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Effects of Climate Change on Annual Streamflow of Kocabaş Stream (Çanakkale, Turkey)

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Authors' contributions

This work was carried out in collaboration between all authors. Author TE designed the study and wrote the first draft of the manuscript. Author SK managed the literature searches, GIS works and statistical analyses. Author OH managed the statistical analyses and draft of the manuscript. Author SA managed the stream flow data for analyses. Author FM managed the climatic data for analyses. All authors read and approved the final manuscript.

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ABSTRACT

Climate change due to global warming have effects upon sustainable use of natural resources. Climatic parameters such as temperature, evaporation and precipitation obtained from 3 meteorological observation stations, and streamflow data of Kocabaş Stream were used to understand the effects of global warming on annual streamflow of Kocabaş Stream. Change years were determined and trend analysis was applied for climatic parameters and streamflow of the river. As specified in the results of analyses it could be enunciated that there was a visible increase in temperature and evaporation, and that there was a decrease in precipitation and annual streamflow of the river. Change year was determined as 1981 for streamflow of the river and trend

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analysis results showed that the streamflow has a decreasing trend and the annual amount of this decrease is predicted to be 0.025005 $m^3 s^{-1}$. Trend analysis results for climatic parameters showed that there is a decreasing trend in precipitation and increasing trends in temperature and evaporation. The paper indicates that the effects of climate change on annual streamflow of the river could be variable and that many effects such as agricultural activities, anthropogenic effects, and geographical location should be considered in predicting of climate change effects on river systems.

Keywords: Climate change; streamflow; trend analysis; change-point analysis; Turkey.

1. INTRODUCTION

Climate change associated with global temperatures rises and precipitation levels changes is originated from increases in the greenhouse gases emissions [1]. These changes can lead to significant decreases in the available water levels in some regions in the world. It means that water shortages or water stress in the availability of resources in sectors such as potable water supplying, agriculture and energy based on water may occur. Changes in temperature and precipitation may lead to an increase in total annual temperature approximately 3-3.5℃ and a decrease in total annual precipitation about 15%-30% in the Mediterranean and south of Europe regions [2,3].

Many studies have published about variations in temperature and precipitation regimes have an impact on streamflow of rivers. Zhang et al. [4] investigated the effects of climate change on the streamflow of the Dongliao river basin and stated that annual streamflow was displaying a decrease trend and that, a significant decrease in the summer and autumn linked to precipitation. Bozkurt and Sen [5] investigated the effects of the climate change on Fırat and Dicle river basins and reported that there was a statistically significant decrease in annual streamflow of the rivers. Herawati et al. [6] stated that the annual streamflow of Kapuas River has a tendency to decrease and that the hydrological characteristics of the river changed attributable to the climate change. Zhou et al. [7] investigated the effects of climate change and anthropological activities on the streamflow of Huangfuchuan river basin and claimed that there was a decrease in the streamflow of the river. Pumo et al. [8] studied the effects of the climate change on streamflow of non-perennial small river basin and reported that annual streamflow of the rivers presented a decrease related to the precipitation and that there were significant changes in the seasonality of streamflow.

Different methodologies can be used to predict the effects of climate change on the hydrology of rivers. Mathematical modelling is the key tool in predicting these effects, however, there are some handicaps in that the consequences gained from the modelling do not ensure that the reciprocal collaboration between ecosystem components is known enough. Otherwise, mechanical intellectual capacity can be developed in controlled experiments nevertheless productive results may usually not be reached linked to area and time.

The aim of this study is to investigate the effects of climate change on Kocabaş Stream by execution an extrapolation of time-based dynamics. Forty-two years of climatic data and 40-years of streamflow data belongs to the Kocabaş Stream will be utilized and the time series of temperature, evaporation, precipitation and streamflow of the river will be produced. Then, the change points will be specified and forthcoming projections will be foreseen by applying trend analysis. Furthermore, the relationships among climatic parameters and hydrological processes of the river will be investigated.

2. MATERIALS AND METHODS

2.1 Study Area

Kocabaş Stream arises from the Ida Mountains and runs through districts of Yenice, Çan, Biga and Karabiga of Çanakkale province, respectively. The river flows into the northern coasts of Çanakkale which is on the southwest of Marmara Sea. Kocabaş Stream is also as known as Biga Stream. Kocabaş Stream is 80 km in length [9] and has various substrata types changing from silt to gravel and it has slow streamflow [10]. Its discharge is about 15-20 m^3sn^{-1} and the highest discharge was recorded as 1345 m^3sn^{-1} [9].

Temperature, evaporation and precipitation data collected from 3 meteorological observation stations belong to the Turkish State Meteorological Service of General Directorate of Meteorology were utilized as elementary climatic parameters. These meteorological observation stations are Bozcaada, Gökçeada and Çanakkale (Fig. 1) located in the coasts of Çanakkale province. Annual average streamflow data belongs to Kocabaş Stream (Fig. 2) was used with the approval of the General Directorate of State Hydraulic Works (DSİ). Discontinuous data in the dataset of river streamflow was taken out and a new dataset was formed by recording sustainable data and a 40 years dataset covering the years between 1968 and 2007 was analysed. Forty-three years of dataset for climatic parameters belong to 1970 - 2012 years were analysed.

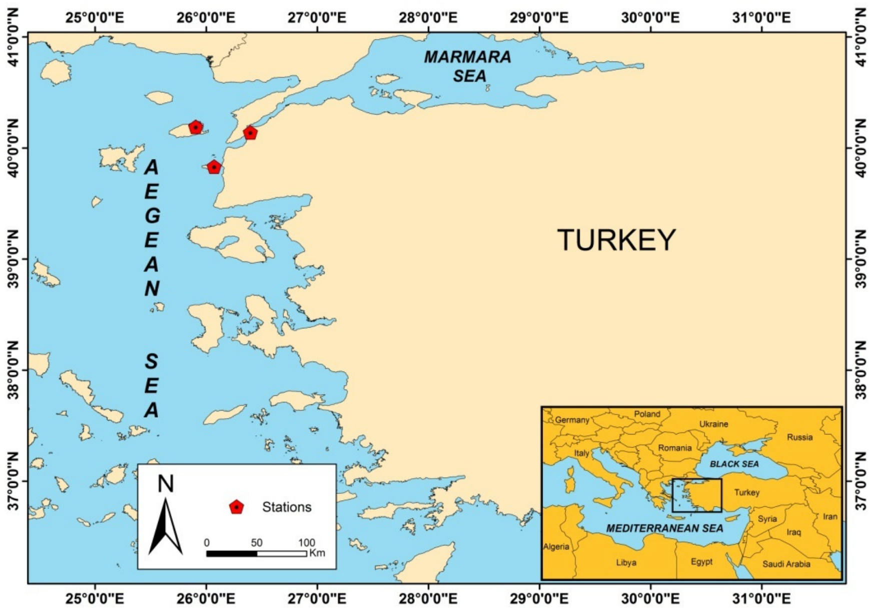

Fig. 1. Meteorological observation stations

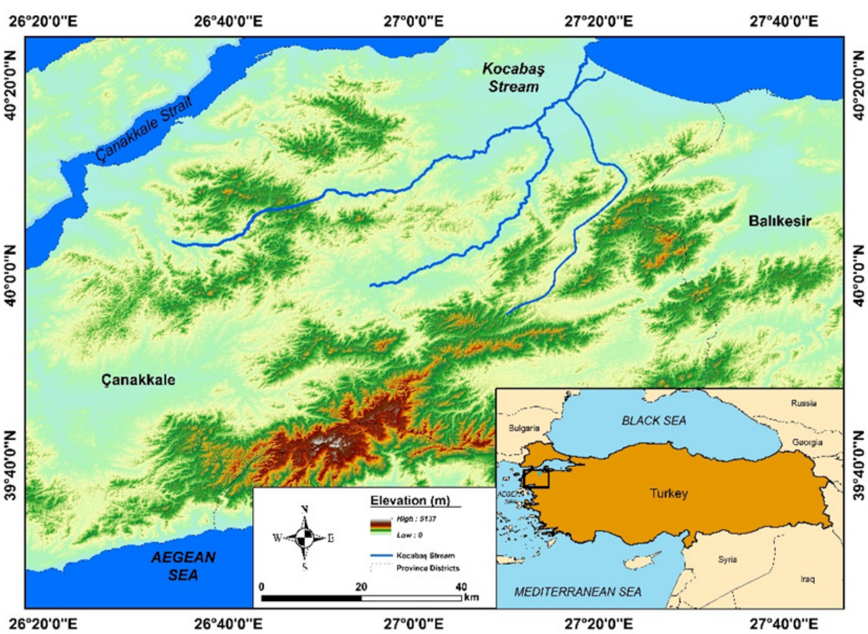

Fig. 2. Digital elevation model of Kocabaş stream

2.2 Change Point Analysis

Pettitt [11] developed a non-parametric approach to detect the change time of the time series of data. In this study, we used Pettitt's change-point analysis to determine the change time of the climatic parameters and river streamflow. This approach detects the significant change in the mean of times series in case where change time is not accurately known. This statistical test which was modified from the Mann-Whitney statistic determines the change by calculating how many times first example's member exceeds a member of the second example. The non-parametric statistic is given as,

$$K_T = max\left|U_{t,T}\right|, \tag{1}$$

Where

$$U_{t,T} = \sum_{i=1}^{t}\sum_{j=t+1}^{T} sgn\left(x_i - x_j\right) \tag{2}$$

$$\text{for } t = 2, \ldots\ldots, T \tag{3}$$

$U_{t,T}$, validates in this calculation whether the two examples ($x_1,\ldots\ldots,x_t$ and $x_{t+1},\ldots\ldots,x_T$) are in the same population or not. Pettitt test's null hypothesis is that there is no a change point. The statistic of this, K_T and associated probability (p) is used for calculating the significance. The probability of significance of K_T is estimated for $p \le 0.05$ with formula given below,

$$p \cong 2\exp\left\{\frac{-6\,{K_T}^2}{T^3+T^2}\right\} \tag{4}$$

2.3 Trend Analysis

Trend analysis is the most widely used method to determine the tendency of changes in a hydrological and climatic time series [12]. In this study, we used Box-Jenkins technique [13] in the trend analysis to determine the tendency and the time series of temperature, evaporation, precipitation and the flow series of Kocabaş Stream. Box-Jenkins technique, based on linear, discontinuous and stochastic processes, is a technique used for analysis and forecast of a time series. Autoregressive (AR), moving average (MA), autoregressive-moving average (ARMA) models are useful for stationary processes and autoregressive integrated moving average (ARIMA) is useful for non-stationary processes. The objective of these models is to specify the best model fits to time series and contains at least parameters [13]. Time series analyses combine the information and observations of earlier times. They also make contribution to the estimation of complex progress to be presented by the data in the future [14]. On the other hand, trends point out the increase or decrease in movements of a series indicated for an evident while [15]. Mean rates of the streamflow and the distribution of the changes that take place around these means demonstrate differences regionally. Hence, available data was structured for statistical analyses. The annual time progresses of precipitation, temperature, evaporation and streamflow series were determined and trend analyses were performed to specify the trends. Trend analyses and correlation were conducted to analysis of relation levels and future trends. The ARIMA (*1, 0, 1*) model was used in trend analyses. Autocorrelation analyses were performed to calculate reliability of the results. It was targeted to present quantitative forecasting by foreseeing the statistical data analysis in the streamflow and the climatic data. It is undertaken to forecast future projections by foreseeing a 5-years range implemented to the time-series. The ARMA model is defined as below [13]:

$$X_t = \Phi_1 X_{t-1} + \cdots + \Phi_p X_{t-p} + e_t - \cdots \theta_1 e_{t-1} - \cdots - \theta_q e_{t-q} \tag{5}$$

where X is the original series, Φ is the AR parameter to be predicted while θ is the MA parameter to be predicted, and e is a series of unknown random errors that are supposed to pursue normal distribution of the probability. A linear combination is used in ARIMA models to forecast a time series. In ARIMA model (*p, d, q*), p indicates the number of AR terms, q indicates the number of MA terms and d indicates the differencing order. The ARIMA model used in this study is given as,

$$X_t = c + \Phi_1 X_{t-1} + \cdots + \Phi_p X_{t-p} + \theta_1 e_{t-1} + \theta_q e_{t-q} + e_t \tag{6}$$

where X_t is the variable will be described in t time, c is the constant, Φ is coefficient of per p parameter, θ is the coefficient of per q parameter, and e_t is the error in t time.

2.4 Mann-Kendall Test

Mann-Kendall test is commonly using for determining the trends in a time series [16,17]. A hypothesis test helps to differentiate the natural functioning mechanism of the hydrological process for long-standing trends of climate change and river streamflow [18]. Extreme values in the dataset have critically impact on the mean. The Mann-Kendall test is an efficient tool for determining the trends in a time series while extreme values exceed [19]. In this study, we used a non-parametric Mann-Kendall test [16,17] to investigate the potential trends in the temperature, evaporation, precipitation and streamflow of Kocabaş Stream with some extreme values. *Kendall's tau* and *Spearman's rho* tests were performed to determine the correlations between streamflow of the river and climatic parameters.

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn(x_k - x_i) \qquad (7)$$

where the time series x_i is from i = 1, 2, …, n-1, and x_k from $k = i + 1, …, n$.

$$sgn(\theta) = \begin{cases} +1, & \theta > 0 \\ 0, & \theta = 0 \\ -1, & \theta = 0 \end{cases} \qquad (8)$$

Z_c and β are given as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, & S > 0 \\ \frac{S+1}{\sqrt{var(S)}}, & {S=0 \atop S<0} \end{cases} \qquad (9)$$

where Z_c is the test statistic. H_0 will be rejected when $|Z_c| > Z_{1-\alpha/2}$, in which $Z_{1-\alpha/2}$ are the standard normal variables and α is the significance level for the test. The magnitude of the trend is given as

$$\beta = \text{Median}\left(\frac{x_i - x_j}{i-j}\right), \forall_j < i \qquad (10)$$

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

3. RESULTS AND DISCUSSION

Time series were generated for temperature, evaporation, precipitation and streamflow of Kocabaş Stream. Then, change-points were determined for these and trend analyses were performed. Also, autocorrelation analyses were conducted to determine the reliability of the results gained from analyses described above.

The Pettitt change-point analysis results showed that the change point for evaporation, temperature and precipitation was 1993, 1997 and 1993, respectively (Table 1). As a result of the trend analyses conducted to determine the trends of climatic parameters, it was found that the levels of temperature (Fig. 3) and evaporation (Fig. 4) have a tendency to increase and that the level of precipitation tends to decrease (Fig. 5). For trend analyses, the prediction interval was forecasted as 5 years and trend analysis was performed for the years in between 2016-2020. Trend analyses results showed that the evaporation and temperature levels will increase annually 1.44425 mm and 0.02875℃, respectively, and they will reach 210.905 mm and 16.1491℃ by 2020. Precipitation is expected to reach 47.9798 mm in 2020 by decreasing 0.099975 mm annually (Table 2).

The change year for Kocabaş Stream was determined as 1981 according to the Pettitt change point analysis carried out to determine the significant change time in streamflow (Table 1). As a result of the trend analyses, it was determined that streamflow of the river tends to decrease (Fig. 6) and the annual amount of this decrease is predicted to be 0.025005 $m^3 s^{-1}$. The streamflow of the river is predicted to reach 5.38956 $m^3 s^{-1}$ in 2020 by the 5-years projection of the trend analysis (Table 2).

Table 1. Results of Pettitt change-point analysis, Kendall's tau and Spearman's rho tests[a]

River and climatic parameters	Pettitt change year	Mann-Kendall				Spearman			
		First stage		Second stage		First stage		Second stage	
		tau	*p*	*tau*	*p*	*rho*	*p*	*rho*	*p*
Kocabaş	1981	-0.436	0.038	-0.074	0.588	-0.615	0.025	-0.109	0.589
Temperature	1997	-0.071	0.602	0.300	0.105	-0.107	0.596	0.113	0.412
Evaporation	1993	0.286	0.070	0.232	0.153	0.406	0.067	0.307	0.188
Precipitation	1993	-0.502	0.001	-0.074	0.650	-0.705	0.0002	-0.108	0.650

**First Stage is from 1968 to the change year and Second Stage is from the change year to 2007 for annual streamflow of Kocabaş Stream. For climatic parameters, First Stage is from 1970 to the change year and Second Stage is from the change year to 2012. tau and rho are test statistics. p is significance level*

Table 2. Trend analysis forecasting for annual streamflow of Kocabaş stream and annual temperature, evaporation, precipitation

Years	Kocabaş stream ($m^3 s^{-1}$)	Temperature (℃)	Evaporation (mm)	Precipitation (mm)
2016	5.48958	16.0341	205.128	48.3797
2017	5.46458	16.0629	206.572	48.2797
2018	5.43957	16.0916	208.016	48.1797
2019	5.41457	16.1204	209.461	48.0798
2020	5.38956	16.1491	210.905	47.9798

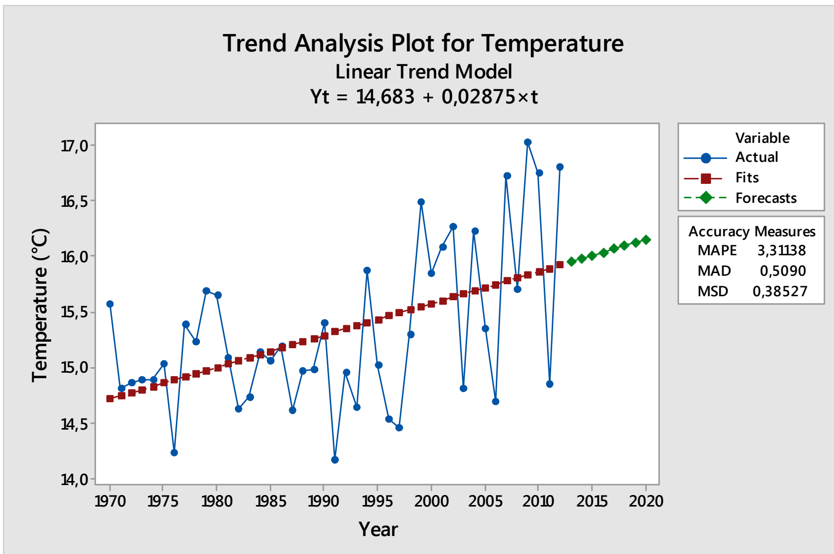

Fig. 3. Trend analysis results for temperature

Non-parametric *Kendall's tau* and *Spearman's rho tests* were applied to determine the correlation between the streamflow of Kocabaş Stream and the climatic parameters. As a result of these non-parametric tests, the correlation between the river streamflow after the change point year and the temperature, evaporation, precipitation was found statistically insignificant ($P>0.05$). However, before the change year, the correlation between the river streamflow and climatic parameters was found statistically significant ($P<0.05$). This variation indicates that annual streamflow of Kocabaş Stream decreased significantly until the change year. Then, the decreasing in the streamflow decelerated.

Changes in temperature and precipitation are the most major and key indicators of global climate change. It is often considered that fluctuations in the precipitation regime will have a straight impact on streamflow of river. Increased temperatures and evaporation, besides a decrease occurs in precipitation leads to intensify in the hydrological cycle and causes rainy seasons to get even rainier and dry seasons to be even drier [20]. Christensen et al. [3] pointed out that although global climate change leads to a small increase in annual precipitation incidences, the annual precipitation rates will probably decrease in the Mediterranean area. Likewise, Durdu [19] notified that climate change will reduce the natural water resources availability in Turkey and there will be a water stress because of the changes in precipitation rates.

Trend analyses and the other statistics tests performed for climatic parameters showed that it is expected to be a decrease in precipitation and an increase in the evaporation and temperature. Chen and Xu [21] stated that global warming may cause to increase the temperature and evaporation. Several authors reported that the evaporation and temperature levels are increased statistically significantly in the Middle East [22], Europe [23], and Turkey [19,24,25]. Christensen et al. [3] notified that although the annual precipitation showed downward trend, the daily precipitation rates density could increase in many areas of the Mediterranean. Bates et al. [26] stated that the in the fluctuations precipitation are not linear temporally and that these fluctuations show significant changeability. The authors reported that the annual precipitation showed downward trend between 1997 and 2005 in Turkey. Sensoy et al. [24] stated that the annual precipitation had a tendency to decrease in Turkey. However, the number of days with downpour increased except the west part of Turkey. Durdu [19 reported that the precipitation showed an insignificantly decrease trend in the Büyük Menderes river basin and the precipitation was higher in rainy seasons while less in dry seasons. Zhang et al. [22] notified that the precipitation trends were commonly very low and statistically insignificant in the Middle East. In climate models, the scientists have an agreement on there is a global warming and there lasts much uncertainty regarding changes in precipitation. Although some scientists anticipate that winters will be rainier in global circulation scenarios, the others expect that the fluctuations in precipitation will be significant in summers and drier winters [27].

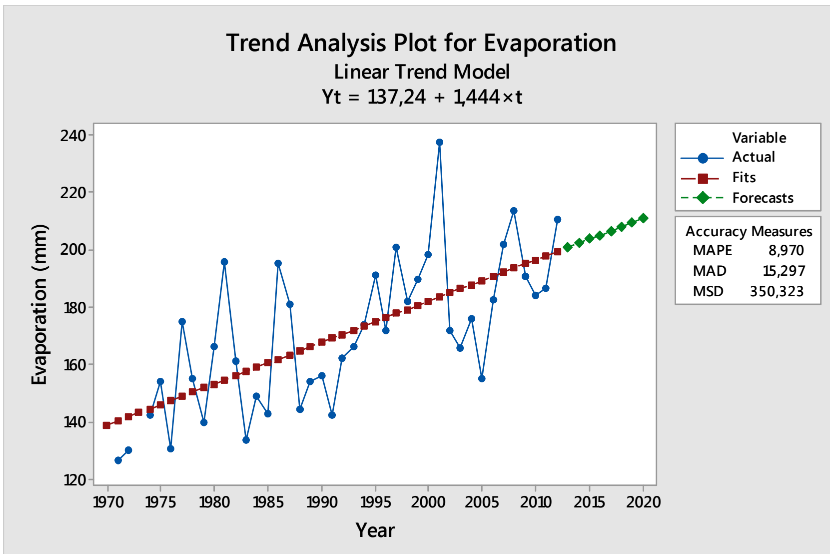

Fig. 4. Trend analysis results for evaporation

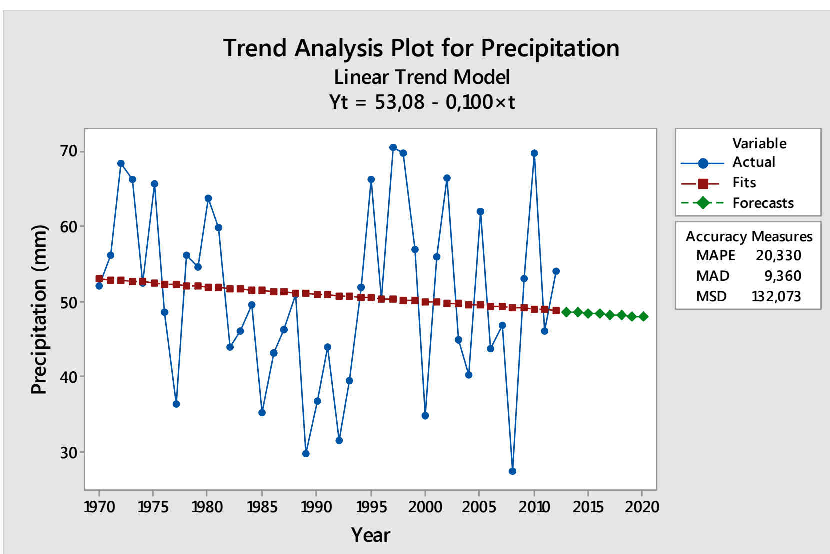

Fig. 5. Trend analysis results for precipitation

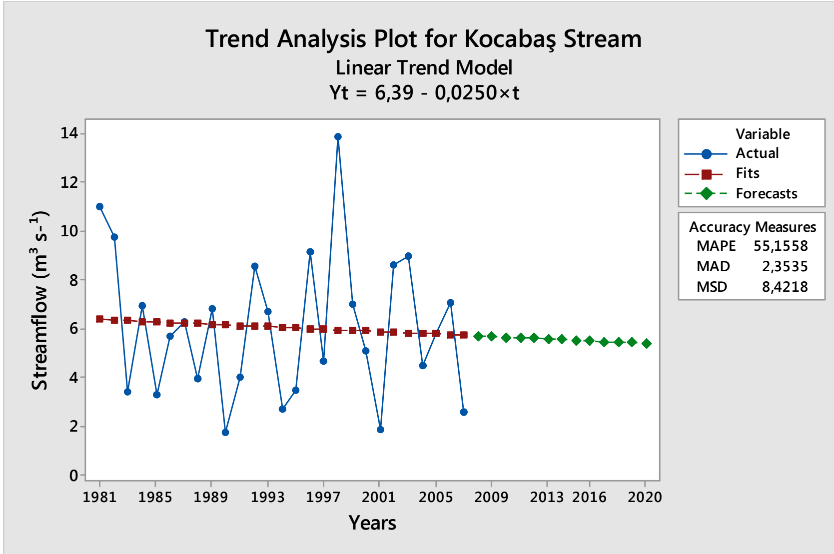

Fig. 6. Trend analysis results for annual streamflow of Kocabaş stream

In this study, it was determined that there was a downward trend in the streamflow of Kocabaş Stream. Several authors reported decreasing trends in the streamflow of the rivers. Alcamo et al. [23] claimed that the streamflow of the rivers in many areas of the southern Europe tended to decrease. Herawati et al. [6] found a decreasing trend in the annual streamflow of the Kapuas river in Indonesia and they notified that the climate change affected the hydrological characteristics of the river. Zhou et al. [7] stated that there was a continuous decrease in the streamflow of Huangfuchuan river in China. Pumo et al. [8] reported that the streamflow and the precipitation rates tended to decrease significantly in non-perennial minor rivers Italy. Ozkul et al. [28] and Ozkul [29] reported that there were decreasing trends in the streamflow of Gediz and Büyük Menderes rivers. Türkeş and Acar Deniz [30] investigated the trends in precipitation and streamflow of the rivers in southern part of Marmara. The authors found a decreasing trend in the streamflow. Ejder et al. [31] found a decreasing trend in the streamflow of Sarıçay Stream.

There are several studies on global warming effects on the streamflow in the western Turkey. It was reported that the river streamflow have a tendency to decrease and this decreasing trend occurred due to the climate change effects such as increasing temperature and decreasing precipitation [19,31-34]. In this study, we found a decreasing trend in the streamflow of Kocabaş Stream contrary to the trends in temperature and evaporation while the similar trend to the precipitation rates. However, the relationship between the streamflow and climatic parameters is statistically insignificant (P>0.05). Bates et al. [26] declared that the trends in the streamflow were not associated to the fluctuations in the precipitation all the time. Otherwise, many authors notified that anthropogenic activities [7,35,36], hydraulic structures [28], agricultural activities [19,37-39] had effects on the river streamflow as like as climate change effects.

To assess the effects of climate change on the hydrological processes of rivers, some different models such as general circulation models (GCM) [4,5,40-42], regional circulation models (RCM) [40], macro-scale hydrological model with variable infiltration capacity (VIC) [43], soil and water assessment tool (SWAT) [4,41], precipitation runoff modelling system (PRMS) [44] were used. Chien et al. [45] stated that the fluctuations in streamflow changes between the locations relying on the climatological conditions. Therefore, choosing the most appropriate hydrological model to forecast the possible climate change effects on streamflow of the rivers is of crucial importance.

4. CONCLUSION

In conclusion, it was found that there were decreasing trends in streamflow of Kocabaş Stream and precipitation, and that there were increasing trends in temperature and evaporation in western Turkey. The trends between streamflow and climatic parameters were statistically insignificant. Therefore, agricultural and anthropogenic activities, geographic location, urbanization areas and population density should also be considered for assessing the variations in the streamflow in addition to climate change effects. Moreover, the most appropriate assessment models for the objective and the locality of the study area should be performed. In this regard, managing the water demands successfully, using water resources sustainably, establishing an appropriate water sharing policy and enhancing early warning systems are of great importance to reduce the negative impacts on streamflow of rivers caused by many factors particularly climate change.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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