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Investigation of Hydrological Droughts in the Eastern Mediterranean Basin Using Hybrid Trend Analysis Methods

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Trend, Mann-Kendall Test, Sen's Slope Estimator, Şen's Innovative Trend Analysis, Eastern Mediterranean Basin, Streamflow

Abstract: This study investigates the impact of climate change on river systems within the Eastern Mediterranean Basin (EMB), utilizing the Mann-Kendall (MK) test, enhanced by Sen's slope estimator (SSE) and Şen's Innovative Trend Analysis (ITA) methods. The research focuses on hydrological changes, particularly in streamflow trends, and examines their implications in the context of climate change and anthropogenic activities. The methodology involves a detailed analysis of hydro-meteorological series, including streamflow data from different observation stations. The research enhances the robustness of trend detection by applying advanced methodologies such as trend-preserving pre-whitening, which satisfies the serial independence requirement of the MK test. The study area comprises 10 sub-basins in the EMB, with a particular attention to the Göksu River and its tributaries. The results reveal significant declines in the annual streamflow values at several stations, demonstrating the considerable influence of climate and environmental changes on the basin's hydrology. These findings are further evaluated using ITA graphs, which offer a detailed analysis of the spatial and temporal variability in streamflow patterns. This research contributes to a better understanding of hydrological responses to climatic variability, providing vital information for water resource management and policies in regions undergoing significant environmental changes.

Hibrit Trend Analiz Yöntemleri Kullanılarak Doğu Akdeniz Havzasındaki Hidrolojik Kuraklıkların İncelenmesi

Anahtar Kelimeler
Trend, Mann-Kendall yöntemi, Şen'in eğim tahmini, Şen'in yenilikçi trend analizi, Doğu Akdeniz havzası, Akış

Öz: Bu çalışma, Şen eğim tahmincisi (SSE) ve Şen'in Yenilikçi Trend Analizi (ITA) yöntemleriyle geliştirilen Mann-Kendall (MK) yöntemini kullanarak, Doğu Akdeniz Havzası'ndaki (DAH) nehir sistemleri üzerindeki iklim değişikliğinin etkisini araştırmaktadır. Araştırma, özellikle akış eğilimlerindeki hidrolojik değişikliklere odaklanmakta ve bunların iklim değişikliği ve antropojenik faaliyetler bağlamındaki etkilerini incelemektedir. Metodoloji, farklı gözlem istasyonlarından gelen akış verileri de dahil olmak üzere hidro-meteorolojik serilerin ayrıntılı bir analizini içermektedir. Araştırma, MK testinin seri bağımsızlık gereksinimini karşılayan gelişmiş metodolojileri uygulayarak eğilim tespitinin sağlamlığını artırmaktadır. Çalışma alanı, DAH'daki 10 alt havzayı kapsamakta olup özellikle Göksu Nehri ve kollarını içermektedir. Sonuçlar, birkaç istasyonda yıllık akış değerlerinde önemli düşüşler olduğunu ortaya koyarak, iklim ve çevresel değişikliklerin havzanın hidrolojisi üzerindeki önemli etkisini göstermektedir. Bu bulgular, akış desenlerindeki mekansal ve zamansal değişkenliğin ayrıntılı bir analizini sunan ITA grafikleri kullanılarak değerlendirilmiştir. Bu araştırma, iklim değişkenliğine karşı hidrolojik tepkilerin daha iyi anlaşılmasına katkıda bulunarak, önemli çevresel değişiklikler geçiren bölgelerdeki su kaynakları yönetimi ve politikaları için önemli bilgiler sağlamaktadır.

1. INTRODUCTION

The evolving dynamics of climate change pose major challenges and opportunities for hydrological research focusing on studying drainage basin systems. Global climate changes, driven by increased greenhouse gas (GHG) emissions. These changes have profound impacts on the hydrological cycle, particularly on river flow and sediment transport. Historical data suggest that the concept of stationarity, which implies temporally invariant statistical characteristics, may no longer be applicable under these changing conditions [1]. This paradigm shift calls for a re-evaluation of conventional hydrological models. It underlines the need for robust trend analysis methods, such as the Mann-Kendall (MK) test, to detect and interpret these changes [2]. The MK test is known for its robustness in identifying trends in hydrological time series, and it is widely employed in various hydro-meteorological analyses. Wu et al. [3] noted the role of streamflow in examining drought characteristics by providing information on the frequency, duration, and severity of drought events. The application of these methods extends beyond drought analysis and covers a wide range of hydrological events.

Yue et al. [4] proposed the trend-preserving pre-whitening technique to eliminate serial correlation effects on time series, noting that the conventional pre-whitening techniques can remove portions of the trends along with the serial correlations. The authors used the Theil-Sen approach [5,6] to calculate trend slopes and hybridized it with the classical Mann-Kendall method, called MK-SSE. The Theil-Sen approach, known as the Sen slope estimator (SSE) in literature, calculates trend slopes using median slope values. However, with the increasing occurrence of extreme values (both low and high) are more frequent with the climate change phenomenon. Therefore, Alashan [7] was the first to hybridize the Mann-Kendal method with Şen's ITA approach (MK-ITA) to include the effects of the extremum events in trend analysis calculations. This hybridization highlighted how combining these methods improves our understanding of trends in hydro-meteorological variables. The classical MK test is effectively hybridized with Sen's slope estimator and Şen's ITA approach. These enhancements address the limitations of the MK test, especially regarding extreme values and serial autocorrelation in hydro-meteorological time series. Applying these methods has revealed significant trends in Oxford City River systems that are vital for understanding the regional impacts of climate change [7]. Furthermore, Bayazit and Önöz [8] and Şen [9] emphasized the crucial role of advanced methodologies in hydrological trend analyses, particularly in addressing the issue of serial correlation a common feature in hydro-meteorological records that can often distort trend analysis results. The innovative approaches, including over-whitening procedures and Şen's ITA, not only enhance the detection of trends in hydrological data but also ensure the preservation of key trend components essential for understanding the hydrological responses to climatic variability. These methodologies have played an important role in deciphering complex patterns in river flow time series records, providing essential data for water resource management and policies. This is especially critical in regions like the Eastern Mediterranean Basin (EMB), where hydrological changes are intricately linked with environmental and socio-economic factors.

Streamflow trend analysis is critical in river basins, where shifts in streamflow have significant consequences for water resource management. Cultivated areas and decreased rainfall are the main reasons for decreasing trends in watershed streamflow [10,11]. Gumus et al., [12] clarified that understanding streamflow trends is essential for designing dams and hydroelectric power plants and effectively managing flood and drought events. The MK test, alongside other methods such as Şen's ITA method, has been applied to various basins worldwide, providing valuable insights into spatial and temporal changes in river systems. Hydrological variability across different timescales is often assessed using standardized indices for both streamflow and precipitation [13]. Comparisons often reveal that innovative trend methods can offer different sensitivities compared to classical methods such as MK test [14]. Furthermore, robust methods are also needed to specifically address seasonal patterns or regional behaviors in hydro-meteorological data [15]. For example, the trend analyses conducted in the Tigris and Euphrates River basins have revealed significant trends in streamflow, emphasizing the effects of climatic and environmental changes [16–18]. These studies underscore the significance of trend analysis in river systems as a critical tool for policy-making and sustainable water resource management.

The trends detected in the EMB highlight the need for further research to ensure holistic water resources management and environmental protection. For instance, the study of the Upper Jhelum River Basin by Ougahi et al. [19] showed how climate change significantly affects vegetation productivity. Similarly, research in the Upper Awash River Basin by Emiru et al. [20] emphasized the future implications of climate change on hydrological conditions, impacting agricultural activities and human water demands. The observed trend in streamflow and sediment in the River Ganga was investigated by Zakwan and Ahmad [21]. In the study, MK, and hybridized versions with the Sen's slope, and Şen's ITA were conducted using annual maximum and minimum flow data in the Ganga River. In another study, where the river flows in the Western Mediterranean Basin of Turkey were analyzed monthly and annually, the Mann-Kendall trend test was applied to observe changes [22].

The Eastern Mediterranean and the Middle East (EMME) regions are particularly vulnerable to the impacts of climate change. The region is characterized by diverse climates, ranging from temperate in the north to arid desert conditions in the south [23]. This climatic diversity, combined with complex topography and varying socio-economic conditions, contributes to the region's unique vulnerability to climate change impacts [24]. The region has already experienced notable shifts in temperature and precipitation patterns, with increasing temperatures and a general drought observed in recent decades [23,25]. These changes have significant implications for the region's water resources, agriculture, and human well-being. Drought events, characterized by prolonged periods of below-average precipitation, have become more frequent and intense, particularly in the southern and eastern parts of the EMME [24,26]. The Standardized Precipitation Index (SPI), a widely used drought index, has been instrumental in quantifying these changes, revealing a trend toward drier conditions in many areas [24,26]. In addition to drought, the EMME has also experienced an increase in the frequency and intensity of heat waves, especially in the northern regions [27]. These extreme weather events have far-reaching consequences for human health, energy consumption, and agricultural productivity. The complex interplay of climatic and anthropogenic factors in the EMME necessitates a comprehensive and nuanced approach to hydrological trend analysis. By understanding the historical context of climate variability and employing advanced statistical methods, researchers can better assess the region's vulnerability to climate change and develop effective adaptation and mitigation strategies.

In efforts to understand hydrological responses to climatic changes, the classical methodologies, while robust, often exhibit limitations in handling non-stationary and extreme conditions prevalent in river systems of regions such as those in the EMB. The development of hybrid trend analysis techniques, such as the Mann-Kendall test enhanced by Sen's slope estimator and Şen's ITA, represents a significant advancement. However, a clear research gap remains, largely because conventional methods are static and struggle to fully capture the dynamic and complex interactions driven by both climatic variability and anthropogenic activities. This study makes a substantial significantly advances hydrological trend analysis by deploying a hybrid methodology that combines the MK test, Sen's slope estimator, and Şen's ITA, overcoming the limitations of classical methods in capturing non-stationary conditions and providing a deeper understanding of the impacts of climate change on the hydrology of the EMB. The urgency of this research is underscored by the observed consistent decrease in streamflow, which has profound implications for water resource management and regional ecological balance, highlighting an imperative need for more dynamic and responsive analytical frameworks in hydrological sciences. In the context of hydrological trend analysis, particularly in the Eastern Mediterranean Basin, the MK test, enhancement by Sen's slope estimator and Şen's ITA, has provided comprehensive insights into the changing patterns of river systems. The aim of this paper is to extend these results by focusing on the Eastern Mediterranean basin and using the MK trend test and other statistical methods to analyze the hydrological changes in river systems and their impacts under the current conditions of climate change and human activities.

2. METHODOLOGY

Mann-Kendall (MK) test is the commonly used method for trend detection. However, it does not provide trend slope values for the examined time series. Trend slopes are calculated through a linear regression, Şen's slope estimator, and Şen's ITA methods. MK method is based on the possible existence of a trend in each time series. If a value in the series is bigger (smaller) than the previous value, then a sign function is 1 (-1). If the data values are equal, then the sign function takes 0 value (Eq. 1). The sum of the sign function gives an S test parameter (Eq.2). The S parameter is accepted to fit a Normal (Gaussian) probability distribution function (PDF), which has zero mean, and a variance value as expressed in Eq. 3 and 4. The normal distribution test statistics values are calculated according to Eq.5. If the values are greater (or smaller) than the tabulated values, then there are increasing (decreasing) trends in the time series. The tabulated values are selected through significance levels such as %99 (2.57), %95 (1.96), and %90 (1.65).

$$sign(z_j - z_i) = \begin{cases} 1 & if\ z_j > z_i \\ 0 & if\ z_j = z_i \\ -1 & if\ z_j < z_i \end{cases} \quad (1)$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(z_j - z_i) \quad (2)$$

$$E(S) = 0 \quad (3)$$

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \quad (4)$$

$$z = \begin{cases} \frac{S-1}{Var(S)} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{Var(S)} & if\ S < 0 \end{cases} \quad (5)$$

Another assumption of the MK method is that the time series must be serially independent. Most of the time, hydro-meteorological series have serially dependent structures, which give rise to a Type-2 error (the MK result gives a trend, although there is no trend in the time series). To use the MK in a serially dependent series, pre-whitening [28], over-whitening [9], trend-free Sen's slope [29], and hybrid Mann-Kendall methods with the SSE approach [4], and Şen's ITA [7] are used in the literature. The pre-whitening (PW) method removes correlation before using the MK method, but sometimes, it might remove a portion of the trend [8,30–32]. To conserve the trend in a time series, hybrid Mann-Kendall methods with Sen's slope (MK-SSE) and Şen's ITA (MK-ITA) method are applied to a dependent series. The MK-SSE calculates all possible trend slopes in the time series and uses the median trend slope value. Climate change affects hydro-meteorological events on low and high values. To consider the effects of low and high values on trend slope calculations, Alashan [7] proposed the MK-ITA method in the literature.

Let Z be a time series (Eq. 6) for which the trend slope is calculated by Eq. 7, where n is the data length, z_j and z_i are the next and previous data values. The SSE trend slope value is subtracted from the original time series to obtain a trendless time series (Z_{SSE}^{d}, Eq. 8). Correlation effects are removed from the trendless time series, and an independent series with a trend is achieved by adding the SSE trend slope value to the trendless serially independent time series (Z_{SSE}^{t}, Eq. 9).

$$Z = \{z_1,\ z_2,\ z_3, \dots \dots \dots \dots \dots \dots \dots \dots, z_n\} \quad (6)$$

$$s_{SSE} = median\left(\frac{z_j - z_i}{j - i}\right) \quad (7)$$

$$for \quad \forall \quad j > i; \quad i\ from\ 1\ to\ n - 1 \quad and \quad j\ from\ 2\ to\ n$$

$$Z_{SSE}^{d} = z_k - s_{SSE}.k; \qquad for\ k\ from\ to\ n; \quad (8)$$

$$Z_{SSE}^{t} = z_k^{i} + s_{SSE}.k \quad (9)$$

Şen [33] proposed a methodology to detect trends on a time series, which also has dependence and skewness. His method, ITA, is applied by dividing the time series into two equal parts and comparing these two halves after sorting on a square graph. Şen's ITA trend slope values are calculated by Eq. 10, where n is the data length, $\bar{x}$ and $\bar{y}$ are the mean of the first and second half sub-series. As mentioned in the MK-SSE method, the trend slope is subtracted from an original time series to conserve the trend slope on the time series (Z_{ITA}^{d}, Eq. 11) before removing correlation effects on the trendless time series (Z^{i}, Eq. 12). The trend slope values calculated by Şen's ITA adding to the independent series to achieve an independent and trendy series (Z_{ITA}^{t}, Eq.13).

$$s_{ITA} = \frac{2(\bar{x} - \bar{y})}{n} \quad (10)$$

$$Z_{ITA}^{d} = z_k - s_{ITA}.k \quad (11)$$

$$Z^{i} = z_k - \rho_1.z_{k-1} \quad (12)$$

$$Z_{ITA}^{t} = z_k^{i} + s_{ITA}.k \quad (13)$$

2.1. Study Area and Data

The EMB region lies in the south of Türkiye, within the Mediterranean climatic zone, (Figure 1). The Göksu River, the most important watercourse in the basin, is fed by numerous tributaries. Although the basin's first and second biggest streams are the Göksu River and Tarsus Stream, they are short and have a high channel slope. The Eastern Mediterranean Basin consists of 10 sub-basins, and its total area is 21,807 km2. The flow data located in the sub-basins of the Eastern Mediterranean Basin are shown in Figure 1. The flow data used in this study were provided by the General Directorate of State Hydraulic Works.

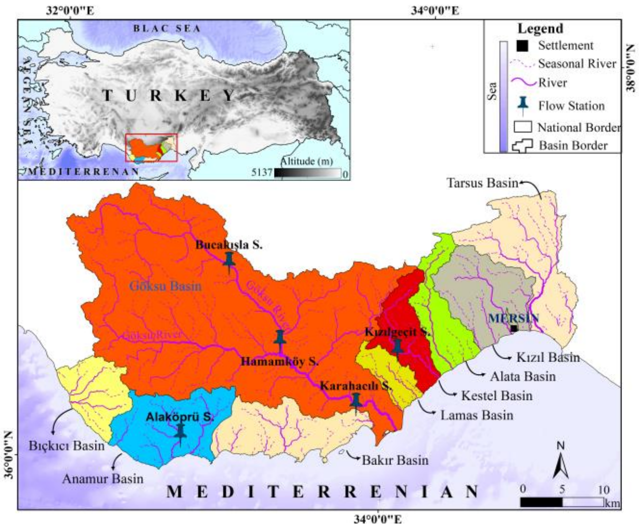


Figure 1. The location and general view of Eastern Mediterranean Basin.

The main branches are E17A017 Kızılgeçit-Lamas Stream, E17A014 Göksu River, E17A020 Hamamköy-Göksu River, E17A021 Alaköprü-Anamur Stream, and E17A012 Bucakkışla-Göksu River. The aim of the selection of this basin has been due to an increase in temperature values in recent years and a slight decrease in the total annual precipitation trend [34]. For this reason, the flow data are analyzed to determine the effect of precipitation on flow.

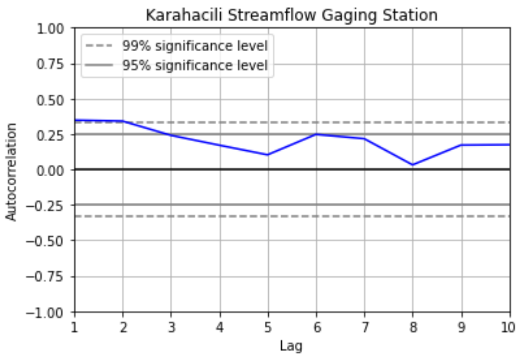
Statistics about stations with long streamflow values are given in Table 1. Göksu is mainstream on the EMB and has potential with 104.79 m^3/s annual flow on average at the Karahacılı station. The annual minimum average streamflow value is 1.80 m^3/s annual flow at Kızılgeçit station. The maximum skewness was calculated as 1.57 at Bucakkışla station, and the stream dries up in spring and summer. The basin has maximum flows in the spring season, with 339.3 m^3/s at the Karahacılı station. Only the Lamas stream at Bucakkışla station has negative skewness equal to -0.59 in the summer season. Minimum flows in the basin are observed in the summer months, ranging from 0 to 23.4 m^3/s.

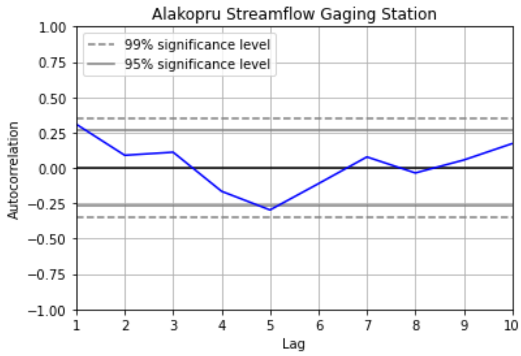
Table 1. Statistical parameters of the streamflow gaging stations of East Mediterranean Basin.

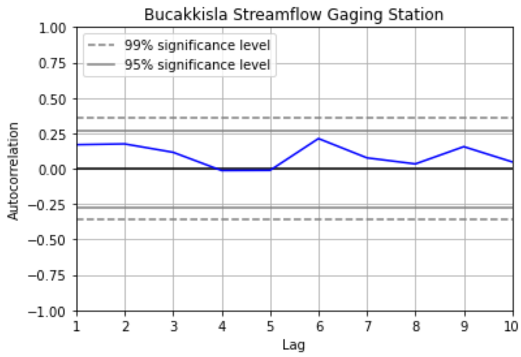
	Stations	Stream	Observed Years	Minimum (m^3/s)	Mean (m^3/s)	Maximum (m^3/s)	Standard deviation (m^3/s)	Skew
Annual	Karahacılı	Göksu	1962-2021	49.66	104.79	194.96	35.79	0.30
	Hamam	Göksu	1966-2021	20.00	48.92	84.70	13.50	0.56
	Kızılgeçit	Göksu	1967-2022	1.80	5.06	13.50	2.30	1.18
	Alaköprü	Anamur	1968-2021	9.30	23.34	39.40	8.02	0.21
	Bucakkışla	Lamas	1962-2013	4.70	27.14	46.40	9.21	0.04
Autumn	Karahacılı	Göksu	1962-2021	27.6	51.0	96.5	14.78	0.55
	Hamam	Göksu	1966-2021	13.0	19.8	33.2	4.67	0.93
	Kızılgeçit	Göksu	1967-2022	1.3	3.08	6.5	1.14	0.85
	Alaköprü	Anamur	1968-2021	4.6	10.0	24.7	5.08	1.35
	Bucakkışla	Lamas	1962-2013	4.1	10.18	21.3	2.81	1.57
Winter	Karahacılı	Göksu	1962-2021	37.2	130.0	320.3	63.63	1.01
	Hamam	Göksu	1966-2021	21.4	50.04	135.3	22.40	1.28
	Kızılgeçit	Göksu	1967-2022	1.6	3.88	9.1	1.70	1.21
	Alaköprü	Anamur	1968-2021	7.8	31.24	64.7	15.38	0.43
	Bucakkışla	Lamas	1962-2013	11.3	31.40	78.3	15.51	0.96
Spring	Karahacılı	Göksu	1962-2021	39.2	184.82	339.3	78.29	0.21
	Hamam	Göksu	1966-2021	23.7	76.92	141.7	31.26	0.26
	Kızılgeçit	Göksu	1967-2022	2.1	9.44	27.4	5.38	1.17
	Alaköprü	Anamur	1968-2021	17.9	40.5	67.8	12.97	0.15
	Bucakkışla	Lamas	1962-2013	0	56.28	100.9	23.18	0.12
Summer	Karahacılı	Göksu	1962-2021	23.4	53.28	111.0	19.51	0.84
	Hamam	Göksu	1966-2021	11.7	20.38	34.6	5.65	0.44
	Kızılgeçit	Göksu	1967-2022	1.0	3.87	11.2	1.95	1.16
	Alaköprü	Anamur	1968-2021	4.2	11.6	32.9	6.03	1.24
	Bucakkışla	Lamas	1962-2013	0	10.7	16.0	2.88	-0.59

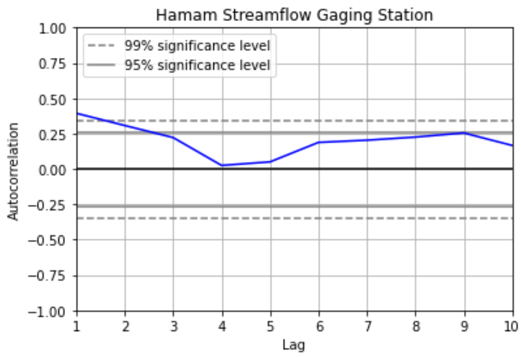
3. RESULTS

In this study, the original MK test, along with its hybrid versions combined with Sen's slope estimator (MK-SSE) and Şen's ITA (MK-ITA), is applied to detect trends in the streamflow values of the EMB. The MK method requires a serially independent time series; therefore, autocorrelation coefficients were calculated for the EMB streamflow are calculated to detect dependencies at each station. Except for the Bucakkışla station, all the EMB streamflow stations (Karahacılı, Alaköprü, Hamam, and Kızılgeçit) are serially dependent according to a 95% significance level (Figure 2). The maximum autocorrelation coefficient is calculated at the Kızılgeçit streamflow station located on the Göksu River.









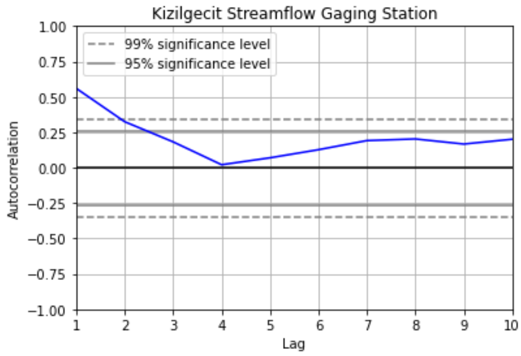


Figure 2. The autocorrelation coefficients of the streamflow gaging stations of the East Mediterranean Basin, Türkiye.

For annual streamflow values, Karahacılı, Hamam, Kızılgeçit, and Bucakkışla stations exhibit crucial decreasing trends. The absolute z values calculated by MK, MK-SSE, and MK-ITA exceed 2.57, indicating significance at the 99% confidence level (see Table 2). The Alaköprü station has important decreasing trends (z=-2.36 and z=-2.49) on annual streamflow values using MK and MK-ITA methods, although there is a crucial decreasing trend detected by MK-SSE (z=-2.87).

For autumn streamflow values, no significant trends are observed at the Karahacılı, Alaköprü, and Bucakkışla stations, whereas the Hamam and Kızılgeçit stations exhibit significant decreasing trends based on the MK, MK-SSE, and MK-ITA methods.

For winter streamflow values, crucial decreasing trends are observed at the Karahacılı, Hamam, and Kızılgeçit stations based on the MK, MK-SSE, and MK-ITA methods. At the Alaköprü station, a decreasing trend have been identified (z<-1.65), whereas the Bucakkışla station showed an important decreasing trend (z < -2.17) confirmed by all three methods: MK, MK-SSE, and MK-ITA.

For spring streamflow values, crucial decreasing trends are evident at Karahacılı, Hamam, Kızılgeçit, and Bucakkışla stations (z < -2.58), while an important decreasing trend is also observed at the Alaköprü stations (z < -2.17), based on the MK, MK-SSE, and MK-ITA methods.

For summer streamflow values, crucial decreasing trends are observed at the Hamam, Kızılgeçit, and Bucakkışla stations, as indicated by the MK, MK-SSE, and MK-ITA methods. At Karahacılı station, the MK and MK-ITA methods reveal decreasing trends (z < -1.74), while the MK-SSE indicates an important decreasing trend (z < -2.11). At the Alaköprü station, significant decreasing trends are detected by the MK-SSE and MK-ITA methods (z < -2.69), whereas the MK method shows an important decreasing trend (z = -2.50).

Table 2. The application of the MK, MK with Şen's slope, and MK with Şen's ITA to the East Mediterranean Basin, Türkiye.

	Stations	Mann-Kendall		Mann-Kendall with Sen's slope			Mann-Kendall with Şen's ITA		
		Z_{MK} (Eq.5)	Decision	S_{SSE} (Eq. 7)	Z_{SSE} (Eq. 9)	Decision	S_{ITA} (Eq.10)	Z_{ITA} (Eq. 13)	Decision
Annual	Karahacılı	-4.16	Crucial decreasing trend (CDT)	-1.212	-4.32	Crucial decreasing trend (CDT)	-1.206	-4.32	Crucial decreasing trend (CDT)
	Hamam	-4.50	CDT	-0.506	-4.60	CDT	-0.473	-4.59	CDT
	Kızılgeçit	-4.24	CDT	-0.080	-4.67	CDT	-0.073	-4.63	CDT
	Alaköprü	-2.36	Important decreasing trend (IDT)	-0.200	-2.87	CDT	-0.120	-2.49	Important decreasing trend (IDT)
	Bucakkışla	-3.15	CDT	-0.300	-3.20	CDT	-0.288	-3.16	CDT
Autumn	Karahacılı	-0.91	No trend	-0.106	-0.91	No trend	-0.303	-1.23	No trend
	Hamam	-5.59	CDT	-0.182	-5.55	CDT	-0.200	-5.58	CDT
	Kızılgeçit	-6.06	CDT	-0.054	-7.24	CDT	-0.052	-7.21	CDT
	Alaköprü	-1.05	No trend	-0.031	-1.01	No trend	-0.006	-1.13	No trend
	Bucakkışla	-1.47	No trend	-0.029	-1.49	No trend	-0.042	-1.49	No trend
Winter	Karahacılı	-2.96	CDT	-1.343	-2.99	CDT	-1.562	-2.98	CDT
	Hamam	-2.88	CDT	-0.456	-2.93	CDT	-0.436	-2.90	CDT
	Kızılgeçit	-3.71	CDT	-0.045	-4.09	CDT	-0.041	-3.97	CDT
	Alaköprü	-1.83	Decreasing trend (DT)	-0.242	-1.88	Decreasing trend (DT)	-0.136	-1.67	Decreasing trend (DT)
	Bucakkışla	-2.14	IDT	-0.294	-2.24	IDT	-0.400	-2.17	IDT
Spring	Karahacılı	-4.57	CDT	-2.730	-4.60	CDT	-2.730	-4.60	CDT
	Hamam	-3.63	CDT	-0.962	-3.79	CDT	-0.974	-3.81	CDT
	Kızılgeçit	-2.87	CDT	-0.125	-2.83	CDT	-0.124	-2.83	CDT
	Alaköprü	-2.17	IDT	-0.282	-2.34	IDT	-0.204	-2.28	IDT
	Bucakkışla	-2.58	CDT	-0.610	-2.58	CDT	-0.602	-2.58	CDT
Summer	Karahacılı	-1.74	DT	-0.297	-2.11	IDT	-0.231	-1.91	DT
	Hamam	-5.98	CDT	-0.263	-6.13	CDT	-0.282	-6.16	CDT
	Kızılgeçit	-5.04	CDT	-0.075	-5.30	CDT	-0.073	-5.25	CDT
	Alaköprü	-2.50	IDT	-0.126	-2.69	CDT	-0.134	-2.74	CDT
	Bucakkışla	-4.49	CDT	-0.100	-4.42	CDT	-0.108	-4.46	CDT

4. DISCUSSION

Annual, winter, spring, and summer streamflow values exhibit decreasing trends accros all stations within the East Mediterranean Basin. The MK, MK-SSE, and MK-ITA methods cannot detect any trend in autumn streamflow values at Karahacılı, Alaköprü, and Bucakkışla stations. ITA graphics for these streamflow values are plotted, where the red and green lines represent a -10% decreasing and +10% increasing trend lines (see Figure 3). The black line represents a trendless case, and the yellow line is the trend slope line for the scatter points (blue dots). The scatter points for Karahacılı and Bucakkışla stations' autumn streamflow values are under the trendless line, which represents a monotonically decreasing trend. However, Alaköprü station autumn flow values, represented by blue scattering points, are distributed over the trendless line, and thus, there is no monotonic trend on these values.

Berhail et al. [35] analyzed rainfall trends in the Macta basin using Sen's slope estimator, Şen's ITA, and MK methods. They found severe drought conditions in the northern part of the Mediterranean basin, and their findings are consistent with the results of this study. Dabanli et al., [36] also found positive trends in seawater temperatures on the Mediterranean coasts. There are gradually increasing meteorological and agricultural droughts in the Macta watershed near the Mediterranean Sea [37].

This study identified a decline in streamflow trends within the EMB, particularly during the spring and summer months. These results reflect broader hydrological concerns on a regional scale. The observed decline in flows may be indicative of more severe or protracted drought events, a finding that aligns with the observations made in the adjacent Euphrates Basin, where a strong correlation was identified between drought duration and severity [38]. However, it should be noted that drought characteristics can vary significantly between regions. Index-based studies in the Yeşilırmak Basin identified substantial trends, primarily at shorter 1- and 3-month timescales, contrasting with the showed annual and seasonal streamflow declines observed in the EMB [13]. While the hybrid MK methods detected clear trends, other research suggests that innovative graphical methods such as ITA/IPTA may be more sensitive than standard MK tests, potentially revealing additional nuances in the data [14]. It is evident that the outcomes of trend analysis for streamflow can vary depending on the analytical method applied. Conversely, consistent regional increases in temperature have been identified as a contributing factor to the hydrological shifts observed across the EMB [15]..

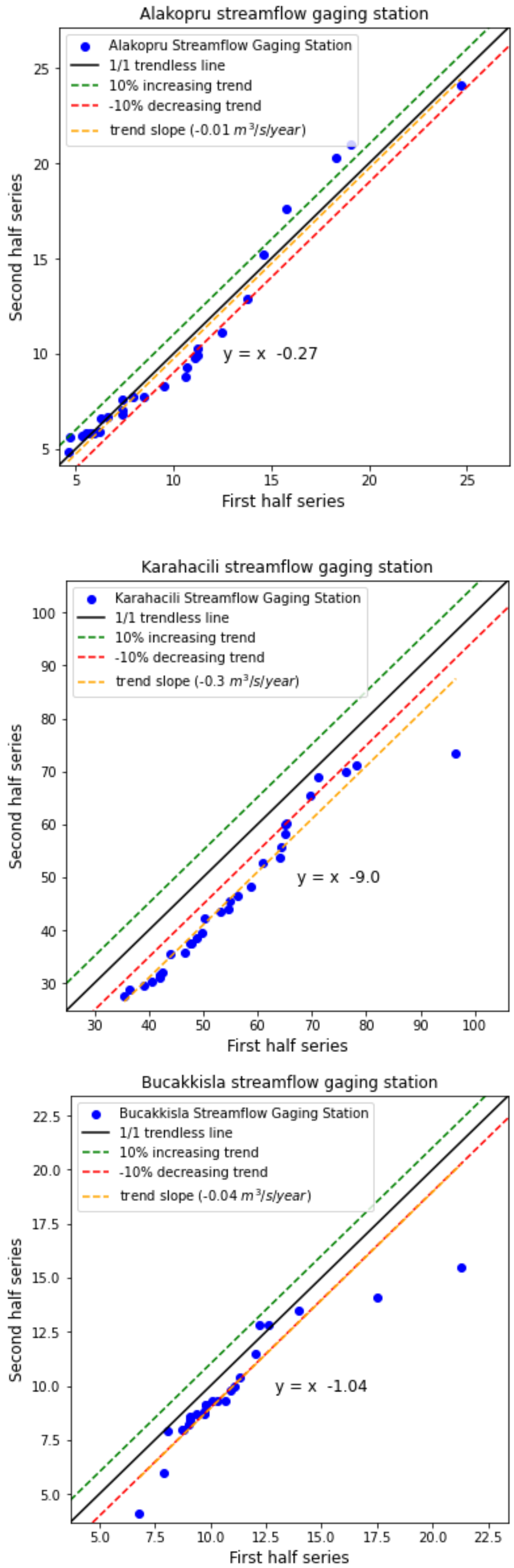


Figure 3. ITA graphs of autumn flow values at Eastern Mediterranean Basin stations, Türkiye.

5. CONCLUSION

The results were derived from carefully examining streamflow data from ten sub-basins in the EMB, considering the importance of serial dependence in hydro-meteorological series.

- The MK method yields consistent results with Şen's ITA and Sen's slope estimator.
- The comprehensive application of the MK test, along with Sen's Slope Estimator and Şen's ITA, has successfully demonstrated a uniformity in identifying decreasing streamflow trends, with annual reductions at critical stations like Karahacılı and Hamam, where trend z-scores of -4.16 and -4.50 respectively underscore the severity of hydrological decline.
- During the spring and summer seasons, which are critical for agricultural activities, the methods have detected significant decreases in streamflow at various stations.
- At Karahacılı, for instance the streamflow exhibited a z-score drop as severe as -4.57, reflecting the considerable seasonal impact on water resources.
- Consistently across the EMB, our enhanced trend analysis methods have highlighted a notable consistency in results, with significant declines in both the spring and summer seasons at stations like Hamam, where z-scores reached -6.16,
- Although no decreasing trends in spring flow values at Karahacılı, Alaköprü, and Bucakkışla stations have been detected employing the MK, hybrid MK-SSE, and MK-ITA methods, visual inspection reveals decreasing trends at Karahacılı and Bucakkışla stations.
- Consequently, the streamflow values in the EMB generally exhibit crucial declining trends. Therefore, future policymakers and designers in the same study area should consider the results of this paper in their planning and decision-making processes.

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Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics

There are no ethical issues with the publication of this manuscript.

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