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Trend Analysis of the Flow and Water Quality Data for the Broad River Basin, South Carolina, USA

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Abstract: Water quality is vital for human health and the protection of natural ecosystems, and demand for quality water is increasing day by day. It is known that changes in precipitation and temperature patterns due to climate change directly or indirectly affect water quantity and quality. In order to understand the potential effects of climate change on water resources, it is very important to know the changes in flow and water quality data over time. Trend analysis methods are the most used methods for this purpose. In this study, monthly, seasonal, and annual changes of dissolved oxygen (DO), water temperature (WT), discharge (Q), and specific conductance (SC) parameters, which are measured and recorded daily between 1987 and 2022 at four monitoring stations in the Broad River Basin (South Carolina, USA), were investigated using the Mann-Kendall test and innovative trend analysis (ITA) methods. Electrical conductivity (EC) values, calculated by considering SC and WT data, were considered. The Mann-Kendall test and ITA identified significant trends in 32.4 and 64.6% of the 272-time series analysed, respectively. It was determined that ITA was more sensitive in identifying decreasing trends. While the spatially and temporally varying trends in the river DO concentration and EC values were associated with human activities, it was concluded that the increasing trends in WT values and decreasing trends in Q values may be due to climate change on precipitation and air temperature parameters. This study, based on long-term data sets, illuminates the global concerns about the impacts of climate change on water quality and provides important findings that will guide sustainable management of water resources and measures to be taken against climate change. It is the first study to examine long-term trends of water quality parameters for the basin.

Keywords: Broad River, innovative trend analysis, Mann-Kendall test, water quality

Broad Nehri Havzası, için Akış ve Su Kalitesi Verilerinin Trend Analizi, Güney Karolina, ABD

Öz: Su kalitesi, insan sağlığı ve doğal ekosistemlerin korunması bakımından hayati öneme sahip olup, kaliteli suya olan ihtiyaç her geçen gün artmaktadır. İklim değişikliği sebebiyle yağış ve sıcaklık rejimlerinde meydana gelen değişimlerin su miktarını ve kalitesini doğrudan veya dolaylı olarak etkilediği bilinmektedir. İklim değişikliğinin su kaynakları üzerindeki potansiyel etkilerinin anlaşılabilmesi için akım ve su kalitesi verilerinin zaman içerisindeki değişimlerinin bilinmesi oldukça önemlidir. Trend analizleri bu amaçla en çok kullanılan yöntemlerdir. Bu çalışmada, Broad Nehri Havzası'nda (Güney Carolina, ABD) seçilen dört gözlem istasyonunda 1987-2022 yılları arasında günlük olarak ölçülmüş ve kaydedilmiş çözünmüş oksijen (DO), su sıcaklığı (WT), debi (Q) ve özgül iletkenlik (SC) parametrelerinin aylık, mevsimlik ve yıllık değişimleri Mann-Kendall testi ve yenilikçi eğilim analizi (ITA) yöntemleri kullanılarak araştırılmıştır. Çalışmada SC ve WT verileri dikkate alınarak hesaplanan elektriksel iletkenlik (EC) değerleri kullanılmıştır. Analiz edilen 272 zaman serisinin %32.4'ünde Mann-Kendall testi, %64.6'sında ise ITA yöntemi anlamlı eğilimler belirlemiştir. ITA yöntemi azalan eğilimleri belirlemede daha hassas olduğu tespit edilmiştir. DO konsantrasyonları ve EC değerlerindeki mekâna ve zamana bağlı olarak değişiklik gösteren eğilimler insani faaliyetler ile ilişkilendirilirken, WT değerlerindeki artma ve Q değerlerindeki azalma eğilimlerinin iklim değişikliğinin yağış ve hava sıcaklığı parametreleri üzerindeki etkilerinden kaynaklanabileceği sonucuna varılmıştır. Uzun süreli veri setlerine dayanan bu çalışma iklim değişikliğinin su kalitesi üzerindeki etkilerine dair küresel endişelere ışık tutmakta ve su kaynaklarının sürdürülebilir yönetimi ve iklim değişikliğine karşı alınacak önlemler konusunda rehberlik edecek önemli bulgular sunmaktadır.

Anahtar Kelimeler: Broad Nehri, yenilikçi eğilim analizi, Mann-Kendall testi, su kalitesi

1. Introduction

Since the Industrial Revolution, rapidly increasing fossil fuel use, deforestation and other human activities have caused greenhouse gases to accumulate in the atmosphere, causing temperatures to rise worldwide. Climate changes are occurring in the world due to global warming. Since climate is one of the main factors controlling the hydrological cycle, climate changes affect the hydrological cycle and therefore water resources (Kundzewicz, 2008). Recent studies have shown that there are significant changes in precipitation and flow patterns worldwide (Da Silva et al., 2015). The effects of these changes on water quality have also become an important research topic, as increasing temperatures and changing precipitation patterns can directly affect water resources. In order to understand the potential effects of climate change and to effectively plan and manage water resources, it is of great importance to know the changes in hydrometeorological and water quality data over time. Trend analysis is used to determine these changes.

Trend analyses are defined as statistical methods used to detect long-term changes in time series data monitored and recorded at specific intervals. These analyses are widely applied in various disciplines, including climate science, economics, and engineering. Trend analyses enable to identify irregularities in hydrological processes and to make estimations for the future (Aytekin, 2012). In recent years, due to missing data, seasonality, and skewed distributions in time series data, non-parametric methods have been increasingly used in trend analyses (Partal & Kahya 2002; Dabanlı, 2017). These methods are typically based on the ranking of data or the differences between ranked data sets (Garcia et al., 2010). In climate science, trend analyses of data such as air temperature, precipitation, discharge, and water quality play a crucial role in understanding the impacts of climate change, and how these effects evolve over time. Various studies have been conducted using different trend analysis methods. Non-parametric methods such as the Mann-Kendall test (Agbo et al., 2023; Gaddikeri et al., 2024; Likinaw et al., 2023), Spearman's Rho test (Swain et al., 2022; Vani et al., 2023), Şen's trend slope (Collaud Coen et al., 2020; Jin et al., 2021), and innovative trend analysis (ITA) (Hirca & Eryilmaz Turkkan, 2022; Tadesse et al., 2024) are commonly employed in literature. Furthermore, various parameters such as air temperature (Acar et al., 2022; Hadi & Tombul, 2018), precipitation (Da Silva et al., 2015; Koruk et al., 2023), evaporation (Javed et al., 2019; Salami et al., 2014), streamflow (Diop et al., 2018; Rogers et al., 2020), humidity (Nourani et al., 2018; Phuong et al., 2020), water temperature (Duy et al., 2022; Ouyang et al., 2021), dissolved oxygen concentration (Hashim et al., 2021; Jamian et al., 2017), hydrogen ion concentrations (Kisi & Ay, 2014), and electrical conductivity (Salvai et al., 2022; Sattari et al., 2020) have been examined.

As in the studies given above, it is important to have long-term data in order to apply trend analysis methods. The Broad River Basin, one of the sub-basins of the Santee River Basin (South Carolina, USA), has long-term monitored flow and water quality data. The basin hosts various industrial facilities, ranging from textile factories to hydropower plants. Despite the implementation of several conservation programs to address environmental threats such as increasing pollution and habitat loss, and the abundance of available monitoring data, studies focusing on water quality in the basin are quite limited. Nacar et al. (2020) modeled surface water quality using the recorded data from two monitoring stations operated in the basin. They concluded that the developed models could estimate the river DO concentrations very close to in situ measurements. Ureta et al. (2020) examined the sediment retention capacity and water yield potential of different land covers. They stated that vegetated areas provide the highest sediment retention capacity and the lowest water yield potential and prevents possible pollution and siltation of streams. Nabi et al. (2021) analysed the effects of rainfall on titanium dioxide (TiO_2) concentrations in the surface waters. They concluded that urban runoff is a major source of TiO_2 engineered particles to urban rivers, and TiO_2 engineered particles, which have high concentrations, may pose environmental risks during and following rainfall events. Maxwell et al. (2022) investigated baseflow levels and found a long-term increase in baseflow over the past millennium. In the literature review conducted by the authors, no trend analysis study on water quality variables was found.

The motivation for this study is the availability of long-term flow and water quality data in the Broad River Basin, coupled with the absence of studies applying trend analysis methods in this basin. Despite the extensive data set, the spatial and temporal variations of dissolved oxygen (DO), water temperature (WT), discharge (Q), and specific conductance (SC) have not been fully explored. This study addresses this gap by applying the Mann-Kendall test and ITA methods to evaluate relevant parameters at four flow and water quality monitoring stations in the basin, operated by the United States Geological Survey (USGS). This study aims to provide new insights into the basin's flow and water quality trends, contributing to a better understanding of the potential impacts of climate change and human activities on the water resources of the region.

There are four main sections in this study. The second section covers the study area, monitoring data, and methods. Results and discussions are presented in the third section, and the final section provides the study's conclusions.

2. Materials and Methods

2.1 Study Area and Monitoring Data

With a surface area of approximately 9.6×10⁶ km², the United States of America (USA) is one of the largest countries in the world. This vast and geographically diverse area encompasses various climate types and water resources. The USA has a complex and extensive network of rivers that are vital to ecosystem health, agriculture, industry, drinking water supply, and recreation. However, changes in precipitation patterns, increasing temperatures, glacial melting, an increase in extreme weather events, and water quality degradation due to climate change pose significant threats to water resources (Schwartz & Randall, 2003). To facilitate the identification, development, and utilization of water resources, the USA is divided into 21 hydrologic regions based on geographic features, climate conditions, and water resource distribution (Santhi et al., 2008). Monitoring studies within these hydrologic regions are conducted by the USGS. These data are critical for water resource management, flood forecasting, water quality monitoring, and environmental research. Thousands of monitoring stations are operated by the USGS across the country, and the collected data are used to ensure the sustainable management of water resources and to study the impacts of climate change.

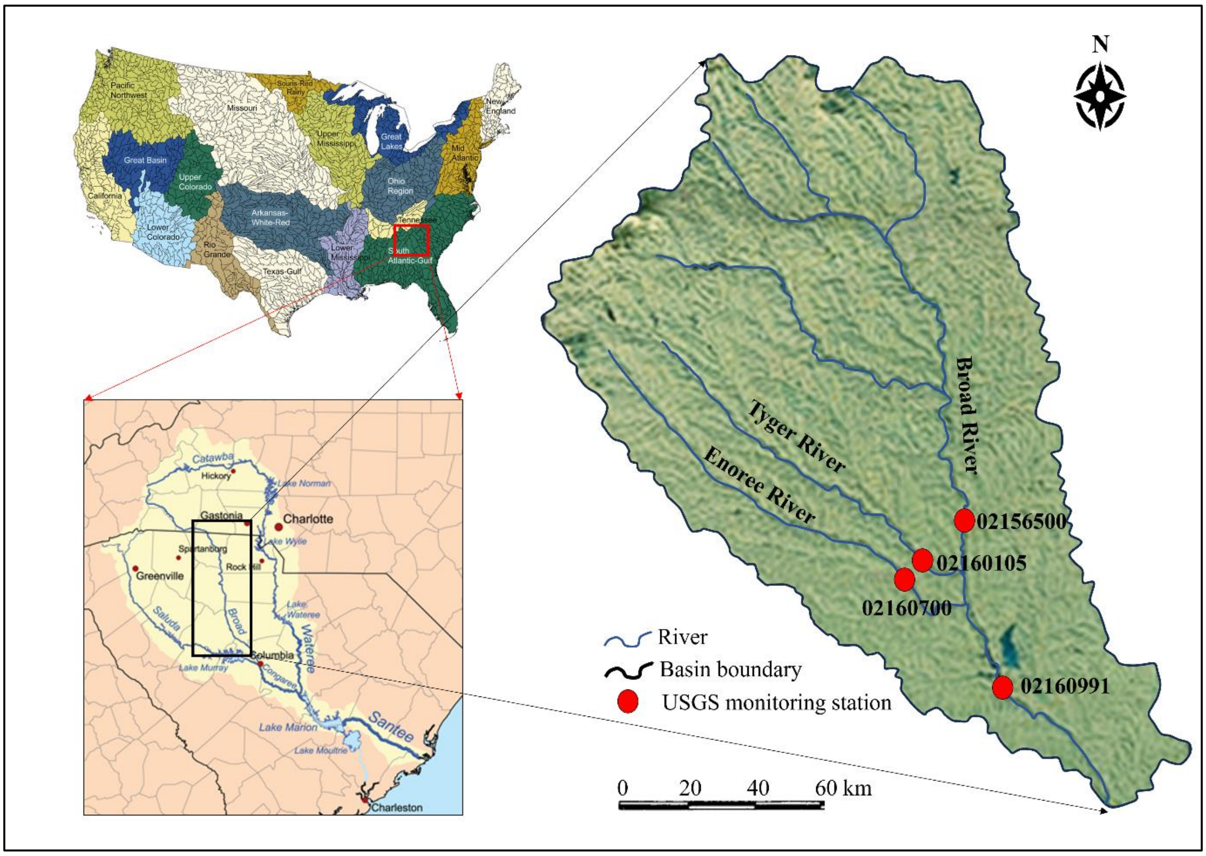

Figure 1. Flow and water quality monitoring stations, Broad River Basin, South Carolina, USA
Şekil 1. *Akım ve su kalitesi gözlem istasyonları, Broad Nehri Havzası, Güney Carolina, ABD*

The Broad River, one of the rivers in the South Atlantic-Gulf Region, originates from the eastern slope of the Blue Ridge Mountains in southwestern North Carolina (approximately 1,219 m) and flows southeastward into South Carolina. The First Broad, Second Broad, Pacolet, Tyger, and Enoree are tributaries of the Broad River (Figure 1). The First and Second Broad rivers are entirely located in North Carolina, and join the Broad River before entering South Carolina. The Broad River Basin covers an area of 9,819 km² within the borders of South Carolina. Approximately 79% of the basin is forest, pastures and row crops are found in approximately 4% and 6% of the total area, respectively. The basin has a temperate climate (Navar et al., 2019; Raschke et al., 1975).

There are 21 monitoring stations in operation, ten of which on the Broad River, five of which on the Pacolet River, two of which on the Tyger River, and five of which on the Enoree River by the South Atlantic Water Science Center in the Broad River Basin. For time series analysis, considering periods of 30 years or more is sufficient for obtaining a valid statistic (Akçay, 2018). Upon review of the stations, therefore, four stations having more than 30 years of simultaneous discharge and various water quality monitoring data, 02156500 (upstream) and 02160991 (downstream) on the Broad River, 02160105 on the Tyger River, and 02160700 on the Enoree River. For each station, daily DO, WT, Q, and SC data for the period between 1987 and 2022 were downloaded from the USGS website. Upon examination of the data, missing values were found to be less than 10%. Missing data were completed using the missForest package in R. Instead of SC data, electrical conductivity (EC) values calculated based on SC and WT data were used.

Trend analyses were conducted based on the monthly, seasonal, and annual mean values of the monitoring data. The basic statistics for the data used from each monitoring station are given in Table 1. S_x, C_s, and C_k are standard deviation, skewness coefficient, and kurtosis coefficient, respectively. C_s and C_k indicate abnormal variation in a statistical series and the values between –1.96 and 1.96 are considered normal by Field (2009). Considering the C_s and C_k values in Table 1, it is seen that the Q data for all stations and the EC data for the USGS 02158500 station show a kurtosis. Explanations of the Mann-Kendall test and ITA methods used in the study are presented under the subsections 2.2. and 2.3., respectively.

Table 1. Basic statistics for monthly mean values of discharge and water quality data in the Broad River Basin, South Carolina, USA

Çizelge 1. *Broad Nehri Havzası (Güney Carolina, ABD) akım ve su kalitesi verilerinin aylık ortalama değerlerine ait temel istatistikler*

USGS station no	Parameter	X_{min}	X_{mean}	X_{max}	S_x	C_s	C_k
02156500	DO	5.22	9.04	13.67	1.81	0.24	–1.12
	WT	4.02	17.86	30.73	7.81	–0.02	–1.41
	Q	10.60	95.23	355.41	66.99	1.45	1.97
	EC	34.48	85.75	263.62	37.06	1.58	3.38
02160105	DO	5.50	8.95	12.70	1.60	0.34	–1.13
	WT	3.70	17.00	28.90	7.20	–0.04	–1.39
	Q	2.10	22.77	100.40	17.64	1.51	2.27
	EC	32.30	84.65	235.80	30.26	1.03	1.60
02160700	DO	6.10	8.92	12.80	1.60	0.34	–1.14
	WT	3.90	16.97	28.60	7.07	–0.04	–1.38
	Q	1.90	13.95	58.80	10.34	1.57	2.50
	EC	35.90	81.76	186.60	28.08	0.85	0.42
02160991	DO	4.80	8.20	12.10	1.84	0.14	–1.22
	WT	5.50	18.96	30.30	7.29	–0.05	–1.41
	Q	16.80	146.52	610.50	111.90	1.53	2.26
	EC	42.30	82.21	147.70	21.85	0.50	–0.23

X_{min}: minimum, X_{mean}: mean, X_{max}: maximum, S_x: standard deviation, C_s: skewness coefficient, and C_k: kurtosis coefficient

DO: mg/L, WT: °C, Q: m^3/s, and EC: µS/cm

2.2. Mann-Kendall Test

The Mann-Kendall test (Mann,1945; Kendall, 1975) is the most applied non-parametric method in trend analysis studies. The test checks for unidirectional (increasing or decreasing) trends in the data set using the two-way null hypothesis H_0 (no trend) and the alternative hypothesis H_1 (Othman et al., 2016). When applying the Mann-Kendall test, the data are ordered chronologically. The S statistic is calculated using Eqs. (1)-(2), in which n is the number of data, x_i and x_j are the data values at time i and j, respectively.

When the number of data is greater than 10, the variance of S is calculated using Eq. (3), in which p is the number of linked groups and t_i is the number of times a data value occurs. After the variance of the series is calculated, the standard normal Z value is obtained using Eq. (4).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n-1} sgn(x_j - x_i) \tag{1}$$

$$sgn(x_j - x_i) = \begin{cases} 1 & ; \quad x_j > x_i \\ 0 & ; \quad x_j = x_i \\ -1 & ; \quad x_j < x_i \end{cases} \tag{2}$$

$$Var(S) = \frac{\left[n(n-1)(2n+5) - \sum_{i=1}^{p} t_i\,(t_i - 1)(2t_i + 5)\right]}{18} \tag{3}$$

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & , \quad S > 0 \\ 0 & , \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & , \quad S < 0 \end{cases} \tag{4}$$

If the absolute value of the calculated Z is greater than the critical z value corresponding to the specified confidence interval, it indicates the presence of a significant trend. Otherwise, it is accepted that there is no significant trend. A positive test statistic indicates an increasing trend, while a negative test statistic indicates a decreasing trend. In this study, a confidence interval of 95% was considered, and therefore the critical z value was determined as 1.96.

2.3. Innovative Trend Analysis

The ITA methodology, developed by Sen (2012) to evaluate climatic trends, is used to examine changes between consecutive time series. Since this method does not require any assumptions, it can be applied to all data series, regardless of whether they exhibit internal dependency (Dabanlı, 2017). When applying the method, the time series for which the trend is to be determined is first divided into two parts, and each half-series is sorted in ascending order. Then, a scatter plot is created, with the values of the first half-series on the x-axis and the values of the second half-series on the y-axis. The 45° trend line is added to the scatter plot. The location of the data points relative to the trend line determines the trends in the data. If the data points lie on or close to the 45° trend line, this indicates that there is practically no trend in the series. Data points located in the triangular area above the 45° trend line indicate an increasing trend, while those in the triangular area below the line indicate a decreasing trend. In cases where the scatter points are very close to the 45° trend line, the relative error (%) between the means of the two half-series is considered an important trend indicator to prevent misinterpretations from visual assessment (Sen, 2020). This value is calculated using Eq. (5).

$$\alpha = \left|\frac{\bar{X}_1 - \bar{X}_2}{\bar{X}_2}\right| \times 100 \tag{5}$$

In Eq. (5), α, $\bar{X}_1$ and $\bar{X}_2$ represent the relative error (%), arithmetic means of the first and second half-series, respectively. In practical applications, when $\alpha < 5\%$ the time series shows no significant trend. When $\alpha > 5\%$, if $\bar{X}_1 > \bar{X}_2$, the time series shows a decreasing trend, and if $\bar{X}_1 < \bar{X}_2$, it shows an increasing trend.

3. Results and Discussions

The Mann-Kendall test and ITA were performed using MATLAB 2020b software. A significance level of 5% was considered to evaluate of analysis results of DO, WT, Q, and EC data. The trend analysis results for the monthly, seasonal, and annual means of discharge and water quality data based on the Mann-Kendall test are presented in Table 2.

For the Broad River (upstream), DO concentrations showed an increasing trend in Jan, Feb, Jul, Sep, Nov, and Dec, while WT values have an increasing trend in Apr, Jun, Sep, and Oct. A decreasing trend in EC values was detected only in Aug. Additionally, WT values showed increasing trends in all seasons, while DO concentrations have increasing trends in all seasons except for Spr. No significant annual trends were detected, except for the increasing trends in DO concentrations and WT values.

For the Tyger River (tributary), a decreasing trend was found in Q values only in Mar. There was an increasing trend in DO concentrations in Aug, Sep, and Nov and WT values in all months except Jan, Feb, Mar, and Nov. In addition, it was determined that WT values had increasing trends in all seasons and DO concentrations had increasing trends in Sum and Aut. No significant trends were found for other parameters and periods. Except for the increasing trends in DO concentrations and WT values, no significant trends were detected annually.

For the Enoree River (tributary), a decreasing trend was detected in Q values only in Mar. WT values showed an increasing trend in all months except Jan, Feb, Mar, and Nov, while EC values had an increasing trend except in Aug and Dec. Seasonally, EC values showed an increasing trend in all seasons, while WT values have increasing trends in all seasons except Win. Annually, no significant trends were observed in DO and Q values, but increasing trends were detected for WT and EC values. No significant increasing or decreasing trends were found for DO concentrations in any period.

For the Broad River (downstream), Q values showed a decreasing trend in Mar, but no significant trends were observed in other months. EC values have a decreasing trend in Aug and Sep. Seasonally, no significant trends were detected except for EC values, which has a decreasing trend in the Aut, while the annual EC values also showed a decreasing trend. WT values showed an increasing trend for all months, except for Feb, Nov, and Dec. No significant increasing or decreasing trends were detected for DO concentrations on a monthly, seasonal, or annual basis.

The α values of monthly, seasonal, and annual trend analyses of discharge and water quality data according to the ITA method are given in Table 3, in which negative values mean decreasing trend while positive values mean increasing trend. For each station, 68 data series (four parameters and 17 time periods) were analysed, and an increasing trend was found for DO (20.6%), WT (41.2%), Q (8.7%), and EC (27.9%). Additionally, a decreasing trend was detected for Q (70.6%) and EC (51.5%).

Table 2. The Mann-Kendall test Z values of monthly, seasonal, and annual means of discharge and water quality data for the Broad River Basin, South Carolina, USA

Çizelge 2. *Broad Nehri Havzası (Güney Carolina, ABD) debi ve su kalitesi verilerinin aylık, mevsimlik ve yıllık ortalamalarının Mann-Kendall testi Z değerleri*

Parameter	Period	USGS 02156500	USGS 02160105	USGS 02160700	USGS 02160991	Parameter	Period	USGS 02156500	USGS 02160105	USGS 02160700	USGS 02160991
DO	Jan	***2.67***	0.49	0.89	–1.29	Q	Jan	–0.31	–0.98	–0.46	–0.67
	Feb	***3.36***	1.42	0.95	1.03		Feb	–0.29	–1.05	–0.49	–0.84
	Mar	1.65	0.51	0.15	0.70		Mar	–1.84	***–2.49***	***–2.10***	***–2.00***
	Apr	1.57	1.16	–0.44	–0.19		Apr	0.56	–0.22	0.08	0.08
	May	0.38	0.82	–1.95	–0.26		May	0.53	0.16	0.35	0.22
	Jun	1.21	0.54	–0.40	0.42		Jun	–0.20	–0.80	–0.25	–0.53
	Jul	***3.58***	1.59	–0.15	0.11		Jul	–0.34	–0.44	0.11	–0.64
	Aug	***2.98***	***2.60***	0.62	–0.03		Aug	–0.14	–0.48	0.10	–0.23
	Sep	***3.73***	***3.02***	1.93	0.42		Sep	–0.86	–1.85	–1.39	–1.09
	Oct	1.29	1.71	0.59	–0.64		Oct	–0.61	–1.74	–1.43	–1.10
	Nov	***3.62***	***2.91***	1.60	1.22		Nov	–0.22	–0.79	–0.46	–0.64
	Dec	***2.30***	–0.51	–0.14	0.56		Dec	0.64	0.12	0.50	0.12
	Win	***3.01***	1.38	0.38	–0.22		Win	–0.18	–0.91	–0.18	–0.64
	Spr	1.35	1.15	–0.53	0.23		Spr	–0.18	–1.05	–0.79	–0.83
	Sum	***3.06***	***2.13***	–0.04	0.30		Sum	–0.26	–0.86	–0.01	–0.45
	Aut	***4.48***	***3.18***	1.50	0.68		Aut	–0.53	–1.63	–1.02	–0.99
	Ann	***4.02***	***2.64***	0.46	0.42		Ann	–0.18	–1.27	–0.67	–0.83
WT	Jan	0.91	1.19	0.98	***2.43***	EC	Jan	–0.20	0.63	***3.42***	–0.34
	Feb	0.59	0.83	1.47	1.32		Feb	–0.15	0.71	***3.04***	–0.50
	Mar	1.65	1.88	1.70	***1.96***		Mar	0.50	1.17	***3.76***	0.01
	Apr	***2.19***	***2.84***	***3.10***	***2.81***		Apr	–0.97	–0.29	***2.70***	–0.94
	May	1.93	***3.15***	***3.34***	***2.54***		May	–1.65	–0.78	***2.57***	–1.48
	Jun	***2.49***	***3.83***	***3.76***	***3.40***		Jun	–1.19	–0.35	***2.93***	–1.83
	Jul	1.54	***3.26***	***3.37***	***2.65***		Jul	–0.99	–0.60	***2.13***	–1.27
	Aug	1.70	***3.33***	***3.20***	***2.58***		Aug	***–2.25***	–1.24	1.47	***–2.02***
	Sep	***2.66***	***3.85***	***4.46***	***2.96***		Sep	–1.48	0.07	***2.96***	***–2.32***
	Oct	***3.99***	***3.79***	***3.81***	***3.86***		Oct	–0.99	0.97	***4.09***	–1.46
	Nov	0.80	0.72	0.03	1.61		Nov	–1.38	–0.16	***2.63***	–1.89
	Dec	1.87	***2.18***	***1.99***	1.36		Dec	–1.04	–0.68	1.93	–1.48
	Win	***1.98***	***2.13***	1.79	***2.33***		Win	–0.20	0.53	***3.06***	–0.59
	Spr	***2.36***	***3.56***	***3.84***	***2.98***		Spr	–1.10	0.01	***3.09***	–1.13
	Sum	***2.30***	***4.21***	***4.48***	***3.28***		Sum	–1.65	–0.80	***2.34***	–1.92
	Aut	***3.61***	***3.94***	***3.58***	***3.54***		Aut	–1.10	0.45	***3.75***	***–1.98***
	Ann	***3.61***	***5.03***	***5.03***	***4.11***		Ann	–1.38	–0.18	***3.64***	***–2.04***

Bold italic: Significant trend for a confidence level of 95%
Critical z value is 1.96

Table 3. Relative error (%) values of innovative trend analysis for monthly, seasonal, and annual means of discharge and water quality data in the Broad River Basin, South Carolina, USA.

Çizelge 3. Broad Nehri Havzası (Güney Carolina, ABD) debi ve su kalitesi verilerinin aylık, mevsimlik ve yıllık ortalamalarının yenilikçi trend analizi yöntemi α değerleri

Parameter	Period	USGS 02156500	USGS 02160105	USGS 02160700	USGS 02160991	Parameter	Period	USGS 02156500	USGS 02160105	USGS 02160700	USGS 02160991
DO	Jan	***5.32***	1.80	1.85	–1.49	Q	Jan	–4.93	***–20.75***	***–8.94***	***–16.00***
	Feb	***7.50***	4.13	3.26	2.67		Feb	***–7.60***	***–28.44***	***–16.10***	***–20.33***
	Mar	4.90	2.06	1.24	3.00		Mar	***–36.11***	***–54.84***	***–43.40***	***–54.43***
	Apr	***6.19***	1.98	0.32	0.13		Apr	***–11.14***	***–26.39***	***–17.11***	***–26.19***
	May	3.94	2.44	–1.83	–0.58		May	2.40	***–10.80***	3.51	–3.05
	Jun	4.84	0.97	0.85	1.33		Jun	***–17.28***	***–21.51***	0.60	***–25.80***
	Jul	***7.34***	4.16	2.27	1.21		Jul	***6.37***	***–14.42***	1.80	***–5.37***
	Aug	***5.96***	4.48	0.78	–0.68		Aug	***–23.93***	***–71.26***	***–42.51***	***–39.21***
	Sep	***6.09***	4.04	2.89	0.96		Sep	***–46.90***	***–105.21***	***–70.11***	***–59.92***
	Oct	3.18	4.94	3.16	1.64		Oct	***–40.72***	***–80.06***	***–44.22***	***–54.74***
	Nov	***8.05***	***7.76***	4.27	2.71		Nov	***6.95***	***–6.34***	1.15	0.09
	Dec	4.53	0.25	0.05	0.56		Dec	***25.69***	***19.07***	***23.37***	***21.24***
	Win	***5.92***	2.34	1.74	0.75		Win	4.56	***–10.53***	–0.97	***–5.92***
	Spr	***5.05***	2.15	0.02	1.01		Spr	***–16.35***	***–33.38***	***–23.93***	***–30.64***
	Sum	***6.04***	3.19	1.29	0.66		Sum	***–11.24***	***–33.15***	***–11.26***	***–22.99***
	Aut	***5.90***	***–5.76***	3.51	1.87		Aut	***–20.89***	***–47.90***	***–28.13***	***–30.61***
	Ann	***5.67***	3.23	1.66	1.01		Ann	***–9.20***	***–26.90***	***–14.11***	***–20.31***
WT	Jan	***6.31***	***7.56***	***7.89***	***11.97***	EC	Jan	***–9.16***	2.06	***17.41***	***–10.62***
	Feb	0.70	1.46	3.83	***5.72***		Feb	–3.70	2.48	***18.06***	***–8.54***
	Mar	4.92	4.54	4.96	***6.30***		Mar	–0.09	***5.73***	***18.64***	–4.89
	Apr	4.54	4.71	***6.26***	4.87		Apr	***–9.02***	–0.22	***16.28***	***–8.55***
	May	3.09	4.94	***5.73***	2.93		May	***–13.47***	***–5.87***	***15.36***	***–11.30***
	Jun	***6.12***	***6.58***	***6.51***	3.96		Jun	***–12.58***	–3.83	***20.40***	***–12.73***
	Jul	2.34	4.02	3.56	2.39		Jul	***–14.23***	***–5.75***	***17.00***	***–12.55***
	Aug	3.52	4.47	4.40	3.39		Aug	***–23.18***	***–13.94***	***11.84***	***–15.07***
	Sep	***5.27***	***5.74***	***6.26***	4.56		Sep	***–20.20***	1.91	***22.74***	***–15.18***
	Oct	***7.61***	***7.54***	***7.47***	***6.89***		Oct	***–11.54***	***5.23***	***25.21***	***–13.53***
	Nov	0.25	–0.88	–2.75	3.80		Nov	***–16.29***	0.29	***18.37***	***–17.46***
	Dec	***10.83***	***14.76***	***13.54***	***7.17***		Dec	***–11.31***	–0.83	***14.58***	***–16.09***
	Win	***5.71***	***7.35***	***8.01***	***8.49***		Win	***–8.88***	1.50	***16.86***	***–12.30***
	Spr	4.02	4.76	***5.71***	4.42		Spr	***–8.15***	–0.69	***16.59***	***–8.48***
	Sum	3.95	***5.00***	4.79	3.23		Sum	***–16.95***	***–8.02***	***16.29***	***–13.49***
	Aut	4.98	4.92	4.72	***5.17***		Aut	***–16.20***	2.59	***22.40***	***–15.30***
	Ann	4.46	***5.26***	***5.43***	4.68		Ann	***–13.36***	–1.79	***18.21***	***–12.55***

Bold italic: Significant trend for a confidence level of 95%

The Mann-Kendall test and ITA results are presented comparatively for monthly, seasonal, and annual periods in Table 4, in which blue, red, and grey cells indicate increasing, decreasing, and no significant trend, respectively. According to the Table 4, it is seen that there are differences between the analysis results. In total, out of 272-time series (four stations, four parameters, and 17 time periods), significant trends were detected in 88 according to the Mann-Kendall test and in 154 according to the ITA. It identified numerous decreasing trends in Q and EC values, while the Mann-Kendall test mostly did not detect significant trends. This suggests that the ITA is more sensitive in detecting trends compared to the Mann-Kendall test (Achite et al., 2021; San et al., 2021).

The decreasing trends in Q values may be attributed to the effects of climate change. In the study conducted by Gentilucci et al. (2023) in the Upper Potenza Basin (Italy), it was stated that changes in precipitation due to climate change and evaporation losses caused by temperature increases were effective in the decreasing trend in the Q values of the river. The Mann-Kendall test identified more trends, particularly in WT values, compared to the ITA. This discrepancy is likely since the ITA evaluates the data, rather than separately for low, medium, and high values. Although the trends in WT values vary temporally, the increasing trends observed at all stations are likely related to rising air temperatures. This is supported by a study by Isaak et al. (2012), who found that WT in various streams in the northwestern USA were increasing due to rising air temperatures driven by climate change.

Table 4. Comparative results of trend analysis of discharge and water quality data from the Broad River Basin, South Carolina, USA

Çizelge 4. *Broad Nehri Havzası (Güney Carolina, ABD) için debi ve su kalitesi verilerinin trend analizlerinin karşılaştırmalı sonuçları*

USGS station no		02156500				02160105				02160700				02160991			
Method	Period	DO	WT	Q	EC	DO	WT	Q	EC	DO	WT	Q	EC	DO	WT	Q	EC
Mann-Kendall test	Jan	🟦	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟦	⬜	🟦	⬜	⬜
	Feb	🟦	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟦	⬜	⬜	⬜	⬜
	Mar	⬜	⬜	⬜	⬜	⬜	⬜	🟥	⬜	⬜	⬜	🟥	🟦	⬜	🟦	🟥	⬜
	Apr	⬜	🟦	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	⬜
	May	⬜	⬜	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	⬜
	Jun	⬜	🟦	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	⬜
	Jul	🟦	⬜	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	⬜
	Aug	🟦	⬜	⬜	🟥	🟦	🟦	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟦	⬜	🟥
	Sep	🟦	🟦	⬜	⬜	🟦	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	🟥
	Oct	⬜	🟦	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	⬜
	Nov	🟦	⬜	⬜	⬜	🟦	⬜	⬜	⬜	⬜	⬜	⬜	🟦	⬜	⬜	⬜	⬜
	Dec	🟦	⬜	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟦	⬜	⬜	⬜	⬜	⬜	⬜
	Win	🟦	🟦	⬜	⬜	⬜	🟦	⬜	⬜	⬜	⬜	⬜	🟦	⬜	🟦	⬜	⬜
	Spr	⬜	🟦	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	⬜
	Sum	🟦	🟦	⬜	⬜	🟦	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	⬜
	Aut	🟦	🟦	⬜	⬜	🟦	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	🟥
	Ann	🟦	🟦	⬜	⬜	🟦	🟦	⬜	⬜	⬜	🟦	⬜	🟦	⬜	🟦	⬜	🟥
Innovative trend analysis	Jan	🟦	🟦	⬜	🟥	⬜	🟦	🟥	⬜	⬜	🟦	🟥	🟦	⬜	🟦	🟥	🟥
	Feb	🟦	⬜	🟥	⬜	⬜	⬜	🟥	⬜	⬜	🟦	🟥	🟦	⬜	🟦	🟥	🟥
	Mar	⬜	⬜	🟥	⬜	⬜	⬜	🟥	🟦	⬜	🟦	🟥	🟦	⬜	🟦	🟥	⬜
	Apr	🟦	⬜	🟥	🟥	⬜	⬜	🟥	⬜	⬜	⬜	🟥	🟦	⬜	⬜	🟥	🟥
	May	⬜	⬜	⬜	🟥	⬜	⬜	🟥	🟥	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟥
	Jun	⬜	🟦	🟥	🟥	⬜	🟦	🟥	⬜	⬜	⬜	⬜	🟦	⬜	⬜	🟥	🟥
	Jul	🟦	⬜	🟦	🟥	⬜	⬜	🟥	🟥	⬜	⬜	⬜	🟦	⬜	⬜	🟥	🟥
	Aug	🟦	⬜	🟥	🟥	⬜	⬜	🟥	🟥	⬜	⬜	🟥	🟦	⬜	⬜	🟥	🟥
	Sep	🟦	🟦	🟥	🟥	⬜	🟦	🟥	⬜	⬜	⬜	🟥	🟦	⬜	⬜	🟥	🟥
	Oct	⬜	🟦	🟥	🟥	⬜	🟦	🟥	🟦	⬜	🟦	🟥	🟦	⬜	🟦	🟥	🟥
	Nov	🟦	⬜	🟦	🟥	🟦	⬜	🟥	⬜	⬜	⬜	⬜	🟦	⬜	⬜	⬜	🟥
	Dec	⬜	🟦	🟦	🟥	⬜	🟦	🟦	⬜	⬜	🟦	🟦	🟦	⬜	🟦	🟦	🟥
	Win	🟦	🟦	⬜	🟥	⬜	🟦	🟥	⬜	⬜	🟦	⬜	🟦	⬜	🟦	🟥	🟥
	Spr	🟦	⬜	🟥	🟥	⬜	⬜	🟥	⬜	⬜	⬜	🟥	🟦	⬜	⬜	🟥	🟥
	Sum	🟦	⬜	🟥	🟥	⬜	⬜	🟥	🟥	⬜	⬜	🟥	🟦	⬜	⬜	🟥	🟥
	Aut	🟦	⬜	🟥	🟥	🟦	⬜	🟥	⬜	⬜	🟦	🟥	🟦	⬜	🟦	🟥	🟥
	Ann	🟦	⬜	🟥	🟥	⬜	🟦	🟥	⬜	⬜	⬜	🟥	🟦	⬜	⬜	🟥	🟥

🟦 Increasing trend ⬜ No trend 🟥 Decreasing trend

4. Conclusions

In this study, monthly, seasonal, and annual trend analyses of discharge and water quality variables monitored in the Broad River Basin were carried out using the Mann-Kendall test and innovative trend analysis (ITA) methods, and the effects of climate change on the relevant variables were examined. A total of four monitoring stations, two of which on the main branch and the rest on the tributaries, were taken into consideration in the trend analyses. The results of the trend analyses performed using dissolved oxygen (DO), water temperature (WT), discharge (Q), and electrical conductivity (EC) data for the period 1987-2022 are given below.

Significant differences were observed in the detection of significant trends between the Mann-Kendall test and ITA methods. The Mann-Kendall test detected significant trends in 32.4% of the time series, while the ITA method detected significant trends in 64.6%. This suggests that different trend analysis methods used in similar studies may have important effects on the results and therefore, a comparative analysis of various methods would be useful.

Trend analyses reveal that there are increasing trends in WT data and decreasing trends in Q data in the basin. These trends could indicate potential challenges for water resources management in the basin. Additionally, decreasing Q indicates water scarcity and deterioration of water quality, while increasing WT may stress aquatic ecosystems, leading to issues such as reduced DO levels, altered species distribution, and habitat changes. It is thought that these trends may be related to the potential impacts of climate change.

The study contributes to the global discussion on the impacts of climate change on water quality, providing essential insights for sustainable water resource management. In order to carry out similar studies in the streams of Türkiye, long-term and continuous monitoring and data recording should be provided as a priority. Such systems are vital for informing climate change adaptation strategies and ensuring sustainable management of water resources in the future.

Methods and trends can be evaluated more comprehensively by applying current trend analysis methods as well as the Mann-Kendall test and ITA methods in examining the trends of flow and water quality data at the relevant stations in future further studies. In addition, it is thought that making scenario-based assessments and examining flow and water quality trends more comprehensively with future period estimated precipitation and temperature data may be the subject of another study. This will offer a more holistic view of the relationships between climate variables and river health.

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