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Investigation of Annual Lake Water Levels and Water Volumes with Şen Innovation and Mann-Kendall Rank Correlation Trend Tests: Example of Lake Eğirdir, Turkey

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Abstract: Lakes are the most important freshwater resources for humans. It is stated that together with population growth, unplanned urbanization, excessive water consumption, industrialization, and unconscious irrigation, global climate change causes changes in the water levels and volumes of lakes. Lake Eğirdir in Turkey, which is important in terms of drinking and irrigation water use, was chosen as the study area. Lake Eğirdir water level (LWL) and water volume (LWV) values measured between 1988–2019 were used. Dependencies in the annual LWL and LWV were examined by autocorrelation analysis, and trend changes were examined by regression analysis, the Mann-Kendall rank correlation test, and the Şen innovation trend test. The research has shown a significant decrease since 2000 in LWL and since 1990 in LWV. The LWL has decreased by −1.272 to −3.514 m and the LWV has decreased by −72.980 to −1082.134 hm^3 in approximately 32 years. The actions to be taken based on the values determined in this study will help protect the water resources of lakes. As a result of the tests used in our study, it was determined that there were decreases in both the water level and the volume of the lake. The climatic changes in the lake basin and the decrease in the water resources feeding the lake are shown as the biggest factor in these reductions.

Keywords: Lake Eğirdir; lake water level and volume; water resources; trend test

1. Introduction

Water is one of the basic elements of life. In addition to being a nutrient, water plays a role in the realization of all kinds of biochemical reactions in our body with the minerals and compounds it contains [1]. Water is not only a necessary source of nutrients for our survival but also a source of civilization and development [2]. The history of humanity is full of examples of many powerful civilizations that collapsed with the wrong use of water [3]. Water on Earth, with a volume of 1 billion 338 million km^3, is mostly found in oceans and seas, as saltwater that people cannot use in a healthy and economical way [3,4]. Regardless of its severity, the concept of drought, which is one of the most serious problems for societies and ecosystems, has become more important in recent years in parallel with climate changes [5]. Turkey is a country that is faced with many different effects of climate change. Heavy rains, floods, drought, and extreme heat are just some of these threats to the climate and environment. It was stated that to postpone the devastating effects of climate change and to be able to combat climate change, all aspects of the current situation should be handled and understood [6–9].

The use of water resources to provide increasingly more water, due to both agricultural water needs and water needs in cities, causes the capacity of water reserves such as lakes to decrease or disappear. Many studies have been carried out in the field of hydrology and hydraulics to protect, develop, and control water resources. In this context, hydraulic structures are being built. Then, studies have been carried out to determine the distribution of water in space and time, its physical and chemical properties, and the relations between water and the environment during the operation stages of these structures [10,11]. In recent years, atmospheric, hydrological, climatological, and agricultural changes have been investigated using classical Mann-Kendall analysis methods [12]. The Mann-Kendall test is used to determine trends in hydrometeorological time series such as flow, temperature, and precipitation [11]. However, testing of the presuppositions of some of the classical trend tests and that the test results provide limited results in the form of no trend, an increasing trend, or a decreasing trend necessitated the development of an alternative method. One of the tests developed as an alternative to these difficulties and deficiencies and which can be applied directly to the series without depending on any basic assumption is the Şen trend test. It is also called innovative trend analysis. The Şen trend test, which does not rely on any pre-acceptance conditions, can be applied to time series of different lengths. The most important feature of the Şen trend test is that it can be applied and interpreted on all data ranges [11].

In recent years, important changes and pressures have occurred regarding water resources due to reasons such as climate change, anthropogenic changes, and various water uses of hydrometeorological variables. Lake Eğirdir, which is located in the west of the Mediterranean region, is one of the largest lakes in the region. Recently, there has been a lot of news about the lake water level, and it has been stated that the lake water level decreases with frequent pressure. The aim of this study was to determine the changes in the annual maximum, average, and minimum values of the water level (LWL) and water volumes (LWV) of Lake Eğirdir. For this purpose, some tests were applied: (1) the dependency (autocorrelation coefficient significance) test (DT); (2) linear regression analysis (LRA), the t-test, and rate of change (RC); (3) elimination of the trend and autocorrelation effects in the series by filtering; and (4) de-trend, the trends in the pre-whitening series were analyzed with the Mann-Kendall rank correlation trend test (MKRCTT) and Şen innovation trend test (SITT).

2. Materials and Methods

2.1. Materials

Lake Eğirdir, located in the lakes region in the west of the Mediterranean region, is Turkey's second largest freshwater lake. It was chosen as the material for this purpose. In this study, the annual maximum, average, and minimum values of the lake water level (LWL, m) and lake water volume (LWV, hm^3) measured between the years 1988 and 2019 by DSI (General Directorates of the State Hydraulic Works) for Lake Eğirdir were used. This study aimed to determine the trend values of the changes in the used lake water level and volume.

Lake Eğirdir, located within the borders of the Eğirdir district of Isparta province, is an important freshwater source, with a karstic and tectonic structure. The karst structure played a role in the formation of Lake Eğirdir, and it was formed by the merging of depression cavities on the main limestone. Lake Eğirdir is fed by underground spring waters and the surrounding streams and springs. The lake depression formed as a result of tectonic origins. Combined with the ancient climate of Anatolia, large water bodies in the region, including Eğirdir, are grouped as pluvial lakes [13,14]. A map of Lake Eğirdir is shown in Figure 1 [15].

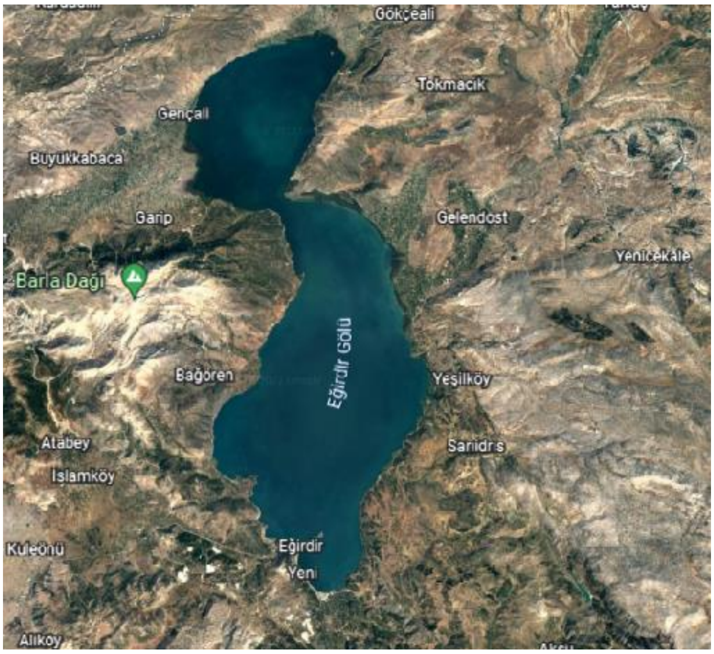


Figure 1. Map of Lake Eğirdir.

The approximate recharge basin of the lake has an area of 3417.04 km^2 and the lake surface area is 480 km^2 on average. Although it varies according to years, its average elevation is 915.0 m and the maximum water elevation is 919.2 m [16,17]. The Lake Eğirdir lake level measurement station and meteorological measurement station features are given in Table 1 [18–21].

Table 1. Features of Lake Eğirdir and the measurement station.

Station	**Coordinate**		**Height (m, a.s.l.)**	**Registration Years**
	Latitude	**Longitude**		
Lake Level Measurement Statom (09–09)	37°53′00′′	30°50′00′′	916	1988–2019
Lake Meteorology Measurement Station (17,882)	37°83′77′′	30°87′20′′	920	1988–2019
	Lake Eğirdir Features			
Height of the lake (m, a.s.l.)			915	
Maximum depth of the lake (m)			13.5–15.00	
Average depth of the lake (m)			8–9	

2.2. Methods

In the study, trend tests (linear regression analysis, Mann-Kendall rank correlation trend test and Şen innovation (innovative) trend test) were applied in order to determine the changes in the measured water level (LWL) and water volume (LWV) of Lake Eğirdir, and the study flow chart is shown in Figure 2.

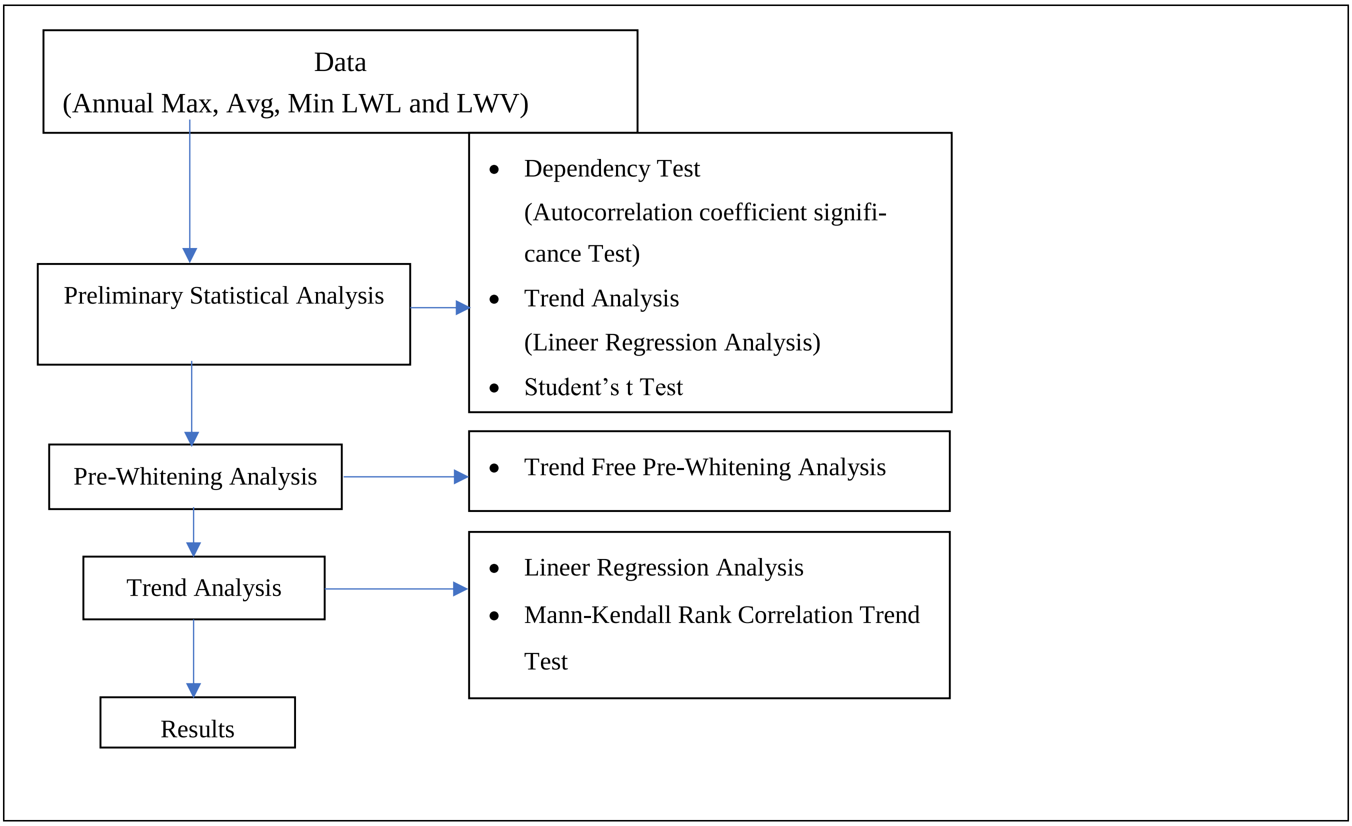


Figure 2. Working flow chart.

2.2.1. Dependency Test (DT)

The consecutive elements of the observation data to be used in any statistical study (such as simulation or frequency analysis) using hydrological or meteorological time series data should be independent of each other. Therefore, the dependency (autocorrelation coefficient significance) test should be applied before using the time series in future studies [22,23].

2.2.2. Autocorrelation Coefficient Significance Test

Data in which hydrometeorological data obtained from observations or measurements are ordered over time is called a time series. Autocorrelation is used to determine whether there is any dependency between the data (x_i) before (x_{i-1}) and after (x_{i+1}) from each data (x_i) in the obtained time series (X_i) [24–31].

In engineering studies that use hydrometeorological observation data, the importance of a delayed autocorrelation coefficient (ρ_1) is generally considered. Therefore, the value of ρ_1 is calculated. The ρ_1 value and two-way confidence limit (*CL*) values at the 95% significance level are calculated and checked. The upper (*CLU*) and lower (*CLL*) confidence breakpoints at the 95% significance level are calculated.

If the value of ρ_1 is in the confidence interval, it is decided that there is no autocorrelation in the time series (H_0: ρ_1 = 0), and if it is outside the interval, it is decided that there is autocorrelation (H_1: $\rho_1 \neq 0$). In the absence of autocorrelation (ρ_1), the data are used in studies to be carried out without making any changes in the time series. However, in the case of autocorrelation (ρ_1), the pre-whitening process is applied to the observation series. The data obtained from the time series are used in studies to be carried out (such as regression analysis) [24,28,32–34].

2.2.3. Linear Regression Analysis (LRA)

The purpose of this analysis is to create a model that predicts the variable (dependent, y) to be determined by making use of the variable or variables (independent, x) that can be obtained more easily or quickly [25,26,32,35–39].

1. Hypothesis tests are used to test whether the β_i coefficients are significant in the developed regression equation. The hypotheses established are: H_0 = no relationship between the dependent and independent variables (β_i = 0), and H_1 = there is a relationship between the dependent and independent variables ($\beta_i \neq 0$), and it is checked whether the parameters are equal to zero.

The t_H value is compared with the table value of the t distribution (t_{Table}) at the chosen significance level (α = 5%) and degrees of independence ($v = n - 2$). If the calculated $t_H > t_{Table}$, it is accepted that the slope is important (H_1 hypothesis), and it is said that the b coefficient is significant. If $t_H < t_{Table}$, the slope is insignificant (H_0 hypothesis) and rejected and it is decided that the coefficient b is statistically insignificant [25,26,38,39].

2.2.4. *t*-Test (Student's *t*)

One of the most frequently used tests in research involving hypothesis testing is the *t*-test. It is used to test whether there is a statistically significant difference between numerical (continuous) variables (or groups) or to determine whether the observed mean value differs from the assumed or predicted (or obtained from previous research) value. In testing (checking) whether the difference between the mean of a single series ($\overline{x}$) or the values of the start of the series ($\overline{x}_1$) and the end ($\overline{x}_2$) is significant H_0: $(\overline{x}_1 - \overline{x}_2) = 0$ or H_1: $(\overline{x}_1 - \overline{x}_2) \neq 0$ hypotheses check), the t_H statistic is used. The following Equation (1) is used for the calculations:

$$t_H = \frac{(\overline{x}_1 - \overline{x}_2)}{\sqrt{\frac{s^2}{n}}}, \quad (1)$$

where:

t_H = calculated test statistic;
$\overline{x}_1$, $\overline{x}_2$ = series start and end average;
n = number of observations;
s = standard deviation.

For the H_0: $\overline{x}_1 = \overline{x}_2$, H_1: $\overline{x}_1 \neq \overline{x}_2$ hypothesis, when the series is divided into two non-overlapping subgroups, the *t*-test is performed according to the conditions that the number of observations of the subgroups is equal or not. While testing the difference between two averages, the following classification is made in terms of test statistics [25,26,32,38–40]. If the series subgroups have equal numbers of data ($n_1 = n_2$), the t_H statistic is calculated using the combined variance according to the Equation (2):

$$t_H = \frac{(\overline{x}_1 - \overline{x}_2)}{\sqrt{\frac{s_1^2 + s_2^2}{n}}}, (n = n_1 + n_2) \quad (2)$$

where:

t_H = calculated test statistic;
$\overline{x}_1$, $\overline{x}_2$ = average of each sub-series;
s_1^2, s_2^2 = standard deviation of each sub-series;
n = total number of data in the series;
n_1, n_2 = number of data for each sub-series.

When the data numbers of the series subgroups are not equal to each other ($n_1 \neq n_2$), the t_H statistic is calculated using Equation (3):

$$t_H = \frac{(\overline{x}_1 - \overline{x}_2)}{\sqrt{\frac{(n_1-1)*s_1^2+(n_2-1)*s_2^2}{(n_1+n_2-2)} * \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}, \quad (3)$$

where:

t_H = calculated test statistic;
$\overline{x}_1$, $\overline{x}_2$ = average of each sub-series;
s_1^2, s_2^2 = variance of each subseries;
n = total number of data in the series;
n_1, n_2 = number of data for each sub-series.

2.2.5. Rate of Change (CR)

This is a test method that is used the percentage of change between the previous and next series data (or periods) between two or more series data to be compared increases or decreases [38,41–43]. Calculations of the rate of change are carried out using Equation (4):

$$CR = \left(\frac{SD_1}{SD_2} - 1\right) \times 100, \quad (4)$$

where:

CR = rate of change (%);
SD_1 = first series average;
SD_2 = second series average.

2.2.6. Pre-Whitening Analysis (PA)

Many filtering or pre-whitening methods are used in statistics. However, in most of the methods, non-stationary time causes some information in the series to disappear during the stationarization of the series [26,44–48]. For this reason, the pre-whitening method proposed by von Storch and Navara [49], which has no information loss and is easy to use among filtering methods, is applied using Equation (5):

$$Y_i = X_i - \rho_1 \times X_{i-1}, \quad (5)$$

where:

Y_i = new (pre-whitening) serial data;
X_i = old serial data;
ρ_1 = lag-1 autocorrelation coefficient of the old (with dependency) series;
X_{i-1} = previous serial data of the X_{i-1} old series;
i = series chronological order number [26,34,49].

2.2.7. Trend Free Pre-Whitening

LRA is applied to the chronologically observed data ($X_t = x_1, x_2 \ldots x_n$) in a hydrometeorological time series to determine the trend/trends in the series. The purpose of removing the trend in the hydrometeorological series is to eliminate or minimize the effects of natural or artificial factors that occur during the chronological acquisition of the series data. Subtraction from the observation series (X_t) by multiplying the slope (β_1) value of the calculated LRA with the time (t) in chronological order is carried out. A new de-trended series (y_t) is obtained according to Equations (6) and (7) [46,50,51]:

$$y_t = x_t - \beta_1 \times t, \quad (6)$$

where:

y_t = de-trend series;
x_t = chronologically ordered (t) observation series value;
β_1 = calculated slope value of the LRA;
t = time in chronological order [41,45–47]:

$$y'_t = y_t - \rho_1 \times y_{t-1}, \tag{7}$$

where:
y'_t = value of the de-trended series at time t;
y_t = de-trend series;
ρ_1 = lagged-1 autocorrelation coefficient of the old (with dependency) series;
y_{t-1} = de-trended series at time $t-1$, the recalculated lag–1 autocorrelation coefficient for the de-trended series is (ρ_1).

To obtain a re-trendless pre-adjusted series (X^*_t), the de-trended pre-corrected residual series is added again by multiplying the slope (β_1) of the calculated LRA with the chronologically ordered time (t) [46,50–52]. The new pre-whitening series with de-trend is calculated using Equation (8):

$$X^*_t = y'_t + \beta_1 \times t, \tag{8}$$

where:
X^*_t = re-trendless pre-adjusted series;
y'_t = value of the de-trended series at time t;
β_1 = calculated slope value of the LRA;
t = chronologically ordered time.

It is determined that the de-trended, pre-whitening series/series (X^*_t) can be used in trend tests such as the Mann-Kendall rank correlation trend test (MKRCTT) and Şen innovation trend test (SITT) in future studies.

2.2.8. Trend Test

The aim of trend analysis is to determine whether there is a significant correlation between the chronological collections of the serial data and the data received. Whether there is a statistically significant trend in a time series is checked with the null hypothesis (H_0). Different methods have been developed to control the null hypothesis, which is expressed as H_0: no trend and H_1: trend [53,54].

2.2.9. Mann-Kendall Rank Correlation Trend Test (MKRCTT)

Since time series data such as temperature, precipitation, and flow are collected by consecutive observations at certain time intervals, the main purpose of trend analysis is to investigate their trends over time to determine irregularities in hydrological processes and to make forward predictions. The non-parametric test is used to determine the trends in the applied series, increasing or decreasing over time. Since the test results are displayed graphically, it can also determine the starting point of the trend [22,55–57]. The features of the distribution function [22,55,57,58], after calculating the total ordinal number Equation (9), average Equation (10), and variance values Equation (11), of MKRCTT can be calculated according to Equation (12):

$$t_i = \sum_{i=1}^{n} m_i, \ \ (2 \le i \le N), \tag{9}$$

$$E(t_i) = \frac{n_i \times (n_i - 1)}{4}, \ \ (2 \le i \le N), \tag{10}$$

$$var(t_i) = \frac{n_i \times (n_i - 1) \times (2n_i + 5)}{72}, \ \ (2 \le i \le N), \tag{11}$$

$$u(t_i) = \frac{(t_i - E(t_i))}{\sqrt{var(t_i)}}, \ \ (i = 1, 2, \ldots, n), \tag{12}$$

where:

m_i = smaller or bigger value after its ordinal number within the ordinal numbers of the serial values;
t_i = m_i total number;
n = number of the observations;
i = serial chronological ordinal number;
N = total number of data in the series;
$E(t_i)$ = series average;
$var(t_i)$ = series variance;
n_i = ordinal number of each data in the series;
$u(t_i)$ = calculated Mann-Kendall rank correlation trend test statistic [22,55,59–61].

2.2.10. Şen Innovation Trend Test (SITT)

In order to determine whether there is a trend in time series data such as hydrological and meteorological data obtained in chronological order, the Şen innovation trend test, which is easier to use and is graphically displayed compared to classical trend test methods, is preferred [62–68]. The process stages of the Şen innovation trend test proposed by Şen [65] are as follows:

1. The slope of the trend test is calculated using Equation (13):

$$s = \frac{2 \times (\overline{y}_2 - \overline{y}_1)}{n}, \tag{13}$$

where:

s = standard deviation;
$\overline{y}_1$, $\overline{y}_2$ = the arithmetic means of each sub-series (first sub-series ($\overline{y}_1$) and second sub-series ($\overline{y}_2$)) formed by dividing the dependent variable series into two;
n = serial total number of data.

2. The relative error of the trend slope is calculated using Equation (14):

$$r_e = 100 \times \left(\frac{\beta_{0r} - \beta_{0g}}{\beta_{0r}}\right), \tag{14}$$

where:

r_e = relative error of the trend slope;
β_{0r} = trend equation β_0 coefficient created by LRA of the new de-trended series;
β_{0g} = β_0 coefficient of the LRA equation created by graphing the two lower series.

It is desirable that the allowable relative error rate is less than the significance level (α) to be selected in the study ($r_e < 5\%$).

3. The cross-correlation coefficient ($\rho_{\overline{y}_2\overline{y}_1}$) is calculated using Equation (15):

$$\rho_{\overline{y}_2\overline{y}_1} = \frac{[E(\overline{y}_2\overline{y}_1) - E(\overline{y}_2) \times E(\overline{y}_1)]}{\sigma_{\overline{y}_2} \times \sigma_{\overline{y}_1}}, \tag{15}$$

where:

$\overline{y}_1$, $\overline{y}_2$ = the arithmetic means of each sub-series (first sub-series ($\overline{y}_1$) and second sub-series ($\overline{y}_2$)) formed by dividing the dependent variable series into two;
$E(\overline{y}_1)$, $E(\overline{y}_2)$ = each subseries slope (first-order moment);
$\sigma_{\overline{y}_1}$, $\sigma_{\overline{y}_2}$ = variance of each subseries slope;
$\rho_{\overline{y}_2\overline{y}_1}$ = the cross-correlation coefficient between two parts.

4. The standard deviation of the trend slope is calculated using Equation (16):

$$\sigma_s = \frac{2 * \sigma}{n} \times \sqrt{\frac{2 \times \left(1 - \rho_{\overline{y}_2 \overline{y}_1}\right)}{n}}, \tag{16}$$

where:

σ_s = standard deviation of the trend slope;
σ = series variance;
n = serial total number of data;
$\overline{y}_1$, $\overline{y}_2$ = the arithmetic means of each sub-series (first sub-series ($\overline{y}_1$) and second sub-series ($\overline{y}_2$)) formed by dividing the dependent variable series into two.

5. The confidence limits of the trend slope (CLU = upper confidence limit, CLL = lower confidence limit) are calculated using Equation (17):

$$CL = 0 \pm t_t \times \sigma_s, \tag{17}$$

CL = confidence limit;
σ_s = standard deviation of the trend slope;
t_t = t distribution is the table value [65].

3. Results and Discussion

In the study, the annual maximum, average, and minimum lake water level (LWL) and lake water volume (LWV) values of Lake Eğirdir between 1988 and 2019 (32 years) were used and their statistical properties are given in Table 2. The changes in the LWL and LWV series measured between 1988 and 2019 in Lake Eğirdir were 7.546% (maximum), 7.388% (minimum), and 7.273% (average). The values of the changes in the measured annual LWL and LWV series by years are given in Figure 3.

Table 2. Statistical variables of the annual LWL and LWV values of Lake Eğirdir.

Variable	Average ($\overline{x}$)		Standard Deviation (σ)		Maximum (x_{max})		Minimum (x_{min})		Coefficient of Change (%)	
	LWL (m)	LWV (hm^3)	LWL (m)	LWV (hm^3)	LWL (m)	LWV (hm^3)	LWL (m)	LWV (hm^3)	LWL (m)	LWV (hm^3)
Maximum	917.5	3566.3	0.57	269.1	918.5	3984.3	916.5	3039.3	0.063	7.55
Average	917.1	3361.7	0.54	244.5	918.1	3774.4	916.0	2872.0	0.059	7.27
Minimum	916.6	3159.2	0.52	233.4	917.5	3613.3	915.6	2683.8	0.056	7.38

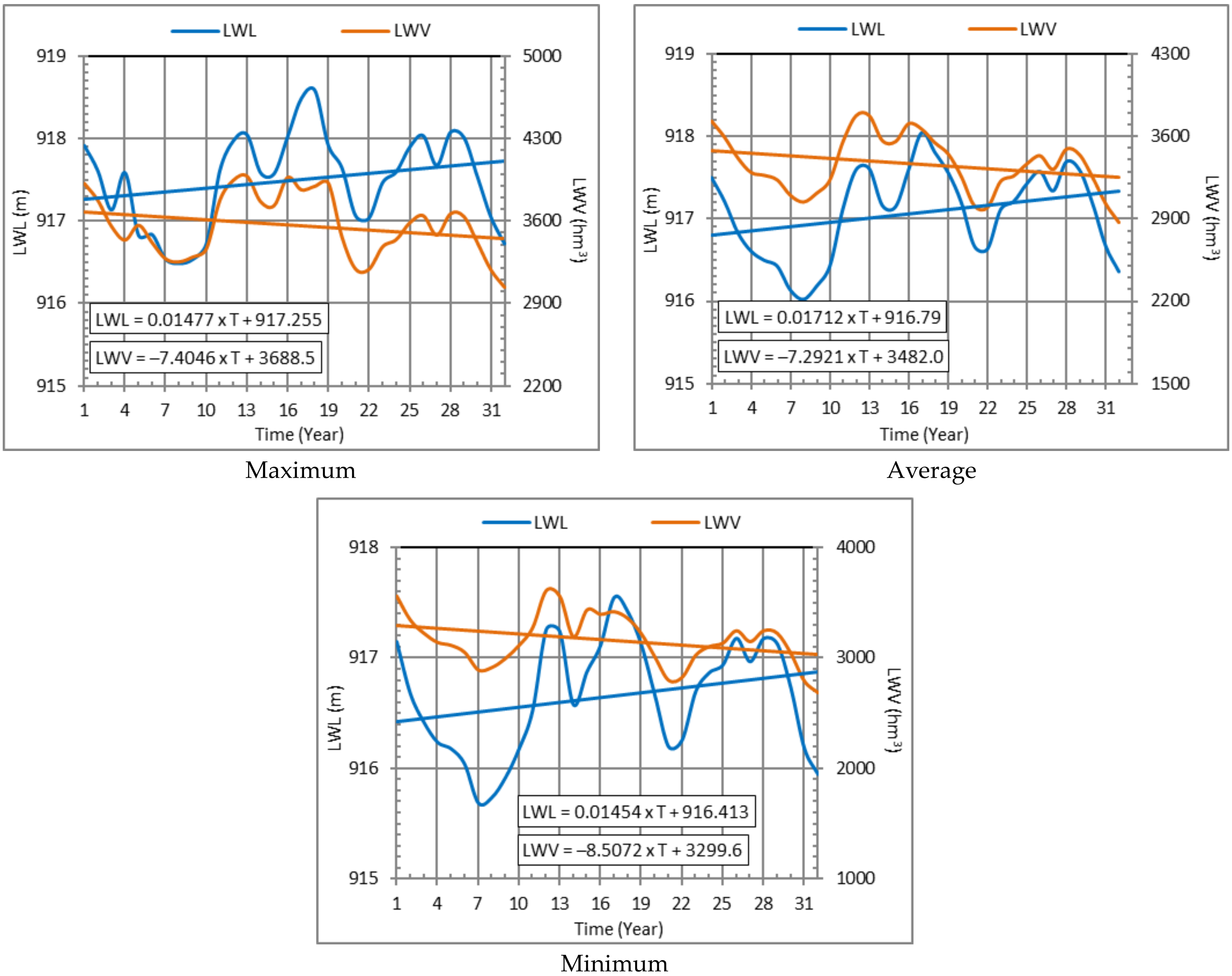
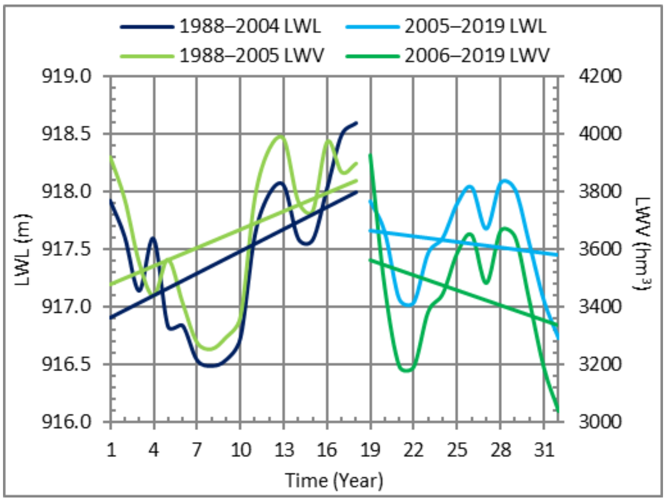


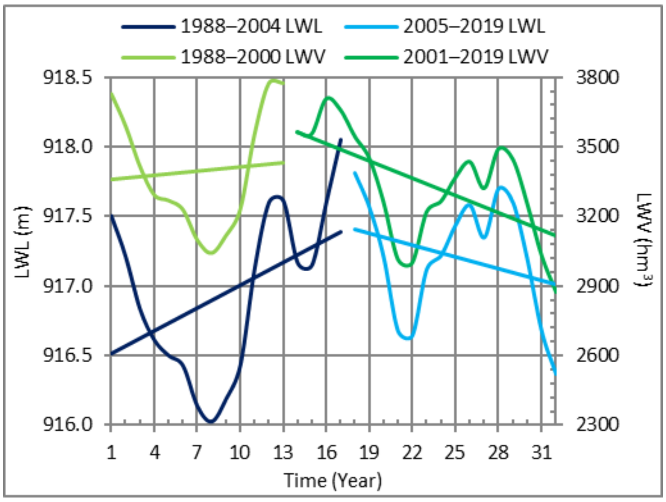
Figure 3. Measured annual LWL and LWV series of Lake Eğirdir.

In order to determine the trends in the maximum, average, and minimum series of the lake water level and volume values measured over time during the observation period, graphs were prepared (Figure 3) and equations were developed with LRA.

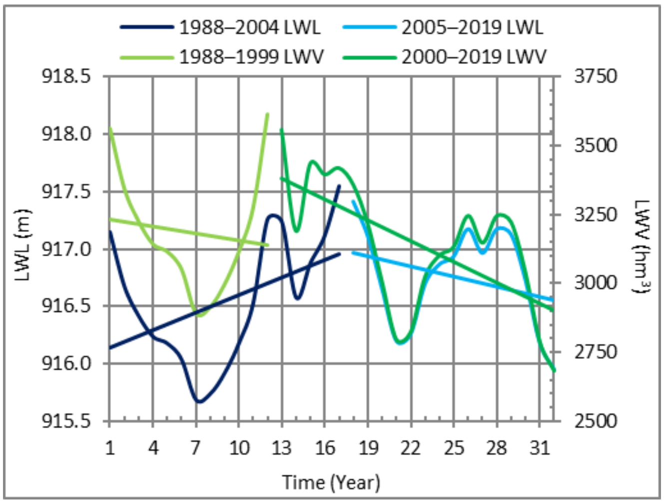
As shown in Figure 3, it was determined that the maximum, average, and minimum values of the lake water level values increased and decreased from time to time, and there was a general decrease in the lake water volume values. In addition, we can say that both the lake water level and the lake water volume have decreased in recent years. However, temporal changes in the hydrometeorological variables affect series data directly and indirectly, causing differences in the random variability of the series [69,70]. Therefore, there may be very important dependencies between the serial data. According to Fethi et al. [16], LWL showed fluctuating changes many times depending on the climate and the water level decreased by 4.5 m between 1969 and 1974, and 3.5 m between 1984 and 1993. They reported that LWL entered a period of decline again between 2003 and 2008. Since LWL and LWV show temporal fluctuations many times depending on the climate, the changes between the annual LWL and LWV series data during different periods should be determined and separated from the series (Figure 4).



Maximum



Average



Minimum

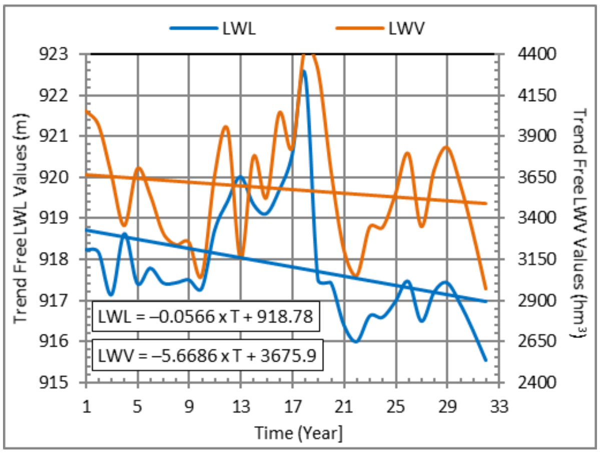
Figure 4. Linear regression analysis for different periods of Lake Eğirdir annual LWL and LWV series.

Visually, it was determined that they showed different changes from each other between 1988 and 2004 and 2005 and 2019 in the LWL series and between 1988 and 2000 and 2001 and 2019 in the LWV series. LRA was carried out for the sub-series at the different periods determined and is presented in Figure 4 and the developed equations are given in Table 3.

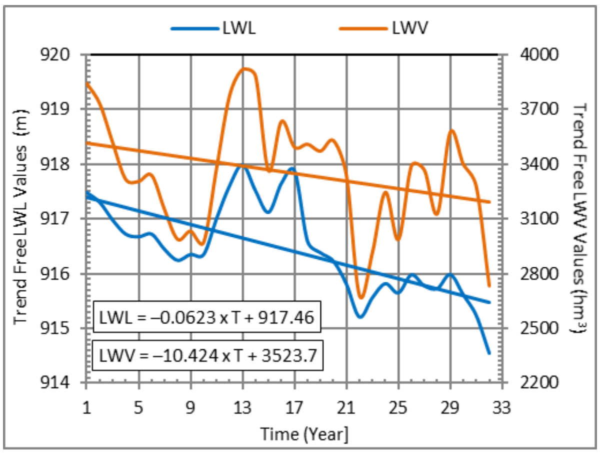
In the sub-series during different periods of the annual maximum, average, and minimum LWL and LWV series, increasing trends were determined in the first period and decreasing trends in the second sub-periods. Using the trend equations calculated for the sub-series during different periods of the LRA and the annual LWL and LWV series, the annual LWL and LWV series, which were subtracted from the general annual LWL and LWV series, were re-trended, and the annual LWL and LWV series were created. Using these annual LWL and LWV series, the LRA equations were developed again for each series and their graphs are shown in Figure 5.

Table 3. Linear regression analysis equations for the different periods of the annual LWL and LWV series.

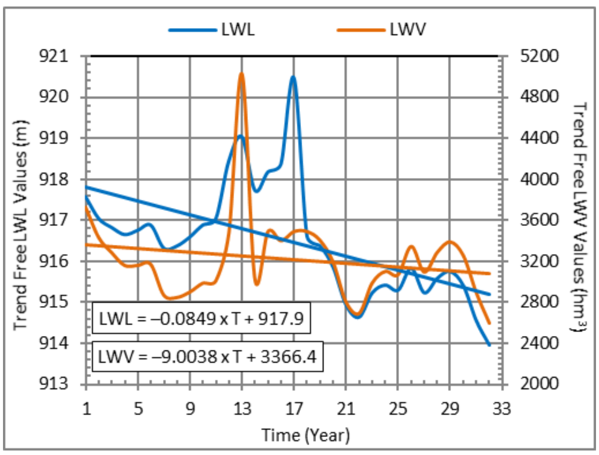
Variable	Period	Equation	Total Number of Data in the Series of Observations (N)	Mean of the Observation Series ($\bar{x}$)	Standard Deviation (s)
Lake Water Level					
Maximum	1988–2004 2005–2019	LWL1 = +0.06413 × T + 916.84 LWL2 = −0.01659 × T + 917.98	18 14	917.45 917.55	0.59 0.45
Average	1988–2004 2005–2019	LWL1 = +0.05427 × T + 916.46 LWL2 = −0.02815 × T + 917.91	17 15	916.55 917.21	0.56 0.44
Minimum	1988–2004 2005–2019	LWL1 = +0.05088 × T + 916.10 LWL2 = −0.02946 × T + 917.50	17 15	916.55 916.77	0.53 0.47
Lake Water Volume					
Maximum	1988–2005 2006–2019	LWV1 = +21.065 × T + 3458.10 LWV2= −17.381 × T + 3891.50	18 14	3658.18 3448.259	242.43 237.01
Average	1988–2000 2001–2019	LWV1 = +5.915 × T + 3552.90 LWV2 = −24.889 × T+3911.80	13 19	3394.29 3339.38	273.06 195.55
Minimum	1988–1999 2000–2019	LWV1 = −8.1228 × T + 3239.40 LWV2 = −25.244 × T + 3710.80	12 20	3186.61 3142.78	240.26 192.02



Maximum



Average



Minimum

Figure 5. Regenerated annual LWL and LWV series for Lake Eğirdir.

3.1. Dependency Test Results

Using the regenerated annual LWL and LWV series, the presence of dependencies between the series data was examined by the dependency test. In this study, the autocorrelation coefficient significance test was performed to determine whether a dependency between the annual maximum, average, and minimum LWL and LWV serial data existed. In the autocorrelation coefficient significance test, the lagged-1 autocorrelation coefficients were calculated for both measured values of the LWL and LWV serial data.

According to the dependency test, the annual maximum (0.725), average (0.780), and minimum (0.749) between the measured LWL serial data and between the LWV series data maximum (0.668), average (0.718), and minimum (0.659) were found to have significant autocorrelations, respectively. Yücel et al., Hirsch, McCuen, Hamed, and Bayazit [22,23,25,46,54] emphasized that the use of the autocorrelated versions of hydrometeorological series in studies such as trend testing, frequency analysis, and simulation leads to erroneous results. Therefore, after removing the autocorrelations (ρ_1) between the LWL and LWV serial data, according to the dependency test results, it was determined that insignificant autocorrelations between the maximum, mean, and minimum values of the LWL and LWV series exist (excluding the annual average LWL series data).

According to the dependency test performed only between the annual average LWL series data, since the autocorrelation coefficient was outside the statistical 5% upper and lower significance levels, another filtering method was applied to this series data for the second time. The new data obtained after re-filtering the annual average LWL serial data was subjected to the dependency test, and the autocorrelation coefficient was calculated as 0.368. Since the calculated autocorrelation coefficient was greater than the 5% upper and lower confidence limit values, a second time dependency test was applied to the same series in order to eliminate the autocorrelation effect between the series values. It was determined that the autocorrelation coefficient calculated for the second time by regenerating the series was smaller than the 5% upper and lower confidence limits.

With the dependency tests, it was determined that the annual maximum, average, and minimum LWL and LWV serial data were not interdependent. The series slope (β_1) of the equations developed separately for each series was checked for statistical significance ($p < 0.05$) and is given in Table 4.

Table 4. Equation coefficient significance test of regenerated LWL and LWV series.

Variable	Slope Coefficient(β_1)		Standard Error of Slope Coefficient (s_b)		Calculated Test Statistic (t_H)		Table Value of the t Distribution (t_{Table})	Probability $p < 0.05$	
	LWL (m)	LWV (hm^3)	LWL	LWV	LWL	LWV		LWL	LWV
Maximum	−0.0566	−5.6686	0.0268	6.450	−2.110	−0.879	+2.0399	0.043	0.345
Average	−0.0623	−10.4240	0.0260	5.830	−5.180	−1.787		0.000	0.084
Minimum	−0.0849	−9.0038	0.0226	8.080	−3.750	−1.114		0.001	0.274

The trend (β_1) of the equations developed for the annual LWL and LWV series (Table 4) was checked for significance at the 5% significance level (α). It was determined that while they are very important for each LWL series, they are insignificant in the LWV series. Mostly, the maximum and minimum series did not show normal distribution characteristics because they showed a skewed distribution. In order to use such series in studies, it is necessary to carry out statistical transformations [26,28].

3.2. t-Test Results

The t-test is used to check whether there is a significant difference between the sub-series formed according to the time of the change in the series. In order to statistically control the changes determined in each annual LWL and LWV series, t-tests were performed with Equations (1)–(3) and the results are given in Table 5.

Table 5. The *t*-test results obtained by dividing the annual lake water level and lake water volume series in two.

Variable	Period	Total Number of Data in the Series (n)	Average ($\bar{x}$)	Standard Deviation (s)	Calculated Test Statistic ($T_{Calculation}$)	Table Value of the t Distribution (t_{Table})	Significance
$t-$ Test Between Sub $-$ Series ($n_1 = n_2$) Formed by Splitting the Series into Two							
Lake Water Level							
Maximum	1988–2003 2004–2019	16	918.332 917.370	0.956 1.755	−2.723	±2.0399	Significant
Average	1988–2003 2004–2019		917.004 915.869	0.538 0.721	−7.135		
Minimum	1988–2003 2004–2019		917.297 915.700	0.827 1.434	−5.457		
Lake Water Volume							
Maximum	1988–2003 2004–2019	16	3579.502 3585.331	325.243 406.322	+0.0634	±2.0399	Insignificant
Average	1988–2003 2004–2019		3448.929 3254.446	322.527 284.644	−2.558		Significant
Minimum	1988–2003 2004–2019		3308.079 3127.627	525.182 228.506	−1.717		Insignificant
$t-$ Test between Sub $-$ Series ($n_1 \neq n_2$) before and after the Time When the Change in the Series Started							
Lake Water Level							
Maximum	1988–2004 2005–2019	18 14	918.687 916.776	1.410 0.606	−26.755	±2.0399	Significant
Average	1988–2005 2006–2019	13 19	916.907 916.115	0.544 0.883	−16.270		
Minimum	1988–2004 2005–2019	17 15	917.483 915.382	1.110 0.688	−35.810		
Lake Water Volume							
Maximum	1988–2000 2001–2019	18 14	3641.296 3506.714	369.866 350.300	−5.910	±2.0399	Significant
Average	1988–2005 2006–2019	13 19	3407.163 3313.731	329.695 307.906	−4.635		
Minimum	1988–1999 2000–2019	13 19	3309.342 3155.255	578.477 275.193	−5.719		
t-Test Inter Sub-Series before and after the Time When Trend Initiation in the Series							
Lake Water Level							
Maximum	1988–2001 2002–2019	14 18	918.179 917.596	0.917 1.777	−6.311	±2.0399	Significant
Average	1988–2000 2001–2019	13 19	916.907 916.115	0.544 0.883	−16.270		
Minimum	1988–2002 2003–2019	15 17	917.225 915.857	0.803 1.533	−17.524		
Lake Water Volume							
Maximum	1988–1990 1991–2019	3 29	3896.705 3549.904	204.211 361.202	−9.166	±2.0399	Significant
Average	1988–1993 1994–2019	6 26	3510.745 3314.982	231.944 323.880	−7.876		
Minimum	1988–1989 1990–2019	2 30	3577.423 3193.882	202.632 425.203	−7.077		
t-Test of All Series (n)							
Lake Water Level							
Maximum Average Minimum	1988–2019 1988–2019 1988–2019	32	917.851 916.437 916.498	1.473 0.850 1.409	−4277.326 −5621.346 −4367.685	±2.0399	Significant
Lake Water Volume							
Maximum Average Minimum	1988–2019 1988–2019 1988–2019	32	3582.417 3351.688 3217.853	362.049 315.118 423.581	−1065.043 −1068.076 −884.449	±2.0399	Significant

It was determined that there were statistically significant changes in the series according to the *t*-test calculated for the whole series and between the sub-series ($n_1 \neq n_2$) before and after the change in the series, which was formed by dividing each annual LWL series into two ($n_1 = n_2$). However, according to the results of the *t*-test performed between the sub-series ($n_1 = n_2$) formed by dividing each annual LWV series into two, there was a statistically insignificant change (+0.0634) between the maximum LWV sub-series. It was determined that the insignificant differences were in the direction of a decrease (−1.717) between the minimum LWV series first sub-series, but there were very significant differences in the direction of the decrease among the second sub-series. In general, it was determined that there were changes in the direction of the decrease (from −1.717 to −5621.346) between 1988 and 2019 in all LWL and LWV series, especially after 2000 in LWLs and after 1990 in LWVs.

3.3. Rate of Change Results

Change rates were calculated to determine the statistical significance of the changes in the LWL and LWV series in parallel with climate change and global warming, a decrease in precipitation, and an increase in temperature in Turkey (Table 6). As shown in Table 6, it was determined that LWLs decreased at a maximum rate of −0.294%, average rate of −0.321%, and minimum rate of −0.396%, and LWVs at a maximum rate of −36.364%, average rate of −40.637%, and minimum rate of −43.632%. In addition, it was determined that the first sub-series (n_1) of the RCs calculated for all conditions of the series was more homogeneous than the second sub-series (n_2). It was determined that there was a decrease of −0.321% in the annual average LWL series, and a decrease of −40.637% in the LWV series. Davraz et al. [71] stated that evaporation from the lake, agricultural irrigation, and drinking and utility water demand increased, but the water flow into the lake basin decreased. Keskin et al. [72] reported that the greatest water loss from the lake came from evaporation, agricultural irrigation, and drinking and utility water, respectively. It was determined that our findings are consistent with these results.

Table 6. Change rates of the annual lake water level and lake water volume in the period 1988–2019.

Variable	Period	Total Number of Data in the Series (*n*)	Sub-Series Change Rate (%)	Series Change Rate (%)
The CR between Sub − Series ($n_1 = n_2$) Formed by Splitting the Series into Two				
Lake Water Level				
Maximum	1988–2003	16	+0.158	−0.294
	2004–2019		−0.547	
Average	1988–2003		+0.019	−0.321
	2004–2019		−0.364	
Minimum	1988–2003		+0.087	−0.396
	2004–2019		−0.712	
Lake Water Volume				
Maximum	1988–2003	16	+0.333	−36.364
	2004–2019		−28.723	
Average	1988–2003		+5.414	−40.637
	2004–2019		−27.827	
Minimum	1988–2003		+8.754	−43.632
	2004–2019		−34.502	
The CR between Sub-Series before and after the Start of Change in the Series				

Table 6. *Cont.*

Variable	Period	Total Number of Data in the Series (*n*)	Sub-Series Change Rate (%)	Series Change Rate (%)
		Lake Water Level		
Maximum	1988–2005 2006–2019	18 14	+0.463 −0.215	−0.294
Average	1988–2000 2001–2019	13 19	+0.097 −0.201	−0.321
Minimum	1988–2004 2005–2019	17 15	+0.314 −0.290	−0.396
		Lake Water Volume		
Maximum	1988–2005 2006–2019	18 14	+8.723 −44.673	−36.364
Average	1988–2000 2001–2019	13 19	+8.680 −27.068	−40.637
Minimum	1988–2004 2005–2019	13 19	+25.931 −16.574	−43.632
		The CR between Sub-Series before and after the Trend in the Series Started		
		Lake Water Level		
Maximum	1988–2001 2002–2019	14 18	+0.121 −0.390	−0.294
Average	1988–2000 2001–2019	13 19	+0.003 −0.281	−0.321
Minimum	1988–2000 2001–2019	13 19	+0.066 −0.483	−0.396
		Lake Water Volume		
Maximum	1988–1990 1991–2019	3 29	+9.596 −12.909	−36.364
Average	1988–1993 1994–2019	6 26	+8.465 −21.372	−40.637
Minimum	1988–1989 1990–2019	2 30	+7.884 −26.579	−43.632

3.4. Pre-Whitening Method Results

In the pre-whitening method, the serial data derived from the trend equation developed with LRA from the serial data measured in chronological order were extracted using Equation (5) and the de-trended series (y_t) were obtained. The re-correlation coefficients (ρ_1) of the de-trended annual LWL and LWV series were calculated and the statistical upper-lower confidence limits were calculated and are given in Figure 6.

The recalculated lagged-1 autocorrelation coefficient (ρ_1) of the de-trended LWL and LWV series is 0.753 (maximum), 0.669 (average), and 0.776 (minimum) for the LWL series, and 0.794 (maximum), 0.809 (average), and 0.773 (minimum) for the LWV series. The t_t determined that the ρ_1 coefficients of each LWL and LWV series do not remain between the 95% upper and lower confidence limits, and there are significant dependencies between the LWL and LWV series data. Therefore, it was determined that in other stages, instead of the de-trended serial, a pre-whitening and pre-whitening residual serial (y'_t) should be used. The autocorrelation effect was eliminated (y'_t) from the LWL and LWV de-trended series data using Equation (7), and finally, new de-trended, pre-purified series (X^*_t) were obtained from Equation (8). It is decided that these series data can be used statistically and safely in future MKRCTT and SITT from now on.

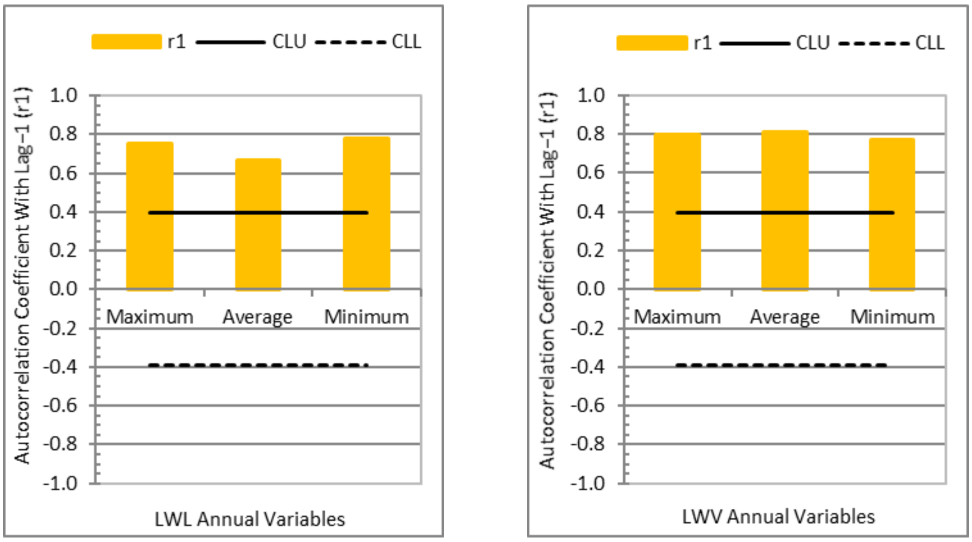


Figure 6. Lagged-1 autocorrelation coefficients of the de-trended LWL and LWV series. CLU = upper confidence limit; CLL = lower confidence limit.

3.5. Mann-Kendall Rank Correlation Trend Test Results

The MKRCTT was performed using the de-trended, pre-whitened new serial data (X_t^*) instead of the measured LWL and LWV serial data. The equations and graphical representations are given in Figure 7.

With this test, this study aimed to determine the magnitude, direction, and approximate start time of the trend in each series (Table 7). According to Figure 7, the approximate start times of the trends were determined as mid-2001 (maximum), mid-2000 (average), and mid-2002 (minimum) in the LWL series, and mid-1990 (maximum), mid-1993 (average), and mid-1989 (minimum) in the LWV series. The trends that occurred depending on the chronological order between the lake water level and volume observation values were the differences between the values of each sub-series.

Using MKRCTT, results were obtained for each LWL and LWV series. It was determined that they were −2.368 (maximum), −4.216 (average), and −3.665 for the LWL series and −1.135 (maximum), −0.616 (average), and −1.058 (minimum) for the LWV series. Accordingly, it was determined that the trends in the LWL series were significant ($CLL < u(t) > CLU$) while the trends in the LWV series were insignificant ($CLL > u(t) < CLU$). In the study of Cengiz and Kahya [69] on the annual average lake water levels in 25 lake stations in Turkey, no trend could be determined in the annual average LWLs of Lake Eğirdir over the 1959–2002 period. Büyükyildiz and Yilmaz [73] studied the water level changes of Turkey's five largest lakes during different periods with MKTT and MKRCTT. In the 1953–2005 period of Lake Eğirdir, at the maximum, minimum, and average water levels, they determined that there was a decreasing trend (−3.57, −4.15, and −3.90, respectively) with the maximum and minimum in 1971, and the average in 1970. Kesici and Kesici [74] argued that this may have occurred due to reasons such as stream flows feeding the lake, precipitation, and decreasing trends of groundwater due to various reasons such as climate change, and increasing evaporation and water use amounts with temperature increases. Goncu et al. [10] investigated the water level changes of Burdur, Egirdir, Sapanca, and Tuz lakes (1943–2005) with non-parametric trend analysis methods such as Mann-Kendall and seasonal-Kendall. They reported that the level of Lake Eğirdir decreased and especially in Kovada I and II HES fed by the lake, the energy production capacity wil decrease and the agricultural activities in the region could be adversely affected. Keskin et al. [72] performed statistical analyses of the monthly water level and lake volume time series of Lake Eğirdir between 1986 and 2016 with the Mann-Kendall trend test and simple linear regression. They stated that there was an insignificant tendency to increase in LWL and LWV during the observation period. Atilgan et al. [14] determined that precipitation decreased significantly in the Lake Eğirdir basin during the period covering the years 1988–2018 and that the maximum, average, and minimum temperatures tended to increase.

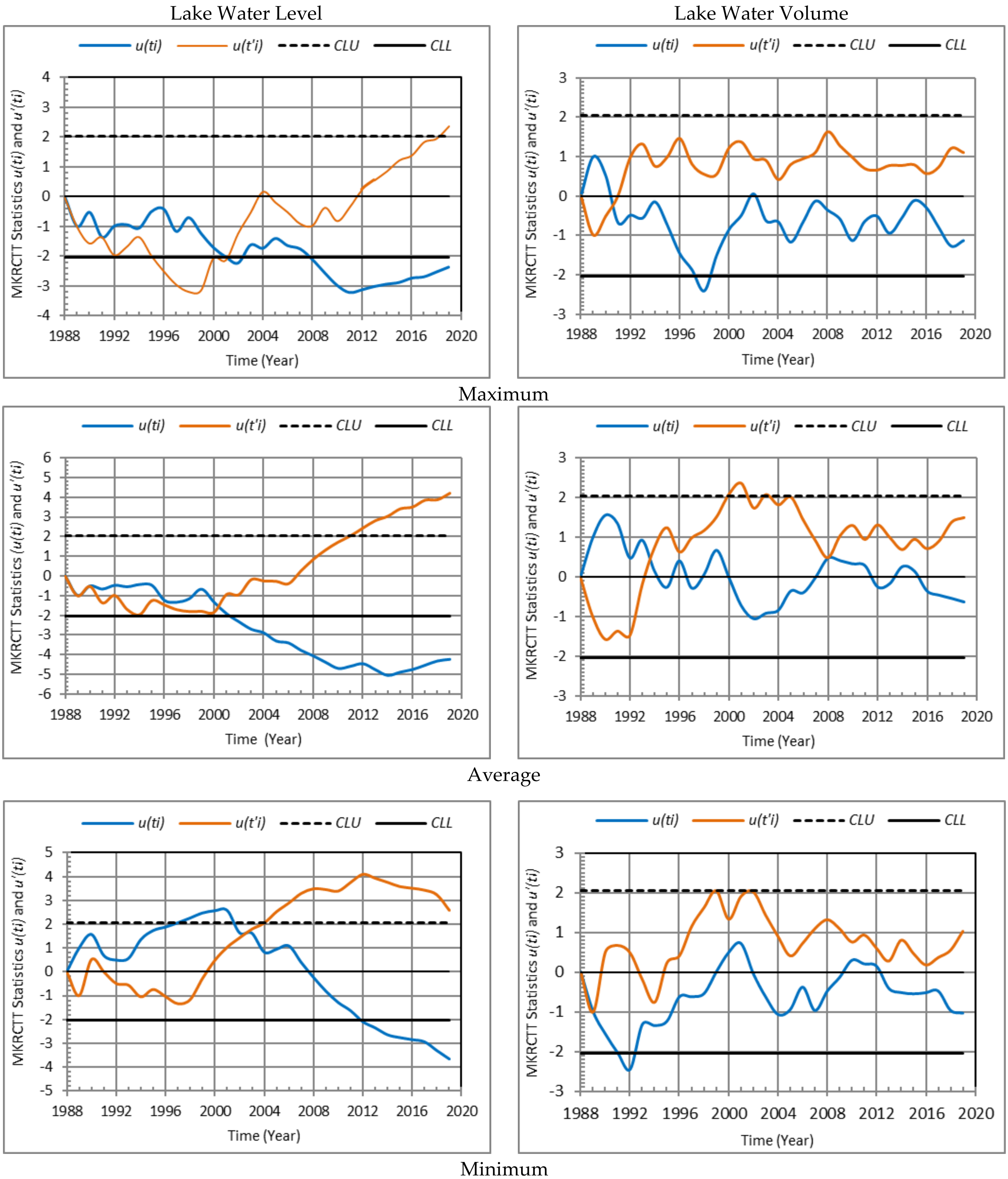


Figure 7. MKRCTT results for the LWL and LWV series. $u(t_i)$ = calculated Mann-Kendall rank correlation trend test statistic; CLU = upper confidence limit; CLL = lower confidence limit.

Table 7. MKRCTT for the lake water level (LWL) and lake water volume (LWV) series.

Variables	Calculated MKRCTT Test Statistics ($u(t)$)		Statistical Confidence Limits		Trend Beginning (Year)		Trend Result	
	LWL	LWV	CLU *	CLL **	LWL	LWV	LWL	LWV
Maximum	−2.368	−1.135	+2.0399	−2.0399	mid-2001	mid-1990	Yes	No
Average	−4.216	−0.616			mid-2000	mid-1993		
Minimum	−3.665	−1.058			mid-2002	mid-1989		

* CLU = upper confidence limit; ** CLL = lower confidence limit.

In the study of Bahadir [75], the water level and volume changes in Kovada Lake and the change in climatic elements in long-term statistical analysis were examined. He determined that the temperature in the study area increased by 0.7 °C, evaporation increased by 120 mm, and the amount of precipitation decreased by 20 mm. It was determined that the change in the lake level and the decrease in the volume of the lake was due to changes in the climatic elements.

In Aydin and Dogu [76], using the long-year water level and climate data of Lake Van, they attempted to propose an opinion on the reason for the change in the level of the lake. They determined that there is a decrease in the average lake water level every 2 years depending on the precipitation, and a tendency to increase in the next year. Statistical analyses also stated that the lake level is affected by the precipitation of the previous year, not the year the precipitation falls.

Zhao et al. [77] analyzed annual and seasonal precipitation, evaporation, and runoff data in the China Poyang Lake basin using non-parametric trend tests (Mann-Kendall and Theil-Şen tests). They emphasized that there is a decreased tendency in dry periods and a 35% decrease in flows in rainy periods. The changes in the water level and volume values we found at Lake Eğirdir are similar to the studies mentioned above.

3.6. Şen Innovation Trend Test Results

Each LWL and LWV serial data recorded in chronological order were divided into two equal halves in the middle. Both sub-series data were separately ordered from smallest to largest. The first sub-series (Y_i) data of each series were arranged on the x-axis and the second sub-series (Y_j) data were arranged on the Cartesian coordinate system on the y-axis, and LRA equations were developed between them. In the Cartesian coordinate system, a 1:1 (45°) line was drawn between the sub-series. According to the first sub-series (Y_i) data of each series, the x-axis in the graph was divided into three different trend intensity regions. In the graph prepared for the series (Figure 8), the direction and level of the trend in the series can be decided according to the positions of the sub-series data pairs (y_i, y_j).

Significant trend differences between the values of each sub-series of the maximum lake water level and the minimum lake water volume general series values were observed, so the series values showed a skewed distribution. Then, as shown in Figure 8, since the first sub-series (Y_i) data (y_i) of each annual LWL and LWV series for the years 1988–2003 showed larger values than the second sub-series (Y_j) data (y_j) for the years 2004–2019, the sub-series in the graphs of the positions of the series pairs (y_i,) remained below the 1:1 (45°) line. In other words, it was determined that there was a decreasing trend in the LWL and LWV series while the series was generally at medium trend levels and there was only a low trend in the minimum LWV series. SITT statistical calculations of the annual maximum, average, and minimum LWL and LWV series of Lake Eğirdir were carried out using Equations (13)–(17) and the results are given in Table 8.

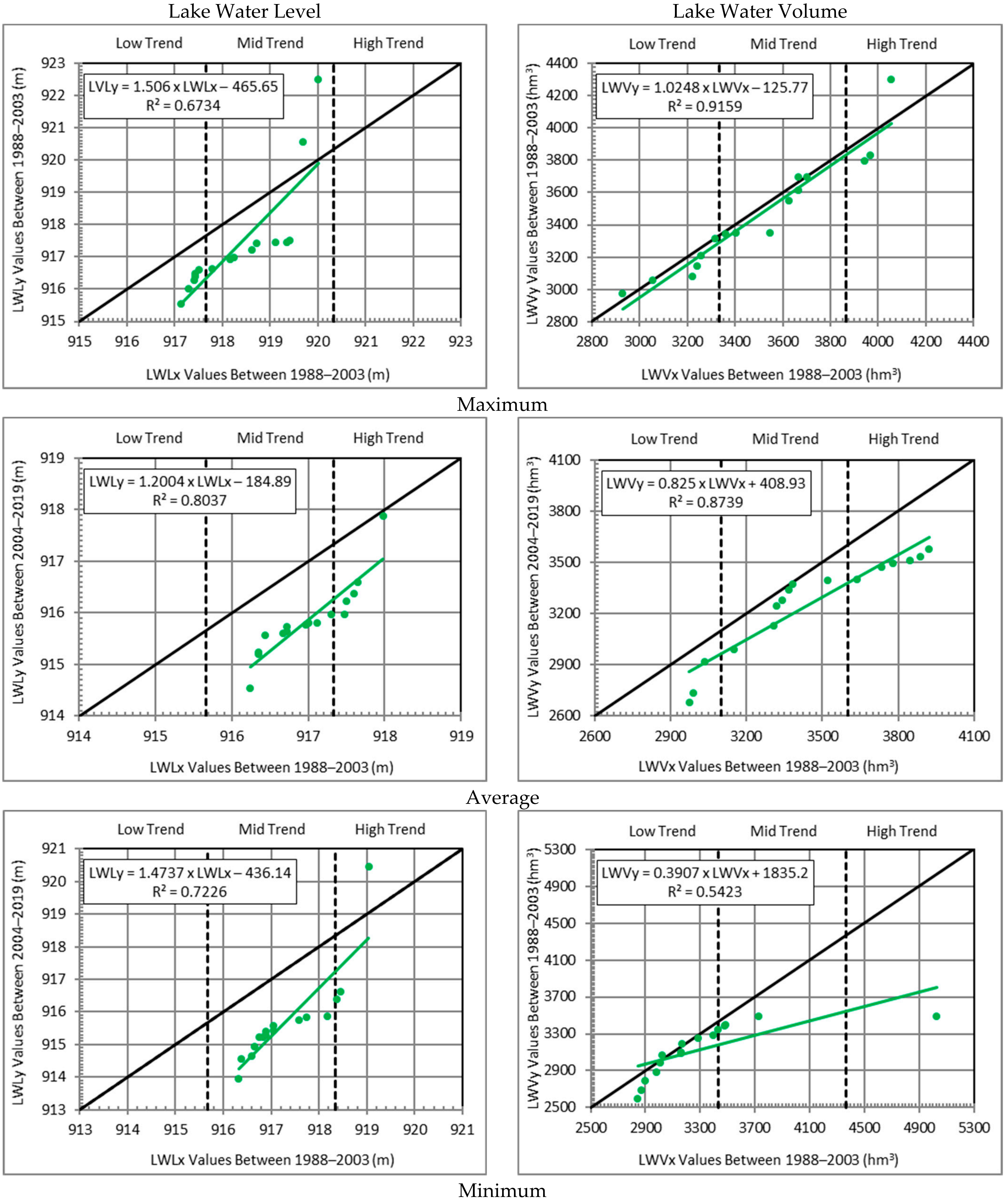


Figure 8. Şen innovation trend test for the annual LWL and LWV series. Dashed lines were used to show the trend levels (low, medium, and high) in each LWL and LWV series. Green dots were used to show a low trend in the minimum LWV series.

Table 8. Şen innovation trend test results for the LWL and LWV series.

Variable	*n* *	Trend Slope (*s*)	Trend Standard Deviation (σ_s)	Trend Correlation Coefficient ($\rho_{LWLx,LWLy}$)	Standard Deviation (σ)	Relative Error (%)	Confidence Limits at 5% Significance		Trend Result
							CLU **	CLL ***	
Lake Water Level									
Maximum	32	−0.03975	0.00975	0.821	1.473	−0.050	+0.001989	−0.001989	
Average	32	−0.07646	0.00428	0.896	0.850	+0.248	+0.008721	−0.008721	Yes
Minimum	32	−0.10982	0.00853	0.850	1.409	−0.119	+0.017392	−0.017392	
Lake Water Volume									
Maximum	32	−2.28063	1.08967	0.957	336.402	+3.817	+2.22281	−2.22281	
Average	32	−11.08250	1.25678	0.935	315.118	+0.020	+2.56370	−2.56370	Yes
Minimum	32	−33.81688	3.39780	0.736	423.581	−6.067	+6.93117	−6.93117	

* n = number of the observations; ** CLU = upper confidence limit; *** CLL = lower confidence limit.

The SITT compliance was carried out by comparing the trend slope (*s*) value calculated for each annual LWL and LWV series with the lower (CLL) and upper (CLU) confidence limit values. Since the trend slope (*s*) value calculated for each series was greater than the CLL and CLU limit values, there was a trend in the series. According to the SITT results (Table 8), in each annual series (-0.039 m year^{-1} (maximum), -0.076 m year^{-1} (average), and -0.109 m year^{-1} (minimum) in the LWL series, and -2.280 hm^3 year^{-1} (maximum), -11.082 hm^3 year^{-1} (average), and -33.816 hm^3 year^{-1} (minimum) in the LWV series), moderately decreasing trends were determined. It was determined that the maximum decrease in the LWL series was -0.109 m year^{-1} in the minimum LWL series and the maximum decrease in the LWV series was in the minimum LWV series with -33.816 hm^3 year^{-1}. The SITT test results were determined to support the MKRCTT results.

Decreases in the level and amount of water in Lake Eğirdir are important for the future position of the lake. In their study of Lake Eğirdir in Büyükyildiz and Yilmaz, they stated that the decrease in the water level and volume should be taken into account and it is very important for the region. Our findings show that the water level and volume of the lake have decreased. Therefore, it is consistent with our study [73]. In order to protect our natural water resources, climatic events, waste management, and drinking and irrigation water planning should be carried out together. Water management planning should consider not only meteorological events but also environmental pollution, agricultural irrigation activities, and energy production to protect our water resources and take more correct steps to protect our resources.

4. Conclusions

This study was carried out in order to determine the trends of changes in the water level and volume values of Lake Eğirdir. For this purpose, the tests given in the method section were used. According to the MKRCTT results, it was determined that the first trends formed in the lake water level after the 2000s and after the 1990s in the lake water volume. In particular, trends towards a significant decrease in the water level and volume of Lake Eğirdir were determined. In addition, the magnitude and direction of the trends formed using SITT were determined. The water level and volume of Lake Eğirdir and the values we obtained are important for the future use and function of the lake. The climatic changes in the lake basin and the decrease in the water resources feeding the lake wereshown as the biggest factor in these reductions. The continuous decrease in the water level and volume of the lake may restrict the use of the water in the lake and cause drought and similar hazards. Therefore, it appears that we should carry out conservation and water management planning together in order to benefit more profitably from our lakes and similar natural water resources. For this purpose, while making plans to protect our water resources, more correct steps to protect our resources need to consider not only meteorological events but also environmental pollution, water management plans, and energy production.

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