Artvin Çoruh Üniversitesi
Doğal Afetler Uygulama ve Araştırma Merkezi
Doğal Afetler ve Çevre Dergisi

Artvin Çoruh University
Natural Hazards Application and Research Center
Journal of Natural Hazards and Environment

Araştırma Makalesi / Research Article, Doğ Afet Çev Derg, 2025; 11(1): 268–289, DOI: 10.21324/dacd.1577479

A Comparative Spatiotemporal Analysis for Long-Term Trends of Hydrometeorological Variables in Maritsa River Basin

Mehmet Seren Korkmaz[1,*], Kevser Merkür Başkesen[2], Ertuğrul Sunan[3]

[1]Samsun University, Özdemir Bayraktar Faculty of Aeronautics ve Astronautics, Dept. of Meteorological Engineering, 55420, Samsun.
[2]Basin Management, Monitoring and Allocations Branch, State Hydraulic Works (DSİ), 11th Regional Directorate,22100, Edirne.
[3]Samsun University, Özdemir Bayraktar Faculty of Aeronautics ve Astronautics, Dept. of Aercraft Maintenance, 55420, Samsun.

Abstract

Revealing long-term trends in hydrometeorological variables plays a critical role in the sustainable management and planning of water resources. These analyses are necessary to understand climate change impacts, taking precautions for natural disasters, plan agricultural activities, and develop water management strategies. The aim of this study is to examine the changes in monthly and annual total precipitation and evapotranspiration values in the Maritsa River Basin, a transboundary water basin between Bulgaria, Greece, and Türkiye. For this, precipitation values for the 1982-2023 water years were taken from the Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) data set, and evapotranspiration values for the 1982-2023 water years were taken from the European Reanalysis 5th Generation-Land (ERA5-Land) data set. The Mann-Kendall, Sen's slope estimator, and Innovative Trend Analysis (ITA) methods were used to determine trends. According to the test results, there is a statistically significant increase in annual total precipitation values within the 95% confidence interval and in annual total evapotranspiration values within the 99% confidence interval. Specifically with all three methods positive and statistically significant trends are observed in precipitation in October, January, May and June. In the monthly evapotranspiration trend analysis, a statistically significant increase is observed except for November, December, June and July. Trend increases were visualized using the graphical method ITA. Significant increasing trends in both monthly and annual precipitation and evapotranspiration reveal changes in the hydrological cycle of the basin. The test results can be used in planning and solving problems related to the basin area.

Keywords
Maritsa River Basin, Precipitation, Evapotranspiration, Trend Analysis, Climate Change

Meriç Nehir Havzası'ndaki Hidrometeorolojik Değişkenlerin Uzun Dönem Eğilimleri için Karşılaştırmalı Mekansal ve Zamansal Analizi

Özet

Hidrometeorolojik değişkenlerdeki uzun dönem eğilimleri ortaya çıkarmak, su kaynaklarının sürdürülebilir yönetimi ve planlamasında kritik bir rol oynar. Bu analizler, iklim değişikliğinin etkilerini anlamak, doğal afetler için önlemler almak, tarımsal faaliyetleri planlamak ve su yönetim stratejilerini geliştirmek için gereklidir. Bu çalışmanın amacı, Bulgaristan, Yunanistan ve Türkiye arasında sınır aşan bir su havzası olan Meriç Nehri Havzası'ndaki aylık ve yıllık toplam yağış ile evapotranspirasyon değerlerindeki değişimleri incelemektir. Bu amaçla, 1982-2023 su yılları için yağış değerleri "Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS)" veri setinden, evapotranspirasyon değerleri ise "European Reanalysis 5th Generation-Land (ERA5-Land)" veri setinden alınmıştır. Eğilimlerin belirlenmesi için Mann-Kendall, Sen'in eğim tahmini ve Yenilikçi Eğilim Analizi (ITA) yöntemleri kullanılmıştır. Test sonuçlarına göre, yıllık toplam yağış değerlerinde %95 güven aralığında ve yıllık toplam evapotranspirasyon değerlerinde %99 güven aralığında istatistiksel olarak anlamlı bir artış görülmektedir. Özellikle 3 yöntemde de Ekim, Ocak, Mayıs ve Haziran aylarında yağışlarda pozitif ve istatistiksel olarak anlamlı eğilimler gözlemlenmiştir. Aylık evapotranspirasyon eğilim analizinde ise Kasım, Aralık, Haziran ve Temmuz ayları dışında istatistiksel olarak anlamlı bir artış gözlemlenmiştir. Eğilimdeki artışlar ITA yöntemi kullanılarak grafiksel olarak görselleştirilmiştir. Hem aylık hem de yıllık yağış ve evapotranspirasyondaki anlamlı artış eğilimleri havzanın hidrolojik döngüsünde değişiklikler olduğunu ortaya koymaktadır. Test sonuçları, havza alanıyla ilgili sorunların planlanmasında ve çözümünde kullanılabilir.

Anahtar Sözcükler
Meriç Nehri Havzası, Yağış, Evapotranspirasyon, Eğilim Analizi, İklim Değişikliği

* Sorumlu Yazar: Tel: +90 (362) 3130055 Faks:+90 (362) 3130200
E-posta: mehmetskorkmaz@samsun.edu.tr (Korkmaz M.S.),
kevsermerkur@gmail.com (Merkür Başkesen K.),
ertugrul.sunan@samsun.edu.tr (Sunan E.)

Gönderim Tarihi / Received : 01/11/2024
Kabul Tarihi / Accepted : 15/01/2025

1. Introduction

Climate change has become a major scientific study area that has been on the agenda and addressed from different perspectives in recent years. The impact of climate change on water resources is being determined through large projects both in the most affected geographies and globally (NASA Science, 2024). Researchers have focused on the temporal changes of hydrological variables, which feed the water resources of a particular basin and are generally called water cycle elements and are used in water budget calculations (Zhu et al., 2020; Massei et al., 2020; Yang et al., 2023). There are many studies (Table 1) conducted mainly on precipitation and temperature in river basins with different climatic characteristics of the world. The common purpose of these studies is to determine regional precipitation and temperature trends (Gulahmadov et al., 2023; D'Oria et al., 2018). Since climate, means the average of temperature and precipitation in a certain region over time by definition, it is extremely logical to conduct studies based on these variables (Hoerling et al., 2010).

Table 1: Recent researches of trends for climatological variables temperature and precipitation trends

Author	Variables	Regions	Methods
Faquseh & Grossi (2024)	Precipitation, temperature and snow water equivalent (1990-2020)	Lombardy region, located in the northwest of Italy	Mann-Kendall, Pettitt's change point detection, Sen's slope estimator
Aksu & Arikan (2017)	Evapotranspiration	Buyuk Menderes River Basin	Metric Model
Esit et al. (2024)	Temperature and precipitation (1958-2021)	Van, Türkiye	Mann-Kendall, Spearman's Rho, Sen's slope estimator, Innovative trend methods (ITA and IPTA), Sequential Mann Kendall (SQ-MK)
Acar et al. (2022)	Rainfall and temperature (1969-2020)	Türkiye	Mann-Kendall, Innovative trend signifcance test (ITST), Innovative polygon trend analyses (IPTA) with star graph
Shah et al. (2022)	Air and dew point temperature, relative humidity, wind speed, and precipitation	Ontario, Canada	Mann–Kendall test and Sen's slope estimator
Katipoğlu (2022)	Temperature, precipitation, relative humidity, windspeed, sunshine duration (1934–2019)	Bursa, Türkiye	ITA, Sequential Mann-Kendall, Standard normal homogeneity test (SNHT), Pettitt test
Muia et al. (2024)	Temperature and rainfall (1991-2020)	Makueni County, Kenya	Mann-Kendall and Sen's slope estimator
Sa'adi et al. (2023)	Temperature and rainfall (1948–2016)	Sarawak, Malaysia	Mann-Kendall, modified Mann-Kendall, extreme climate indices
Larbi et al. (2018)	Temperature and rainfall (1985–2016)	Vea Catchment, Ghana	Mann–Kendall (MK), Sen's slope estimator, rainfall indices, temperature indices
Kliengchuay et al. (2024)	Temperature, relative humidity, and precipitation (2001-2020)	Thailand	Mann-Kendall, ITA
Serencam (2019)	Rainfall and temperature (1970-2013)	Yesilirmak, Türkiye	ITA
Titkova et al. (2023)	Evaporation and soil moisture (1980-2021)	South of European Russia	Ten year lineer trends, correlation analysis
Rani et al. (2023)	Precipitable Water Vapor (PWV) (1960-2021)	Indus River Basin	Sen's slope estimator and Mann Kendall
Liu & Yang (2022)	Soil moisture and soil temperature (1950-2020)	Mongolian Plateau	Correlation and Granger causality analysis

In addition to investigating trends climatological variables, many studies (Table 2) have been focused on climate indices (Frich et al., 2002) calculated to understand extreme meteorological conditions.

Future climate projections are produced for various goals, and it is revealed how the climate on a global scale changes according to different RCP (Representative Concentration Pathway) scenarios and in what direction the change will follow as a result of these projections (World Climate Research Programme, n.d.) (Table 3).

Table 2: Recent researches of climate indices

Author	Variables	Regions	Methods
Alexander et al. (2006)	Temperature and precipitation (1951-2003)	Global	Temperature indices and precipitation indices
Mohammed (2024)	Rainfall (1981-2019)	Lake Tana, Ethiopia	Rainfall indices
Felix et al. (2021)	Temperature and precipitation (1988-2020)	Geum River	Temperature indices, precipitation indices, Trend-Free Pre-Whitening (TFPW) Method, Mann-Kendall, Theil–Sen Slope (TS) Estimator, Mann–Whitney–Pettit (MWP) Test, Pearson's Correlation Coefficient
Al-Shamayleh et al. (2024)	Precipitation(1987-2017)	Wala Basin, Jordan	Precipitation indices
Medina et al. (2023)	Rainfall (1982–2019)	Northern Argentina	Rainfall indices, Mann-Kendall, Sen's slope estimator
Iqbal et al. (2024)	Precipitation (1985-2016)	Pakistan	Precipitation indices, Mann-Kendall, modified Mann-Kendall

Table 3: Researches for climate projections and trend analysis

Author	Variables	Regions	Methods
Nacar et al. (2024)	Temperature and Precipitation [(2021–2050), (2051–2080), (2081–2100)]	Eastern Black Sea, Türkiye	GCMs (CNRM-CM5.1, HadGEM2-ES, and MPI-ESM-MR, from CMIP5 (5. Climate Model Intercomparison Project)) RCP4.5, and RCP8.5, ITA, IV-ITA
Aksoy et al. (2008)	Precipitation, air temperature, and streamflow	European part of Türkiye	ECHAM4, HadCM2 and HadCM3
Koubodana et al. (2020)	Discharge, rainfall, temperature (2020-2045)	Mono River, West Africa	RCP4.5 &RCP8.5, Mann-Kendall, Sen's slope estimator, rainfall indices, temperature indices
Rahaman et al. (2024)	Temperature and rainfall (2021-2030)	India	Random forest and artificial neural network-multilayerperceptron (ANN-MLP), Mann-Kendall, Sen's slope estimator
Ali et al. (2023)	Temperature, solar radiation and precipitation (2020-2070)	Astore River, Pakistan	GCM's (BCC-CSM2-MR, INM-CM5-0, and MPI-ESM1-2-HR), Mann-Kendall, Sen's slope estimator
Kant et al. (2024)	Temperature and precipitation (2000-2099)	Beas River, Northern India	GCMs (BNU-ESM, Can-ESM2, CNRM CM5, MPI-ESM MR, and MPI-ESM LR), RCP4.5, and RCP8.5 scenarios, ITA, Mann–Kendell, and Sen's slope trend

All research is carried out with certain commonly accepted parametric or non-parametric trend analysis methods whether it is just the change of current climate variables, the frequency of occurrence of extreme meteorological conditions, or research on the direction of changes in the climate of the future period (Table 4).

Table 4: Actual studies of trend analysis methods

Author	Variables	Regions	Methods
Chowdari et al. (2023)	Rainfall (1901-2002)	Karnataka, India	Mann-Kendall, modified Mann-Kendall (mMK), Spearman's rho test, ITA
Şen & Şişman (2024)	Discharge (1840-2003), precipitation (1940-2012)	Danube River and Antalya	Sen's slope calculation
Bağdatlı & Arıkan (2020)	Evaporation (1978-2019)	Nigde, Türkiye	Mann-Kendall, Spearman's Rho, Sen's slope estimator
Güçlü (2020)	Rainfall (1966-2015)	Türkiye	Mann-Kendall, ITA, IV-ITA
Kesgin et al. (2024)	Precipitation and temperature (1972–2020)	Mediterranean coastal region, Türkiye	ITA, IV-ITA
Birpınar et al. (2023)	Precipitation (1901-2002)	Assam, India	Mann-Kendall, modified Mann-Kendall, ITA
Boudiaf et al. (2022)	Rainfall (1982-2019)	Northeastern coastal part of Algeria	IPTA

Table 4 continued

Author	Variables	Regions	Methods
Karacosta et al. (2023)	Precipitation (1971-2020)	Thessaloniki, Greece	IPTA
Gopakkali et al. (2023)	Precipitation (1951-2020)	Karnataka, India	Mann-Kendall, ITA
Ashraf et al. (2023)	Precipitation (1961–2018)	Indus River	Modified Mann-Kendall, Sen’s slope estimator, ITA, Standardized Precipitation Evapotranspiration Index (SPEI)
Koycegiz & Buyukyildiz (2024)	Precipitation (1971–2020)	Konya, Türkiye	Innovative polygon trend analysis (IPTA) and trend polygon star concept (TPSC)
Hussain et al. (2022)	Temperature (1995-2020)	Soan River, Pakistan	Innovative Trend Pivot Analysis Method (ITPAM) and Trend Polygon Star Concept Method

The most widely used non-parametric statistical methods are known as Mann–Kendall (MK) test (Mann, 1945; Kendall, 1975) and Sen’s slope estimator (Sen, 1968) in the literature. In recent years, with the innovative trend analysis (ITA) method developed by Şen (2012) can be used in all time series because it does not have any assumptions. Additionally, this test divides the data set into two, comparing the first and second halves and highlights extreme events in the trend (Şen, 2014).

The primary aim of this research is to evaluate the trends in precipitation and evapotranspiration over the water years from 1982 to 2023 for precipitation and evapotranspiration in the Maritsa River Basin. For this purpose, daily precipitation data for the 42-year period, sourced from the Climate Hazards Group Infrared Precipitation Station (CHIRPS) (Funk et al., 2015), and monthly evapotranspiration data for the 42-year period from the European Reanalysis 5th Generation-Land (ERA5-Land) data set (ECMWF) are analyzed. Trend analyses were conducted on both monthly and annual scales for the precipitation and evapotranspiration data. The methods employed include the Mann-Kendall test, Sen's slope estimator, and the Innovative Trend Analysis (ITA).

The results obtained from these three analytical methods were then compared and presented through tables and figures, offering a comprehensive view of the trends in precipitation and evapotranspiration in the Maritsa River Basin over the specified period.

2. Data and Methods

2.1. Study Area

In this study, Maritsa River Basin (Meriç (Mherich) in Turkish, Εβρος, Evros in Greece and Марица, Maritza in Bulgarian), which is a transboundary water basin between Bulgaria, Greece and Türkiye, has been chosen as the study area (Figure 1). Maritsa River Basin originates from the fountains on Musalla Peak in the Aegean Sea following a path of approximately 492 km (Korkmaz, 2019). The total surface area of the basin from the outlet point where it flows into the sea is 50903 km^2.

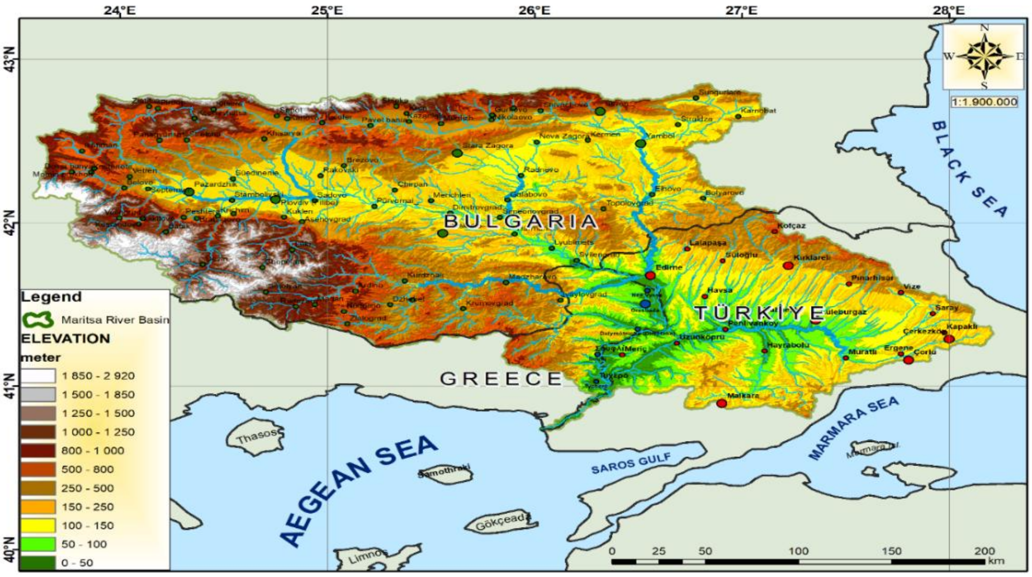


Figure 1: Location of the study area

2.2. Data

In order to understand the direction of the trends of meteorological variables in a region and to present them with quantitative results, a sufficiently long-term, uninterrupted and highly representative data set is needed on a spatial and temporal scale according to the size of the study area.

Maritsa River is a river that has come to international attention due to the floods that occurred especially in the 2000s (Figure 2). In order to prevent the river from being damaged by floods, managers and technical experts in the three countries come together through various projects and try to ensure that supportive measures such as structural measures for the rehabilitation of the river bed and flood early warning systems are taken (Malkaralı et al., 2008).

Figure 2: Maritsa river flood near Edirne in 2010 (DSI Edirne Regional Directorate, 2010)

However, the river passes through three different countries and there are many dams – small dams, irrigation channels, etc. over the tributaries of the river (Figure 3).

Figure 3: Hamzadere irrigation channel near Ipsala (General Directorate of State Hydraulic Works, 2020)

The availability of storage facilities seems to have a significant impact on water users in the basin in the coming years. For example; Turkish Farmers' Unions, which are engaged in agriculture in the very fertile plains downstream of the basin, take the water from the river bed with pumps during the winter months when the flow rate of the river is high and then store it in large man-made constructed storage facilities in the plain. This stored water is used to grow plants that consume high water, especially rice during the irrigation season. Approximately 60% of the paddy production in Türkiye is made with this water provided only from the Maritsa River (Ipsala Kaymakamlığı, n.d.). Therefore, the water potential of the Maritsa River lies at the essential of strategic agricultural production. Possible meteorological or hydrological drought risks in the river basin can lead to huge socioeconomic negativities.

Since Maritsa River Basin is the most important river in that region, both for floods and agricultural irrigation, this study is intended to be carried out as obtaining the trends of both precipitation and evapotranspiration in this river basin will provide very valuable information.

Uninterrupted and highly representative data set is needed on a spatiotemporal scale according to the size of the study area in order to understand the direction of the trends of meteorological variables in a region and to present them with quantitative results.

Dataset of the meteorological observation stations of national meteorological organizations are provided as general data sets in studies aimed at determining climatological trends in water basins. However, there is a general drawback here. There are many inadequacies, especially in precipitation datasets, regarding continuity and spatial representation of the basin. Because river basins are natural formations and rainfall supports the flow in the stream bed from the upstream of the basin. However, it is preferred to establish and operate meteorological observation stations in residential areas as a common understanding all over the world. So, there are no sufficient observation stations and qualified precipitation datasets with measurement periods at the upper elevations of the basins for this reason.

Another compelling issue is the difficulties and methodological differences in obtaining data by the meteorological organizations of many countries in transboundary river basins. Since the Maritsa River basin, is located in three different countries, it is very difficult to obtain meteorological data for the past period. Conducting a joint international project, consenting to data sharing by the meteorological institutions of all three countries, and providing meteorological data with high representativeness in the basin over a determined long-term period is not considered a practical approach for a spatiotemporal research.

In addition, we aim to work with 'evapotranspiration' datasets, which are one of the most ‘laborious’ datasets to obtain meteorologically (Aksu & Arikan, 2017). As emphasized above, when the scientific literature is scanned, there is no in-depth climatologic research on the region. One of the main goals of this study is to strive for a direct hydrological analysis for the basin water budget. Therefore, trend analysis of the evapotranspiration dataset is performed. Moreover evapotranspiration can also indirectly represent an aspect about temperature.

As a result, data sets produced from satellite observation products have been used to study with precipitation and evapotranspiration data that are both temporally and spatially representative (Table 5).

Table 5: Data used in the study

Meteorological Variable	**Temporal Resolution**	**Spatial Resolution**	**Data Source**	**Time Period**
Total Precipitation	Daily (kg/m^2)	4.8 km x 4.8 km	CHIRPS (Funk et al. 2015)	1982 - 2023 Water Years
Total Actual Evapotranspiration*	Daily (kg/m^2)	0.1° (≈ 9 km)	ERA5-Land (ECMWF)	1982 - 2023 Water Years

*: In the catalog of the dataset, it titled as ‘evaporation’, but it defines the total actual evapotranspiration.

Daily precipitation data as the CHIRPS (The Climate Hazards group Infrared Precipitation with Stations) product (Funk et al., 2015) are provided at the basin scale for the 42-year uninterrupted period between 1981-2023. Then, daily evaporation data (including transpiration from vegetation) as the ERA5-Land (European Reanalysis 5th Generation-Land) product (ECMWF) are provided at the basin scale for the 42-year uninterrupted period between 1981-2023 for the study. Web Platform of Google Earth Engine is used to obtain whole spatiotemporal dataset. The written javascript codes gave the spatial amount of daily precipitation and evapotranspiration in the basin for each year.

As a result, meteorological data sets with a period of at least 40 years are evaluated as the most appropriate approach to conduct trend analysis using different methods in a transboundary river basin with an area of approximately 50 000 km^2 and located in three countries. Spatial precipitation and evapotranspiration data is actually a multi-dimensional dataset where there are 'temporal' average 'values' for each grid. For example, each grid contains a 'value' dependent on latitude, longitude, and time. The average of these ‘average values' contained in each grid is then reduced to a single value for that date for the whole basin (which could be the relevant day, month, or year, for example).

In this study, while conducting trend analyses, spatial datasets were transformed into time series in this way, and these daily temporal resolution values were used for the basin. These daily 'average values' representing the entire basin were downloaded on a daily basis at the water year scale using *JavaScript* scripts written in *Earth Engine Code Editor*. Then, monthly and annual (water year) totals were calculated from the daily time series produced at the basin scale using scripts written in the *R* programming language. Subsequently, trend analyses were performed with these monthly and annual datasets.

2.3. Methods

Monthly and annual trend analyses of meteorological variables were carried out in the study area using three different methods with daily total precipitation amounts and monthly total evapotranspiration amount data sets, which are considered as meteorological time series (Figure 4). Precipitation and evapotranspiration data were pre-organized using the R programming language and several R-packages. Trends in water year-based data sets were interpreted using the Mann-Kendall, Sen's Slope estimator, and Innovative Trend Analysis (ITA) methods.

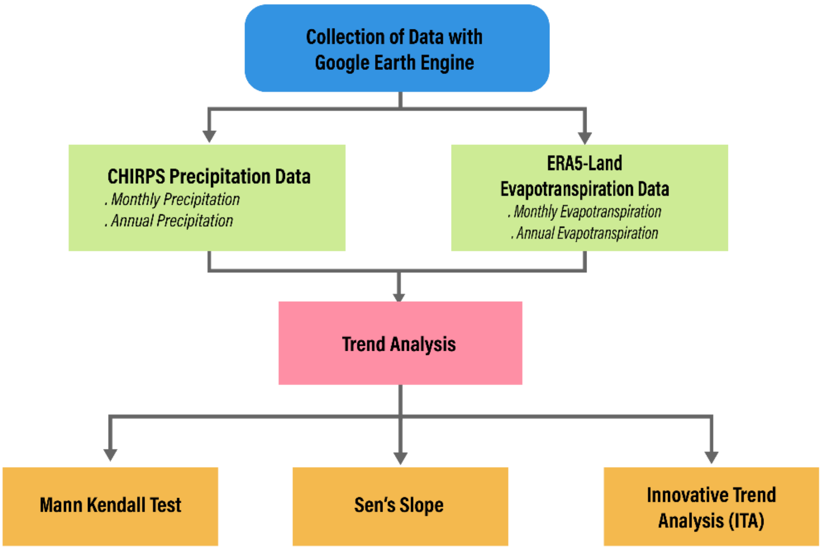


Figure 4: Flow chart of the methodology of the study

2.3.1. Mann-Kendall Trend Analysis

The Mann-Kendall test statistic S (Mann, 1945; Kendall, 1975) is calculated as (1);

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

where n is the number of data points, x_i and x_j are the data values in time series i and j ($j > i$), respectively and $\text{sgn}(x_j - x_i)$ is the sign function as (2):

$$sgn(x_j - x_i) = \begin{cases} +1, if\ x_j - x_i > 0 \\ 0, if\ x_j - x_i = 0 \\ -1, if\ x_j - x_i < 0 \end{cases} \quad (2)$$

The variance is computed as (3);

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \quad (3)$$

where n is the number of data points, m is the number of tied groups and ti denotes the number of ties of extent i. A tied group is a set of sample data that have the same value. In cases where the sample data is bigger than 10 (n > 10), the standard normal test statistic Z_S is computed using the equation (4):

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, \text{if } S > 0 \\ 0 \quad , \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, \text{if } S < 0 \end{cases} \quad (4)$$

Positive values of S indicate increasing trends while negative S values show decreasing trends. The specific α significance level is used to test trends. The null hypothesis (H_0), meaning that no significant trend is possible, is supported when the α significance level $|Z_s| \leq Z\alpha/2$.

The null hypothesis (H_0) assumes that the data are independent and identically distributed random variables, while the alternative hypothesis (H_1) indicates a statistically significant trend. If the Z value exceeds the critical value from the standard normal distribution at the chosen significance level α, the null hypothesis (H_0) should be rejected. This means that there is a statistically significant positive or negative trend in the data series.

Accordingly, significance levels of 5% (p = 0.05) and 1% (p = 0.01) were used as thresholds for identifying trends. For a 5% significance level, Z = ±1.96, and for 1%, Z = ±2.58. Statistical significance is confirmed when p < 0.05, and trends are considered highly statistically significant when p < 0.01.

Additionally, Kendall's Tau (τ) statistic, related to the Mann-Kendall test, measures the strength and direction of association between variables. The Tau value ranges from -1 to +1, where +1 indicates a perfect positive correlation, -1 a perfect negative correlation, and 0 indicates no correlation (Kendall, 1938).

2.3.2. Sen's Slope Trend Analysis

Sen (1968) developed equation (5) for estimating the slope (Q_i) of trend in the sample of N pairs of data:

$$Q_i = \frac{x_j - x_k}{j - k} \quad for \;\; i = 1,2,3 \ldots N \tag{4}$$

where x_j and x_k are data values at times j and k (j > k), respectively.

If there is only one datum in each time period, then $N = \frac{n(n-1)}{2}$, where n is the number of time periods. If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$, where n is the total number of observations.

The N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as (6)

$$Q_i = \begin{cases} Q_{[\frac{N+1}{2}]} & if\ n\ is\ odd \\ \frac{1}{2}\left(Q_{[\frac{N}{2}]} + Q_{[\frac{N+2}{2}]}\right) & if\ n\ is\ even \end{cases} \tag{5}$$

2.3.3. Innovative Trend Analysis

Şen presented a trend analysis method based on the 1:1 line of the coordinate system (Şen, 2012). According to this approach, the hydrometeorological data series is divided into two equal halves from the median year. The two new subseries formed are sorted from smallest to largest. In the Cartesian coordinate system, the first subseries is lined up on the x-axis and the second subseries is lined up on the y-axis. If the data is above the 1:1 line, no trend can be observed; if the data is located in the lower triangular region of the 1:1 line, there is a decreasing trend; if the data is located in the upper triangular region, there is an increasing trend (Şen, 2012). In addition to determining the increasing and decreasing trend, the Şen ITA method offers 5 options; monotonic increasing, non-monotonic increasing, monotonic decreasing, nonmonotonic decreasing and no trend (Şen, 2012) (Figure 5).

1. The dataset, represented as $X = \{x_1, x_2, \ldots, x_n\}$, consists of data points in a time series. The data series is first divided into two equal halves based on the median year.
2. First subseries $X_1 = \{x_1, x_2, \ldots, x_m\}$ and second subseries $X_2 = \{x_{m+1}, x_{m+2}, \ldots, x_n\}$ are both sorted in ascending order.
3. X_1 is plotted on the x-axis, X_2 is plotted on the y-axis.
4. The 1:1 line defined by y=x is drawn and then the data points are placed on the Cartesian plane. The data points are plotted as (x_i, y_i), where $i = 1,2, \ldots, n$.
5. Trends are identified by looking at which side of the 1:1 line the data points fall on.

If $y_i > x_i$ then the points are above the 1:1 line and this indicates an increasing trend.
If $x_i > y_i$ then the points are below the 1:1 line and this indicates a decreasing trend.
If $y_i = x_i$ then the points are near the 1:1 line and there is no trend.

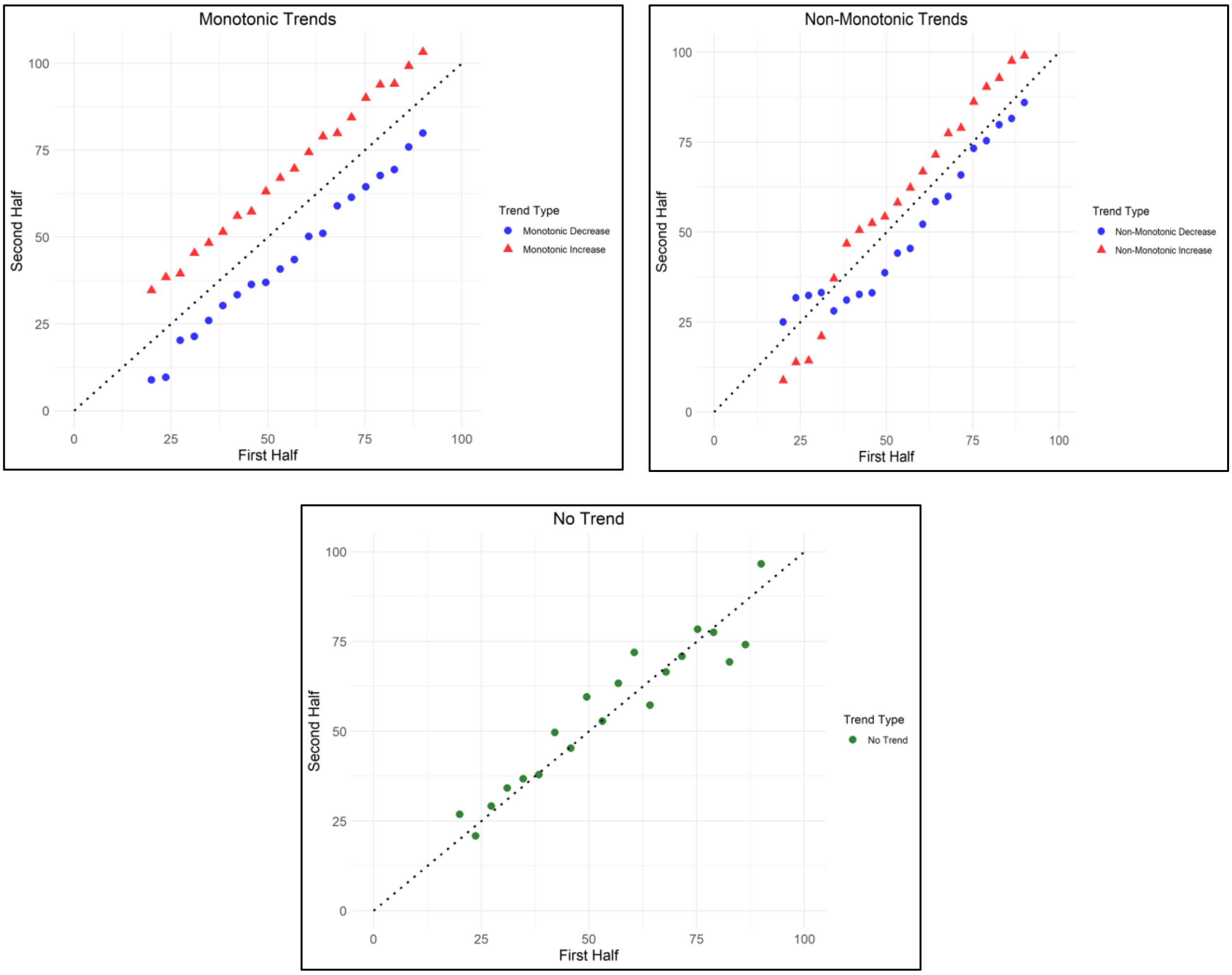


Figure 5: Trend options according to ITA (Şen, 2012)

3. Findings

3.1. Trend Analysis of Maritsa River Basin Precipitation Amount

The Mann-Kendall, Sens's slope estimator and Innovative Trend Analysis (ITA) methods are used to analyze monthly and annualannual precipitation trends in Maritsa River Basin area between 1982 and 2023. It is calculated as 685.80 kg/m^2/year is total annual precipitation for long-term period average by using CHIRPS spatial precipitation dataset (Figure 6).

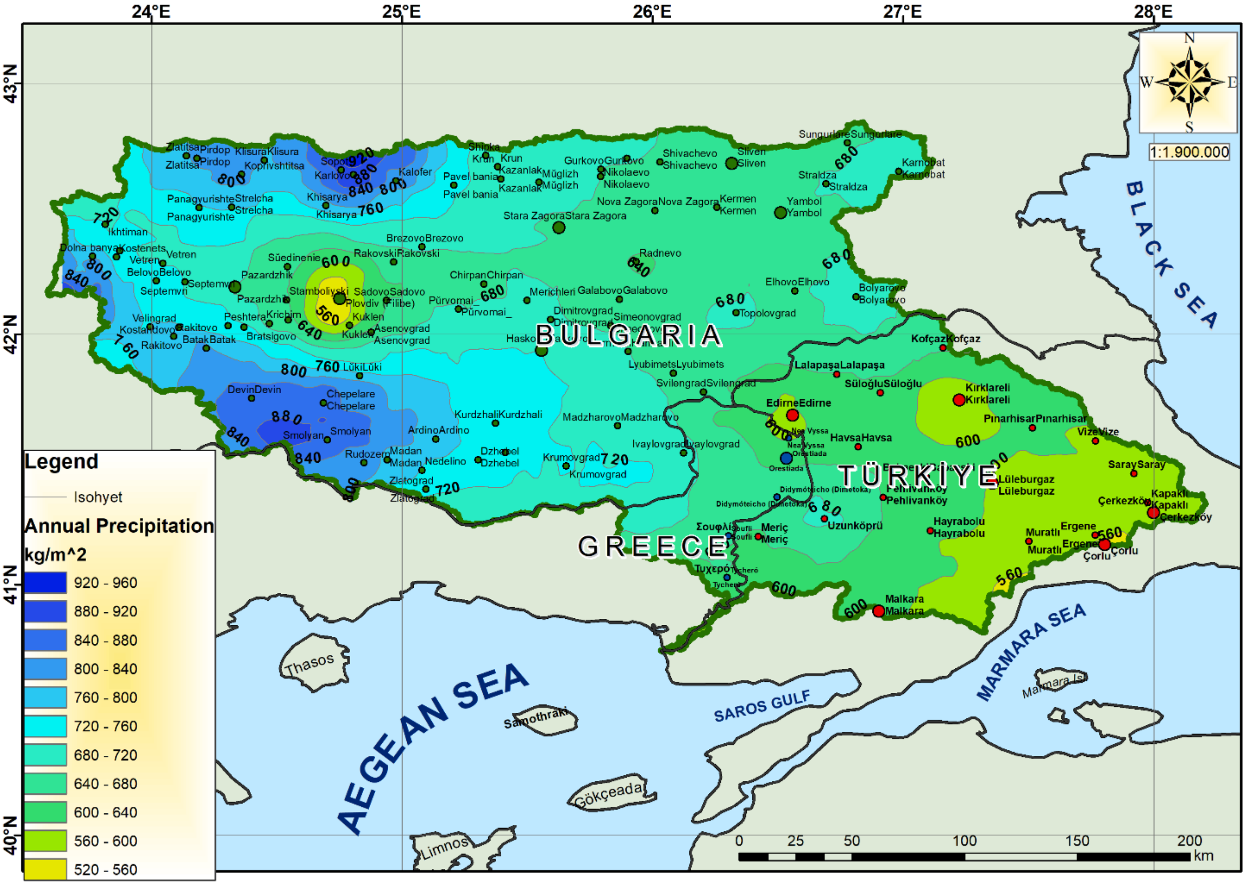


Figure 6: Spatial distribution of annual precipitation in Maritsa River Basin (Average of 1982-2023)

Similarly, but this time, according to the study conducted for Annual Evapotranspiration, the long-term average of the annual actual evapotranspiration amount is calculated as 629.78 kg/m^2/year by using ERA5-Land Evapotranspiration Dataset (Figure 7).

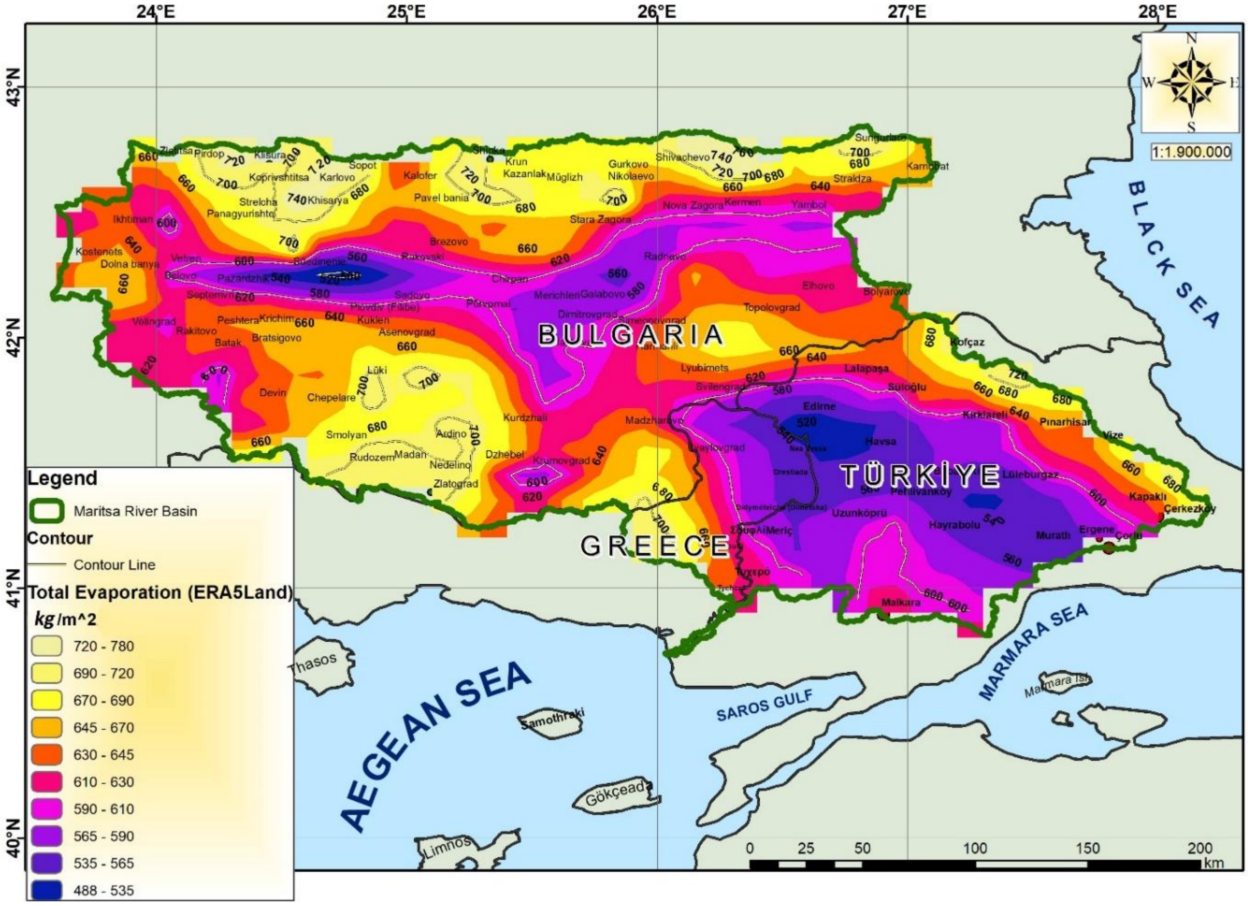


Figure 7: Spatial distribution of annual evapotranspiration in Marista River Basin (Average of 1982-2023)

3.1.1. Trend analysis of monthly precipitation data

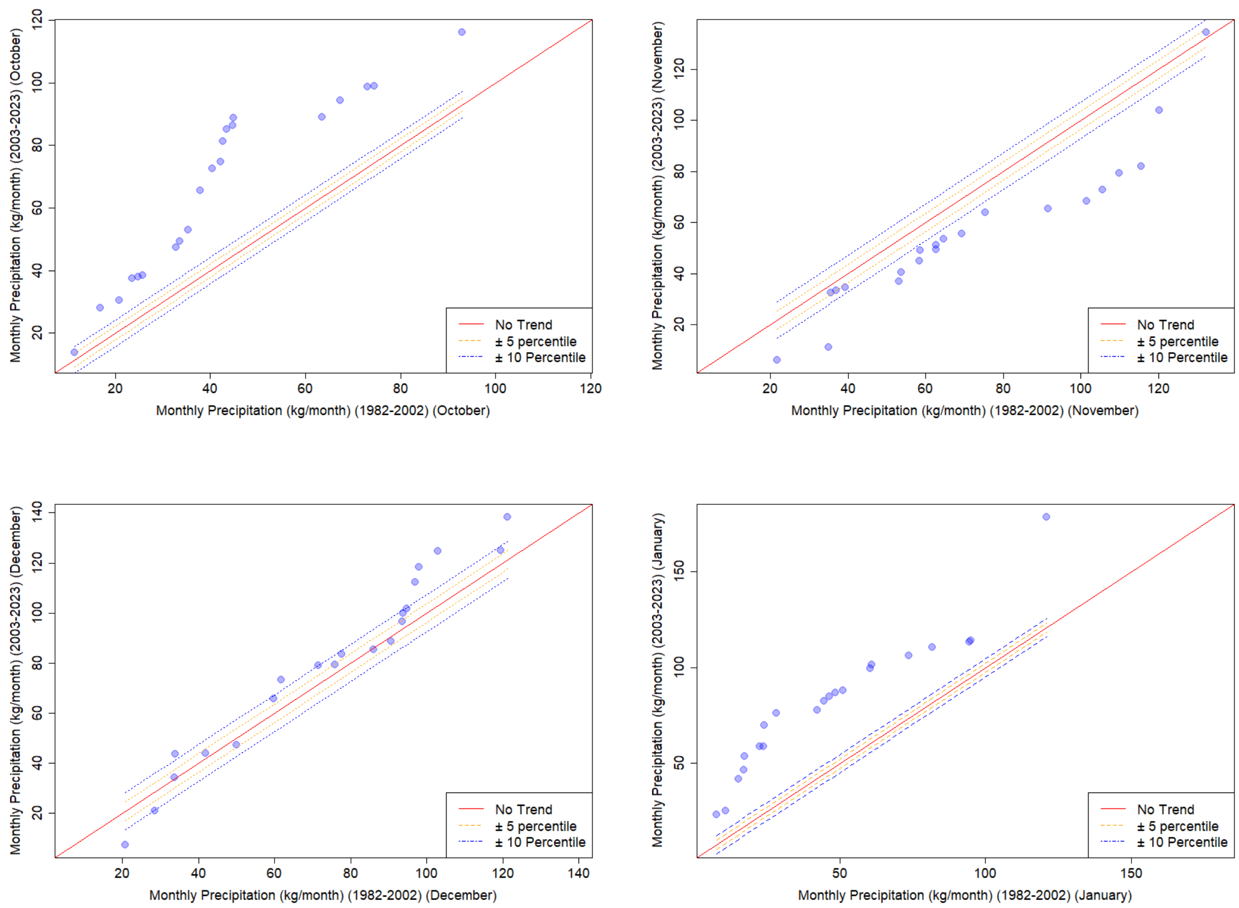
Table 6 shows the test results of Mann-Kendall and Sen's slope estimator tests. In the Mann-Kendall test, the presence of a trend was evaluated at the 0.05 significance level (i.e. 95% confidence interval) to prevent false negative results due to the variability of precipitation data and seasonal fluctuations. In the trend analysis of monthly precipitation, a statistically significant increasing trend is observed in October, January, May and June. The trend is considered strong as the S value is high in these months. Although there is an increase in precipitation in December, February, March, April, July, and September, this is not statistically significant. There is a decrease in precipitation in November and August, but since the p value is greater than the significance level, the decreasing trend is not significant. In addition, since the S value is not very large, a slight decrease in precipitation is observed in August and November. When Tau values are examined, it shows that there is a moderate positive correlation in October and January, meaning that as one variable increases, the other also increases. Negative tau values in November and August indicate a weak negative correlation, meaning that as one variable increases, the other tends to decrease. Low Tau values in other months show weak or no monotonic correlation. According to these results, stronger positive trends are observed in winter months and weaker trends in summer months. For the months with statistically significant increasing trends, Sen's trend slope result shows an average monthly increase of 0.837 mm for October, 1.191 mm for January, 0.5 mm for May and 0.658 mm for June.

- **October:** A statistically significant increasing trend in precipitation is observed, with an average monthly increase of 0.837 mm according to Sen's slope estimator.
- **January:** There is a statistically significant increasing trend in precipitation, with an average increase of 1.191 mm per month. Also, the strongest trend increase is seen in this month.
- **May:** There is a statistically significant increasing trend in precipitation, with an average monthly increase of 0.5 mm.
- **June:** A statistically significant increasing trend in precipitation is present, with an average increase of 0.658 mm per month.
- **November:** Despite a decrease in precipitation, the trend is not statistically significant, as indicated by the p value being greater than the significance level.

Table 6: Mann-Kendall and Sen's slope trend test results for monthly precipitation

Period	Z value	*p* value	Sen's slope	S	Tau	Trend
October	2.298	0.022	0.837	213	0.247	↑
November	-1.344	0.179	-0.502	-125	-0.145	
December	0.650	0.516	0.293	61	0.071	
January	2.319	0.020	1.191	215	0.250	↑
February	0.975	0.329	0.337	91	0.106	
March	0.455	0.649	0.151	43	0.050	
April	1.105	0.269	0.270	103	0.120	
May	1.972	0.049	0.500	183	0.213	↑
June	2.406	0.016	0.658	223	0.259	↑
July	0.780	0.435	0.239	73	0.085	
August	-0.802	0.423	-0.184	-75	-0.087	
September	1.366	0.172	0.281	127	0.148	

For innovative trend analysis, monthly total precipitation data between 1982 and 2023 (42 years) are divided into two sub-series: the 1982–2002 period (first half) and the 2003–2023 period (second half). The graphical results obtained by applying the ITA method to the two sub-series obtained for the Maritsa Basin are presented in Figure 8. According to ITA results, while the points representing October, January, February, May, and June show a strong increasing trend because they appear to be far from the non-trend (1:1) line, it can be said that the point representing November also shows a strong decreasing trend. Additionally, as seen from the graph, an increasing trend is observed in July and September, although it is not strong. According to Mann-Kendall and Sens Slope results, December, March, April and August, which are some of the months with a statistically non-significant trend, are seen as no trend when examined with the ITA method. In addition, precipitation changes from an increasing trend to a no trend from June to August.



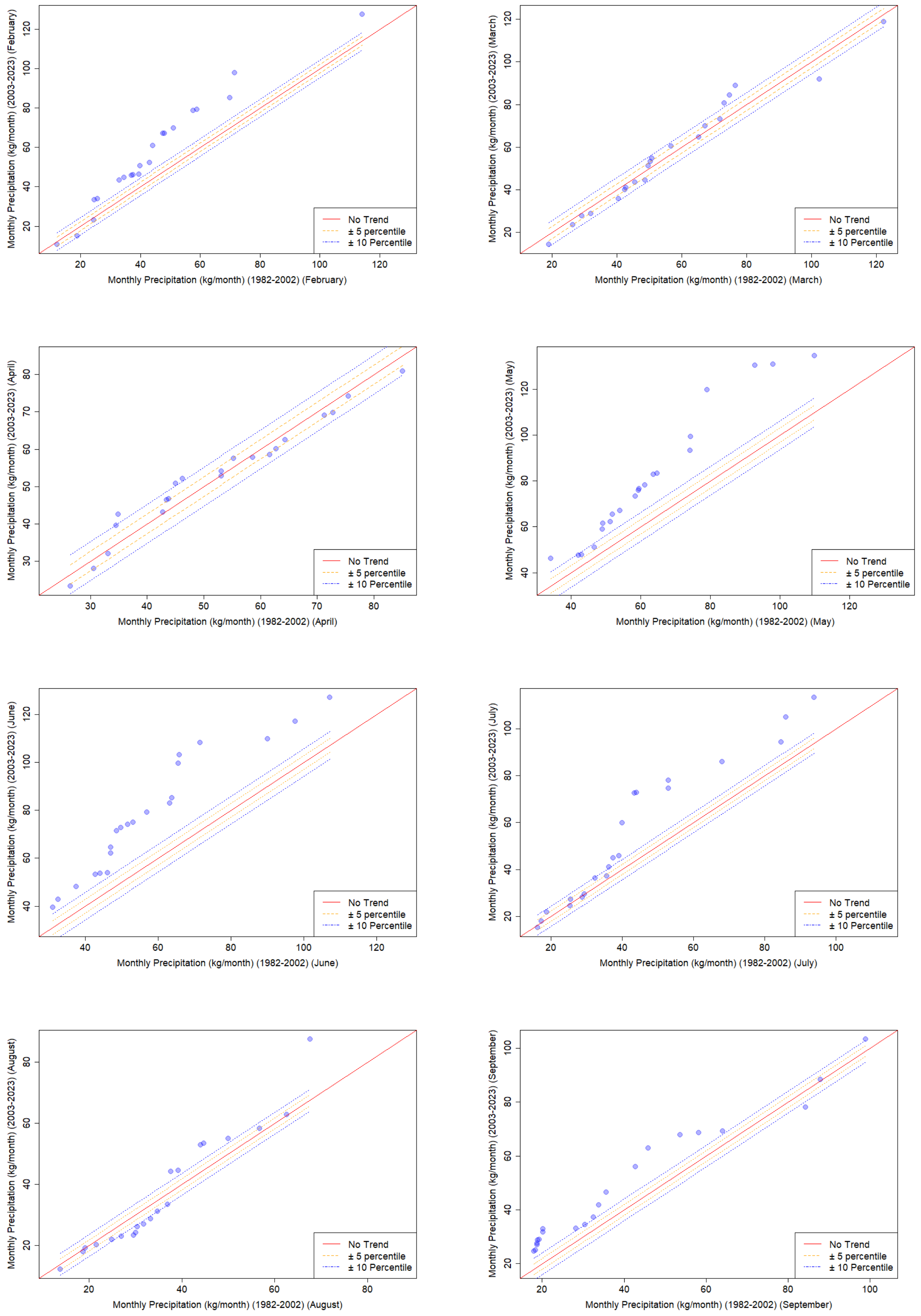


Figure 8: Results of ITA method for monthly precipitation

3.1.2. Trend analysis of water year annual precipitation data

Table 7 shows the test results of Mann-Kendall and Sen's slope estimator tests for annual precipitation. According to the test results, a statistically significant increasing trend is observed within the 0.05 significance level. It was concluded that there was a statistically significant increase in precipitation amounts over time. The Tau value of 0.268 indicates a weak positive correlation between the variables in the annual data. With the Sen's Slope value, it is understood that the annual precipitation increases by approximately 3.8 mm per year.

Table 7: Mann-Kendall and Sen's slope trend test results for annual precipitation

Period	Z value	p value	Sen's slope	S	Tau	Trend
Annual	2.493	0.013	3.796	231	0.268	⇧

When the innovative trend analysis result for annual total precipitation is examined in Figure 9, it is understood that there is a strong increase in precipitation values. Most of the precipitation is above the yellow dashed lines. This indicates that there is an increase beyond the 5% percentage deviation and that this increase is statistically significant, consistent with Mann-Kendall and Sen's slope estimator test results.

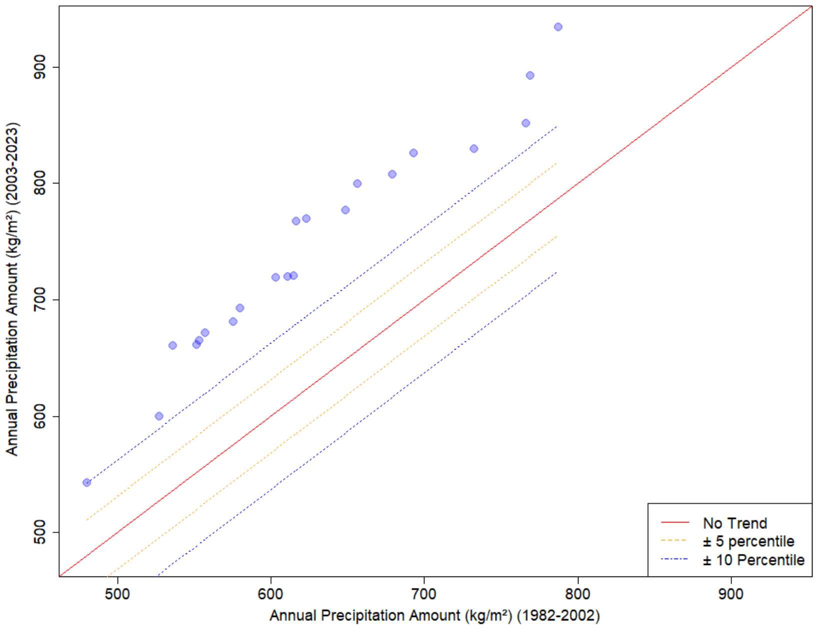


Figure 9: Results of ITA method for annual precipitation

3.2. Trend analysis of Maritsa River Basin Evapotranspiration Amount

The Mann-Kendall, Sens's slope estimator and Innovative Trend Analysis (ITA) methods were used to analyze monthly and water year annual evapotranspiration trends in Maritsa River Basin area between 1982 and 2023.

3.2.1. Trend analysis of monthly evapotranspiration data

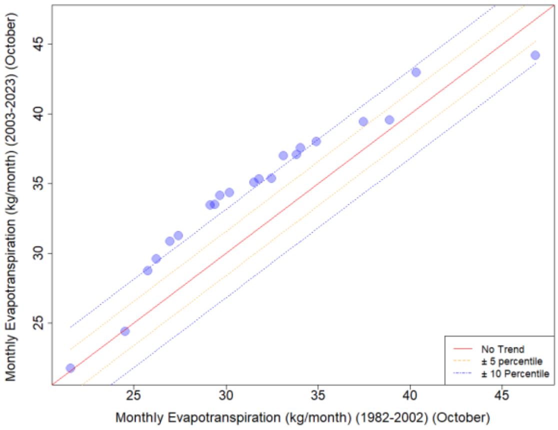
Table 8 shows the test results of Mann-Kendall and Sen's slope estimator tests. In the Mann-Kendall test, the presence of a trend was evaluated at the 0.01 significance level (i.e. 99% confidence interval) to prevent false positive results since evapotranspiration data are more stable and less affected by seasonal effects. Statistically significant increasing trends are observed in December, February, March, April, May. All of this months show a strong increasing trend within the 0.01 significance interval. Although there is an increasing trend in October, November, January, June and July it is not statistically significant. There is no trend in August and September. Tau values for July, August and September are close to zero indicating weak to no correlation for these months, while August and September show negative correlations but are not statistically significant. Among the positive correlations in other months, February shows the strongest correlation with a value of 0.338. These values generally indicate a positive trend in evapotranspiration for most months, with stronger correlations in colder months.

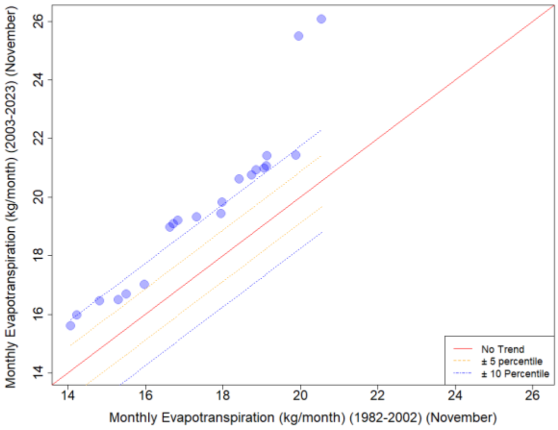
- **December:** There is a highly statistically significant increasing trend in evapotranspiration, with Sen's slope indicating an average increase of 0.095 mm per month.
- **February:** A highly statistically significant increasing trend in evapotranspiration is observed, with an average increase of 0.174 mm per month.
- **March:** There is a highly statistically significant increasing trend in evapotranspiration, with Sen's slope indicating an average increase of 0.276 mm per month. Additionally, the highest trend increase is seen this month.
- **April:** A highly statistically significant increasing trend in evapotranspiration is observed, with a monthly average increase of 0.237 mm according to Sen's slope.
- **May:** There is a highly statistically significant increasing trend in evapotranspiration, with a substantial monthly average increase of 0.272 mm as indicated by Sen's slope.

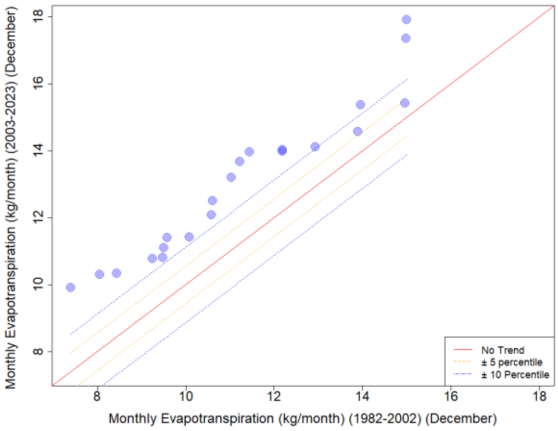
Table 8: Mann-Kendall and Sen's slope trend test results for monthly evapotranspiration

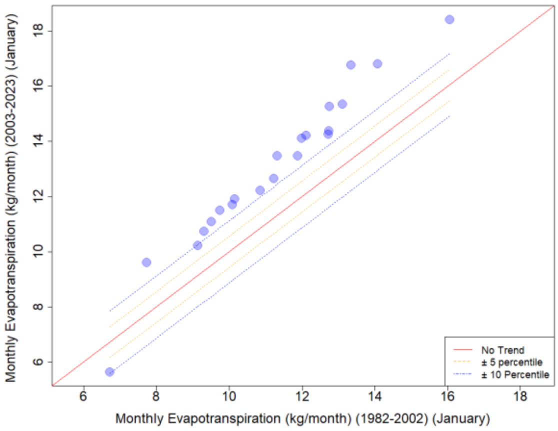
Period	Z value	p value	Sen's slope	S	Tau	Trend
October	1.604	0.109	0.132	149	0.173	
November	2.406	0.016	0.067	223	0.259	
December	2.861	0.004	0.095	265	0.308	⇧
January	2.146	0.032	0.077	199	0.231	
February	3.143	0.002	0.174	291	0.338	⇧
March	3.013	0.003	0.276	279	0.324	⇧
April	2.818	0.005	0.237	261	0.303	⇧
May	2.926	0.003	0.272	271	0.315	⇧
June	2.449	0.014	0.219	227	0.264	
July	0.585	0.558	0.075	55	0.064	
August	-0.108	0.914	-0.028	-11	-0.013	
September	-0.607	0.544	-0.059	-57	-0.066	

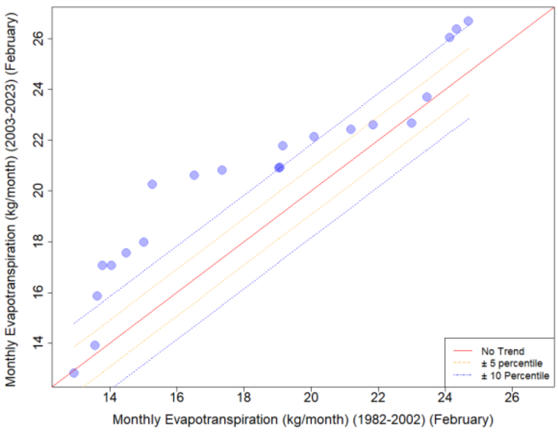
For innovative trend analysis, monthly total evapotranspiration data between 1982 and 2023 (42 years) are divided into two sub-series: the 1982–2002 period (first half) and the 2003–2023 period (second half). The graphical results obtained by applying the ITA method to the two sub-series obtained for the Maritsa River Basin are presented in Figure 10. When the graphics are examined, it is seen that there is a strong increasing trend in other months except June, July, August and September. Although an increasing trend is seen in June and July, there is no strong increase. There is no trend in August and a decreasing trend is seen in September, but there is no strong decrease. When compared with Mann Kendall and Sen's slope results, the non-significant increasing trend months of October, November and January are seen as strong increasing trends in ITA. Also, the non-significant decreasing trend month of August is seen as no trend with ITA. According to Mann Kendall, Sen's slope and ITA test results, the most significant increase is in February and March.

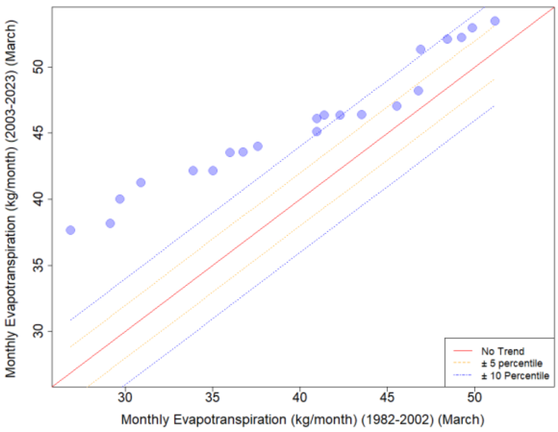

Monthly Evapotranspiration (kg/month) (2003-2023) (October)
Monthly Evapotranspiration (kg/month) (1982-2002) (October)
No Trend
± 5 percentile
± 10 Percentile


Monthly Evapotranspiration (kg/month) (2003-2023) (November)
Monthly Evapotranspiration (kg/month) (1982-2002) (November)
No Trend
± 5 percentile
± 10 Percentile


Monthly Evapotranspiration (kg/month) (2003-2023) (December)
Monthly Evapotranspiration (kg/month) (1982-2002) (December)
No Trend
± 5 percentile
± 10 Percentile


Monthly Evapotranspiration (kg/month) (2003-2023) (January)
Monthly Evapotranspiration (kg/month) (1982-2002) (January)
No Trend
± 5 percentile
± 10 Percentile


Monthly Evapotranspiration (kg/month) (2003-2023) (February)
Monthly Evapotranspiration (kg/month) (1982-2002) (February)
No Trend
± 5 percentile
± 10 Percentile


Monthly Evapotranspiration (kg/month) (2003-2023) (March)
Monthly Evapotranspiration (kg/month) (1982-2002) (March)
No Trend
± 5 percentile
± 10 Percentile

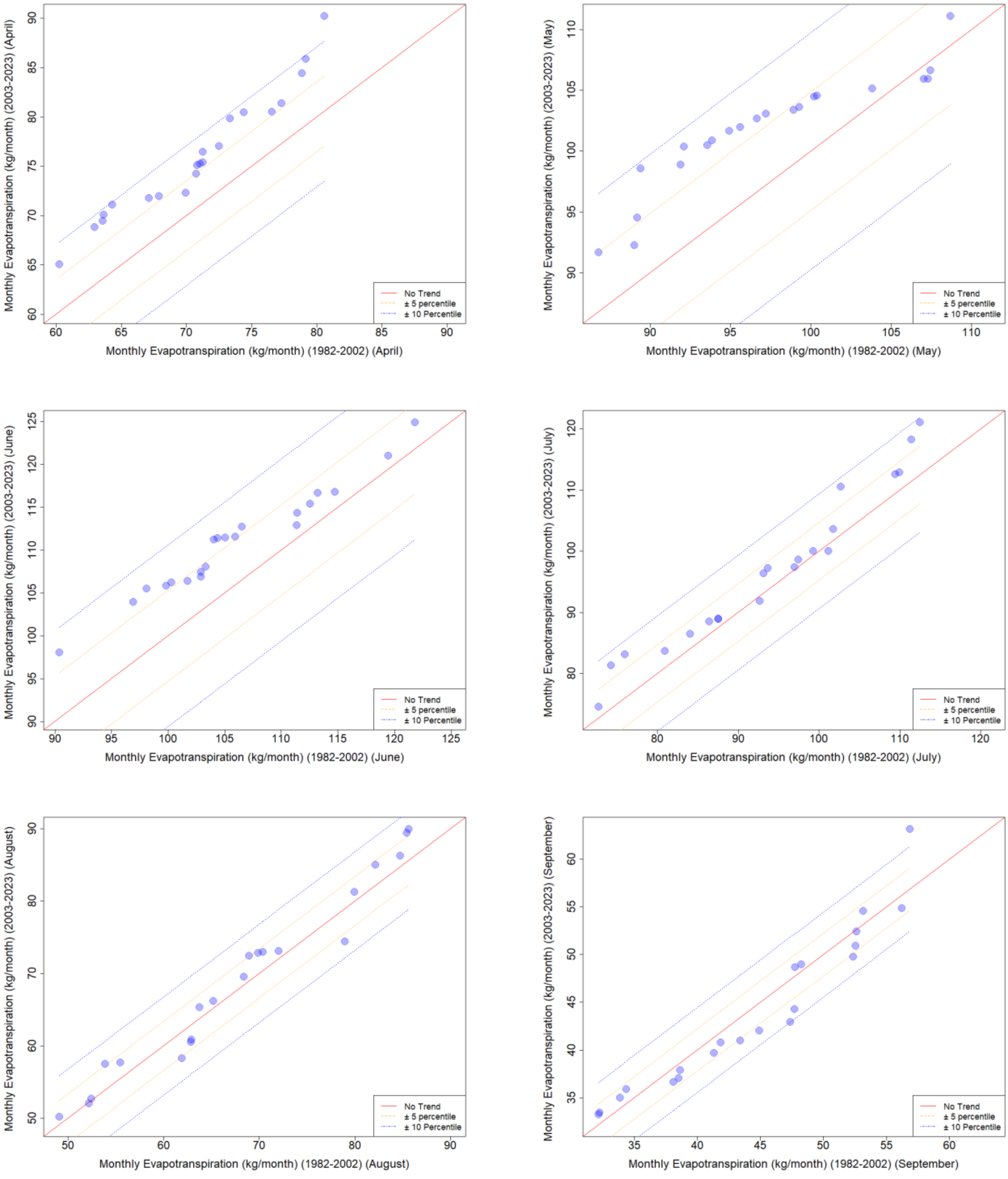


Figure 10: Results of ITA method for monthly evapotranspiration

3.2.2. Trend analysis of water year annual evapotranspiration data

Table 9 shows that there is a statistically significant increasing trend in annual evapotranspiration data at the 0.01 significance level. In addition, the ITA result in Figure 11 supports that evapotranspiration has a strong increasing trend. The Tau value of 0.324 for annual evapotranspiration indicates a moderate positive correlation. This indicates a statistically significant increasing trend in evapotranspiration throughout the year as confirmed by the positive Tau and p-value of 0.002. The annual amount of evapotranspiration increases by approximately 1.419 mm every year.

Table 9: Mann-Kendall and Sen's slope trend test results for annual evapotranspiration

Period	Z value	p value	Sen's slope	S	Tau	Trend
Annual	3.013	0.002	1.419	279	0.324	⬆

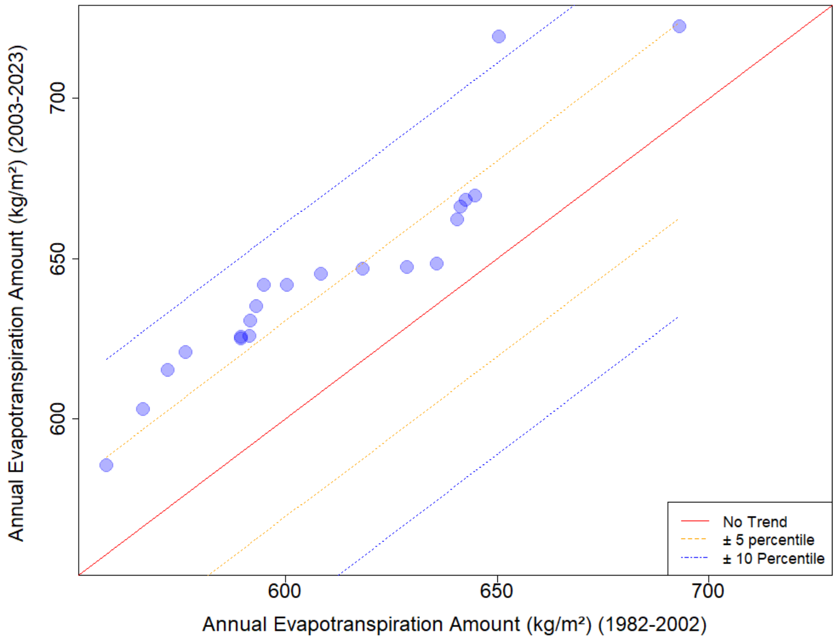


Figure 11: Results of ITA method for annual evapotranspiration

When the annual total precipitation values for the 1982-2023 water year for the Maritsa River Basin are examined (Figure 12), no specific increase or decrease trend is observed.

The year with the highest annual total evapotranspiration amount was 2014, and the year with the highest annual total precipitation amount was 2010. In addition, the year with the lowest annual total evapotranspiration was 1993, and the year with the lowest annual total precipitation was 1985.

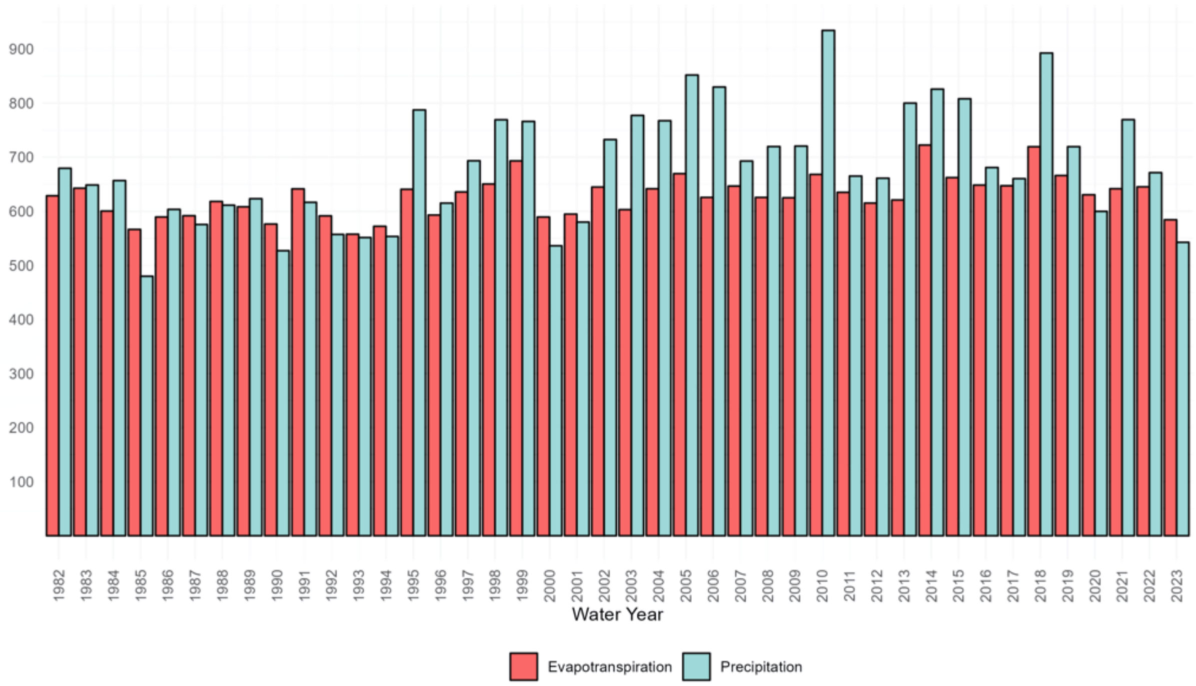


Figure 12: Annual evapotranspiration and precipitation between the water years of 1982-2023

4. Results and Discussion

In conclusion, this comprehensive analysis of long-term precipitation and evapotranspiration trends in the Maritsa River Basin has provided insights into the evolving hydrological patterns of this transboundary watershed. Using Mann-Kendall, Sen's slope estimator, and Innovative Trend Analysis (ITA) methods, the study detected significant increasing trends during the 1982-2023 water year for precipitation and evapotranspiration. These trends indicate an increase in the hydrological cycle of the region. The main conclusions from this study are:

- There is a statistically significant increasing trend in precipitation values in *October, January, May and June* at a 95% confidence interval.
- According to the annual precipitation trend test results, a statistically significant increasing trend is observed within the 0.05 significance level.
- There is an increase in evapotranspiration rates throughout most of the year except August and September. *December, February, March, April, and May* also show a strong increasing trend within the 0.01 significance interval.
- According to the annual evapotranspiration trend test results, a statistically significant increasing trend is observed within the 0.01 significance level.
- It is observed that the trend increase in precipitation is stronger than the trend increase in evapotranspiration.

These results are compatible with the precipitation and evapotranspiration trend results of some previous studies on the Maritsa River Basin and its surroundings.

In one of these studies (Touhedi et al., 2023), a trend analysis of precipitation values between 1975-2015 for seven regions of Türkiye was conducted using the Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975), innovative trend analysis (ITA) (Şen, 2012), and ITA's improved visualization (IV-ITA) (Güçlü, 2020) methods. According to the results, a strong increasing trend was observed as a result of all tests conducted for the Marmara region, which includes the Maritsa River Basin.

Like the previous study (Hadi & Tombul, 2018), Mann-Kendall and Sen's slope tests were applied using precipitation values between 1901-2014 for seven regions in Türkiye. When the results were examined, an increasing trend was seen for the Marmara region.

In another study (Abbasnia & Toros, 2018) conducted for the Marmara region, it is mentioned that an increasing trend was observed when the Mann-Kendall test was applied to precipitation for the period 1961-2016.

As a result of the linear regression analysis of precipitation and evapotranspiration values for the years 1952-2021 in Edirne, a province of Türkiye, it was observed that evapotranspiration and total precipitation values decreased between 1952-1986 and increased between 1987-2021 (Aykut & Turoğlu, 2024).

In another study (Eroğlu, 2021), a trend analysis study was conducted for the Maritsa River Basin for the years 1965-2015 using the Mann-Kendall and Sen's slope method. As a result of this study, the general trend was found to be increasing in the period 1991-2015.

In another study (Erkal & Topgül, 2020), precipitation values between 1986-2016 for the lower Maritsa River Basin, the part of the basin in Türkiye, were tested with Mann-Kendall and Sen's slope. As a result of the tests, it was seen that there was an increasing trend in every season. Accordingly, it has been concluded that the form of floods has changed, and there has been a serious increase in floods.

In these and other studies, increasing precipitation trends indicate intense hydrological cycles caused by climatic changes. Increased precipitation contributes to surface and groundwater, but increased evapotranspiration can balance this increase. This negatively affects water resources management for the Maritsa River Basin. In addition, increasing evapotranspiration trends can change soil moisture levels, causing negative effects on agriculture and ecosystems. Increasing precipitation trends can reduce dependency on irrigation, but can also lead to floods.

The increasing trend in evapotranspiration indicates that cloudiness is decreasing. As cloudiness decreases, precipitation is expected to decrease, but increases in precipitation indicate heavy precipitation on a daily basis. In order to understand the long-term effects of the increase in evapotranspiration, climate indices should be examined in future studies. In addition, the effect of land use on evapotranspiration will be considered in another study, where its impact on the increase in evapotranspiration amounts will be examined.

The findings highlight the importance of continuous analysis to examine the effects of changing climate conditions. Sustainable water resource management is required to ensure the long-term availability and quality of water in the Maritsa River Basin. Because the water basin is transboundary, countries must take these trends into account and plan to reduce potential negative impacts on agriculture, ecosystems, and societies.

References

Abbasnia, M., & Toros, H. (2018). Analysis of long-term changes in extreme climatic indices: A case study of the Mediterranean climate, Marmara Region, Turkey.*Pure and Applied Geophysics,175*(10), 3861–3873. https://doi.org/10.1007/s00024-018-1888-8

Acar, E., Kankal, M., Akçay, F., & Şan, M. (2022). Innovative polygon trend analyses with star graph for rainfall and temperature data in agricultural regions of Turkey. *Environmental Earth Sciences, 81*(23), Article 530. https://doi.org/10.1007/s12665-022-10646-9

Aksoy, H., Unal, N. E., Alexandrov, V., Dakova, S., & Yoon, J. (2008). Hydrometeorological analysis of northwestern Turkey with links to climate change. *International Journal of Climatology, 28*, 1047–1060. https://doi.org/10.1002/joc.1599

Aksu, H., & Arikan, A. (2017). Satellite-based estimation of actual evapotranspiration in the Buyuk Menderes Basin, Turkey. *Hydrology Research, 48*(2), 559–570. https://doi.org/10.2166/nh.2016.226

Alexander, L. V., et al. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research, 111*, Article D05109. https://doi.org/10.1029/2005JD006290

Ali, Z., Iqbal, M., Khan, I.U., Masood, M.U., Umer, M., Lodhi, M.U.K., & Tariq, M.A.R. (2023). Hydrological response under CMIP6 climate projection in Astore River Basin, Pakistan. *Journal of Mountain Science, 20*, 2263–2281. https://doi.org/10.1007/s11629-022-7872-x

Al-Shamayleh, S., Tan, M. L., Samat, N., Rahbeh, M., & Zhang, F. (2024). Performance of CHIRPS for estimating precipitation extremes in the Wala Basin, Jordan. *Journal of Water and Climate Change, 15*(3), 1349–1363. https://doi.org/10.2166/wcc.2024.611

Ashraf, M. S., Shahid, M., Waseem, M., Azam, M., & Rahman, K. U. (2023). Assessment of variability in hydrological droughts using the improved innovative trend analysis method. *Sustainability, 15*, Article 9065. https://doi.org/10.3390/su15119065

Aykut, T., & Turoğlu, H. (2024). Effects of climate change on streamflow in NE Edirne (NW Türkiye): Implications for sustainable hydrological development. *Sustainable Water Resources Management, 10*, Article 2. https://doi.org/10.1007/s40899-023-00985-1

Bağdatlı, M. C., & Arıkan, E. N. (2020). Evaluation of maximum and total open surface evaporation by using trend analysis method in Nigde Province of Turkey. *International Journal of Geography and Regional Planning, 6*(1), 138–145.

Birpınar, M. E., Kızılöz, B., & Şişman, E. (2023). Classic trend analysis methods' paradoxical results and innovative trend analysis methodology with percentile ranges. *Theoretical and Applied Climatology, 153*, 1–18. https://doi.org/10.1007/s00704-023-04449-6

Boudiaf, B., Şen, Z., & Boutaghane, H. (2022). North coast Algerian rainfall monthly trend analysis using innovative polygon trend analysis (IPTA). *Arabian Journal of Geosciences, 15*, Article 1626. https://doi.org/10.1007/s12517-022-10907-8

Chowdari, K., Deb Barma, S., Bhat, N., Girisha, R., Gouda, K. C., & Mahesha, A. (2023). Trends of seasonal and annual rainfall of semi-arid districts of Karnataka, India: Application of innovative trend analysis approach. *Theoretical and Applied Climatology, 152*, 241–264. https://doi.org/10.1007/s00704-023-04400-9

D'Oria, M., Cozzi, C., & Tanda, M. G. (2018). Future precipitation and temperature changes over the Taro, Parma and Enza River basins in Northern Italy. *Italian Journal of Engineering Geology and Environment, 2018*(Special Issue), 49–63. https://doi.org/10.4408/IJEGE.2018-01.S-05

DSI Edirne Regional Directorate. (2010). *Archive of DSI Edirne Regional Directorate*. Retrieved July 1, 2024, from https://bolge11.dsi.gov.tr/

Erkal, T., & Topgül, İ. (2020). Aşağı Meriç Nehri akımlarının mevsimsel ve yıllık değişiminin taşkınlar üzerine etkisi. *Türk Coğrafya Dergisi, 74*, 33–38. https://doi.org/10.17211/tcd.645865

Eroğlu, İ. (2021). Meriç Nehri Havzası'nda sıcaklık ve yağış değerlerinin dönemsel trend analizi. *Avrupa Bilim ve Teknoloji Dergisi, 23*, 750–760. https://doi.org/10.31590/ejosat.882937

Esit, M., Yuce, M. I., Deger, I. H., & Yaşa, İ. (2024). Trend and variability analysis in rainfall and temperature records over Van Province, Türkiye. *Theoretical and Applied Climatology, 155*, 451–472. https://doi.org/10.1007/s00704-023-04644-5

Faquseh, H., & Grossi, G. (2024). Trend analysis of precipitation, temperature and snow water equivalent in Lombardy region, northern Italy. *Sustainable Water Resources Management, 10*, Article 18. https://doi.org/10.1007/s40899-023-00992-2

Felix, M. L., Kim, Y.-k., Choi, M., Kim, J.-C., Do, X. K., Nguyen, T. H., & Jung, K. (2021). Detailed trend analysis of extreme climate indices in the Upper Geum River Basin. *Water, 13*, Article 3171. https://doi.org/10.3390/w13223171

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., & Michaelsen, J. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data, 2*(1), Article 150066. https://doi.org/10.1038/sdata.2015.66

Frich, P., Alexander, L.V., Della-Marta, P., Gleason, B., Haylock, M., Klein Tank, A. M. G., & Peterson, T. (2002). Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research, 19*(3), 193–212. https://doi.org/10.3354/cr019193

General Directorate of State Hydraulic Works. (2020, December 23). *Hamzadere barajı sulaması ile 131 bin 570 dekar tarım arazisi sulamaya hazır hale getirildi*. Retrieved July 1, 2024, from https://dsi.gov.tr/Haber/Detay/989

Gopakkali, P., Sridhara, S., Kashyap, G. R., & Manoj, K. N. (2023). Trend detection of annual precipitation of Karnataka, India during 1951–2020 based on the innovative trend analysis method. *Environmental Earth Sciences, 82*, Article 551. https://doi.org/10.1007/s12665-023-11239-w

Güçlü, Y. S. (2020). Improved visualization for trend analysis by comparing with classical Mann-Kendall test and ITA. *Journal of Hydrology, 584*, Article 124674. https://doi.org/10.1016/j.jhydrol.2020.124674

Gulahmadov, N., Chen, Y., Gulakhmadov, M., Satti, Z., Naveed, M., Davlyatov, R., Ali, S., & Gulakhmadov, A. (2023). Assessment of temperature, precipitation, and snow cover at different altitudes of the Varzob River Basin in Tajikistan. *Applied Sciences, 13*(9), Article 5583. https://doi.org/10.3390/app13095583

Hadi, S. J., & Tombul, M. (2018). Long-term spatiotemporal trend analysis of precipitation and temperature over Turkey. *Meteorological Applications, 25*, 445–455. https://doi.org/10.1002/met.1712

Hoerling, M., Eischeid, J., & Perlwitz, J. (2010). Regional precipitation trends: Distinguishing natural variability from anthropogenic forcing. *Journal of Climate, 23*(8), 2131–2145. https://doi.org/10.1175/2009JCLI3420.1

Hussain, F., Ceribasi, G., Ceyhunlu, A. I., Wu, R. S., Cheema, M. J. M., Noor, R. S., Anjum, M. N., Azam, M., & Afzal, A. (2022). Analysis of temperature data using the innovative trend pivot analysis method and trend polygon star concept: A case study of Soan River Basin, Potohar, Pakistan. *Pure and Applied Geophysics, 180*, 475–507. https://doi.org/10.1007/s00024-022-03203-9

Iqbal, J., Khan, N., Shahid, S., & Ullah, S. (2024). Evaluation of gridded dataset in estimating extreme precipitations indices in Pakistan. *Acta Geophysica*, *72*, 4597–4612 https://doi.org/10.1007/s11600-024-01286-7

Ipsala Kaymakamlığı. (n.d). *İpsala pirinci sofralarda bir'inci*. Retrieved May 8, 2024, from http://www.ipsala.gov.tr/ipsala-pirinci-sofralarda-birinci

Kant, C., Kumar, A., & Meena, R. S. (2024). Exploring climate variables and drought patterns: A comprehensive trend analysis and evaluation of Beas Basin in Western Himalaya. *Earth Systems and Environment, 8*, 449–464. https://doi.org/10.1007/s41748-024-00376-2

Karacosta, P., Pakalidou, N., Douka, M., & Karacostas, T. (2023). Innovative Polygon Trend Analysis (IPTA): A case study for precipitation in Thessaloniki during the last 50 years (1971–2020). *Environmental Science Proceedings, 26*, Article 161. https://doi.org/10.3390/environsciproc2023026161

Katipoğlu, O. M. (2022). Analyzing the trend and change point in various meteorological variables in Bursa with various statistical and graphical methods. *Theoretical and Applied Climatology, 150*, 1295–1320. https://doi.org/10.1007/s00704-022-04231-0

Kendall, M. G. (1938). A new measure of rank correlation. *Biometrika, 30*(1-2), 81–93. https://doi.org/10.1093/biomet/30.1-2.81

Kendall, M. G. (1975). *Rank correlation methods*. Oxford University Press.

Kesgin, E., Yaldız, S. G., & Güçlü, Y. S. (2024). Spatiotemporal variability and trends of droughts in the Mediterranean coastal region of Türkiye. *International Journal of Climatology, 44*(4), 1036–1057. https://doi.org/10.1002/joc.8370

Kliengchuay, W., Mingkhwan, R., Kiangkoo, N., Suwanmanee S., Sahanavin, N., Kongpran, J., Aung, H. W., & Tantrakarnapa, K. (2024). Analyzing temperature, humidity, and precipitation trends in six regions of Thailand using innovative trend analysis. *Scientific Reports, 14*(1), Article 7800. https://doi.org/10.1038/s41598-024-57980-5

Korkmaz, M. S. (2019). Trakya Bölgesi'nin yüzey suyu potansiyeli. In F. Konukçu, S. Albut, & B. Altürk (Eds.), *TR21 Trakya Bölgesinde İklim Değişikliğinin Etkileri ve Uyum Stratejileri* (pp. 73–87). Tekirdağ Belediyesi & Namık Kemal Üniversitesi.

Koubodana, H. D., Adounkpe, J., Tall, M., Amoussou ,E., Atchonouglo, K., & Mumtaz, M. (2020). Trend analysis of hydro-climatic historical data and future scenarios of climate extreme indices over Mono River Basin in West Africa. *American Journal of Rural Development, 8*(1), 37–52. https://doi.org/10.12691/ajrd-8-1-5

Koycegiz, C., & Buyukyildiz, M. (2024). Applications of innovative polygon trend analysis (IPTA) and trend polygon star concept (TPSC) methods for the variability of precipitation in Konya Closed Basin (Turkey). *Theoretical and Applied Climatology, 155*, 2641–2656. https://doi.org/10.1007/s00704-023-04765-x

Larbi, I., Hountondji, F. C. C., Annor, T., Agyare, W. A., Gathenya, J. M., & Amuzu, J. (2018). Spatio-temporal trend analysis of rainfall and temperature extremes in the Vea Catchment, Ghana. *Climate, 6(*4), Article 87. https://doi.org/10.3390/cli6040087

Liu, Y., & Yang, Y. (2022). Detecting a declining trend of multidepth soil moisture over the Mongolian Plateau from 1950 to 2020 using ERA5-Land reanalysis datasets. *IEEE Access, 10*, 1234–1245. https://doi.org/10.1109/ACCESS.2022.1234567

Malkaralı, S., Korkmaz, M. S., & Sezen, N. (2008, June 19–20). *Meriç Nehri taşkınları ve taşkınlar için geliştirilen uluslararası projeler* [Conference presentation]. 5. Dünya Su Formu Türkiye Bölgesel Su Toplantıları Taşkın Konferansı, Edirne, Türkiye.

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica*, *13*, 245–259. https://doi.org/10.2307/1907187

Massei, N., Kingston, D. G., Hannah, D. M., Vidal, J.-P., Dieppois, B., Fossa, M., Hartmann, A., Lavers, D. A., & Laignel, B. (2020). Understanding and predicting large-scale hydrological variability in a changing environment. *Proceedings of the International Association of Hydrological Sciences*, *383*, 141–149. https://doi.org/10.5194/piahs-383-141-2020

Medina, F. D., Zossi, B. S., Bossolasco, A., & Elias, A. G. (2023). Performance of CHIRPS dataset for monthly and annual rainfall indices in Northern Argentina. *Atmospheric Research, 283*, 106545. https://doi.org/10.1016/j.atmosres.2022.106545.

Mohammed, J. A. (2024). Trend analysis of the extreme rainfall indices from Lake Tana Sub-Basin of the Upper Blue Nile, Ethiopia. *Natural Hazards Research*. https://doi.org/10.1016/j.nhres.2024.01.005

Muia, M. V. K., Opere, A. O., Ndunda, E., & Amwata, D. A. (2024). Rainfall and temperature trend analysis using Mann-Kendall and Sen's slope estimator test in Makueni County, Kenya. *Journal of Materials and Environmental Science, 15*(3), 349–367.

Nacar, S., Şan, M., Kankal, M., & Şan, M., Okkan, U. (2024). Trends and amount changes of temperature and precipitation under future projections in high–low groups and intra-period for the Eastern Black Sea, the wettest basin in Türkiye. *Natural Hazards*. Advance online publication. https://doi.org/10.1007/s11069-024-06588-z

NASA Science. (2024). *Evidence*. Retrieved May 8, 2024, from https://science.nasa.gov/climate-change/evidence/

Rahaman, M. H., Saha, T. K., Masroor, M., Roshani, & Sajjad, H. (2024). Trend analysis and forecasting of meteorological variables in the lower Thoubal river watershed, India using non-parametrical approach and machine learning models. *Modeling Earth Systems and Environment, 10*, 551–577. https://doi.org/10.1007/s40808-023-01799-y

Rani, S., Singh, J., Singh, S., Singh, S., Tiwari, P., & Mal, S. (2023). Decadal trends in precipitable water vapor over the Indus River Basin using ERA5 reanalysis data. *Journal of Mountain Science, 20*(11), 2928–2945. https://doi.org/10.1007/s11629-023-8112-8

Sa'adi, Z., Yaseen, Z. M., Farooque, A. A., Mohamad, N. A., Muhammad, M. K. I., & Iqbal, Z. (2023). Long-term trend analysis of extreme climate in Sarawak tropical peatland under the influence of climate change. *Weather and Climate Extremes, 40*, Article 100554. https://doi.org/10.1016/j.wace.2023.100554

Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association, 63*(324), 1379–1389. https://doi.org/10.1080/01621459.1968.10480934

Serencam, U. (2019). Innovative trend analysis of total annual rainfall and temperature variability case study: Yesilirmak region, Turkey. *Arabian Journal of Geosciences, 12*(21), Article 704. https://doi.org/10.1007/s12517-019-4903-1

Shah, L., Arnillas, C. A., & Arhonditsis, G. B. (2022). Characterizing temporal trends of meteorological extremes in Southern and Central Ontario, Canada. *Weather and Climate Extremes, 35*, Article 100411. https://doi.org/10.1016/j.wace.2022.100411

Şen, Z. (2012). Innovative trend analysis methodology. *Journal of Hydrologic Engineering, 17*, 1042–1046. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556

Şen, Z. (2014). Trend identification simulation and application. *Journal of Hydrologic Engineering, 19*, 635–642. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000811

Şen, Z., & Şişman, E. (2024). Risk attachment Sen's Slope calculation in hydrometeorological trend analysis. *Natural Hazards, 120*, 3239–3252. https://doi.org/10.1007/s11069-023-06329-8

Titkova, T. B., Zolotokrylin, A. N., & Cherenkova, E. A. (2023). Current climatic trends in evaporation and soil moisture changes in the south of European Russia. *Arid Ecosystems, 13*(3), 239–247. https://doi.org/10.1134/S2079096123030150

Touhedi, H., Kankal, M., & Yıldız, M. B. (2023). Trend analysis of maximum rainfall series of standard durations in Turkey with innovative methods. *Natural Hazards, 119*, 1479–1511. https://doi.org/10.1007/s11069-023-06085-9

World Climate Research Programme. (n.d.). *WCRP Coupled Model Intercomparison Project (CMIP).* Retrieved May 8, 2024, from https://www.wcrp-climate.org/wgcm-cmip

Yang, P., Zhang, Y., Li, J., Xia, J., Huang, H., & Zhu, Y. (2023). Characterization of precipitation and temperature equilibrium and its driving forces in the Yangtze river basin under climate change. *Climate Dynamics, 61*(11), 5861–5873. https://doi.org/10.1007/s00382-023-06888-3

Zhu, Y., Luo, P., Zhang, S., & Sun, B. (2020). Spatiotemporal analysis of hydrological variations and their impacts on vegetation in semiarid areas from multiple satellite data. *Remote Sensing, 12*(24), Article 4177. https://doi.org/10.3390/rs12244177