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ORIGINAL PAPER

Hydrological low flow and overlapped trend analysis for drought assessment in Western Black Sea Basin

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Abstract

Drought is a major disaster known for hundreds of years, but its impact has recently increased due to climate crisis, making it a common concern of the whole society worldwide. There is no clear definition of drought, as many disciplines evaluate it from different perspectives. Utilizing water and reducing the impact of drought are directly related issues. It is essential to determine our rivers' future conditions, reveal the effects of possible changes on drought, and take the necessary precautions against them in advance to prevent possible economic and social crises. In this study, among the 126 flow observation stations whose records were kept in the Western Black Sea Region, 26 observation stations with suitable data between 1984 and 2020 were selected to evaluate the drought effect. The Mann–Kendall Rank Correlation test was used to determine the starting years of the detected trends. In order to detect trends, the Spearman's Rho (SR) test, the Mann–Kendall (MK) test, Sen's Trend Slope (TS) method, Şen's Innovative Trend Analysis (ITA) test, and, Mann–Kendall Order Correlation (MKOC) test. According to all analysis methods, decreasing trends were detected at stations D13A014, D1A032, and E13A036. In addition, MKOC test results showed the trend starting in 2001 was at D13A014, 1990 at D13A032, and 1990 at E13A036. However, no significant trend was detected in minimum flows at other stations. It would be appropriate to make such studies on the evaluation of water resources a country policy and to conduct studies on the direction and value of drought in the basin in the future using trend analysis or other methods.

Keywords Climate change adaptation · Drought risk management · Probability distribution · Sustainable development · Vulnerability

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1 Introduction

Water is the fundamental source of life on earth for all living things. It is one of the most critical resources in nature because of being indispensable (Akhtar et al. 2021). All living things in a wide range, from micro-scale life forms to all living things belonging to complex systems, survive with water. Since the formation of the world, water has been moving on the earth through various cycles. Water in oceans, seas, lakes, and all kinds of sources undergoes a hydrological cycle. This cycle occurs when the energy carried by sunlight evaporates the water in the lands and oceans, and the evaporated water falls to the earth as precipitation (Herrera-Estrada and Diffenbaugh 2020; Liu et al. 2021). Global warming, climate change, and environmental disasters significantly affect water resources, such as droughts (Feng et al. 2021; Abdalzaher et al. 2024a). Considering its disastrous consequences and costly adverse effects, global warming is humanity's most severe and vital problem. The 1.5 °C Special Report on Global Warming, prepared by the Intergovernmental Panel on Climate Change (IPCC) in 2018 by examining more than 6000 scientific studies, revealed that the climate will experience extreme changes if temperatures increase between 1.5 °C and 2.0 °C compared to today's levels. These changes include increases in terrestrial average temperatures, extreme temperatures in people's living spaces, significant increases in the likelihood of drought and lack of precipitation in some regions, and agricultural drought risks (IPCC 2018; Isinkaralar and Isinkaralar 2023). Although global warming and climate change are intertwined and often used in the same sense, they have noticeable differences. While global warming refers to increases in the earth's atmosphere that may affect the climate and cause it to change, climate change causes temperature, humidity, wind, precipitation, etc., in certain regions (Liu et al. 2020; Yang et al. 2020).

Climate is defined as the average condition of all weather events observed and occurring over many years in any region of the earth. However, when defining the climate, it is necessary to consider extreme events, change frequencies, and probabilities. For this reason, the climate is identified as the average state of weather events or conditions (Wilhite et al. 2014). However, in recent years, it has been defined as a synthesis of meteorological events such as humidity, temperature, air pressure, wind, precipitation, and precipitation type observed over long periods, and extreme events and extreme conditions (Guo et al. 2020; Abdalzaher et al. 2024b). Climate change refers to a long-term change in global or regional climate patterns (IPCC 2014; Isinkaralar et al. 2024a, 2024b) and is a natural consequence of global warming and changes in the balances in hydrological cycle systems and processes. The metamorphosis in the atmosphere due to climate change will reflect on all processes, including precipitation, evaporation, and flow in the basins. The effects that will be seen worldwide are an increase in evaporation and precipitation, precipitation being showers instead of falling regularly and intermittently, melting of glaciers, rising sea levels, natural events such as hurricanes and typhoons becoming more frequent, etc. there will be effects (Pulwarty and Sivakumar 2014; Sung and Liaw 2021). Changes in atmospheric events will affect long-term averages and be seen in extreme events' frequency, magnitude, and distribution. While drought and water scarcity problems will occur in wetlands, severe and sudden flood disasters will occur in areas where floods are rare at the neighborhood scale (Abdrabo et al. 2023). However, scientific studies show that global warming and climate change will reduce water resources (Yuan et al. 20222022). Climate change science is a well-studied and mature subject today. French mathematician

Fourier put forward the concept of greenhouse gas in 1827, stating that our atmosphere absorbs heat; otherwise, this heat would be reflected in space. According to Fourier, the greenhouse effect has two crucial consequences for our world (Fourier 1827).

First, the earth's average surface temperature is kept at approximately 15 °C by the solar radiation-absorbing effect of the atmosphere. Without the warming effect of greenhouse gases, the average surface temperature would be − 18 °C, which would cause life on the planet to differ from its current state. The second is that night temperatures would be much lower than they would be without the insulating effect of greenhouse gases. Fourier's work was followed in 1860 by the English scientist Tyndall's discovery that nitrogen and oxygen, the main components of our atmosphere, do not absorb heat (infrared radiation reflected from the earth) and have a greenhouse effect. This effect results from a minority of atmospheric gases, primarily water vapor, carbon dioxide, and methane (Yoro and Daramola 2020). There are positive and negative effects of global climate change. An example of a positive effect is the increase in grain yield due to the increase in temperature in northern latitudes. However, the adverse effects in hot climates in middle and equatorial latitudes pose real risks. In the future projections made by the IPCC, the extreme climatic hazards that we may be exposed to in the future are listed as follows: long-term forest fires, heat waves, agricultural pests, drought, increase in floods in cities and rural areas as a result of sudden and heavy rains, increase in the number and severity of hurricanes, typhoons and cyclones in tropical regions, effects on agriculture, livestock and freshwater products, diseases transmitted by carrier animals. The spread of diseases to different areas due to suitable climatic conditions and similar dangers (Skytt et al. 2020; Hamdy et al. 2022). The areas where climate risk will have the most devastating effects are drought and the resulting changes in agricultural production.

Drought is a disaster known for hundreds of years, but its impact has increased recently. There is no clear definition of drought, as many disciplines evaluate it from different perspectives (Orimoloye et al. 2022). Drought is characterized as a natural disaster that deeply affects a wide range of socioeconomic life, especially agriculture, social life, and industry, where a long-term lack of precipitation results in water scarcity (Ortega-Gaucin et al. 2021). Drought can be examined into six main classes according to its impact areas: meteorological drought, climatological drought, atmospheric drought, agricultural drought, hydrological drought, and water resources drought (Salehnia et al. 2018). Utilizing water and reducing the impact of drought are directly related issues. It is essential to determine our rivers' future conditions, reveal the effects of possible changes on drought, and take the necessary precautions against them in advance to prevent possible economic and social crises. This study seeks answers to the following research questions:

RQ1 How can alternative trend analyses be applied to determine the future drought direction in the basin?

RQ2 What suggestions can be developed for practice regarding drought?

The trends of minimum flows obtained from flow observation stations established on the Western Black Sea Basin rivers were examined, and the drought results were evaluated in the Western Black Sea Basin. The paper present was to develop suggestions for more efficient water use in the basin, especially in agricultural and water management.

2 Materials

Stream flow data can be used in climate science studies to make stream bed arrangements and create canals, bridges, dams, regulators, ponds, flood traps, dams, improvement terraces, irrigation facilities, etc. It is observed and recorded to create hydraulic design criteria in engineering structures such as flow observation stations built at designated points of the rivers to observe the data of the rivers periodically. The flow data obtained is used in studies to examine, interpret, and apply statistical criteria. Flow data are interpreted in three ways: average, maximum, and minimum flows according to the determined time criterion. Average flows are used extensively in studies to reveal the water potential of a river basin and to make hydraulic calculations of engineering structures. Maximum flows are essential in flood studies, and minimum flows are essential in drought studies.

2.1 Features of West Black Sea Basin study

The Western Black Sea Basin is located between 40°34′42″–41°27′52″ northern latitudes and 30°52′33″–35° 12′12″ eastern longitudes. The basin covers a total area of 2,896,766 hectares. The Western Black Sea Basin is bordered by the Sakarya Basin in the southwest, the Kizilirmak Basin in the southeast, and the Black Sea in the north. Figure 1a shows the location of the Western Black Sea Basin in Türkiye. The elevation map of the Western Black Sea Basin DEM (Digital Elevation Model) data of the basin is given in Fig. 1b.

All or part of the provinces of Ankara, Bartın, Bolu, Çankırı, Düzce, Karabük, Kastamonu, Sakarya, Samsun, Sinop and Zonguldak are located in the basin. The Western Black Sea Basin is surrounded by the Black Sea in the north, with the water separation line passing through the peaks of Çangal Mountain, Zindan Mountain, Küre Mountains, Ilgaz Mountains, Benlidağ, Bolu Mountains, Karadağ, Işık Mountain and Elmacık Mountain from the east. The minimum flow data was used to evaluate the drought effect. An inventory list of all open and closed flow observation stations was prepared to keep records in the basin. A total of 126 flow observation stations were identified to create the mapping, and visuals were created by positioning them in the ArcGIS 10.0 software. After the station identification studies, the stations were selected, and the main framework of the study was created by collecting and organizing the minimum flow data at the selected stations. In the examinations, it was seen that there was a lot of missing data in the flow observations. It has been observed that the deficiencies in the minimum flow data must be completed to carry out the studies healthily. A systematic process has been created to complete the data flow, and stations close to each other have been grouped. Stations on the same mainstream

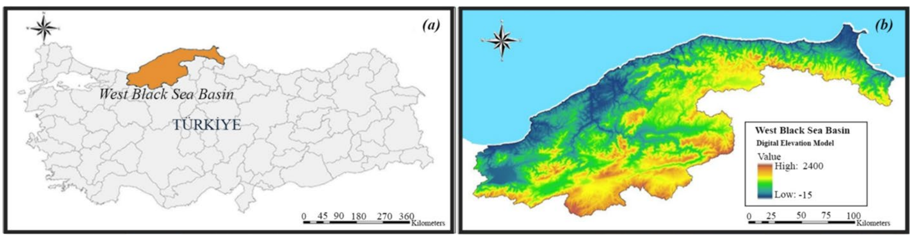

Fig. 1 Location map of the West Black Sea Basin **a** Location in Türkiye, **b** Elevation map according to sea level rise

and its tributaries were listed, and missing data were completed among the pairs with the highest correlation coefficient. In this way, selecting the most suitable stations grouped in the Western Black Sea Basin can produce a result that reflects the entire basin as closely as possible. All stations throughout the basin were examined and subjected to elimination. In the selection of flow observation stations, i) the on–off status of the stations to ensure up-to-date data; ii) the data should be as accurate and complete as possible; iii) station locations to accurately represent the entire basin; iv) location of the stations on the main-branch and their basin areas; v) approximate elevation values of stations; vi) conflicts with stations in order to evaluate irrigation areas in terms of drought taken into account.

2.2 Sub-basins

The Western Black Sea Basin constitutes 3.7% of Türkiye's surface area. It is divided into five main basin sections and many sub-basins within them. Figure 2a shows the

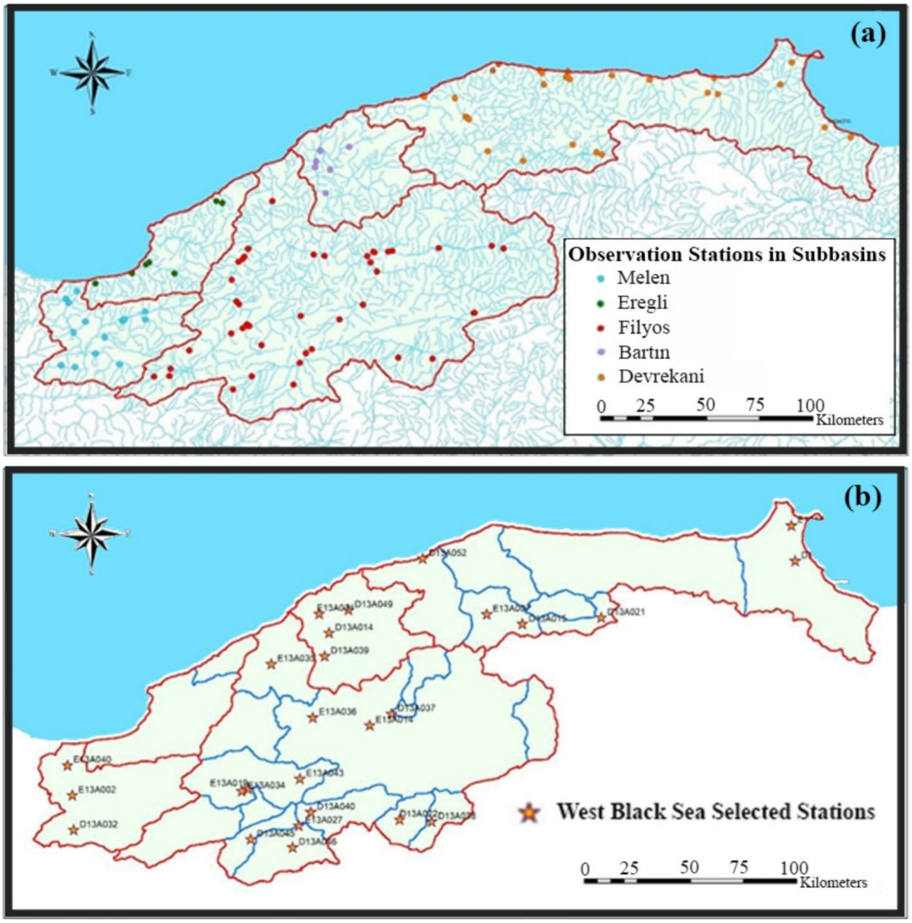

Fig. 2 Stations based on **a** sub-basin borders and their observation stations in sub-basins, and **b** sub-basin of the selected station in the Western Black Sea Basin

stations containing all records of the basin, and some streams give their names to sub-basins, such as Melen Stream, Bartın Stream, Filyos Stream, Devrekani Stream, Alaplı Stream, Gülüç Stream, Aydos Stream, Zerbana Stream, Güble Stream, which comes from the foothills of the mountain ranges along Black Sea and continues along the valleys and flows directly into the Black Sea. Ezine Stream, Sarımsaklı Stream, Helaldi Stream, İnebolu Stream, Akçay, Ayancık Stream, Güzelçay (Kanlıçay) etc. Many teas, side streams, and streams within the basin combine to form large streams and rivers, as shown in Fig. 2b.

2.3 Topography

Due to the Northern Anatolian Mountains parallel to the coast in the basin, the altitude increases rapidly as it moves from the seashore towards the inland areas. The rapid increase in altitude prevents the marine effect from affecting the inland areas and causes slope precipitation. Although the average elevation is relatively lower in Düzce, Zonguldak, and Bartın provinces, sudden increases are seen in the area from Amasra to Sinop. It is possible to see the same effect in the section from Sinop center to the south. Some plateaus and plains are more suitable for agriculture in the upper parts. In the Western Black Sea Basin, due to the ruggedness of the land structure in the northern parts, agricultural lands cover more area in the inner parts where there are wide plains. There is little need to establish irrigation systems in the agricultural lands on the coastal surfaces of the mountains in the basin. The need for irrigation is felt more in the inland areas where water is more scarce, according to Basin Protection Action Plans in 2014. The usage areas of the lands in the Western Black Sea Basin are as reported by the General Directorate of Water Management in 2013: Artificial Areas 37,009 ha (1.28%), Agricultural Areas 607,414 ha (20.97%), Forest and Semi-Natural Areas 2,240,422 ha (77.34%), Wetlands 777 ha (0.03%) and water. Its surface area is divided into 11,144 ha (0.38%).

3 Data and analysis

In the selection of flow observation stations, care was taken to ensure that the data of recent years were as complete as possible, and due to the current situation, emphasis was placed on open observation stations. The data in the flow observing stations (AGIs) were examined, and the 37-year period started in 1984 when it was seen that the data were kept healthy and obtained from the General Directorate of Meteorology (MGM 2022). This way, coordination was achieved throughout the basin by evaluating the data in the same period. However, to conduct a study that represents the entire basin, all sub-basins from Düzce to Sinop were examined, and care was taken to ensure that the stations were distributed homogeneously throughout the basin. Data missing on one or both sides are excluded from the regression coefficient calculation to be completed later. The compatibility of the stations is determined according to the correlation coefficient calculated with the remaining data. The fact that the coefficient determined as a result of the correlation calculation is close to 1 indicates that the stations have strong hydraulic relations with each other. The correlation coefficient is calculated using the Eq. (1).

$$r_x = \frac{\sum_{i=1}^{n} \left(x_i - \overline{x}\right)(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n} \left(x_i - \overline{x}\right)^2 \sum_{i=1}^{n} \left(y_i - \overline{y}\right)^2}} \tag{1}$$

where r_x: correlation coefficient, x_i and y_i: flow data measured at flow observation stations in the same period, $\overline{x}$ and $\overline{y}$: average values of flow data of flow observation stations.

A mathematical line equation is created to complete the missing data with the data of the neighboring station that is most suitable for the station to be built. With this line equation created, the missing data of the months to be realized are calculated by using the data at the base station in Table 1.

3.1 Preparing data for analysis

It is essential to question the homogeneity of data in climate science studies. Homogeneous data indicates that the records are affected only by climatic conditions. In order to evaluate the data as homogeneous, statistical parameters such as Homogeneity, Pettitt, Buishand, and Standart Normal Homogeneity were applied and should not show sudden and extreme changes (Peterson et al. 1998). Ullah et al. (2020) reported that long-term, homogeneous, and continuous rainfall series are essential in climatic and hydrological studies. However, they stated that precipitation data may suffer from inhomogeneity due to various non-climatic factors. Borah et al. (2022) emphasized that the changes occurring in homogeneous series result from climatic and atmospheric effects. Various homogenization methods have been proposed in the literature for climate and non-climatic time series (Adeyeri et al. 2022; Ahmed 2023). Kabbilawsh et al. (2023) suggested several statistical methods and metadata information as the most effective way to evaluate homogeneity in climatic series. They also reported that the homogeneity tests to be applied to time series could be divided into two groups: the absolute method, in which only the analyzed station data are used, and the relative method, in which the related station data are also utilized during the analysis.

There is a two-stage progression in the absolute method as follows: i) first of all, the homogeneity of the data of all stations was determined by the Von Neumann Ratio Test—VNRT (Von Neumann 1941), Pettitt's Test (Pettitt 1979), Buishand's Test (Buishand 1982) and Standard Normal Homogeneity Test—SNHT (Alexandersson 1986); ii) according to the results of the four methods mentioned above, the stations are categorized into Homogeneous, Suspicious, and Extremely Suspicious.

Although the Von Neumann ratio test (1941) is a potent method, it cannot determine when the change occurred. Von Neumann test statistic NVN is defined with Eq. (2).

$$\mathrm{N}_{NV} = \sum_{i=1}^{n-1} (Y_i - Y_{i-1})^2 / \sum_{i=1}^{n} (Y_i - \overline{Y_i})^2 \tag{2}$$

Homogeneous acceptance limits for Von Neumann test results according to 1% and 5% significance levels are given in Table 2.

Pettitt (1979) developed a non-parametric method to detect the formation points of breaks in monthly or annual series. The null hypothesis shows that the series are identical, randomly distributed, and independent, while the alternative hypothesis shows shifts and sudden changes from the average values. The procedure steps of the Pettitt test are explained below (Conte et al. 2019):

Table 1 Information table of stations of Western Black Sea Basin

Order		Station no	Station name	Stream name	Amount of observations (Year)	Rainfall area (km^2)	Approx. elevation (m)	Coordinate
1	Melen sub-basin	D13A032	Dereevi	Aksu	45	71.5	873	30°59′50″ East—40°42′34″ North
2		E13A002	Yakabaşı	Büyük Melen	68	1988	115	30°59′9″ East—40°51′22″ North
3		E13A040	Beyler	Büyükmelen	40	2174	23	30°57′18″ East—40°58′57″ North
4	Bartın sub-basin	D13A014	Bayıryüzü	Ulus	56	1016	50	32°24′41″ East—41°33′37″ North
5		D13A039	Boğazköy	Kocanaz	46	332	130	32°23′15″ East—41°27′42″ North
6		D13A049	Darıören	Arıt	37	137	230	32°31′14″ East—41°39′32″ North
7		E13A031	Bartın	Kocaırmak	52	1342	15	32°21′20″ East—41°38′30″ North
8	Filyos sub-basin	D13A022	Akhasan	Akhasan	51	76.5	1180	32°48′0″ East—40°46′0″ North
9		D13A036	Yalaközü	Hacılar	49	88.3	1179	32°59′27″ East—40°45′43″ North
10		D13A037	Çevrikköprü	Eflani	49	537.1	322	32°45′51″ East—41°13′9″ North
11		D13A040	Bahçedere	Gerede	44	1343	1095	32°19′0″ East—40°48′0″ North
12		D13A045	Yağbaşlar	Ulusu	38	196	1183	31°59′0″ East—40°41′0″ North
13		D13A046	Salur	Markoşa	38	240	1200	32°59′27″ East—40°45′43″ North
14		E13A014	Karabük	Soğanlı	55	5086.8	271	32° 38′ 35″ East—41° 10′ 11″ North
15		E13A019	Gökçesu	Mengen	56	786.3	507	31°58′2″ East—40°53′47″ North
16		E13A027	Afatlar	Ulusu	54	953.6	1142	32°15′3″ East—40°44′32″ North
17		E13A034	Beşdeğirmenler	Bolu	50	1095.3	541	31° 55′ 48″ East—40° 53′ 12″ North
18		E13A035	Çaycuma	Filyos	57	13,300.4	19	32°5′15″ East—41°25′36″ North
19		E13A036	Yenice	Yenice	42	8966	117	32°19′24″ East—41°12′6″ North
20		E13A043	Arak	Korubaşı	29	125	780	32°15′17″ East—40°56′28″ North

Table 1 (continued)

Order		Station no	Station name	Stream name	Amount of observations (Year)	Rainfall area (km^2)	Approx. elevation (m)	Coordinate
21	Devrekâni Gerze sub-basin	D13A015	Cürümören	Devrekâni	55	729	924	33°30′8″ East—41°35′58″ North
22		D13A021	Çorbacı	Devrekâni	53	45.5	1094	33°56′49″ East—41°37′24″ North
23		D13A050	Şamlıoğlu	İspa	37	17	85	35°2′54″ East—41°50′57″ North
24		D13A052	Cide	Kocaçay	36	2303.7	5	32°56′20″ East—41°52′39″ North
25		E13A007	Azdavay	Devrekâni	67	1097.6	815	33°18′3″ East—41°38′28″ North
26		E13A032	Hacılar	Karasu	52	340	20	35°1′57″ East—41°59′57″ North

Table 2 NVN critical values for 95% and 99% confidence intervals according to the number of data

AD	n					
	20	**30**	**40**	**50**	**70**	**100**
%95	1.30	1.42	1.49	1.54	1.61	1.67
%99	1.04	1.20	1.29	1.36	1.45	1.54

1. X_i refers to a sequence of random variables with change point at time *t*, which is divided in two sets with distinct distributions functions ($F_1(X_t)$ and $F_2(X_t)$) hypotheses to be tested (H_0 ($F_1(X)=F_2(X)$ refer to no change point) and H_1 ($F_1(X)\neq F_2(X)$ refer to change point).
2. Pettitt test statistic $U_{t,T}$ is calculated with Eq. (3) and (4).

$$\mathrm{Ut,\ T} = \sum_{i=1}^{t}\sum_{j=t+1}^{T} \operatorname{sgn}\left(X_i - X_j\right), \quad 1 \le t < T \tag{3}$$

$$\operatorname{sgn}(x) = \left\{ \begin{array}{l} 1, \ \text{if } x > 0 \\ 0, \ \text{if } x = 0 \\ -1 \ \text{if } x < 0 \end{array} \right\} \tag{4}$$

3. Calculated $U_{t,T}$ values are graphed. If it is accepted that the year in which the change occurred in the series is E, the absolute largest value in the graph should be seen in Eq. (5) and Eq. (6) define approximate *p* value of the test, given a significance level α, if p < α, the null hypothesis, H_0 that the two distributions are equal is rejected.

$$K_t = \mathrm{Ut,\ T} = \max|Ut, T| \ \ 1 \le t < T \tag{5}$$

$$p \sim 2\exp\left(\frac{-6K_t^2}{T^3 + T^2}\right) \tag{6}$$

If the homogeneity test statistic $U_{t,T}$ is smaller than the value corresponding to the determined significance level, the series is considered homogeneous in Table 3.

This test detects a change in the mean by examining the cumulative deviation from the mean. The calculation method is based on adjusted partial sums or cumulative deviation from the mean. Buishand (1982) stated that the null hypothesis represents the situation where the data are homogeneous and normally distributed, and the alternative hypothesis represents the situation where there is a change in the mean. The process steps of the Buishand test are given below. Firstly, corrected partial totals must be calculated with Eq. (7). The fact that the S_k^* value is around 0, indicating that the data series is homogeneous.

Table 3 $U_{t,T}$ critical values for 95% and 99% confidence intervals depending on the number of data

n	**20**	**30**	**40**	**50**	**70**	**100**
%95	57	107	167	235	393	677
%99	71	133	208	293	488	841

Table 4 $R/\sqrt{n}$ critical values for 95% and 99% confidence intervals depending on the number of data

AD	n					
	20	**30**	**40**	**50**	**70**	**100**
%95	1.43	1.50	1.53	1.55	1.59	1.62
%99	1.60	1.70	1.74	1.78	1.81	1.86

Table 5 T_0 critical values for 95% and 99% confidence intervals according to the number of data

AD	n					
	20	**30**	**40**	**50**	**70**	**100**
%95	6.95	7.65	8.10	8.45	8.80	9.15
%99	9.11	10.15	10.77	11.19	11.73	12.22

$$S_0^* = 0 \text{ and } S_k^* = \sum_{i=1}^{k} (Y_i - \bar{Y}) \qquad k = 1, 2, 3, \dots n \tag{7}$$

Buishand test statistic R is calculated using the Eq. (8): Here S_k^* denotes partial sums, and s denotes standard deviation.

$$\mathrm{R} = (\max_{0 \le k \le n} S_k^* - \min_{0 \le k \le n} S_k^*)/s \tag{8}$$

Critical values calculated for the Buishand test are given in Table 4. If the $\mathrm{R}/\sqrt{n}$ value is less than the values corresponding to the confidence intervals specified, the series is considered homogeneous.

The SNHT test was developed by Alexandersson (1986) and has been used to determine the homogeneity of series in many climatic and hydrological studies. The process steps of the SNHT method are given below.

The series is first divided into two at a determined point, k. The test statistic $T_{(k)}$ and $\bar{z}_1$ ve $\bar{z}_2^2$ are calculated with Eq. (9) and Eq. (10).

$$\mathrm{T(k)} = \mathrm{k}\bar{z}_1^2 + (\mathrm{n} - \mathrm{k})\bar{z}_2^2 \qquad \mathrm{k} = 1, 2, 3, \dots \mathrm{n} \tag{9}$$

$$\bar{z}_1^2 = \frac{1}{k} \sum_{i=1}^{k} (Y_i - \overline{Y})/s \quad ve \quad \bar{z}_1^2 = \frac{1}{n-k} \sum_{i=k+1}^{k} (Y_i - \overline{Y})/s \tag{10}$$

If there is a change in the specified year k in the data set, the test statistic $T_{(k)}$ reaches the maximum value. Suppose the statistical value T_0 determined according to the calculated values exceeds the value corresponding to the significance level determined that the series is not homogeneous Eq. (11).

$$\mathrm{T}_0 = \max_{1 \le k \le n} \mathrm{T(k)} \tag{11}$$

Critical value limits determined according to 95% and 99% significance levels are shown in Table 5.

In order to complete the missing data in the AGIs selected within the scope of the study, the equation of the slope line that gave the highest correlation coefficient obtained according to the Linear, Exponential, Logarithmic, Exponent, 2nd Degree Polynomial, and 3rd

Degree Polynomial graphs in the Correlation Master Excel program was selected, and the data were completed.

Kaiser–Meyer–Olkin (KMO) and Bartlett's test were applied to check the model's robustness and whether the variables used were suitable for PCA when the sample adequacy fit and sphericity test were $p<0.01$. The KMO index ranges from 0 to 1, with 0.90, 0.80, 0.70, 0.60, 0.50, and below 0.50 referred to marvelous, meritorious, middling, mediocre, miserable, and unacceptable (Samian et al. 2015; Patil et al. 2020).

3.2 Missing data completion studies

In the studies of completing the minimum current data at the stations, D13A014, D13A015, D13A022, D13A032, D13A036, D13A037, D13A040, D13A045, D13A049, D13A052, E13A002, E13A007, E13A014, E13A019, E1 3A027, E13A031, E13A032, E13A034, E13A035, E13A035, E13A036, E13A040, The data in the flow observation stations numbered E13A043 have been completed. Station D13A050 was observed to be a dry stream for most of the year and was excluded from the scope of the study since sufficient data could not be obtained. During the completion of the missing data of station D13A021, due to the low correlation coefficient, the data completion was not found reliable, and the stations were excluded from the scope of the study. Station D13A039 was excluded from the scope of the study due to the years that could not be completed due to incompatibility with the base station data and records. Although the desired results were not obtained for the stations specified in the minimum flow data, they were not removed from the map to shed light on the specified stations for future researchers who will work in this region.

3.3 Homogeneity tests

The minimum flow data measured at Western Black Sea Basin flow observation stations are used, and drought situations that occur under extreme conditions are examined. When the literature on studies on homogeneity is examined, it is seen that studies on homogeneity are carried out on average values and standard deviation etc., of a series. It will be seen that statistical studies are concerned with the part free of deviations.

Since the data used within the scope of this study reflects the risks of the basin, no progress can be made based on average values. Similarly, maximum flow data to be used in examining flood events are also included in this scope. Floods are natural disasters that develop suddenly and occur quickly, with precipitation that can fall for months when they occur, causing the water level to rise rapidly. For example, the flood in Bozkurt district of Kastamonu province in August 2021 left deep, painful consequences for the region's people and our country. In this flood event, enough rainfall fell to approximately four times the maximum water level expected to flow under normal conditions. Excluding the data of these and similar events that occurred quickly from the scope of flood studies is considered harmful. Purifying these data within the scope of homogeneity studies will prevent drought and flood studies from giving accurate results. This issue should be taken into consideration in studies on drought, as well as in flood studies. In this study, dataset with a Kaizer–Meyer–Olkin's Measure of Sampling Adequacy (KMO $=0.367$, smaller than 0.50, marvelous) and Bartlett's test of sphericity ($p>0.01$) were considered not suitable for principal component analysis. The four methods detailed below were applied to the minimum data obtained from selected Western Black Sea Basin stations. Remarkable results regarding homogeneity were obtained even at some stations analyzed entirely with measurement data without any missing data problems. In other studies for the basin, inhomogeneities were observed at stations whose homogeneity was proven in analyses based on average values. It was decided that it would be beneficial to carry out homogeneity studies with all their requirements for the general water capacity and water potential of the basin. However, the homogeneity status of the stations should be ignored for flood and drought situations.

3.4 Trend analysis

3.4.1 Spearman's rho

On the basis of completing this method, used to determine whether there is a correlation between two observation series, is a fast and simple test to investigate the existence of a linear trend (Spearman 1961). R_{xi}, the rank statistic, is determined by ordering the data from smallest to largest or largest to smallest. The observation series is the vector $X=(x_1, x_2, \ldots \ldots, x_n)$. According to the H_0 hypothesis defined by the two-way test, x_i ($i=1, 2, 3, \ldots \ldots, n$) values are equiprobable distributions. According to the H1 hypothesis, x_i ($i=1, 2, 3, \ldots \ldots, n$) values increase over time or decrease. Spearman's Rho (SR) test value (r_s) is calculated with the Eq. (12) (Hirsch et al. 1982).

$$r_s = 1 - 6\frac{\left[\sum_{i=1}^{n}(R\left(x_i - i\right)^2\right]}{(n^3 - n)} \tag{12}$$

In this method, time series and data series are numbered and ordered within themselves. The transaction is made based on the sequence number of the relevant year and the sequence number of the data. When the number of samples exceeds 30, the r_s distribution approaches normal. For this reason, standard normal distribution tables are used. The Eq. (13) containing the r_s value calculates the test statistic.

$$Z = r_s\sqrt{n-1} \tag{13}$$

The absolute value of the calculated test statistic |Z| If the selected α is greater than the $Z_{\alpha/2}$ value determined according to the significance level and determined from the standard normal distribution table ($|Z|>Z_{\alpha/2}$), the H_0 hypothesis, which is based on the observation values not changing over time, is rejected. It is concluded that there is a particular trend. According to the SR Test results for 23 AGIs in the basin, the H0 hypothesis, in which it was assumed that there was no trend in stations numbered D13A014, D13A022, D13A040, D13A045, E13A014, E13A027 and E13A036, was rejected and the presence of a trend was detected in the relevant stations (Table S1).

3.4.2 Mann–Kendall test

This test, commonly known as Kendall's τ statistic, is widely used to test randomness against hydrology and climate science trends. The Mann–Kendall (MK) test is a rank-based method that is resistant to the influence of extreme events and is suitable for use against asymmetric variables (Kendall et al. 1976). According to the test, the null hypothesis H_0 refers to n seasonally adjusted ($x_1,\ldots, x_n$) independent and identical randomly distributed variables. The alternative H_1 hypothesis of the two-sided test is *k,*

$j \leq n$, and $k \neq j$, all conditions that meet x_k and x_j expresses their distribution (Hirsch and Slack 1984). In this process, the test statistic S is calculated with Eq. (14) and Eq. (15).

$$\mathrm{S} = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \tag{14}$$

$$\operatorname{sgn}\left(x_j - x_k\right) = \begin{cases} +1 & \text{if } \left(x_j - x_k\right) > 0 \\ 0 & \text{if } \left(x_j - x_k\right) = 0 \\ -1 & \text{if } \left(x_j - x_k\right) < 0 \end{cases} \tag{15}$$

The Eq. (16) given to calculate the standard deviation is used, assuming all values differ. When the number of observations n exceeds 10, it ensures that the test statistic follows the standard normal distribution (Kendall 1948). If our data has equal and similar values, the variance and the standard deviation due to the variance are calculated with Eq. (17).

$$\sigma s = \sqrt{n(n-1)\,(2n+5)/18} \text{for } n \geq 10 \tag{16}$$

$$\operatorname{Var}(\mathrm{s}) = \frac{n\,(n-1)\,(2n+5) - \sum_t t\,(t-1)\,(2t+5)}{18} \tag{17}$$

In order to use the normal distribution in the MK test, whose variance is determined, we need to determine the standard normal deviation (Z) value in Eq. (18).

$$Z = \begin{cases} \frac{\mathrm{S}-1}{\sqrt{\operatorname{Var}(\mathrm{S})}} & \text{if } \mathrm{S} > 0 \\ 0 & \text{if } \mathrm{S} = 0 \\ \frac{\mathrm{S}+1}{\sqrt{\operatorname{Var}(\mathrm{S})}} & \text{if } \mathrm{S} < 0 \end{cases} \tag{18}$$

The value corresponding to the α significance level chosen for our scientific study is determined from the standard normal distribution table. If this value is less than the absolute value of the Z value obtained from the calculations ($|Z| \leq Z_{\alpha/2}$), the H_0 hypothesis is accepted; otherwise, it is rejected. We determine the direction of a possible trend by looking at the calculated S value. If our S value is positive, there is an increasing trend; if it is negative, there is a decreasing trend (Douglas et al. 2000). This method is practical because it allows the existence of missing data and does not require the data to fit a specific distribution (Yu et al. 1993).

MK Test was applied to 23 selected AGIs, and the H0 hypothesis, in which it was assumed that there was no trend in stations numbered D13A014, D13A032, D13040, D13A045, E13A002, E13A027, E13A032 and E13A036, was rejected and the presence of a trend was detected in the relevant stations (Table S2). It can be said that there is a decreasing trend in stations numbered D13A014, D13A032, D13A045, E13A014, and E13A036. An increasing trend is observed at stations D13A040, E13A002, E13A027 and E13A032 stations. The conclusion can be reached by evaluating the u(t) and u′(t) functions together with other analysis results (Fig. S1). At station D13A014, it is seen that the functions approached and diverged from each other many times in the period before 2001. However, a decreasing trend has been observed in minimum flows since 2001.

3.4.3 Mann–Kendall order correlation test

Like all correlation methods, MK Rank Correlation is a distribution-independent method used to find the relationship between two variables. Positive values of the test statistic (u(t)) indicate a tendency to increase over time, and negative values ($u(t) < 0$) indicate a tendency to decrease over time. When u(t) reaches critical values corresponding to the significance level, it indicates that the reliability level of the trend is significant. Graphically, u(t) and u′(t), calculated as the backtest statistic, approach each other where the change begins and then move away from each other, showing their significance with the place where the trend begins. If there is no trend in the series, *u(t)* and *u′ (t)* will come close to each other many times and oscillate closely. In this test, the data is numbered correctly from beginning to end, and (i) the rank (mi) of the data in the series is used instead of the actual data. Each "mi" is defined by a number like "ni," counting the smaller ones than the previous levels. The sum of the "ni"s and the test statistic "t" are found with Eq. (19), its mean is found with Eq. (20), and its variance is found with Eq. (21) if the Mann–Kendall Order Correlation (MKOC) Test statistic is u(t) found with Eq. (22).

$$t = \sum_{1}^{i} n_i \tag{19}$$

$$\mathrm{E(t)} = \frac{\mathrm{n(n\ -1)}}{4} \tag{20}$$

$$\mathrm{Var(t)} = \frac{\mathrm{n(n\ -1)(2n\ +5)}}{72} \tag{21}$$

$$u(t) = [\mathrm{\ t\ -\ E(t)}]/\sqrt{\mathrm{Var(t)}} \tag{22}$$

The backward MK Test statistic u′ (t) is calculated similarly. This time, the data are numbered from end to end (i′). Instead of real data, for each "m_i", which is the rank of the data in the series, the number of "n_i′"s that are smaller than itself in the years before it (literally in the years after it) is calculated from the end to the beginning. The test statistic "t′" is found by the sum of "n_i′" s. In this way, in the backward MK Test statistic ($u'(t) = —u(t')$) calculated with Eq. (23)- Eq. (25) (Sneyers 1990)."

$$n_i + n_i' = m_i - 1 \tag{23}$$

$$i' = (n+1) - 1 \tag{24}$$

$$t' = \sum_{i=1}^{n} n_i' \tag{25}$$

The method is based on interpreting the scattering points formed by two equivalent time series according to the 1:1 (45°) line in the Cartesian Coordinate system. It does not matter whether the time series has a normal distribution, a short sample length, or a serial correlation. The final result is determined by whether the data values are in the increasing or decreasing region according to the 1:1 line. In the Cartesian Coordinate system, the area under the 1:1 (45°) curve represents the decreasing trend region, and the area above it represents the increasing trend region.

3.4.4 Sen's slope method

If there is a linear trend in the time series, the actual slope (change per unit time) can be determined using a non-parametric method. This method can be applied to records unaffected by data errors, extreme values, and missing values (Yu et al. 1993). Data at times j and k to be x_j and x_k (j > k with the condition); N = n(n-1)/2 (n number of periods) number Q_i (i = 1, 2,……., N) and the value is calculated according to the Eq. (26).

$$Q_i = \frac{(x_j - x_k)}{(j - k)} \tag{26}$$

Calculated Q_i values are sorted from smallest to largest. The median of these N Q_i values is Sen's Slope Estimator, a relevant statistic for estimating the linear trend slope parameter in question. By taking the median of N Q_i values, the change of the relevant observation per unit of time is determined by Eq. (27) if N is odd and Eq. (28) if N is even (Sen 1968).

$$Q = Q_{(N+1)/2} \tag{27}$$

$$Q = \left\{ \frac{1}{2} \left[Q_{N/2} + Q_{(N+2)/2} \right] \right\} \tag{28}$$

3.4.5 Şen's innovative trend method

The method is applied according to the order of operations specified below: i) in the first method, the data series of the measured hydrological variable is ordered temporally from the measurement start date to the last measurement date. The resulting series is divided into two equal parts starting from the first date. The data set parts are sorted separately from smallest to largest; ii) according to the Cartesian coordinate system, the first of the two data columns is placed on the X-axis and the other on the Y-axis; iii) if the data points on the two-dimensional chart are concentrated above the 1:1 (45°) line or follow a very close trend, there is no trend; iv) if the scattering curve is below the 1:1 line, there is a decreasing trend; v) if the scattering curve is above the 1:1 line, there is an increasing trend. The scattering curve may not remain entirely in the increasing or decreasing region, and transitions according to the 1:1 curve may be observed. A monotonic trend is observed if all points remain in the decreasing or increasing region. However, a transition between increasing and decreasing trend regions in the scatter curve corresponds to a non-monotonic trend.

The current values evaluated at the stations are revealed in Table S3. As can be seen at D13A014 station, a decreasing trend was observed in all low, medium, and high flow values of minimum flows. It can be mentioned that there is a non-monotonic increasing trend at station D13A015. This is especially true for high values. It can be said that there is no trend in midstream values. A non-uniform trend slope is observed at station D13A022. A significant decreasing trend is observed in low flows between 2003 and 2020. While medium flows are in the increasing region, the trend curve returns to the decreasing region in high flows. The low and medium flow data of station D13A032 shows a clear decreasing trend, while the situation seems more stable in the high flow data. At the flow observation at D13A036, the scatter points of the data are not distributed homogeneously, making trend detection difficult. Although low flows remain in the increasing direction, the trend indicates a decreasing trend in high-flow data.

According to the results of Şen's innovative trend analysis (ITA) method, it is impossible to reach a definitive conclusion for the station. It would be correct to decide by comparing other analysis methods. An apparent monotonous decreasing trend is observed at the flow observation at D13A037. The scattering points are concentrated at the starting point of the Cartesian plane. Low flows are the parts where the decreasing trend is most intense. Medium flows have somewhat converged to the non-trend zone. All flow data remained below the 1:1 line and were in the decreasing trend region. At D13A040, low-flow data started in the non-trend region but then moved to the increasing trend region. It is seen that almost all flow data, from medium flows to high flows, remain in the increasing trend region. In light of this data, it has been determined that there is a clear increasing trend in station D13A040 numbers according to ITA method. When the data of the flow observation at D13A045 is examined, it is seen that the low flow data remains in the increasing trend region. Midstream data was partially located in the non-trend 1:1 (45°) line region and then transitioned to the decreasing trend region according to Fig. 3.

On the other hand, high-flow data is completely located in the decreasing trend region, and it is seen that the data transitions to an almost horizontal plane after a certain point. When the reasons for this were examined, it was seen that the data were very close to each other in part, covering the years 1984–2002, which was obtained by dividing the flow data set in the middle. When the graph is examined and integrated, it is seen that the flow data has moved from the increasing trend region to the decreasing trend region, and the final result is in the direction of the decreasing trend. A non-monotonous decreasing trend is observed for station D13A046. Evaluating the analysis results in coordination with the data obtained from other methods would be beneficial. A non-monotonic increasing trend is observed at station D13A049. Although low flow data is in the decreasing region, medium and high flow data indicate an increasing trend at the station. A non-monotonic decreasing trend was detected at D13A052 station. This can be seen in the medium rather than

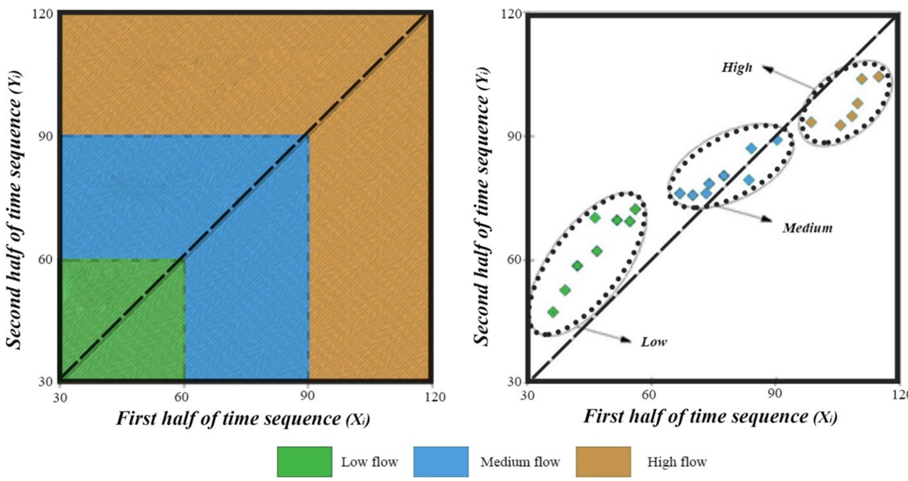

Fig. 3 Classification of data with Şen's innovative trend analysis method (adapted from Şen 2012)

low and high current data. It converges to the 1:1 line where there is no trend for low and high flow data. It can be mentioned that there is a non-monotonic increasing trend at station E13A002. It can be said that low and high flow data remain in the increasing region. However, midstream data falls on the 45° curve in the graph, where it is indicated that there is no trend. When the data of the flow observation at E13A007 is examined, it is seen that the scattering points start from the decreasing trend region in the part where low flows are represented and are then positioned above the 1:1 line. Medium currents are the section where the transition is made to the increasing trend region via the 1:1 line, representing the non-trend region. High flow data is completely in the increasing trend region. When the graph is examined integrated, no decreasing trend is seen. The fact that low and medium flow data are almost completely located in the non-trend region strengthens the idea that there is no trend in the station area. However, the fact that high flow data is in the increasing trend region indicates that the station should be re-analyzed with updated data in the future. When the data of the flow observation at E13A014 is examined according to the Şen innovative trend method, it is seen that the station's data are entirely below the 1:1 line of 45° (Fig. S2).

In addition, in the Şen Method, flows are classified as low, medium, and high so that their boundaries are evaluated according to the status of the data. Divining the scatter diagram into three clusters allows us to make detailed interpretations. As seen above, low flows are located in the upper ascending triangle region. This shows us an increase in low flows in the second half of the time series compared to the first half. It can be said that there is no trend in the middle cluster. A high cluster indicates a decrease. All these explanations show various flow trend patterns in the annual flow series. Based on these results of comprehensive weighting, comments can be made on water stress, drought, and floods based on flow classifications (Şen 2012; 2018).

4 Holistic view for the trends

With the findings obtained, trend situations in the study area exposed to drought hazards were determined at a 95% significance level. When an evaluation is made throughout the basin, it is seen that the general situation regarding drought is stable, but certain risks and opportunities are observed in different locations. As those meteorological events and cycles suggest, they are effective in forming significant differences between sub-basins and within basins, and that the location, elevation, aspect, topographic structure, and geological structure of the basins are different, as well as their differentiation under human influences is effective. Observation of different trends in observation stations located on different river branches in close areas supports this idea.

Meteorological factors affecting trends are temperature, humidity, precipitation, wind speed and direction, etc., which can be listed. Not all basin regions are affected by these factors in the same amount and way. For example, the angle of incidence of the sun's rays decreases as you move north, and the temperature effect decreases. As you move north in the basin, the marine effect increases, and humidity and slope precipitation become effective. The topographic structure has been seen as one of the most important reasons for differentiation across the basin. Rapid geographical changes occurring over short distances also affect climate characteristics. The geological structure is vital in transforming the water falling to the ground through precipitation into surface and underground resources. Considering that the data measured at flow observation stations are flow data, it is seen that every factor that changes the water flowing into the flow also affects the trend analysis results. Every structure built by people to utilize and control water causes natural flow data to differ. It would be appropriate to examine the effects of the mentioned factors on the basin in detail through a study specific to trend formations and their causes. The trends were determined using minimum flow data, and determinations were made about the possible consequences and how to act according to the results rather than the reasons for forming the trends in Table 6.

Table 6 Trend analysis results throughout the Western Black Sea Basin for all results

Station No	Spearman rho test (Z)	MK test (Z)	Şen's innovative trend method	Mann–Kendall rank correlation test	Sen's slope method
D13A014	↓	↓	↓	Beginning from 2001	−0.0177
D13A015	→	→	→	NT	0.0038
D13A022	→	→	↘	NT	0.0002
D13A032	↓	↓	↓	Beginning from 1990	−0.0045
D13A036	↗	↗	→	DDT	0.0007
D13A037	↘	↘	↓	DDT	−0.0010
D13A040	↑	↑	↑	Beginning from 1990	0.0091
D13A045	↓	↓	↘	Beginning from 1985	−0.0029
D13A046	→	→	↘	NT	−0.0001
D13A049	↗	↗	↗	IDT	0.0014
D13A052	↘	↘	↘	DDT	−0.0216
E13A002	↗	↑	↗	IDT	0.0308
E13A007	→	→	↗	NT	0.0041
E13A014	↓	→	↓	Beginning from 2001	−0.0351
E13A019	→	→	↘	NT	−0.0009
E13A027	↑	↑	↑	Beginning from 1987	0.0007
E13A031	→	→	↘	NT	−0.0016
E13A032	↗	↑	↑	IDT	0.0022
E13A034	→	→	→	NT	0.0001
E13A035	→	→	↓	NT	−0.0734
E13A036	↓	↓	↓	Beginning from 1990	−0.1363
E13A040	→	→	→	NT	0.0000
E13A043	→	→	↗	NT	0.0014

Increasing trend (IT), increasing directional trend (IDT), no trend (NT), decreasing directional trend (DDT), decreasing trend (DT)

↑IT
↗IDT
→NT
↘DDT
↓DT

5 Overlapped spatial construction

Today, the change in climate characteristics is a fact proven by scientific studies and adopted by the world. We have entered a climatically unstable period in which drought periods are longer, and rainfall occurs more suddenly due to longer waits. The effects of this change have now begun to be seen in Türkiye, located in the middle climate zone, and the climate has become hotter and drier. Irrigation activities are gaining more importance in agricultural areas. Although winters are not as harsh as in previous years, this also affects the amount, type, and precipitation regime. Areas under water for years in the accumulation chambers have become visible. However, it has been observed that in some locations, water amounts are on an increasing trend, which has created new opportunities. Increasing the income from agriculture by choosing products with higher economic returns can be an example. The need to take precautions against these changes and evaluate the opportunities has become undeniable and unpostponable. It is observed in overlapped spatial construction that two of the stations selected in the region have increasing, four have increasing directional, ten have no trend, three have decreasing directional and 4 have decreasing trend in Fig. 4.

6 Discussion

There is a local and limited increase in minimum flow data due to the harsh weather conditions becoming milder in various upper basins of the Western Black Sea Basin. Although the positive effects of these increases may be seen in the short term, it is necessary to examine whether this situation is permanent, considering the increase in temperature. If water decreases in the long term, taking precautions against the effects of drought and drought becomes necessary.

Stream flow data depends on many parameters (Minea et al. 2022; Teutschbein et al. 2022). In this study, observing different trains and trends in close locations showed that a uniform planning perspective for large areas would be erroneous. In particular, land

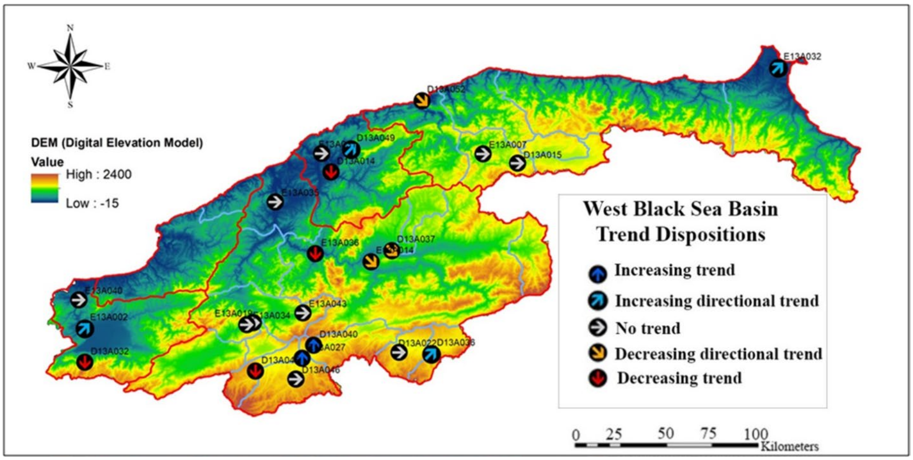

Fig. 4 Trend analysis results for all analyses used in the Western Black Sea Basin

formations, mountain locations, elevations, and the geological structure of stream beds are the main reasons for the differences. Considering the tests performed, it was seen that MK and Spearman Rho tests indicated the existence of a trend, but other analyses were needed to confirm the results. For this reason, Şen's innovative trend analysis method, MKOC method, and Sen's trend slope method were used in the analysis to support the studies. All these analyses and the results show that water has become more important today than at any time in the past. In light of this information, it becomes clear that precautions must be taken immediately, without any ifs or buts. It is possible to minimize the devastating effects of drought and drought with the help of measures to be taken with the participation of public and private sector representatives, non-governmental organizations, and each of our people.

The trend situations in the areas of the study area exposed to drought hazard were determined at a 95% significance level. When an evaluation is made throughout the basin, it is seen that the general situation regarding drought is stable, but certain risks and opportunities are observed in different locations. It is thought that meteorological events and cycles are effective in forming significant differences between sub-basins and within basins and that the location, elevation, aspect, topographic structure, and geological structure of the basins are different, and their differentiation under human influences is effective (Yenigün et al. 2008; Dehghan et al. 2020; Elhadidy et al. 2021; Brighenti et al. 2024). Observation of different trends in observation stations located on different river branches in close areas supports this idea.

From the research of domestic and foreign scholars, meteorological factors affecting trends are temperature, humidity, precipitation, wind speed, and direction. These results are in line with Sharafi et al (2020), Meza et al (2021) and Azam and Rahman (2022). Not all basin regions are affected by these factors in the same amount and way. For example, the angle of incidence of the sun's rays decreases as you move north, and the temperature effect decreases. As you move north in the basin, the marine effect increases, and humidity and slope precipitation become effective. The topographic structure has been seen as one of the most important reasons for differentiation across the basin (Mallick et al. 2022). To date, rapid geographical changes occurring over short distances also affect climate characteristics (Moustafa et al. 2022; Savari et al. 2022; Pitscheider et al. 2024). The geological structure is vital in transforming the water falling to the ground through precipitation into surface and underground resources. Considering that the data measured at flow observation stations are flow data, it is seen that every factor that changes the water flowing into the flow also affects the trend analysis results (Carrão et al. 2016). Every structure built by people to utilize and control water causes natural flow data to differ. It would be appropriate to examine the effects of the mentioned factors on the basin in detail through a study specific to trend formations and their causes (Dai et al. 2020). Where available, trends were determined using minimum flow data, and determinations were made about the possible consequences and how to act according to the results rather than the reasons for the formation of the trends.

Over the years, much debate has been about which drought indices and practices should be used in certain climates. Findings from many drought definitions and indices have been developed, and attempts have been made to guide on this subject. For this purpose, the Interregional Workshop on Indices and Early Warning Systems for Drought was held at the University of Nebraska-Lincoln in December 2009. This workshop, which included 54 participants from 22 countries in total, was organized by the University of Nebraska School of Natural Resources (SNR), the United States National Drought Mitigation Center (NDMC), the World Meteorological Organization (WMO), the United States National Oceanic and

Atmospheric Administration (NOAA), the United States of America. It has been supported by leading institutions and organizations such as the United States Department of Agriculture (USDA) and the United States Convention to Combat Desertification (UNCCD). Participants evaluated the indices currently used to explain meteorological, agricultural, and hydraulic droughts occurring in different parts of the world and discussed the need for a standard index to explain different types of droughts. Experts at the meeting created and approved the "Lincoln Declaration on Drought Indices" in detail. In the declaration, the SPI (Standardized Precipitation Index) method was recommended to national meteorological and hydrological services worldwide to characterize meteorological drought and other drought types in the same way worldwide. At the 16th World Meteorological Congress held in June 2011, the recommendations for index use and the creation of a user guide recommended in the declaration were confirmed. With the proposal of the Congress, the SPI Guide was published and distributed to the United Nations in all languages (WMO 2012).

Meanwhile, Karavitis et al. (2011) stated that Greece frequently faces the dangerous effects of drought and that it constitutes an ideal example for applying the SPI method. For this reason, they applied the SPI method for all of Greece by evaluating historical data. Within the scope of the study, data covering the period 1947–2004 from 46 rainfall observation stations were compiled and analyzed according to time scales of 1, 3, 6, 12, and 24 months. Calculation of the index is achieved through the on-site use of a suitable software tool. Spatial representation of SPI values was made using the geostatic methods of the SURFER 9 software package. The results emphasize the importance of using the SPI method in drought early warning and drought forecasting studies. Wambua et al. (2015) reported that droughts in Kenya's upper Tana River Basin negatively affected water resources, hydropower production, and agricultural production. However, although it is an important river basin for Kenya, limited research work has been done on the region to evaluate and characterize drought. Within the scope of their study, they used 41 years of precipitation data from eight observation stations located in the upper regions of the Tana River Basin in Kenya and made analyses with the SPI method to evaluate spatial–temporal drought characteristics. While the Kriging Interpolation Technique was used to estimate spatial drought occurrences in the basin, the non-parametric MK trend test was used to detect trend occurrences. Analysis has shown that the southeastern parts of the basin have the highest drought severity, while the northwestern parts have the lowest drought values. However, in both regions, the areal extent of drought severity increased from 4868.7 to 6880 km^2 and from 6363.9 to 6987.5 km^2 for the southeast and northwest regions, respectively, between 1970 and 2010. While the drought trend increased at 90% and 95% significance levels in the southeastern parts of the basin, no trend was detected in the northwestern regions. It has been stated that creating early warning systems for droughts will especially benefit water resources managers in planning and managing water resources in the basin.

Gümüş et al. (2016) analyzed drought using the SPI method using 78-year rainfall data covering the years 197–2004 from Şanlıurfa station in the Southeastern Anatolia Region of Türkiye. By analyzing monthly precipitation data, 1, 3, 6, and 12-month SPI outputs were obtained, and the severity, magnitude, and distribution of rainy and dry periods were evaluated. It has been determined that the number of dry months in the 29 years between 1986 and 2014 for the region where the station is located was higher than the 49 years between 1937 and 1985. It was noted that within the entire study period, the largest SPI value was calculated in the analyses made for October–December 1972. Salehnia et al. (2017), in their study, made drought analyses with eight different drought indices and compared them in order to evaluate historical drought events using rainfall observation stations and

AgMERRA rainfall data covering the years 1987–2010 in the Kashafrood Basin of Iran. At the same time, these indices are SPI, 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) are methods that include rainfall-based analyses. They also used the DDI (Degree of Dryness Index) method to compare the intensities of different drought categories for each year of the studied period. Drought index correlations calculated with AgMERRA rainfall data were generally higher than those obtained from rainfall observation stations. According to all indices calculated for the study period, the most severe drought occurred between 2001 and 2008. Although drought conditions could be examined with all analyses, it was observed that SPI, PNI, and DI methods were in a close relationship with each other, CZI and MCZI methods with each other, and ZSI and RAI methods as a pair, creating a high correlation coefficient. Based on the strong correlation between the drought indices obtained from AgMERRA precipitation data and the drought indices obtained from the precipitation data obtained from the observation station, they reported that AgMERRA precipitation data could be adopted to fill the gaps in the precipitation data observed by the station in future studies in Iran. A comprehensive consideration stated that AgMERRA precipitation data can be used for data-deficient areas by comparing it with station-observed precipitation data. Yenigün and Ibrahim (2019) conducted drought analysis with the SPI method for 1, 3, 6, 9, and 12-month time intervals, using data from 15 meteorological stations in the Northern Iraq Region covering the years 1979–2013. They used the SPI module in the MATLAB program to perform the analyses. Study results showed that dry period persistence was higher for 6, 9, and 12-month intervals than for 1 and 3-month intervals. According to calculations, it was determined that the driest year was 2008. The study is important because it provides all the information about the longest dry and rainy periods for all regional stations. Shatanawi et al. (2022) stated that climate change seriously threatens the availability of water resources in Semi-Arid Regions. Therefore, studying drought trends to develop and maintain water resources is crucial. Their study evaluated the effects of climate change in Jordan by analyzing long-term precipitation trends in the Jordanian Zerk Basin during the water years from 1971 to 2016. For analysis, daily rainfall data were collected for six rainfall stations located throughout the basin. The SPI changes were examined monthly. Control charts, hypothesis testing, t-tests, variance differences, and trend analysis have been used to determine climatic trends. The analysis results showed that 2003 marked an acceleration point in the rate of precipitation decline.

Additionally, a change in the rainfall pattern was observed with the change in seasonal rainfall contribution for the pre-2003 period compared to the post-2003 period. Alzarouq Albaqoul (2022) analyzed the monthly average precipitation and temperature data of 8 meteorology stations in the provinces of Sinop, Kastamonu, and Bartın, which are located in the Western Black Sea Basin, with the Reconnaissance Drought Index (RDI) and Stream Drought Index (SDI) methods. They made agricultural and meteorological drought analyses for 3, 6, 12 months and were carried out on monthly average flow data of 3 flow observation stations to determine hydrological drought. In drought studies, SPI, PDSI, PNI etc., are mainly used with various drought indexes using meteorological data. In this study, a road map was created based on the trends of hydrological data using minimum flow data, and the basin was discussed from a different perspective. With a straightforward qualitative assessment, the reflections of meteorological phenomena on water resources can be in different shapes and sizes. It is deemed beneficial to elaborate the studies by evaluating the drought analysis methods specified with the results obtained in coordination. In this regard, it is important to evaluate the Western Black Sea Basin drought management plan, which is being prepared under the coordination of the general directorate of water management. The studies were interpreted to create economic evaluation criteria for policymakers to take the necessary precautions in the identified possible risk areas and to protect and develop the socioeconomic structure of the region. Although there are many trend analysis methods and their derivatives in the literature, it has been observed that SR, MK test, Sen's slope method, and ITA methods have been extensively applied to provide safe and meaningful results. Here, the four methods mentioned above were used using the annual minimum data of the Western Black Sea Basin, and the results were compared and interpreted. In order to determine the start times of trends, the Mann–Kendall Rank Correlation test, a method derived from the MK method, was applied, and the results were presented graphically. Below, studies carried out within the scope of trend analysis worldwide and in Türkiye are summarized. Although there have been some studies in the Western Black Sea Basin, it has been seen that a more comprehensive study with current data is needed. Burn et al. (2010) used at least 50 years of data obtained from 68 flow observation stations in Canada for two analysis periods of 40 and 50 years and applied MK analysis to determine trends in maximum and minimum flows, considering extreme hydrological events. The results showed that more trends were emerging than expected. When discussing decreasing trends, they were observed in the amounts of annual and spring maximum flows and the duration of extreme events. They detected both increasing and decreasing trends in minimum flows. Gautam and Acharya (2011) applied trend analyses on the flow data of Nepal, which is a country that has not been studied sufficiently despite being in a critical location in terms of being in the southern part of the Himalayan snow cover and being exposed to heavy monsoon rains. They applied MK and Sen's trend tests to two data sets consisting of 23 hydrological stations with 31 years of data and 33 hydrological stations with more than 20 years of data. Significant increasing and decreasing trends were detected at 23% in the data set consisting of 33 stations. Similarly, in the other data set containing 23 stations, they detected 24% trends, 41% decreasing, and 59% increasing. They stated that snowmelt was significant in the increasing trends detected in the average flows in the pre-monsoon and winter seasons and that no trend was generally observed in the stations where large basins flowed. Subash et al. (2011) stated that the monsoon season is the source of rainwater in almost all sub-basins in India. In their study, they questioned the existence of the trend on a monthly and annual basis and examined the extreme events and water shortages between 1871 and 2008. They determined the magnitude of the trends using Sen's Slope Method. Trend results were determined by MK and SR trend tests, and similar results were obtained in 30 sub-basins of India. A decreasing trend in monsoon rainfall was found in most of the sub-basins. Shadmani et al. (2012) investigated the temporal trends of evapotranspiration (water loss from plants and soil + water surface) (ETo) values in the arid regions of Iran. For this purpose, they used 41 years of data covering the period 1965–2005 from 11 meteorological stations that provide quality data. By applying non-parametric MK and SR tests to the compiled data, significant trends in ETo were detected for monthly, seasonal, and annual periods according to the 5% significance level. Increasing and decreasing trends were detected in ETo values of different regions. The performance and proficiency of MK and SR tests were generally significantly consistent. Hajani et al. (2014) stated that climate change can affect the hydrological cycle in various ways, such as evaporation and rainfall, and they addressed the Australian state of New South Wales in their study. They analyzed the annual maximum precipitation data of 30 stations they determined in New South Wales for different periods from 6 min to 3 days, using MK and SR tests. While precipitation in periods less than an hour showed an increasing trend, they detected significant decreasing trends in long-term events. They also stated that MK and SR tests showed remarkable differences in some precipitation events. Sulaiman et al. (2015), Lubuk Paku, located on the Pahang River in Malaysia, Sg. They analyzed the data at Yap and Temerloh stations with the non-parametric MK trend test. Although a significant increasing trend was observed for the Lubuk Paku station, no trend was observed for the other two stations. They stated that the eastern monsoon rains in the South China Sea and Pahang in November–March significantly affect hydrological models and trends.

Dabanlı et al. (2016) stated that hydro-meteorological time series showed trend formations due to climate change in the last 30–40 years. They reported different methods for trend detection in the literature, and the two important methods known for providing different perspectives are the MK trend test and the recently prominent Sen's Innovative Trend Method. The study's primary purpose is to reveal the important differences and possible similarities between the two methods. Although the MK test does not indicate a significant trend at almost all stations, the Innovative Şen Method categorizes the results as very low, low, medium, high, and very high. The "very high" result of the categorizations should be considered in flood studies, and the "very low" result should be considered in future drought studies. Thus, precipitation, temperature, relative humidity, and flow data of 8 stations selected in the Ergene River Basin in the European part of Türkiye were compiled and analyzed from 1961 to 2010. The results show that Ergene Basin temperatures have a significantly increasing trend in the "high" and "very high" ranges, supporting the idea that the basin may be prone to drier seasons in the future. Alashan et al. (2016) carried out studies to complete the missing data using the river flow equations method using the flow observation stations on the Murat River in the Middle Euphrates Basin. The study stated that statistical analyses would not be reliable if the data sets were short or if there were large gaps in long-term data sets. Considering the basin area, equation coefficients, and correction coefficients in the method, it can be seen that it is more of an empirical method. Considering the studies, the best and most appropriate definition cannot be made for a single method. It can be seen that all methods have advantages and disadvantages compared to each other.

7 Practical implications

In this study, among the 126 flow observation stations whose records were kept in the Western Black Sea Region, 26 observation stations with suitable data for the last 40 year"s were selected to evaluate the drought effect. In order to detect trends, the MK test, SR test, ITA test, and Sen's Trend Slope method, which take into account assumptions such as normality, linearity and independence in flow data rather than parametric methods, were used. The Mann–Kendall Rank Correlation test was used to determine the starting years of the detected trends. The analysis results were examined by overlapping the irrigation areas in the Western Black Sea Basin, and the following results were reached, taking into account the drought threat;

- According to all analysis methods, decreasing trends were detected at stations D13A014, D1A032, and E13A036. According to the MKOC test results, the trend starting in 2001 was at D13A014, 1990 at D13A032, and 1990 at E13A036.
- Analyzes conducted at stations D13A045 and E13A014 concluded a decreasing trend. Different results were obtained in several of the analyses carried out within the two stations. However, when the results of the method used within the scope of th"e study

were examined in an integrated manner, it was determined that there was a decreasing trend. The trend at the start year was found to be 1985 at D13A045 and 2001 at E13A014.

- Decreasing trends were observed at stations D13A037 and D13A052. Trend analysis results remained below critical values. However, serious results indicating the formation of a downward trend were obtained. It would be beneficial for policymakers to make extra efforts in these areas, where the risk of experiencing water scarcity and related drought is increasing in the future.
- No significant trend was detected in minimum flows at stations numbered D13A015, D13A022, D13A046, E13A007, E13A019, E13A031, E13A034, E13A035, E13A040 and E13A043.
- According to the results of the analysis, increasing trends were found at stations numbered D13A036, D13A049, E13A002, and E13A032. The test statistics from the analysis remained below the limit values determined for an increasing trend. However, the results converged to these limit values.
- According to all analysis results, increasing trends were recognized at stations D13A040 and E13A027. According to the MKOC test results, the trend started in 1990 at D13A040 and in 1987 at E13A027.

It is deemed useful to carry out trend tests during the planning and survey stages of water structures built throughout our country to draw clearer boundaries for each basic engineering principle: economy, aesthetics, and safety. It would be appropriate to make such studies on the evaluation of water resources a country policy and to conduct studies on the direction and value of drought in the basin in the future using trend analysis or other methods. Although we cannot influence the amount and pattern of precipitation, it is in our power to use the accumulated water more rationally. The flow observation station minimum flow data were subjected to trend analysis, and regional interpretations were made by matching them with irrigation areas. Some measures have been considered since water conservation is vital in preventing drought. General precautions to be taken are stated below. In our study conducted for the Western Black Sea Basin, the importance of keeping drought-related data regularly and planned was seen again. Considering that the missing data should be completed with scientific methods, but it is impossible to capture the actual conditions and values exactly while completing the data, it will be understood that keeping these data in order in the field is the definitive solution to work with the correct values. In order to properly examine the field in terms of drought, flow values, precipitation, temperature, and humidity, institutions and organizations such as the State Hydraulic Works and the General Directorate of Meteorology, which is responsible for keeping the data, are required to carry out the necessary investment, operation, and maintenance, and reporting activities.

For the identified risky areas, it should be ensured that the construction tenders for the facilities deemed important in the savings, training, new facility construction, rehabilitation of existing facilities, master plan, preliminary examination, planning, and project stages are made as soon as possible and then brought to the operating phase. While designing the facilities that will store water, the storage facilities' capacity and other structural features must be determined, taking into account the drought-related risks identified by scientific studies. The use of water is as important as its retention and storage. Monitoring and controls regarding water use need to be followed instantly by today's technology, and emergency plans should be created considering possible risks. Stored water should be monitored regarding loss and leakage, and structural and operational monitoring, control, and recommendations should be created. Irrigation systems should be revised, and their operation and maintenance should be carried out meticulously. When designing irrigation systems, a closed-type irrigation system should be preferred instead of open-type irrigation. Revising open-type irrigation systems such as canals and transmission channels that are currently in operation and converting them into closed systems will ensure protection from effects such as evaporation and exposure to negative human external influences. Water used in homes and workplaces has a vital place in water use. Considering that millions of people benefit from and use water every day, it will be seen that the amount of water saved by seemingly small precautions and precautions amounts to significant figures. Public service announcements, radio broadcasts, television commercials and programs, posters, etc., about the correct use of water in our homes and workplaces need to be adopted by the public through methods.

In industrial production, water is used in many areas, especially in the food, textile, and chemical manufacturing sectors. In order to minimize the process of water use in the industry, production stages should be reviewed, and, if necessary, technology renewal investments should be made to use water more effectively. In order to prevent pollution of our existing waters, wastewater should not be released into nature without treatment, and the number of treatment and disposal facilities should be increased. It is seen from the field research that in the majority of villages, domestic and animal garbage is thrown into stream beds. This garbage, which consists of all kinds of organic and inorganic, poses the threat of microbiological contamination of our waters. It is necessary to provide garbage containers to our villages to meet the local people's needs and ensure that garbage is collected at specified intervals, even if it cannot be visited daily. It would be appropriate to determine the plant species that should be preferred in dry and wet season situations for the region through a study in which all public and private sector representatives operating in agricultural areas is participate. Desicion makers should consider water consumption and supply.

8 Conclusion

Climate change is a natural consequence of global warming and changes in the balances in hydrological cycle systems and processes. The main risks are the negative effects in hot climates in middle and equatorial latitudes. This study was carried out on a sub-basin scale and focused on irrigation infrastructure and agricultural drought. The comprehensive evaluation planning for water management in the basin should be made comprehensively with the participation of all institutions authorized in this regard, existing studies should be re-evaluated, and studies and operations should be continued according to the current situation. Therefore, the research is important for the basin to examine the trends in minimum flow data and the effect of drought together.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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Consent to participate Not applicable.

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