipitation of the period 2015-2022 in the study area shows that some months have upward trends and some have decreasing trends. Five months including January, February, May, June and December show a positive (rising) trend. While the remaining seven months including March, April, July, August, September, October and November present a falling trend. Monthly trend lines are presented in Figure 9.

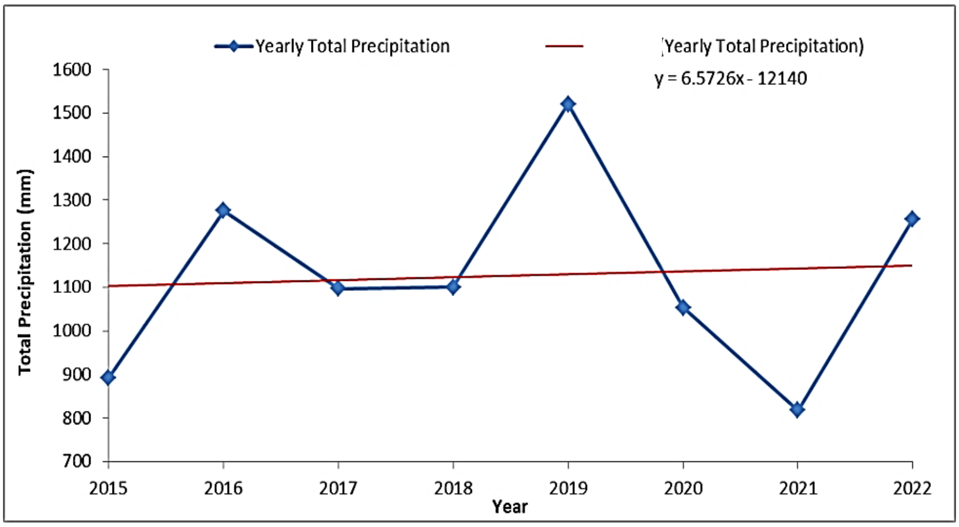


Figure 8: Yearly total precipitation for period of 2015-2022

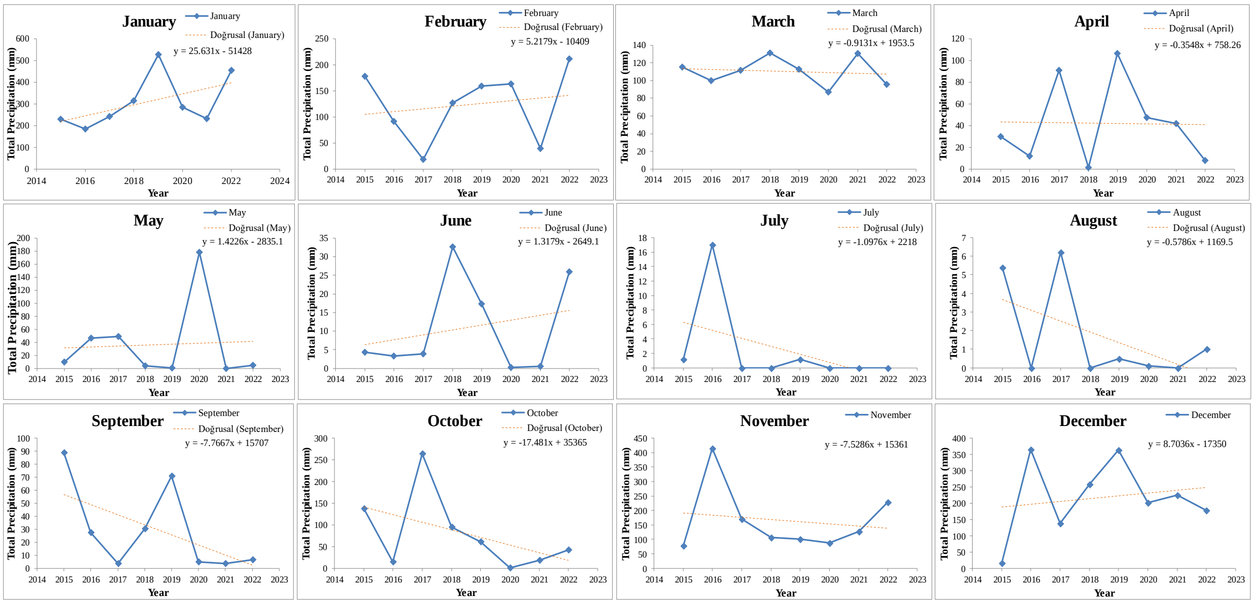
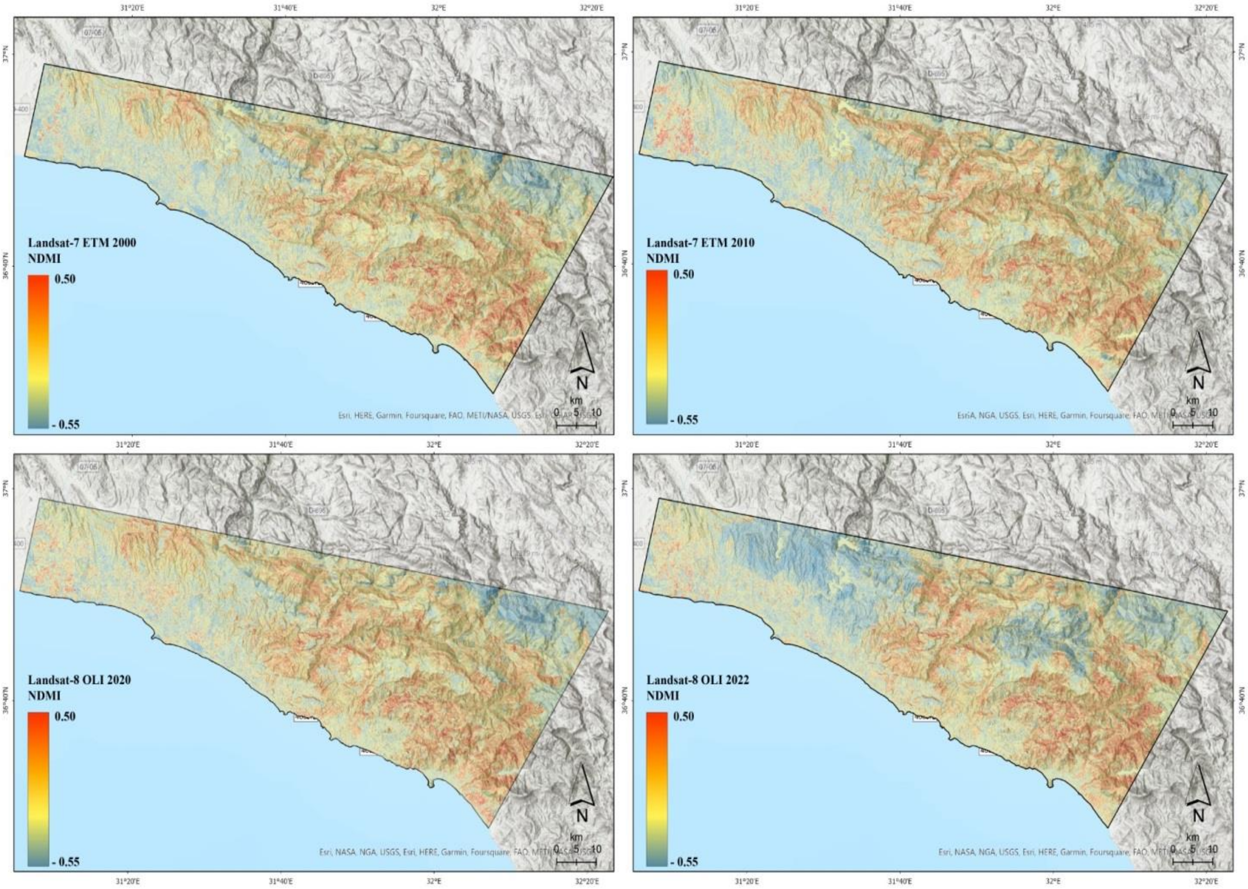


Figure 9: Monthly trend analysis of precipitation for period of 2015-2022

4.2. Investigation of soil moisture and vegetation in the study area

Examining soil moisture data for the years 2000, 2010, 2020 and 2022 in the study area, indicates that the soil moisture in 2022 has decreased significantly compared to 2000 and 2010. The soil moisture maps for the years 2000, 2010, 2020 and 2022 are presented in Figure 10.



Landsat-7 ETM 2000 NDMI

Landsat-7 ETM 2010 NDMI

Landsat-8 OLI 2020 NDMI

Landsat-8 OLI 2022 NDMI

Figure 10: Soil moisture for the years 2000, 2010, 2020 and 2022

The values measured in the years 2000, 2010, 2020 and 2022 for the amount of soil moisture in different parts of the selected region, as shown in Figure 11, show a decrease in the value of this parameter in 2022 compared to 2000, 2010 and 2020, which indicates the beginning of a drought event in the region. However, in some points, the increase in soil moisture in 2022 compared to 2000, 2010 and 2020 is evident.

According to the data shown in Figure 11, it can also be seen that the soil moisture recorded in 2000 had a much lower rate compared to years 1974 and 2020, and this was caused by drought events experienced in 2000 and previous years. In addition, the map prepared from the available vegetation data for the years 1975, 1985, 2000, 2010, 2020 and 2022 in the area (Figure 12) shows the increase in vegetation. As can be seen from Figure 12, vegetation started to decrease in the selected region from 1975 and was at its lowest level in 2022, and this is due to drought, thus indicating that the region is in a dry period. It seems to be normal considering the increase in soil moisture in recent years and the decrease in the number of droughts after 2007 according to Tables 6 and 7.

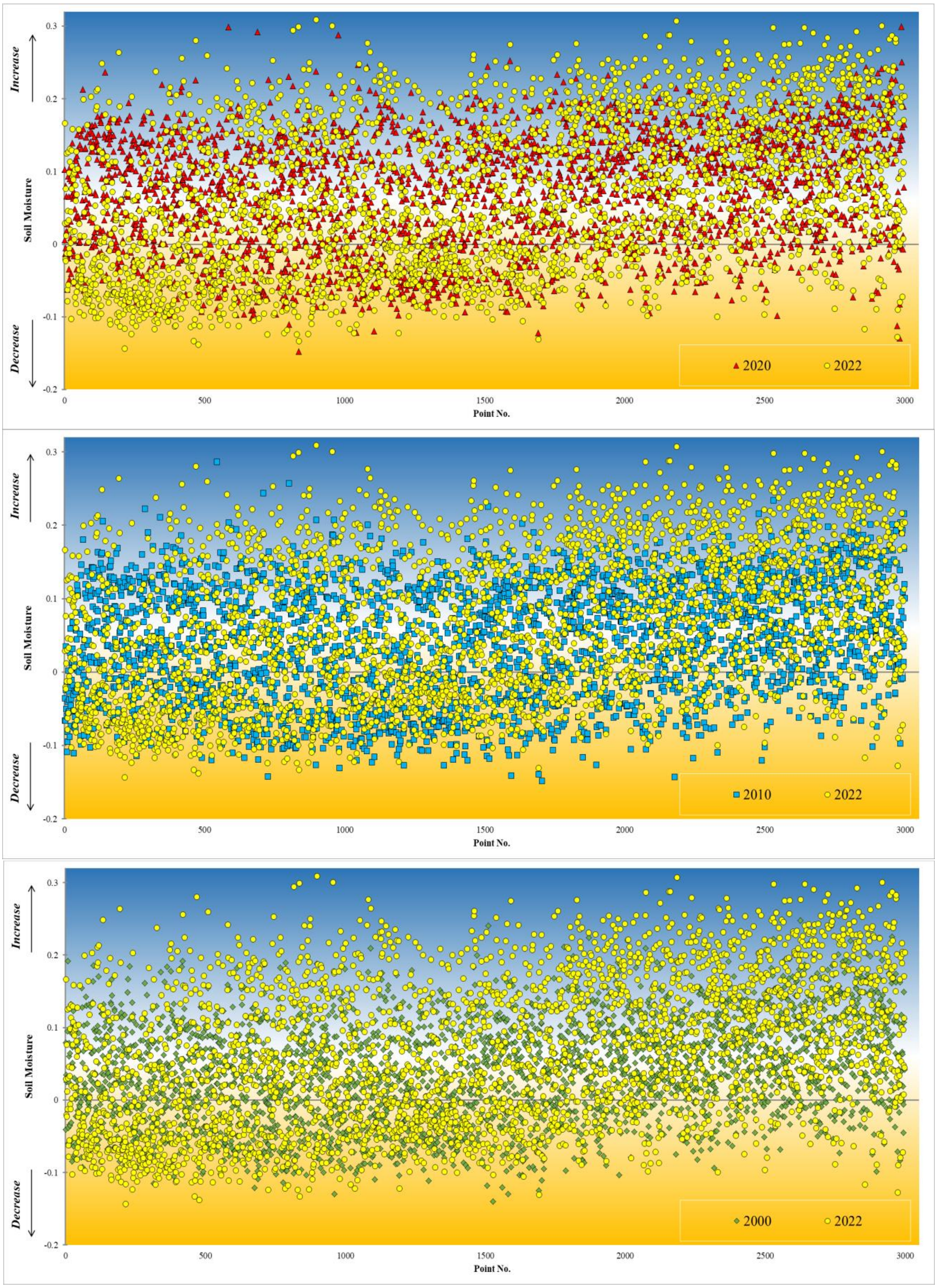


Figure 11: Soil moisture variations during the years 1975, 2000, 2020, and 2020

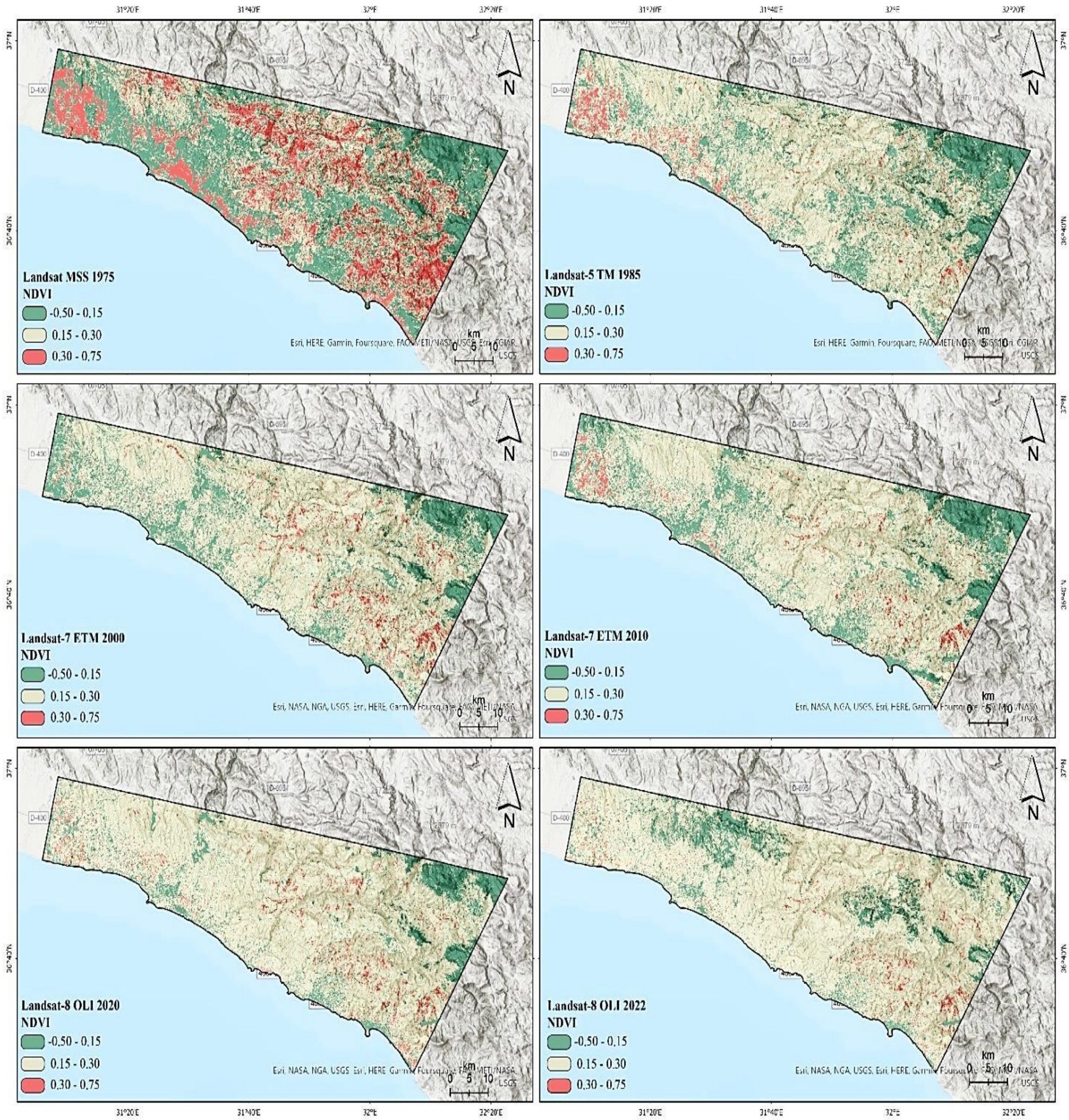
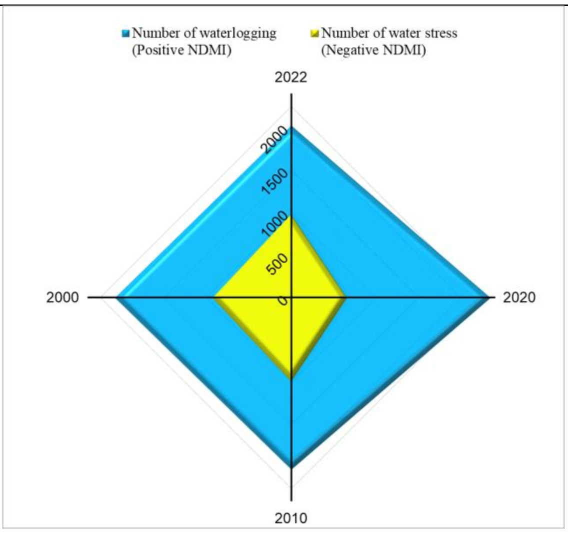


Figure 12: Vegetation data for the years 1975, 1985, 2000, 2010, 2020 and 2022 in the study area

Based on the given data in Figures 11 and 12, the number of Water stresses is presented for years 2000, 2010, 2020, and 2022 in the Table 8, which are indicated by the negative values of the Normalized Difference Moisture Index (NDMI). From this table it is obvious that years 2010 and 2012 have a greater number of water stress NDMI than the other two years, which shows the dry situation of the soil and vegetation cover. The values obtained from NDVI and NDMI analyses conducted for the years 1975, 1985, 2000, 2010, 2020, and 2022 consistently align with the results of the Standard Precipitation Index. Understanding these changes, especially in relation to precipitation patterns and climate characteristics, is essential. The observed decreases, particularly in connection with the Standard Precipitation Index, are largely attributed to changes in precipitation regimes. Climate changes can influence the quantity, distribution, and seasonal patterns of precipitation, which is reflected in the results of NDVI and NDMI analyses. Comparing this result with NDMI and NDVI analyses, it's evident that the indices align with the overall trend of increased drought conditions and changes in vegetation and soil moisture. The correlation between precipitation data and these remote sensing indices provides a comprehensive understanding of the evolving environmental conditions in the Alanya region. The increasing water stress points in 2010 and 2022, as indicated by soil moisture data, further support the signs of drought occurrence observed in the study.

Table 8: Number of water Stress and waterlogging

Year	2022	2020	2010	2000
Number of water stress (Negative NDMI)	976	653	979	922
Number of water logging (Positive NDMI)	2022	2345	2019	2076



5. Conclusion

The study utilized 69 years of precipitation data to investigate drought conditions of the Alanya, which was collected from Alanya station in the Antalya province. The first 61 years data was used to calculate various drought indices, including SPI, CZI, MCZI, and ZSI. These indices were employed to assess drought events at different time scales of 1, 6, 12, and 24 months. Over the entire study period, the Alanya station exhibited a statistically significant upward trend in all these time scales, indicating an increase in drought conditions. The research findings revealed that the SPI, CZI, and Z-Score indices performed similarly in identifying and monitoring drought severity. Specifically, the SPI and CZI indices stood out for their high effectiveness in this regard when compared to the other drought indices considered in the study. Notably, the SPI and CZI indices exhibited the strongest correlations. On the other hand, the MCZI was found to be less suitable for detecting drought in the chosen station. In addition to analyzing dry events, the study also examined wet events, which showed a series of wet periods in the later years of the study period in the region. The findings highlighted that the year 1973 was the driest within the chosen period due to an unusually high number of extremely dry months in that year. Consequently, similar extremely dry events were observed for the 6-month time scale. The variability in the responses of the selected indices underscores the importance of considering other indices and factors when detecting drought events at the Alanya station.

Based on the available data and the maps prepared for the study area, it is clear that in the period 2007-2014 the number of extremely and severely dry events decreases. Although the total yearly rainfall for the last eight years (2015-2022) shows an upward trend, but the analysis of the monthly rainfall for the mentioned last eight years indicates the downward trend of rainfall in most months. The map of vegetation and soil moisture also confirm this issue. It seems that dry events in the region will not be far from expected in the coming years. However, it should not be forgotten that droughts themselves will cause flood events after sudden rains. In this way, the probability of flooding in the region in the coming years seems very high. Investigating the available soil moisture data showed that the number of points with Water stress was higher in 2010 and 2022 comparing the years 2000 and 2020, which is one of the signs of the occurrence of drought.

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