RESEARCH

Hydrological drought analysis of Yeşilırmak Basin of Turkey by streamflow drought index (SDI) and innovative trend analysis (ITA)

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Abstract

Drought is a natural disaster that has potential effects on the environment, life quality, water resources and economy. It has been clustered into 4 classes which are meteorological, hydrological, agricultural and socio-economic. Hydrological drought means reductions and deficiencies in the surface and ground waters that occur as a result of the long-term lack of precipitation. In this study, using the Streamflow Drought Index (SDI) and mean monthly streamflow data from 24 stations for the time scales of 1, 3, 6, 9 and 12 months, a hydrological drought analysis for the Yeşilrmak Basin of Turkey has been investigated. Being an extreme occurrence, droughts have been identified by their length of duration and severity. Finally, in order to more accurately and thoroughly assess the trends based on the classifications of dry and wet conditions, Innovative Trend Analysis (ITA) has been enhanced by the addition of 5 vertical and 5 horizontal lines, which constitute a novel side of the study. Results shows that the distribution of percentage drought occurance, wet categories are greater than drought categories. All throughout the basin, the mild drought class dominates with the highest occurrence percentages. Furthermore, according to evaluations of drought severity and duration, the longest-lasting drought—145 months—occurs in SDI-9 from 1997 to 2009, while the most severe drought—136.13—happens in SDI-12 from 2001 to 2009. Beginning around 2000, the region has been exposed to some of the longest-lasting and worst droughts ever recorded. By IDW, it has been analyzed that different parts of the basin are affected by droughts based on time scale while SDI-9 and SDI-12 show a similar distribution in drought and wet categories. According to ITA data, there is generally a trend in most drought time scale categories, and these trends have exhibited a majority of decreasing trend characteristics.

1 Introduction

The term "drought" refers to precipitation levels that are significantly below those observed during normal conditions. The drought which is a natural disaster that can cause great environmental and socio-economic impacts has been associated with some properties by various studies throughout the world (Erian et al. 2021; Prodhan et al. 2022). There are numerous definitions of drought in the literature. For example, while Shiau et al. (2007) define the drought as one of the normal and repeated events, Kao and Govindaraju (2010)

have stated that drought is the most expensive and one of the least understood natural disasters. Shiau and Modarres (2009) have taken up the drought as complex and having many attributes. Vazifehkhah et al. (2019) have taken into account that drought is the longest-lasting and most persistent natural occurrence and Eşıt and Yüce (2021) have specified that drought is destruction that has important environmental and economic influences and it may occurs in any part of the world and climate as independent from forests and deserts. In the Interngovernmental Panel on Climate Change report (IPCC 2022), drought has been noted as one of the most common climatic drivers for migration and it also has been added that in developing and industrialised countries in short term extreme events such as drought, floods decreased the economic development and in coming decades will continue to decrease. From this point, there are either direct or indirect effects of drought on society, the environment, and the economy. While drought may directly result in the loss of life, a shortage of water supplies, and environmental harm, it may also result indirectly

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in a decrease in life quality, malnutrition, and starvation. In addition to this, drought has the potential to damage the countries' economies in the sectors of agricultural, livestock, forestry, energy, industry and water sectors.

In the literature, drought has various classifications. Drought has been associated with streamflow, precipitation, soil moisture, or any combination of the three by Dracup et al. (1980). While, Tate and Gustard (2000) investigated drought by dividing 5 groups which are climatological drought, agro-meteorological drought, river flow drought, ground-water drought, and operational drought, according to (Wilhite and Glantz 1985; Mishra and Singh 2010), drought has been clustered into four types as meteorological, agricultural, hydrologic and socio-economic. Meteorological drought is associated with precipitation deficits that are significantly below average levels (Akturk et al. 2022); agricultural drought refers to a lack of moisture in plant roots that prevents growth (Botterill and Fisher 2003; Gümüş et al. 2021). A hydrological drought happens when there is not enough precipitation, which lowers groundwater levels, streamflow, reservoir water levels, and soil moisture (Rahmat et al. 2014; Yuce and Esit 2021). Socioeconomic drought is characterized by inadequate water supplies compared to demand.

There are many indices to define hydrological drought in the literature (Tsakiris et al. 2007; Zargar et al. 2011) The indexes such as Palmer Hydrological Drought Severity Index (PHDI), Standardized Streamflow Index (SSFI), Standardized Reservoir Supply Index (SRSI), Standardized Water-level Index (SWI), Streamflow Drought Index (SDI), Surface Water Supply Index (SWSI) are used to analyze hydrological drought (Svoboda and Fuchs 2016). Hydrological drought analysis is utilized by using the Streamflow Drought Index, which was developed by (Nalbantis and Tsakiris 2009). For the usage, it only needs to mean monthly streamflow data. Its computation manner is the same as Standard Precipitation Index (SPI) developed by (McKee et al. 1993). Mishra and Singh (2010) stated that a drought variable should be able to assess the drought in different time scales, the most commonly used one is the year, followed by the month. While the yearly time scale is long and can be utilized to summarize drought events, the monthly time scale provides a more suitable monitoring of the effects of drought events. Because drought indices can be used to detect drought characteristics (Wilhite et al. 2000; Hong et al. 2015), drought severity and duration can be calculated using Yevjevich's (1967) method. In addition to its classifications and indexes, drought has been characterized by two parameters which are severity and duration (Zargar et al. 2011). Drought severity has been defined by Wilhite (2007) as the level of deficit of precipitation or the level of influences as a result of the deficit. Drought duration has been defined by Dracup et al. (1980) as the period between the beginning and end of a drought.

It is crucial to evaluate the spatial distribution of drought occurrences based on a drought categorization to identify the potential effects of droughts for a specific area. Such a way makes drought interpretation easier and visible. For this purpose, spatial interpolation methods such as Inverse Distance Weighting (IDW), Radial Based Functions (RBF), Kriging, Global Polynomial Interpolation (GPI) are utilized (Katipoğlu and Acar 2022). IDW is a deterministic model in spatial distribution which is one of the most frequently used method (Lu and Wong 2008). The method considers that each known point is of an influence on forecasted point (Hao and Chang 2013).

Many scientists have considered trends of drought monitoring in various research around the world (Tosunoglu and Kisi 2017; Myronidis et al. 2018; Elouissi et al. 2021; Yuce and Esit 2021; Katïpoğlu et al. 2022). Innovative Trend Analysis (ITA) method has been developed by (Şen 2012). The method which provides more information than other trend methods (Mann–Kendall and Spearman Rho) is utilizied because it is simple and efficient (Ashraf et al. 2021; Seenu and Jayakumar 2021; Elouissi et al. 2021; Gumus et al. 2022). On the other hand, the classical trend analysis methods are strictly statistical approaches that do not enable the detection of trends in low, medium, and high values in a single calculation step. Without graphical and exploratory data analysis, the majority of non-parametric tests may occasionally be useless (Cengiz et al. 2020) (Onyutha 2016) established that utilizing a combination of graphical and statistical trend testing techniques provides more insightful information than using only statistical techniques. When using the ITA approach, it is not effected if the data do not follow a normal distribution, are short, or are serially dependent.

Numerous research has been conducted for the analysis of hydrological droughts in Turkey and other regions of the world. Tabari et al. (2013) investigated a hydrological drought analysis for Northwest Iran using SDI. They worked with time scales of 3, 6, 9, and 12 months and obtained that the most severe streamflow drought occurs during the hydrological year of 2000–2001, and extreme droughts were most frequent in the last 12 years from 1997–1998 to 2008–2009. Pathak and Channaveerappa (2016) performed a study to compare two hydrological drought indexes which are streamflow drought index (SDI) and standardized runoff index (SRI) for the Ghataprabha river basin, India. They concluded that the correlation coefficient between SRI and SDI increases concerning duration which means that these two indices become the same for longer periods of drought analysis for 3, 6, 9, and 12-month periods. Boudad et al. (2018) examined the relationship between meteorological and hydrological drought for the Inaouen Basin in Northern Morocco using the SPI and SDI index for time scales of 3, 6, and 9 months. They also used Mann-Kendal

and the quantile regression method to detect trends. Myronidis et al. (2018) performed an analysis about streamflow and hydrological drought trend analysis and forecasting for Cyprus. The Mann–Kendall test results of yearly and seasonal streamflow volumes suggest decreasing but insignificant trends. In addition, the same test also revealed that the island's hydrological drought increases with time. They reported that SDI successfully detects hydrological drought occurrences. Jahangir and Yarahmadi (2020) performed a study for hydrological drought analyzing and monitoring using the Streamflow Drought Index (SDI) and streamflow data of 10 stations in Lorestan, Iran at 3,6,9,12-month time scales. They concluded that SDI results showed that all stations have at least one severe drought. Most parts of the region have been influenced by the drought for 11 years from 2005 to 2016. Junqueira et al. (2022) investigated meteorological and hydrological drought analysis for the upper Grande River basin, Brazil using SPI and SDI indices with an annual time scale.They discovered that the most severe droughts occurred in the water years 2000/01, 2013/14, and 2014/15, and their findings have demonstrated that SDI has longer-lasting effects on streamflow. Abro et al. (2022) made a meteorological and hydrological assessment for Qinhuai River Basin, China using the multiple drought indices including SPI, Reconnaissance Drought Index (RDI), and SDI at 1 to 12-month time scales. Mann–Kendall and Sen's slope tests were utilized for detection of trends of droughts. Results showed that 2002 is the year in which the maximum drought months have been seen in all indices, the indices in 1993–1994 and 2013–2014 years have been analyzed as common dry years.

Gümüş (2017) studied hydrological drought in the Asi River Basin of Turkey using streamflow index (SDI) for time scales of 3, 6, and 12 months. The year 2000 has been identified as the one with the severe drought. The rates of extreme, severe and moderate droughts were found to be 3%, 5%, and 10%, respectively, in all stations. Özfidaner et al. (2018) performed a study about hydrological drought analysis of Seyhan Basin in Turkey using streamflow drought index (SDI) for 3,6,9, and 12 months. They stated that hydrological drought increased in recent years and especially from 2000 the drought exists at 3, 9, and 12-month time scales. Furthermore, drought severity increased in 2002 and later years. Gümüş et al. (2018) studied hydrological drought assessment as a case study for Murat River-Palu in the Euphrates basin utilizing SDI for 1, 3, 6, and 12-month time scales. They stated that the driest periods belong to November, February and March months at 1-month time scale; January has the driest period, while July is the lowest dry period at 3-month; October and April have been noted as 34% and 30% in dry period respectively at 6-month time scale. In addition, the dry period occurrence is 32% for the annual (12-month) analysis. Ozkaya and Zerberg (2019) investigated hydrological drought analysis for 47 stations of

upper Tigris Basin Turkey using a data set ranging from 1972 to 2011 data period by utilizing SDI for the time scales of 3,6,12 months.They obtained almost all stations have at least one severe drought and SDI-6 series more decreases during the April-September period compared to the October–March period. Simsek (2021) studied hydrological drought analysis of Mediterranean basins of Turkey using SDI for 3, 6, 12-month periods and employed Mann–Kendall for monotonic trend Sen's slope method for slope values.According to the results, there has been a noticeable increase in drought severity across all timescales in recent years. Mild droughts are the most common type of drought across all timescales, and the frequency of extreme droughts is higher in the middle of the basin. Furthermore, for various periods, he obtained a significantly decreasing trend at 35% of the stations. Katipoğlu and Acar (2022) studied for mapping the Spatio-temporal variations of hydrological droughts for Euphrates Basin, Turkey,using the Standardized Runoff Index (SRI).They performed a set of interpolation methods such as Kriging and IDW, and trend methods such as Mann–Kendall and Modified Mann Kendall. Based on obtained maps, they discovered that the basin has been significantly affected by hydrological droughts. A few studies of hydrological drought analysis have been conducted in the Yeşilrmak basin in Turkey. Katipoğlu et al. (2022) investigated trend analysis of hydrological droughts using Mann–Kendall, Innovative Trend Analysis, and Theil-Sen Approach. They reported that ITA has superiority over the Mann–Kendall test because ITA showed hydrological droughts trends as graphically and more precisely.

In this study, the aim is to perform a hydrological drought analysis for the Yeşilırmak Basin of Turkey by utilizing streamflow data of 24 stations and SDI for the time scales of 1,3,6,9,12-month. Two key drought characteristics which are severity and duration as well as their maximum values have been determined with their drought occurrence in all stations. IDW which is one of the most common spatial distribution methods has been used for monitoring drought based on drought categories (mild, moderate, severe, and extreme drought) for all time scales. The ITA technique has been combined with drought and wet classes used in the study which is a novel side of the study and applied to drought and wet categories to detect possible trends in more detail. The results of this study are expected to be beneficial for water resources planning, and management of the basins.

2 Methodology

2.1 Streamflow drought index (SDI)

SDI, proposed by Nalbantis and Tsakiris (2009), is an index that is used in hydrological drought analysis. The calculation process is similar to that of the Standard Precipitation Index

(SPI) (McKee et al. 1993) with the exception that streamflow data is employed in place of rainfall data (Malik et al. 2021). In this index, the total streamflow is denoted by $X_{i,j}^k$ in a given month j and year i depend on the time scale k (1, 3, 6, 9, 12 months) can be computed from the following equations (Paulo et al. 2003; Hong et al. 2015).

$$X_{i,j}^k = \sum_{l=13-k+j}^{12} V_{i-1,l} + \sum_{l=1}^{j} V_{i,l} \, if j < k \quad (1)$$

$$X_{i,j}^k = \sum_{l=j-k+1}^{j} V_{i,l} \, if j \geq k \quad (2)$$

where $V_{i-1, l}$ and $V_{i,l}$ represent streamflow volumes in the years of *i-1* and *i*, respectively. So based on this Nalbantis and Tsakiris (2009) have stated that since streamflow data can have a skewed probability distribution, the Gamma distribution functions family can be used for approximation. Therefore, in this study, Gamma distribution has been employed for fitting, before the computation of SDI. The probability distribution function of Gamma distribution $g(x)$ is computed by (Thom 1966).

$$g(x) = \frac{1}{\beta^a \Gamma(a)} x^{a-1} e^{-\frac{x}{\beta}} \quad (3)$$

where $\Gamma(a)$ is the gamma function and it is computed by (Edwards 1997).

$$\Gamma(a) = \int_0^\infty y^{a-1} e^{-y} dy \quad (4)$$

For maximum likelihood method estimation, the parameters of Gamma distribution which are shape (α), scale (β) can be calculated by (Thom 1966) as follows:

$$a = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (5)$$

$$\beta = \frac{\bar{x}}{a} \quad (6)$$

And where A is determined by (Thom 1966; Eşit and Yüce 2022)

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (7)$$

n is the number of streamflow records instead of rainfall records and $\bar{x}$ is the mean of x.

Then cumulative distribution function is computed by (Thom 1966).

$$H(x) = q + (1 - q)G(x) \quad (8)$$

Table 1 Drought classification (Hong et al. 2015)

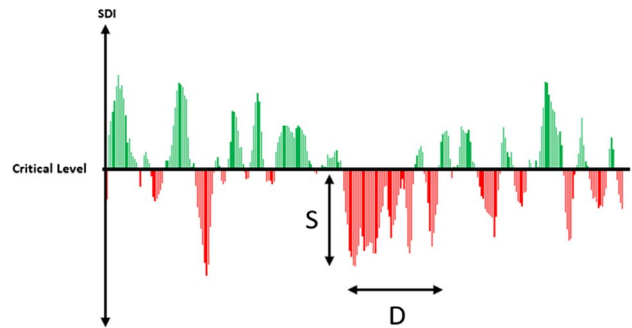| SDI Value	Category
$SDI \geq 2.00$	Extremely Wet
$1.50 \leq SDI < 2.00$	Severely Wet
$1.00 \leq SDI < 1.50$	Moderately Wet
$0 \leq SDI < 1.00$	Mildly Wet
$-1 \leq SDI < 0.00$	Mild Drought
$-1.50 \leq SDI < -1.00$	Moderate Drought
$-2.00 \leq SDI < -1.50$	Severe Drought
$SDI \leq -2.00$	Extreme Drought

Fig. 1 Description of drought characteristics

where q represents the probability of zero and $G(x)$ shows the cumulative distribution for the selected month and time scale. If m is shown as the number of zeros, then q can be calculated from $q = m/n$ (Thom 1966). After these calculations, $H(x)$ is converted to the standard normal variable Z which has 0 mean and 1 as variance and represents the SDI value. Then SDI values in a month and desired time scale are associated with a drought class based on its value according to drought classifications in Table 1 (Hong et al. 2015).

2.2 Drought characteristics

After calculation of SDI values, it is possible to obtain drought characteristics such as severity and duration via the help of Run Theory which has been proposed by (Yevjevich 1967). Looking at the definitions of these characteristics in Fig. 1, drought duration (D) can be defined as the period between the beginning and end of drought while drought severity (S) means a cumulative summation of SDI values below the critical level with the unit of the month (Dracup et al. 1980; Hong et al. 2015).

2.3 Innovative trend analysis (ITA)

ITA, proposed by Şen (2012), is a method using by numerous researchers due to its simplicity and efficiency

(Elouissi et al. 2021), Unlike the most frequent tests of the Mann–Kendall trend test and Spearman's rho test which require the independent structure of the time series, normality of the distribution, and length of the data, the suggested method is avoided these assumptions (Şen 2012). To apply this method to a data set, the data set is divided into two equal parts with the condition that both parts must be in ascending order, the first part and second part are plotted on the x and y-axis, respectively. Secondly 1:1 line (45°) which shows a no trend line between increasing and decreasing trends is drawn (Şen 2012; Ashraf et al. 2021; Mallick et al. 2021; Elouissi et al. 2021; Berhail et al. 2022). Based on Fig. 2(a),any point above the 1:1 line shows the existence of an increasing trend while any point below the 1:1 line represents the presence of decreasing trend. Any point clustered on the 1:1 line shows no trend case. To classify the trend type of any dataset from deterministic way, trend slope and its sign must be known. In a such manner trend slope (s) and slope standard deviation (σ_s) can be calculated from following formulas (Şen 2017; Alashan 2020).

$$s = \frac{2(\overline{y}_2 - \overline{y}_1)}{n} \qquad (9)$$

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1 - \rho_{\overline{y}_2 - \overline{y}_1}} \qquad (10)$$

where $\overline{y}_1$ and $\overline{y}_2$ are described as arithmetic averages of first and second halves, n shows the number of data and $\rho_{\overline{y}_2 - \overline{y}_1}$ describes cross-correlation coefficient between first and second halves. For a selected significance level α, if the confidence limits of standart probability distribution function with zero mean and standard deviation is s_{cri} then confidence limits of a trend slope can be determined from following equation (Şen 2017; Alashan 2020; Esit 2022).

$$CL_{(1-\alpha)} = 0 \pm s_{cri}\sigma_s \qquad (11)$$

Beside of these explained trend cases, trends may show either monotonic or non monotonic cases. Because trends can be determined by their visual inspection (Güçlü et al. 2019) and since it is not easy to asses trends which are non monotonic directly from Fig. 2(a), in this study as it is shown in Fig. 2(b), the ITA method is combined with drought classification given by Table 1, by adding 5 vertical and 5 horizontal lines in order to evaluate the trends of the SDI series graphically, in more detail and accuracy. The trend is evaluated in 6 categories in the ITA graph. These categories are Mild Drought(MD), Moderate Drought (MOD), Severe and Extreme Drought (SED) which is a combination of the last two drought categories (SDI ≤ -1.5), Mild Wet (MW), Moderate Wet (MOW), Severe and Extreme Wet(SEW) which is a combination of last two wet categories (SDI ≥ 1.5). Therefore in this study at first, ITA has been employed to evaluate trend of each SDI series from trend slopes based on 99% confidence limit, secondly ITA is combined with drought and wet classes used in the study to detect trend types by a visual inspection.

2.4 Inverse distance weighting method (IDW)

IDW is comparatively easy, fast and one of the most commonly used deterministic models in spatial interpolation (Lu and Wong 2008). It is a traditional method that is related to the first law of geography which specifies that the closer the distance between two points, the higher the similarity of their attribute values (Tobler 1970; Zhao et al. 2022). The method considers that every known point has an impact on the estimated point, the weight is proportional to the p-th power of distance (Hao and Chang 2013; Katipoğlu and Acar 2022). In this study, IDW has been applied to percentage occurrence of SDI values of drought and wet(SDI ≥ 0) classifications in any specific time scale to monitor spatial distribution.

Fig. 2 Graphical description of **a**) ITA method by (Şen 2012) **b**) Developed ITA
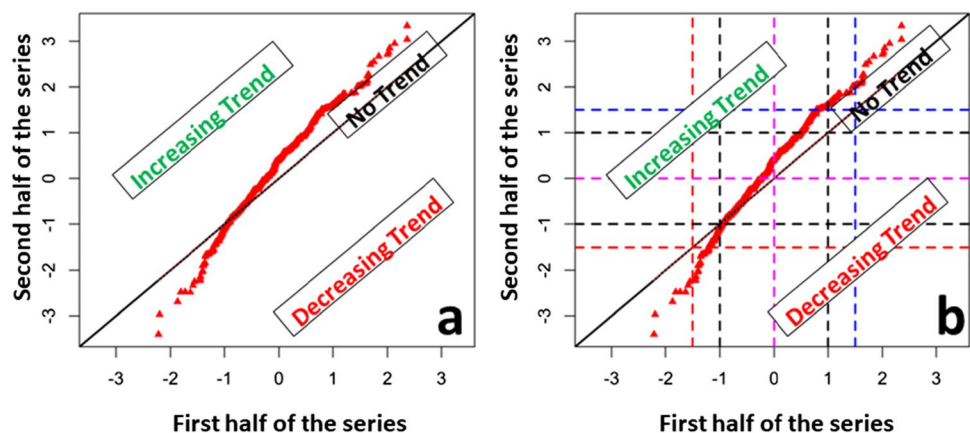
3 Data and study area

Yeşilırmak Basin is situated in the North Anatolian part of the Turkey and it involves the entire Tokat province, 86% of Amasya province, %50 of Samsun province, 30%of Yozgat province, 33% of Çorum province, 14% of Sivas province, 43% of Gümüşhane province, 39% of Giresun province, 9% of Erzincan province, 10% of Amasya province, 1% of Bayburt province. The basin is located on the coordinates of 40° 38′ 54″ North latitude 35° 49′ 52″ East longitude. It is the basin that brings its water to the Black Sea via -519 km long- Yeşilırmak River. The basin covers almost an area of 3,873,280 hectare (ha) and this occupies of 5% of Turkey. The basin consists of %39 forestlands, %39 cultivated areas, and 19% grass areas. The basin is neighbors to the basins of Kızılırmak, Euphrates-Tigris, West and East Black Sea, and Seyhan. The annual flow of the basin is $5.28*10^9$ m^3which forms ~2.87% of the surface waters of Turkey (TUBITAK MAM 2010). In the basin Middle Black Sea, West Black

Sea, and Central Anatolia climates are seen. In the areas on the coast line, influences of the Black Sea climate is seen and while summers are hot, winters are warm and wet there, in central areas due to mountains winters are wet and snow and summers are cool (TUBITAK MAM 2010). The Basin map and stations have been shown in Fig. 3.

The mean monthly streamflow data of 24 streamflow gauge stations located in Yeşilırmak Basin are obtained from the General Directorate of State Hydraulic Works (DSİ). Detailed information on streamflow stations is given in Table 2.

4 Results

4.1 Assesment of hydrological drought on yeşilırmak basin

For hydrological drought analysis of Yeşilırmak Basin, SDI values are obtained for 1, 3, 6, 9, and 12, time scales using SDI procedure and statistical calculations based
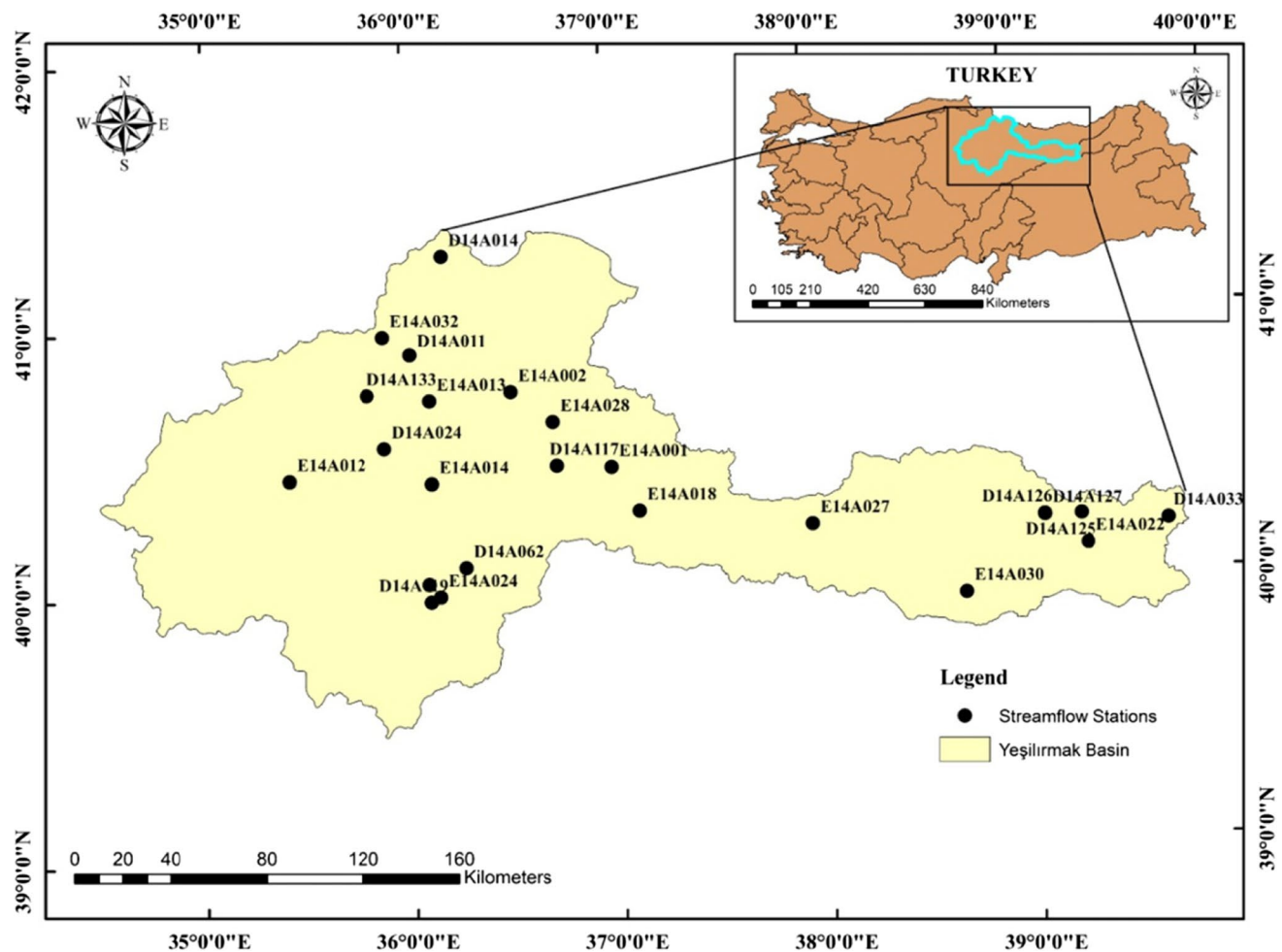

Fig. 3 Location of selected streamflow stations of Yeşilırmak basin

on the percentage of occurrences in drought and wet categories of some stations in which minimum and maximum percentages of most reputable categories have been obtained in all time scales are given in Table 3. The calculations of all stations have been given with Appendix 1. To evaluate the time series, SDI graphs are constructed for all stations. To give an example, SDI graphs belonging to the longest drought and the drought which has the highest value are presented in Fig. 4.

According to SDI-1 results given in Table 3 and Appendix 1, the highest SDI-1 values are detected in the Mild Drought and Wet categories. According to these two categories, the lowest values are seen at station D14A062 with a value of 22.91% (Mild) and at station D14A033 with a value of 41.89% (Wet), while the highest values are captured at stations D14A033 and D14A062 with values of %48.14 and %73.39, respectively. According to SDI-3 results, higher SDI values are mostly captured in Mild Drought and Wet categories. While the lowest values are noted as 25.39% (Mild) and 46.97% (Wet) at stations D14A011 and E14A030, respectively, the highest values are seen at stations E14A014 and D14A062 as 41.41% and 63.46%, respectively. In the SDI-6 time scale, SDI values show similar behavior to SDI-1 and SDI-3. Mild Drought and Wet categories are analyzed with the lowest value of
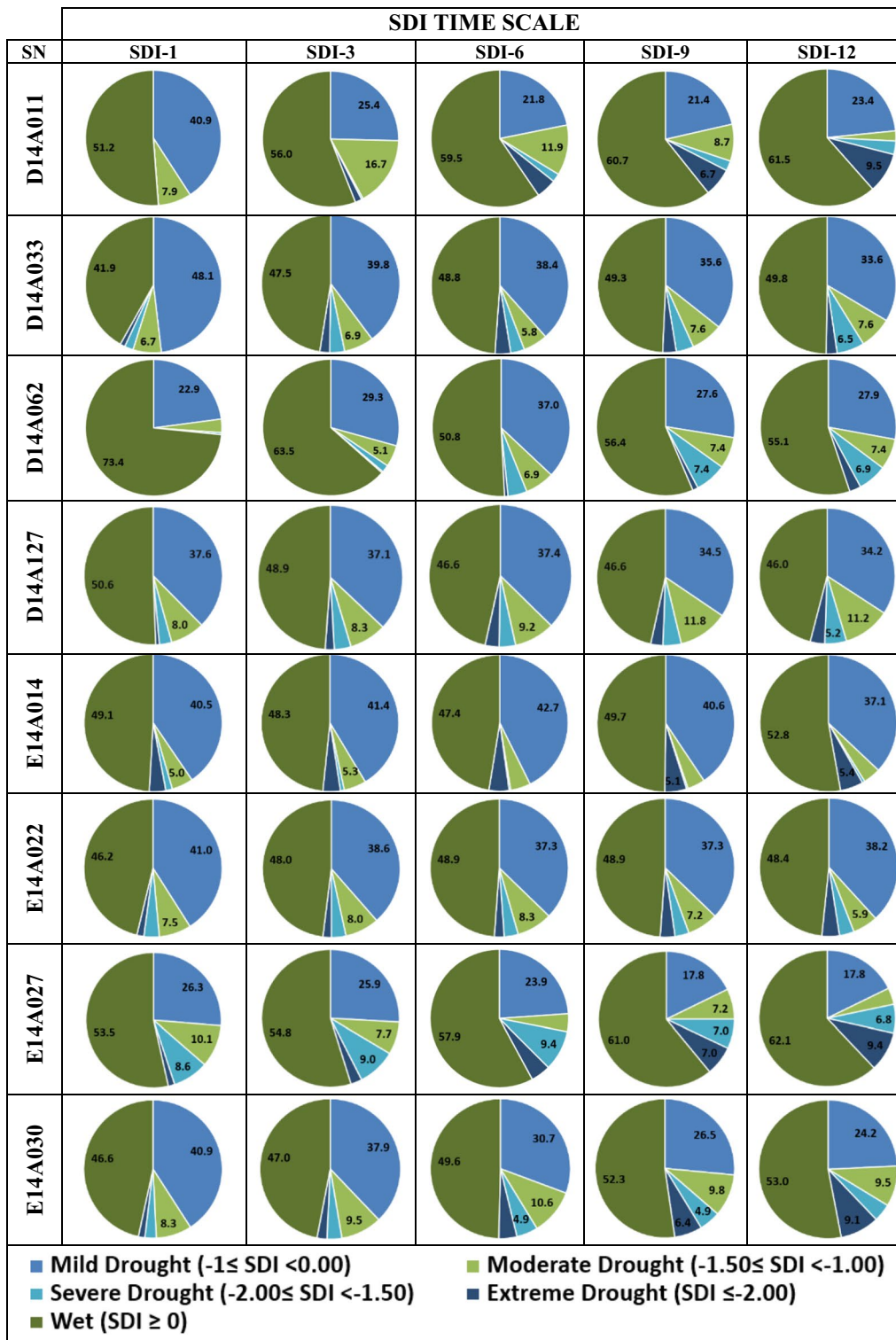
21.82% (D14A011), 46.55% (D14A127), and the highest value of 42.69% (E14A014) and 59.52% (D14A011), respectively. SDI-9 time scale analyses of all stations are shown as similar to previous time scales(1,3,6-month time scales). Mild Drought and Wet categories dominate the SDI values throughout the basin. The lowest Mild Drought and Wet occurrence is 17.76% (E14A027) and 46.55% (D14A127), respectively, whereas, the highest maximum value in Mild Drought is %40.64 (E14A014), and the highest maximum value in the Wet category occurance is seen as 60.96% (E14A027). According to the Long-term SDI analysis which is linked to SDI-12 results, calculated SDI values mostly belong to Mild Drought with 17.76% (E14A027) and Wet with %45.97 (D14A127) as the lowest occurrence and the highest values of both categories, Mild Drought occurrence has 38.23% (E14A022) while the Wet category has 62.6% (E14A027).

In all time scales, it has been obtained that the other drought categories are between 0% and 16.66% in which moderate drought class becomes 16.66% in SDI-3. To make the assessment simpler, if all wet categories are considered as wet (SDI $\geq$ 0) and all drought categories are considered as dry (SDI $\leq$ 0), by Appendix 1, it can be concluded that in SDI-1 10, in SDI-3 9, in SDI-6, 4, in SDI-9 6, in SDI-12 5 stations dry percentages are higher

Table 2 Location features of selected streamflow stations in the Yeşiılırmak Basin

Station No	Latitude (N)	Longitude(E)	Elevation(m)	Data Interval
D14A011	40°55′13″	36°1′14″	862	1999–2019
D14A014	41°17′10″	36°11′13″	140	1964–2019
D14A024	40°34′7″	35°53′9″	502	1976–2019
D14A033	40°11′27″	39°42′39″	1558	1984–2019
D14A062	40°6′56″	36°16′26″	1232	1968–2019
D14A106	40°3′22″	36°5′33″	1095	1979–2017
D14A117	40°29′21″	36°43′56″	734	1985–2018
D14A119	39°59′23″	36°6′5″	1050	1988–2015
D14A125	40°13′39″	39°17′13″	1610	1988–2013
D14A126	40°13′56″	39°6′28″	1500	1990–2017
D14A127	40°13′47″	39°6′28″	1497	1989–2017
D14A133	40°46′10″	35°48′18″	600	1996–2019
E14A001	40°28′42″	36°59′56″	375	1938–2011
E14A002	40°46′18″	36°30′45″	190	1962–2019
E14A012	40°27′6″	35°25′3″	530	1954–2019
E14A013	40°44′40″	36°6′43″	301	1955–2012
E14A014	40°25′59″	36°6′56″	510	1955–2019
E14A018	40°18′42″	37°7′43″	820	1965–2019
E14A022	40°6′55″	39°18′42″	1350	1969–2019
E14A024	40°0′29″	36°8′47″	1040	1969–2019
E14A027	40°14′17″	37°58′21″	690	1982–2019
E14A028	40°39′15″	36°43′7″	275	1990–2013
E14A030	39°57′17″	38°42′28″	1475	1998–2019
E14A032	40°59′13″	35°53′15″	758	2000–2018

Table 3 Percentage occurrences of drought and wet categories in some stations based on SDI values

SN	SDI TIME SCALE				
	SDI-1	**SDI-3**	**SDI-6**	**SDI-9**	**SDI-12**
D14A011	40.9; 7.9; 51.2	25.4; 16.7; 56.0	21.8; 11.9; 59.5	21.4; 8.7; 6.7; 60.7	23.4; 9.5; 61.5
D14A033	48.1; 6.7; 41.9	39.8; 6.9; 47.5	38.4; 5.8; 48.8	35.6; 7.6; 49.3	33.6; 7.6; 6.5; 49.8
D14A062	22.9; 73.4	29.3; 5.1; 63.5	37.0; 6.9; 50.8	27.6; 7.4; 7.4; 56.4	27.9; 7.4; 6.9; 55.1
D14A127	37.6; 8.0; 50.6	37.1; 8.3; 48.9	37.4; 9.2; 46.6	34.5; 11.8; 46.6	34.2; 11.2; 5.2; 46.0
E14A014	40.5; 5.0; 49.1	41.4; 5.3; 48.3	42.7; 47.4	40.6; 5.1; 49.7	37.1; 5.4; 52.8
E14A022	41.0; 7.5; 46.2	38.6; 8.0; 48.0	37.3; 8.3; 48.9	37.3; 7.2; 48.9	38.2; 5.9; 48.4
E14A027	26.3; 10.1; 8.6; 53.5	25.9; 7.7; 9.0; 54.8	23.9; 9.4; 57.9	17.8; 7.2; 7.0; 7.0; 61.0	17.8; 6.8; 9.4; 62.1
E14A030	40.9; 8.3; 46.6	37.9; 9.5; 47.0	30.7; 10.6; 4.9; 49.6	26.5; 9.8; 4.9; 6.4; 52.3	24.2; 9.5; 9.1; 53.0

- ■ Mild Drought (-1≤ SDI <0.00)
- ■ Moderate Drought (-1.50≤ SDI <-1.00)
- ■ Severe Drought (-2.00≤ SDI <-1.50)
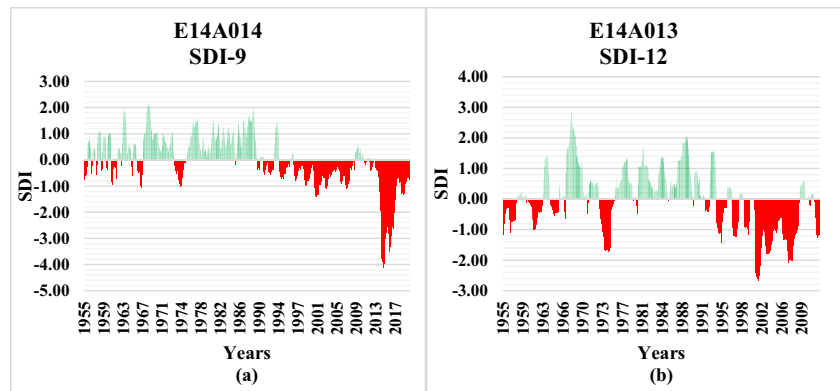- ■ Extreme Drought (SDI ≤-2.00)
- ■ Wet (SDI ≥ 0)

than wet ones while in other all stations wet percentages are higher than dry ones.

Based on the percentage of occurrence of SDI values, the Mild Drought category has the highest percentages in all time scales of all stations considering all drought categories.

Simsek (2021) has found the same results for Mediterranean Basins. Additionally, Katïpoğlu et al. (2022) used SDI to conduct hydrological research for the Yeşilrmak Basin, and their findings are consistent with our findings. While many mild droughts have been observed, there have only been a

Fig. 4 SDI Time Series, **a**) The longest lasted drought, **b**) The most Severe Drought

small number of extreme droughts in monthly and annual series. Akturk et al. (2022) have performed an meterological drought assessment by SPI for Kızılırmak River Basin which is neighbour to Yeşilırmak Basin and found that 31 years of study period have been affected by drought categories while 28 of 31 years belong to mild drought categories. Topçu et al. (2022) have performed a drought analysis for Mediterranean, Seyhan, Ceyhan, and Asi Basins by utilizing aggregate drought index (ADI) and reported that mild drought dominates the all study area.

Drought severity and duration are calculated for all time scales of all stations using Yevjevich's Run theory (1967) and SDI data computed in the time scales of 1, 3, 6, 9 and 12- months. Due to the extreme nature of droughts, their maximum and lowest values are evaluated separately together with their periods and given in Table 4. The longest lasted and highest droughts which have been detected among all time scales have been graphically displayed in Fig. 4. As it can be seen in Fig. 4. and Table 4; the longest drought record have been found with 145 months (E14A014) between 1997(1) – 2009(1) with SDI-9 time scale while the highest drought has been captured as 136.13 (E14013) between 2001(2)—2009(4) with SDI-12 time scale.

In all SDI time scales of almost all stations, it has been seen that the droughts either the longest lasting or having the greatest severity generally occur in the 2000s (2000 and up to 2017). Based on hydrological drought analysis (Tabari et al. 2013; Gümüş 2017; Myronidis et al. 2018; Özfidaner et al. 2018; Simsek 2021; Junqueira et al. 2022; Katipoğlu et al. 2022) in the different parts of the world several drought events have been detected in 2000 and later. Boustani and Ulke (2020) have made meterological drought analysis for Yeşilırmak Basin of Turkey and found droughts in 1974, 2001, 2014 which are also detected same years in this study. Akturk et al. (2022) have reported that in 2007–2008, 2013 and 2017 there are major drought events in Kızılırmak River Basin which is consistent with our findings.

4.2 Spatial distributions of dry and wet categories

The spatial distribution of drought classes as well as the wet class which is the combination of all wet classifications (SDI ≥ 0) given in Table 1 has been done by IDW method and an spatial distribution of all time scales is presented in Fig. 5. As can be seen from Fig. 5, in SDI-1; mild droughts are seen in the northern and eastern parts of the basin and the

Table 4 The longest lasted and highest droughts

The Longest Lasted Droughts				
Time Scale	*Date*	*Station*	*Severity*	*Duration (Months)*
1	2000(5)-2003(10)	E14A022	42.71	42
3	2011(9)-2019(9)	E14A027	126.54	97
6	2000(12)-2009(4)	E14A012	112.53	101
9	*1997(1)-2009(1)*	*E14A014*	*89.49*	*145*
12	1997(2)-2009(1)	E14A014	96.41	144
The Highest Droughts				
Time Scale	*Date*	*Station*	*Severity*	*Duration (Months)*
1	2013(9)-2016(9)	E14A014	87.28	37
3	2011(9)-2019(9)	E14A027	126.54	97
6	2000(12)-2009(1)	E14A013	116.81	98
9	2000(1)-2009(2)	E14A013	129.19	97
12	*2001(2)-2009(4)*	*E14A013*	*136.13*	*99*

highest occurrence is detected in the eastern part. Moderate droughts are seen in the western, middle, and eastern parts of the basin. In addition, severe droughts are mostly observed in almost the middle part while extreme droughts are partly detected in the middle and some parts of the northern. Wet cases are mostly observed in the southern part where the highest value of this category has been also seen.

In SDI-3, mild droughts are mostly seen in the parts the eastern, southern, middle, and upper parts of northern with a range of 25.4—41.4. Furthermore, the middle part is of the highest occurrence of mild drought. Moderate droughts are mostly found in western, upper northern, and some the parts of the eastern parts of the basin with a higher occurrence percentage than SDI-1. Severe droughts are detected in the western and upper northern parts but the highest occurrence has been observed in the eastern part of the basin. Extreme droughts with an occurrence percentage of 0.32–4.38, are mostly observed in the northern, southern, and middle parts while wet categories are seen mostly in the southern part and the highest occurrence is evaluated on the southern side.

According to SDI-6 spatial distribution, mild drought is highly distributed on the middle, southern and some parts of eastern sides of the basin while moderate droughts are seen in the northern, western, and eastern parts over the basin. Severe droughts are captured in the western part. But as can be seen from Fig. 5, some parts of the basin in the middle and near the eastern have droughts. Extreme droughts are seen almost in all parts of the basin. However, the highest occurrence is seen in the northern part. Having an occurrence percentage range of 47.44–57.89 which is lower than SDI-1 and SDI-3 wet category occurrence percentage, wet categories are mostly seen in the northern and eastern parts of the basin.

In SDI-9 spatial distribution results have shown that mild drought has been distributed mostly in the middle, southern, western, and eastern sides with a range of 17.76–40.62 and the highest value is also seen in the middle part. When moderate droughts are investigated, it is seen that middle parts near the northern side and a big part of the eastern parts are affected. In addition, the eastern, and western parts of the basin are
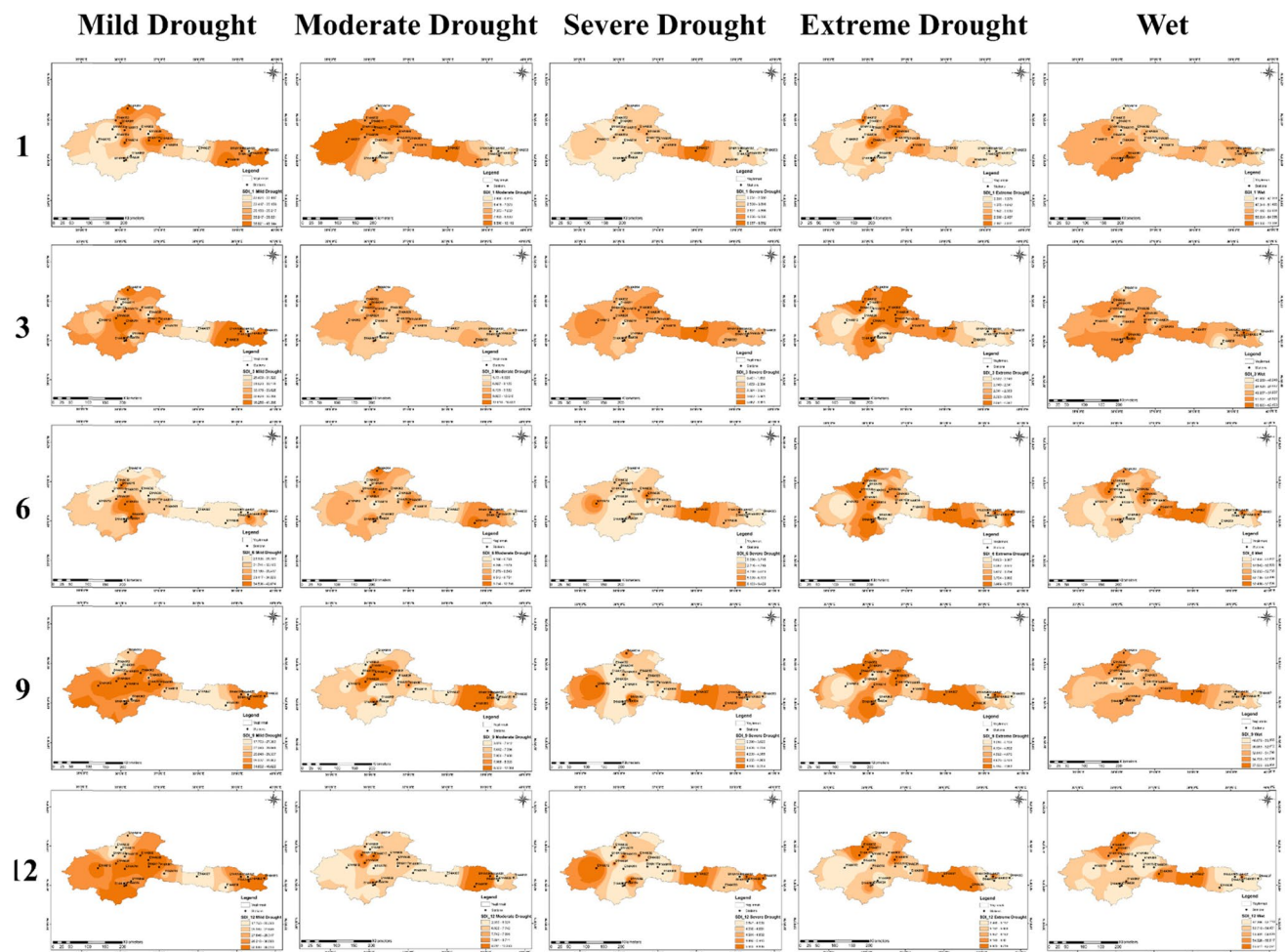

Fig. 5 Spatial Distribution of drought and wet categories for all time scales

Table 5 Innovative Trend Analysis results of selected stations in Yeşilırmak basin **TS:** Trend Slope, **LCL:** Lower Confidence Limit, **UCL:** Upper Confidence Level ↑: Increasing Trend, ↓: Decreasing Trend, **0**: No Trend

Station	SDI-1			SDI-3			SDI-6			SDI-9			SDI-12			Type of Trend				
	TS	LCL (99%)	UCL (99%)	TS	LCL (99%)	UCL (99%)	TS	LCL (99%)	UCL (99%)	TS	LCL (99%)	UCL (99%)	TS	LCL (99%)	UCL (99%)	1	3	6	9	12
D14A011	-0.0017552	-0.0001832	0.0001832	-0.0016231	-0.0002911	0.0002911	-0.0013409	-0.0004409	0.0004409	-0.0012026	-0.0003877	0.0003877	-0.0013790	-0.0003016	0.0003016	→	→	→	→	→
D14A014	-0.0005014	-0.0000520	0.0000520	-0.0005825	-0.0000632	0.0000632	-0.0006100	-0.0000749	0.0000749	-0.0006322	-0.0000984	0.0000984	-0.0006566	-0.0001156	0.0001156	→	→	→	→	→
D14A024	-0.0033390	-0.0000751	0.0000751	-0.0040869	-0.0000535	0.0000535	-0.0042840	-0.0000811	0.0000811	-0.0043139	-0.0000856	0.0000856	-0.0044111	-0.0000837	0.0000837	→	→	→	→	→
D14A033	-0.0028001	-0.0000886	0.0000886	-0.0029671	-0.0000908	0.0000908	-0.0030924	-0.0001202	0.0001202	-0.0032971	-0.0001283	0.0001283	-0.0034761	-0.0001156	0.0001156	→	→	→	→	→
D14A062	-0.0006421	-0.0000705	0.0000705	-0.0011601	-0.0000541	0.0000541	-0.0018014	-0.0000357	0.0000357	-0.0019709	-0.0000563	0.0000563	-0.0021630	-0.0000625	0.0000625	→	→	→	→	→
D14A106	-0.0018110	-0.0001008	0.0001008	-0.0025304	-0.0001002	0.0001002	-0.0033172	-0.0000968	0.0000968	-0.0036838	-0.0000968	0.0000968	-0.0039314	-0.0001045	0.0001045	→	→	→	→	→
D14A117	-0.0031049	-0.0002047	0.0002047	-0.0036292	-0.0002199	0.0002199	-0.0037587	-0.0002016	0.0002016	-0.0037435	-0.0001457	0.0001457	-0.0039297	-0.0001303	0.0001303	→	→	→	→	→
D14A119	-0.0015483	-0.0001415	0.0001415	-0.0026351	-0.0001662	0.0001662	-0.0029493	-0.0001691	0.0001691	-0.0027290	-0.0002448	0.0002448	-0.0029052	-0.0002900	0.0002900	→	→	→	→	→
D14A125	-0.0016682	-0.0002040	0.0002040	-0.0021528	-0.0001814	0.0001814	-0.0034100	-0.0002430	0.0002430	-0.0040270	-0.0003233	0.0003233	-0.0047278	-0.0004177	0.0004177	→	→	→	→	→
D14A126	-0.0001124	-0.0001795	0.0001795	-0.0002196	-0.0001980	0.0001980	0.0002594	-0.0001641	0.0001641	0.0007886	-0.0001602	0.0001602	0.0010701	-0.0002191	0.0002191	→	→	→	→	↑
D14A127	0.0007694	-0.0001636	0.0001636	0.0013279	-0.0002160	0.0002160	0.0023117	-0.0002821	0.0002821	0.0031737	-0.0003078	0.0003078	0.0037078	-0.0003317	0.0003317	↑	↑	↑	↑	↑
D14A133	-0.0002668	-0.0001384	0.0001384	-0.0009020	-0.0002091	0.0002091	-0.0007309	-0.0001927	0.0001927	-0.0006043	-0.0003058	0.0003058	-0.0010632	-0.0003904	0.0003904	→	→	→	→	→
E14A001	0.0006790	-0.0000271	0.0000271	0.0005551	-0.0000224	0.0000224	0.0001174	-0.0000238	0.0000238	-0.0003098	-0.0000229	0.0000229	-0.0006013	-0.0000216	0.0000216	↑	↑	→	→	→
E14A002	-0.0003291	-0.0000505	0.0000505	-0.0006378	-0.0000385	0.0000385	-0.0012823	-0.0000315	0.0000315	-0.0018737	-0.0000535	0.0000535	-0.0022020	-0.0000715	0.0000715	↑	↑	→	→	→
E14A012	-0.0011559	-0.0000331	0.0000331	-0.0014142	-0.0000331	0.0000331	-0.0016865	-0.0000409	0.0000409	-0.0018521	-0.0000494	0.0000494	-0.0019265	-0.0000592	0.0000592	→	→	→	→	→
E14A013	-0.0007921	-0.0000436	0.0000436	-0.0009562	-0.0000479	0.0000479	-0.0012423	-0.0000399	0.0000399	-0.0014293	-0.0000334	0.0000334	-0.0014595	-0.0000489	0.0000489	→	→	→	→	→
E14A014	-0.0020267	-0.0000791	0.0000791	-0.0022310	-0.0000907	0.0000907	-0.0025479	-0.0000937	0.0000937	-0.0028254	-0.0000782	0.0000782	-0.0029597	-0.0000557	0.0000557	→	→	→	→	↑
E14A018	-0.0011712	-0.0000653	0.0000653	-0.0011982	-0.0000738	0.0000738	-0.0011513	-0.0000922	0.0000922	-0.0011554	-0.0000957	0.0000957	-0.0012348	-0.0000927	0.0000927	→	→	→	→	→
E14A022	-0.0006368	-0.0000460	0.0000460	-0.0007561	-0.0000788	0.0000788	-0.0009128	-0.0001119	0.0001119	-0.0010789	-0.0001371	0.0001371	-0.0012229	-0.0001576	0.0001576	→	→	→	→	→
E14A024	-0.0012296	-0.0000335	0.0000335	-0.0017064	-0.0000312	0.0000312	-0.0024500	-0.0000291	0.0000291	-0.0029567	-0.0000431	0.0000431	-0.0032050	-0.0000507	0.0000507	→	→	→	→	→
E14A027	-0.0039735	-0.0001367	0.0001367	-0.0043840	-0.0001442	0.0001442	-0.0050189	-0.0001455	0.0001455	-0.0054149	-0.0001766	0.0001766	-0.0056508	-0.0001911	0.0001911	→	→	→	→	→
E14A028	-0.0009465	-0.0001673	0.0001673	-0.0012489	-0.0002053	0.0002053	-0.0017271	-0.0002763	0.0002763	-0.0018621	-0.0003234	0.0003234	-0.0023120	-0.0002859	0.0002859	→	→	→	→	→
E14A030	0.0004360	-0.0002016	0.0002016	-0.0005578	-0.0002236	0.0002236	-0.0009894	-0.0002111	0.0002111	-0.0012109	-0.0001969	0.0001969	-0.0017969	-0.0002193	0.0002193	↑	→	→	→	→
E14A032	0.0007279	-0.0003304	0.0003304	0.0010983	-0.0003285	0.0003285	0.0017008	-0.0004641	0.0004641	0.0018339	-0.0005087	0.0005087	0.0025004	-0.0006792	0.0006792	↑	↑	↑	↑	↑

Table 6 Graphical results of Innovative Trend Analyses of selected stations in the Yeşilırmak Basin based on drought classification. Mild Drought (**MD**), Moderate Drought (**MOD**), Severe and Extreme Drought (**SED**) (SDI ≤ −1.5), Mild Wet (**MW**), Moderate Wet (**MOW**), Severe and Extreme Wet (**SEW**) (SDI ≥ 1.5) ↑: Increasing Trend, ↓: Decreasing Trend, **0**: No Trend

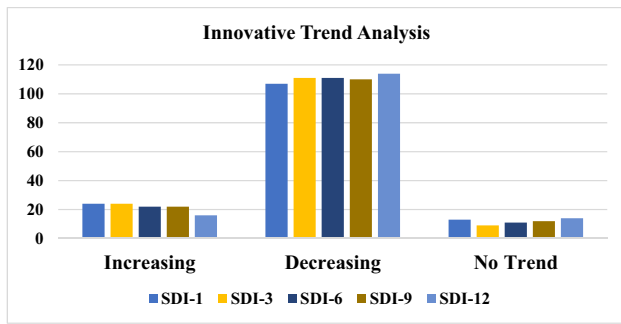| Station	SDI-1						SDI-3						SDI-6						SDI-9						SDI-12					
	MD	MOD	SED	MW	MOW	SEW	MD	MOD	SED	MW	MOW	SEW	MD	MOD	SED	MW	MOW	SEW	MD	MOD	SED	MW	MOW	SEW	MD	MOD	SED	MW	MOW	SEW
D14A011	→	→	0	→	→	→	→	→	←	→	→	→	→	→	←	→	→	0	→	→	←	→	←	0	→	→	→	0	0	0
D14A014	0	→	→	→	→	→	0	→	→	→	→	→	0	→	→	→	→	→	0	→	→	→	0	→	0	→	→	0	→	→
D14A024	→	→	→	→	→	→	→	→	0	0	→	→	→	0	0	→	→	→	→	0	0	→	0	→	→	0	0	→	→	→
D14A033	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
D14A062	→	0	→	→	→	→	→	→	0	→	→	→	→	→	→	→	→	→	→	→	0	→	→	→	→	→	0	→	→	→
D14A106	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
D14A117	→	→	0	→	→	→	→	→	→	→	→	→	→	→	←	→	→	←	→	→	→	→	→	→	→	→	→	→	←	←
D14A119	→	0	0	→	→	→	→	→	→	→	→	→	→	→	0	→	→	←	→	→	←	←	→	→	→	←	←	←	←	→
D14A125	→	←	←	→	→	→	←	→	←	←	←	→	←	←	←	←	←	←	←	0	←	←	←	←	←	0	←	→	←	→
D14A126	→	←	→	←	←	→	→	→	0	←	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	←	0
D14A127	→	←	←	←	←	→	→	←	←	0	←	←	→	←	←	←	←	→	←	←	←	←	←	→	←	←	←	←	←	→
D14A133	0	0	←	0	→	→	←	→	→	→	→	→	←	→	→	→	→	→	←	→	→	→	→	→	→	→	←	→	→	→
E14A001	←	→	→	←	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
E14A002	0	0	→	0	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	0	→	→	→	→	→	→	→	→	→
E14A012	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	0	→	→	→
E14A013	→	→	←	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	0	→	→	→	→	→	→	→	→	→
E14A014	→	→	→	→	→	→	→	→	0	→	→	→	→	→	→	→	→	→	→	→	0	→	→	→	→	→	0	→	→	→
E14A018	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
E14A022	→	→	→	→	0	→	→	→	→	→	0	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
E14A024	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	0	0	→	→	→
E14A027	→	→	←	→	→	→	→	→	←	→	→	→	→	←	→	→	→	→	→	←	←	→	→	→	←	←	←	→	→	→
E14A028	→	→	→	→	←	←	→	→	→	→	→	→	→	←	→	→	→	→	→	←	→	→	→	→	→	←	→	→	←	→
E14A030	←	←	→	0	←	←	←	←	→	→	→	→	0	→	→	→	→	→	←	0	→	→	→	→	←	0	→	→	0	→
E14A032	←	←	→	←	←	←	←	→	→	←	→	←	←	←	→	←	←	←	←	←	→	←	←	0	←	←	→	←	0	←

Fig. 6 Distribution of trend cases for SDI time scales based on ITA analysis

exposed to severe droughts which have a range of 0.39–8.20 throughout the basin. Except at some small portions, extreme droughts are seen almost in the basin with a range of 1.28–7.98 (on darkest sides). Wet categories have been distributed to the basin with a percentage of 48.67 – 60.96 and mostly captured the northern and eastern sides of the basin.

In long-term (SDI-12) spatial distribution analysis, mild drought is distributed to basin almost similar to SDI-9 but with a lower percentage (17.76–38.20). Moderate droughts are found in the basin very similar to SDI-9 but less distributed in the middle portions. Severe droughts are detected in the eastern, and western parts of the basin which is also almost the same distribution and same percentage as SDI-9. However extreme droughts, as well as wet categories, are highly seen in the eastern and northern parts.

4.3 Identification of trend analysis of dry and wet categories

Using ITA procedure and equations of 9, 10, 11; ITA has been applied to 1, 3, 6, 9, 12-month SDI series, trend slopes have been determined based on 99% percent confidence limits. Trend slopes, lower and upper confidence limits as well as trend types of SDI series of all stations have been given with Table 5. SDI series having decreasing trend type are shown by "↓", those having increasing trend denoted by "↑" and if a serie doesn't have any trend in which trend slope is equal to 0, then they are described by "0". As it can be seen from Table 5, in all time scales of all stations a trend is existent which also means that no trend case has not been detected. In SDI-1 20, in SDI-3 21, in SDI-6 20, in SDI-9 21, in SDI-12 21 stations have shown decreasing trends. Additionally, it is also possible to say 19 stations have shown decreasing trends in all time scales. From Table 5, D14A127 and E14A032 stations have increasing trends in all time scales while D14A126 (6, 9, 12-month) and E14A001 (1,3,6-month) stations have increasing trends in 3 time scales.

ITA method which has been combined with drought and wet classes in this study has been applied to the SDI series and

graphical results of some of them are given in Fig. 7 and all other graphical ITA analysis have been given in Fig. 8, Fig. 9 and Fig. 10 with Appendix 2. In this study, as it has been mentioned the categories are classified as Mild Drought (MD), Moderate Drought (MOD), Severe and Extreme Drought (SED) which is a combination of the last two drought categories (SDI ≤ -1.5), Mild Wet (MW), Moderate Wet (MOW), Severe and Extreme Wet (SEW) which is a combination of last two wet categories (SDI ≥ 1.5) in SDI series, and again the groups which have increasing trend is shown by "↑", for decreasing trend case by "↓" and if a group shows no trend, then it is denoted by "0". The trend results are presented in Table 6. A brief description of trend cases is given in Fig. 6. In Fig. 7 the stations whose categories show different trend behaviour have been given. As it can been seen in D14A011 trends are nonmonotonic, SDI values in both drought and wet categories have different trends; in D14A117 all groups have same trends that are monotonic and decreasing; in D14A127 except at some time scales, all groups have same trends which are monotonic and increasing trends.

ITA results of the SDI-1 series are shown that among the total of 144 analyses for 6 groups of 24 stations, most of the groups are detected as decreasing trend (108 = 75%), while 24 groups are an increasing trend and 12 of them are found no trend. In addition, 10 stations indicate a completely decreasing trend. An increasing trend is mostly detected in station E14A032 (5 groups) among all stations. ITA analysis in SDI-3 time scale, most of the groups show a decreasing trend (112 = 77.77%) and 9 stations have completely shown decreasing trend. Furthermore, an increasing trend is detected in 25 groups which is the highest amount of increasing trends, among all time scales. No trend cases are seen with 7 groups. ITA analysis in SDI-6 time scale, decreasing trend case are found as 115 times (79.86%) and 12 stations are entirely shown decreasing trend. Increasing trend case (22) became lesser than increasing trend case amount of SDI-1 and SDI-3 while no trend case takes a part of 7 groups which is equal to SDI-3's no trend case.

ITA in the SDI-9 time scale results, decreasing trends are found with an amount of 110 times (76.38%) and 8 stations indicate significantly decreasing trend in all groups. Furthermore, increasing trends are analyzed as equal to SDI-1's increasing trend case by 24 groups. No trend case is slightly higher than the no trend case of SDI-3 and SDI-6 time scales with 10 (6.94%).

Finally, ITA in SDI-12 results, it has been seen that the amount of increasing, decreasing, and no trend cases are, 20(13.88%), 108(75%), and 16(11.11%), respectively. From a point of view, trend case of no trend is observed at its maximum in this time scale, while the increasing trend is minimum among all SDI time scales. Also, it is worth noting that, station D14A127 shows increasing trends in all groups of SDI-6, SDI-9 time scales. The stations of D14A033, D14A117, E14A018, and E14A024 have an entirely decreasing trend in all groups of all time scales. In the stations of D1A014 and D14A024, the no trend case is the highest at 7, among all stations.

When it comes to drought and wet classification trend analysis from Table 6, Mild drought (MD) have decreasing trend in all time scales of 17 stations while increasing and no trend cases have been detected at one station each. While moderate drought (MOD) have decreasing trends in all time scales of 12 stations, Severe and Extreme drought (SED) class (SDI ≤ -1.5) has 10 stations of decreasing trend. Mild wet(MW) has decreasing trends in all time scales of 14 stations and Moderate wet (MW) has 19 stations of decreasing trends in all time scales and 2 stations of increasing trends. Severe and Extreme Wet (SEW) class (SDI ≥ 1.5) has 17 stations which have decreasing trends in all time scales.

Serencam (2019) has applied ITA method to precipitation data of 5 stations in Yeşilırmak Basin, Turkey and found significant decrasing trends. Katïpoğlu et al. (2022) used ITA for analyzing the trends of hydrological droughts in the Yeşilırmak basin by taking 0 as the threshold value in order to separate dry(SDI < 0) and wet(SDI > 0).They found that trends in both dry and wet periods except at some stations are decreasing trends. Gumus et al. (2022) have used ITA method for streamflow trends using monthly mean streamflow data of 16 stations in Tigris River Basin, Turkey and they have found strong and very strong decreasing trends at 80% of stations. The results of these studies verify the results of this study.

5 Conclusion

In this study, The SDI and mean monthly streamflow data from 24 stations in the Yeşilrmak Basin were used to perform a hydrological drought analysis. SDI values are obtained for the time scales of 1, 3, 6, 9, 12-month. Using run theory two important drought characteristics that are severity and duration as well as the highest values of them with occurrence terms are analyzed. IDW technique is utilized for the spatial distribution of each drought category and Wet which is the combination of all wet categories (SDI ≥ 0) to monitor the distribution of these categories. ITA technique is developed by adding 5 vertical and 5 horizontal lines to detect possible trends in more detail in terms of three cases which are increasing, decreasing, and no trend.

SDI results have shown that in most of the time scales of stations, wet categories are higher than drought categories. Among all drought categories,the mild category is dominant with the highest occurrence percentages. Even severe and extreme drought categories have reached only 8.83% and 9.72% respectively on some time scales. Simsek (2021); Topçu et al. (2022); Katïpoğlu et al. (2022);

Akturk et al. (2022) have found that mild drought category is mostly seen drought category in their studies. The highest severity and duration of drought events, it is captured that starting with year 2000. The basin is exposed to the most severe and longest-lasting droughts. The longest drought, measured in 145 months (E14A014), occurs in SDI-9, whereas the most severe drought, measured as 136.13 (E14A013), occurs in SDI-12.Tabari et al. (2013); Gümüş (2017); Myronidis et al. (2018); Özfïdaner et al. (2018); Boustani and Ulke (2020); Simsek (2021); Junqueira et al. (2022); Katïpoğlu et al. (2022); Akturk et al. (2022) have reported the drought events in 2000 and later in their study areas. IDW results have shown that different parts of the basin were affected by drought categories based on different time scales. For example, SDI-9 and SDI-12 have shown similar distribution in drought and wet categories. According to trend analysis results, the majority of the drought categories across time scales have trends, and these trends have demonstrated a decreasing trend tendency based on the ITA results. A decreasing trend of SDI value under the dry categories indicates the presence of drought significantly, whereas an upward trend shows no drought. It is also worth to consider that some of stations have shown decreasing trend in all classifications of all time scales. These results show that increasing dry condition at significant level. Among all stations, D14A127 station have increasing trend in all groups of SDI-6, SDI-9 time scales and D1A014 and D14A024 stations have the highest number of no trend case which is 7, among all stations. Based on ITA analysis of drought and wet categories it has been obtained that even there are some increasing and no trend results, all categories have decreasing trends at least more than half of the 24 stations, in all time scales except at severe and extreme drought (SED) class. Many researches (Serencam 2019; Gumus et al. 2022; Katïpoğlu et al. 2022) in which decreasing trends have been detected verify results of this study. Analyzes have shown that basin needs an effective drought management plan so as to keep water resources from future possible droughts. Therefore, results of this study are expected to be beneficial for drought action plans of basin and water resources management.

Appendix 1

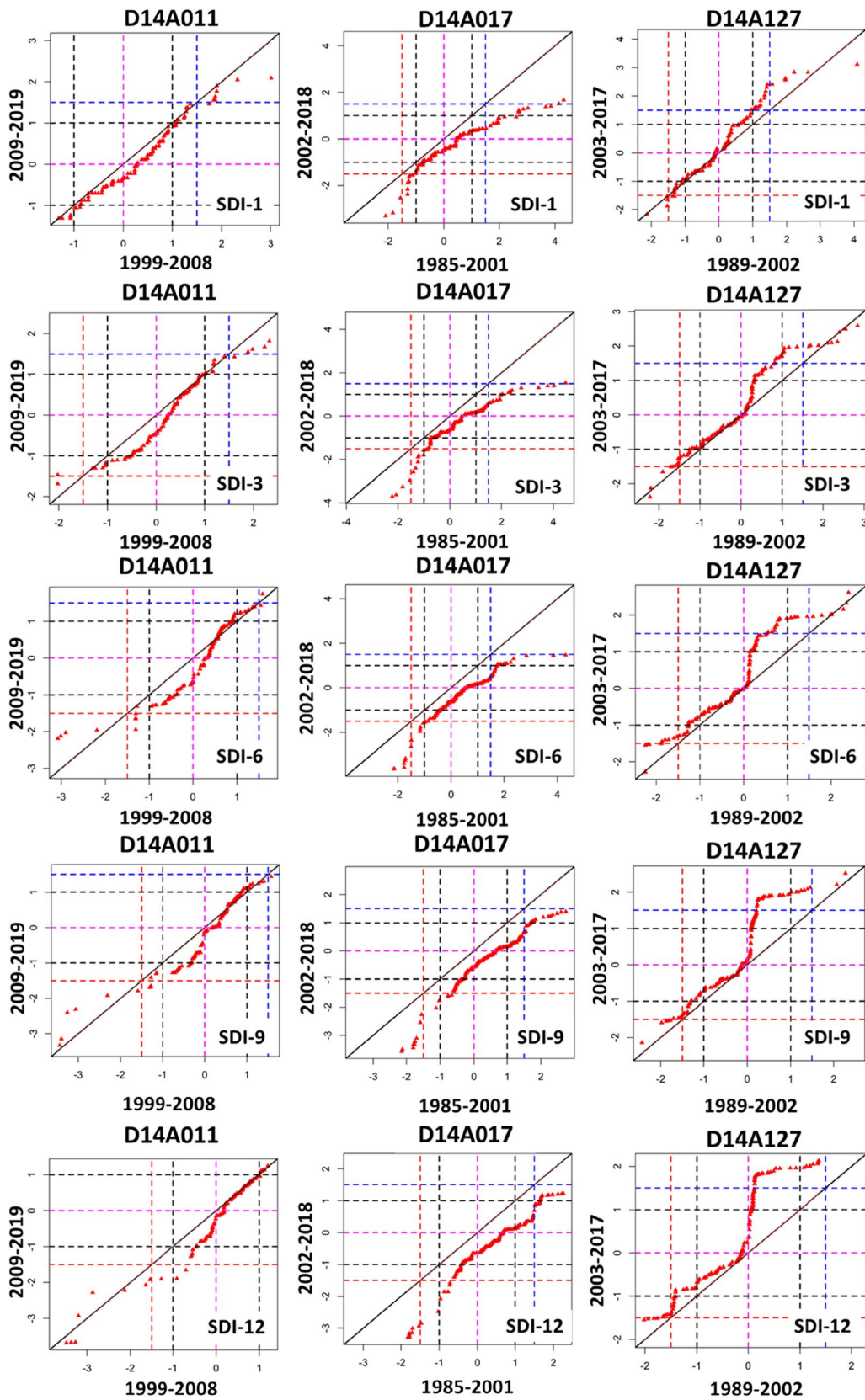SDI Statistical Results of Each Station Based on Percentage of Occurences of All Time Scales.

Fig. 7 ITA results of the stations having different trend behaviours

Table 7 Percentage occurrences of drought and wet categories based on SDI values

SN	SDI TIME SCALE				
	SDI-1	SDI-3	SDI-6	SDI-9	SDI-12
D14A011	40.9 / 7.9 / 51.2	25.4 / 16.7 / 56.0	21.8 / 11.9 / 59.5	21.4 / 8.7 / 6.7 / 60.7	23.4 / 9.5 / 61.5
D14A014	42.0 / 7.1 / 45.8	38.5 / 8.5 / 47.5	32.0 / 8.5 / 52.1	28.6 / 6.5 / 5.1 / 55.8	26.2 / 7.3 / 57.6
D14A024	30.9 / 8.3 / 57.0	36.2 / 10.6 / 48.1	35.8 / 9.7 / 48.1	34.5 / 10.8 / 48.7	32.6 / 9.1 / 5.1 / 50.2
D14A033	48.1 / 6.7 / 41.9	39.8 / 6.9 / 47.5	38.4 / 5.8 / 48.8	35.6 / 7.6 / 49.3	33.6 / 7.6 / 6.5 / 49.8
D14A062	22.9 / 73.4	29.3 / 5.1 / 63.5	37.0 / 6.9 / 50.8	27.6 / 7.4 / 7.4 / 56.4	27.9 / 7.4 / 6.9 / 55.1
D14A106	35.0 / 57.3	38.0 / 6.4 / 50.9	29.1 / 11.1 / 53.4	27.4 / 9.8 / 5.8 / 56.0	25.2 / 10.0 / 6.2 / 56.0
D14A117	41.9 / 6.6 / 47.8	35.8 / 6.9 / 52.2	33.3 / 7.1 / 52.7	32.1 / 7.6 / 5.1 / 52.0	32.1 / 6.9 / 5.6 / 52.2
D14A119	27.1 / 7.1 / 64.0	31.5 / 8.9 / 56.0	33.6 / 5.1 / 53.0	33.3 / 7.7 / 53.0	36.3 / 8.0 / 50.6

Table 7 (continued)

Table 7 (continued)

Legend
■ Mild Drought (-1≤ SDI <0.00)
■ Moderate Drought (-1.50≤ SDI <-1.00)
■ Severe Drought (-2.00≤ SDI <-1.50)
■ Extreme Drought (SDI ≤-2.00)
■ Wet (SDI ≥ 0)
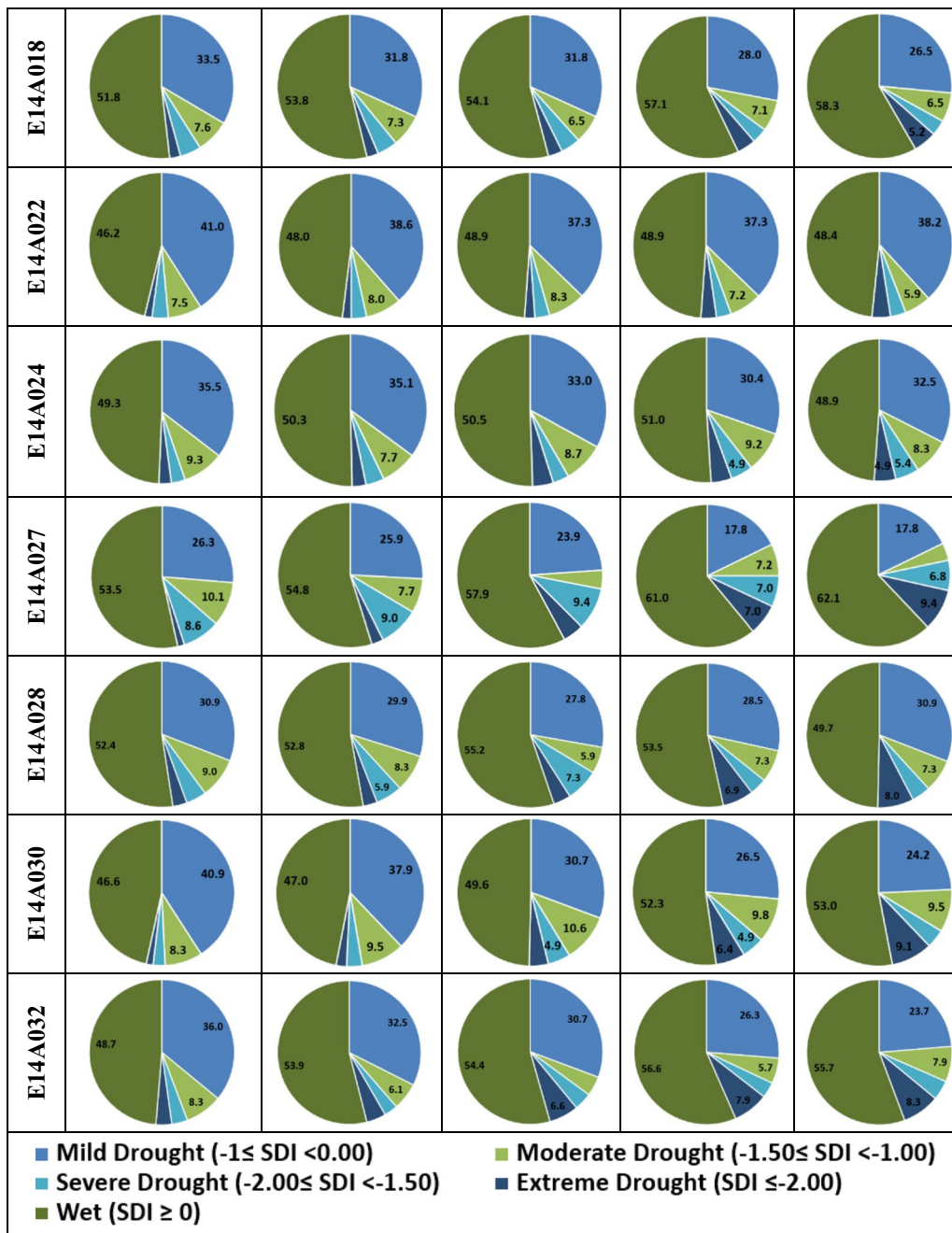
Appendix 2

ITA Analysis Results of each station at 1-, 3-, 6-, 9- and
12-month time scales.
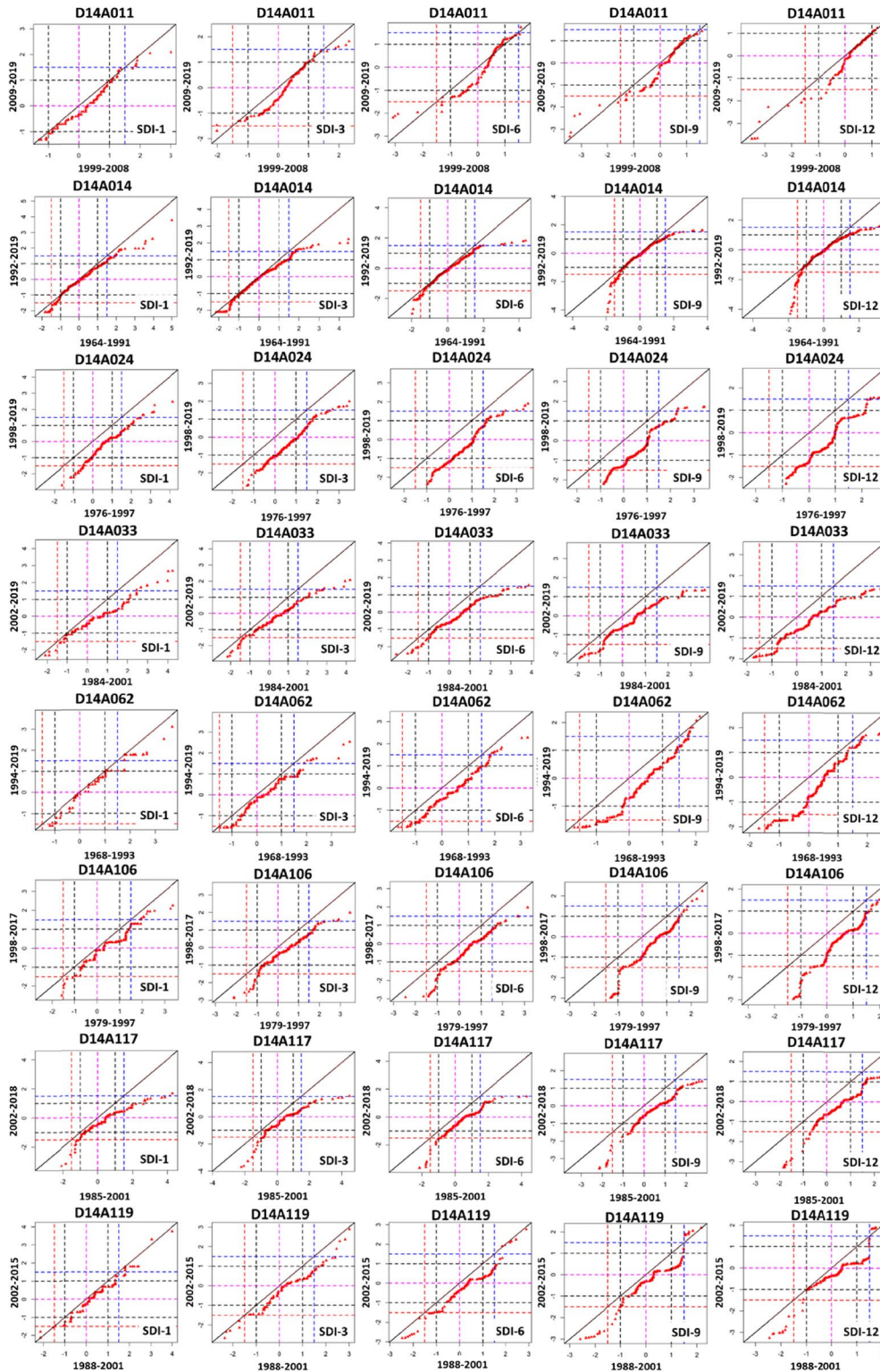
Fig. 8 ITA Results
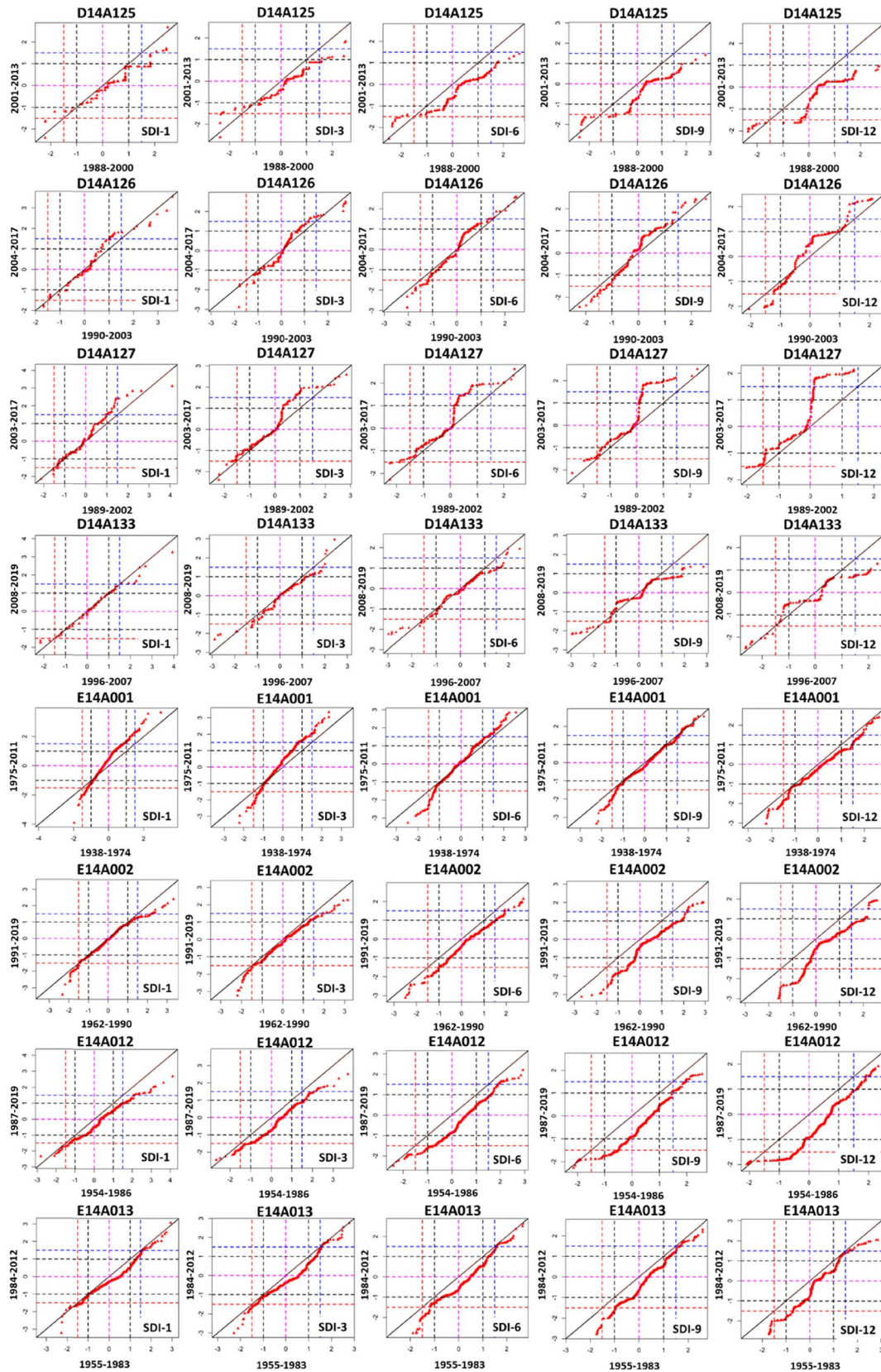
Fig. 9 ITA Results

Fig. 10 ITA Results

Declarations

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