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ANALYSIS OF CLIMATIC TRENDS IN EVAPORATION FOR ÇANAKKALE (TURKEY)

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ABSTRACT:*In this study, temporal changes and trends in the series of annual, seasonal, and monthly evaporation of Çanakkale station of Turkish State Meteorological Service were analyzed. Time series of evaporation data set has been organized as climatological seasons that spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February). Non-parametric tests and Box-Jenkins method were used to determine climatic trends. Pettitt change-point analysis was applied to determine the change point of evaporation. Trend analysis results showed that a statistically significant increasing trend occurred in evaporation. Mean annual evaporation is estimated to increase 1.4498 mm per year and it is anticipated to reach 215.3356 mm in 2022. Furthermore, mean seasonal evaporation are estimated to increase 1.2251 mm, 1.6485 mm, and 0.4117 mm per year for spring, summer, and autumn, respectively. Therefore, Çanakkale is thought to be affected by global warming and climate change and this effect will continue. Evaporation should be continuously measured and monitoring program should be established to allow sustainable use and management of water resources. Global or regional climate change scenarios and projections must be considered in order to moderate the possible effects of climate change and global warming on Çanakkale.*

Key words*: Climate change, Evaporation, Trend analysis, Çanakkale*

1. Introduction

Evaporation is an important climatic factor affecting life of animal and plant. Changes in evaporation have big effect on management and planning of water resources, agricultural production, and irrigation control [1]. Climate change resulting from global warming has a significant impact on evaporation. Therefore, availability of water resources are affected by these changes [2]. Although changing climatic conditions, determination of evaporation trends will contribute to revealing the possible effects of climate change on evaporation.

Several authors analyzed climatic trends in evaporation that lead to different results for many regions around the world. Increasing trends in evaporation were reported in Israel [3], Brazil [4], eastern Asia including Tibetan Plateau, China and Japan [5], western Africa [6] and Iran [7]. On the other hand, decreasing trends were also reported in the USA [8], the USA and former Soviet Union [9], Italy [10], Australia [11], Japan [12], China [13-14], Thailand [15-16], Canada [2], and India [1, 17]. In Turkey, although many researchers [18-33] have investigated climatic changes in temperature and precipitation, the same interest has not been shown for evaporation. However, studies conducted on temporal trends in evaporation have been reported to be slightly different results in different regions. [34] found a declining trend in the evaporation in the south east of Turkey. Nevertheless, [35] reported that evaporation in 5 of the 9 stations evaluated in the study conducted in the west of Turkey showed a tendency to decrease while it showed an increasing tendency at 4 stations. In other studies carried out in the west of Turkey, increasing trend in evaporation have been reported [36-41].

Çanakkale plays a key role and makes a huge contribution for national agriculture production. Any major change in water structures can have serious consequences for hydrological processes. Therefore, studies on the monitoring of evaporation levels in Çanakkale are important for the sustainable use and management of water resources and agricultural activities. In this context, this study has been carried out to investigate the temporal changes of evaporation in Çanakkale by annual, seasonal and monthly analyses and to determine climatic trends of evaporation.

2. Material and Method

2.1. Study Area and Climatic Data

Climatic data used in this study were obtained from Çanakkale meteorological observation station (**Figure 1**) of Turkish State Meteorological Service (TSMS). These climatic data consists of measured evaporation data between 1971 and 2011. Time series were arranged as climatic seasons that spring (March, April, May), summer (June, July, August), autumn (September, October, November) and winter (December, January, February).

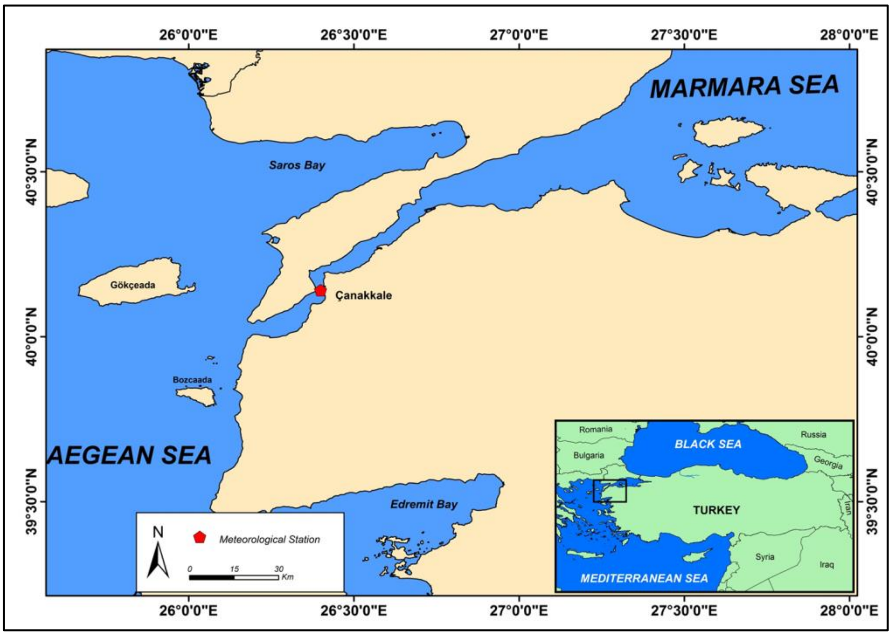

Figure 1. The location of the meteorological observation station

Çanakkale is located in the west of Turkey. It is surrounded by Aegean Sea, Marmara Sea and Çanakkale Strait. It has a transition climate type and summer is hot and dry while winter is cold and rainy. Mean monthly temperatures show that July is the warmest month while January is the coldest month with the long term averages of 6.4°C and 25°C [42].

2.2. Change Point Analysis

A non-parametric approach developed by Pettitt [43] was used to determine the change point of evaporation data. This approach determines a significant change in the time series which is time of change is exactly unknown. This non-parametric test is described below:

$$K_T\text{=max}\left|U_{t,T}\right| \text{ and for } t = 2,\ldots\ldots,T,$$

$$U_{t,T} = \sum_{i=1}^{t}\sum_{j=t+1}^{T} sgn(x_i - x_j)$$

$U_{t,T}$ confirms that whether both samples are in the same population or not. The null hypothesis of Pettitt test is that there is no change point in the dataset. Test statistic (K_T) and related probability (p) are used for significance calculating. The probability of significance for the test statistic is estimated with

$$\text{p} \cong 2\exp\left(\frac{-6\ \text{K}_\text{T}^2}{\text{T}^3+\text{T}^2}\right)$$

Pettitt change point analysis was executed with the usage of “trend” package [45] in R statistical software [44].

2.3. Trend Analysis

Trend analysis is the widely used method for detecting changes in the time series of climatic data [46]. Box-Jenkins method was applied for determining trends in mean annual, seasonal, and monthly evaporation. This method is based on linear, discontinuous and stochastic processes, and used for forecast and analysis of a time series. Autoregressive (AR), moving average (MA), and Autoregressive-moving average (ARMA) models are used for stationary processes while autoregressive integrated moving average (ARIMA) is used for non- stationary processes. These models aimed to decide that which model fits best and includes least parameter [47]. ARIMA model used in this study is explained as follow:

$$X_t = c + \Phi_1 X_{t-1} + \cdots + \Phi_p X_{t-p} + \theta_1 e_{t-1} + \theta_q e_{t-q} + e_t$$

X_t is a variable that will be explain at t time, Φ is the coefficient of per p parameter, θ is the coefficient of per q parameter, c is the constant, and e_t is error at t time.

2.4. Mann-Kendall Test

Non-parametric Mann-Kendall test [48-49] is a commonly used test for determining trends in the time series. Average is affected by extreme values in the dataset. [36] pointed out that Mann-Kendall test is an effective test to determine the trends in the time series contain extreme values. Kendall’s tau and Spearman’s rho tests were applied to investigate possible trends in evaporation. These non-parametric tests provide more fitting and trustworthy results than parametric tests. Mann-Kendall test is explained below.

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn(x_k - x_i)$$

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, & S > 0 \\ & S = 0 \\ \frac{S+1}{\sqrt{var(S)}}, & S < 0 \end{cases}$$

Z_c is the test statistic, H_0 will be rejected if $|Z_c| > Z_{1-\alpha/2}$ when $Z_{1-\alpha/2}$ is standard normal variable and α is the degree of significance. Trend magnitude can be determined as follow:

$$\beta = Median\left(\frac{x_i - x_j}{i-j}\right), \forall_j < i$$

where $1 < j < i < n$. A negative value of β indicates a decreasing trend while a positive value of β indicates an increasing trend.

3. Results and Discussion

Time series were identified and change points of evaporation were determined annually, seasonally and monthly. There are no records of evaporation measurements for winter period including December, January, February and March.

Pettitt's change point analysis results indicated that change point for mean annual evaporation was 1992 (**Table 1**). Trend analysis results pointed out that mean annual evaporation has increasing trend (**Figure 2**). This increase was found statistically significant ($p<0.01$). Mean annual evaporation is forecasted to increase 1.4498 mm/yr and to reach 215.3356 mm in 2022 (**Table 2**).

Table 1. Results of non-parametric statistic tests and change years of evaporation

	Mean Evaporation (mm)	**Pettitt Change Points**	**Mann-Kendall**		**Spearman**	
			tau	***p***	***rho***	***p***
	Annual	1992	0.524^{**}	0.000	0.693^{**}	0.000
Seasonal	*Spring*	1992	0.490^{**}	0.000	0.683^{**}	0.000
	Summer	1992	0.359^{**}	0.001	0.505^{**}	0.001
	Autumn	1984	0.206	0.058	0.292	0.064
	Winter	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]
Monthly	*January*	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]
	February	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]
	March	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]
	April	1996	0.238^{*}	0.028	0.344^{*}	0.028
	May	1993	0.315^{**}	0.004	0.519^{**}	0.001
	June	1992	0.272^{*}	0.012	0.394^{*}	0.011
	July	1992	0.379^{**}	0.000	0.530^{**}	0.000
	August	1995	0.315^{**}	0.004	0.441^{**}	0.004
	September	1995	0.244^{*}	0.025	0.360^{*}	0.021
	October	1992	0.158	0.147	0.202	0.204
	November	1984	0.020	0.889	-0.008	0.971
	December	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]

* *Correlation is found significant at 0.05 level.*

** *Correlation is found significant at 0.01 level.*

[a] *NA indicates that evaporation could not measure due to freezing of the water in evaporation pans.*

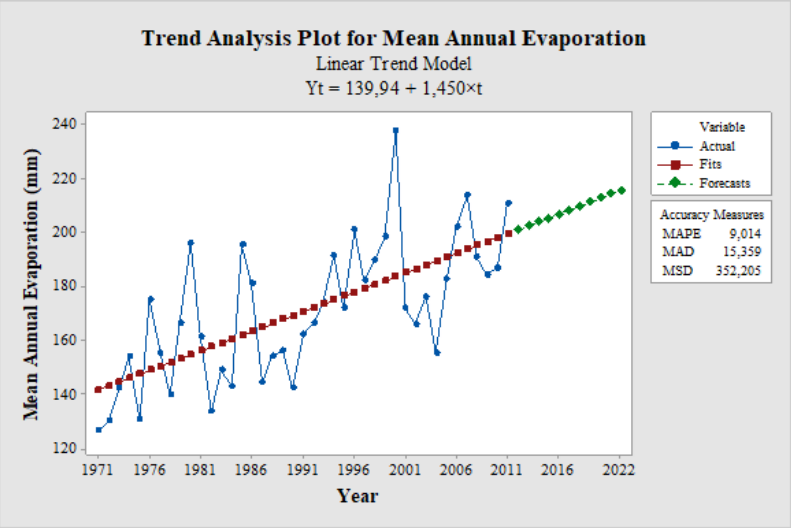

Figure 2. Trend analysis results of mean annual evaporation

Change points of mean seasonal evaporation for spring, summer, and autumn were determined as 1992, 1992, and 1984, respectively (**Table 1**). Results of trend analysis showed that evaporation tends to increase for all seasons (**Figure 3**). This trend was found statistically insignificant for autumn while significant ($p<0.01$) for spring and summer. Mean seasonal evaporation is predicted to increase 1.2251 mm, 1.6485 mm, and 0.4117 mm per season and to reach 174.2956 mm, 295.7466 mm, and 134.2265 mm in 2022 for spring, summer, and autumn, respectively (**Table 2**).

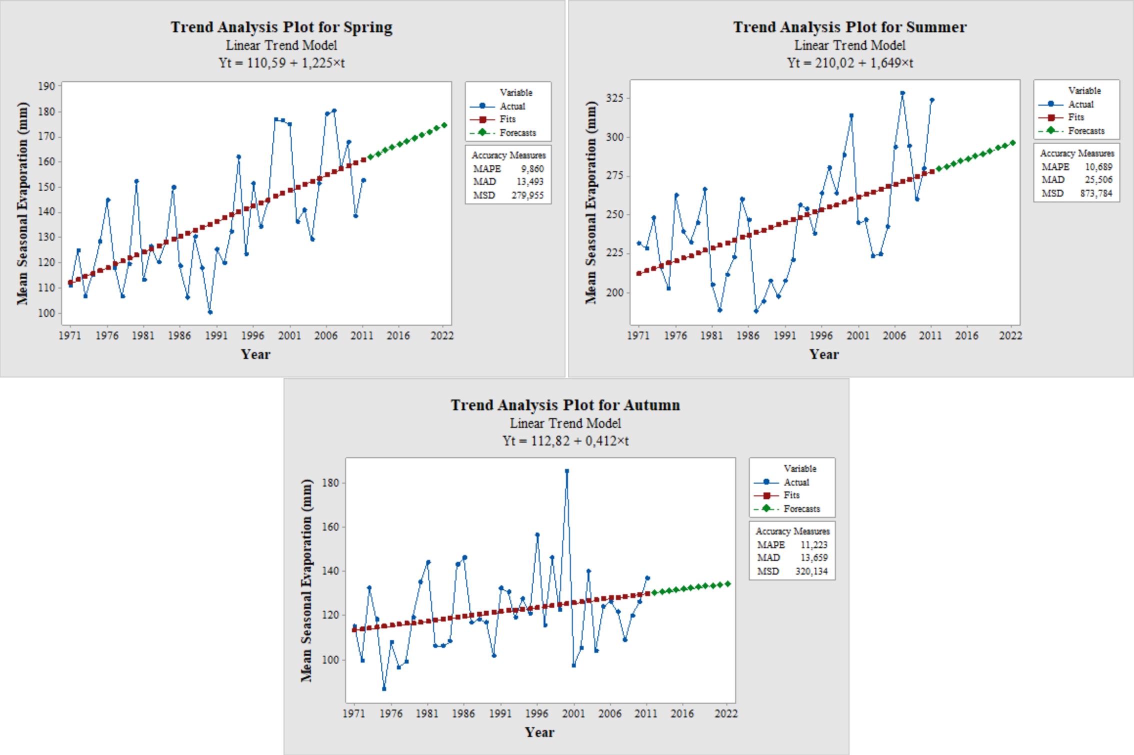

Figure 3. Trend analysis results for mean seasonal evaporation

Change points for mean monthly evaporation were given in **Table 1**. Unfortunately, change point analysis and trend analysis could not be carried out for January, February, March and December because of the evaporation values were not measured due to freezing of the water in evaporation pans. For the other months, trend analysis results pointed out that there were increasing trends for all months (**Figure 4**). These increasing trends were also found statistically significant for all months excepting October and November. Moreover, a significance level was determined at the 0.01 level for May, July, and August while at the 0.05 level for April, June, and September. Mean monthly evaporation is predicted to increase 0.6036 mm/yr, 1.3912 mm/yr, 1.3958 mm/yr, 1.9744 mm/yr, 1.5753 mm/yr, 0.7964 mm/yr, 0.2804 mm/yr and 0.0166 mm/yr from April to November. Furthermore, it is expected that mean monthly evaporation will reach 128.5132 mm, 209.2809 mm, 260.7406 mm, 327.7129 mm, 298.7870 mm, 195.5405 mm, 112.6295 mm, and 61.9774 mm in 2022, respectively (**Table 2**).

Table 2. Forecasted values of evaporation for 2018-2022

Evaporation (mm)		***Years***				
		2018	**2019**	**2020**	**2021**	**2022**
Mean Annual		209.5363	210.9861	212.4359	213.8858	215.3356
Mean Seasonal	*Spring*	169.3951	170.6202	171.8453	173.0704	174.2956
	Summer	289.1526	290.8011	292.4496	294.0981	295.7466
	Autumn	132.5799	132.9916	133.4032	133.8149	134.2265
	Winter	NA*	NA*	NA*	NA*	NA*
Mean Monthly	*January*	NA*	NA*	NA*	NA*	NA*
	February	NA*	NA*	NA*	NA*	NA*
	March	NA*	NA*	NA*	NA*	NA*
	April	126.0989	126.7024	127.3060	127.9096	128.5132
	May	203.7161	205.1073	206.4985	207.8897	209.2809
	June	255.1574	256.5532	257.9490	259.3448	260.7406
	July	319.8154	321.7898	323.7641	325.7385	327.7129
	August	292.4856	294.0610	295.6363	297.2117	298.7870
	September	192.3548	193.1512	193.9476	194.7441	195.5405
	October	111.5079	111.7883	112.0687	112.3491	112.6295
	November	61.9112	61.9277	61.9443	61.9609	61.9774
	December	NA*	NA*	NA*	NA*	NA*

* *NA indicates that evaporation could not measure due to freezing of the water in evaporation pans.*

In this study, maximum evaporation value was recorded in July 2011 by 366.6 mm while minimum value was recorded in November 1975 by 41.6 mm (**Table 3**). The highest mean annual evaporation was calculated in 1971 while the lowest was measured in 2000. For seasonal evaporation values, the highest evaporation was observed in 2007, 2007, and 2000; and the lowest was observed in 1990, 1987, and 1975 for spring, summer, and autumn, respectively. On the other hand, maximum evaporation values for mean monthly evaporation were measured in 2006, 1999, 2000, 2011, 2007, 2000, 2000, 1998; and minimum values were measured in 1990, 1987, 1988, 1982, 1975, 1977, 1975, 1975 from April to November, respectively (**Table 3**).

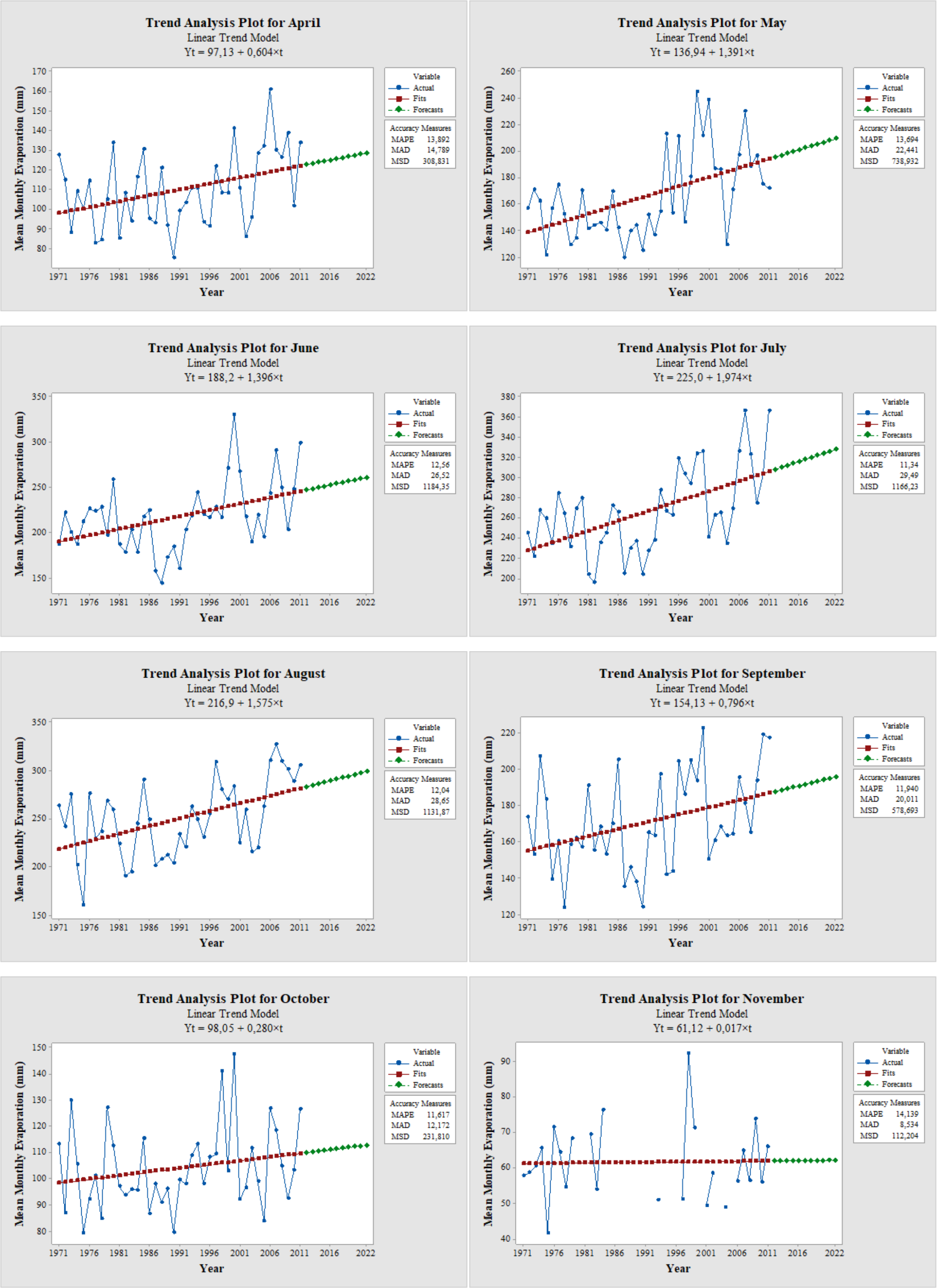

Figure 4. Trend analysis results for mean monthly evaporation

Table 3. Maximum and minimum values of mean evaporation for annual, seasonal and monthly

Period	**Mean Evaporation (mm)**	
	Maximum	***Minimum***

	Annual	126.33	237.53
Seasonal	*Spring*	100.30	180.10
	Summer	187.67	328.07
	Autumn	86.70	185.00
Monthly	*April*	75.40	161.20
	May	119.60	245.00
	June	144.20	330.70
	July	195.50	366.60
	August	159.80	327.10
	September	123.70	222.60
	October	79.20	147.40
	November	41.60	92.10

Evaporation measurements are requiring both more time and high-costly equipment [50]. Moreover, measurements could not be carried out due to the freezing of the water in evaporation pans when the air temperature is low. On the other hand, it is widely known that evaporation occurs during periods even the temperature is low. Evaporation occurs at high level in hot periods while at low level in cold periods.

A better understanding of future trends in evaporation due to climate change is of a great importance. This requires to revealing the structure of local or regional changes and the response given to the observed changes in a better way [51]. There are many studies worldwide that found both increasing and decreasing trend for evaporation. [8] reported a significant decreasing trend in the USA, Europe, Middle Asian and Siberian regions of the former Soviet Union for the period of 1945-1990. Decreasing trends were also reported in India [1, 17, 52], Canada [2], Italy [10], Japan [12], China [13-14], Australia [11], and Thailand [15-16]. [53] pointed out that evaporation for New Zealand was decreasing 2 mm annually since 1970. [54] stated that evaporation was statistically significantly decreased with average 3.3 mm/yr in Mexico for 1961-2010. On the other hand, statistically significant increasing trends were also reported in the south of Europe [55] and Middle East [56]. The largest change was reported by 97 mm increase for the western USA in a warm season during past 45 years [57]. Likewise, increasing trends were reported in Israel [3], Brazil [4], eastern Asia [5], western Africa [6], and Iran [7]. In Turkey, [34] reported a decreasing trend while [35] reported both decreasing and increasing trends in different regions. [38-41] reported increasing trend and forecasted to increase in the future projections. Similarly, in this study, evaporation is predicted to increase by annual, seasonal and monthly analyses.

Although there are contradictions in the results of studies on climatic trends of evaporation, there are different ideas to explain this paradox. Worldwide studies have shown that evaporation is affected by climatic factors such as wind speed [58-60] and air temperature [38-41, 61]. [57] reported that the decrease in evaporation is also related to the decrease in temperature and the increase in low cloud cover.

Therewithal, [62] reported that increased evaporation may be associated with global warming. Therefore, it is known that evaporation will increase with the temperature increases. Similarly, the results of this study also show that the evaporation tends to increase with the effect of the increase in temperature due to global warming.

4. Conclusion

In conclusion, it has been determined that there is a statistically significant upward trend in mean annual, seasonal and monthly evaporation for Çanakkale. It is predicted that evaporation will increase in future projections. Therefore, Çanakkale is thought to be affected by global warming and climate change and this effect will continue. Monitoring the changes in the amount of evaporation contributes to the prediction of changes in the volumes of available water resources. Evaporation should be continuously measured and monitoring program should be established to allow sustainable use and management of water resources and to continue of agricultural activities in an efficient manner. Global or regional climate change scenarios and projections must be considered in order to moderate the possible effects of climate change and global warming on Çanakkale.

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