



Investigation of Meteorological Drought Indices for Environmental Assessment of Yesilirmak Region

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Abstract

Generally, as drought, inadequate rainfall means; the concept of drought is not just about reducing rainfall. When years of humidity in an area are lower than average, this is caused by the disruption of our balance between rainfall and evapotranspiration. The reason for droughts is not always the same. It is also difficult to estimate the start and end of the drought. Drought, a mysterious pest, has emerged mysteriously, showing its effects slowly and it goes on for a long time. In this study, drought analysis of the Yesilirmak River basin area in the Black Sea region between 1970 and 2014 was performed. Initially to conduct research, meteorological stations in the basin area that had been collecting data for a long time were investigated, required hydro meteorological data have been obtained from the Meteorological Office which is calculated accurately based on meteorological drought values. Rainfall and drought performance have been investigated with different indices. In this study, monthly precipitation data for inland basin stations, with 7 different meteorological drought indices (PN, DI, RAI, ZSI, CZI, MCZI and SPI) on 7 time scales 1,3,6,12,24,36 and 48 are used and so there is a comparison between drought indices and time periods and all droughts were also recorded during the study period. Finally, the 12-month SPI index was selected as the best index and time scale for the basin and the drought maps for the area were extracted using the SPI index results.

Keywords: Yesilirmak River Basin, Drought Indices, Meteorological Drought, GIS drought map

1 Introduction

Although drought is one of the most dangerous natural pests, there is still no precise definition of it in world literature. At the same time, the effects of drought are becoming more and more evident all over the world. Humans generally become aware of droughts as water shortages increase [1].

1.1 Types of drought

1.1.1 Meteorological drought

The decrease in precipitation over certain periods of time (at least 30 years) relative to its normal values is called meteorological drought. The first sign of drought is a decrease in rainfall. For this reason, meteorological drought is the first stage of drought. Continued meteorological droughts may increase rapidly or end abruptly [2]. The drought started with meteorological drought and continued with agricultural and hydrological droughts, respectively, and ended with famine droughts. Figure 1 illustrates this process.

1.1.2 Agricultural drought

Agricultural drought, which means the lack of water needed by the plant in the soil, is caused by a decrease in water resources. Plants need different amounts of water during their growth stages. Agricultural drought can also mean the lack of water in the root part of the plant, depending on its growth and development needs.

Thus, at the most sensitive time when the plant needs water, agricultural drought occurs when the soil does not have enough moisture. Agricultural drought, even if the soil depth is rich in water, reduces crop yields by a significant percentage. This reduction can also reduce the amount of crop and cause a serious deterioration by preventing the animals from being properly fed. Agricultural drought is a special situation between meteorological and hydrological droughts [3,4].

1.1.3 Hydrological drought

Hydraulic drought, which means a decrease in surface and groundwater, is due to a prolonged decrease in rainfall. In other words, with the one-year surface flow lower than its average over long years, it can be said that hydrological drought has begun [5]. Hydrological drought is usually caused by a combination of meteorological drought and agricultural drought, which results in socio-economic drought [6]. Hydrologic calculations cannot be one of the early signs of hydrological drought, when there is a decrease in rainfall, a delay in running water, and a decrease in water storage reserves. Even after long periods of meteorological drought, hydrological droughts can continue [7,8].

2 Model Scope

The Yesilirmak basin, in northern Anatolia, covers the area between the waters of the Yesilirmak River and the Black Sea.

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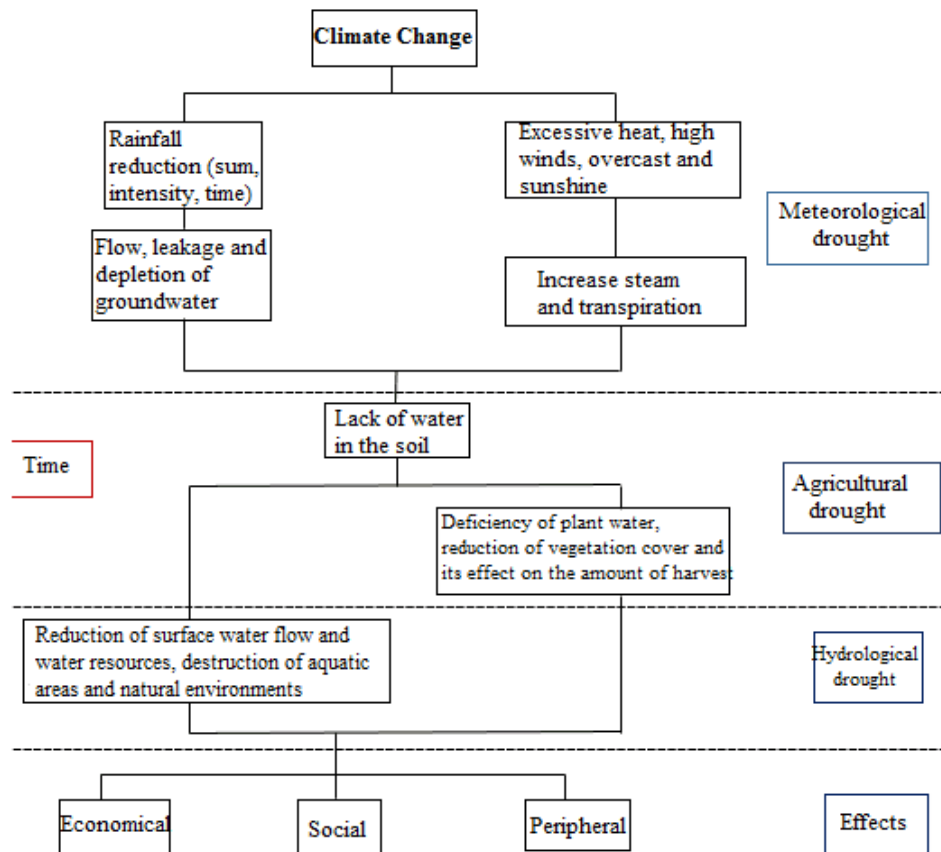


Figure 1: Types of droughts and their effects

Eastbound with Canik, Giresun, Gumushane, Pulur, Cimen, Kizildag, Kose, Tekeli, Yildiz, Camlibel, Akdaglar, Karababa, Inegol and a divisive blue line crossing the hot Kunduz Dagi and the Black Sea is surrounded. The basin area is approximately 3873280 hectares. The basin area is about 5% of Turkey's total area and 3% of the total population of Turkey. The basin area of Yesilirmak basin area is 39129 sq. Km. The average annual rainfall is 646 mm. The average annual water flow is 5.80 cubic kilometers, and the basin average efficiency is 5.1 liters/s/km² [9,11]. Within the Yesilirmak River basin are the provinces of Tokat, Samsun, Amasya, Corum, Sivas, Yozgat. The settlements in the basin area are shown in Figures 2. As can be seen from the map, the Yesilirmak River basin area is in neighborhood of the Kizilirmak, Euphrates-Tigris, and East and West of Black Sea basins.



Figure 2: Yesilirmak basin area

3 Research Methodology

3.1 Drought indices

There are indicators that in drought expression accept a certain amount of rainfall as a base [1]. An index created for one region cannot be used for another, or the research that is being done cannot be comparable. For this reason, spatial and temporal analyzes cannot be performed with such indices. Each of the drought indices is generally evaluated as a review of climate change.

With such a drought index at different time intervals and long periods, regional and temporal analyzes can be performed. Typically, the time frame used is one month or one year for drought analysis. It can be said that monthly time series are more suitable for agricultural problem analysis and water supply [10]. We know that many drought indicators have been created to date. There have been many written studies and classification studies on these indices, although the indices have been compared to each other in order to have a single definition of drought, and there is also no single drought index that covers all purposes. The World

Meteorological Organization has suggested that rainfall parameters alone or in combination with other meteorological parameters be obtained in drought indices. This section explains the indicators selected in the research that were the result of previous research.

3.2 Percent of normal (PN)

Percentage of normal precipitation is one of the simplest criteria for precipitation in an area. When it is used for an area or season, it is very effective. The percentage of normal precipitation as seen in Equation 1-3 is obtained by dividing the actual precipitation by the minimum 30-year average of the precipitation value and multiplied by 100. The percentage of normal precipitation can also be calculated for time scales. Usually these time scales can be based on a month that represents a particular season rather than a series of months, years, or water years [12].

$$PN = \frac{X_i}{\bar{X}} \times 100 \quad (1)$$

In this equation: PN: Normal Precipitation Size, X_i : In a given series (month, season, year) of each precipitation value, represents the mean $\bar{X}$ of long years (at least 30 years). In (12, 13), the classification of normal precipitation index is proposed in Table 1.

Table 1: Classification of PN Index

PN Classification	Value of PN Index
Mild drought	70 - 80
Semi-severe drought	55 - 70
Severe drought	40 - 55
Very severe drought	40 and less than

3.3 The Decile Index

The Precipitation Decile Index has been developed by [12] to avoid the disadvantages of the normal precipitation index. Precipitation decimils are calculated using real precipitation series. Initially, precipitation values (in months or groups of months) range from small to large and the cumulative frequency distribution is created. This distribution is then divided into decks (one-tenths of a dozen), each of which is 10% dry to wet. The first sequence has the lowest rainfall group, indicating the driest months and the last the wettest months. It is easier to calculate the decay method than other indicators, which is why it has been chosen as the drought detection method in the Australian drought monitoring system [10]. One of the disadvantages of integer computation is the need to use long-term recorded meteorological data. To calculate the precipitation deck, the following steps are performed:

- 1- The data is sorted from small to large,
- 2- The degree of decay is determined by Equation 2,

$$D_i = \frac{i \cdot (n+1)}{10} \quad (2)$$

In equation: D_i : denotes decile to i , i : denotes tenth, n : denotes the number of precipitation data.

- 3- On each deck, the rainfall limit is specified,
- 4- Each period is categorized by decks.

However, given that the precipitation in their general state is not proportional to the normal distribution, the precipitation data should be converted to the normal distribution. For this purpose and for the sake of simplicity, the "Box-Cox" conversion created by Box and Cox in 1964 is used.

$$R_n = \frac{R - \lambda}{\lambda} \quad (3)$$

In this equation: R_n : precipitation data converted to normal, R : observed precipitation data, λ Indicates the parameter of the equation (obtained by trial-error method). The classification of DI given in Table 2.

Table 2: Classification of DI index

DI Classification	Value of DI Index	Decile number
Mild drought	30 - 40	Fourth
Semi-severe drought	20 - 30	Third
Severe drought	10 - 20	Second
Very severe drought	And less than 10	First

3.4 Rainfall Anomaly Index (RAI)

Created by Rainfall Anomaly Index [13], it is based on calculating precipitation deviation from its original value. For this purpose, by calculating the mean of long-run series ($\bar{P}$), select the 10 values that have the most value between time points of the work environment and calculate their mean ($\bar{M}$) and so on the 10 values that have the least value. Selection and mean are computed ($\bar{X}$), after obtaining the data Equations 4 and 5 are used and the index value is obtained. If $p > \bar{p}$, the anomaly is positive and the index value is calculated by:

$$RAI = +3 \left[\frac{P - \bar{P}}{\bar{M} - \bar{P}} \right] \quad (4)$$

If $P < \bar{p}$, the anomaly is negative and the index value will be calculated by:

$$RAI = -3 \left[\frac{P - \bar{P}}{\bar{X} - \bar{P}} \right] \quad (5)$$

The classification of the Rainfall Anomaly Index given in Table 3.

Table 3: Classification of RAI Index

RAI Classification	Value of RAI Index
Mild drought	(0) ~ (-1.2)
Semi-severe drought	(-1.2) ~ (-2.1)
Severe drought	(-2.1) ~ (-3)
Very severe drought	And less (-3)

3.5 Z-Score Index (ZSI)

The Z-Score Index calculation method, which is a dimensionless index, uses the original precipitation data. As can be seen in Equation 6, the specified time period before the precipitation becomes normal distribution is obtained by subtracting it from the mean and dividing by the standard deviation. The Z-Score Index has standard deviation and standard deviation, which means that the standard deviation of the Z-Score Index (0) and their standard deviation are equal to (1), high values are positive and low values are negative.

$$ZSI = \frac{X_i - \bar{X}}{\sigma} \quad (6)$$

Here: X_i Precipitation values over time (month, season, or year), $\bar{X}$: Mean of all precipitation data over time, σ : Standard deviation of all precipitation data over time. The Z-Score Index classification is given in Table 4.

Table 4: Classification OF ZSI Index

ZSI Classification	Value of ZSI Index
Mild drought	(0) ~ (-0.99)
Semi-severe drought	(-1) ~ (-1.49)
Severe drought	(-1.5) ~ (-1.99)
Very severe drought	And less than that (-2)

3.6 China-Z index (CZI)

The Z-index (CZI) is an index that accepts precipitation data matching with the Pearson Type 3 scattering. It has been used throughout the country since 1995 to monitor drought conditions by the National Climatic Center of China and is calculated as shown in Equations 7 and 8.

$$CZI = \frac{6}{C_s} \left(\frac{C_s}{2} ZSI + 1 \right)^{\frac{1}{3}} - \frac{6}{C_s} + \frac{C_s}{6} \quad (7)$$

$$C_s = \frac{\sum_{j=1}^n (X_j - \bar{X})^3}{n \cdot \sigma^3} \quad (8)$$

In this equation: X_j : The amount of precipitation that has become normal dispersion over time, n : Sum of time zones, ZSI : Z-Score Index results, C_s : Time zones show the skewness coefficient of precipitation data.

3.7 China-Z index (CZI) modified

The modified China-Z index (MCZI) calculations are similar to the China-Z index (CZI) calculations, with only the mean values used in Equations 7 and 8 instead of the mean. The method of obtaining the index is described in Equations 9-11.

$$MCZI = \frac{6}{C_s} \left(\frac{C_s}{2} \varphi_j + 1 \right)^{\frac{1}{3}} - \frac{6}{C_s} + \frac{C_s}{6} \quad (9)$$

$$C_s = \frac{\sum_{j=1}^n (X_j - Me)^3}{n \cdot \sigma^3} \quad (10)$$

$$\varphi_j = \frac{X_j - Me}{\sigma} \quad (11)$$

In Equations φ_j : Standard Variable Me : represents the median value of all precipitation over time.

3.8 Standardized Precipitation Index (SPI)

In [14], they created the Standardized Precipitation Index (SPI) for the purpose of introducing and tracking regional droughts. The Standardized Precipitation Index (SPI), in principle, provides standardized probability of precipitation under observation and can be calculated in the required time ranges of 1, 3, 6, 9, 12, 24 and 48 months. While short-term timeframes

(weekly and monthly) are important in terms of agricultural water demand and water potential, long-term time series, such as year (12, 24, 36 months) in terms of network water supply, water resources management and groundwater activities are important. The Standardized Precipitation Index (SPI) is computable by normal scatter, normal logarithm, and gamma. However, print sources have shown that, among the scattering, gamma scattering shows the best of the precipitation series. Gamma scattering is similar to Equations 12 and 13.

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad (12)$$

Here: $\alpha > 0$ and α : Formal parameter $\beta > 0$ and β : Critical parameter $x > 0$ and x : Precipitation, respectively.

$$\Gamma(\alpha) = \int_0^\infty y^{\alpha-1} e^{-y} dy \quad (13)$$

$\Gamma(\alpha)$: is a gamma function. For a station, the Standardized Precipitation Index (SPI) needs to provide a probabilistic gamma density function for the scattering frequency of the given precipitation. The alpha and beta parameters of the gamma probability density function are estimated for each station and for each time criterion separately. For maximum likelihood solutions, the average estimates of α and β are used. α and β are calculated as equations 14-16.

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right) \quad (14)$$

$$\beta = \frac{\bar{x}}{\alpha} \quad (15)$$

$$A = \ln(\bar{X}) - \frac{\sum \ln(x)}{n} \quad (16)$$

Here n represents the number of observations, the parameters obtained in Equation 17 being used to create the probability function.

$$G(x) = \int_0^x g(x) dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \quad (17)$$

When we consider $t = x/\beta$, then the gamma function is transformed into Equation 18;

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-t} dt \quad (18)$$

Gamma scattering for zero x values is meaningless, however, because the precipitation series can have zero values, for zero and different from zero scattering, the cumulative probability is transformed into Equation 19.

$$H(x) = q + (1 - q)G(x) \quad (19)$$

Here the " q " is a zero probability. If " m " in the precipitation series represents zero, it is estimated as $q = m/n$. The probability function $H(x)$ is converted to the Standardized Precipitation Index (SPI) by a random normal standard with a mean of zero and one variance. The value of Standardized Precipitation Index (SPI) is calculated according to $H(x)$ according to Equations 3-20 and 21.

$$SPI = - \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad 0 < H(x) \leq 0.5 \quad (20)$$

$$SPI = + \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad 0.5 < H(x) < 1.0 \quad (21)$$

The t in these equations is obtained from Equations 22 and 23.

$$t = \sqrt{\ln \left(\frac{1}{(H(x))^2} \right)} \quad 0 < H(x) \leq 0.5 \quad (22)$$

$$t = \sqrt{\ln \left(\frac{1}{1 - (H(x))^2} \right)} \quad 0.5 < H(x) < 1.0 \quad (23)$$

On the other hand, the values of C_0 , C_1 , C_2 , d_1 , d_2 and d_3 are constant throughout the equation and their sizes are as follows;

$C_0 = 2.515517$; $C_1 = 0.802853$; $C_2 = 0.010328$; $d_1 = 1.432788$; $d_2 = 0.189269$; $d_3 = 0.001308$

As a result of standardizing the Standardized Precipitation Index (SPI) values, within the selected time period, dry periods and wet periods are simulated. When a drought is assessed according to the Standardized Precipitation Index (SPI), it is interpreted as a "dry period" in the period when the index is consistently negative. In fish where the index drops below a negative one, the beginning of the drought is considered, and in the fish that the index increases positively, the end of the drought is considered. Table 5 defines the drought classification according to the Standardized Precipitation Index (SPI) values.

Table 5: Classification of SPI Index

SPI Classification	Value of SPI Index
Mild drought	(0) ~ (-0.99)
Semi-severe drought	(-1) ~ (-1.49)
Severe drought	(-1.5) ~ (-1.99)
Very severe drought	And less than that (-2)

3.9 Drought quantities

To quantify, track and interpret the drought, some quantities need to be analyzed. Among these quantities can be severity, duration (D), degree (M: magnitude), power (I: intensity) and return duration (L: length). In a series of times when drought

values are created, the values of ZSI, CZI, MCZI, and SPI, as soon as they fall below negative one (-1), we realize that the drought has begun. The drought continues until the value of the index becomes zero and when it reaches a positive value, the drought is over, this begins in the RAI Abnormal Rainfall Index when the value drops below -1.2. The time elapsed from the beginning to the end of the drought is called the "duration". The magnitude of the drought event is called the "width" and "degree" is the cumulative name of the index values obtained during the drought and calculated according to Equation 24.

$$\text{Drought degree} = - \sum_{i=1}^D \text{Index value } (i) \quad (24)$$

The value of the drought power is proportional to the length of time the value of the elapsed time is calculated as follows:

$$(I) = \frac{M}{D} \quad (25)$$

The return period (L) is the time between two droughts.

4 Results

Changes in monthly precipitation directly affect annual averages. On the other hand, there are large differences in mean values between years. In Figure 3-5 for the Samsun, Gumushane and Sivas Graphic stations, rainfall variations are plotted over long years. The graphs show that for 1981, Samsun recorded the lowest and highest rainfall with an average of 497 mm and 999 mm of precipitation, respectively. For Gomushane also showed the lowest and highest rainfall in 1988 with an average of 651 mm and 1994 with 311 mm, while May was the month with the highest rainfall of the year with 142 mm of precipitation falls within the driest month. The highest and lowest average annual precipitation, respectively, was found in the Sivas data of 2012 with 587 and 1973 with 285 mm of precipitation. The least amount of rainfall occurs in August in all regions, with 6.1 mm of rainfall at Tokat Station in August, with the highest amount of rainfall with 170.2 mm at Giresun Station and October. When the stations are checked, October and April are the most productive months, respectively, and July and August are the least humid months. Giresun, on the other hand, is designated as the most abundant station with an annual rainfall of 1267.3 mm.

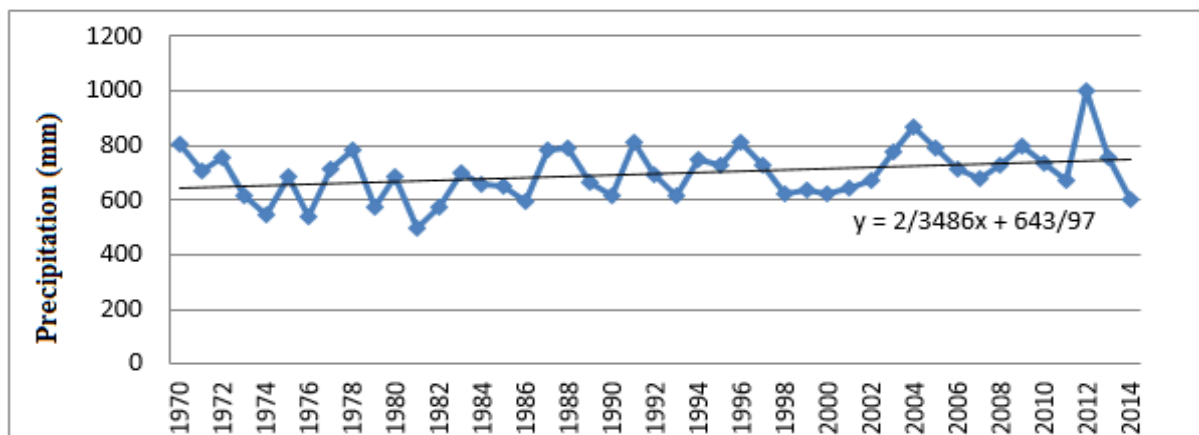


Figure 3: Total changes in annual rainfall in Samsun

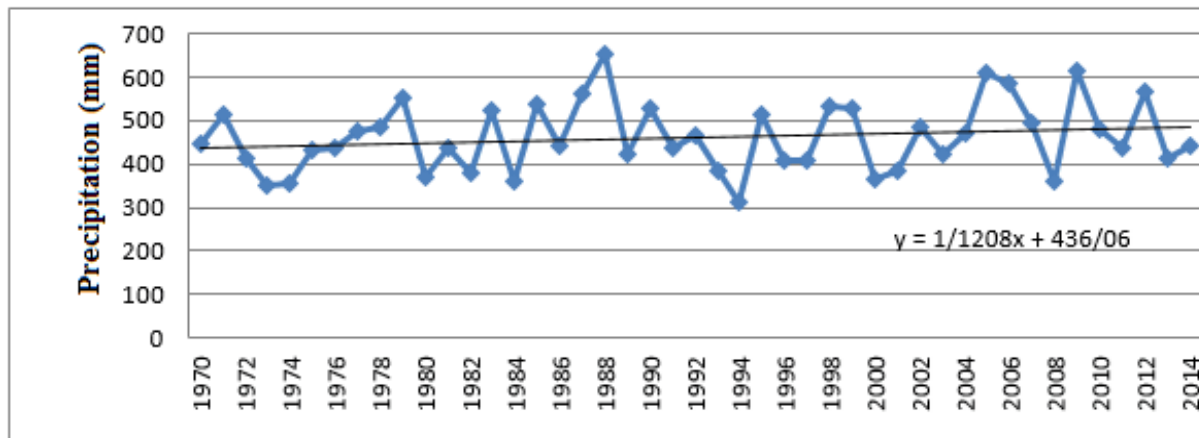


Figure 4: Total changes in annual rainfall in Gumushane

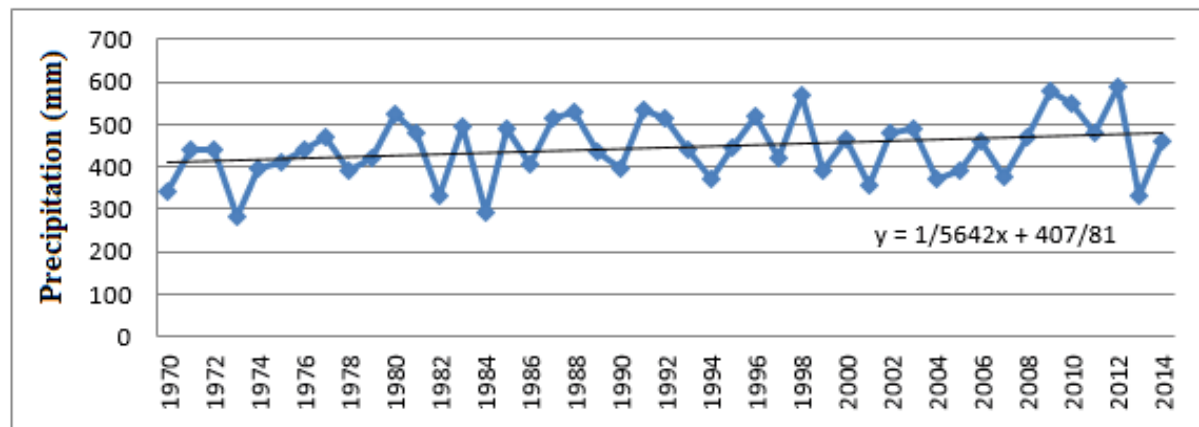


Figure 5: Total changes in annual rainfall in Sivas

4.1 Results of Precipitation Indicators

In 19 stations studied within this study, using 7 rainfall and heat data over a 45 years period, 7 indices at 7 different time points were investigated. As a result of this analysis all the dry periods and duration and severity of these droughts have been determined. In this study, not only the Yesilirmak basin stations were used, but also some of the Black Sea coastal strip stations such as Sinap, Unye, Ordu, Giresun and Trabzon. The reason is when we look at the drought in the Yesilirmak basin by looking around it, we see the whole together. Based on the findings, it has been determined that droughts with similar intensity have occurred throughout the basin area at similar intervals. Tables 6-8, show the correlations matrices prepared for the Samsun, Gumushane and Sivas stations, respectively.

Table 6: Correlation Coefficient for Samsun Station (1970-2014)

	ZSI	CZI	MCZI	SPI	RAI	DI
ZSI	1	0.97	0.97	0.94	0.92	0.89
CZI	0.97	1	0.99	0.95	0.98	0.96
MCZI	0.97	0.99	1	0.94	0.98	0.95
SPI	0.94	0.95	0.94	1	0.96	0.93
RAI	0.92	0.98	0.98	0.96	1	0.96
DI	0.89	0.96	0.95	0.93	0.96	1

Table 7: Correlation Coefficient for Gumushane Station (1970-2014)

	ZSI	CZI	MCZI	SPI	RAI	DI
ZSI	1	0.97	0.97	0.94	0.92	0.89
CZI	0.97	1	0.99	0.95	0.98	0.96
MCZI	0.97	0.99	1	0.94	0.98	0.95
SPI	0.94	0.95	0.94	1	0.96	0.93
RAI	0.92	0.98	0.98	0.96	1	0.96
DI	0.89	0.96	0.95	0.93	0.96	1

Table 8: Correlation Coefficient for Sivas Station (1970-2014)

	ZSI	CZI	MCZI	SPI	RAI	DI
ZSI	1	0.99	0.99	0.99	0.99	0.93
CZI	0.99	1	0.99	0.98	0.98	0.93
MCZI	0.99	0.99	1	0.98	0.98	0.93
SPI	0.99	0.98	0.98	1	0.99	0.91
RAI	0.99	0.98	0.98	0.99	1	0.91
DI	0.93	0.93	0.93	0.91	0.91	1

In the tables for each indicator at seven time points, the droughts are reviewed and the longest and longest are identified, with the drought start and end values given. While the degree of drought is obtained by adding up the index values during this period, the power is also obtained by dividing the degree of

drought by the duration of the drought. It is thus seen that both the 3-station indices selected as models and the indices that have been in the basin area are or are in complete harmony. All results are increasing with increasing intervals, duration and degree of drought.

4.2 Drought maps

With the maps prepared, the dry and blue zones are visible in a given year, on the other hand, with the accumulation of all maps in the 45 years studied, the dry years of the basin area are

identified. As the maps show, the drainage over the entire basin area during 1974, 2001 and 2014 was severe and in 2010 was the 45th most water year in the study area. A closer look at the maps reveals that the Yesilirmak River basin has had more and more droughts than the Black Sea coastline. Figure 6 demonstrates the drought maps for mentioned years. By aggregating 45-year maps, the droughts in the Yesilirmak basin area and the Black Sea coastal area were mostly dry and moderate water and it also indicates that the region has had a moderate climate except for certain years.

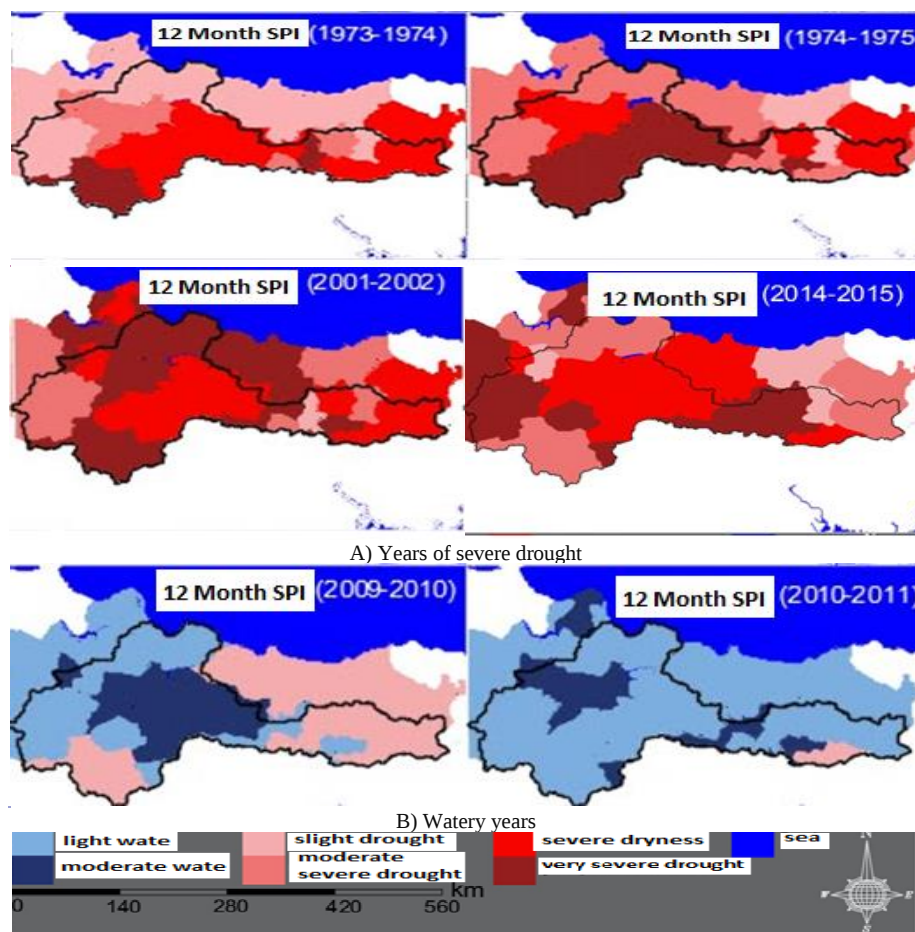


Figure 6: Comparison of drought maps for drought and watery years

5 Conclusion

In this study, the drought model trend in the Yesilirmak area was calculated by examining 7 different meteorological drought indices that require precipitation data (PN, DI, RAI, ZSI, CZI, MCZI, and SPI) and drought quantities (severity, duration, degree and power) have been investigated. By comparing the droughts within the Yesilirmak River Basin and the Black Sea coastal area, it was found that severe droughts have occurred over the years in both parts. In that sense there is a kind of identity between the basin and the beach but between the droughts in the interior of the basin area, while the worst of them were -1.88 and -1.89 respectively, on the Black Sea coast these values were -0.26 and -1.9, respectively. In summary, the droughts in the interior areas have been more severe and more severe. By evaluating all workplace drought maps, droughts have been identified for 45 years. As shown in the maps throughout the basin area during the

years of 1974, 2001 and 2014, with severe droughts, 2010 was the 45th most probable year in the basin area. It is recommended that further research be carried out on agricultural and hydrological drought. Indicators can be found from different value sources and they can be used for drought analysis. Different modeling methods such as ANFIS or neural network can also be assisted and comparisons can be made between the models while improving the models developed in this study. Drought analysis and drought maps prepared for each individual basin area are important for the preparation of practical basin maps by the Department of Water and the Ministry of Environment. In terms of integrated management of basin continuity, drought analysis due to climate change in the basin area will be possible by further determining existing water potentials.

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