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RESEARCH ARTICLE

Actual and Potential Trend Analysis Under Climate Change Using Risk Sen's Slope (RSS) in Western Black Sea Basin in Türkiye

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ABSTRACT

Several classical and innovative trend methods exist in the literature to identify and evaluate the effects of climate change on hydro-meteorological variables. Among the classical methods, the most commonly used ones are modified Mann–Kendall (MMK) and Sen's slope (SS). As for the innovative methods to identify potential trends (probable risk levels) in hydro-meteorological variables depending on changing the initial conditions and temporal dynamic development behaviour of the trends, the risk Sen's slope (RSS) method was proposed based on different risk values. The actual trends are proposed in this research to comprehensively understand and analyse the climate change trend over the entire period. It uses RSS and the classical trends MMK and SS. Also, the spatiotemporal classical, actual and potential trends in meteorological variables are evaluated. Additionally, the advantages of the RSS method compared with classical SS are discussed in detail. The Western Black Sea basin in Türkiye, with monthly total precipitation and monthly average temperature data from 1961 to 2023, is selected as a representative application. The temperature trend results show that the 0.99 risk level gave approximately 25% higher slope than SS. The maximum temperature-increasing trend within the study area and the time period at 0.99 risk level is 2.10°C. However, the differences between precipitation trend slopes obtained by SS and RSS for different risk levels are relatively low. Furthermore, using different slopes corresponding to several risk levels allows for more proactive and effective measures for sustainable agricultural activities and water management. The actual temperature trend within the basin ranges between 1.33°C and 2.09°C, and the actual precipitation trend ranges between 2.78 and 12.74 mm over the study period.

1 | Introduction

The effects of global warming and climate change, which have become significant issues due to the increase in greenhouse gas emissions, have reached a noticeable level worldwide in various regions after the 2000*s* (Menzel et al. 2020; Tabari et al. 2011; Tirkey et al. 2021; Abu Arra and Şişman 2024). Given that fact, trend analyses have been shown as an essential and primary aspect across different sectors, especially considering the increase in greenhouse emissions and response to the increasingly

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adverse effects of climate change (Abu Arra, Alashan, and Şişman 2024; Alashan 2020). Understanding this increase and its trends considering its drivers in different climatic variables is highly important and crucial due to its adverse effects on several sectors, including water resources, hydrological cycles (Kundzewicz 2008; Stagl et al. 2014), precipitation patterns, and agriculture (Malhi, Kaur, and Kaushik 2021; Doulabian et al. 2021; Ostad-Ali-Askari et al. 2020). Additionally, trend analyses are crucial for decision-makers and policymakers, providing them with all the necessary information for mitigation and adaptation plans.

Parametric and non-parametric methods are used for trend evaluation and calculation. Compared with non-parametric methods, parametric methods are more sensitive and robust in trend detection, but assumptions are crucial in their applicability (Şen and Şişman 2024; Güçlü 2018). Trend analysis methodologies are divided into classical and innovative methods. Classical ones are the Mann–Kendall (MK) and modified Mann–Kendall (MMK) (Mann 1945; Kendall 1975) and Sen's slope (SS) (Sen 1968). Regarding the literature, the MK and classical SS are the most commonly used trend methods. The former determines if there is a trend in a specific data series, and the latter determines the trend slope. Both of them have been applied in several studies in the existing literature (Dawood 2017; Da Silva et al. 2015; Thenmozhi and Kottiswaran (2016); Ali and Abubaker 2019; Şişman, Kizilöz, and Birpinar 2022; Şen 2014). MK and SS have been utilised in different sectors and variables, including short- and long-term precipitation, streamflow, temperatures as well as different climatic variables.

In most trend analysis methodologies, especially those using the MK methodology, the trend slope is calculated using SS over a specific time period (Sen 1968). SS has a one median slope. One of the most important advantages of SS methodology is that outliers do not affect its value, providing a powerful technique in climate studies facing extreme values.

Along with trend detection, investigating and understanding the risk levels related to the resulting trends provide an advantage for climate change studies (Şen and Şişman 2024; Kesgin, Yaldız, and Güçlü 2024). Risk can be defined as the probability of occurrence/exceedance for a specific trend value. For instance, an increasing trend in precipitation with its risk level indicates a higher risk of floods, and a decreasing trend in precipitation with its associated risk value may indicate a drought event (Şen 2014).

Regarding the SS and risk levels concept, Şen and Şişman (2024) proposed a new concept and improved the well-known SS methodology. In their article, they aimed to determine long-term trends by initially calculating the trends of each series, created based on consecutive time intervals of 30 years or more, using the classical SS methodology. Subsequently, they generalised the results obtained from the classical method to different risk levels. With the newly proposed risk Sen's slope (RSS) procedure by Şen and Şişman, instead of a single statistical trend value determined by the classical SS methodology, numerous dynamic trend values based on risk levels are calculated, which can be used for predicting possible future trend magnitudes. Using this new method, Şen and Şişman identified trends in precipitation in Antalya and discharge data from the Danube River. The study concluded with determining trend values at different risk levels for these two datasets.

Regardless of the common use of the well-known SS methodology in climate studies, and considering the article mentioned above, which has integrated SS with different risk levels, there is a need to comprehensively discuss their applicability, limitations and future implications along with providing a new concept, such as the actual trend associated with each risk level instead of using one median value. Furthermore, SS with different risk levels provides a dynamic trend behaviour by considering the initial time conditions.

This research aims to investigate and calculate the potential trends (possible risk levels) using RSS, which mainly depends on different risk levels and cumulative distribution functions (CDFs), as well as the newly proposed actual trends for both SS and RSS. Furthermore, this research covers spatiotemporal classical and actual trends in meteorological variables. Actual trends and the actual trend maps corresponding to classical SS and RSS are presented for the first time in this research. Notably, the SS method can be viewed as a specific case derived from the broader framework of RSS. Monthly total precipitation and monthly average temperature data at eight selected stations in the Western Black Sea basin from 1961 to 2023 are selected as a case study to achieve the main objectives of this research. The study consists of five sections. The study area, data, MMK, SS and RSS methods are introduced in the next section. Section 3 presents the results as classical SS with MMK, RSS and actual trend maps. Then, Section 4 discusses the main results, a comparison between SS and RSS, and the importance of RSS. In the last section, the conclusion is presented.

2 | Materials and Methods

2.1 | Study Area and Data Collection

With its diverse topography and climatic variations, Türkiye encompasses several river basins crucial in shaping its hydrological system. Each basin exhibits distinct climates due to variations in geographical characteristics. One noteworthy basin in Türkiye that influences hydrological patterns is the Western Black Sea basin. This basin features diverse landscapes, from mountains to coastal plains and discharges into the Black Sea through several rivers. Figure 1 illustrates the Western Black Sea basin, covering approximately 28,855 km^2, with an annual average precipitation of about 877 mm and an average temperature of 12.66°C.

Significant differences exist between coastal and interior areas in the Black Sea region, primarily because of the east–west direction of mountains that run parallel to the Black Sea coastline, hindering humid air from reaching the interior. The Zonguldak meteorological station records the maximum mean monthly total precipitation at 102.22 mm compared with other stations. In contrast, the minimum mean monthly precipitation occurs at Bolu station, situated in the interior of the basin, with 47.15 mm.

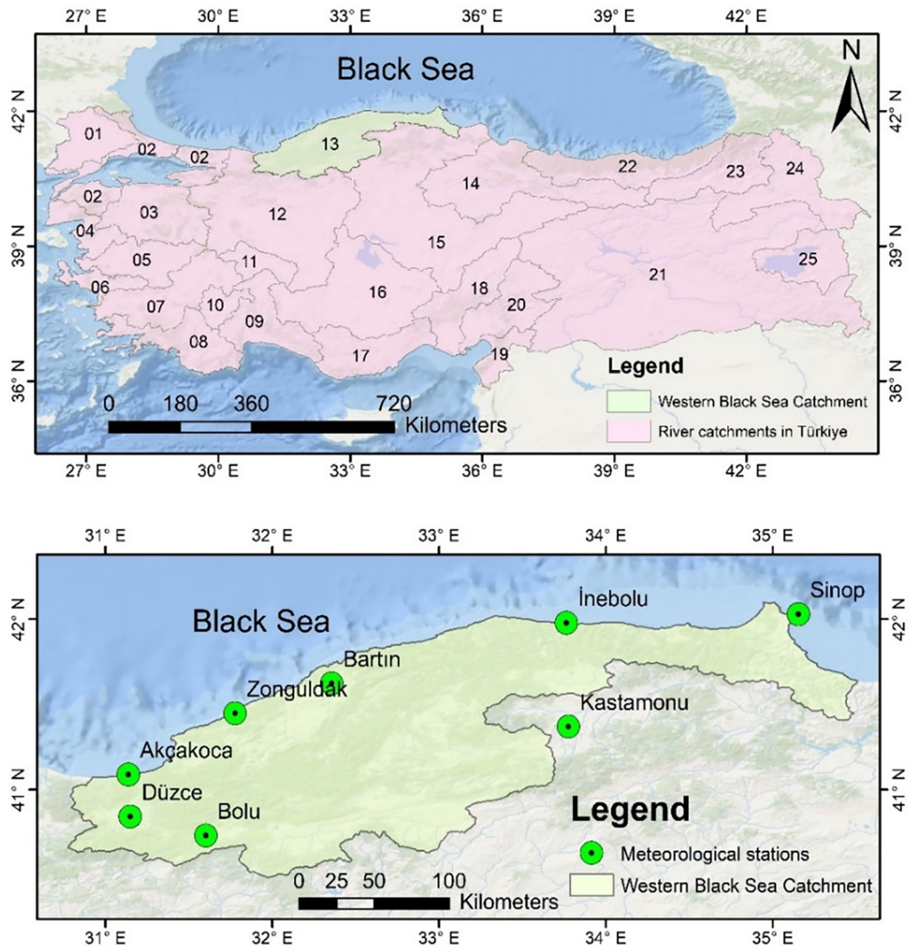


FIGURE 1 | Study area and meteorological stations. [Colour figure can be viewed at wileyonlinelibrary.com]

The climate of the Western Black Sea basin is influenced by its proximity to the Black Sea, generally characterised by a temperate climate with relatively mild temperatures throughout the year. Summers are warm, and winters are typically cool, with Sinop station in the northeast registering the highest maximum average temperature at 14.39°C.

Monthly precipitation and temperature records spanning from 1961 to 2023 for eight meteorological stations were obtained from Türkiye's General Directorate of Meteorology (MGM). Seven stations are located within the Western Black Sea basin, and an additional station is positioned outside the basin in the southeast part. This station, close to the basin, was included to enhance the quality of the resulting SS maps. Table 1 summarises the stations' codes, names, coordinates, monthly total precipitation, standard deviation, monthly average temperature and standard deviation for each station.

2.2 | Methodology

2.2.1 | Homogeneity Tests

The variations observed within homogeneous data series are attributed to weather and climate changes. Therefore, ensuring the homogeneity of time series data is crucial for conducting climate analyses (Conrad and Pollak 1950). Due to inevitable changes such as the relocation of measurement stations, replacement of measurement instruments over time (WMO 1996), increasing urbanisation around the stations, maintenance or calibration problems with the measurement instruments at the station and similar reasons, observation data are influenced to some extent, and it is rarely possible to obtain entirely homogeneous data of the desired quality in practice (WMO 1996). Conducting climate, meteorology and hydrology research with non-homogeneous data will produce biased results. Therefore, in this study, the homogeneity of the data will first be tested. There are many methods in the literature for testing the homogeneity of precipitation, temperature, and various variables. Therefore, both absolute and relative homogeneity tests have been considered in this research. Various absolute homogeneity tests, including Von Neumann (1941), Pettitt (1979), Buishand (1982), and Standard Normal Homogeneity tests (SNHTs) proposed by Wijngaard, Tank, and Können (2003), are commonly used to assess homogeneity in hydro-meteorological data. As for the relative homogeneity tests, RHtests and Climatol are among the most utilised packages to conduct homogeneity tests. Homogeneity is evaluated based on the null hypothesis (H_0), assuming no change within the data. Classifications are then assigned based on the number of absolute homogeneity tests accepting and rejecting the null hypothesis as follows:

1. Set 1 indicates "Homogenous" if four or three out of the four methods accept the null hypothesis (H_0);

TABLE 1 | Statistics of monthly precipitation and temperature records at the meteorological stations.

#	Station code	Station name	Latitude (N)	Longitude (E)	Precipitation (mm)_mean	Std. Dev. (mm)	Temperature (°C)_Mean	Std. Dev. (°C)
1	17020	Bartın	41.62	32.36	87.76	60.44	12.84	6.55
2	17070	Bolu	40.73	31.60	47.15	30.25	10.47	6.93
3	17015	Akçakoca	41.09	31.14	91.08	60.79	13.27	6.05
4	17072	Düzce	40.84	31.15	69.46	43.21	13.22	6.80
5	17024	İnebolu	41.98	33.76	86.80	60.40	13.49	6.04
6	17026	Sinop	42.03	35.15	57.88	43.02	14.39	6.11
7	17022	Zonguldak	41.45	31.78	102.22	68.23	13.83	5.90
8	17074	Kastamonu	41.37	33.78	42.29	32.99	9.77	7.44

2. Set 2 indicates “Doubtful” if two homogeneity tests accept the null hypothesis (H_0);
3. Set 3 indicates “Suspect” if only one or none of the four homogeneity tests accept the null hypothesis (H_0).

Climatol is an R statistics package widely used for quality control and relative homogenization of climate parameter datasets. Climatol uses daily and monthly climate data and requires the observation stations' longitude, latitude and elevation. The package utilises distance as a criterion for reference series selection, reference as a detection method and the SNHT as detection statistics. The SNHT is a statistical test commonly used to assess the relative homogeneity of a time series by detecting abrupt changes or shifts in its mean, which may indicate alterations in climate conditions, instrument changes or other factors affecting data consistency. The calculation logic of the SNHT involves comparing the observed differences between consecutive data points with the expected differences under the assumption of homogeneity (Conrad and Pollak 1950; WMO 1996).

Another method, RHtests, is a set of homogeneity tests used to assess the relative homogeneity of climate data time series. The package includes various statistical methods for detecting shifts, trends and other changes in the data. It is particularly useful for identifying abrupt changes or trends in climate variables over time. RHtests package produces various output metrics, including test statistics, *p* values and graphical representations.

2.2.2 | Modified MK

MK test is a non-parametric test used to assess the presence of trends in a dataset without making assumptions about the data distribution. The MMK test proposed by Hamed and Rao (1998) is a variation of the MK trend test, designed to account for autocorrelation in time series data. MMK test helps to address the autocorrelation issue, which can affect the standard MK test. The variance of the MMK is computed as:

$$V(S) = \frac{n(n-1)(2n+5)}{18}\left[1 + \frac{2}{n(n-1)(n-2)}\right]\sum_{i=1}^{n-1}(n-i)(n-i-1)(n-i-2)\rho_i \quad (1)$$

where n is the number of data and ρ_i is the autocorrelation function of the ranks of the data. The MMK test offers a more dependable trend analysis, ensuring that the test results remain unaffected by potential serial correlation in the data.

2.2.3 | Sen's Slope Estimator

SS (Sen 1968) is a robust, non-parametric approach to estimating linear trend slopes without relying on distributional assumptions. This characteristic makes it particularly advantageous when dealing with outliers and non-normally distributed data. The method calculates the slope for each pair of data values ($i = 1, 2, \ldots, n$) where $j > k$ in a sample of n pairs by the formula:

$$SS_i = \frac{x_j - x_k}{j - k} \quad (2)$$

where x_j and x_k are the data values of rank j and k, respectively.

The SS_i values are arranged in ascending order, and the median serves as SS. The calculation of the median involves different formulas based on whether n is odd or even, as follows:

$$SS_{med} = \begin{cases} SS_{[(n+1)/2]}, & \ldots \text{(if } n \text{ is odd)} \\ \dfrac{SS_{\left[\frac{n}{2}\right]} + SS_{\left[\frac{n+2}{2}\right]}}{2} & \ldots \text{(if } n \text{ is even)} \end{cases} \quad (3)$$

For an odd n, the median is determined as the data in the middle, while for an even n, the mean of the two midmost slopes is calculated as the median.

2.2.4 | Risk SS

Şen and Şişman (2024) proposed an innovative probabilistic (risk) median slope calculation methodology based on the well-known SS method for identifying trends in long-term hydro-meteorological records. The methodology combines statistical analysis, median slope calculations and probability distribution functions (PDFs). Şen and Şişman (2024) discussed the limitations of traditional statistical SS method for trend determination and proposed RSS approach as a solution. The new methodology enables the identification of a set of trends within the domain of the hydro-meteorological variable, including extreme (low and high) variables around the classical SS. Also, RSS suggests that it is preferable to consider different SS values reflecting various risk levels rather than relying solely on classical trend definition. The proposed probabilistic slope approach provides a wider scope for future slope variation possibilities. Moreover, the RSS procedure presents all possible alternatives in a convenient CDF form with a set of risk-level slope values. This approach provides valuable insights into the changing hydro-meteorological patterns and their implications for extreme events in the studied regions.

The RSS calculations can be summarised as follows:

- The first step involves deriving multiple time period data sets by changing the initial condition, and these time period data sets must be more than 30 years. The initial dataset covers 30 years, the second dataset covers 31 years and so on. The last dataset is the classical time period dataset determined by the classical SS.
- The classical SS is applied for each time period data set derived from the first step. For example, using 30 years gives the first median SS, using 31 years gives the second median SS and so forth. This process results in a new set of several SSs.
- The distribution of the obtained SS in the previous step is matched and fitted with the most suitable probability distribution function (PDF) among the different alternatives, deriving the CDF of the SS values.
- The obtained SS series is subjected to the exceedance CDF approach, resulting in a collection of exceedance probabilities (risk) at predetermined percentage levels. The probability of exceedance (risk) can be any value. Then, the resulting SSs corresponding to risk levels can be used.

Figure 2 shows the methodological flowchart step by step used in this research.

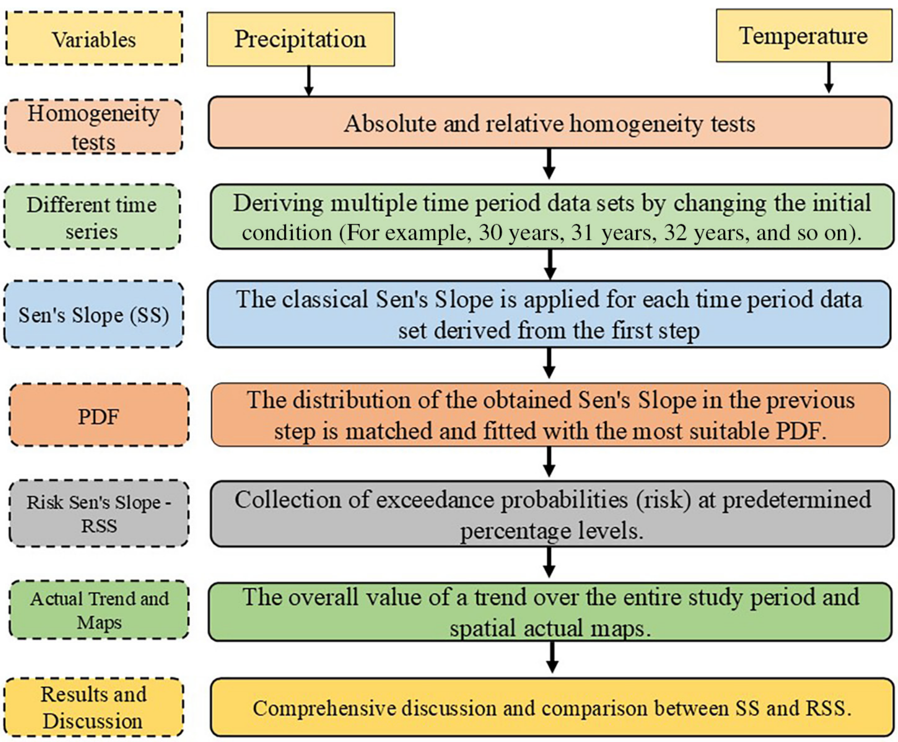


FIGURE 2 | Methodological flowchart. [Colour figure can be viewed at wileyonlinelibrary.com]

3 | Results

3.1 | Homogeneity Test Results

The monthly total precipitation and mean temperature data from the meteorological stations utilised in this study were first subjected to absolute homogeneity tests using the two-stage approach suggested by Wijngaard, Tank, and Können (2003). Four methods were employed: Pettitt, Buishand, SNHT and Von Neumann. These methods are widely utilised in the literature. Results were checked for homogeneity regarding a 95% confidence level. Table 2 summarises the main homogeneity results, including tests' names, test statistics, change year and the homogeneity results. Each test has its assumptions, strengths and limitations, and the choice of a particular test may yield different results based on the dataset's characteristics. Also, the test is more sensitive to extreme values or outliers than other tests. As a result of these tests, all precipitation and temperature data were homogenous except for the Kastamonu station for precipitation data, being in the Set 3 “suspect” class.

To enhance the depth of the data analysis, relative homogeneity tests were finally conducted using the RHtests and Climatol packages. These tests unveil homogeneity within the basin more clearly by analysing data derived from reference series and neighbouring stations. For the monthly average temperature data, common changepoints were identified in several stations by the RHtests. Akçakoca, Düzce, Zonguldak and Kastamonu stations showed similar changepoints in 1971, while an individual changepoint was found in Bolu in 1993. Demircan (2019) also identified changepoints in many stations in Türkiye, including the Western Black Sea basin, in 1971. Similarly, in 1993, there were significant changepoints in many stations in Türkiye, including Bolu station. These findings align with this study, suggesting that the changepoints are due to natural climate changes. Due to natural factors, the other common changepoints were also observed in January 1982 for Akçakoca, Bartın and Düzce stations. The other quality control and relative homogeneity analysis of monthly average temperature data conducted by the Climatol package indicated no issues with the dataset. Stations showed a high correlation, influencing the reliability of the homogeneity test. Stations located farther apart, such as Station 6 (Sinop) and Station 8 (Kastamonu), exhibited higher RMSE values, consistent with their remote locations. Additionally, Kastamonu station, situated outside the basin, has distinct climate characteristics compared with other stations. In conclusion, the temperature data showed good quality, and data diversities stemmed from natural climate changes.

The homogeneity test for total monthly precipitation data revealed a few changepoints by RHtests. Stations such as Sinop in 1966 and 1969, Kastamonu in 2008 and Düzce in 2014 exhibited changepoints, which do not appear to share common characteristics. Regarding total monthly precipitation data, two anomalous data points were identified by the Climatol package: 324 mm in Sinop Station in October 1988 and 278.7 mm in Kastamonu Station in June 2010. Metadata assessment concluded that these anomalies were natural occurrences related to seasonal floods, supported by high values observed in nearby stations. According to the quality control, absolute and relative homogeneity test results conducted for long-term data in the Western Black Sea basin, it has been determined that there are no inhomogeneities requiring adjustments in the monthly total precipitation and average temperature data for the eight stations. Therefore, trend research presented in the following sections has been conducted using the original data.

3.2 | MMK and Classical SS Results

The MMK test results for the monthly average temperature from 1961 to 2023 indicate high Z values for the majority of the region, signifying a significant increasing trend for all stations except one (Akçakoca) (Table 3). Among these stations, the highest trends are calculated for Düzce, Bolu and Bartın stations, while relatively lower trends are observed in the Zonguldak and Kastamonu stations. Notably, stations located roughly on the 41° N latitude, such as Düzce and Bolu, exhibit the highest trends, whereas those on the 42° N latitude, including Bartın, İnebolu and Sinop, show somewhat moderate trends. The stations falling between 41° N and 42° N, such as Zonguldak and Kastamonu, exhibit the lowest trends, with one even showing an insignificant trend (Akçakoca).

According to the classical SS trend test for the monthly average temperature from 1961 to 2023, relatively high trend slopes are observed in Düzce, Sinop and İnebolu stations. Düzce station shows the highest trend in both the MMK and classical SS tests, and according to SS calculations, a temperature increase of 2.01°C has been observed over the 63-year period. The stations Zonguldak, Kastamonu and Akçakoca yield relatively low slopes, consistent with the MMK results, but differences are noted in the lowest values. For the SS test, the lowest value is obtained from the Zonguldak station, while for the MMK test, the lowest value is observed in the Akçakoca station.

The MMK test results for the monthly total precipitation from 1961 to 2023 reveal a more diverse trend distribution than temperature trends across the basin (Table 4). Significant increasing trends are observed in five stations (İnebolu, Sinop, Bartın, Akçakoca and Zonguldak), all located on the Black Sea coast. The other three stations showing no trend are located inland (Kastamonu, Bolu and Düzce). Düzce shows a negative trend value among these stations, while Kastamonu and Bolu show positive trend values.

The classical SS test exhibits high trend slopes for Akçakoca, Sinop and İnebolu stations, mostly paralleling the results of the MMK test. Like the MMK results, all coastal stations show higher trend slopes than the inland stations, and additionally, the only station showing a negative slope is Düzce, similar to the result of the MMK test.

3.3 | RSS Results

For RSS applications, trend analyses using the classical SS approach were performed for each time series created by adding 1 year at each step from 1961–1990 to 1961–2023. The time series of trend magnitudes obtained for temperature and precipitation data for 34 different scenarios performed between

TABLE 2 | Homogeneity tests results for precipitation and temperature data.

		Precipitation (P)				Temperature (T)			
Stations	Homogeneity test	Test statistics	Change year	Result	Homogeneity	Test statistics	Change year	Result	Homogeneity
Bartın	Pettitt	11,537	September 1994	Accept	Set 1: homogenous	12,212	March 1998	Accept	Set 1: homogenous
	Buishand	28.423	September 1994	Accept		27.919	March 1998	Accept	
	SNHT	5.672	March 1961	Accept		7.167	March 1961	Accept	
	Von Neumann	1.791	—	Reject		0.329	—	Reject	
Bolu	Pettitt	11,077	October 1994	Accept	Set 2: doubtful	13,079	March 1998	Accept	Set 1: homogenous
	Buishand	30.718	October 1994	Accept		30.563	April 1993	Accept	
	SNHT	13.493	August 2000	Reject		5.109	March 1998	Accept	
	Von Neumann	1.801	—	Reject		0.352	—	Reject	
Akçakoca	Pettitt	14,954	October 1994	Accept	Set 2: doubtful	16,029	April 2006	Accept	Set 1: homogenous
	Buishand	43.372	September 1989	Reject		35.551	April 2006	Accept	
	SNHT	10.084	September 1989	Accept		8.727	April 2007	Accept	
	Von Neumann	1.783	—	Reject		0.329	—	Reject	
Düzce	Pettitt	8202	April 2014	Accept	Set 1: homogenous	15,848	March 1998	Accept	Set 1: homogenous
	Buishand	21.714	April 2014	Accept		35.939	March 1998	Accept	
	SNHT	5.016	April 2014	Accept		8.778	March 1961	Accept	
	Von Neumann	1.845	—	Reject		0.343	—	Reject	
İnebolu	Pettitt	8985	August 1990	Accept	Set 1: homogenous	15,178	March 1998	Accept	Set 1: homogenous
	Buishand	21.795	August 2008	Accept		35.145	April 2006	Accept	
	SNHT	3.817	July 2021	Accept		9.103	April 2017	Accept	
	Von Neumann	1.559	—	Reject		0.344	—	Reject	
Sinop	Pettitt	17,396	October 1986	Accept	Set 2: doubtful	16,735	April 1998	Accept	Set 2: doubtful
	Buishand	41.294	September 1988	Reject		37.247	April 1998	Reject	
	SNHT	9.198	September 1988	Accept		7.996	April 2007	Accept	
	Von Neumann	1.566	—	Reject		0.326	—	Reject	

(Continues)

TABLE 2 | (Continued)

Stations	Homogeneity test	Precipitation (*P*)				Temperature (*T*)			
		Test statistics	Change year	Result	Homogeneity	Test statistics	Change year	Result	Homogeneity
Zonguldak	Pettitt	8593	October 1994	Accept	Set 1: homogenous	13,100	March 1998	Accept	Set 1: homogenous
	Buishand	21.007	August 1989	Accept		28.722	March 1998	Accept	
	SNHT	3.183	February 1961	Accept		5.219	April 2006	Accept	
	Von Neumann	1.691	—	Reject		0.361	—	Reject	
Kastamonu	Pettitt	11,454	February 2008	Accept	Set 3: suspect	9844	March 1994	Accept	Set 1: homogenous
	Buishand	44.867	February 2008	Reject		22.146	March 1994	Accept	
	SNHT	19.663	April 2023	Reject		5.25	March 1961	Accept	
	Von Neumann	1.661	—	Reject		0.328	—	Reject	

these dates are provided in Figures 3 and 4, respectively. When examining the graphs, it is evident that temperature trends significantly increase over time. Patterns related to the temporal changes in precipitation trends do not allow a clear assessment of an increase or decrease. Figures 5 and 6 depict risk model graphs based on probability levels, showing the trend slopes obtained through the classical SS method for the same 34 scenarios. These analyses employed two different probability distribution functions (PDF) for temperature and two for precipitation. Considering 34 different scenarios as a reference in the temperature RSS analyses, the generalised extreme value (GEV) cumulative probability distribution function (CDF) was chosen for seven stations, expecting Zonguldak station, for which the appropriate CDF function was the normal distribution function.

Regarding precipitation data, except for Düzce and İnebolu, which were suitable for the Normal CDF, six selected models used the GEV, predominantly used in temperature RSS models. In this study, the classical SS trend magnitudes obtained for temperature and precipitation based on the mentioned scenarios on a station basis were compiled as a time series, depicted in Figures 3 and 4. Detailed examinations and evaluations of the RSS model results created in this manner are provided below.

Figure 3 displays the time series of trend slopes calculated based on the scenarios determined using the classical SS method. When examining these figures, it is observed that the temperature trend generally increases over time, but the rate of increase varies from station to station. In the early years, temperature trends for Akçakoca, İnebolu, Sinop, Zonguldak and Kastamonu showed a decrease, while in recent years, this trend has shifted towards an increase. It is possible to make various inferences when the trend values obtained from SS analysis of each scenario created for temperature are examined on a station basis. Examining Figure 3a for the Bartın station, it is seen that there is no distinct trend direction until 2005 for trend magnitudes. Starting from 2005, a trend magnitude of 0.001°C/month is reached within 5 years, and it is understood that the rate of increase slows down until 2023, reaching its highest value of 0.002°C/month in 2022. Classical SS calculates the trend magnitude for 1961–2023 as 0.0018°C/month. According to the SS time series graph for Bolu station in Figure 3b, the trend magnitude obtained for the station is calculated as 0.0019°C/month. When examining the graph, the increase of 0.0025°C/month in 2015 represents the largest trend magnitude for this station. Detailed examination of the graph reveals significant increases in trends in two short periods between 1998–2001 and 2006–2010, reaching trend magnitudes of 0.001°C/month and 0.0021°C/month, respectively. After 2010, the increases continued until 2015, reaching 0.0025°C/month; then, in an unprecedented manner compared with the other seven stations analysed in the basin, it decreased to 0.0019°C/month with a decrease of 0.0006°C/month from the highest value.

When the Akçakoca station in Figure 3c is examined, one of the most striking points is undoubtedly the difference between the trend values calculated for 1961–1990 and 1961–2023. While the classical SS method shows a trend slope of −0.004°C/month

TABLE 3 | Comparison between classical Sen's slope and risk Sen's slope for temperature data.

#	Station	T_MMK Z corr.	SS (°C/month)	RSS (°C/month)	Actual *T* trend with SS[a] (°C)	Actual *T* trend with SS / mean *T*	Actual *T* trend with RSS[a] (°C)	Actual *T* trend with RSS / mean *T*
1	Bartın	3.18	0.0018	0.00217	1.35	10.50%	1.63	12.66%
2	Bolu	3.45	0.0019	0.00246	1.42	13.59%	1.84	17.60%
3	Akçakoca	1.77	0.0017	0.00187	1.27	9.60%	1.40	10.55%
4	Düzce	4.08	0.00269	0.00279	**2.01**	15.24%	**2.09**	15.81%
5	İnebolu	2.24	0.00201	0.00236	1.51	11.16%	1.77	13.10%
6	Sinop	2.86	0.00227	0.00239	1.70	11.82%	1.79	12.44%
7	Zonguldak	2.05	0.00149	0.00274	**1.12**	8.08%	2.05	14.84%
8	Kastamonu	2.10	0.00149	0.00167	**1.12**	11.49%	**1.25**	12.80%

Note: The bold values represent the maximum and minimum trend values for SS and RSS.
Abbreviations: RSS: risk Sen's slope at **0.99** risk level, SS: classical Sen's slope, *T*: temperature.
[a]The actual temperature trends were calculated based on the whole time period in this research, which is 63 years.

TABLE 4 | Comparison between classical Sen's Slope and risk Sen's slope for precipitation data.

#	Station	P_ MMK Z corr.	SS (mm/month)	RSS (mm/month)	Actual *P* trend with SS[a] (mm)	Actual *P* trend with SS / mean *P*	Actual *P* trend with RSS[a] (mm)	Actual *P* trend with RSS / mean *P*
1	Bartın	3.32	0.0088	0.00953	6.58	7.50%	7.14	8.13%
2	Bolu	0.40	0.0038	0.00368	2.86	6.07%	2.76	5.85%
3	Akçakoca	3.07	0.0159	0.01701	**11.87**	13.03%	**12.74**	13.99%
4	Düzce	−0.17	−0.0015	0.00288	**−1.12**	−1.62%	**2.16**	3.11%
5	İnebolu	9.61	0.0110	0.01403	8.20	9.45%	10.51	12.11%
6	Sinop	4.40	0.0135	0.0157	10.07	17.41%	11.76	20.32%
7	Zonguldak	2.44	0.0076	0.01223	5.68	5.55%	9.16	8.96%
8	Kastamonu	0.59	0.0060	0.00935	4.52	10.68%	7.00	16.56%

Note: The bold values represent the maximum and minimum trend values for SS and RSS.
Abbreviations: RSS: risk Sen's slope at **0.99** risk level, SS: classical Sen's Slope, *P*: precipitation.
[a]The actual precipitation trends were calculated based on the whole time period in this research, which is 63 years.

for 1961–1990, the analysis for the years 1961–2023 indicates a temperature increase of 0.0017°C/month. For Akçakoca, the difference of approximately 0.006 ˚C/month between these years represents an important change in terms of first a significant decrease in the temperatures in this region, then the end of the decreasing trend, and then a continuous increase. One of the most noticeable points for Düzce, given in Figure 3d, is undoubtedly having the largest increasing trend in the basin compared to other stations. According to the classical method, the trend magnitude for 1961–2023 is 0.0027°C/month, indicating an increasing temperature trend. The analysis shows increased 0.001°C/month values in 2001, 0.002°C/month in 2010 and 0.0028°C/month in 2020. Periods of stagnation in the increase rate are observed in 2001–2006, 2014–2017 and 2019–2023. Similar patterns of stagnation are also noticeable when examining the SS time series for the Bolu station closest to Düzce in the basin.

Upon examining the SS time series presented in Figure 3e,f for İnebolu and Sinop stations, which are situated close to the coastal part of the basin, it is immediately evident that the trend magnitudes exhibit similarities. Additionally, their classical SS analysis results closely align with each other. According to the SS methodology for 1961–2023, İnebolu's temperature increase trend is 0.00201°C/month, while it is calculated as 0.00227°C/month for Sinop. These values are very close to the highest values these stations have seen for temperature trends until the last year. According to the analysis results for İnebolu and Sinop stations, temperatures show a significant decrease trend between 1990 and 1995. While a decrease magnitude of −0.003°C/month was calculated for İnebolu in 1993, it was −0.002°C/month for Sinop. After this period, although there were occasional constant trends, the decreasing trend ended in the last 15 years, reaching a noteworthy increase in 2023 compared with other basin stations. Finally, when examining the SS

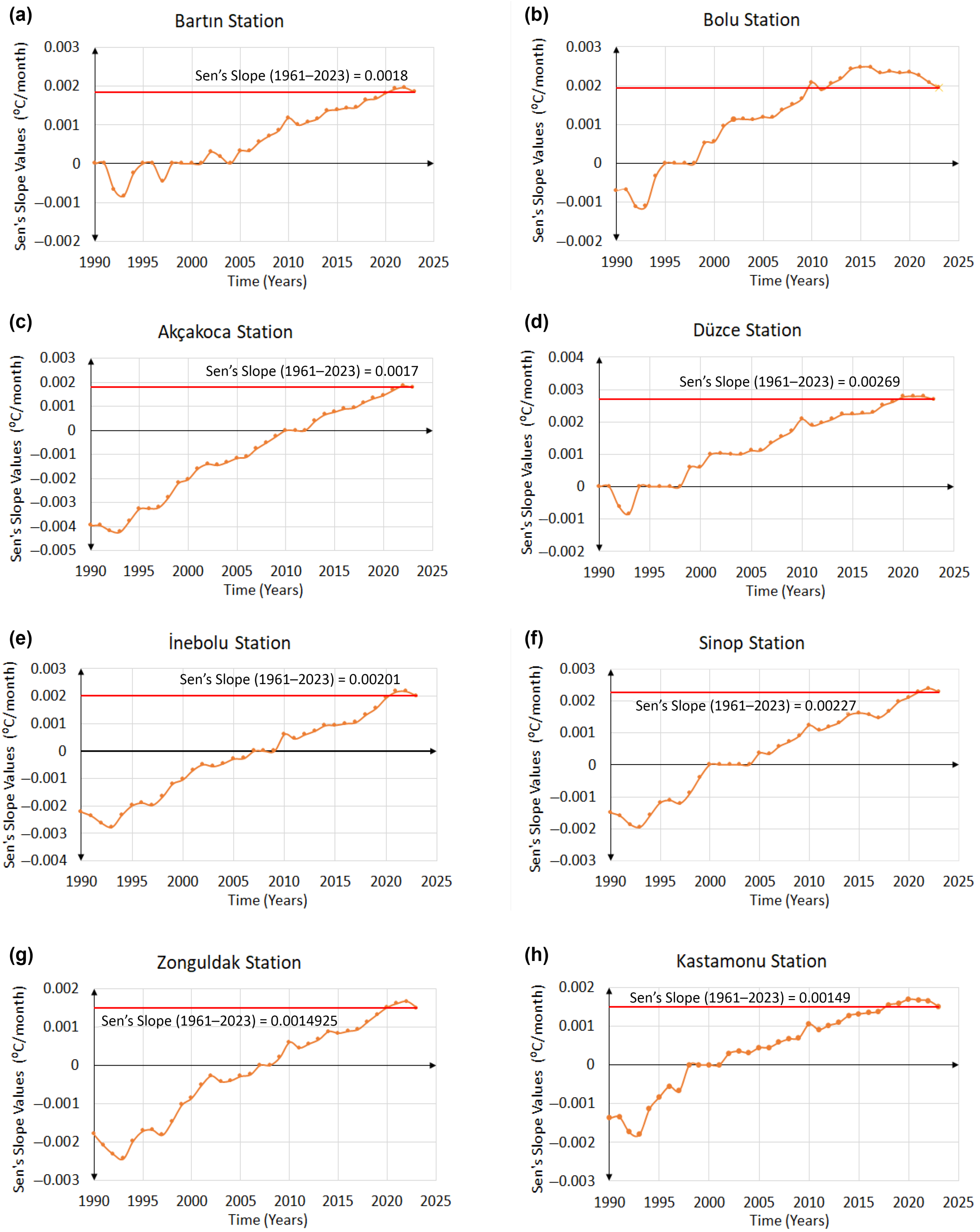


FIGURE 3 | Sen's slope variation for temperature data within the Western Black Sea basin. [Colour figure can be viewed at wileyonlinelibrary.com]

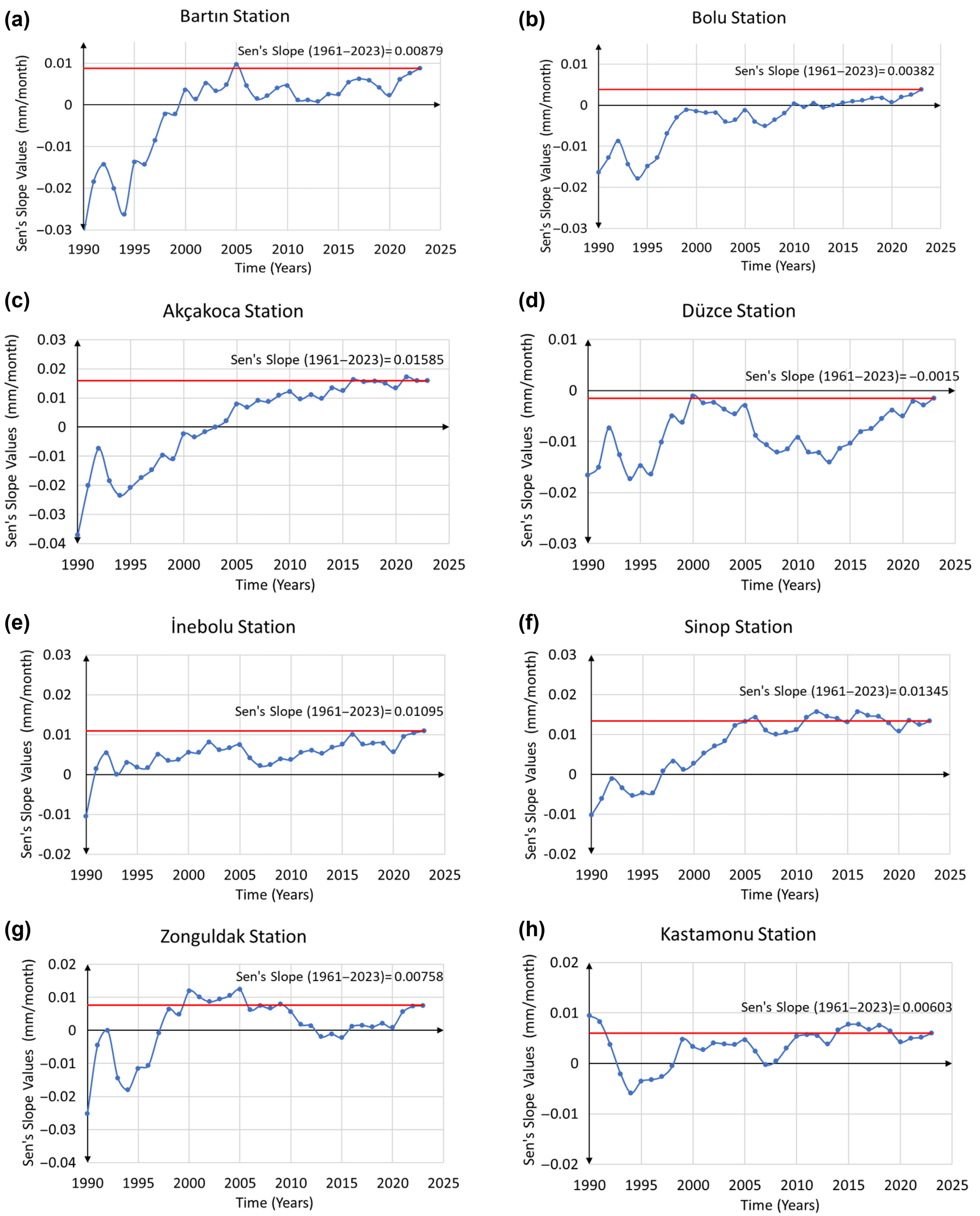


FIGURE 4 | Sen's slope variation for precipitation data within the Western Black Sea basin. [Colour figure can be viewed at wileyonlinelibrary.com]

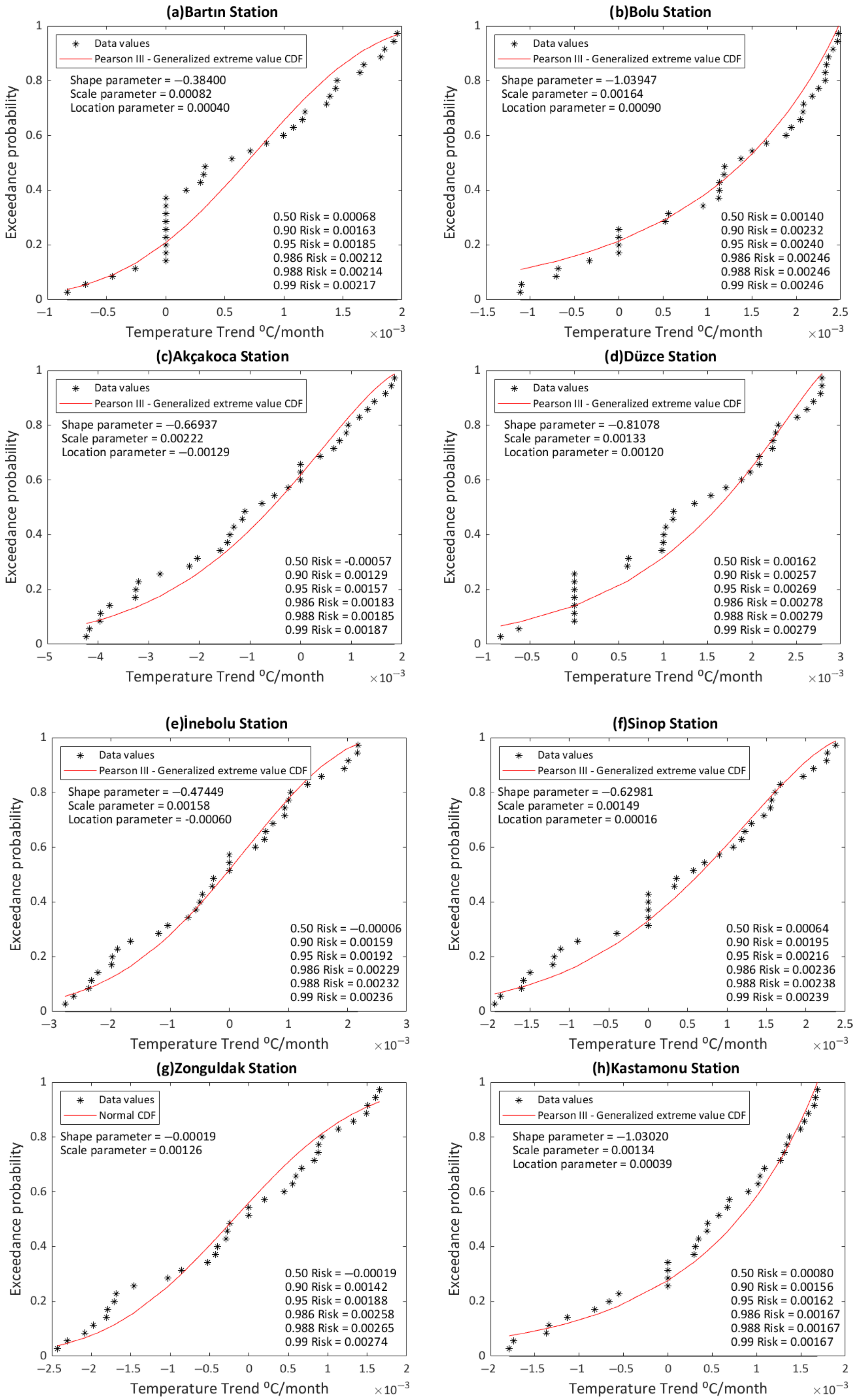


FIGURE 5 | Exceedance probability levels correspond to a set of risk levels for temperature data. [Colour figure can be viewed at wileyonlinelibrary.com]

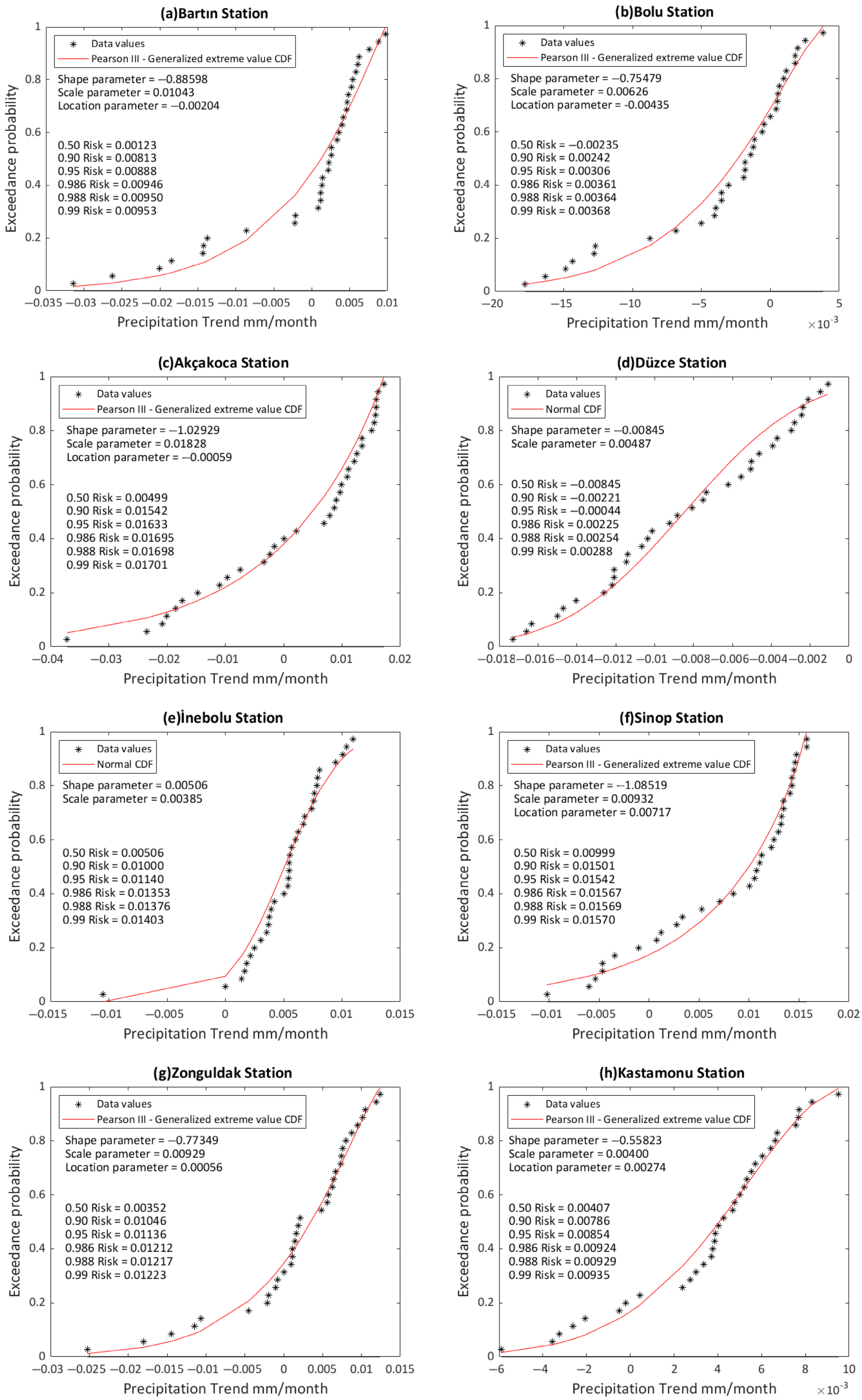


FIGURE 6 | Exceedance probability levels correspond to a set of risk levels for precipitation data. [Colour figure can be viewed at wileyonlinelibrary.com]

calculation results for Zonguldak and Kastamonu stations given in Figure 3g,h for 34 different scenarios, it is observed that temperatures for Zonguldak and Kastamonu show a decreasing trend in the initial years.

In contrast, in recent years, there has been an increasing trend. According to the classical SS method results, these two stations exhibit the lowest increasing trend in temperature with a magnitude of 0.00149°C/month. One noteworthy thing is that in all stations except Akçakoca, slope values made a distinctive local peak in 2010.

As part of the RSS precipitation analysis, similar to temperature analysis for RSS, 34 different scenarios have been applied using classical SS starting from 1961 to 1990 by adding 1 year to each step until 1961–2023. In Figure 4a, it is seen that Bartın station yields a −0.03 mm/month from 1961 to 1990. For the larger periods, trend slopes begin to increase but not consistently. It turns to a positive slope in the year 2000. Then, after rising to a peak value of 0.01 mm/month precipitation in 2005, the slope goes up and down, maintaining the positive slope. After 2020, it increases consistently, reaching a slope value of 0.0088 mm/month for the whole time period. Bolu station starts with a value of −0.016 mm/month for 1990, then continues with a negative slope until 2010, as seen in Figure 4b. Then, after 2015, the precipitation slope becomes permanently positive, showing relatively more minor slope values. It peaks in 2023 with a value of 0.0038 mm/month.

Akçakoca station starts with a value of −0.0037 mm/month, the lowest slope in all stations. As seen in most stations, the slope went up and down until 2003. Then, the slope becomes positive afterward with little changes. The slope value of the whole time period is 0.0016 mm/month. Düzce station, located inland, exhibits a rather inconsistent slope change during the period. It starts with a −0.012 mm/month value and never reaches positive slope values. The highest value is in 2000, with a slope of −0.001 mm/month. For the year 2023, the slope is −0.0015 mm/month. İnebolu station had a slope value of −0.01 mm/month in 1990. Then, the slope goes up to positive values a year after that and peaks in 2023 with a slope value of 0.0109 mm/month. As seen in temperature analysis, Sinop station shows a similar character to İnebolu station. It starts with the same slope value of −0.01 mm/month and reaches positive values in 1997. Then, in 2012, it peaked at 0.0157 mm/month; finally, in 2023, the slope value was 0.0134 mm/month. Zonguldak station starts with a slope value of −0.025 mm/month, and in 1998, the slope becomes positive. After reaching a peak value of 0.0124 mm/month in 2005, the slope became negative again in 2013. Then, in 2016, it became positive again and remained positive afterward, finishing the whole time period with a slope of 0.0076 mm/month. Kastamonu station is distinguished from other stations in one aspect, starting with a positive slope value of 0.01 mm/month in 1990. The slope became negative in 1993. Then, it turns positive in 1999 with a slope value of 0.0047 mm/month. It remains positive until 2023, when the slope value becomes 0.006 mm/month, except in 2007 when it turns negative with a rather small value.

The goodness-of-fit test is conducted for each variable and station using the Kolmogorov–Smirnov test at the 95% significance level. The critical value for this test was determined based on the number of samples, which in this case was 34, corresponding to the classical Sen slope method applied over time periods exceeding 30 years. The critical value is calculated as 1.36 divided by the square root of the sample size, resulting in 0.233. Subsequently, each station's D statistic is computed, and all D values are less than the critical value. This outcome supports accepting the null hypothesis, indicating a good fit of the probability distribution function to the observed data. Figure 5 displays the exceedance probability levels corresponding to certain risk levels for temperature data. It is worth noting that the slopes of trends corresponding to a specific risk level are estimated based on the best fit of the CDF model of the classical SS data. For the temperature analysis in all stations, the probability model graph shows probability levels according to the GEV CDF, except for Zonguldak station, which displays a normal CDF. The results indicate that, at a risk level of 0.99, the predicted rise in temperatures in descending order is 0.0028°C/month, 0.0027°C/month, 0.0025°C/month, 0.00239°C/month, 0.00236°C/month, 0.0022°C/month, 0.0019°C/month and 0.0017°C/month for Düzce, Zonguldak, Bolu, Sinop, İnebolu, Bartın, Akçakoca and Kastamonu stations, respectively.

As observed in Figure 6, during the precipitation data analysis, all stations exhibit probability levels based on the GEV CDF, except for Düzce and İnebolu stations, for which the data fit the Normal CDF. The results show that, at a risk level of 0.99, the predicted change in precipitation amount in descending order is 0.017, 0.016, 0.014, 0.0122, 0.0095, 0.0094, 0.0037 and 0.0029 mm/month for Akçakoca, Sinop, İnebolu, Zonguldak, Bartın, Kastamonu, Bolu and Düzce stations, respectively.

3.4 | Actual Temperature and Precipitation Trends

In this section, actual trends emerging over 63 years and potential trends at the 0.99 risk level are made using classical SS and new RSS methods. In this research, the term "actual" is utilised to explain the overall value of a trend over the entire study period (Equation 4). While slope values typically represent changes monthly (per month), the term "actual" is employed to provide a comprehensive perspective that considers the trend's cumulative impact across the entire study duration. This allows for a holistic assessment of the trend's value over time, providing a clearer understanding of its long-term implications and significance within the context of the research objectives. Table 3 presents the SS and RSS methodology results for eight selected Western Black Sea basin stations. Additionally, the spatial variation of 63-year increasing trends and potential trend increases at a risk level of 0.99 with a 1% probability across the basin, depicted in Figure 7, utilising model maps prepared using the Spline interpolation method (Dubrule 1984). As described in Figure 7, the classical SS method results show that the region with the highest increasing trend includes Düzce and its surroundings, indicating a temperature increase of approximately 2°C over 63 years. This increase implies a 15.24% rise in average temperature for this station across the entire period. Analysing the SS results for Bolu station, located near Düzce, reveals a trend increase percentage in long-term averages of 13.59%, the second most significant increase after Düzce. At the end of the 63-year period, a temperature increase was 1.42°C. According to the RSS model results, at

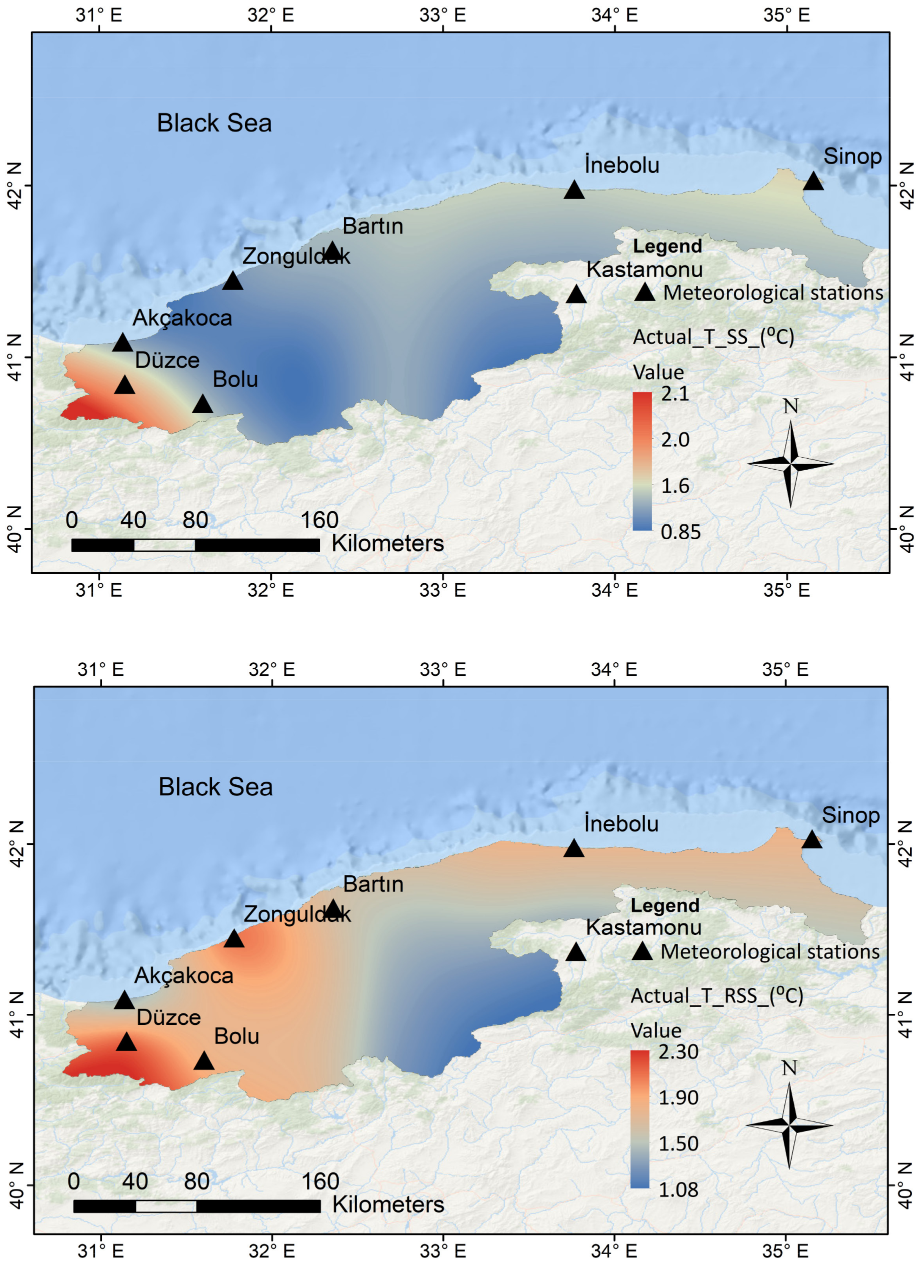


FIGURE 7 | Comparison between actual temperature trends based on classical Sen's slope and risk Sen's slope (within 63 years). [Colour figure can be viewed at wileyonlinelibrary.com]

a risk level of 0.99, the expected temperature increases in these two provinces and their immediate surroundings are 2.09°C and 1.84°C for Düzce and Bolu, respectively. Accordingly, while an additional temperature increase of 0.1°C is expected for Düzce at a risk level of 0.99, this increase is 0.42°C under similar conditions in Bolu. Concerning Akçakoca, located on the coast from Düzce to the north, the SS method indicates a temperature increase of 1.27°C. RSS predicts a temperature increase of up to 1.40°C at a risk level of 0.99.

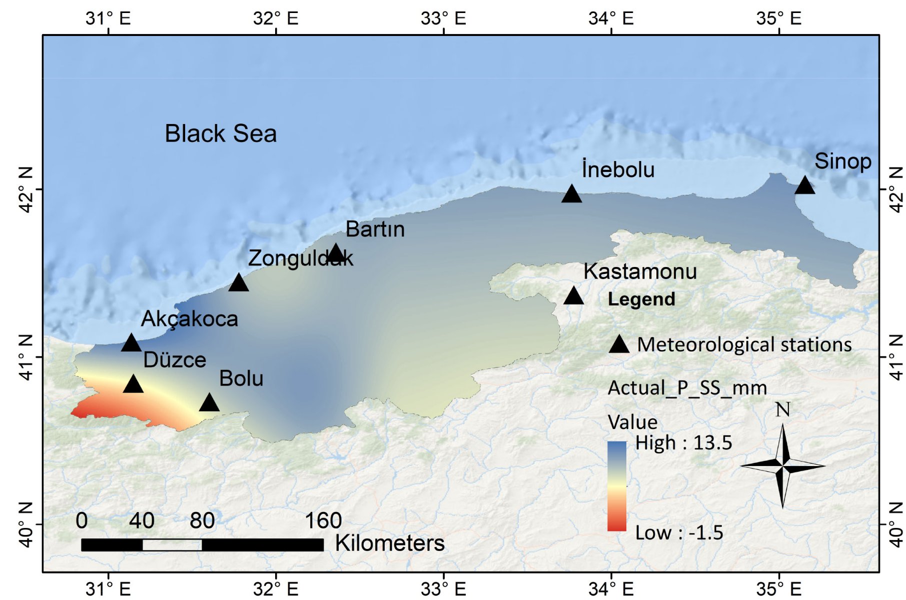
When examining the temperature increases in the Black Sea coastal area according to the SS method, the most significant increase is 1.70°C in the Sinop station in the east. The increasing temperature trends, decreasing from east to west, were calculated as 1.51°C in İnebolu, 1.35°C in Bartın and 1.12°C in Zonguldak. According to the 0.99 risk level, the province where the highest temperature increase is expected is Düzce. According to RSS model results, there is a potential for temperature increases to reach 2.09°C within 100 years. According to the 0.99 risk scenario for Sinop and Bartın, the largest increases expected to occur in temperatures after 2023 are 0.09°C (from 1.70°C to 1.79°C) and 0.28°C (from 1.35°C to 1.63°C), respectively. When all the results given in Table 3 are examined, it is seen that, according to the SS results, there is a 1.12°C increase trend in average temperatures in Kastamonu until 2023, and according to RSS, the temperature increase may reach up to 1.25°C at a risk level of 0.99. Therefore, it is understood that a significant increase trend is not expected within 100 years compared with 1961. Figure 7 shows the spatial distribution of increasing temperature trends in detail, according to SS and RSS results. According to these results, at a risk level of 0.99, it is understood that the trend increases will continue in the Western

Black Sea basin in the coming period. Additionally, as seen in the RSS maps, temperature increases will approach 2°C in the basin and exceed it in some regions. These trend increases indicate significant rises in average temperatures.

$$\text{Actual trend} = \text{Trend} \times \text{Entire study period} \times 12 \quad (4)$$

Table 4 presents the precipitation data results for the entire (actual) period using the SS and RSS. Furthermore, Figure 8 illustrates the spatial distribution of 63-year increasing precipitation trends, and the potential trend increases at a risk level of 0.99 across the basin. According to the classical SS results for the entire period, the highest precipitation increase is observed in the Akçakoca station, with Sinop following closely with 11.87 and 10.07 mm, respectively. However, the increase rate is higher for Sinop, reaching 17.41%, while it is 13.03% for Akçakoca. Moving from Sinop, which is in the easternmost part of the basin, to the west, the precipitation gradually decreases. The actual amounts of precipitation from east to west become 8.2, 6.58 and 5.68 mm for İnebolu, Bartın and Zonguldak, respectively. From Zonguldak to the west, precipitation rises again until it reaches the highest value in the Akçakoca station.

However, to the south of Akçakoca, the precipitation drastically drops. According to classical SS analysis, it even reaches negative values in the Düzce station, with a decrease of −1.12 mm. Based on the mean value, this represents a rate of change of −1.62% for the analysis period. Düzce, with an elevation of 150 m, is very close to Akçakoca, a coastal town, but the heights between them, which can reach up to 1000 m, account for the change in precipitation amount between the



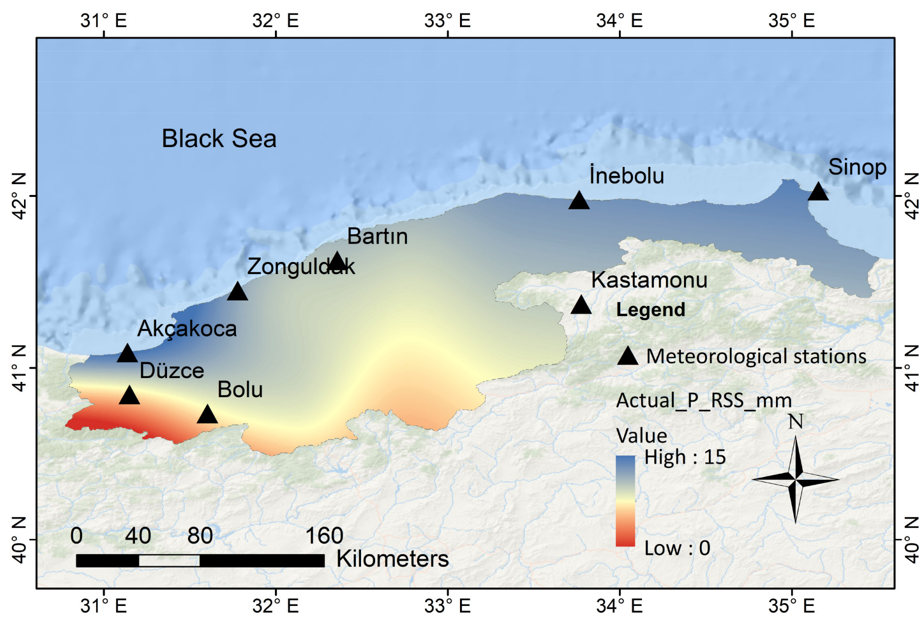


FIGURE 8 | Comparison between actual precipitation trends based on classical Sen's slope and Risk Sen's slope (within 63 years). [Colour figure can be viewed at wileyonlinelibrary.com]

two stations. Bolu station, to the east of Düzce station, shows characteristics similar to those of Düzce station, with a slight increase of 2.86 mm of precipitation for the whole period. Kastamonu station has a mid-range value of a 4.52 mm change in precipitation. However, it has a significant increase rate of 10.68% in precipitation. According to the RSS analysis model, at a risk level of 0.99, the increased amounts of precipitation are 12.74, 11.763, and 10.51 mm for Akçakoca, Sinop and İnebolu stations, respectively. For the most part, results align with classical SS methodology. The differences from SS results mostly occur in the change rate evaluations. Similar to the SS analysis, the Düzce station exhibits the lowest change rate of precipitation across the basin; however, it never yields a negative change rate in the RSS results (3.13%). Also, the change of precipitation rate is in a different order in RSS analysis. Although the highest change rate still happens in Sinop station (20.45%), the second-highest rate happens in Kastamonu (17.36%) instead of Akçakoca.

It is possible to make some predictions about the change in precipitation. Although a decrease is seen in the amount of precipitation for the 63 years for the SS test in Düzce, a change of 3.29 mm increase is predicted at a risk level of 0.99 according to RSS results. This becomes the second-highest prediction across the basin, as in the case of Zonguldak; it is predicted to increase by 3.48 mm. These two stations are among those that have the lowest precipitation amount, but the RSS results remarkably reveal their potential. On the other hand, the two stations (Akçakoca and Sinop) with the highest actual precipitation amounts are calculated to have a relatively smaller amount of change (0.87 and 1.69 mm, respectively).

4 | Discussion

Based on SS variations for temperature data, it can be noticed that the trend is negative until approximately the end of 2000, and then it starts increasing. In 2022, the maximum classical SS is generally observed for all stations within the study area. The decrease in the trend for temperature data is attributed to the utilisation of a long-term period that incorporates the earliest years, specifically 1961. During this period, the impact of climate change was comparatively limited. The maximum classical SS value is observed at Düzce station, which has a relatively high standard deviation of about 6.80°C, and the minimum classical SS value is observed at Zonguldak and Kastamonu stations with about 0.00149°C/month. For Akçakoca station, the SS values are negative until 2010, which considers the period between 1961 and 2010. For this station, and based on the homogeneity tests, it is noticed that the change year was in 2007, which is consistent with its SS values. On the other hand, the SS variations for precipitation data do not have a consistent pattern, fluctuating over different periods, which can be noticed clearly in Figure 4. All SS values show an increase in precipitation over 63 years, except Düzce station, which has a decreasing trend of −0.0015 mm/month with the maximum SS values for temperature data. For more information, Figures 3 and 4 and show the variations of SS for each station for temperature and precipitation data by changing the utilised period based on different initial conditions.

Considering the results obtained from the exceedance probability functions, the first conclusion is that the fitted PDF impacts the corresponding risk levels, highlighting the importance of the goodness-of-fit tests to check the suitability of each CDF. In this research, the Kolmogorov–Simirnov test was used (Stephens 1970). Additionally, these CDFs have a mix of extremely low (negative), extremely high and zero values, indicating no increasing or decreasing trend with their corresponding risk level. No temperature trends (zero values) are different; for example, for Düzce station and temperature data, it is a 0.17 risk level, but for Akçakoca station, it is a 0.58 risk level. This can be attributed to the differences in the original temperature data and the fitted CDF. When the slope values of SS and RSS are compared for temperature data, it is clear that there is considerable variation. As summarised in Table 3, there is a variation of 25% more than SS. For the Zonguldak station, based on SS, the slope is 0.00149°C/month, and based on RSS, the slope is 0.00274°C/month at 0.99 risk level, which is double from the classical SS (Table 3).

On the contrary, the precipitation results for SS and RSS are more consistent with small differences. To reflect the slope values obtained from both SS and RSS methods, these slopes are converted to actual temperature and precipitation values over the studied period (63 years) for simplification. Figures 7 and 8 show the actual temperature and precipitation trend distribution over the basin with the same scale (colour) using the spline technique. It is obvious in both figures that the red colour (more temperature and precipitation) is dominant in the second part of the figures. This is due to using a 0.99 risk level with a considerable increase.

Based on the previous discussion and the difference between SS and RSS, the necessity of using different risk levels is evident. The integration of risk analyses, exceedance probability assessments and trend analyses play pivotal roles in flood design, hydraulic structures and water resources management, with particular significance in addressing flood-related challenges, particularly in regions facing floods, such as the Western Black Sea basin, which faced several floods (Arman et al. 2010; Celik et al. 2006). In flood design, a thorough understanding of potential risks associated with different exceedance probabilities is crucial for developing resilient infrastructure and sustainable urban planning. Also, understanding the historical trends in precipitation values through trend analysis is foundational for predicting future patterns. For example, based on the results obtained, there is a difference between SS and RSS precipitation values, which must be considered in terms of flood schedules. Hydraulic structures, such as dams, must be designed with a comprehensive understanding of the exceedance probabilities of precipitation and temperature trends to ensure their ability to withstand and mitigate the impacts of such occurrences.

Moreover, water resources management relies on accurate risk trend analyses to develop effective water allocation and supply strategies, especially for countries depending on surface water as the main water resource. By integrating risk exceedance probability assessments with trend analysis into these domains, professionals and policymakers can make informed decisions, enhance the resilience of infrastructure and develop adaptive strategies to mitigate the adverse impacts of climate change on communities and ecosystems. Furthermore, previous studies have primarily focused on calculating a single slope for trend analysis, which may limit the comprehensive understanding of risk levels associated with climate change (Jiang et al. 2024). However, using the RSS method in this research has offered a broader range of slope values corresponding to various risk levels. Unlike traditional approaches, which typically yield a singular slope value, the RSS method provides a spectrum of slopes, enabling a more nuanced risk assessment. This advancement addresses a significant shortcoming in previous studies, particularly regarding risk management strategies and guiding future research. By incorporating the RSS method, this research enhances the robustness and applicability of trend analysis in climate change studies.

Considering previous studies related to the Western Black Sea basin, Ay (2020) identified a rising trend in monthly average temperature variations across the Bartın, Bolu, Kastamonu, Sinop and Zonguldak stations. Through the application of the SS method, Ay reported positive trends for the Bartın, Bolu and Düzce stations, with values of +0.00074°C/month, +0.0019°C/month and +0.0012°C/month, respectively. Similarly, the slope values derived from the RSS trend analysis were 0.001°C/month, 0.0019°C/month and 0.0010°C/month for Bartın, Bolu and Düzce, respectively. These results indicate a difference of 0.00026 for Bartın, an identical slope for Bolu, and a difference of 0.0002 for Düzce. In parallel, a trend analysis conducted by Ceyhunlu et al. (2021) also revealed a significant increase in temperatures, particularly at the Bartın station. These findings align with the present study, suggesting a notable regional warming trend.

The findings derived from this study demonstrate that the MMK and SS methods reveal a significant declining trend at the Düzce station, with a slope value of −0.0048 mm/month. Similarly, Cengiz et al. (2020) also identified a negative trend in the precipitation variable for the Düzce station. Also, Ay (2020) reported positive trends in the precipitation data for the Kastamonu and Bolu stations, with slope values of +0.0095 mm/month for Kastamonu and +0.0197 mm/month for Bolu. Compared with the RSS trend analysis, the slope for Kastamonu was found to be 0.0094 mm/month, so it closely corresponds to Ay's findings. Although variations in trend results can be attributed to the differing methodologies employed, the time period utilised for trend analysis in this study encompasses a broader temporal range than those in previous studies in the literature. Expanding the temporal range enhances the robustness of the dataset, thereby increasing the reliability of the results (Sagiroglu and Sinanc 2013).

Ay (2020), Zarifoglu, Yanmaz, and Baduna Koçyiğit (2022) and Cengiz et al. (2020) applied the MK test to precipitation data from the Zonguldak and Bartın stations, identifying statistically insignificant trends in precipitation. In the present study, however, the MMK method indicates an increasing trend in precipitation for the Zonguldak station. This result is considered further evidence that the MMK method overcomes certain limitations inherent in the original MK test. Research on the Western Black Sea region, the focus of this study, remains limited in the literature. The overlap in slope results for some stations, as observed in the studies by Zarifoglu, Yanmaz, and Baduna Koçyiğit (2022), Cengiz et al. (2020) and Ay (2020), enhances the credibility of the findings produced in this article.

According to the Intergovernmental Panel on Climate Change (IPCC) reports in IPCC (2007, 2023), the Mediterranean Basin, including Türkiye, is anticipated to be among the regions most extremely impacted by climate change in the 21st century. More severe increased temperatures, heat waves, and decreased soil moisture are expected. In the case of the Western Black Sea basin, where most of the agricultural land relies on precipitation, and less than 10% is irrigated, these climatic changes pose significant challenges. Moreover, agricultural irrigation accounts for over 50% of the country's water resources (General Directorate of Agriculture and Forestry 2023). As per the Food and Agriculture Organization (FAO) data, Türkiye holds the fifth position globally in sugar beet production. Furthermore, Türkiye's rankings include the sixth position for sunflower seeds, ninth for barley, eleventh for wheat and 22nd for maize production, and all of these crops are present in the studied basin. Also, a significant temperature increase is expected based on the SS and RSS results. Subsequently, RSS values with several risk levels can be obtained to ensure that agricultural sectors will not be affected by this increasing trend, and appropriate measures must be taken to mitigate related effects. RSS procedure presents all possible alternatives in a convenient CDF form with a set of risk levels slope values, leading to a more comprehensive framework for trend analysis.

5 | Conclusion

This research applied classical SS and RSS to evaluate and analyse the actual and potential precipitation and temperature trends with different risk levels, such as 0.95 and 0.99 risk for the Western Black Sea basin. The main results can be summarised as follows:

- Using RSS has the advantage of deriving several dynamic slopes for each risk level for any hydro-meteorological variable. Also, the SS method can be viewed as a specific case derived from the broader framework of RSS.
- The actual temperature and precipitation trend maps corresponding to classical SS and specific risk levels are presented for the first time in the literature.
- The dominant fitted PDF is GEV, a function with three parameters. The fitted PDF is tested using the Kolmogorov–Smirnov test.
- The maximum trend slope using SS is 2.01°C, while the maximum trend slope using RSS with a 0.99 risk level is 2.09°C at different locations in the Western Black Sea basin.
- The maximum temperature increasing trend at a 0.99 risk level is at Düzce station, northwest of the Western Black Sea basin.
- The differences between precipitation trend slopes obtained by SS and RSS for different risk levels are relatively low.
- Due to the persistent challenges of floods in this particular basin, the RSS method is a valuable tool for comprehensive analysis, strategic planning and practical mitigation efforts.

- The agricultural sector in this basin is susceptible to the potential impacts of increasing trends; utilising the RSS can significantly contribute to managing these effects, emphasising the need for proactive and effective measures to safeguard agricultural activities.

Author Contributions

Muhammed Zakir Keskin: conceptualization, investigation, data curation, methodology, formal analysis, visualization, writing – original draft, writing – review and editing. **Ahmad Abu Arra:** conceptualization, investigation, methodology, visualization, writing – review and editing, writing – original draft, formal analysis. **Seyma Akca:** writing – original draft, visualization, formal analysis. **Eyüp Şişman:** conceptualization, investigation, data curation, methodology, supervision, writing – original draft, writing – review and editing.

Ethics Statement

The authors affirm adherence to ethical and professional conduct principles within the manuscript.

Consent

The manuscript has received approval from all contributing authors, who assert that it constitutes an original contribution. Furthermore, they affirm that none of the content within this paper is currently under consideration for publication elsewhere.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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