SENSITIVITY OF STREAMFLOW TO CLIMATE CHANGE IN MELEN RIVER BASIN (NW TURKEY)

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ABSTRACT

This study investigates the impact of climate changes in natural streamflow in the Melen River Basin. Being the main drivers of variability in streamflow, daily temperature and rainfall data from 1963 to 2014 were analyzed to determine long term trends of each characteristic in the Melen River Basin area. These data also served as a basis for estimating evapotranspiration in the area. With the addition of trend analysis of the streamflow data from 1997 to 2014 the correlation between streamflow data and changes in climate were established. Long-term Melen River Basin temperature and precipitation trends indicate that both the mean annual temperature is increasing steadily every year (y=0.0209x+12.727, R^2= 0.169) and the annual rainfall is also decreasing (y=-2.2014x+877.86, R^2= 0.0602). Thornthwaite's methodology was applied to calculate monthly potential evapotranspiration for last 52 years. A regression analysis for the period yielded y=0.7536x+641.96, and R^2=0.2065, with a steady growth of monthly evapotranspiration values over the last 52 years. The study shows a very high correlation between streamflow of Melen River and the changes in temperature, rainfall and evapotranspiration. This supports the initial hypothesis that streamflow of Melen River is highly sensitive to climate changes and therefore climate changes must be considered in any long term water management project.

Keywords: Streamflow, Sensitivity, Climate change, Melen River Basin.

INTRODUCTION

Climatic conditions play a decisive and effective role on surface runoff [1], [2]. As a result, changes in annual and seasonal mean values of temperature and precipitation have direct impact on surface runoff and therefore flow characteristics of rivers are likely to be very sensitive to climate changes. This sensitivity must be taken into consideration while planning for water management in river basins. The Melen River Basin (40° 40′ - 41° 05′ N and 30° 50′ - 31° 40′ E) (Fig. 1) is the most important supply for the Istanbul Water & Sewage Administration (IWSA) and the keystone for Istanbul's water management projects in the near and medium future. Therefore, it is crucial to understand the flow sensitivity of the Melen River to changes in climate conditions. This study investigates the sensitivity of streamflow in the Melen River to variations in climatic conditions is aimed to investigate.

Regression analyses were carried to understand the relationship between climatic parameters around the river basin and the resulting streamflow. Climatic data such as temperature and rainfall, observed by the Düzce Meteorological Station (40° 8437′ N and 31° 1488′ E, h: 146m) (Fig. 1) from 1963 to 2014 were used to create trend analysis of temperature and rainfall. The same climatic data was used to calculate the change in potential evapotranspiration. The final parameter used to correlate streamflow with climate elements was the actual streamflow data of the Melen River. A daily time series of streamflow data, observed from a streamflow a gauging station (41° 0451′ N and 31° 0042′ E, h: 10m) (Fig. 1) over the period 1997-2014, was obtained from “The General Directorate of State Hydraulic Works (DSI)”.

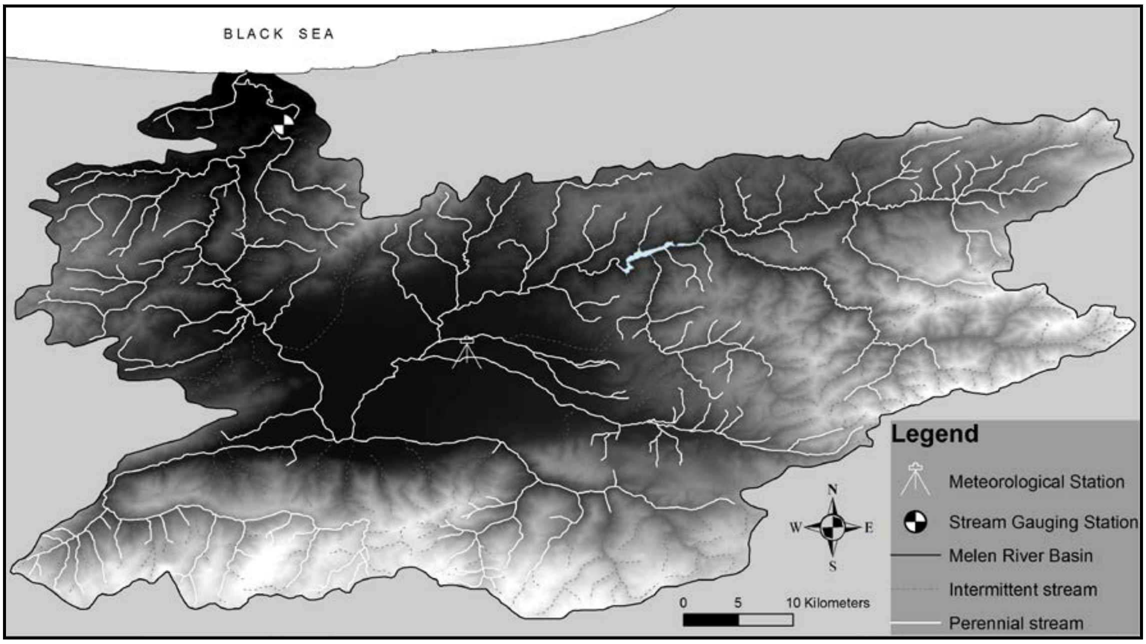

Figure 1: Melen River Basin and locations of Düzce Meteorological Station and streamflow gauging station in drainage basin.

Climatic Regression Analysis

While lithology, geomorphology, vegetation, soils, land use play an important role, climatic conditions are the predominant factors in shaping a river’s streamflow characteristic. Increase in annual mean Temperature (T), Potential Evapotranspiration (PET) and decrease in annual Precipitation (P) have clear negative effects on streamflow [2], [3]. Accordingly, linear rates of changes in long-term seasonal and annual average temperatures and total precipitation for Melen River Basin have been analyzed.

A linear regression analysis of temperature and precipitation trends, based on 52 years (from 1963 to 2014) of measurement, was created.

First the 52-year Temperature, Precipitation, Potential Evapotranspiration and Water Deficiency trends were used to create a linear regression equation and R^2 coefficient. Second 18-year streamflow data separately associated with temperature, precipitation, and potential evapotranspiration and water deficiency trends.

The average annual temperature fluctuations of the last 52 years are highly meaningful (Fig. 2). Their linear regression equation clearly indicates the trend of Average Annual Temperature (AAT) in the Melen River Basin. The data yields a regression equation for average annual temperature as y=0.0209x+12.727. This clearly indicates an increasing linear trend over the 52 years from 1963 to 2014. The R^2 coefficients of AAT (R^2=0.169) also confirms this result (Fig. 2) indicating 17% of incremental change.

Precipitation also has a direct effect on streamflow and therefore annual precipitation trends have been identified by using long-time series data of precipitation. The linear regression equation of annual precipitation trend shows a significant reduction trend (Fig.3).

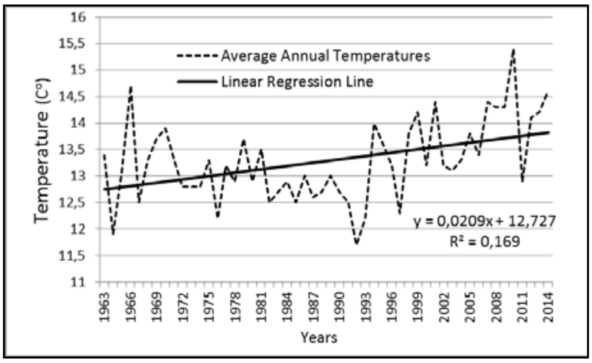

Figure 2: Mean Annual Temperatures and trend graph for the 1963-2014 period.

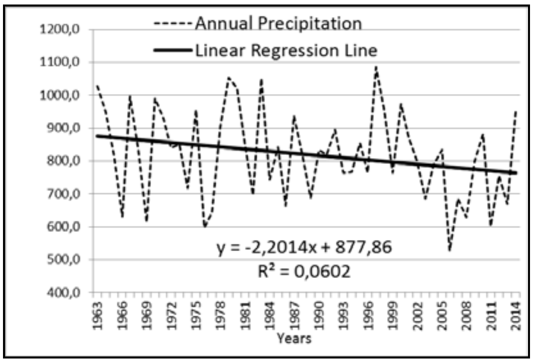

Figure 3: Annual Precipitation and trend graph for the 1963-2014 period.

Potential Evapotranspiration (PET), directly related to temperature is another important parameter in the water balance. Temperature and precipitation factors play a decisive role on PET [4]. If the PET is high, the volume of streamflow will likely be negatively affected.

Water Deficiency (WD) is another important indicator of the streamflow amount. Water Deficiency over a long-term period indicates reduced streamflow in the following river sections. Both Annual Potential Evapotranspiration (PET) and Annual Water Deficiency (WD) values for 52 year were calculated by using the "Thornthwaite Rational Classification of Climate" technique [4]. The results of annual PET and WD have also been subjected to a linear regression analysis. The linear regression equations and R-squared values of PET and WD are presented below clearly indicating increasing trends (Fig. 4 and 5).

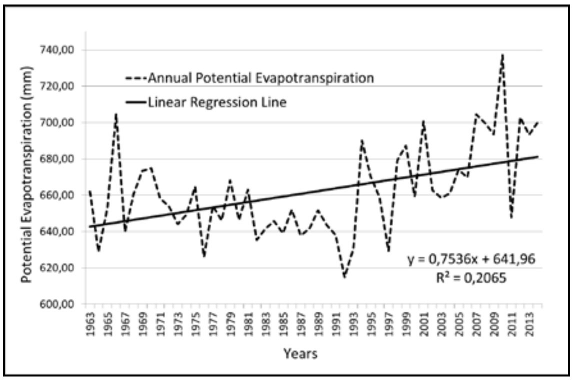

Figure 4: Annual Potential Evapotranspiration trend graph for the 1963-2014 period.

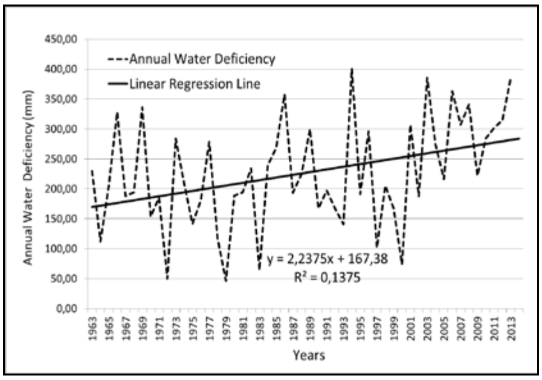

Figure 5: Annual Water Deficiency trend graph for the 1963-2014 period.

Relationship between streamflow and climatic parameters

The relationship among temperature, precipitation, evaporation, water deficiency and streamflow is particularly important in terms of water management. This relationship had previously been investigated by empirical and statistical methods and quite remarkable results were obtained.

According to Stockton and Boggess [7], a 2°C increase in temperature and a 10% reduction in precipitation will decrease the runoff rate by 40 to 76%. The research by Revelle and Waggoner [8] on the same topic estimates that a 2°C increase in temperature and a 10% increase in precipitation would cause an 18% a reduction in the runoff. Nemec and Schaake [9], proposed that in humid climate regions a 1 degree increase in temperature and a 10% decrease in precipitation will lead to a 25% reduction in average annual runoff rate. The results of empirical, statistical and hydrological analyses consistently indicate that temperature, evapotranspiration and precipitation are very effective on streamflow, and that precipitation is more effective than temperature and evapotranspiration on streamflow [5], [6], [7], [8], [9], [10], [11], [12].

Long-time (1997-2014) linear regression analysis, applied to series of streamflow and climatic data of the Melen River and its environs indicated the same results. Regression equations and R^2 values of annual streamflow and average annual temperature trends clearly indicate the expected inverse relationship. While the average annual temperature increases in the Melen River Basin, the annual streamflow of the Melen River is decreases over the 1997-2014 period (Fig. 6).

The regression analysis of actual annual precipitation and annual streamflow values shows a similar decreasing trend. However, the difference between the reduction trend rate of precipitation with the decline trend rate of streamflow is very remarkable and meaningful (Fig. 7). The graph and values of the regression equation and R^2 values clearly show that streamflow is indeed very sensitive to precipitation.

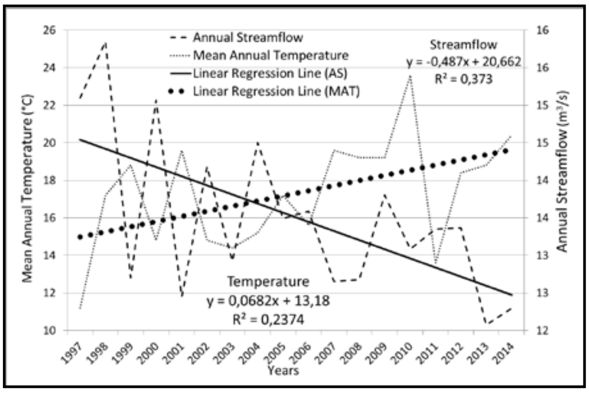

Figure 6: Temperature-Streamflow trend graph for the 1997-2014 period.

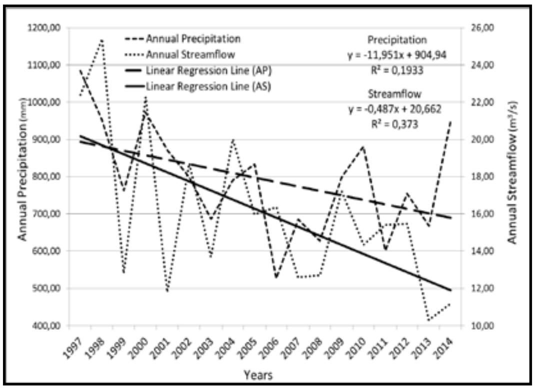

Figure 7: Precipitation-Streamflow trend graph for the 1997-2014 period.

While snow melt, soil moisture, groundwater storage, storm runoff, etc. clearly have effect on streamflow, the data shows that trends of annual potential evapotranspiration and annual water deficiency in the Melen River Basin are a reliable indicator of surface water balance [13].

Increasing trends of annual potential evapotranspiration and annual water deficiency in the Melen river basin, have negatively affected the surface water balance and reduced the amount of annual streamflow (Fig. 8 and 9). Linear Regression equation and R^2 values of these variables also indicate a clear reverse relationship on streamflow year over year.

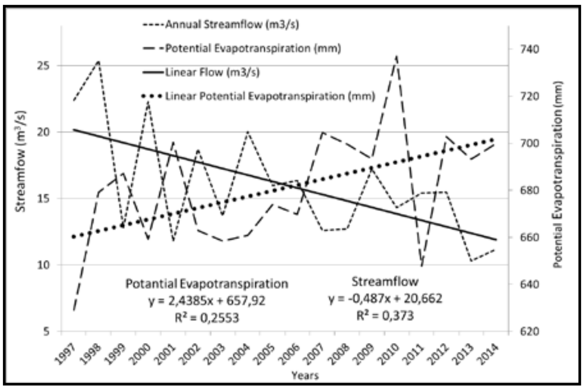

Figure 8: Potential Evapotranspiration-Streamflow trend graph for the 1997-2014 period.

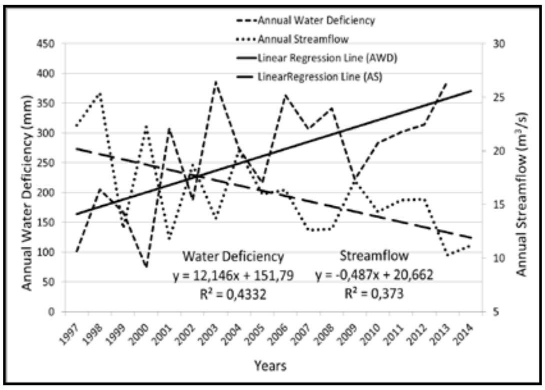

Figure 9: Water Deficiency-Streamflow trend graph for the 1997-2014 period.

Linear regression analysis results of Annual Precipitation, Average Annual Temperature, Annual Potential Evapotranspiration, Annual Water Deficiency for the1963-2014 and the 1997-2014 periods are presented in Table 1. The regression equations clearly indicate the main reason for the decreasing trend of streamflow to be the increase in temperature and decrease in precipitation over the time period.

Table 1: Regression equation and R^2 values of annual temperature, precipitation, potential evapotranspiration, water deficiency and streamflow in the 1963-2014 and 1997-2014 periods.

<table>
<tr><td>1963-2014</td><td>1997-2014</td><td>1997-2014</td></tr>
<tr><td colspan="2">Average Annual Temperature (°C)</td><td>Annual Streamflow (mm/s)</td></tr>
<tr><td>Y=0.0209x+12.727
R^2= 0.169</td><td>Y=0.0682x+13.18
R^2= 0.2374</td><td rowspan="7">Y=-0.487x+20.662
R^2 =0.373</td></tr>
<tr><td colspan="2">Annual Potential Evapotranspiration (mm)</td></tr>
<tr><td>Y=0.7536x+641.96
R^2= 0.2065</td><td>Y=2.4385x+657.92
R^2= 0.2553</td></tr>
<tr><td colspan="2">Annual Precipitation (mm)</td></tr>
<tr><td>Y=-2.2014x+877.86
R^2= 0.0602</td><td>Y=-11.951x+904.94
R^2= 0.1933</td></tr>
<tr><td colspan="2">Annual Water Deficiency (mm)</td></tr>
<tr><td>Y=2.2375x+167.38
R^2= 0.1375</td><td>Y=12.146x+151.79
R^2= 0.4332</td></tr>
</table>

The effect size of Mean Annual Temperature and Annual Precipitation on Streamflow of Melen River were derived using the Cohen's effect-size correlation technique [14]. Cohen's "r" values were calculated by using mean and standard deviation data belonging to 18-years rainfall, temperature and streamflow of the Melen River (Table 2). The "r" value ranges between 0 and 1. If there is no effect, the value of "r" is 0; a value of 1 indicates a very high effect size.

Table 2: Result of Cohen's effect-size correlation shows the dominant effect of precipitation on streamflow as compared to temperature.

	Temperature- Streamflow	Precipitation - Streamflow
Effect Size "r"	0.3400116	0.966681

CONCLUSION

Variations in climatic parameters must carefully be considered in the planning of important water projects on water resource systems as rivers. They have dramatic effects on the expected streamflow of rivers. Long-term linear regression analyses on climatic data provide important and useful information for the future water potential of rivers.

Trend analysis results indicate a significant correlation between the streamflow of the Melen River and temperatures, precipitation, potential evapotranspiration, water deficiency trends in the Melen River Basin. Comparative trend assessments over an18 year period show that streamflow of the Melen River has a significant sensitivity to variations in temperature and precipitation.

R-squared value of Annual Streamflow over 18-years indicates a reduction of 37.3%. This reduction in Annual Streamflow comes as a result of decline on annual precipitation by 19.33%. This interaction and result of Cohen's effect-size correlation clearly show the sensitivity of streamflow to precipitation. Furthermore R-squared values of Annual Temperature (23.74%) and Annual Potential Evapotranspiration (25.53%) exchange rates were calculated to be very close to the value of R-squared in the streamflow trend equation for the Melen River.

52-year regression analysis results show that Average Annual Temperature, Annual Potential Evapotranspiration, Water Deficiency will continue to increase, and Annual Precipitation will continue to decrease in the Melen River Basin. It is obvious that streamflow of the Melen River is highly sensitive to both 52-years and 18-year climatic variation. Because of this high sensitivity further decrease in streamflow of the Melen River should be expected over the next years.

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