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Spatiotemporal Trend Analysis of Temperature in Euphrates River Basin

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Abstract

Euphrates is the largest river in Iraq. Due to the changing climate and intensifying human activities, the river hydrologic system has changed. In this study, temperature and climate variables were among the leading causes of the changes in the Euphrates River Basin. The nature of the changes is examined using data gathered from 19 weather stations between 1981 and 2021. The four sub-catchments of the River Basin are studied using the sequential Mann-Kendall test analysis to identify temporal trends and abrupt changes. An annual trend test for non-parametric trends at the basin scale reveals an upward trend in the temperature over the previous 40 years. Throughout the entire time, there has been an upward trend in potential evaporation, which has increased since 1981. These factors significantly decrease runoff in addition to being impacted by human activity.

Keywords: Mann–Kendall, Sen's slope, Spatiotemporal analysis, weather databases, Euphrates River, Statistical evaluations.

تحليل الاتجاهات المكانية والزمنية لدرجات الحرارة ضمن حوض نهر الفرات

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الخلاصة

يعد نهر الفرات هو أكبر نهر في العراق وبسبب تغيرات المناخ وتكثيف الأنشطة البشرية، أدى إلى تغير النظام الهيدرولوجي للنهر. في هذه الدراسة، كانت متغيرات درجة الحرارة والمناخ من بين الأسباب الرئيسة للتغيرات في حوض نهر الفرات. تم إجراء فحص طبيعة التغييرات باستخدام البيانات التي تم جمعها من 19 محطة أرصاد جوية بين عامي 1981 و 2021. تتم دراسة أحواض المياه الفرعية الأربعة لحوض النهر باستخدام تحليل اختبار مان- كيندال المتسلسل لتحديد الاتجاهات الزمنية والتغيرات المفاجئة. يكشف اختبار الاتجاه السنوي للاتجاهات غير المعيارية على مقياس الحوض عن اتجاه تصاعدي في درجة الحرارة على مدى السنوات الأربعين السابقة. طوال الوقت، كان هناك اتجاه تصاعدي في التبخر المحتمل، والذي زاد منذ عام 1981. تعمل هذه العوامل على تقليل الجريان السطحي بشكل كبير بالإضافة إلى تأثرها بالنشاط البشري.

الكلمات المفتاحية: معامل ارتباط كندال, معامل سبيرمان, التحليل المكاني والزماني, بيانات الطقس, حوض نهر الفرات, التقيم الاحصائي.

1. Introduction

The hydrological cycle is significantly affected by climate change. Anticipated changes in temperature over the next century may completely alter the hydrological regime (Pratap & Markonis, 2022). The rise in average surface air temperature over the 20th century has amplified global hydrological cycles (Wu et al, 2022; Xu et al, 2022). The air temperature in Iraq has increased by 1.1 °C, or 0.22 °C per decade, since the 1980s, which exceeds the global average (Al-Hasani & Shahid, 2023; Ayada et al, 2024). Over the past century, the air temperature near Earth's surface has increased by 0.74 °C (Xiao et al, 2020). Rising global temperatures have been linked to changes in climate and weather. Heat waves, droughts, and floods have become more frequent and severe due to widespread changes in temperature (Walsh et al, 2020; Seneviratne et al, 2021). Streamflow, a vital output variable of the hydrological cycle, can be used to assess the impacts of climate change at a basin scale by combining changes in temperature, precipitation, and other hydrological cycle components (Saedi et al, 2022; Rahmani & Danesh-Yazdi, 2022). Human activities are the primary cause of the increasing water shortage in most river basins (Omer et al, 2020). In most river basins, runoff, a crucial source of replenishment for groundwater and surface water storage, is decreasing (Xu, 2021; Hou et al, 2023). Conventional regression techniques and hydrological models are often used to assess the severity of the impacts of climate change on runoff (Baig et al, 2021). The Mann-Kendall and Pettitt test methods are additional techniques that can detect changes in climatic events. Over the past 50 years, the temperature in the basin has increased by 0.3 °C per decade (Abdelmohsen et al, 2022). The annual and seasonal precipitation along the Euphrates River (ER) show decreasing trends, especially in the summer, which significantly surpass the global average temperature's rate of increase. Recent studies indicate a considerable drop in the Euphrates River's runoff, leading to a severe water shortage in the basin (Adamo et al, 2020; Abdelmohsen et al, 2022). The fluctuating temperature in the ER has attracted the attention of the local government and academic communities. The study aims to identify climatic changes using non-parametric test and to analyze long-term historical temperature data for the most extended time series and most stations in the ER. This study's motivation can be summed up as follows (1) fill a knowledge gap by analyzing the temperature pattern trends along the Euphrates River (ER) basin. (2) Combined the Mann-Kendal test and Sen's slope estimator for several time scales (annual, wet seasonal, and dry seasonal) at mean temperature for the years 1981–2021. (3) determine the variability of long-term historical records of climate and hydrological data for the Euphrates River Basin's longest time series and highest number of stations.

2. Materials and Methods

2.1 Study Area

The Euphrates is the longest river in Western Asia. Turkey, Syria, and Iraq border it. Twenty-three million people from five different nations share the river's basin (Naseer, 2022). The primary source of precipitation flowing into the Euphrates is the Armenian Highlands, with the other riparian countries contributing a smaller portion of the flow. In Syria, the principal rivers that contribute to the flow of the Euphrates are the Sajur, Balikh, and Khabour, as shown in Figure (1) along with a few intermittent streams (Venturi, 2020). The natural flow rate of the Euphrates along the Syrian-Turkish border used to be about 30 BCM per year. However, over the past 70 years, a declining trend in the data records has led to a decrease in the mean annual flow to roughly 25 BCM (Venturi & Capozzoli, 2017). Human activities, particularly water engineering projects in Turkey and Syria, have significantly altered the Euphrates' flow regime and reduced seasonal fluctuation. In the Euphrates River Basin (ERB), water is mainly used for irrigation, hydropower, and drinking water supply, with agriculture accounting for over 70% of the water usage (Lai et al, 2022).

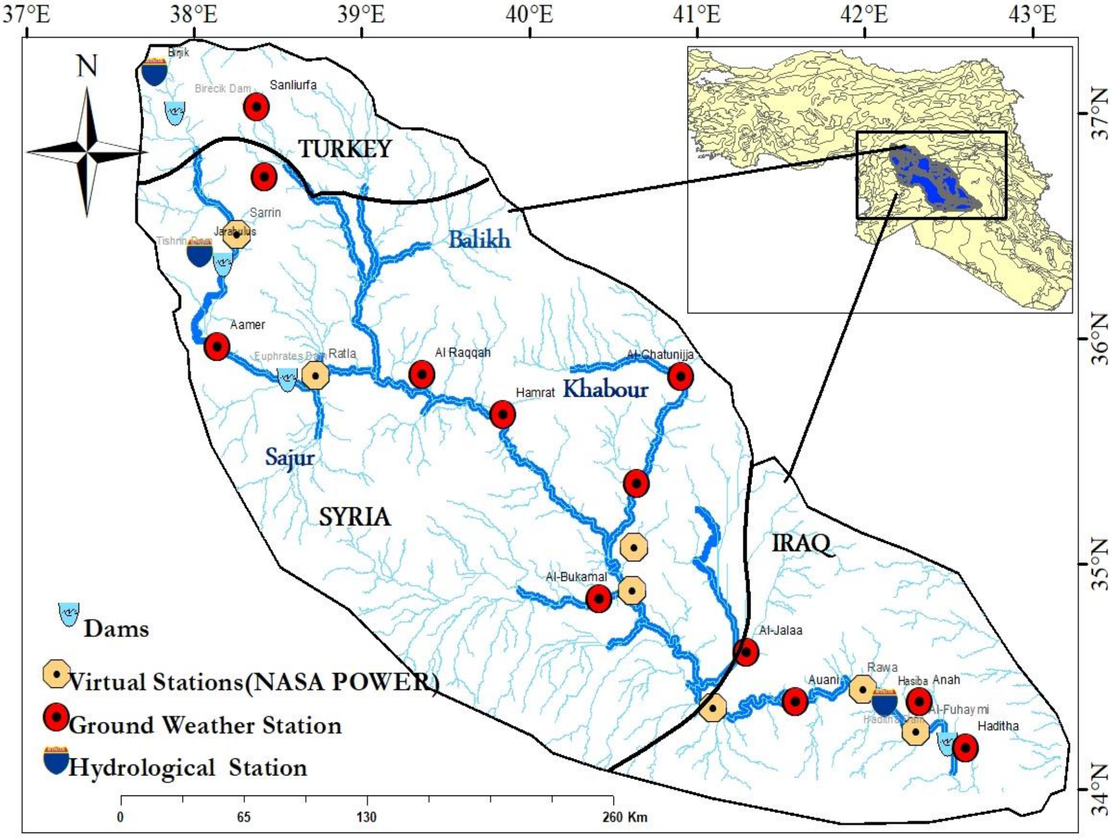

Figure (1): The climatic zone and weather station sites in Euphrates River basin.

2.2 Climatic Data Collection

For basin-scale hydrological simulations, obtaining representative meteorological data could be difficult and time-consuming. Land-based meteorological stations usually need to sufficiently cover the climate seen over a basin due to many issues, including the chance that they are located away from the area of interest and are connected to missing data relevant to the research basin. In this study, NASA satellite data was used to cover areas lacking climate records within the basin after testing their reliability by (Tayyeh & Mohammed, 2023) in conjunction with ground weather stations. To acquire historical meteorological data and investigate its potential use in investigating climate change, hydrologic changes, and drought severity. NASA POWER stations with ground stations were used to compile the historical daily temperature data from 1981–2022. The geographic characteristics of the weather stations used in study area are listed in Table (1).

Table (1): Geographic characteristics of the weather stations used in study area.

Station ID	Latitude (°)	Longitude (°)	Altitude (m)	Temp(°C)
Sanliurfa	37.103	37.878	983	16.99
Jarabulus	36.791	38.037	735	16.99
Sarrin	36.531	38.262	701	17.84
Aamer	36.035	38.152	641	17.84
Raqqah	35.914	39.052	549	18.83
Ratla	35.911	38.729	521	18.83
Chatunijja	35.891	40.865	481	19.62
Hamrat	35.732	39.822	462	19.51
Karamah	35.42	40.597	385	20.15
Shheell	35.134	40.573	334	20.48
Quriyah	34.944	40.558	312	20.48
Bukamal	34.909	40.37	301	20.48
Al-Jalaa	34.66	41.215	276	20.98
Rawa	34.48	41.874	242	20.71
Auani	34.433	41.487	203	20.98
Anah	34.418	42.003	196	20.71
Baghuz	34.4158	41.014	156	20.98
Fuhaymi	34.2863	42.173	112	20.71
Haditha	34.2023	42.3589	98	21.85

2.3 Climatic Data Analysis

Statistical techniques examined the climatic series' spatial variability and temporal trends. (1) The Mann-Kendall (MK) test method and Sen's Slope Estimator a non-parametric test for identifying trends, was used to test the non-linear and changing points. (2) To detect inhomogeneity in the time series, the standard normal homogeneity test (SNHT) and the Pettitt test was applied at nine ground station. The empirical method of significance level (p-value) was established using (XLSTAT) and a significance level of 5% (Marie et al, 2021).

2.3.1 Mann-Kendall Method

Kendall tau method (MK), is a distribution-free evaluation of the significance of monotonic trends and determine when a trend began. in hydro-climatic data (Almazroui & Şen, 2020). The null hypothesis H_0 in the MK method states that O_1 and O_n are trials of n independently distributed stochastic parameters that do not exhibit cyclical variations. For a two-sided test, the alternative hypothesis H_1 states that the distributions of O_k and O_j are non-identical for every $k, j \leq n$; with $k \neq j$. Eqs. 1 can be used to calculate the test statistic S, which is asymptotically normal and has a zero mean and computed variance:

$$S = \sum_{j=1}^{n-i} \sum_{k=j+1}^{n} \mathrm{Sgn}\,(O_k - O_j) \qquad (1)$$

If the sample size n more than ten, the standard normal variate Z is computed Eqs.2 (Douglas et al, 2000).

$$Z = \begin{Bmatrix} (S-1)/\sqrt{Var\ (S)} & S > 0 \\ 0 & 0 \\ (S+1)/\sqrt{Var\ (S)} & S < 0 \end{Bmatrix} \quad (2)$$

Consequently, in a two-sided trend test, H_0 is accepted if $|Z| \leq Z\alpha/_2$ at α level of significance. An upward trend (positive S), whereas a downward trend (negative S). H_0 is rejected if $|Z| \leq Z\alpha/_2$ at two-tail test (Sneyers, 1991).

2.3.2 Sen's Slope Estimator

Sen's test A non-parametric test (Sen, 1968) used to estimate changes when a linear trend is present in a time series and the variance of the residuals should remain constant throughout time (Da Silva et al, 2015). The expression of Eq. 3 can be used to determine the slope trend's magnitude of sample N data pairs:

$$H_i = \frac{O_j - O_k}{j-k}\ , i = 1,2, \dots \dots \dots N, j > k \quad (3)$$

where (j > k) and Oj and Ok represent the values of the data at j and k periods, respectively [23]. If each period has a single datum, as occurs in our case, then N = n(n-1)/2, where n is the number of time periods (Gilbert, 1987; Gocic & Trajkovic, 2013). The Sen's estimator of slope Hi is the median of these values. This method's strength and freedom from statistical restrictions allow it to minimize and limit the impact of outliers on the slope (Collaud Coen et al, 2020; Garba & Udokpoh, 2023). Mann-Kendall A 95% confidence level was used to assess the Sen slope test and confidence interval. The computations were carried out using statistical software (XLSTAT 2022v.1).

3. Result and Discussion

Based on the data used, this section describes the temperature climatology and spatial distribution of mean temperature for the ERB. After that, the results of the homogeneity tests were displayed. In the final subsection, present the results of the trend analysis.

3.1 Spatial Distribution

Climate data (temperature) using the observed annual, dry, and wet seasons classified according to monthly climatic change, which available for the nineteen stations combined from 1981 to 2021. The selected atmospheric variables are used to compute the weather data. In order to cover all basins in the chosen area, The ArcGIS 10.5 software used to interpolate these annual climates between stations. As can be seen in Figure (2), the annual, dry season, and wet season averages of the climate data are subsequently effectively spatially interpolated. Shows that using the aforementioned three-time scale, the average temperatures were (31.83, 25.24 and 32.7) °C. The findings show that for three-time scales, the spatial distribution of average temperature is low along the coast and gradually increase in the south. This can be explained by the fact that the Mediterranean Sea considerably impacts weather data in the high Euphrates River basin, with a minor impact in the middle and an influence that gradually decreases and nearly disappears at the lower level of the basin.

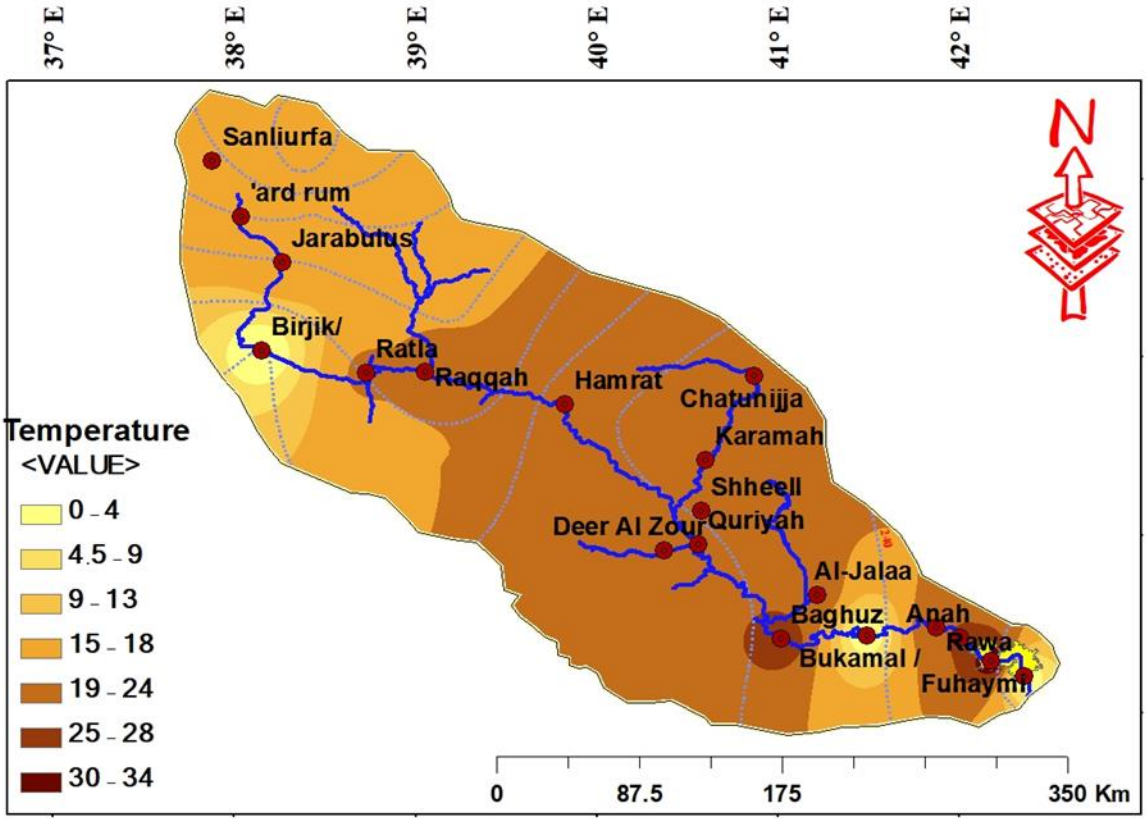

Figure (2): Spatial distribution of mean Temperature (°C) of the study area.

3.2 Homogeneity Test

The statistics test for homogeneity at one station does not follow the trend of other stations as shown in Figure (3). Where, the test statistic remained below the critical line for the entire period. A climate data station must return the best statistic above a critical value to be considered homogeneous. For the Pettit and SNHT tests, critical values were obtained from Pettitt. Apart from Sarrin, all eight stations' annual temperature test statistics stayed above the 5% significance level (Marie et al, 2021). These stations were considered homogeneous at this significance level. However, irregularities in climate data collection at the Sarrin station led to rejection. The field center in charge of data collection found irregularities in how climate data was collected at this station, which resulted in the abandonment of the Sarrin station.

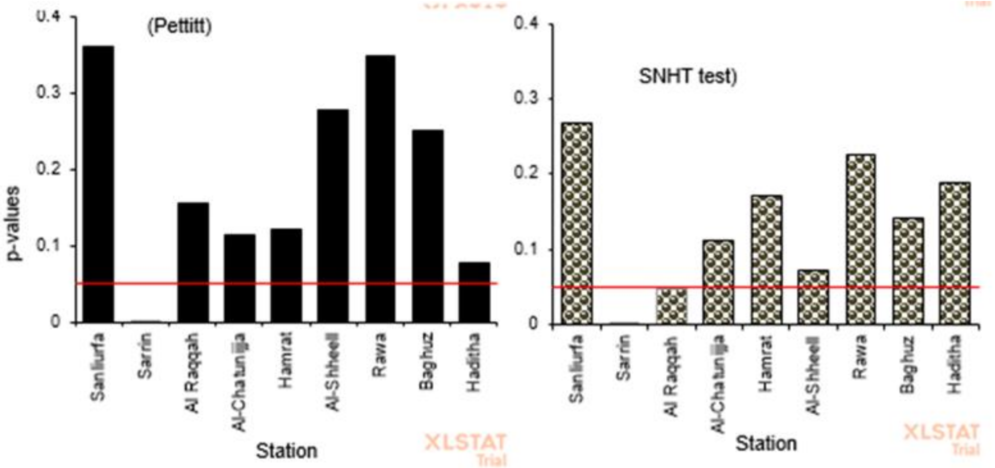

Figure (3): Homogeneity test for temperature data. a Pettitt test, b. SNHT test

3.3 Temporal Distribution

The value of these climatic variables during the studied period (1981-2022) and for each period (1981-1989, 1990-1999, 2000-2010, and 2011-2021) was estimated and linked Figure (4) in order to investigate the inter-annual difference between annual and seasonal weather data, including air temperature. The Autoregressive Integrated Moving Average (ARIMA) statistical model examined historical annual and seasonal rainfall and temperature for decadal change. The values of the two meteorological components were estimated and compared for the entire study period (1980-2021) and each decade (1980-1989, 1990-1999, 2000-2010, and 2011-2021). The period (2010–2021) was warmer than the long-term average by 18.33 °C. In contrast, decadal temperature variations were less than the long-term average before 1990. The mean decadal fluctuations in precipitation are barely perceptible upstream of the ERB. The period (2010-2021) is 21.62 °C warmer than the long-term average, although the decadal temperature swings were smaller before 1989.

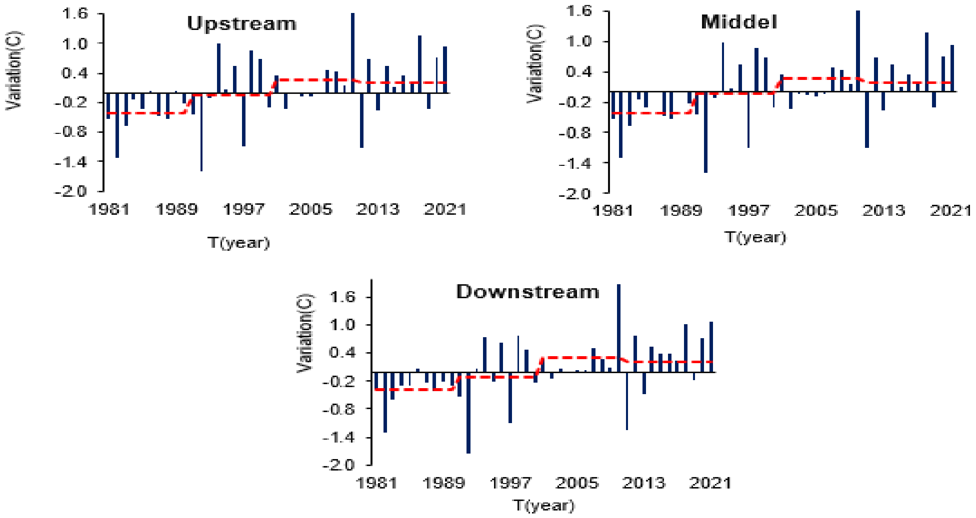

Figure (4): The annual temperature variations of decadal values to the long-term mean in ERB.

3.4 Trend Analysis

The trend analysis was done on the stations that passed the quality control checks. The following sections cover the trend of climate indices for monthly, dry, and wet seasons separately. For 1980–1999 and 2000–2021, mean annual, dry, and wet seasonal temperature series were created using data from all station grids. Table (2) contains the findings for mean, autocorrelation, Z statistics of (MK) test, Sen's slope estimator test, and% change for series. In the entire basin from 1980 to 1999, there was statistically no discernible decreasing trend in the annual and seasonal series. Over the basin, there was a statistically insignificant increase in annual and seasonal temperature from 2000 to 2021. A basin's annual increased decreased by 6 per cent overall between 1980 and 1999. Figure (5) displays the p-value for temperature on a three-time scale with a significant level of 5%.

Table (2): Results of Mann Kendall (MK) test statistic, Sen's slope and percentage of change over the Al Euphrates River Basin for temperature from 1981-2021.

Water year	Period	Temperature			
		Mean	MK	Sen's slope	Change %
1980 to 1999	Annual	19.29	0.33	0.07	57
	Dry Season	27.30	0.32	0.06	55
	Wet Season	11.28	0.36	0.08	61
2000 to 2021	Annual	20.06	0.42	0.05	88
	Dry season	28.03	0.36	0.05	76
	Wet Season	12.09	0.30	0.04	62

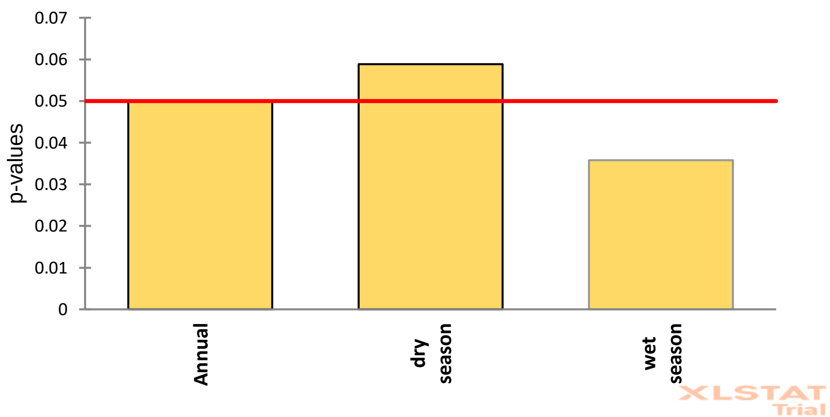

Figure (5): P-value for temperature at three-time scale with significant level 5%

4. Conclusions

This study examined the Euphrates River basin's yearly, dry, and wet seasons' temporal patterns in temperature and their geographic distributions in the basin was investigated.

1- Before the trend test, the data's homogeneity was assessed using the Standard Normal Homogeneity Test (SNHT) and the Pettitt test. All nine of the stations—except Sarrin—were found to be homogenous.
2- The Mediterranean Sea's influence causes the mean temperature to decline in coastal stations and gradually rise in the southern stations of the basin. In contrast, the southern ERB stations recorded the highest annual temperatures.
3- The temperature exhibits an increased tendency for the period. After a year, the temperature in the four sub-catchments is higher than the long-term average (2010-2021).
4- The temperature climbed significantly at each station at a significance level of 0.05, according to the findings of the sequential Mann-Kendall test.
5- Because human activities like increasing water consumption, irrigation projects, and evaporation have a more significant impact on runoff than rainfall, runoff in the ERB decreased in the post-development period.

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