IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES ON EASTERN MOUNTAINOUS REGION OF TURKEY

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ABSTRACT

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES
ON EASTERN MOUNTAINOUS REGION OF TURKEY

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Temperature and precipitation are the most important indicators of climate change. Especially for the basins fed by snow, the shifts of melting to earlier times, affects the streamflow. Increase in temperature causes to shifts of melting of snow to shift to earlier times so that hydrologic regime of the river system changes, and leads to changes in climatic conditions of the region.

In this study the shifts of snow melting times are analyzed for the selected 15 streamflow stations located in Euphrates, Tigris, Aras, and Çoruh basins in Eastern Anatolia of Turkey along with period from 1970 to 2010. The shifts in snowmelt runoff are determined by Center Time (CT) method. Meteorological stations representing the stream gauge stations regarding the basin characteristics are also selected to be used in the analyses. In order to relate CT shifts to temperature and precipitation changes, trend analysis are applied to temperature, precipitation and streamflow data. In addition to these, days with daily average temperature less than freezing and wet days below freezing until CT for each station pair between stream gauge and meteorological stations and each year are also analyzed. These days till CT within a year for each station pair can be indirectly linked to snowy days and accumulated snow amount. Complete analyses show significant warming at each station in the region and no important trends in annual precipitation. However at a few stations meaningful seasonal changes in precipitation are observed. Regional warming and associated changes in precipitation and snowmelt runoff cause significant shifts to earlier times of snowmelt runoff. In the region eight out of fifteen stream gauge stations in Euphrates, Tigris and Aras basins showed significant time shifts according to statistical trend tests.

Keywords: Climate change, water resources, melting of snow, shifts in melting, center time, statistical analysis, Euphrates basin, Tigris basin.

ÖZ

İKLİM DEĞİŞİKLİĞİNİN TÜRKİYENİN DOĞUSUNDA DAĞLIK ALANLARDAKİ SU KAYNAKLARINA ETKİSİ

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Sıcaklık ve yağış, iklim değişikliğinin en önemli göstergeleridir. Özellikle kar yağışından beslenen havzalar için, karların erime döneminin erkene çekilmesi akarsu akımlarını etikler. Sıcaklık artışı, kar erime dönemlerinin erkene çekilmesine sebep olmakta ve bunun sonucunda akarsuların hidrolojik rejimleri değişmektedir, ve bölgenin iklim koşullarının değişmesine yol açmaktadır.

Bu çalışmada, Fırat, Dicle, Aras ve Çoruh havzalarından seçilen 15 tane akarsu gözlem istasyonu için 1970-2010 yılları arasında, kar erimelerindeki geriye çekilme Merkez-Zaman metodu ile analiz edilmiştir. Havza karakterlerine göre akım istasyonlarını temsil eden meteoroloji istasyonları da analizlerde kullanmak üzere seçilmiştir. Merkez zamanlardaki değişimi sıcaklık ve yağış ile ilişkilendirmek için, sıcaklık, yağış ve akım verilerine trend analizleri uygulanmıştır. Buna ilaveten, merkez zaman gününe kadar, günlük ortalama sıcaklığı donma noktası olan 0^0C'nin altında olan gün sayısı, ve bu günlerde yağışlı olan gün sayısı analiz edilmiştir. Yıl içerisinde merkez zaman gününe kadarki bu günler kar yağışı ve kar miktarı ile dolaylı olarak ilgilidir. Bütün analizler bölgede belirgin olarak sıcaklık artışı olduğunu ancak yıllık yağışlarda belirgin bir değişim olmadığını göstermiştir. Ancak birkaç istasyonda mevsimsel olarak yağış trendleri gözlemlenmiştir. Bölgesel ısınma ile yağış ve kar erimelerindeki ilişkili değişiklikler kar erimelerinde önemli geri çekilmelere sebep olmaktadır. Bölgedeki Fırat, Dicle ve Aras havzalarındaki on beş istasyonun sekiz tanesi istatistiksel trend analizi sonuçlarına göre belirgin geri çekilmeler göstermiştir.

Anahtar Kelimeler: İklim değişikliği, su kaynakları, kar erimesi, erime zamanının kayması, merkez zaman, istatistiksel analiz, Fırat havzası, Dicle havzası.

To my little miss sunshine, Elif

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Hydrology is the study of the movement, distribution, occurrence, and quality and quantity of water on Earth. Water, which is the main element of hydrology, circulates throughout the Earth through different pathways and at different rates. This movement of water is named as "Water Cycle". The most vivid image of this is in the evaporation of water, which forms clouds. These clouds drift over the land and produce precipitation. The water flows into lakes, rivers, or aquifers. The water in lakes, rivers or aquifers then either evaporates back to the atmosphere or flows back to the ocean, completing a cycle. Water changes its physical state several times throughout this cycle.

Observational and historical hydrologic data are used in planning phase and construction phase of water resources projects. The hydrometeorological observations such as precipitation, temperature, surface runoff, and evaporation should be precise and should be periodically obtained for handling future water resources projects using hydrologic prediction models. Testing and parameter development of hydrological models are also carried out by using historical observations.

According to the Water Report of Turkey prepared by DSI (2009), there is a large variation in annual precipitation, evaporation and surface run-off parameters from basin to basin whose locations and spatial distributions across the county is shown in Figure 1. Total of 26 basins are formed according to their geomorphologic and hydrologic/hydrometeorologic characteristics. Precipitation is not evenly distributed in time and space throughout the country.

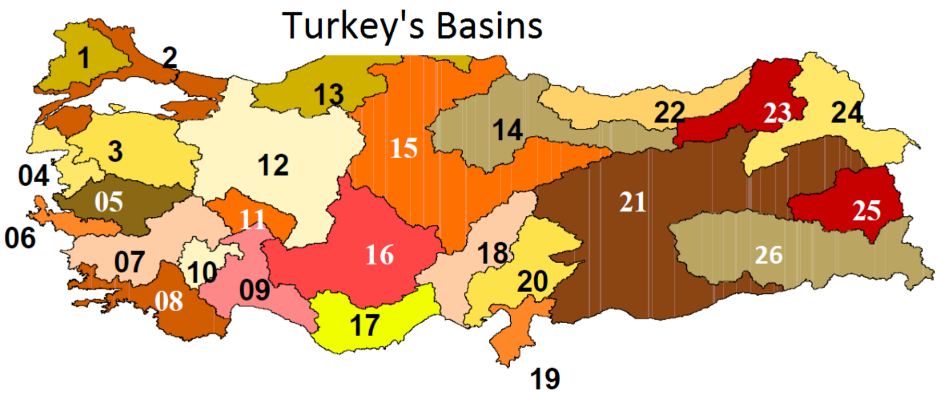


Figure 1. 26 basins located in Turkey

The annual average precipitation in Turkey is estimated as 643 mm, corresponding to a volume of 500 km^3. Considering the average surface water run-off which is 186 billion m^3/year with the surface runoff of 7 billion m^3/year coming from neighboring countries, the total surface run-off within the basins of Turkey (Figure 1) reaches to the amount of 193 billion m^3/year. 31% of the potential is constituted by the Euphrates (Fırat) and the Tigris (Dicle) Rivers both of which have their sources in the eastern part of the country (DSI, 2009). However, not all the renewable water resources can be utilized due to economic and technical reasons. Exploitable portions of surface run-off including inflow from bordering countries, and groundwater are 98 and 14 billion m^3/year, respectively. Thus, the total of economically exploitable water resources potential amount to 112 billion m^3/year. (DSI, 2009)

Since the climate is the main factor affecting all hydrological terms, the changes in climate directly affect the quantity and quality of water resources. The increases in concentrations of carbon dioxide and other gases in atmosphere are expected to change the heat equilibrium of the earth and causes global climate change. These gasses allow solar radiation from the sun to travel through the atmosphere but prevent the reflected heat from escaping back into space. This causes the earth's temperature to rise.

Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems. Because much of the solar energy received by the Earth is used to drive the hydrological cycle, higher levels of solar energy trapped in the atmosphere will lead to changes in global temperatures and also variation of this cycle, resulting in changes in precipitation patters. Observed warming over several decades has been linked to changes in the large-scale hydrological cycle such as: increasing atmospheric water vapor content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff (IPCC, 2007).

Mountain snowpack and spring runoff are critical for surface water resources as they serve an important and regionally integrated indicators of climate variability and change. The decreasing snow cover depth, especially in the spring, is of critical importance because of the effect of the timing and magnitude of spring snowmelt runoff to regional hydrologic systems. Eastern Turkey is characterized by mountainous terrain and a dry climate. Stream flow that occurs mainly due to snowmelt in the mountainous eastern part of Turkey during spring and early summer months is important as it constitutes approximately 60-70 % of total annual volume of runoff (Şorman, 2004). For this reason, forecasting the timing and the quantity of stream flow due to snowmelt in Euphrates and Tigris basins, where large reservoirs are located, is crucial for effective management of water resources.

1.2 Aim of the Study:

In this study, daily streamflow measurements from 15 stream gauging stations on the mountainous eastern part of the Turkey (Euphrates, Tigris, Aras and Çoruh basins) are obtained from EIE (General Directorate of Electrical Power Resources Survey and Development Administration). Meteorological data of temperature (daily maximum, minimum and average) and daily precipitation are also obtained from 10 MGM (Turkish State Meteorological Service) stations, which are usually located in the city center but are selected close to stream gauge stations. The probable long-term trends of the temperature, streamflow and precipitation time series are identified by nonparametric trend analyses methods, and the interrelation between these parameters are analyzed. The aim of the study is to explore regional climate change in the eastern Anatolia, to demonstrate the relation between climate change and the variability of hydrological process response via changes in mass and timing of snowmelt runoff, and to clarify the value of climate change impacts on the hydrological processes. .It is envisaged that these results can offer decisional references for the water resource managers of the Euphrates, Tigris, Çoruh, and Aras river basins.

1.3 Literature Review

Some studies have shown significant trends in some indicators of runoff/streamflow, and some have demonstrated statistically significant links with trends in precipitation or temperature (IPCC, 2007). In some regions of the world, variations in flow from year to year have been found to be much more strongly related to precipitation changes than to temperature changes. In large parts of eastern Europe, a major shift in runoff/streamflow from spring to winter has been associated not only with a change in precipitation totals but more particularly with a rise in temperature; in other words, precipitation has fallen as rain, rather than snow, and therefore has reached rivers more rapidly than before (Arnell, 1999).

The effects of climate change on hydrology have been investigated in many studies across the world. The followings provide a brief description of each of these studies related to subject of the present study.

Chen et al. (2007) investigated the effects of climate change on water resources of the Tarim river basin in Northwest China. The long-term trend of the hydrological time series including temperature, precipitation, and streamflow are detected by using both parametric and nonparametric techniques. They found that there was an increasing trend in temperature, precipitation, and stream flow. The conclusion obtained in this investigation shows that the temperature experienced a significant monotonic increase at the 5% level of significance during the past 50 yr, and precipitation also exhibited an upward tendency during the past several decades.

Bou-Zeid and El-Fadel (2002) studied climate change and water resources in Lebanon and the Middle East. According to this research, climate change is expected to further exacerbate existing water shortages. Although decrease in precipitation was not predicted in Lebanon, temperature increases of 0.6–2.1°C would impact the water balance and reduce available resources.

Mizyed (2009) evaluated the impacts of climate change scenarios on water resources availability and agricultural water demand in the West Bank. The West Bank was taken as a case study from the Mediterranean basin to evaluate the effects of such climate change on water resources availability and agricultural water demands. GIS spatial analyses showed that the increase in temperature predicted by climate change could potentially increase agricultural water demands by up to 17% and could also result in reducing annual groundwater recharge by up to 21% of existing values.

Loukas et al. (2007) assessed climate change on drought impulses in Thessaly, Greece and emphasized that according to examined climate change scenarios, frequent, extreme, and spatially extended droughts would be expected in the future.

The effects of climate change on water resources in Turkey have been studied by several researchers.

Fujihara et al. (2007) evaluated potential impacts of climate change on the hydrology and water resources of the Seyhan river basin located in southern Turkey. They indicated that, compared with the present, precipitation decreased and this resulted in a considerable decrease in streamflow, in which the peak monthly flow occurs earlier than at present.

Demir et al. (2007) investigated climate change effects on temperature and precipitation in Turkey. According to the precipitation and temperature values of 1961-1990 interval, changes for the period of 2071-2080 were evaluated. They found that highest temperature increases were in the summer season, the changes in total annual precipitation amounts had a generally decreasing tendency.

Özkul (2009) evaluated the impact of expected climate change on hydrology and water resources at regional and local levels. This study covers the generation of climate change scenarios, modeling of basin hydrology, and testing the sensitivity of runoff to changes in precipitation and temperature in the Buyuk Menderes and Gediz basins. Simulation results of the water budget model shown that nearly 20% of the surface waters in the studied basins will be reduced by the year of 2030. By the years 2050 and 2100, this percentage will increase up to 35% and more than 50%, respectively.

Mengu et al. (2008) studied effects of climate change on agriculture and water resources of Turkey. They concluded that along with an expected increase in temperature of 1-3 °C, rainfall was replaced with snow in winter, annual precipitation showed a significant decrease, and streamflow dramatically dropped. According to results of this study, they declared that, as the largest user of water, the agricultural sector is expected to be affected by global climate change more than the other sectors

Durdu (2010) studied on effects of climate change on water resources of the Büyük Menderes river basin based on temperature and precipitation data for the period of 1963-2007. According to the results of analysis of the parametric t-test and nonparametric Mann-Kendall statistical test results showed an increasing trend of the temperature. For the selected period the temperature increased just about 1 °C. This study emphasized that, the decreasing trend of the streamflow in the tributaries had a strong correlation with changes in temperature and precipitation.

Gümüş (2006) evaluated the Fırat river basin streamflow by trend analysis. 22 stations were selected and non-parametric Mann-Kendall test applied for temperature and precipitation data of these stations. A declining meaningful trend was observed in the study in annual average streamflows in the 2 stations at the Lower Fırat River Basin, and a meaningful trend was observed in 10 stations throughout the river basin in minimum streamflows, with an increasing meaningful trend in 1station and no meaningful trend in maximum streamflows.

Şen et al (2011) used Center Time method to analyze 7 streamflow stations from Euphrates and Tigris basins to indicate the shifts in streamflow timings to earlier times. 6 of the 7 selected stations show significant trend. This study concluded that, the increases in temperature, whether they are due to climate change and/or teleconnections, may affected significantly water resources in eastern mountainous part of the Turkey.

Altürk (2008) analyzed 8 stations from Tigris and Euphrates basins by Center Time method in order to show the shifts of melting of snow times to earlier times. A shift in the timing of springtime snowmelt towards earlier years was observed during 1970-2007 in many rivers. Trend analysis was done by Mann-Kendall and T tests. This study was the first study in Turkey about shifts of melting of snow times. The difference of our study from this study is that, additional basins and stations are used in our study. In addition to center time analysis, the snow quantity and changes in precipitation phases are also analyzed in our study.

1.4 Description of Thesis

In the first chapter of this study, brief information about the topic and the goal of the study are given. Second chapter gives information about the data, study area and the methodology used in analysis.

The third chapter presents analysis results with trends and graphical information while the fourth chapter gives discussions of the results. The last chapter provides the summary and conclusions for the study.

CHAPTER 2

DATA, STUDY AREA AND METHODS

2.1 Data and Study Area

Turkey is divided into 26 surface hydrological basins as shown in Figure 1. Euphrates (21), Tigris (26), Çoruh (23) and Aras (24) basins located in a mountainous terrain of eastern part of Turkey are used to perform the study in this thesis.

Daily streamflow records from 15 stations compiled by EIE were used across the selected basins. Total of 15 stations is distributed on the entire region of mountainous eastern part of Anatolia as 8 in the Euphrates basin, 3 in Tigris basin, 2 in Çoruh basin, and 2 in Aras basin, which are shown with their station numbers and black filled circles on the physical map of Turkey in Figure 2.

The Euphrates basin is studied through three sub-basins, which are Upper Euphrates, Middle Euphrates, and Lower Euphrates. Among eight stream gauge stations in Euphrates basin, 2, 4, and 2 of them are respectively located in upper, middle, and lower parts of the Euphrates basin. These stations with their river basins and network prepared in GIS (Geographic Information System) are also shown in Figure 3. This figure clearly shows that selected stream gauge stations are located at upstream part of the basins where the influence of available reservoirs on discharges is negligible.

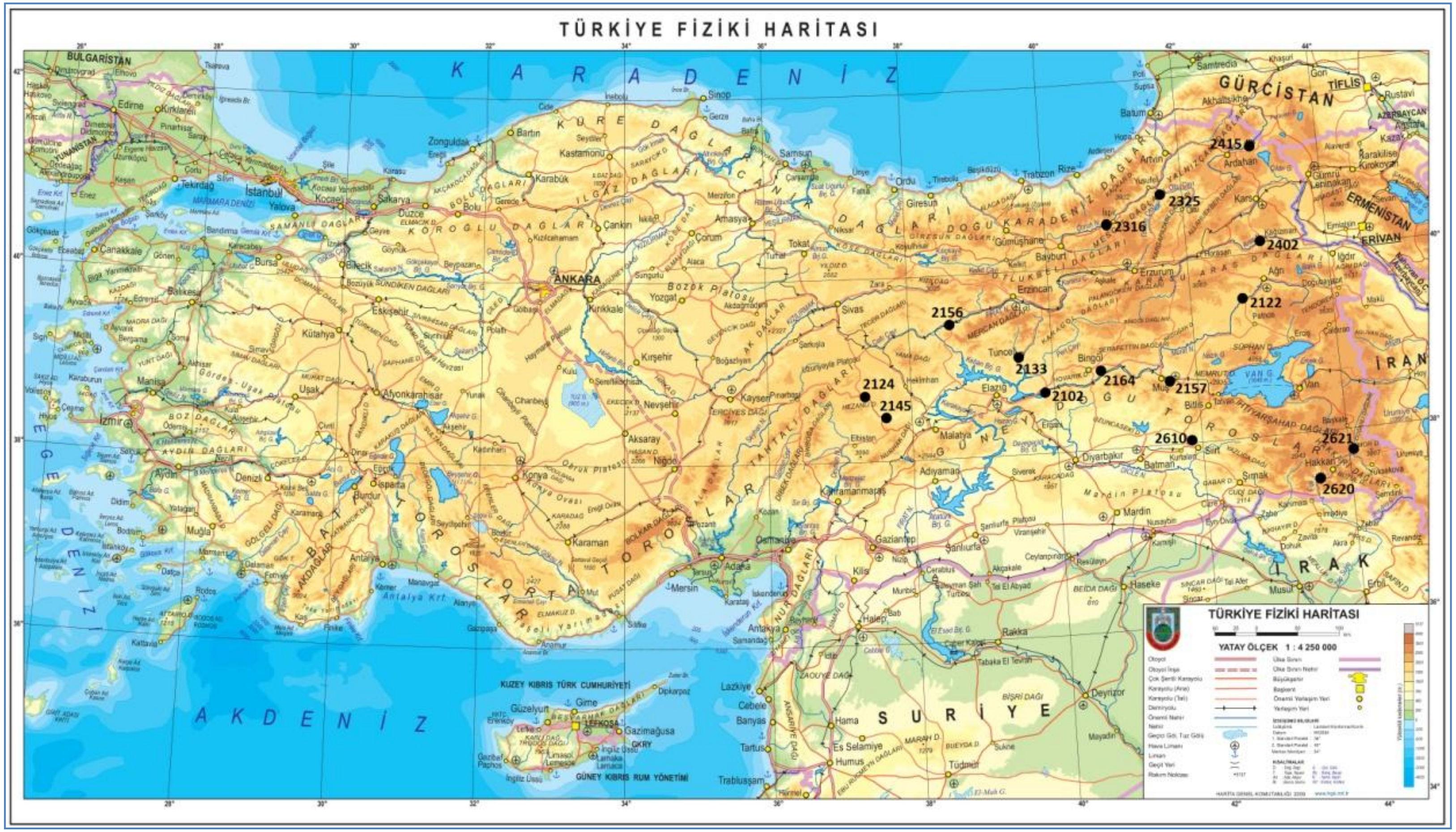


Figure 2. Selected stream gauge stations are shown with their numbers as black filled circles on Turkey physical map.

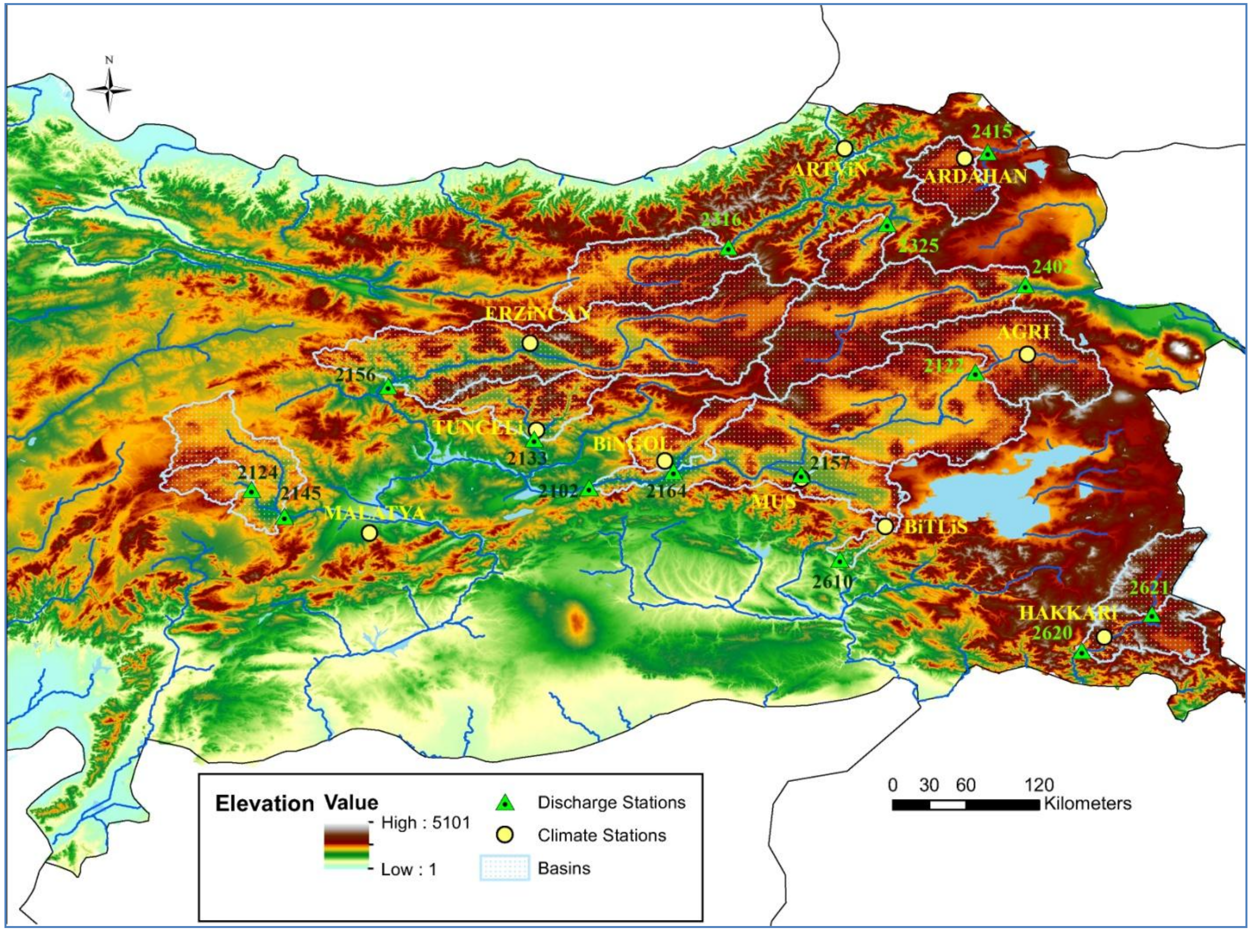


Figure 3. Selected 15 streamflow stations with their basins and channel network are shown. Triangles represent stream gauge while circles represent meteorological stations. Background also shows topography.

The selection of the stations in the region is based on the length of the records and the continuous nature of the data. The selected streamflow gauging stations are not regulated by large storage reservoirs and their effect on streamflow is described by 10% (Şen et al., 2011). The rivers included in this study have relatively natural flow. Moreover, the elevations of these stations are higher than 800 meters. Table 1 gives information about number, name, river, record length, and elevation of the selected streamflow stations. The tables of the all stream gauge stations in the region are attached to the Appendix A. As seen in Table 1, all selected stations have adequate record length (i.e. at least 40 years) for making statistical analysis to detect possible trends in streamflow data.

Table 1. Data period and elevations of selected streamflow stations.

NUMBER	STATION			DATA PERIOD	ELEVATION (m)
EUPHRATES BASIN					
2102	Murat Suyu	-	Palu	1936-2010	852
2122	Murat Nehri	-	Tutak	1953-2010	1552
2124	Tohma Suyu	-	Yazıköy	1954-2010	1193
2133	Munzur Suyu	-	Melekbahçe	1953-2009	875
2145	Tohma Suyu	-	Hisarcık	1962-2010	933
2156	Fırat Nehri	-	Bağıştaş	1968-2010	865
2157	Karasu	-	Karaköprü	1968-2007	1250
2164	Göynük Çayı	-	Çayağzı	1968-2010	990
TIGRIS BASIN					
2610	Bitlis Çayı	-	Baykan	1954-2010	698
2620	Zap Suyu	-	Üzümcü	1968-2010	1072
2621	Zap Suyu	-	Musahan	1968-2010	1725
ÇORUH BASIN					
2316	Çoruh Nehri	-	İspir Köp.	1964-2010	1170
2325	Oltu Suyu	-	Aşağı Kumlu	1973-2010	1129
ARAS BASIN					
2402	Aras Nehri	-	Kağızman	1953-2010	1140
2415	Kura Nehri	-	Ur Köp.	1969-2010	1750

In order to support trends available in streamflow data, meteorological variables such as maximum, minimum and mean air temperature and precipitation are required. These meteorological data representing the streamflow stations are obtained from MGM and their station details such as number, name, record length, and elevation are provided in Table 2. Usually these stations are situated at the city center and their locations can be seen in the physical map of Turkey in Figure 2 and GIS layer in Figure 3.

Table 2. Data period and elevations of selected meteorological stations

NUMBER	STATION	DATA PERIOD	ELEVATION (m)
17199	MALATYA	1970-2010	947
17203	BİNGÖL	1970-2010	1177
17165	TUNCELİ	1970-2010	981
17204	MUŞ	1970-2010	1322
17099	AĞRI	1970-2010	1632
17094	ERZİNCAN	1970-2010	1218
17848	BİTLİS	1970-2010	1573
17285	HAKKARİ	1970-2010	1727
17630	ARDAHAN	1970-2010	1829
17045	ARTVİN	1970-2010	628

It is noted that streamflow data for the year 1989 represents an outlier among other stations with a relatively warm winter and dry water year (Cullen and deMenocal, 2000). The outlier is replaced with an average value by using data values of the years 1970 to 2010.

2.2 Methods

In this chapter, the following sub-sections describe each method that is applied to minimum, maximum and mean air temperature, precipitation, and streamflow data to detect any discernible changes and determine significance level of the results. In addition, Center-Time method is introduced to show whether there is a temporal shift in streamflow data or not because of the increased temperature in time.

2.2.1 Center-Time (CT) Method

In order to detect the changes in the streamflow timing, researchers have used different measures, such as "spring pulse onset" that defines the date when snowmelt streamflow begins to make the major "climb up" in spring or early summer (Cayan et al., 2001), and "center time" (CT) that defines the date that marks the timing of the center of mass of annual flow (Stewart et al., 2005). In this study, we used CT method to detect any shifts in streamflow timing.

As it is mentioned, CT is defined as the date marking the center of mass of annual flow for each water year (Stewart et al., 2005), or the date when half of the flow for each water year has occurred (Şen et al., 2011). As simple, from the beginning of the water year (1st of October), for 12 months period, the half of the cumulative streamflow is counted. The date when this quantity is reached is named as Center Time (Altürk, 2008).

The CT date is calculated by this equation (Equation 1).

$$CT = \frac{\sum(t_i q_i)}{\sum q_i} \tag{1}$$

Here t_i is the time in days since the beginning of the water year (1st of October), and q_i is the corresponding streamflow for day i. This equation was adopted from Stewart et al. (2004, 2005).

The CT's of each streamflow station was calculated for the selected period (1970-2010). The CT graphs of each station is plotted.

2.2.2 Mann-Kendall Test

A series of observations of a random variable (daily streamflow, daily precipitation etc.) have been collected over some period of time. We would like to determine if their values generally increase or decrease (getting "better" or "worse"). In statistical terms this is a determination of whether the probability distribution from which they arise has changed over time. We would also like to describe the amount or rate of that change, in terms of changes in some central value of the distribution such as a mean or median (Helsel et al., 2002).

The time trends of streamflow, precipitation, and air temperature for all stations are investigated by computing the statistical test called Mann-Kendall test. In addition to that, the changes in CT of each station are analyzed. Mann-Kendall is a nonparametric or, distribution free test for trends.

A parametric test like linear regression is not considered appropriate since streamflow characteristics generally are not normally distributed (Gebert and Krug, 1996). Many authors have successfully used Mann-Kendall test to identify the trends in the stream flow and precipitation data (Gebert and Krug, 1996, Yue and Wang, 2002, Kahya and Kalayci, 2004, Rose, 2008). The null hypothesis, H_0, is that there is no (x_1,……x_n) significant temporal trend in the series. The alternative hypothesis, H_1, is that the dataset show significant temporal trend.

In this study, 90% confidence level is used. The confidence level is a measure of confidence in rejecting the null hypothesis. The corresponding (Z-critical) standard deviate for 90% confidence level is 1.65.

The test statistic S, which has mean zero and a variance computed by Equation (4), is calculated using Equations (2) and (3), and is asymptotically normal (Hirsch and Slack, 1984):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{2}$$

$$sgn(x_j - x_k) = \begin{Bmatrix} +1 & if & (x_j - x_k) > 0 \\ 0 & if & (x_j - x_k) = 0 \\ -1 & if & (x_j - x_k) < 0 \end{Bmatrix} \tag{3}$$

$$Var(S) = \frac{[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)]}{18} \tag{4}$$

The notation t is the extent of any given tie and ∑t denotes the summation over all ties. In cases where the sample size n > 10, the standard normal variate z is computed by using Equation (5) (Douglas et al., 2000). In a two-sided test for trend, H_0 should thus be accepted if $|z| \leq z\alpha/2$ at the α level of significance. A positive value of S indicates an ‘upward trend’; likewise, a negative value of S indicates ‘downward trend’:

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \tag{5}$$

2.2.3 Sequential Mann-Kendall Test

Sequential values u(t) and u'(t) from the progressive analysis of the Mann–Kendall test were determined in order to see change of trend with time (Sneyers, 1990). Herein, u(t) is a standardized variable that has zero mean and unit standard deviation. Therefore, its sequential behavior fluctuates around the zero level. u(t) is the same as the z values that are found from the first to last data point. This test considers the relative values of all terms in the time series (x_1, x_2……x_n)The following steps are applied in sequence:

1. The magnitudes of x_j annual mean time series, (j = 1, . . ., n) are compared with x_k, (k = 1, . . ., j-1). At each comparison, the number of cases $x_j > x_k$ is counted and denoted by n_j.

2. The test statistic t is then given by equation

$$t_j = \sum_{1}^{j} n_j \tag{6}$$

3. The mean and variance of the test statistic are

$$\mathrm{E(t)} = \frac{\mathrm{n(n-1)}}{4} \quad \text{and} \quad \mathrm{Var(t_j)} = \frac{[\mathrm{j(j-1)(2j+5)}]}{72} \tag{7}$$

4. The sequential values of the statistic u(t) are then calculated as

$$u(t) = \frac{t_j - E(t)}{\sqrt{Var(t_j)}} \tag{8}$$

Similarly, the values of u'(t) are computed backward, starting from the end of the series. The sequential version of the Mann–Kendall could be considered as an effective way of locating the beginning year(s) of a trend (Partal et al., 2006).

If u(t) graph and u'(t) graph lines come closer to each other and intersects each other one or a few times, this means a meaningful trend and these intersection points are accepted as the start of trend. If the two graphs u(t) and u'(t) coincides each other several times and moves almost parallel to each other, this means that there is no such a meaningful trend. For example, Figure 4(a) shows that the data set proves Ho (no trend), and Figure 4(b) shows that the data set has a meaningful trend and the year 2003 can be accepted as the start of trend.

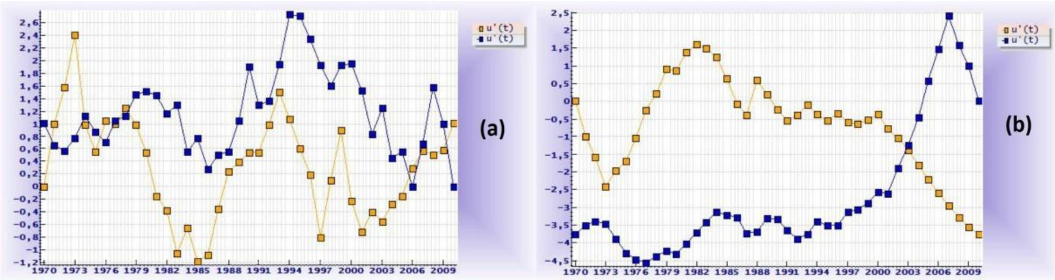


Figure 4. (a) and (b) Example u(t) and u'(t) graphs.

2.2.4 Spearman's Rho Test

Spearman's Rho Test is a non- parametric measure of statistical dependence between two variables described by Charles Spearman. Assesses how well the relationship between two variables can be described using a monotonic function.

The rank statistics R_{xi} is determined by sequencing the data in ascending order or descending order. The null hypothesis, H_0, is that there is no $(x_1,\ldots\ldots x_n)$ significant temporal trend in the series. The alternative hypothesis, H_1, is that the dataset show significant temporal trend.

The Spearman's Rho test statistic is given by equation

$$r_s = 1 - 6\,\frac{[\sum_{i=1}^{n}(R(x_i - 1)^2)]}{(n^3 - n)} \tag{9}$$

In cases where the sample size n > 30, since the r_s is approaching to normal, the standard normal table is used.

The test statistic (Z) for r_s, is computed by equation

$$Z = r_s\sqrt{n-1} \tag{10}$$

H_0 should thus be accepted if $|z| \leq z\alpha/2$ at the α level of significance. H_1 should be accepted if $|z| \geq z\alpha/2$ at the α level of significance.

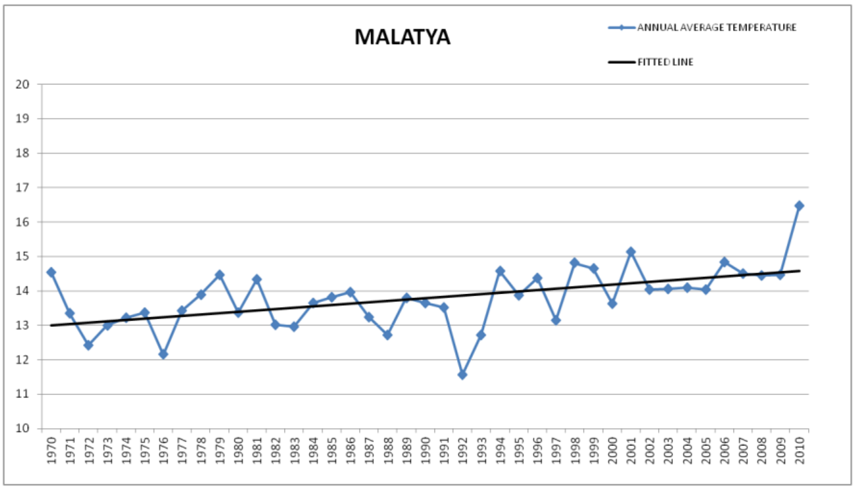
CHAPTER 3

RESULTS

3.1 Temperature Analysis

Daily temperature data of the selected stations (Table 2) are obtained from MGM. These data are analyzed to show the fact that, whether there is an increase in temperature for these selected basins or not. From the obtained data, the analyses are done in daily, average, maximum, seasonal, and period bases as 1970-1990 and 1991-2010 periods separately.

The averages of daily temperature between the years 1970 and 2010 are calculated from data of stations. The average temperatures show increasing trend as expected. Figure 5 shows the trends of annual average temperatures for each meteorological station.



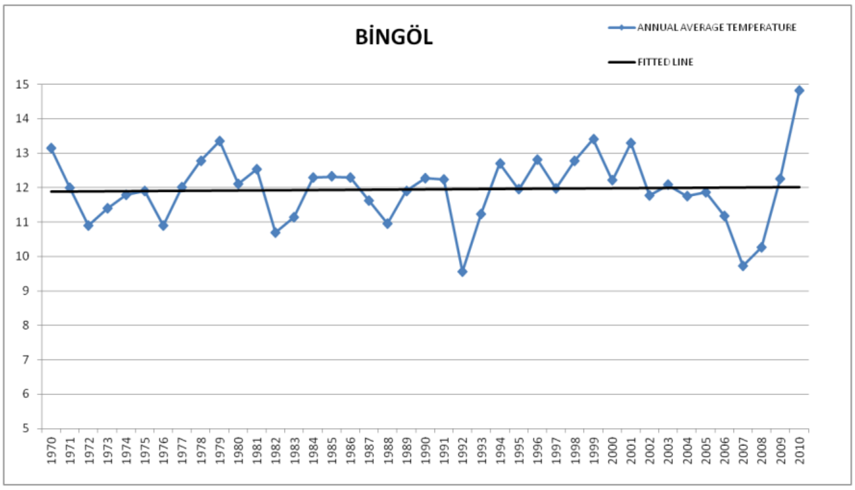
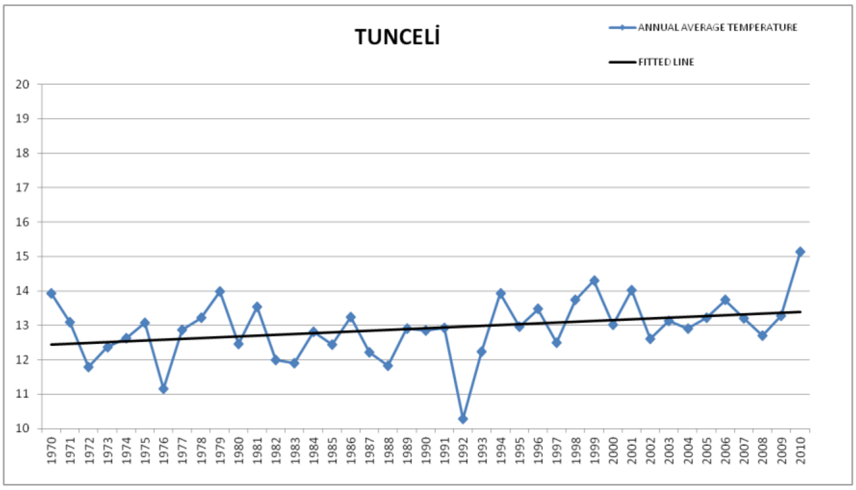
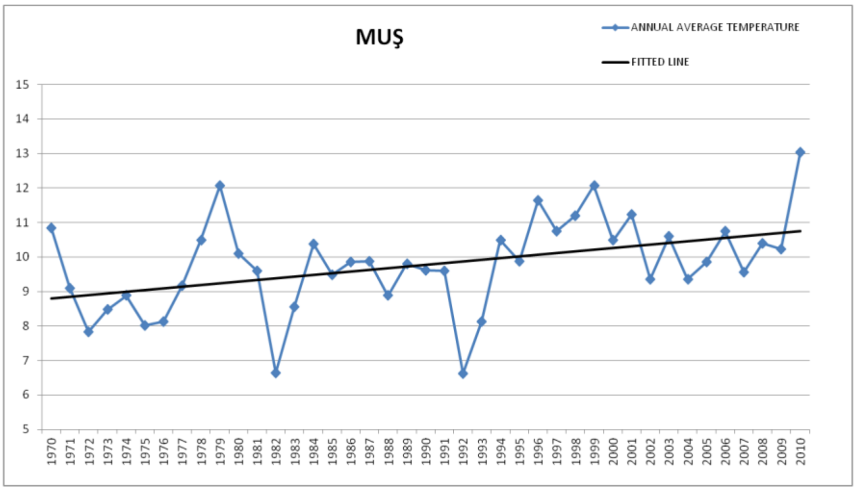
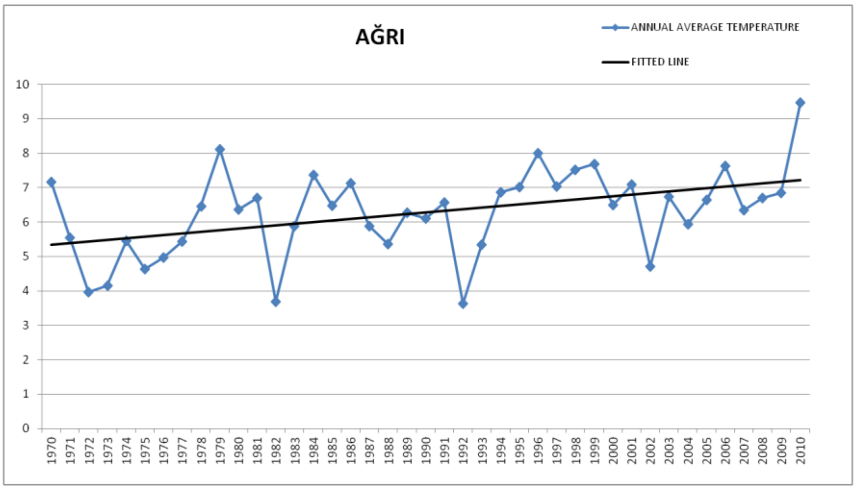


Figure 5. Annual average temperatures of meteorological stations.







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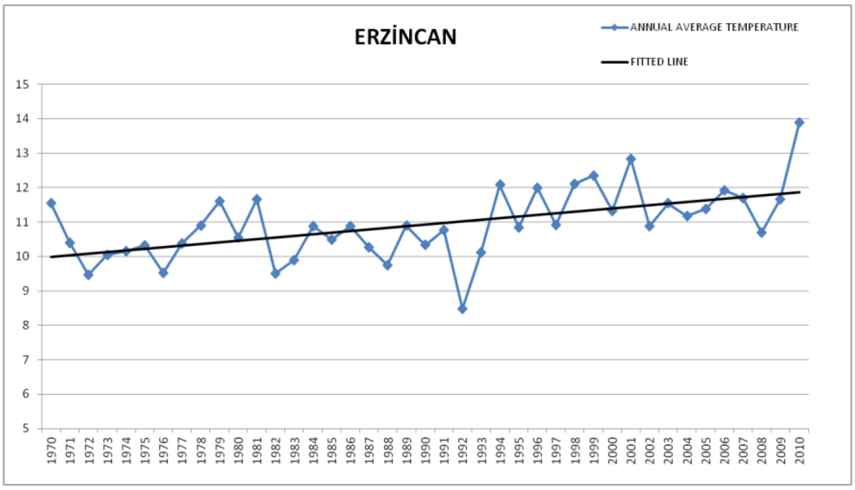

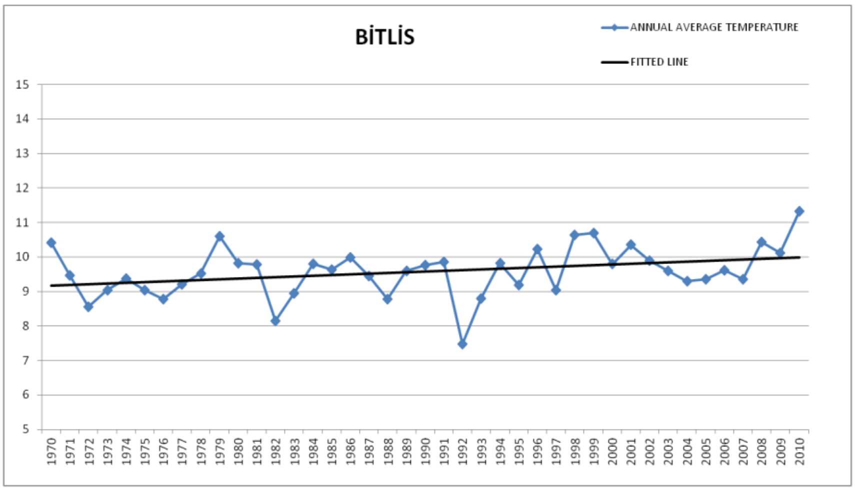

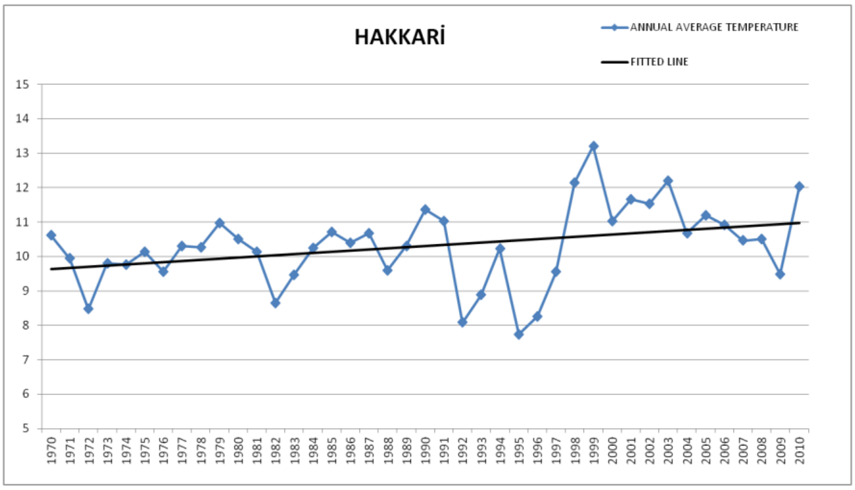

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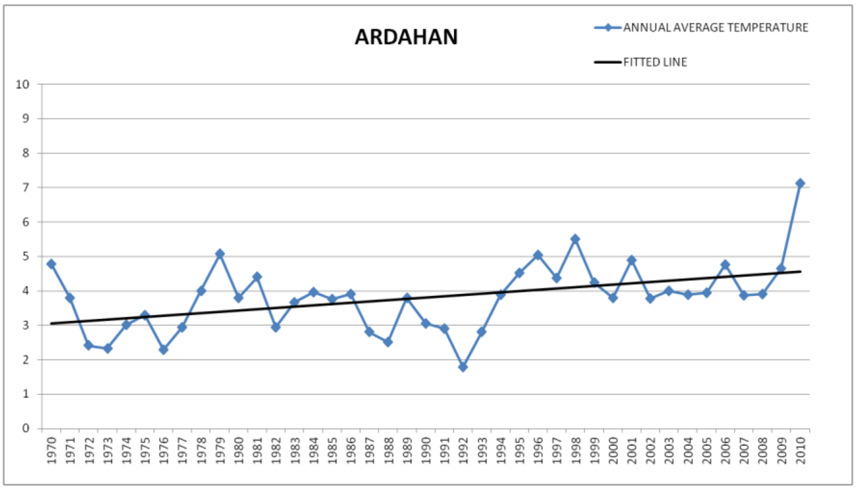


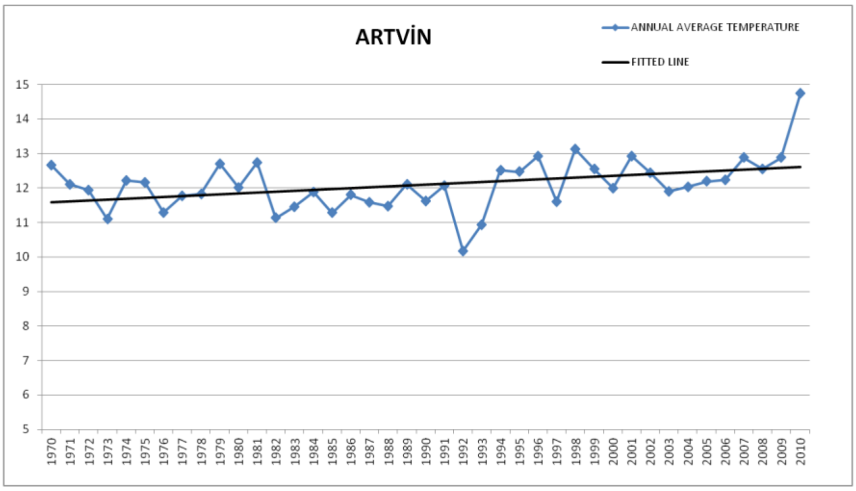
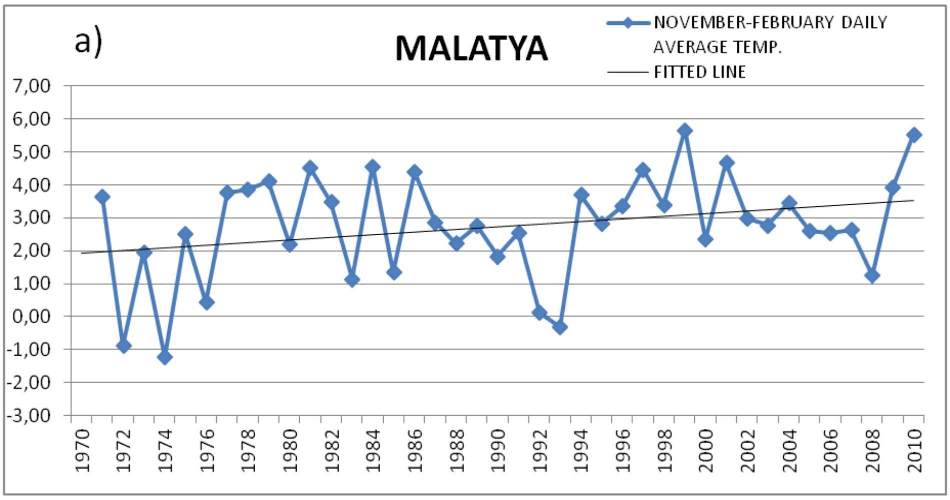
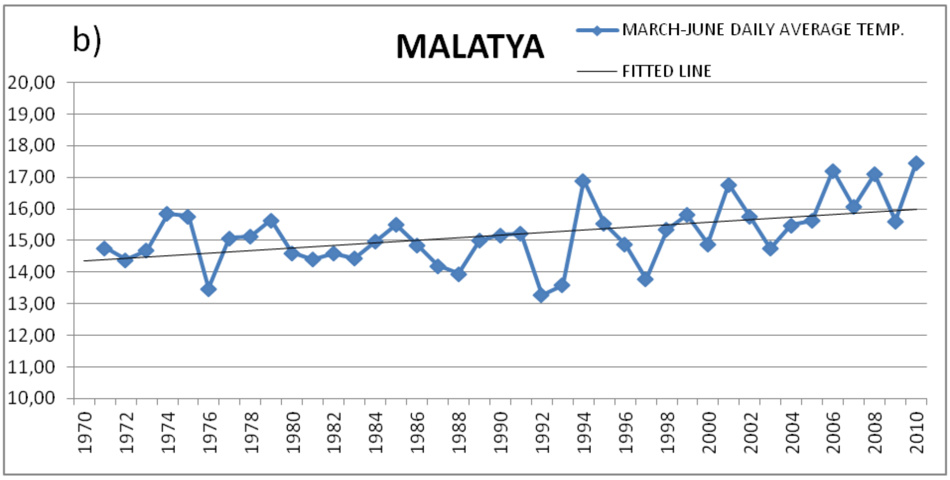


Figure 5 (continued)

As can be seen in the graphs, all the stations have an increasing trend in annual average temperatures. Muş station has the highest slope with an increase of $+2.0^{0}$C in temperature, and the smallest slope is seen on Bingöl station with an increase of $+0.10^{0}$C in temperature. Although the slopes of the trends are different, there is $+1.3^{0}$C increase in temperatures as an avearage of selected 10 meteorological stations between the years 1970 and 2010 for selected stations.

The snow accumulation period is known as from November to February for this region while the melting period continues from March to June. In order to show in which period the warming trend is more significant, daily average temperatures of each station along with accumulation and melting periods are obtained and shown in Figure 6.





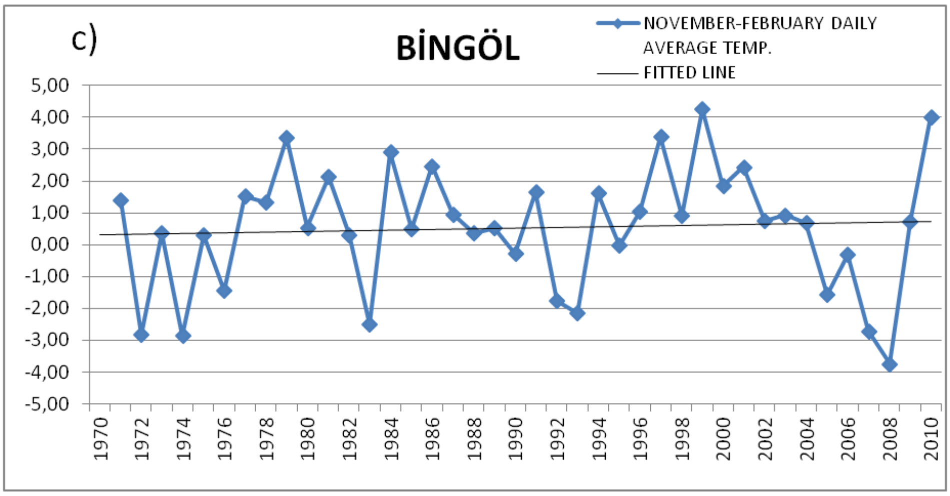
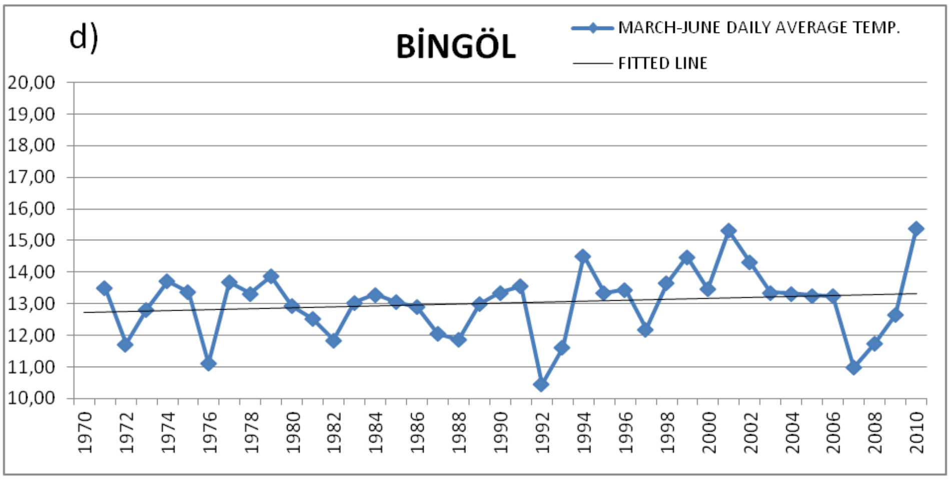
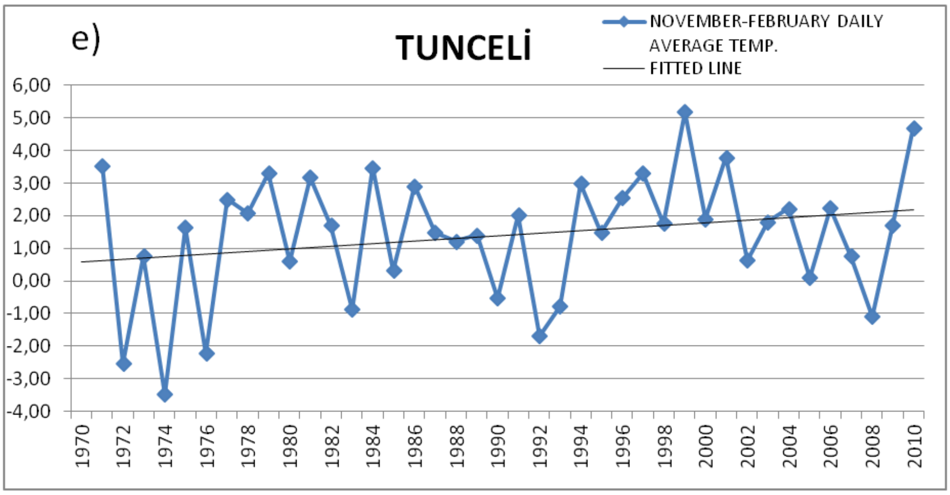
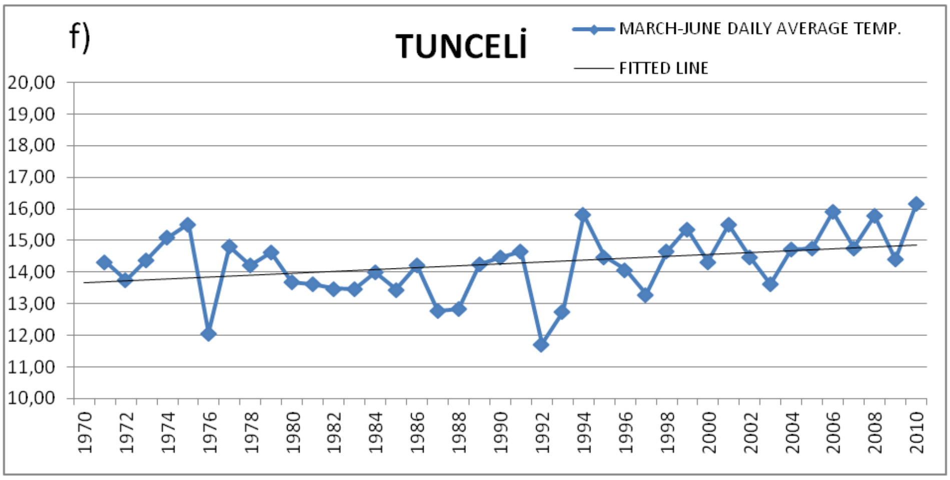


Figure 6. Daily average temperatures for snow accumulation periods (Figures: a-c-e-g-i-k-m-o-q-s) and snow melting periods (Figures: b-d-f-h-j-l-n-p-r-t) of meteorological stations.







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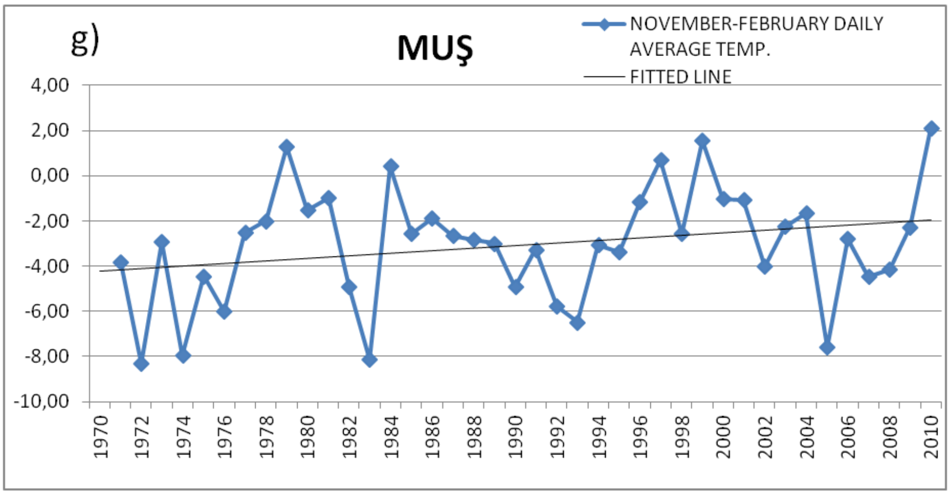

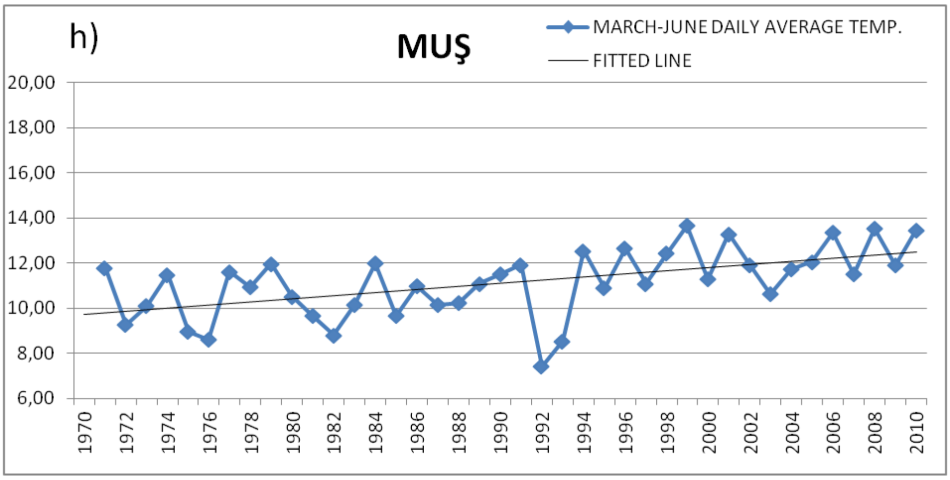

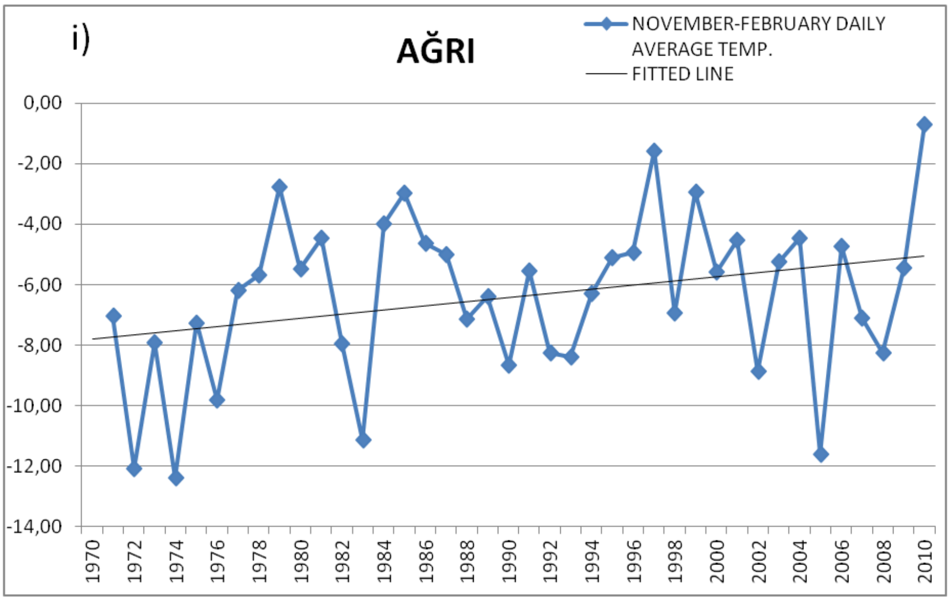

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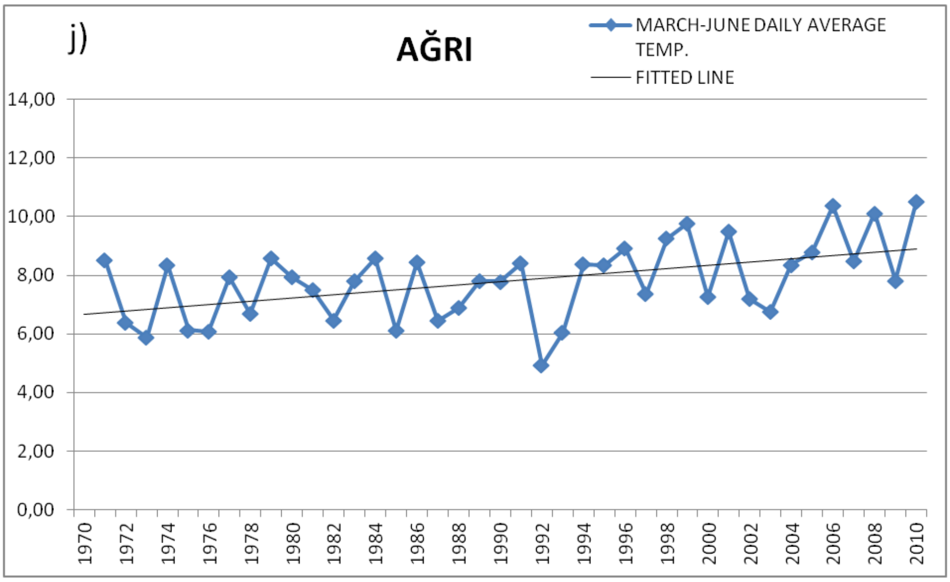

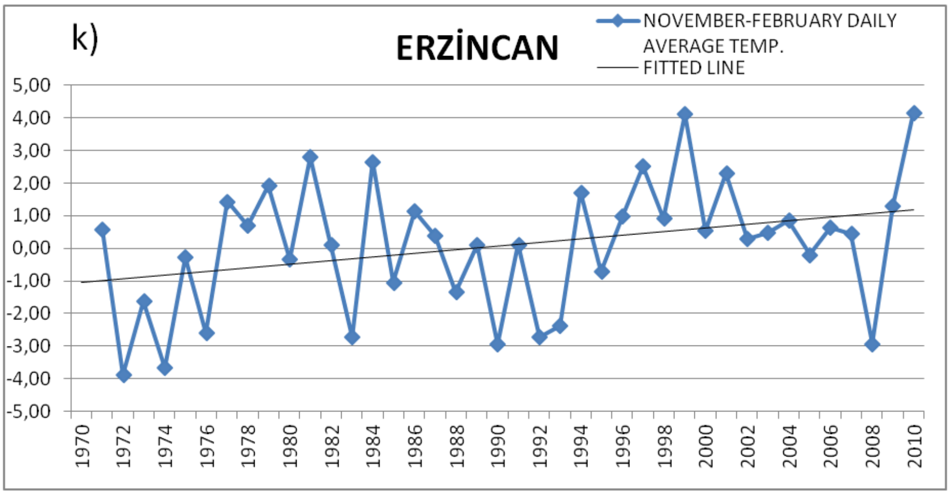

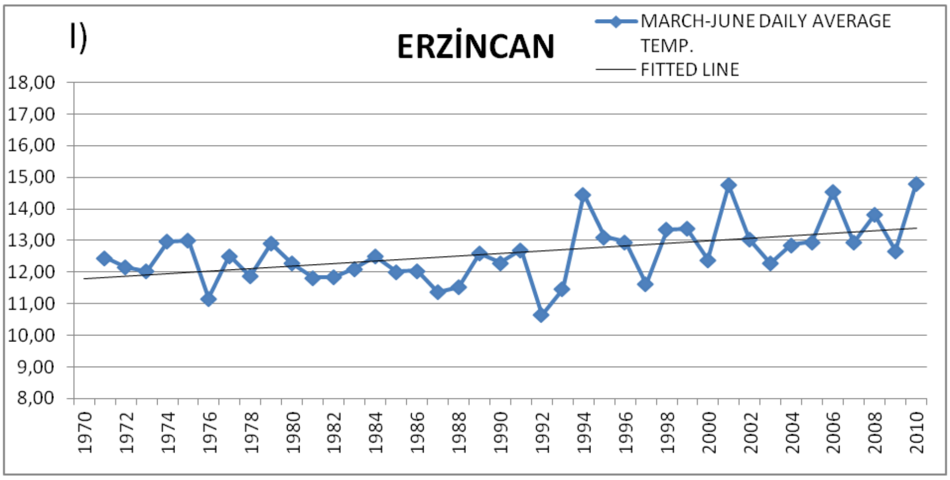

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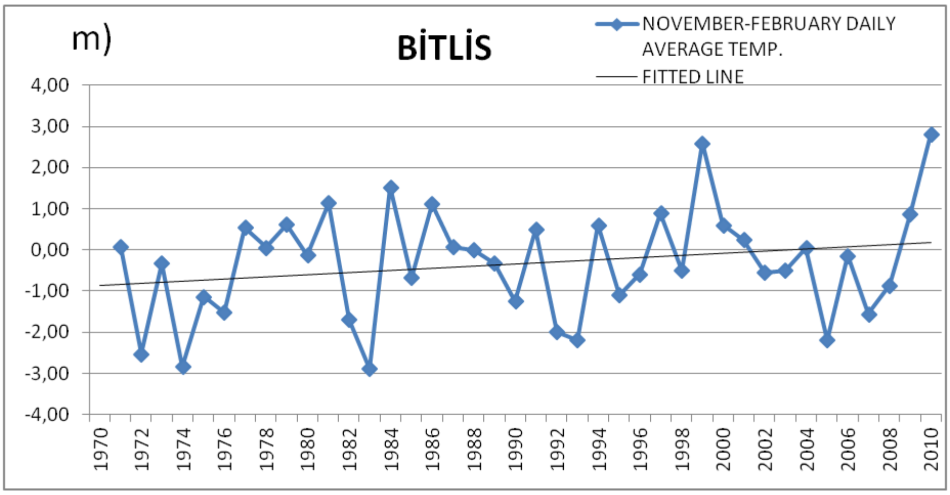

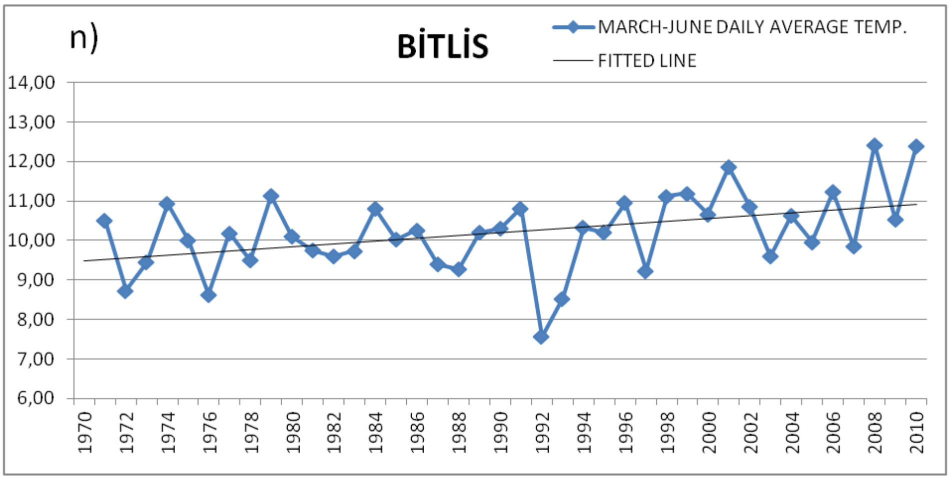

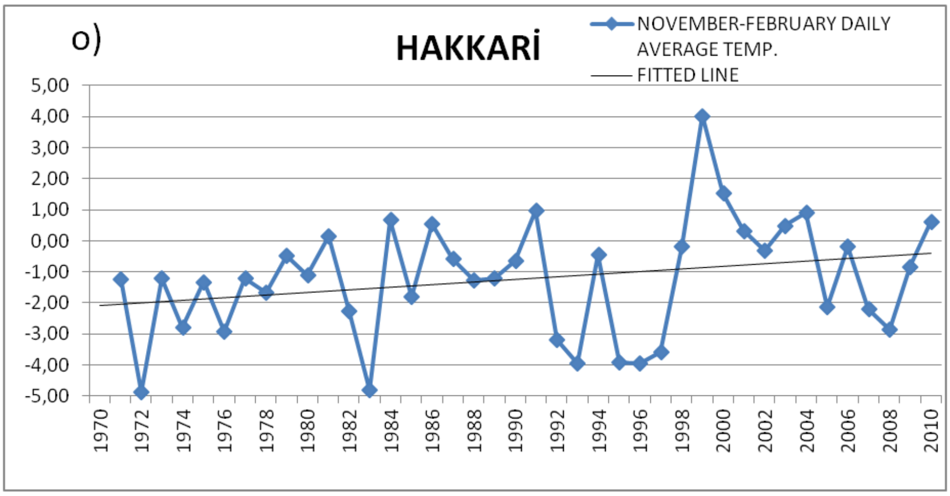

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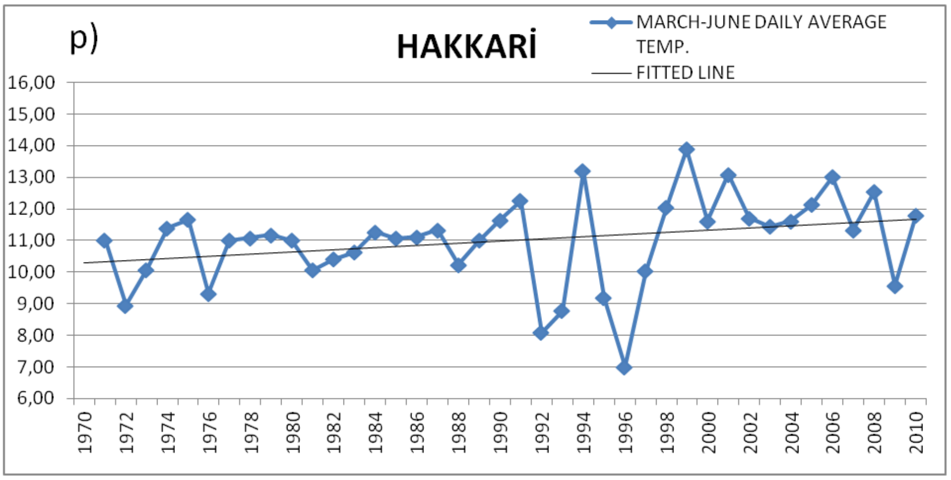

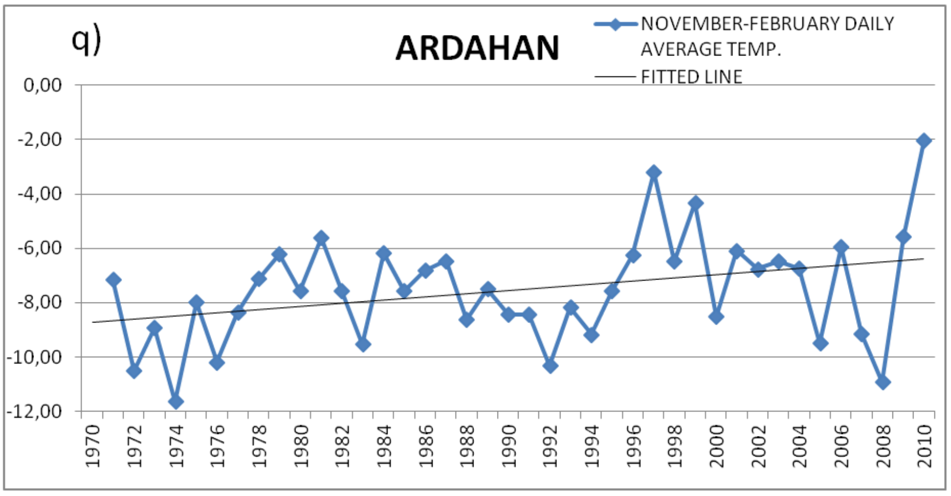

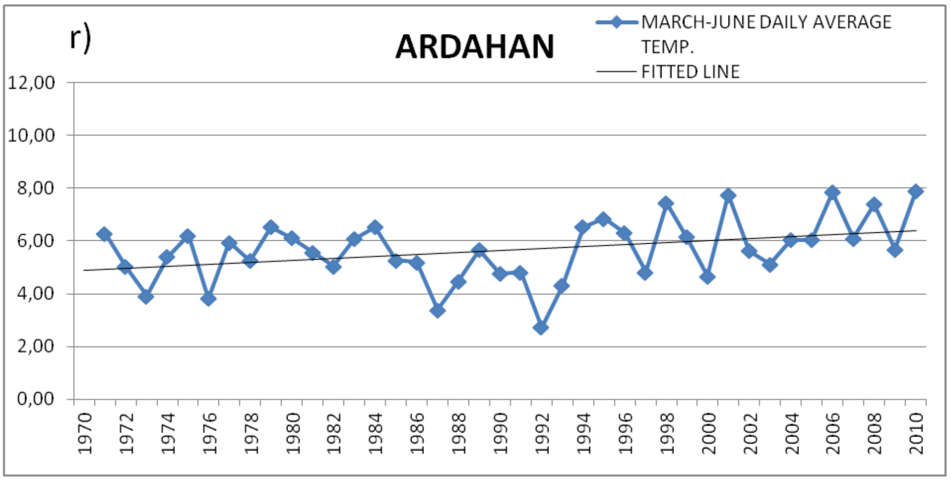

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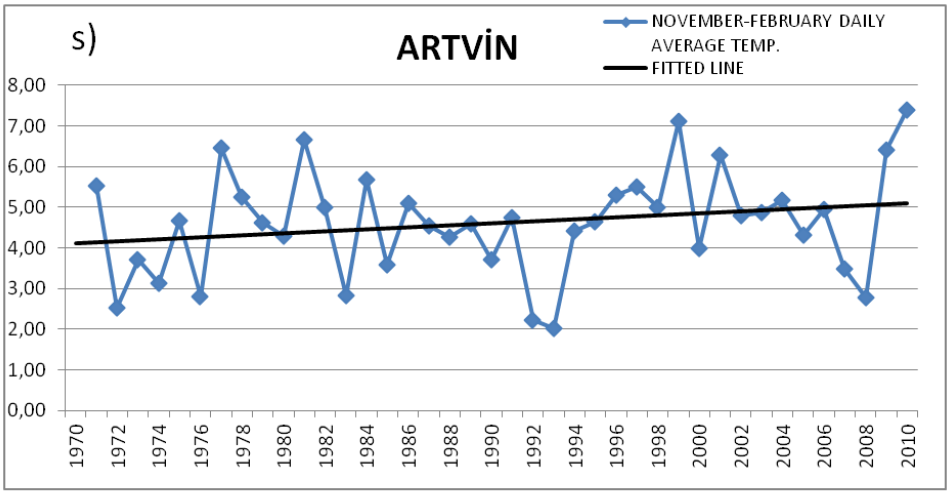


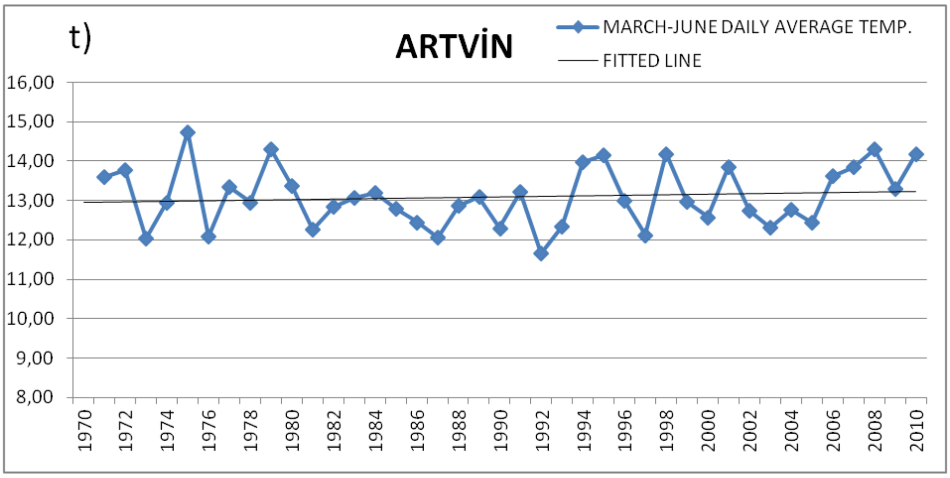


Figure 6 (continued)

These graphs emphasize that, the slightly higher slopes in accumulation period than that in melting period releases more warming trends. This means that increases in winter temperatures are higher than increases in spring temperatures (see Table 3). With the analysis of streamflow and precipitation data through these two periods, such an increase in temperature will be investigated whether it does lead to decrease in snow cover or not.

The averages of daily minimum and maximum temperatures from 1970 to 2010 are calculated from data of stations for more information. Daily minimum and maximum temperature plots of these stations are shown in Appendix B.

According to trend analysis of these plots, all the stations have positive trend for both maximum and minimum temperatures. Same as in the daily average temperature analysis, the highest slope is in the Muş station and the smallest slope is in the Bingöl station. As an average of total 10 meteorological stations, there is +1.45^{0}C increase in daily minimum temperatures and +1.37^{0}C increase in daily maximum temperatures. The increases in minimum temperatures are results of increases in nighttime temperatures. This may indicate the phase change in precipitation from snow to rain. Table 3 summarizes the results of temperature changes.

Table 3. Changes in temperatures of selected stations between the years 1970-2010

STATION	MAXIMUM TEMP.	MINIMUM TEMP.	AVERAGE TEMP.	NOVEMBER-FEBRUARY AVERAGE TEMP.	MARCH-JUNE AVERAGE TEMP.
MALATYA	+ 2.0	+ 1.2	+ 1.6	+ 1.6	+ 1.6
BİNGÖL	+ 0.5	0.0	+ 0.1	+ 0.4	+ 0.6
TUNCELİ	+ 2.0	+ 1.0	+ 1.0	+ 1.6	+ 1.2
MUŞ	+ 1.5	+ 2.5	+ 2.0	+ 2.3	+ 2.8
AĞRI	+ 2.0	+ 2.4	+ 1.9	+ 2.7	+ 2.2
ERZİNCAN	+ 1.5	+ 2.5	+ 1.9	+ 2.2	+ 1.6
BİTLİS	+ 1.5	+ 0.6	+ 0.8	+ 1.1	+ 1.4
HAKKARİ	+ 0.5	+ 0.9	+ 1.3	+ 1.7	+ 1.4
ARDAHAN	+ 1.2	+ 2.2	+ 1.4	+ 2.3	+ 1.5
ARTVİN	+ 1.0	+ 1.2	+ 1.0	+ 1.0	+ 0.3
AVERAGE	**+ 1.37**	**+ 1.45**	**+ 1.30**	**+ 1.69**	**+ 1.46**

As can be seen from the Table 3, temperature was increased during this 40 years period. All of the selected stations data show a positive trend for temperature analysis. The most temperature increase is obtained during accumulation period (+1.69) particularly with Tunceli, Ağrı, Erzurum, Hakkari, Ardahan, and Artvin stations, whose temperature increases are greater than temperature increases in melting (spring) period at these stations. The increases in November-February period probably affect the phase of precipitation since this period reflects the accumulation period for study region. In addition to that, increases in nighttime (minimum) temperatures are higher than increases in daily average and maximum temperatures.

Changes in annual average temperatures from 1970 to 1990 is also shown in Figure 7. This figure emphasizes that, March is the transition month in the region when the temperatures change from below zero to above zero.

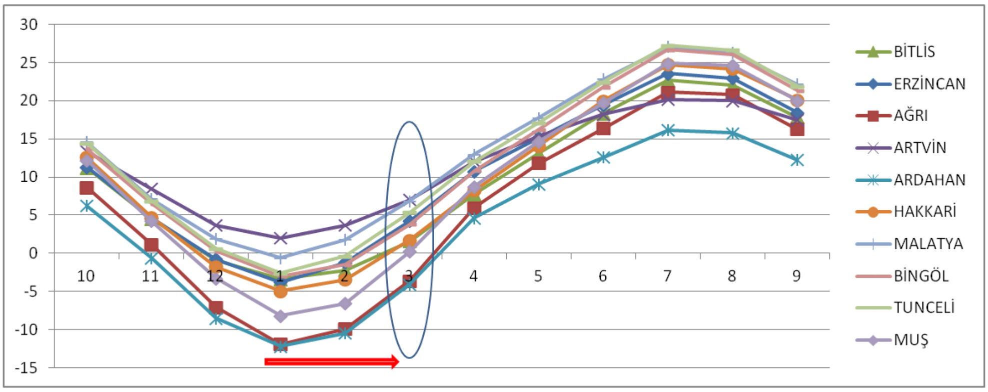


Figure 7. Monthly average temperatures from 1st of October to end of September for the years between 1970 to1990.

The differences in monthly average temperatures between the periods 1991-2010 and 1970-1990 is also shown in Figure 8. Regional temperatures increase in almost all months in the second period (global climate change). March warming tends more to keep the near-zero temperatures at the positive side, so increases the snowmelt and river discharges in this month (Şen et al., 2011).

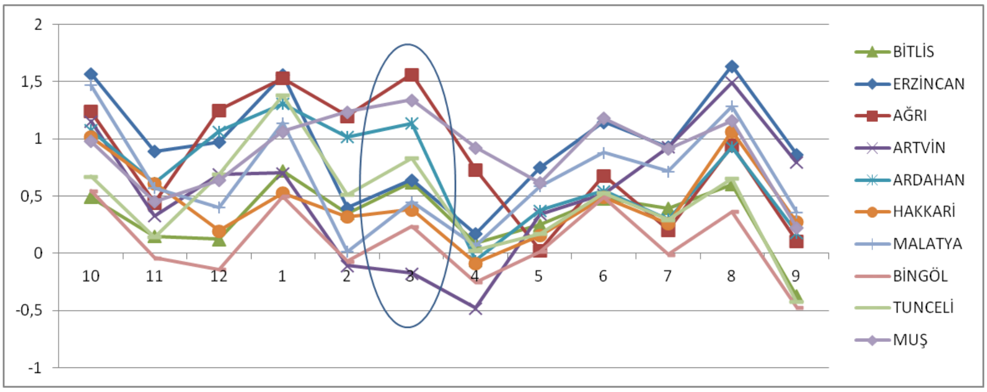


Figure 8. The differences in monthly average temperatures between the periods 1991-2010 and 1990-1970

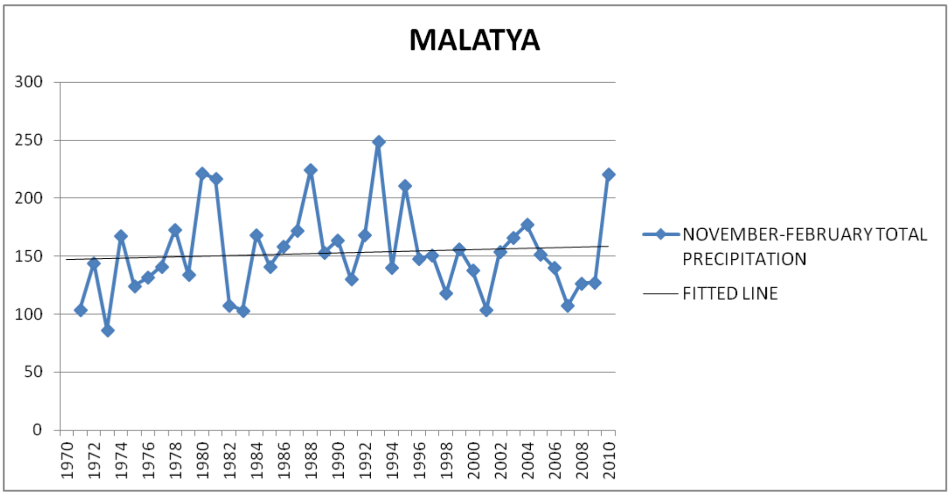
3.2 Precipitation Analysis

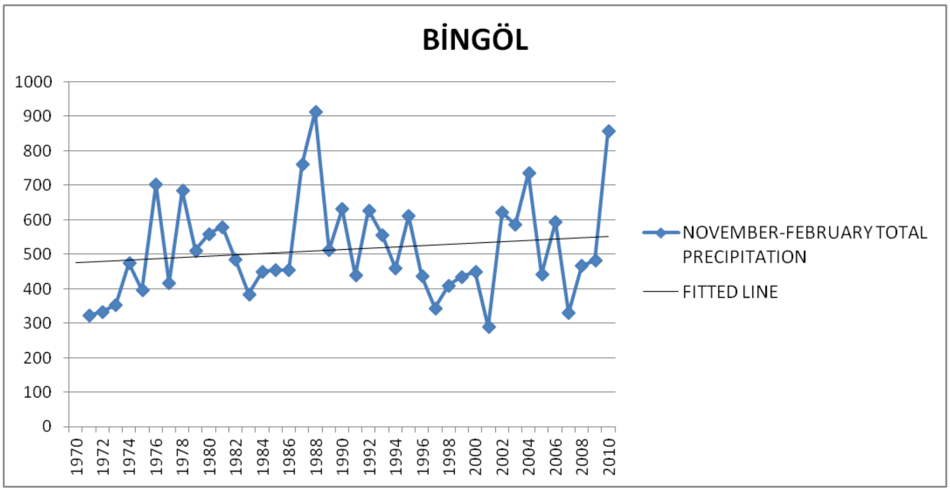
Daily precipitation data of the selected stations (Table 2) are obtained from MGM. Using daily precipitation data, annual average precipitation and annual cumulative precipitation values along with 1970-2010 period are calculated. Annual average precipitation plots of each station from 1970 to 2010 are shown in Appendix C.

In addition to these plots, the cumulative deviation analysis is performed in order to exhibit the dry and wet periods through the entire analysis period.

The changes in annual average precipitation in this study region are not so significant. As an average of selected 10 meteorological stations, annual average precipitation is increased 7.5% from 1970 to 2010. Annual average precipitation of selected stations showed an increasing trend except Malatya, Ağrı and Bitlis stations. It is noted that precipitation changes (increase or decrease) are not significantly important for the entire period while significant temperature increases are obtained for the same period. This may indicate the changes in intensity/duration of precipitation due to the attribution of important warming in this region.

In order to examine changes in precipitation during snow accumulation period, total precipitation amount within this period from November to February at each year from 1970 to 2010 is shown in Figure 9.





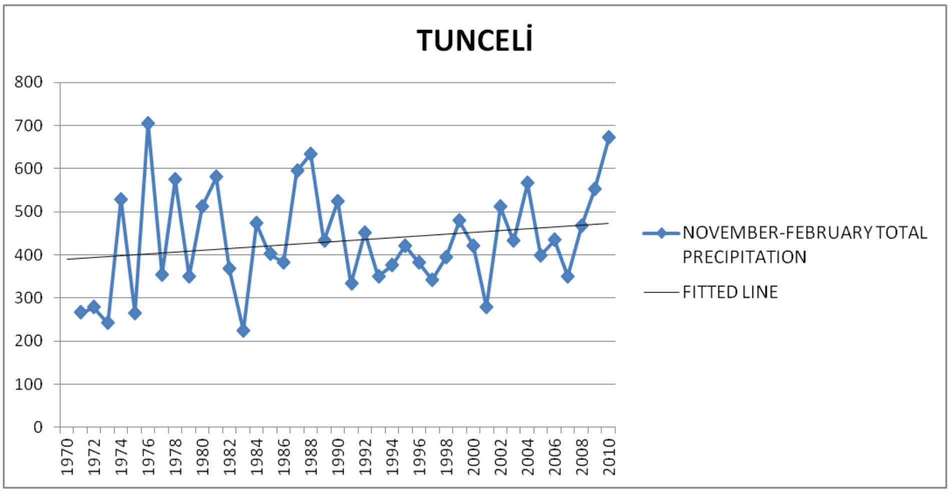
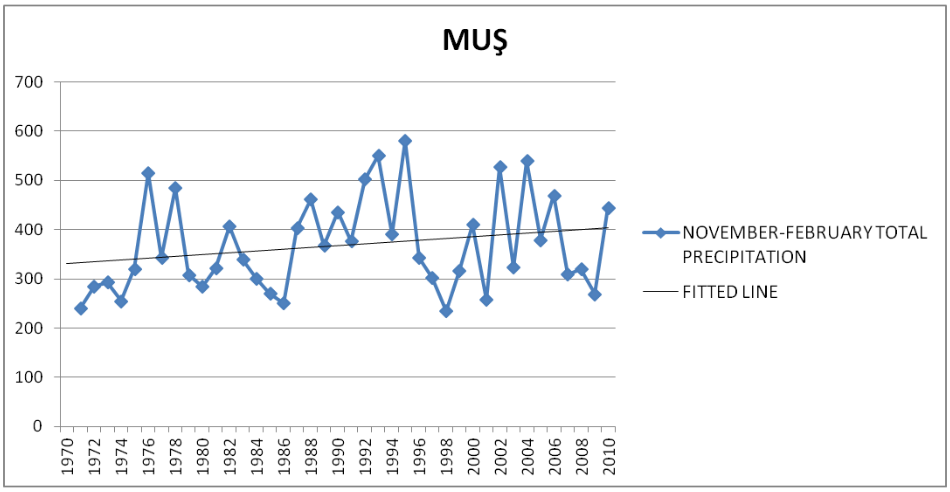
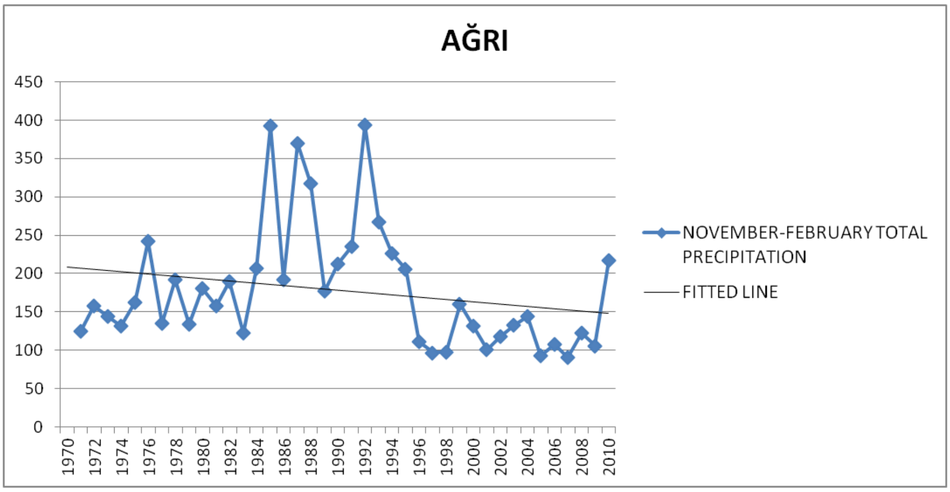


Figure 9. Total precipitation from November to February at each year from 1970 to 2010





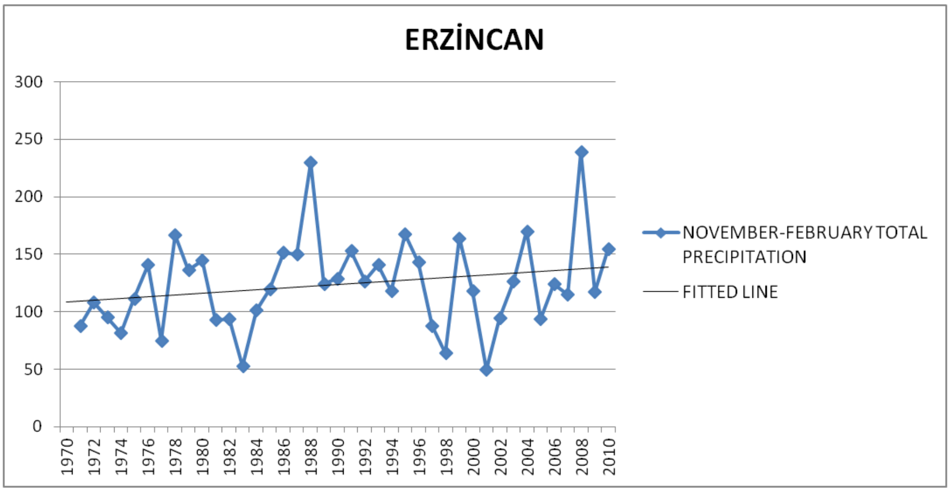
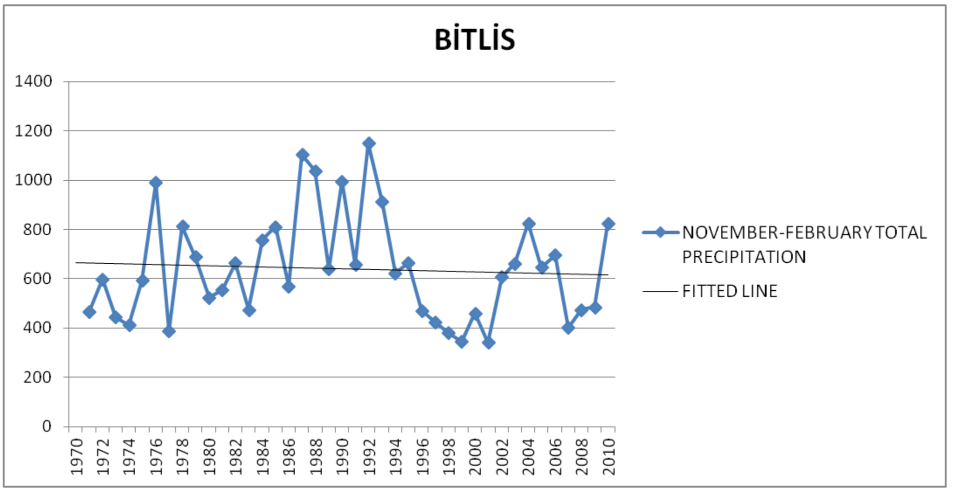
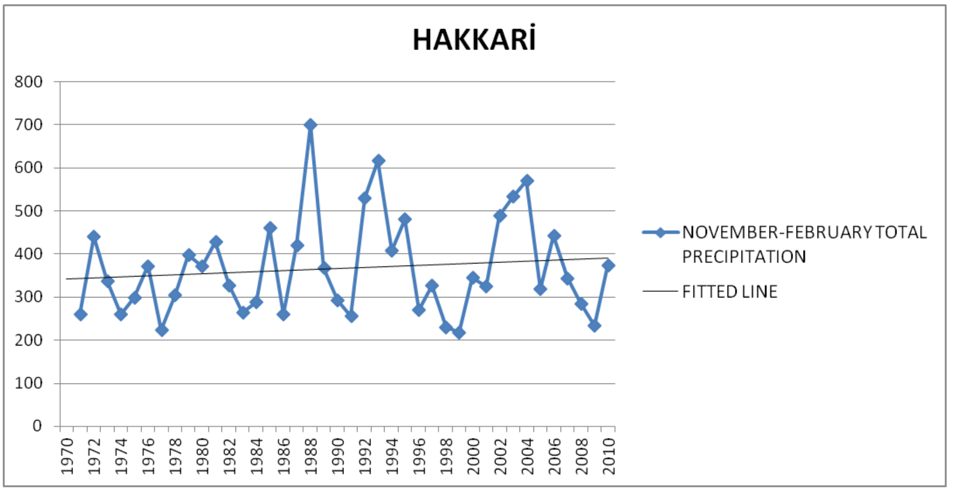


Figure 9 (continued)





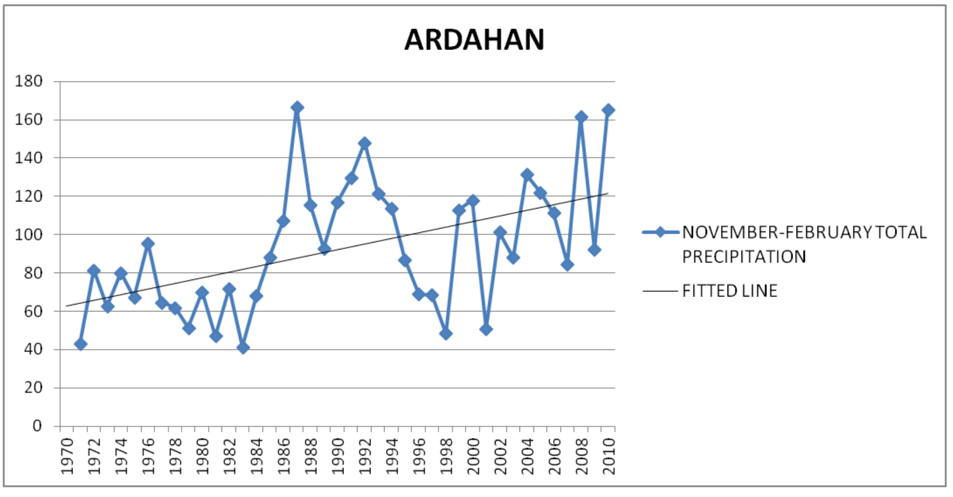


Figure 9 (continued)

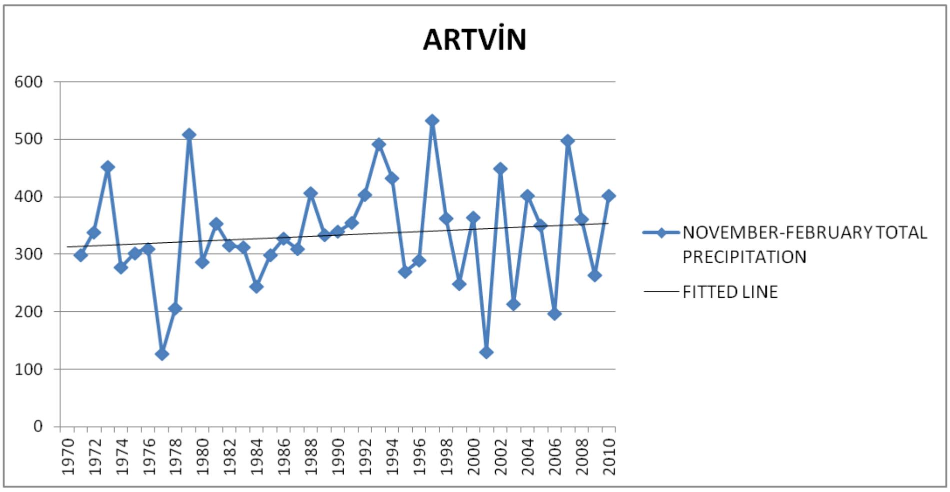


Figure 9 (continued)

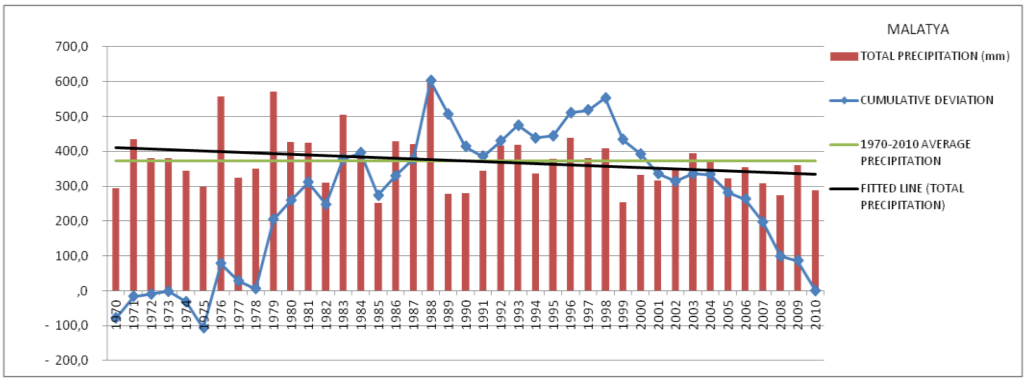
As can be seen from the Figure 9, except two stations (Ağrı and Bitlis), which are also the stations where annual average precipitation shows negative trend all eight stations have positive trend that shows increase in winter precipitation. Precipitation trend in accumulation period is much more significant than the trend in annual average precipitation in 1970-2010 time span. Although there is an increase in accumulation period precipitations, there is a decrease in melting period trends. As can be seen on Table 4, average change in total precipitation for accumulation period is +31.48 mm, whereas the melting period has -18.51mm. The increases in accumulation precipitations represent the increases in winter precipitations. The most temperature increase (+1.69 ^{o}C in all region) in accumulation period coincides with precipitation increase (+31.48 mm in all region) in the same period. Therefore, it is likely that warming effect influences the phase of precipitation during accumulation period. Additional comments about the phase and intensity of the precipitation may be done after analyzing the streamflow changes.

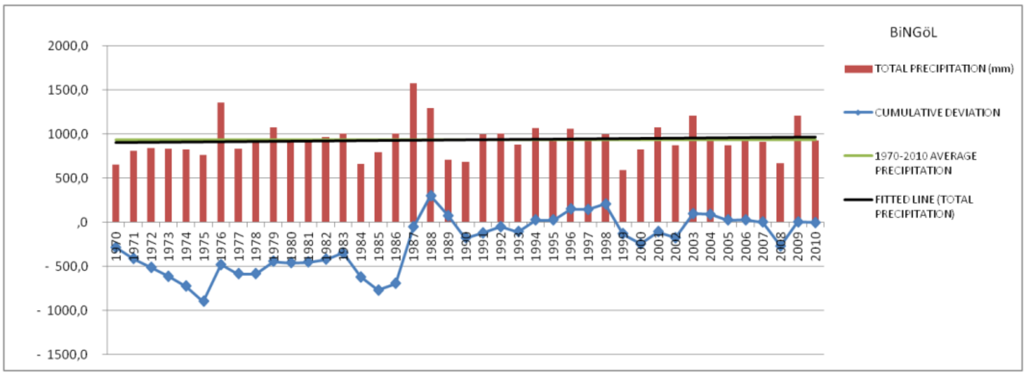
In order to find the changes in precipitation as a proportion from 1970 to 2010 (see Table 4), the trend equations of the fitted lines are used. These proportions represent the changes in precipitation from the starting point of the fitted line to the end point of the line.

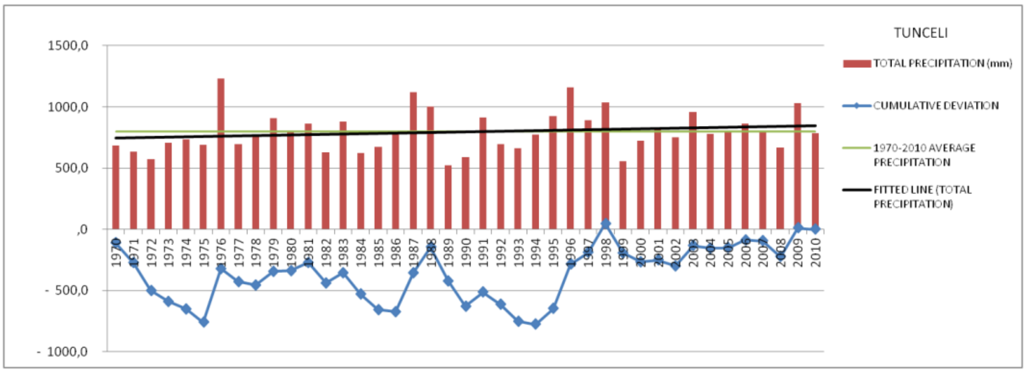
Table 4. Precipitation changes from 1970 to 2010 for the accumulation and melting periods of the meteorological stations

STATION	CHANGE IN TOTAL PRECIPITATION (NOV-FEB)		CHANGE IN TOTAL PRECIPITATION (MAR-JUNE)		CHANGE IN ANNUAL PRECIPITATION
	(mm)	Proportion (%)	(mm)	Proportion (%)	PROPORTION (%)
MALATYA	+ 11.1	7.3	- 110.9	- 46.3	- 18.24
BİNGÖL	+ 76.0	15.6	- 58.5	- 14.7	6.9
TUNCELİ	+ 82.6	20.6	- 17.8	- 5.7	13.0
MUŞ	+ 73,.8	21.8	- 17.5	- 5.3	10.8
AĞRI	- 60.3	- 28.2	+ 1.7	0.7	- 5.1
ERZİNCAN	+ 30.3	24.4	+ 1.0	0.6	10.9
BİTLİS	- 47.5	- 7.4	- 7.2	- 1.5	- 3.1
HAKKARİ	+ 49.6	13.5	- 84.5	- 26.8	0.05
ARDAHAN	+ 58.9	63.3	+ 99.5	43.4	45.5
ARTVİN	+ 40.3	11.8	+ 9.1	4.1	15.1
AVERAGE	**+ 31.48**	**14,3**	**- 18.5**	**- 5.2**	**7.5**

Annual total precipitation together with cumulative deviation at each station from 1970 to 2010 was calculated and shown in Figure 10.







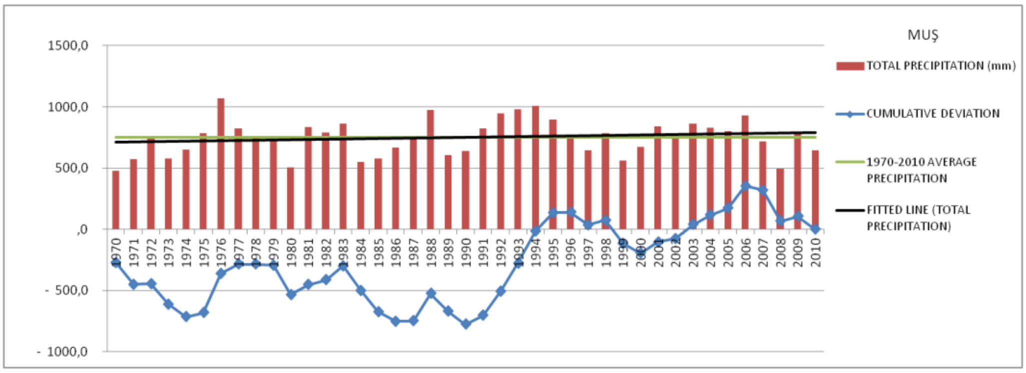
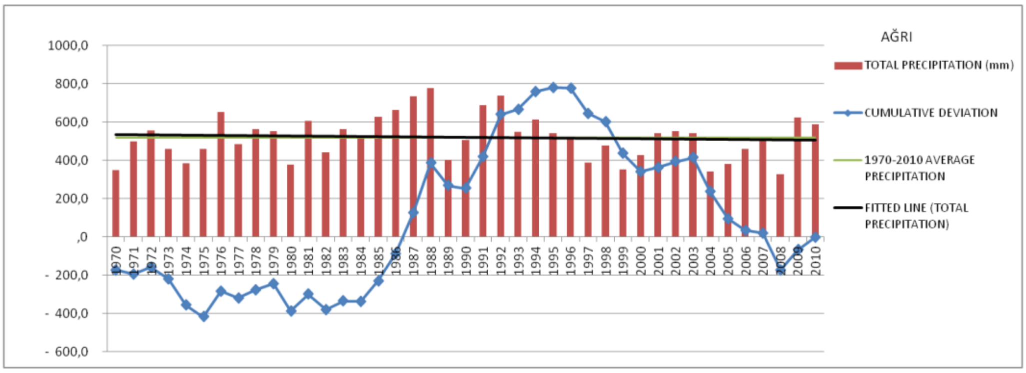
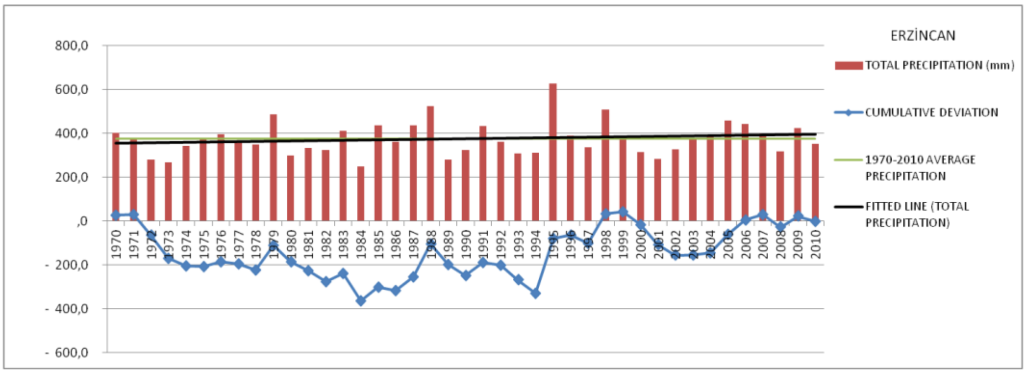
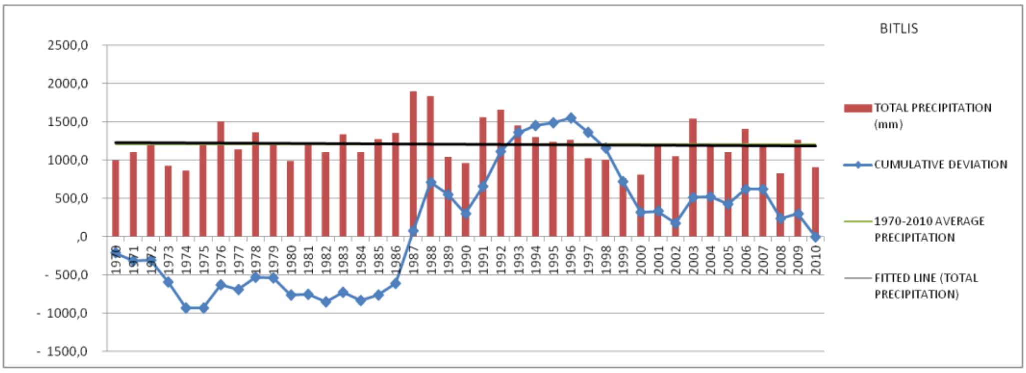


Figure 10. Annual total precipitation and cumulative deviation line at each station from 1970 to 2010







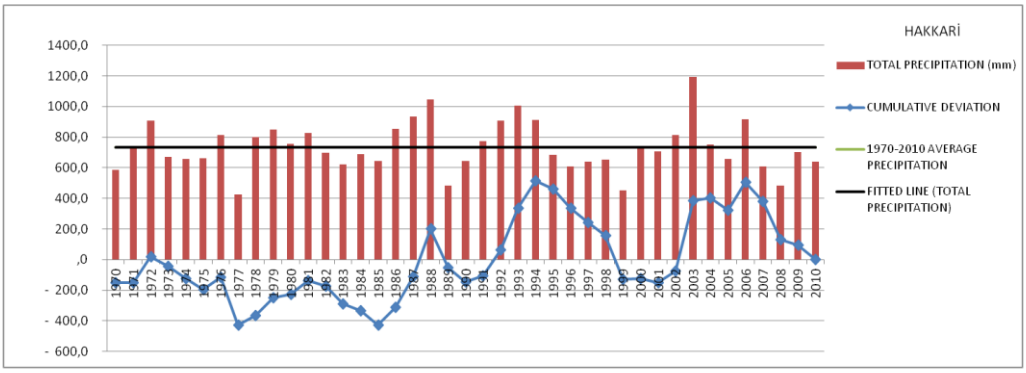
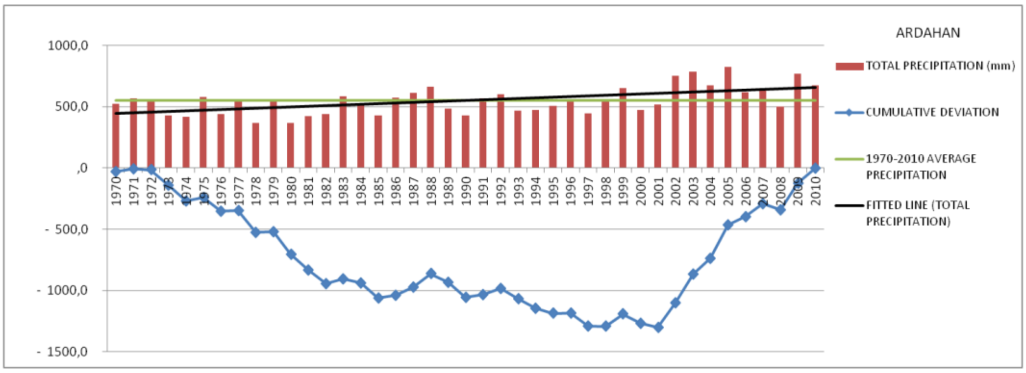


Figure 10 (continued)



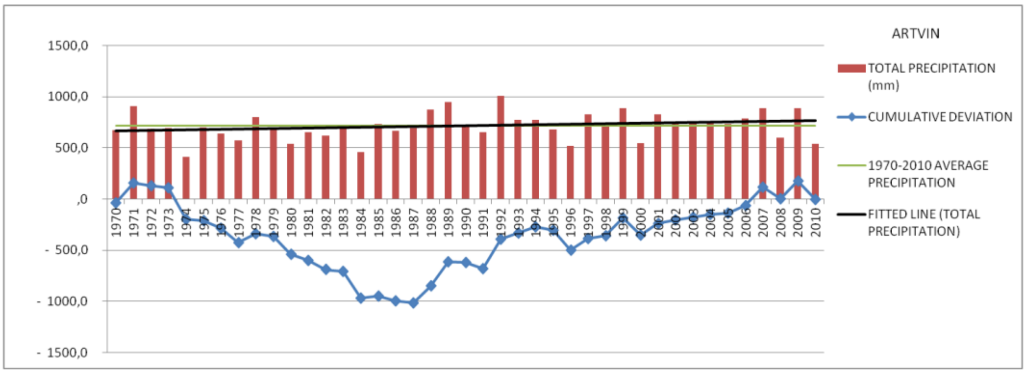


Figure 10 (continued)

Similar to annual average precipitation trends (see Figure 5), annual total precipitation values do not show any significant change through the time span from 1970 to 2010. These analyses show that increases in accumulation period is balanced by decreases in melting period so that annual precipitation trends do not show significant changes in precipitation along with evaluation period. This means that precipitation does not show inter-annual variation but it does show intra-annual or seasonal changes because of the climate change. The changes in precipitation during accumulation period are much more discernible in all stations for the same data period. When inspecting the precipitation trends at each station in Figure 9 and Figure 10, Malatya, Ağrı and Bitlis indicate some negative trend while other stations show either no trend or slight positive trend. Trend decrease in Ağrı and Bitlis stations are caused by precipitation decrease in accumulation period (-60.3 mm and -47.5 mm, respectively) while such decreasing trend in Malatya is attributed by precipitation decrease in melting period (e.g. -110.9 mm). A slight increase trend of annual or average precipitation at all other stations along with evaluation period is caused by precipitation increase in accumulation period at these stations (see Table 4). For example, among these stations, Ardahan shows the most significant increasing trend in total precipitation because such trend is seen in both accumulation (58.9 mm) and melting (99.5) periods. In general, it appears that significant warming trend at all stations (shown previously) has some consequences on precipitation through its type, intensity and duration at these stations. These changes will be examined with changes in temperature and streamflow data.

Cumulative deviation lines identify the wet and dry years along with data period from 1970 to 2010. In these graphs (Figure 10), three stations showed negative trend in precipitation (Malatya, Ağrı, Bitlis) indicate a dry period while the rest of the stations showed positive trend indicates a wet period towards the end of the evaluation period from 1970 to 2010. Especially, wet periods of Artvin and Ardahan are very distinguishable from others.

3.3 Streamflow Analysis

Daily average streamflow data obtained from 15 EIE stations whose information is given in Table 1 are analyzed. These daily data are used to calculate the monthly average streamflow and the average streamflow for snow accumulation period and melting periods for each year.

According to Figure 11 (MGM, 2011), positive temperature anomaly is more pronounced after the year 1990 especially when that period is compared to the years prior to 1990. Substantial increase in atmospheric greenhouse gasses concentration in recent years is responsible for positive temperature anomaly shown in Figure 11.

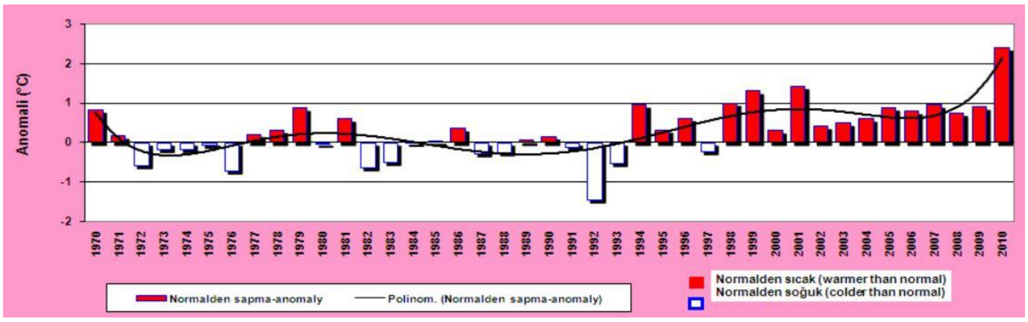


Figure 11. Annual average temperature anomalies in Turkey (MGM, 2011)

In order to show whether there is an earlier shift in melting of snow because of increase in temperature monthly streamflow data at each station during 1970-1990 and 1990-2010 periods are calculated and shown in Appendix D. In addition to these figures, the differences in these two periods are also plotted in Figure 12.

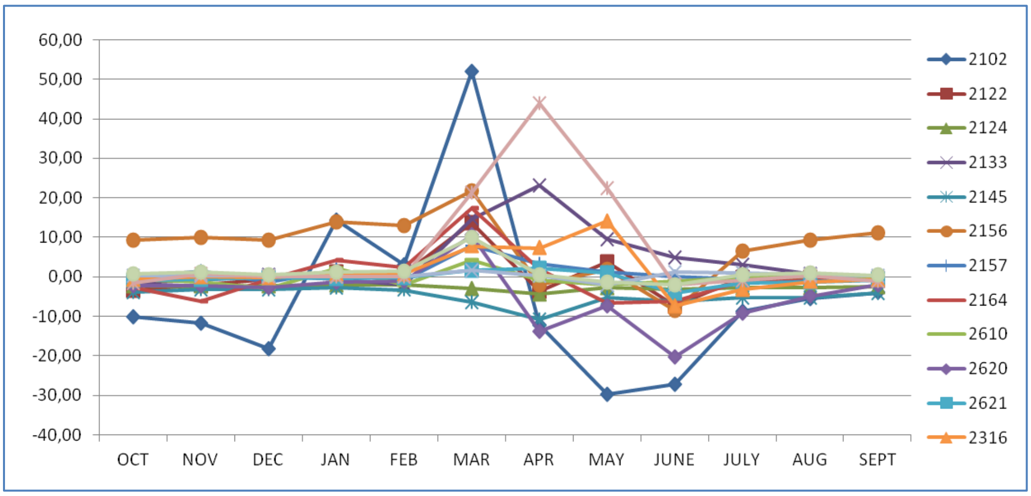


Figure 12. Differences in average monthly streamflow between two time periods of 1991-2010 and 1970-1990.

The sign of warming effect on streamflow data during the 1990-2010 period can be interpreted with the higher monthly discharge values in March and the lower monthly discharge values in May or June than the corresponding monthly flows during 1970-1990 period as they are describing the starting and ending months of melting period respectively. Monthly streamflow values of 1990-2010 period at 2124 and 2145 stations are always lower than the streamflow values during 1970-1990 period. The warming effect during 1990-2010 seems to be more pronounced at these two stations (see Appendix D) and therefore, it creates a large discrepancy in monthly streamflow values along with entire water year. A great decreasing trend in precipitation (-110.67 mm) during melting period from 1970 to 2010 at Malatya station may attribute to this large discrepancy at these two stream gauge stations. Additionally, 2620 and 2621 stations during 1991-2010 also show consistent lower discharges in summer months because of the fact that significant decreasing trend in precipitation (-84.98 mm) during melting period from 1991 to 2010 at Hakkari station is evident. Altürk (2008) concluded the same result in his study. Altürk (2008) emphasized on the starting year as 1990 for the warming period of Turkey.

According to temperature analysis (Figure 8), the increases in melting period temperatures (mostly March), caused early melting and as a result increased the streamflow in the starting days of melting (mids of March) (Figure 12).

As an example of annual streamflow data, annual streamflow graph for the station 2402 for these periods (1970-1990 and 1991-2010) is shown in Figure 13. On the graph, the fraction of the accumulated streamflow from 1st of October is shown. The shift in Center Time between these two periods is also shown on the same Figure.

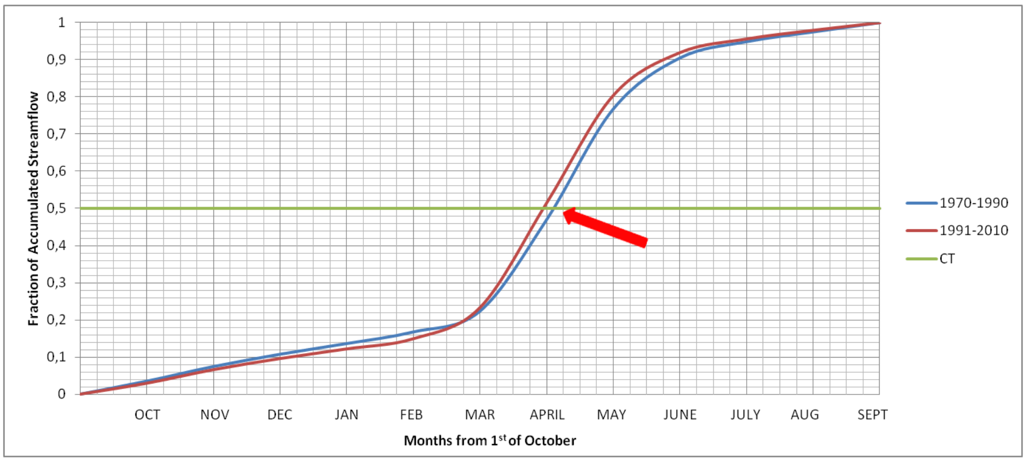
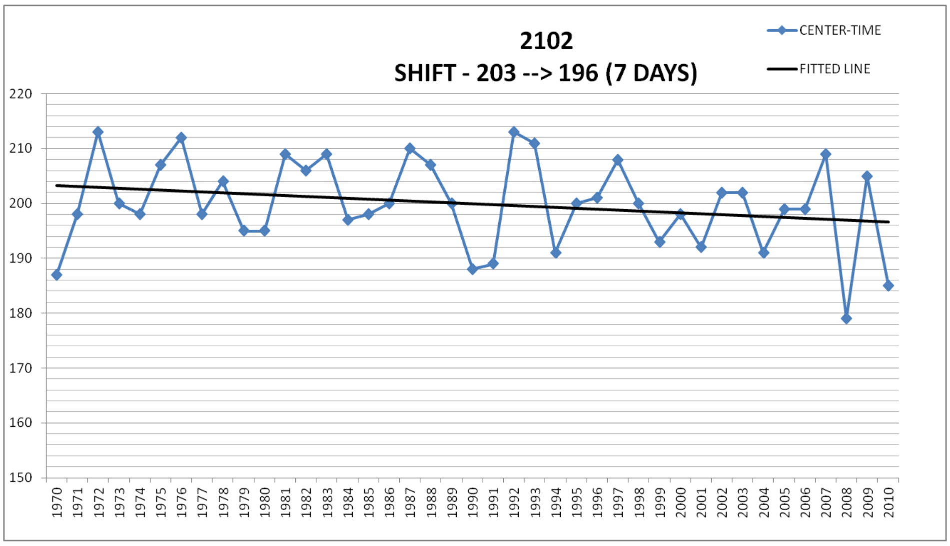


Figure 13. 2402 Stream gauge station accumulated streamflow for the periods of 1970-1990 and 1991-2010.

For the whole period (1970-2010) changes in streamflow for snow accumulation period and melting period are analyzed (Appendix E). According to these results, again discharges at stations 2124 and 2145 show the most discernable general decreasing trend during melting period of the years from 1970 to 2010. Similarly, discharges during accumulation period at these two stations also show a general decreasing trend as these stations showed a consistent warming effect along with each month of the water year in 1990-2010. Decreasing trend in these two stream gauge stations is also attributable to significant precipitation decreases in melting period observed at Malatya station (Table 4). A similar but less significant decreasing trend observed at 2620 station during melting period is also probably because of decrease in summer precipitation at Hakkari station (Table 4). Contrary to this, stream gauge stations 2316 and 2415 show increasing trend in discharge during melting period because meteorological stations (Artvin and Ardahan) close to these two stream gauges indicate important increases in precipitation during both accumulation and melting periods (58.9 mm and 99.5 mm in Ardahan; 40.9 mm and 9 mm in Artvin) (Table 4). In addition, 2133 station also shows appreciable increasing trend in discharge during melting period because of the largest increase observed in precipitation (82 mm) during accumulation period at Tunceli station. In other stations, discharge values during accumulation period do not show any statistically significant trend while some plausible general increasing trends (e.g. stations 2156, 2157, 2402, 2415) appear during melting period.

In order to show and better interpret the possible impact of climate warming on streamflow data, the CT graphs of each station from 1970 to 2010 are prepared and shown in Figure 14. According to trend lines, the shifts of CT of each station are also shown on each plot.



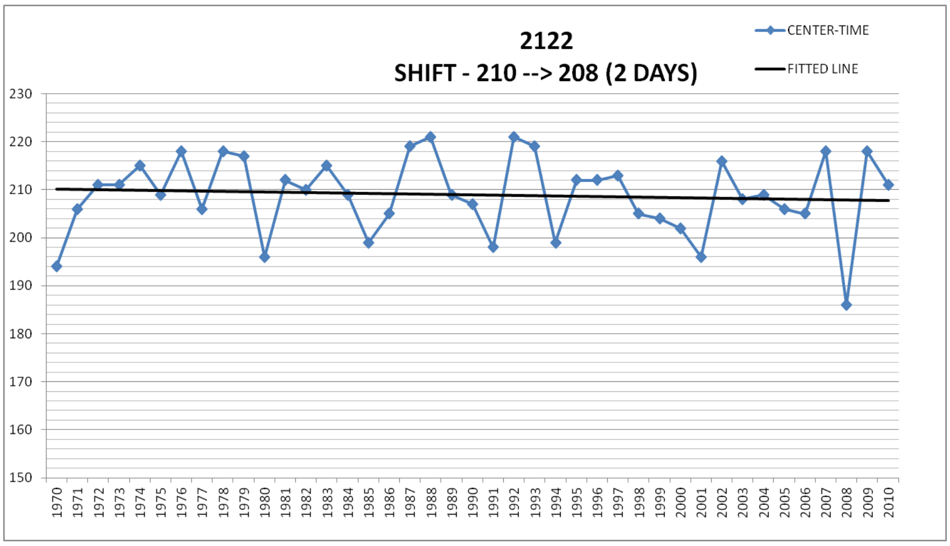
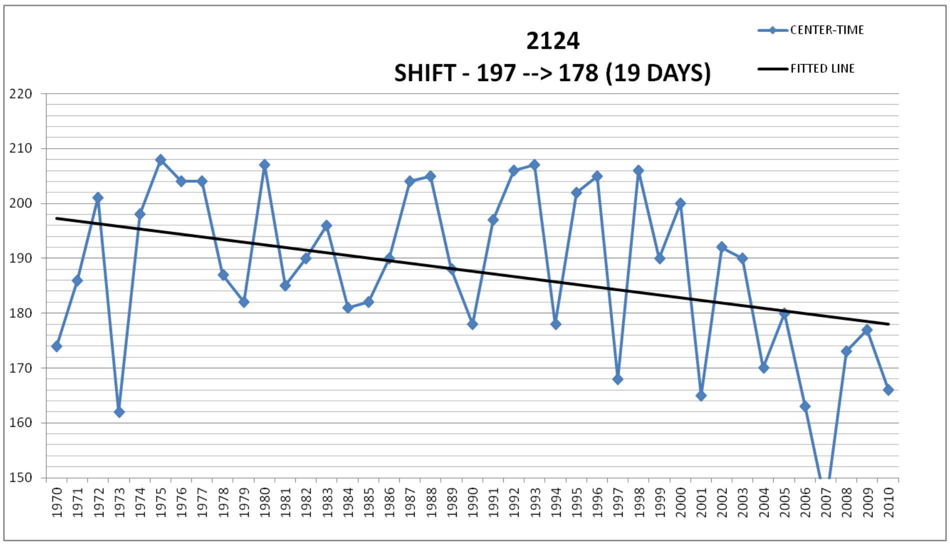
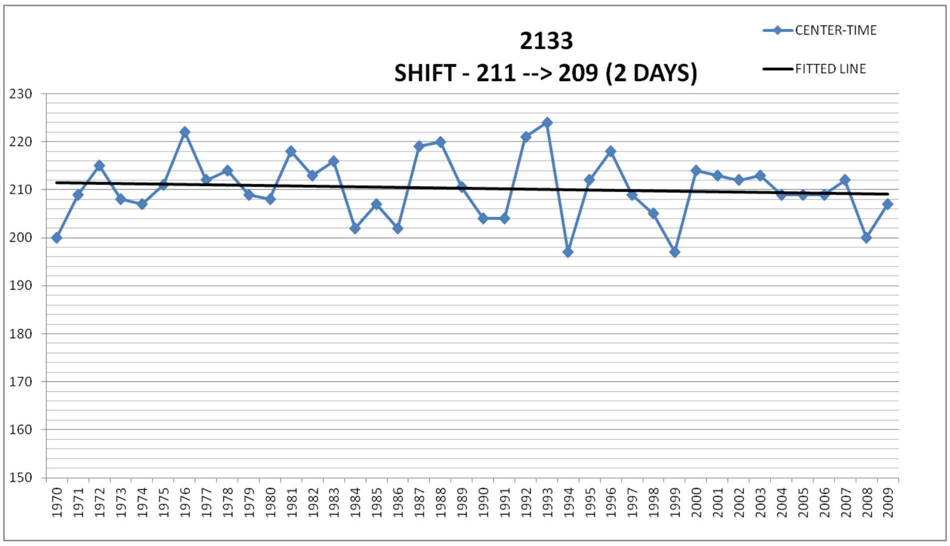


Figure 14. Center Time graphs of each streamflow station





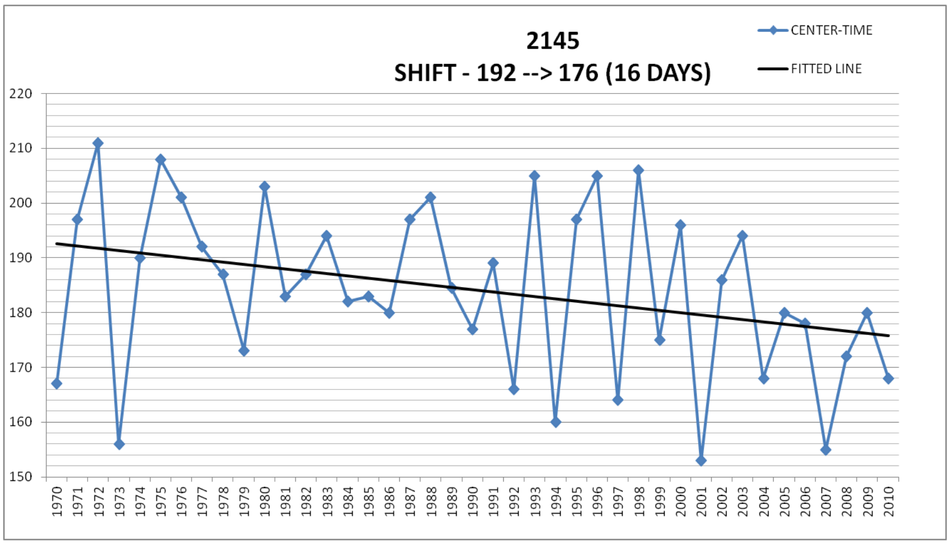
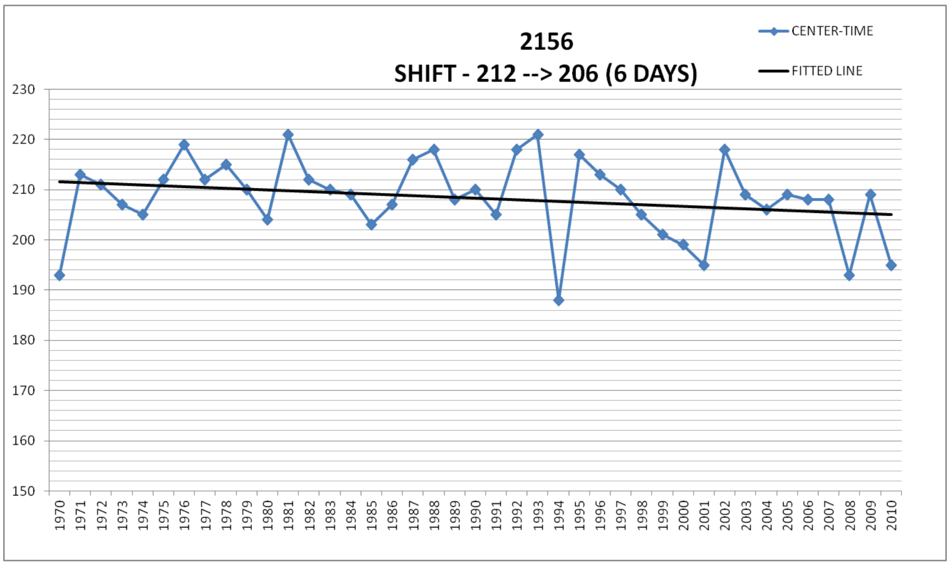
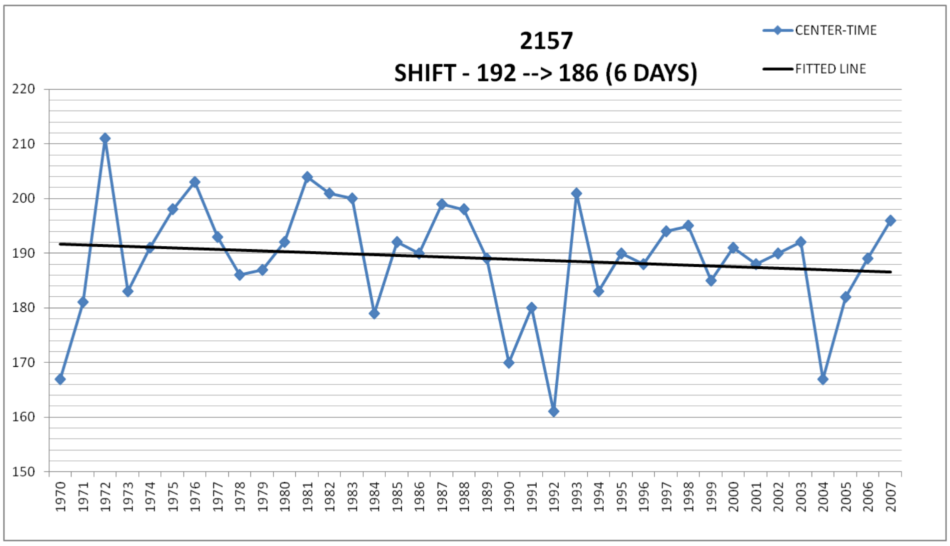


Figure 14 (continued)





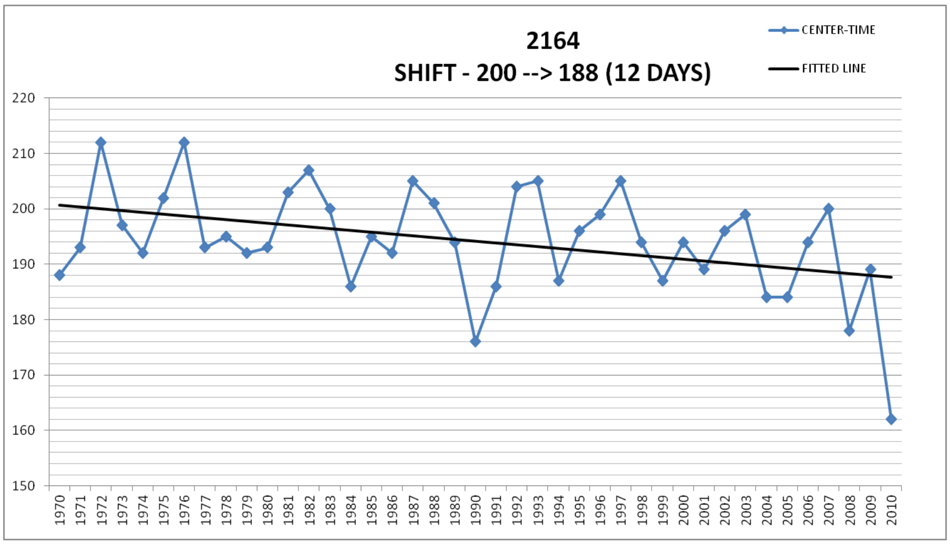
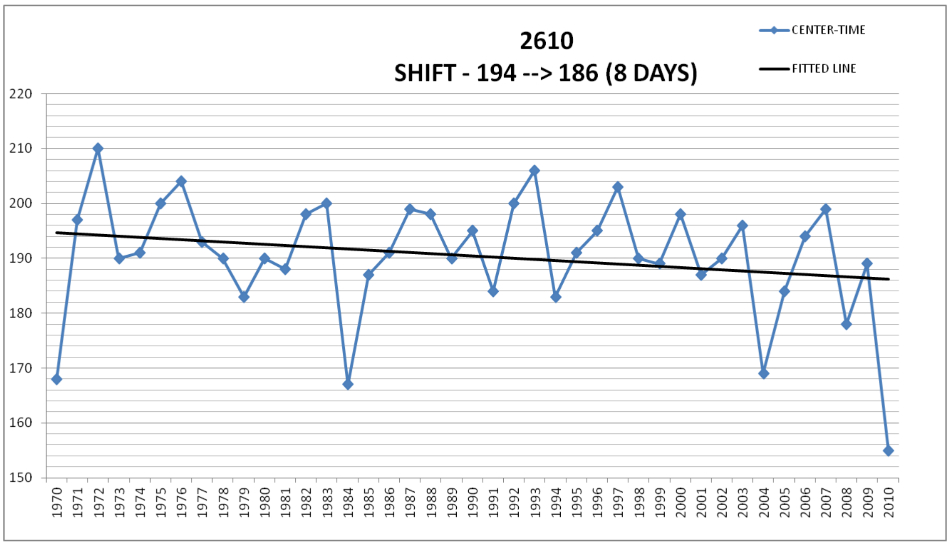
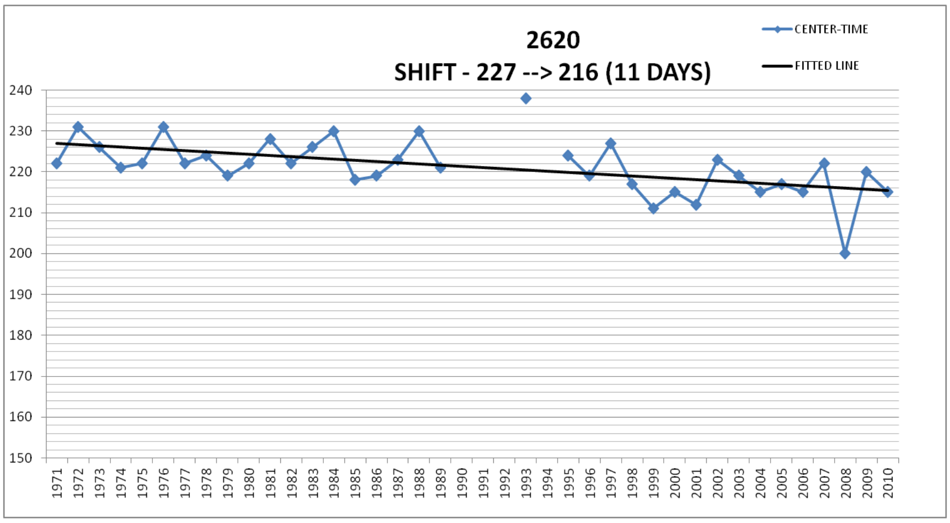


Figure 14 (continued)





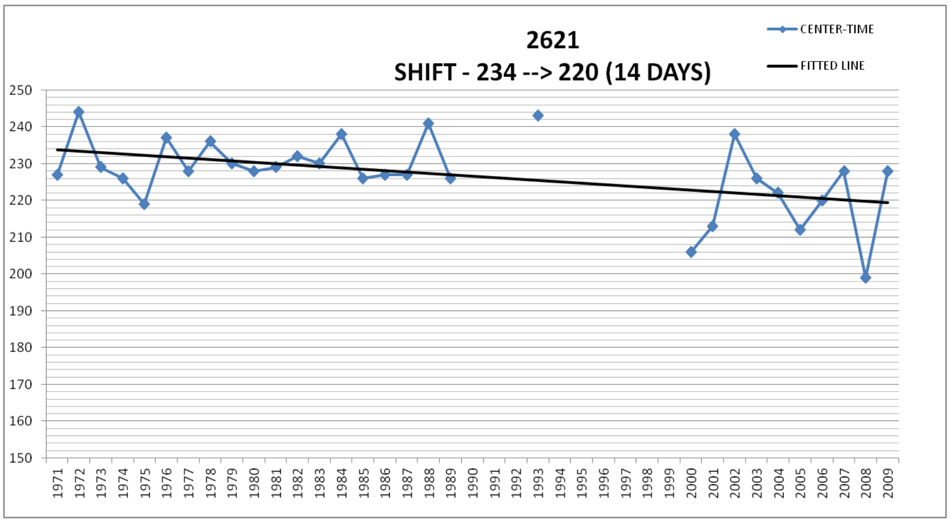
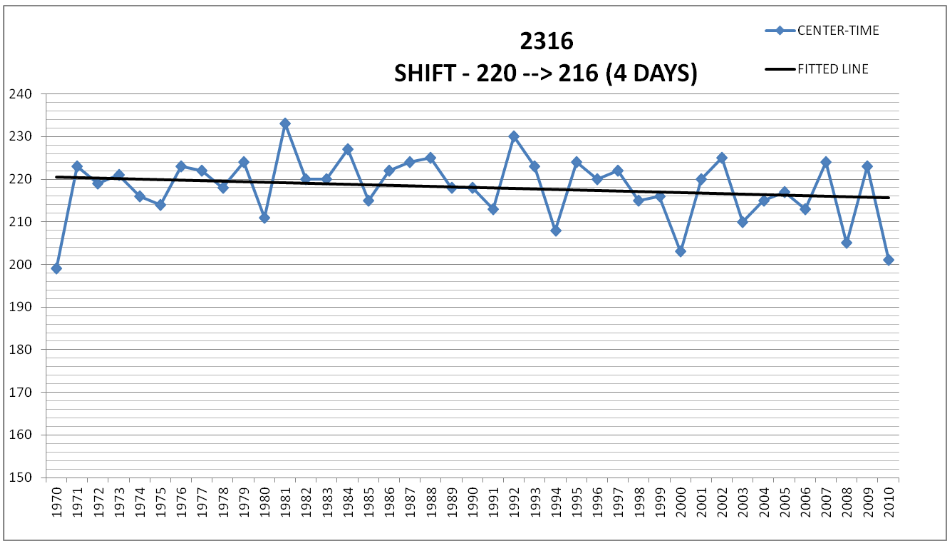
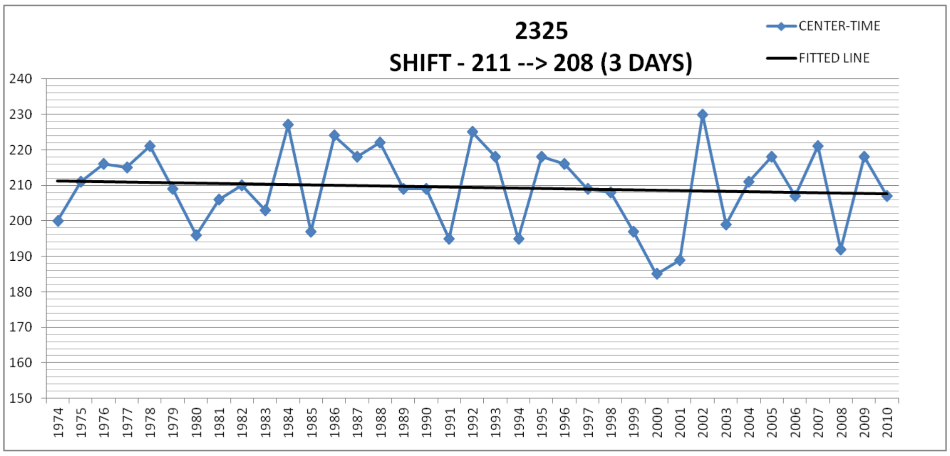


Figure 14 (continued)





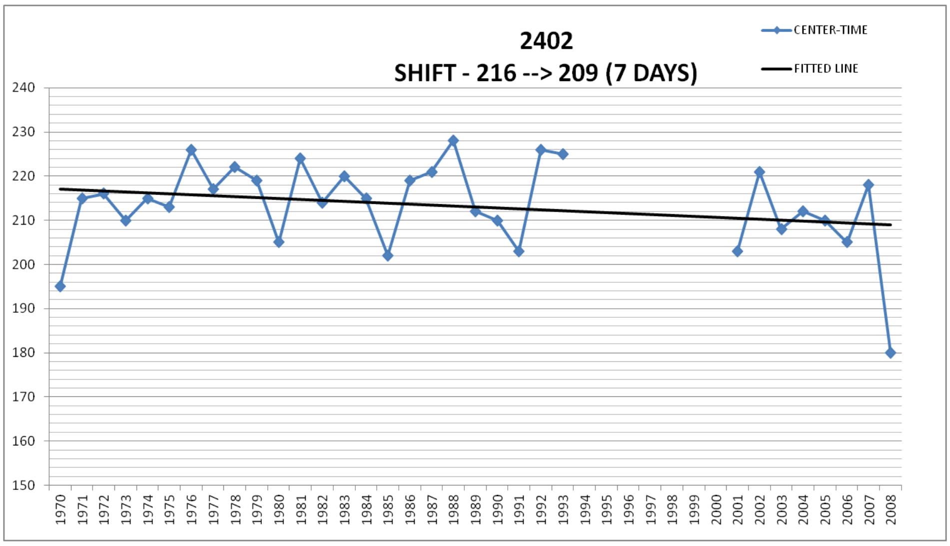


Figure 14 (continued)

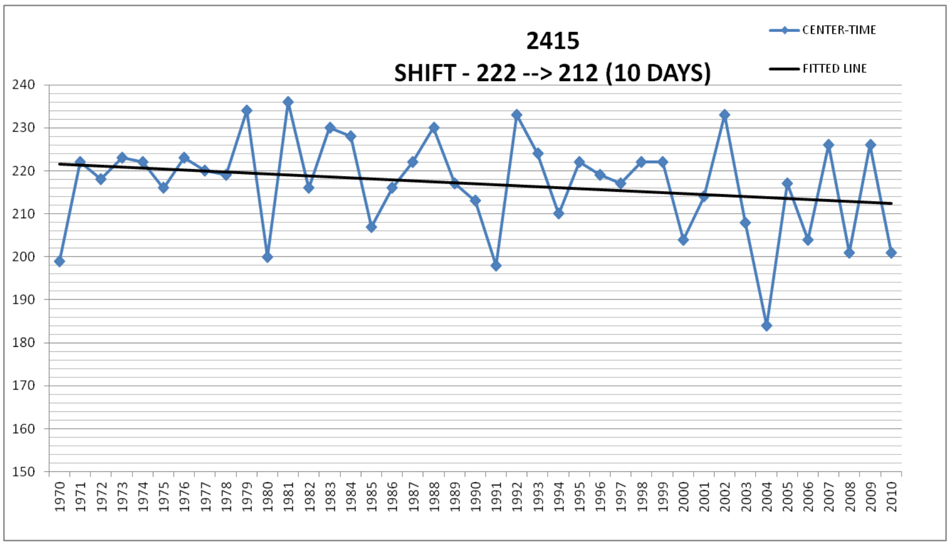


Figure 14 (continued)

Whether or not there is an increasing or decreasing trend in discharges, the CT plots at all stations have negative trends. This explains the fact that climate warming is clear evidence in the region because in various orders at all stations, the melting time of snow shifts to earlier from 1970 to 2010. Stations 2124 and 2145 shows the most largest CT shifts to earlier along with the trend line with the values of 19 and 16 days respectively between 1970 and 2010 as shown in Table 5, which summarizes the CT shifts in days according to the trend line at each station. High CT shifts are generally consistent with decreasing or no trends in discharges during melting period (see stations 2124, 2145, 2610, 2620, 2621, and 2164). On the other hand, the least CT shifts to earlier occurred on stations 2122, 2133, 2316 and 2325 with the values of 2, 2, 4, and 3 days respectively (see Table 5). These stations also correspond to a general increasing trend in discharges during melting period (see Table 4). Even though discharges at stations 2156, 2157, and 2402 show a general increasing trend during melting period there is still a considerable warming effect on them because they show CT shifts to earlier in 6, 6, and 7 days, respectively.

Table 5. CT shifts to earlier times of streamflow stations

NUMBER	STATION		ELEVATION (m)	CT SHIFTS TO EARLIER
2102	Murat Suyu	Palu	852	7 DAYS
2122	Murat Nehri	Tutak	1552	2 DAYS
2124	Tohma Suyu	Yazıköy	1193	19 DAYS
2133	Munzur Suyu	Melekbahçe	875	2 DAYS
2145	Tohma Suyu	Hisarcık	933	16 DAYS
2156	Fırat Nehri	Bağıştaş	865	6 DAYS
2157	Karasu	Karaköprü	1250	6 DAYS
2164	Göynük Çayı	Çayağzı	990	12 DAYS
2610	Bitlis Çayı	Baykan	698	8 DAYS
2620	Zap Suyu	Üzümcü	1072	11 DAYS
2621	Zap Suyu	Musahan	1725	14 DAYS
2316	Çoruh Nehri	İspir Köp.	1170	4 DAYS
2325	Oltu Suyu	Aşağı Kumlu	1129	3 DAYS
2402	Aras Nehri	Kağızman	1140	7 DAYS
2415	Kura Nehri	Ur Köp.	1750	10 DAYS

3.4 Streamflow - Temperature - Precipitation Analysis

Since the streamflow stations have no temperature and precipitation observations, meteorological stations are used to determine the interrelations among these variables. Using daily average temperatures of all meteorological stations, days with average temperature values that are smaller than $0^{o}C$ are counted from October 1 to CT of each year and they are shown for each station from 1970 to 2010 period in Figure 15. Streamflow and meteorological station pairs used in preparing these plots are also given in Figure 15. These plots help us to comment about the shifts of CT to earlier. The higher the number of daily average temperature days below freezing the higher the station elevation and the more inland position of the station in Figure 15. For example, Artvin is located close to Black Sea and thus having the least number of days having daily average temperature below freezing comparing to other stations in Figure 15.

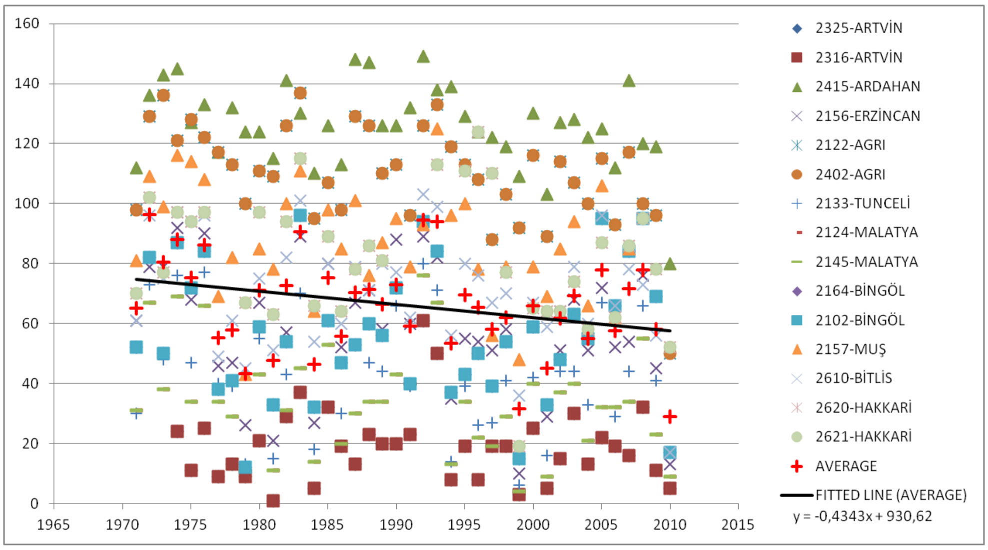


Figure 15. Number of days smaller than 0°C daily average temperature, from 1st of October to Center Time of each station and average of total 15 stations

The trend analysis in Figure 15 complies with the trend analysis already shown in CT plots of each station in Figure 14. Decrease in the number of days having daily average temperature less than freezing from 1970 to 2010 indicates the warming effect with the release of an increase in average temperature of these days toward the year 2010 at the analysis stations. Therefore, a pronounced increase in temperature causes to shift of melting of snow to earlier times as shown in CT analysis. For example, temperature increase toward year 2010 and subsequent shift in snow melt can be more obvious at 2124 and 2145 discharge stations paired with Malatya meteorological stations in Figure 15. When increasing trend in temperature (minimum) associates with decreasing or no trends in discharge, number of days below freezing towards 2010 decreases. However, such interrelationship can be weakly described with station pairs of 2122-Agrı, and 2133-Tunceli, which showed the least CT shifts.

In a further analysis precipitation data is introduced to previous analysis to determine number of wet days and accumulated precipitation amount at the same station pairs along with 1970-2010 period. These plots are respectively shown in Figure 16 and Figure 17 for wet days and accumulated precipitation amount up to CT of each year. The number of wet days and accumulated precipitation amount in these figures implicitly describe the number of snowy days and accumulated snow amounts up to CT at the meteorological stations. On average, cumulative wet days decreased from 26 days to 21 days for 40 years of analysis period while cumulative precipitation decreased from 148 mm to 140 mm for the same period. Station pair of 2415-Ardahan shows increasing trend in wet days as Ardahan station also indicates very significant increases in precipitation during accumulation and melting periods (58.9 mm and 99.5 mm). Particularly, station pairs of 2316-Artvin, 2402-Agri, 2145-Malatya display a considerable decreasing trends in both wet days and accumulated precipitation amount between 1970 and 2010 years. In a reliable interpretation of the analysis obtained from these figures the role of the distance between discharge station and meteorological station is very important because the type and amount of precipitation greatly varies with altitude in short distances. In addition, we should also consider that meteorological stations are located within city center and the climate will differ from the basin where discharges are measured. These facts introduce additional uncertainties into the analysis shown in Figures 16 and Figure 17.

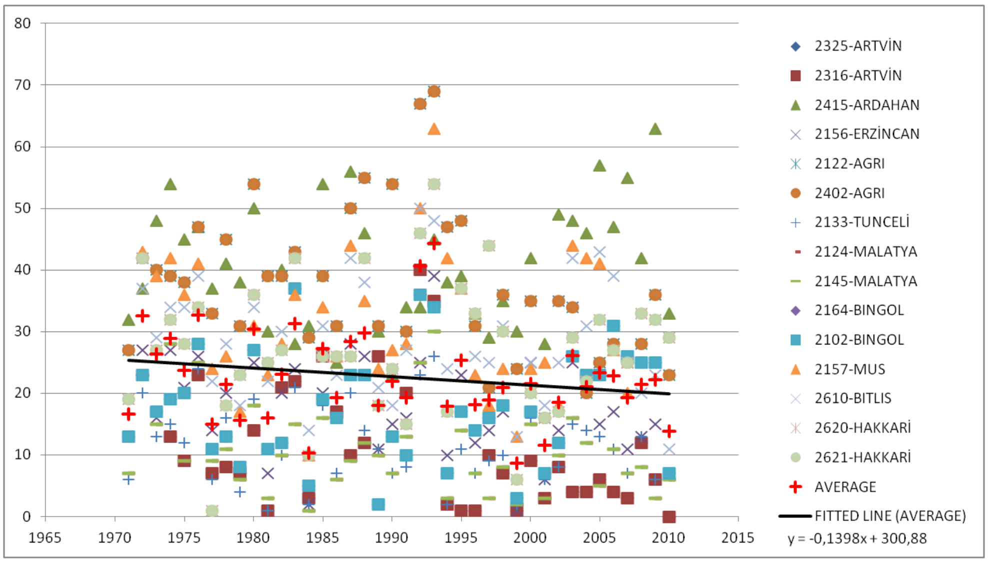


Figure 16. Cumulative number of wet days smaller than 0°C daily average temperature, from 1st of October to Center Time of each station and average of total 15 stations.

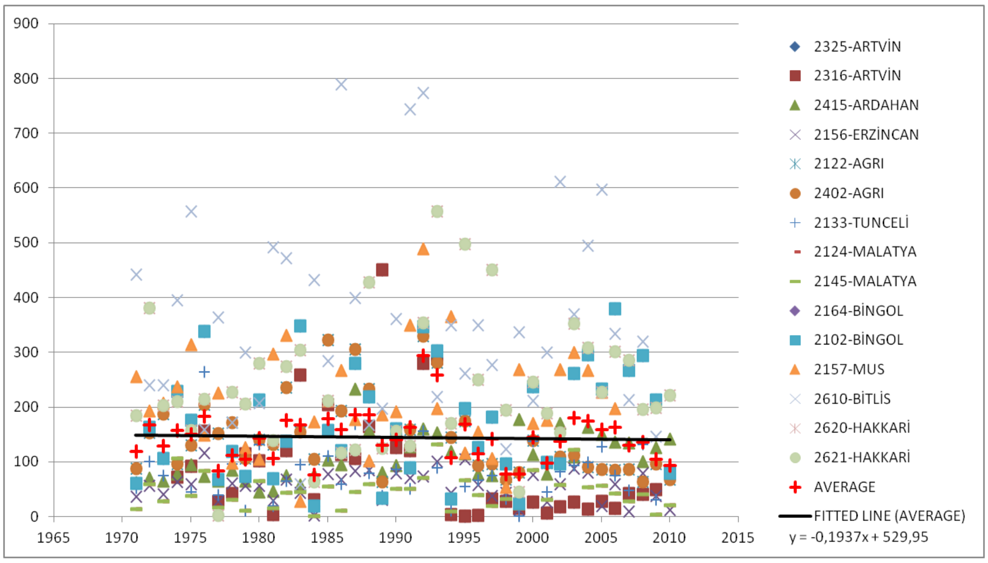


Figure 17. Cumulative precipitation value of the wet days smaller than 0°C daily average temperature, from 1st of October to Center Time of each station and average of total 15 stations.

3.5 Statistical Trend Analysis

Trend analysis is performed using a computer program of "Trend Analysis For Windows" written in Delphi 7 programming language that is developed by Gümüş (2006). This program is useful to analyze data with Mann-Kendall test, Sequential Mann-Kendall test and Spearman's Rho test.

First trend analysis is done on daily average temperature values in order to see that, these increases in temperature are significant or not. Table 6 summarizes the results of this analysis.

As already mentioned in Methods part, the α values are related with significance level. 90% confidence level, which corresponds to 1.65 threshold value, is used in all trend analysis. If the confidence level is increased to 95%, the value of the threshold becomes 1.96. According to trend analysis results, directions of trends are shown as (+) or (-) as increasing trend or decreasing trend. The results of these two tests in respect to power of trends differ from each other due to methodology of these tests. In this study, two different tests are used in order to strengthen the significance of trends.

Table 6. Statistical trend analysis to daily average temperature data of selected meteorological stations

STATION	ELEVATION (M)	α=0.10	MANN-KENDALL	TREND	SPEARMAN'S RHO	TREND
AGRI	1632	1,65	2,75	(+)	2,62	(+)
ARDAHAN	1829	1,65	2,64	(+)	2,66	(+)
ARTVIN	628	1,65	2,48	(+)	2,53	(+)
BINGOL	1177	1,65	0,17		0,17	
BITLIS	1573	1,65	2,26	(+)	2,14	(+)
ERZINCAN	1218	1,65	3,79	(+)	3,64	(+)
HAKKARI	1727	1,65	2,41	(+)	2,5	(+)
MALATYA	947	1,65	3,63	(+)	3,46	(+)
MUS	1322	1,65	2,75	(+)	2,72	(+)
TUNCELI	981	1,65	2,19	(+)	2,12	(+)

All stations except Bingöl show meaningful trend results for both Mann-Kendall and Spearman's Rho tests. The highest trends are on Erzincan and Malatya stations. Temperature increases for these two stations are much smoother than the other stations.

Trend analyses are done on precipitation data of snow accumulation period (November-February). Table 7 summarizes the results of these analyses.

Table 7. Statistical trend analysis to total precipitation from November to February period of selected meteorological stations

STATION	ELEVATION (M)	α=0.10	MANN-KENDALL	TREND	SPEARMAN'S RHO	TREND
AGRI	1632	1,65	-1,85	(-)	-2,23	(-)
ARDAHAN	1829	1,65	3,16	(+)	3,25	(+)
ARTVIN	628	1,65	0,99		0,87	
BINGOL	1177	1,65	0,9		0,93	
BITLIS	1573	1,65	-0,15		-0,14	
ERZINCAN	1218	1,65	1,32		1,4	
HAKKARI	1727	1,65	0,71		0,8	
MALATYA	947	1,65	0,34		0,4	
MUS	1322	1,65	1,46		1,49	
TUNCELI	981	1,65	1,6		1,44	

According to trend analysis results of accumulation period total precipitation, the increases are not so meaningful. The decrease in Agri station is statistically significant. On the contrary, Ardahan station shows an expressive positive trend, which is also consistent with previous analysis. These changes in precipitation quantities are analyzed in order to see the changes in phases of precipitation. Because, most of the precipitation in this period are snow and also the changes in snow quantity may also be a result of temperature increase.

Trend analyses are done on annual average streamflow data. For missing data, in order to sustain continuity average values not changing the slope of the trend are used. Table 8 summarizes the results of this analysis.

Table 8. Statistical trend analysis to annual average streamflow of selected meteorological stations

STATION	ELEVATION (M)	α=0.10	MANN-KENDALL	TREND	SPEARMAN'S RHO	TREND
2102	**852**	1,65	0,1		0,11	
2122	**1552**	1,65	0,78		0,97	
2124	**1193**	1,65	-3,74	(-)	-3,61	(-)
2133	**875**	1,65	1,41		1,33	
2145	**933**	1,65	-3,74	(-)	-3,59	(-)
2156	**865**	1,65	1,58		1,65	(+)
2157	**1250**	1,65	0,8		0,65	
2164	**990**	1,65	0,62		0,65	
2610	**698**	1,65	0,33		0,39	
2620	**1072**	1,65	-1,7	(-)	-1,25	
2621	**1725**	1,65	0,64		0,03	
2316	**1170**	1,65	2,17	(+)	1,98	(+)
2325	**1129**	1,65	0,8		0,96	
2402	**1140**	1,65	1,7	(+)	0,82	
2415	**1750**	1,65	0,1		1,03	

In addition to that, since dealing with the shifts of melting of snow to earlier times, trend analysis to the average streamflow of melting period (March-June) are done. Table 9 summarizes the results of this analysis.

Table 9. Statistical trend analysis to average streamflow of melting period of selected meteorological stations

STATION	ELEVATION (M)	α=0.10	MANN-KENDALL	TREND	SPEARMAN'S RHO	TREND
2102	**852**	1,65	-0,80		-0,07	
2122	**1552**	1,65	0,93		1,04	
2124	**1193**	1,65	-3,38	(-)	-3,28	(-)
2133	**875**	1,65	1,46		1,49	
2145	**933**	1,65	-2,84	(-)	-2,79	(-)
2156	**865**	1,65	0,10		1,10	
2157	**1250**	1,65	0,70		0,55	
2164	**990**	1,65	0,15		0,23	
2610	**698**	1,65	0,33		0,28	
2620	**1072**	1,65	-1,22		-1,08	
2621	**1725**	1,65	-0,01		-0,10	
2316	**1170**	1,65	2,80	(+)	1,94	(+)
2325	**1129**	1,65	0,38		0,49	
2402	**1140**	1,65	2,20	(+)	1,60	
2415	**1750**	1,65	0,60		0,56	

These two tables are very similar to each other according to trend results. For example regarding the 2124 station, the decrease in annual average streamflow is so explicit. For the melting period the power of trend is also obviously clear. Looking at the Sequential Mann-Kendall test results of this station shows that, these two graphs indicate the same year 2003 as the start of trend. (Figure 18 and Figure 19)

Figure 18. Sequential Mann Kendall test u(t) - u'(t) graph for annual average streamflow data of 2124 station

Figure 19. Sequential Mann Kendall test u(t) - u'(t) graph for melting period average streamflow data of 2124 station

Approximately same negative trend can be seen on 2145 station. Trend analyses results are also obvious. 2316 station shows oppositely positive trend with meaningful trend results.

Trend analyses are done on Center-Time data of the streamflow stations. Table 10 summarizes the results of these analyses.

Table 10. Statistical trend analyses to CT data of selected meteorological stations

STATION	ELEVATION (M)	α=0.10	MANN-KENDALL	TREND	SPEARMAN'S RHO	TREND
2102	**852**	1,65	-0,64		-0,9	
2122	**1552**	1,65	-0,6		-0,3	
2124	**1193**	1,65	-1,85	(-)	-1,94	(-)
2133	**875**	1,65	-0,1		-0,69	
2145	**933**	1,65	-1,94	(-)	-1,1	
2156	**865**	1,65	-1,38		-1,65	(-)
2157	**1250**	1,65	-0,63		-0,88	
2164	**990**	1,65	-1,61		-1,88	(-)
2610	**698**	1,65	-1,9	(-)	-1,26	
2620	**1072**	1,65	-2,99	(-)	-3,5	(-)
2621	**1725**	1,65	-3,12	(-)	-3,1	(-)
2316	**1170**	1,65	-0,71		-0,85	
2325	**1129**	1,65	-0,25		-0,39	
2402	**1140**	1,65	-1,35		-2,06	(-)
2415	**1750**	1,65	-0,95		-1,03	

CT analyses indicate a sign of warming on streamflow through snowmelt and this was the motivation point of this study. The meaningful changes in CT for the stations (2124, 2145, 2156, 2164, 2610, 2620, 2621 and 2402) are analyzed in order to obtain an idea about the causes of these shifts.

For the temperature - precipitation analysis, trend analyses are done on the data of Figure 15, Figure 16 and Figure 17. Table 11, Table 12 and Table 13 show the results of these trend analyses.

Table 11. Statistical trend analyses to number of days smaller than 0^oC daily average temperature, from 1st of October to CT of each station of selected meteorological stations

STATION	ELEVATION (M)	α=0.10	MANN-KENDALL	TREND	SPEARMAN'S RHO	TREND
2102-BINGOL	852	1,65	0,50		0,33	
2122-AGRI	1552	1,65	-2,81	(-)	-2,82	(-)
2124-MALATYA	1193	1,65	-1,13		-1,47	
2133-TUNCELİ	875	1,65	-1,22		-1,56	
2145-MALATYA	933	1,65	-1,13		-1,47	
2156-ERZINCAN	865	1,65	-1,74	(-)	-1,95	(-)
2157-MUS	1250	1,65	-1,63		-1,99	(-)
2164-BINGOL	990	1,65	0,50		0,33	
2610-BITLIS	698	1,65	-1,22		-1,21	
2620-HAKKARI	1072	1,65	-1,62		-1,76	(-)
2621-HAKKARI	1725	1,65	-1,62		-1,76	(-)
2316-ARTVIN	1170	1,65	-0,17		-0,56	
2325-ARTVIN	1129	1,65	-0,17		-0,56	
2402-AGRI	1140	1,65	-2,81	(-)	-2,82	(-)
2415-ARDAHAN	1750	1,65	-1,83	(-)	-1,80	(-)

Table 12. Statistical trend analyses to number of wet days smaller than 0^oC daily average temperature, from 1st of October to CT of each station of selected meteorological stations

STATION	ELEVATION (M)	α=0.10	MANN-KENDALL	TREND	SPEARMAN'S RHO	TREND
2102-BINGOL	852	1,65	0,87		0,57	
2122-AGRI	1552	1,65	-2,37	(-)	-2,80	(-)
2124-MALATYA	1193	1,65	-1,43		-2,16	(-)
2133-TUNCELİ	875	1,65	-0,53		-1,16	
2145-MALATYA	933	1,65	-1,43		-2,16	(-)
2156-ERZINCAN	865	1,65	-1,41		-1,65	(-)
2157-MUS	1250	1,65	-0,78		-0,96	
2164-BINGOL	990	1,65	0,87		0,57	
2610-BITLIS	698	1,65	-0,75		-0,10	
2620-HAKKARI	1072	1,65	0,31		0,16	
2621-HAKKARI	1725	1,65	0,31		0,16	
2316-ARTVIN	1170	1,65	-1,82	(-)	-2,73	(-)
2325-ARTVIN	1129	1,65	-1,82	(-)	-2,73	(-)
2402-AGRI	1140	1,65	-2,37	(-)	-2,80	(-)
2415-ARDAHAN	1750	1,65	0,87		0,74	

Table 13. Statistical trend analyses to cumulative precipitation value of the wet days smaller than 0°C daily average temperature, from 1st of October to CT of each station of selected meteorological stations

STATION	ELEVATION (M)	α=0.10	MANN-KENDALL	TREND	SPEARMAN'S RHO	TREND
2102-BINGOL	**852**	1,65	1,41		1,48	
2122-AGRI	**1552**	1,65	-2,95	(-)	-3,13	(-)
2124-MALATYA	**1193**	1,65	0,1		0,15	
2133-TUNCELİ	**875**	1,65	-0,36		-0,4	
2145-MALATYA	**933**	1,65	0,1		0,15	
2156-ERZINCAN	**865**	1,65	-0,1		-0,37	
2157-MUS	**1250**	1,65	0,4		0,39	
2164-BINGOL	**990**	1,65	1,41		1,48	
2610-BITLIS	**698**	1,65	-0,15		-0,07	
2620-HAKKARI	**1072**	1,65	1,4		1,05	
2621-HAKKARI	**1725**	1,65	1,4		1,05	
2316-ARTVIN	**1170**	1,65	-2,16	(-)	-2,88	(-)
2325-ARTVIN	**1129**	1,65	-2,16	(-)	-2,88	(-)
2402-AGRI	**1140**	1,65	-2,95	(-)	-3,13	(-)
2415-ARDAHAN	**1750**	1,65	3,72	(+)	3,96	(+)

These trend analyses are the main differences from the past studies. The number of snowy days and the quantity of snow as precipitation release important information about the climate change and shifts of melting times. These analyses are interpreted in detail in discussions section.

CHAPTER 4

DISCUSSIONS

In this study the shifts of snow melting times are analyzed for the selected 15 stations by CT method. Although all the CT graphs (Figure 14) show negative slope, only five of these trends are significant according to Mann-Kendall trend analysis (see Table 10) and only six of them (see Table 10) are significant according to Spearman's Rho test with 90% significance level.

After CT analysis, trend analysis is done on temperature and precipitation time series. All these analyses give us information about the significance of the shifts in center times, and as a result effect of climate change on snow melting.

Some of the stations showing higher trends can be summarized as follows:

a. 2124 Station:

This station is located on "Tohma Suyu" - "Euphrates Basin" with an elevation of 1193m (Table 1). Malatya meteorological station's data are used for this station.

According to CT trend results, there is a very significant trend in CT for the selected period for 90% significance level. For both Mann-Kendall trend analysis and Spearman's Rho test, the trend is negative (-1.85 and -1.94 respectively). The Sequential Mann-Kendall test graphs also show the trend in Figure 20.

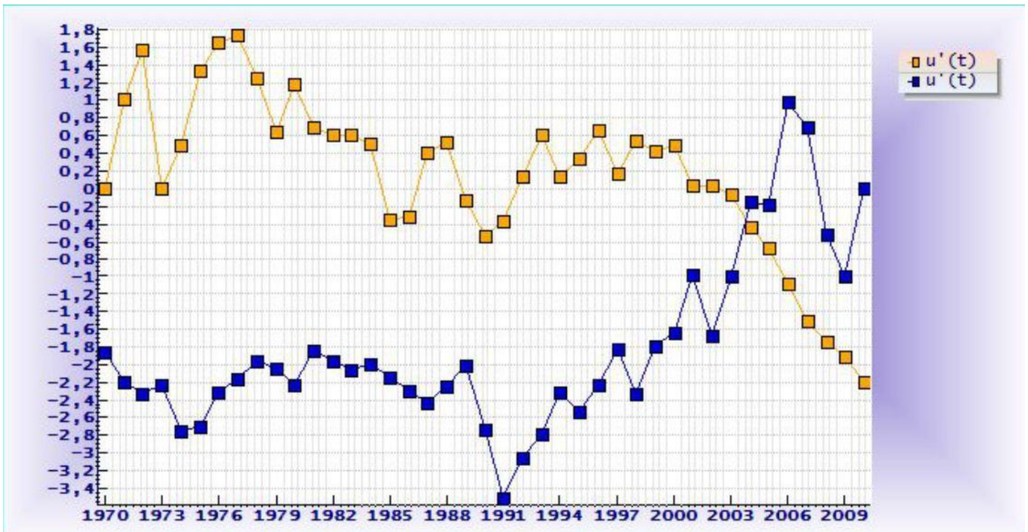


Figure 20. Sequential Mann Kendall test u(t) - u'(t) graph for CT data of 2124 station

The intersection time for the u(t) graph and u'(t) graph (year 2004) is named as the start of statistically significant trend.

For the temperature data of Malatya, the trends are positive. There is 1.6 ^{0}C increase in daily average temperature and approximately 2.0 ^{0}C increase in maximum temperature (Table 3). Statistical trend analyses results for daily average temperature data is very clear. For Mann-Kendall test the trend is +3.63 and for Spearman's Rho test +3.46. So these results conclude that, there is a strong increase in temperature for this station. The Sequential Mann-Kendall test graphs also show the trend. (Figure 21) The intersection time for the u(t) graph and u'(t) graph (year 1998) is named as the start of statistically significant trend.

Figure 21. Sequential Mann Kendall test u(t) - u'(t) graph for annual average temperature data of Malatya

For the precipitation data of Malatya, contrary to other stations there is a decrease in annual average and annual total precipitation. As can be interpreted from the cumulative deviation line in Figure 10, the dry period was started in 1998 and continued up to 2010. Although there is a slightly increase in total precipitation from November to February graph (Figure 9) for Malatya station, the trend analysis results shows that this increase is not so meaningful. Mann-Kendall test result is +0.34 and Spearman's Rho test result is +0.40. As a consequence, there is no any obvious change in precipitation for the 40 years period.

Monthly average streamflow graph for 2124 station (Appendix D) coincides with the cumulative deviation of total precipitation of Malatya station. The monthly average streamflow value for the period 1990-2010, which is a dry period, is smaller than the period 1970-1990 period.

Annual average streamflow trends are analyzed with Mann-Kendall and Spearman's Rho tests. The results are -3.74 and -3.61 respectively. The decreasing trend in annual average streamflow is meaningful according to results of tests. The sequential Mann-Kendall test graph is also shown on the Figure 18. As can be seen from the figure, the year 2003 was the start of the meaningful trend.

The average streamflow graph trends for both melting and accumulation period are the same as negative (Appendix E).Trend analysis results for the melting period are -3,38 and -3,28 for Mann-Kendall and Spearman's Rho tests respectively. This trend is important because the changes in streamflow are mostly due to melting of snow and results to shifts of center time to earlier times. The year 2003 was again the start of decreasing trend according to Sequential Mann-Kendall test result. (Figure 19)

The number of days smaller than 0^{0}C trend is negative for all the selected stations. For 2124-Malatya station pair the trend values are -1.13 and -1.47 for Mann-Kendall and Spearman's Rho tests respectively. Although there is an obvious negative trend, these values are not high enough to prove the H1 hypothesis (there is trend for the selected data) statistically.

The number of wet days smaller than 0^0C is most likely the snowy days. The trend of the number of wet days with daily average temperature below 0^0C is shown in Figure 16 for this station pair. The trend is a negative trend but this trend is not significant according to Mann-Kendall test results with a value of -1.43. However, according to Spearman's Rho test, the trend is strongly meaningful with a value of -2.16. So, the number of precipitating days, which are implicitly assumed to be snowing days decreased significantly for 40 years period.

The precipitation quantity for those wet days is also determined and trend analysis is made. This quantity is the total snow amount and gathered from the data of Malatya and 2124 stream gauge stations. Trend analysis of these results is +0.10 for Mann-Kendall test and +0.15 for Spearman's Rho test. So, there is no any meaningful change in the quantity of the snow. Although the number of days below freezing and the number of snowy days decreased, the total quantity of snow remained unchanged. This may be a result of the change in the intensity of the snow.

To summarize the analysis results for this station pair, the decrease in melting period streamflow is mostly due to decrease in melting period precipitation values (Table 4). In addition to this fact, the significant decrease in number of days and number of wet days below freezing in accumulation period affected the melting period streamflow in a decreasing manner. This result also shifted the melting from mids of April to 19 days back (Figure 14).

b. 2145 Station:

This station is also located on "Tohma Suyu" - "Euphrates Basin" with an elevation of 933m (Table 1). Malatya meteorological station's data are also used for this station.

Like in the previous station pair (2124-Malatya), this station pair also showed the most significant trend. According to CT trend results, there is a significant trend according to 90% significance level in Mann-Kendall test results with a value of -1.94. The sequential Mann-Kendall test graph is shown in Figure 22.

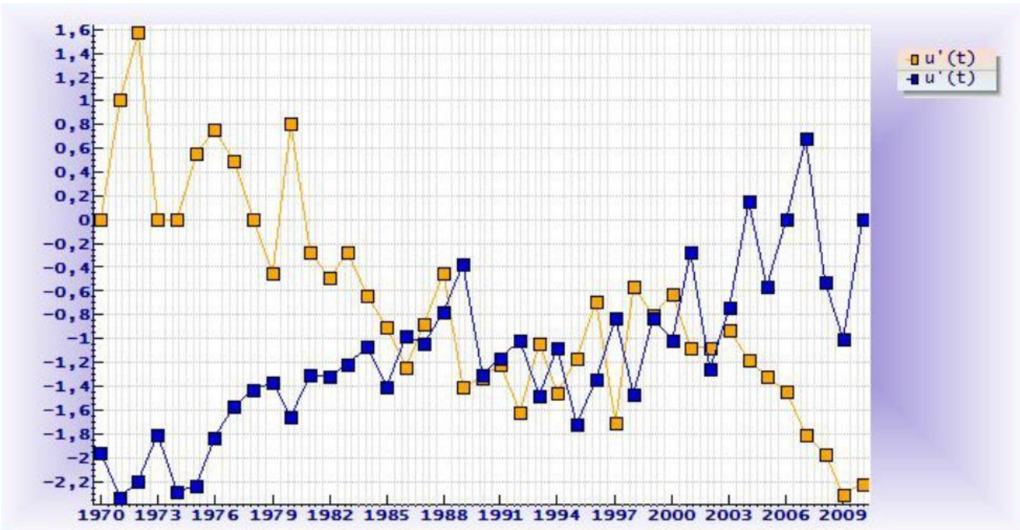


Figure 22. Sequential Mann Kendall test u(t) - u'(t) graph for CT data of 2145 station

According to this graph, the decreasing trend can be seen easily for the whole period. However the starting year of the trend is not so clear. Although, for the years between 1970-1986 and 2003-2010 the decreasing trend is obvious, between the years 1985-2003 the lines are intersecting each other many times, so for this period, there is no such a significant trend.

Analysis of temperature and precipitation time series for the Malatya station was already shown on previous sub-section with 2124 station's analysis. There is a strong increase in annual average temperature, and not so much change in annual average and annual total precipitation.

Monthly average streamflow time series results of 2145 station have similarity with the 2124 station results. For example, these streamflow values for the period 1990-2010 (drier period) is smaller than the period 1970-1990 period.

Annual average streamflow trend results are also similar to 2124 station with the same value for Mann-Kendall test result (-3.74), so the trend is meaningful.

Mann-Kendall trend analysis result for the melting period (March-June) of average streamflow for this station is -2,84 and Spearman's Rho test result for the same analysis is -2.79. This means, the melting period streamflow was decreased in 40 years period and this change is statistically significant. Sequential Mann-Kendall test graph shows the starting year of the trend as 2001 (Figure 23).

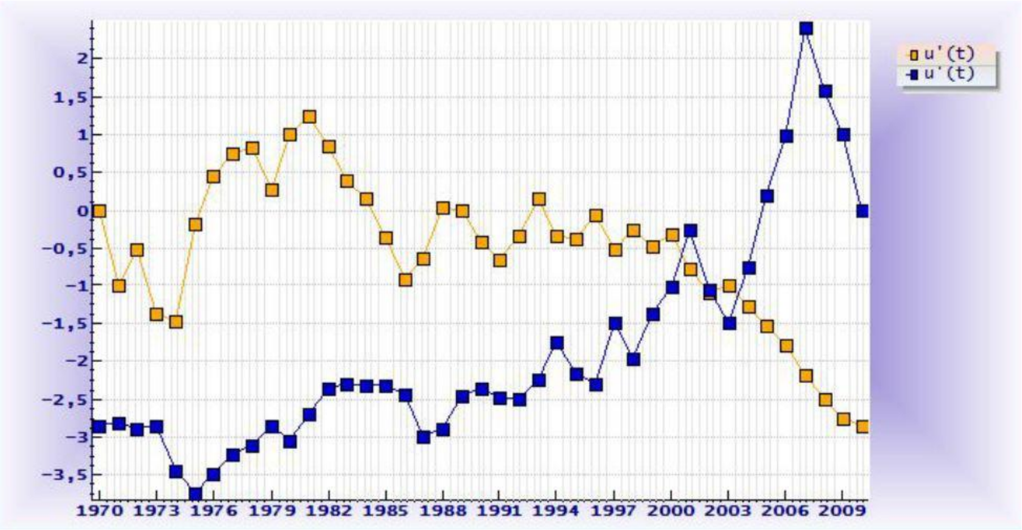


Figure 23. Sequential Mann Kendall test u(t) - u'(t) graph for melting period average streamflow data of 2145 station

There is a decreasing trend for the number of days below freezing of 2145-Malatya station pair (Figure 15). However, this trend is not statistically significant with 90% significance level. Both Mann-Kendall and Spearman's test result are -1.13 and -1.47, respectively.

Since the meteorological station used for 2124 station and 2145 station is same as Malatya station, the temperature and precipitation based analysis results are the same. So, the decrease in number of snowy days for the selected period is statistically significant for Spearman's test with a value of -2.16, and the change in quantity of snow is almost zero.

As a result, the analysis results are similar to results of 2124-Malatya station pair because two stream gauges stations (2124 and 2145) are close to each other and the same meteorological station (Malatya) is used for both. The higher elevation at stream gauge station of 2124 (1193 m) resulted in higher CT changes during 40 years than that of 2145 (933 m). (see Table 10 for CT shifts during 40 years). In higher elevations, the changes in temperature and snow quantities are more effective for snowmelt runoff.

c. 2164 Station:

This station is on "Göynük Çayı" - "Euphrates Basin" with an elevation of 990m (Table 1). Bingöl meteorological station's data series are used for this station.

CT trend analysis results are -1.61 and -1.88 for Mann-Kendall and Spearman's Rho tests. This trend can be accepted as a significant trend. The Sequential Mann-Kendall test graph also shows the decreasing trend, but the starting year of the trend is not clear enough. (Figure 24)

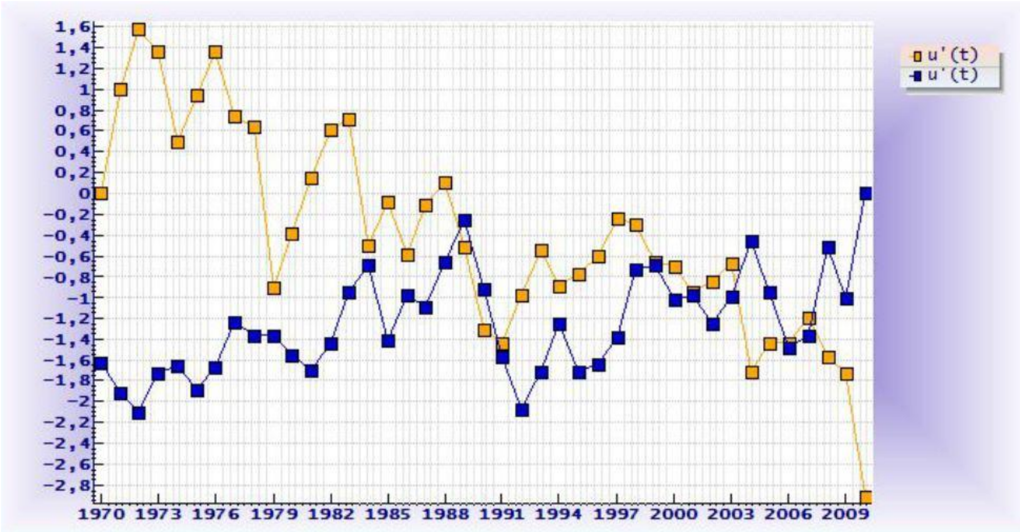


Figure 24. Sequential Mann Kendall test u(t) - u'(t) graph for CT data of 2164 station

Among meteorological stations used in study region, Bingöl station is the only one which does not show any significant increasing trend in temperature. So, the shifts of CT are not related with temperature changes. All other remaining analyses also do not show any significant trend.

The possible change in precipitation intensity during accumulation period may attribute to the changes in CT.

d. 2610 Station:

2610 station was set up on "Bitlis Çayı" - "Tigris Basin" with an elevation of 698m (Table 1). Time series of Bitlis meteorological station are used for this stream gauge station.

CT trend analysis results indicate a statistically significant change with a negative value of -1.90. But, Spearman's Rho test does not give the same result, it shows the negative trend but the significance is not strong enough to prove the H1 hypothesis with a value of -1.26. Sequential Mann- Kendall test result is also shown in Figure 25. According to this graph, it is not easy to point the starting year of the trend.

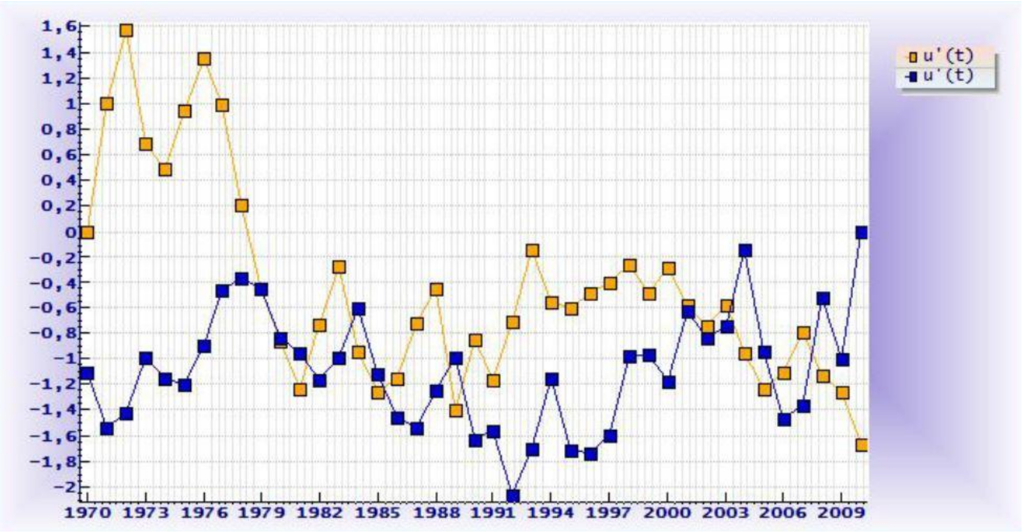


Figure 25. Sequential Mann Kendall test u(t) - u'(t) graph for CT data of 2610 station

Bitlis meteorological station's temperature data are analyzed with both Mann-Kendall and Spearman's Rho tests. The results are +2.26 and +2.14 respectively (Table 10). With the 40 years observed data shown in Figure 5, the results of statistical trend analysis prove the increase in temperature for this meteorological station. The Sequential Mann-Kendall test shows the starting year of this significant trend as 1996 (Figure 26).

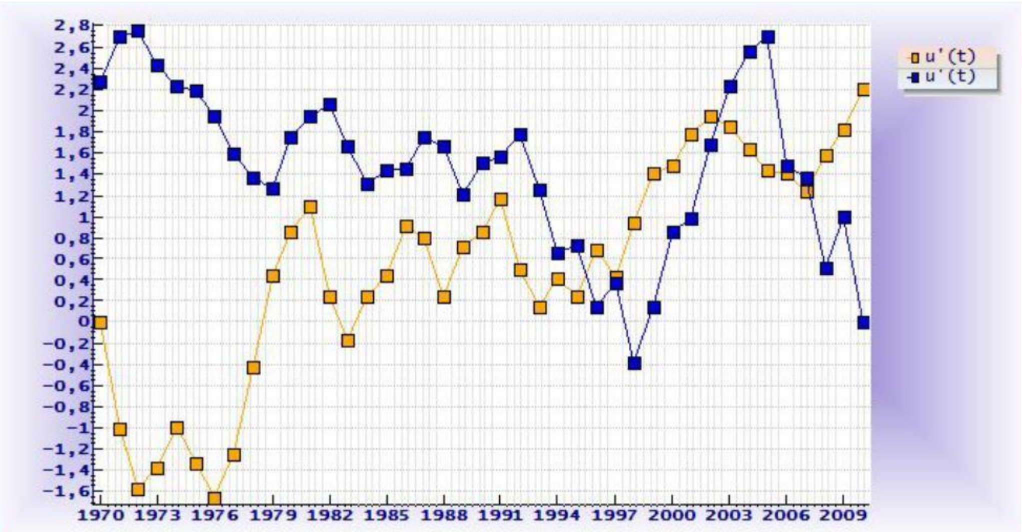


Figure 26. Sequential Mann Kendall test u(t) - u'(t) graph for annual average temperature data of Bitlis

Bitlis station precipitation analysis show that, there is no such a change in annual average and annual total precipitation values for 40 years period. Not also for annual data, but also the accumulation period data have almost zero trends. As a result, there is no obvious change in precipitation.

Streamflow data analysis of 2610 station show that, monthly streamflow values of 1990-2010 period are almost same with the 1990-2010 period. Moreover, annual average streamflow data of station, has no trend according to results of statistical trend analysis.

In a similar way, the average streamflow values for melting and accumulation period have no trend for this station.

The number of days smaller than freezing trend is negative. Trend analysis results of this station are -1.22 and -1.21 for Mann-Kendall and Spearman's Rho trend tests respectively. This result means that, the existence of the trend is not suspicious but the trend is not strong enough.

Since the precipitation values have no trend, all other remaining analysis i.e.; number of wet days below freezing and precipitation quantity for wet days below freezing, have no trend.

As a result, the shifts of CT, is only related with temperature increase for this station, because there is no such a change in precipitation and streamflow parameters. This increase in temperature also decreased the number of days below freezing for accumulation period and therefore, resulted in acceleration in snowmelt.

e. 2620 & 2621 Station:

These two stations are located on the same river "Zap Suyu" - "Tigris Basin" (Table 1). The elevations of these two stations are the only difference between them. Although 2620 station has an elevation of 1072m, 2621 station has a much higher elevation of 1725m. Hakkari meteorological station is used for both two stream gauge stations.

CT trend analysis results of them are very significant according to Mann-Kendall and Spearman's Rho tests results. 2620 station's results are -2.99 and -3.50, while 2621 station's results are -3.12 and -3.10 for these two tests respectively. Results are significant for both 2620 and 2621 stations.

According to Sequential Mann-Kendall test results, the year 1990 is the start of meaningful trend for both stream gauge stations (Figure 27 and Figure 28).

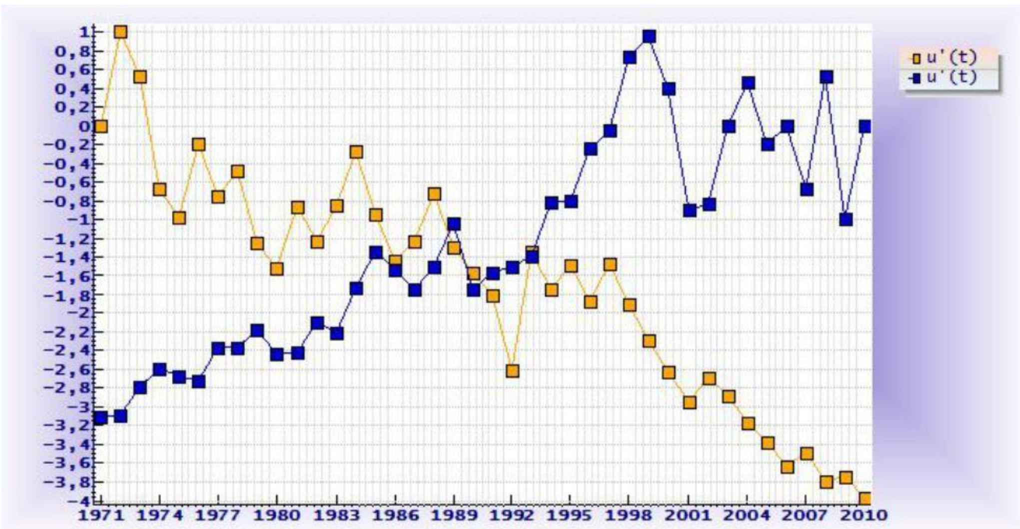


Figure 27. Sequential Mann Kendall test u(t) - u'(t) graph for CT data of 2620 station

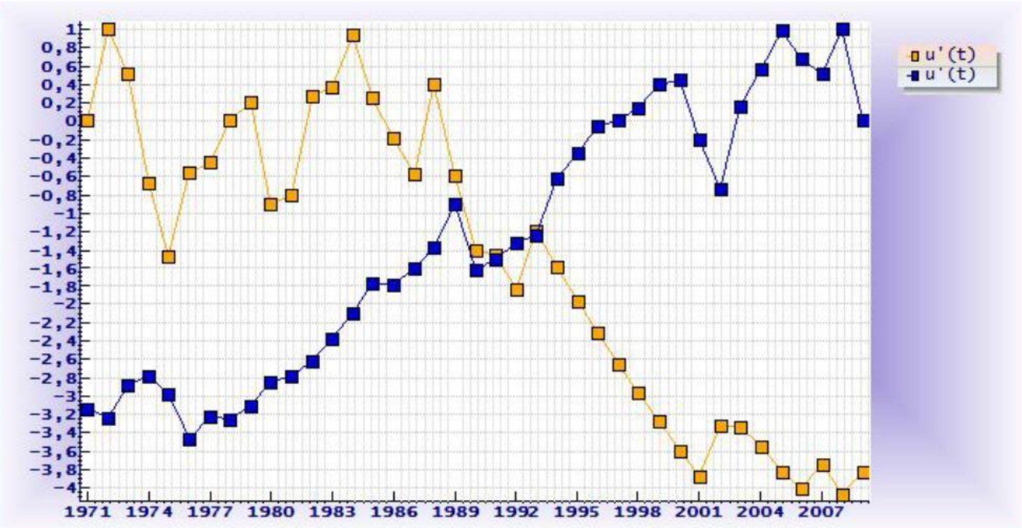


Figure 28. Sequential Mann Kendall test u(t) - u'(t) graph for CT data of 2621 station

For the temperature data of Hakkari, the trend is positive with a value of +2.41 and +2.50 for Mann-Kendall and Spearman' Rho tests respectively. The Sequential Mann-Kendall test result shows the start of trend as the year 1988 (Figure 29).

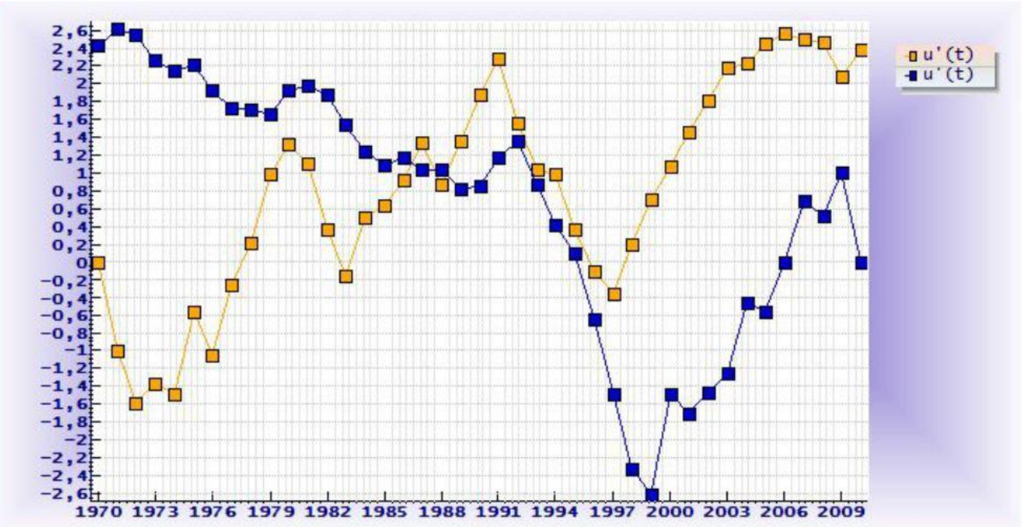


Figure 29. Sequential Mann Kendall test u(t) - u'(t) graph for annual average temperature data of Hakkari

For the precipitation data of Hakkari, annual average precipitation trend line is almost horizontal. Although there is a slight increase in accumulation period precipitation, the trend is not strong enough to be a statistically significant trend. Mann Kendall and Spearman's Rho tests results for accumulation period precipitation trends are +0.71 and +0.80.

For these streamflow stations, according to monthly average streamflow figure (Appendix D), the decrease in streamflow from 19970-1990 to 1990-2010 periods for the April - May - June period can be easily seen. This picture coincides with the CT shifts of these stations.

Streamflow data analysis results of 2620 and 2621 stations are different from each other. Although annual average streamflow trend for 2620 station has a negative trend, 2621 station has no trend. Mann-Kendall and Spearman's Rho tests results are -1.70 and -1.25 for 2620 station, whereas +0.64 and +0.03 for 2621 station. The trend is obvious for 2620 station, and strong with 90% significance level according to Mann-Kendall test. More tributaries contributing to 2620 station (located at lower elevation) have influence on streamflow trend (see Figure 3 for stream gauge locations).

In a similar way, the average streamflow trends for melting and accumulation period are parallel to annual average streamflow trends. 2620 station has negative but not strong enough to become statistically significant trend, 2621 station has no trend (Table 9).

The trends of number of days below freezing are negative for both these two station pairs. The analysis results of these stations are -1.62 and -1.76 for Mann-Kendall and Spearman's Rho tests respectively. This result may be regarded as a statistically significant trend. Sequential Mann-Kendall results show the year 2000 as the start of significant trend (Figure 30).

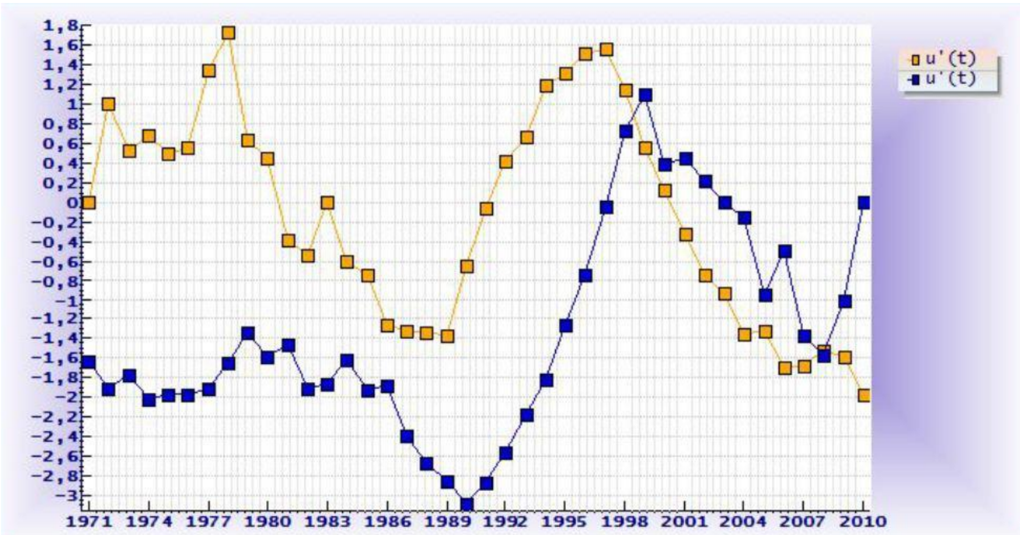


Figure 30. Sequential Mann Kendall test u(t) - u'(t) graph for number of days smaller than $0^{o}C$ daily average temperature, from 1st of October to Center Time of 2620-Hakkari and 2621-Hakkari station pairs.

The number of wet days below $0^{0}C$ trend is almost zero for these stations. Although, the number of days below freezing decreased significantly, the number of wet days did not decrease.

On the contrary to these results, the precipitation quantities for the wet days below freezing increased from 1970 to 2010. Trend analysis results of these data are +1.40 and +1.05 for Mann-Kendall and Spearman's Rho test respectively. These trends are not strong but, the increase in quantity of snow is a fact.

As a result, the increase in temperature influenced the number of days below freezing and snow amount by keeping the precipitating days unchanged. These results can be attributable to possible change in phase and intensity of precipitation.

f. 2402 Station:

2402 station is set up on "Aras Nehri" - "Aras Basin" with an elevation of 1140m (Table 1). Agri meteorological station, which has an elevation of 1632m, is used for this station.

CT trend analysis results show that, the decreasing trend shown in Figure 14 is a meaningful trend. Mann-Kendall test result is -1.35 and Spearman's Rho test result is -2.06. Although Mann-Kendall test result is not significant with 90% significance level, the trend is evident because of the high statistical value obtained from Spearman's Rho test. Sequential Mann-Kendall test also shows the trend and the year 1996 is the start of significant trend (Figure 31).

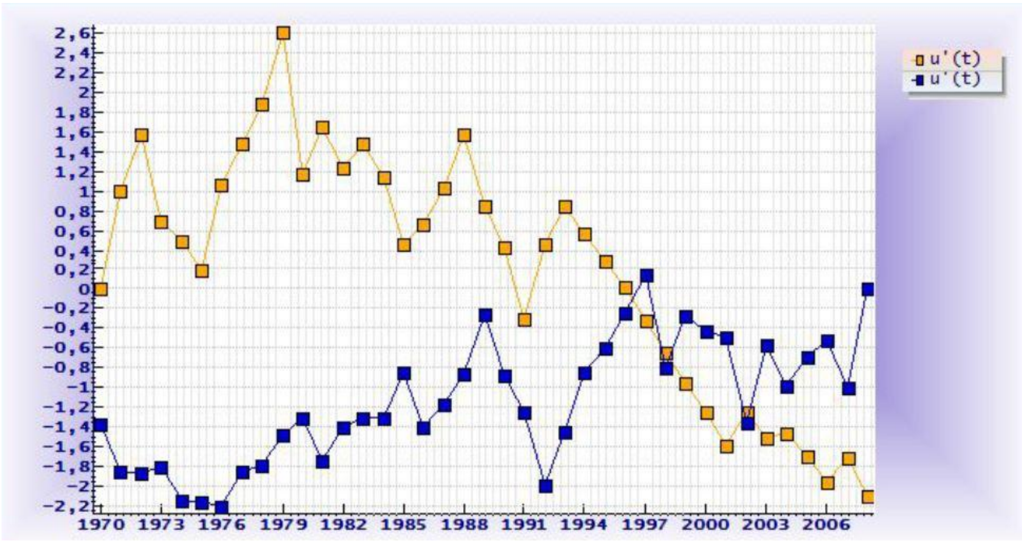


Figure 31. Sequential Mann Kendall test u(t) - u'(t) graph for CT data of 2402 station

Agri meteorlogical station's temperature trend is positive similar to other stations. Trend analysis results are +2.75 and +2.62 according to Mann-Kendall and Spearman's Rho tests respectively. Sequential Mann- Kendall test result is also shown in Figure 32. According to this graph, it is not easy to point the starting year of the trend.

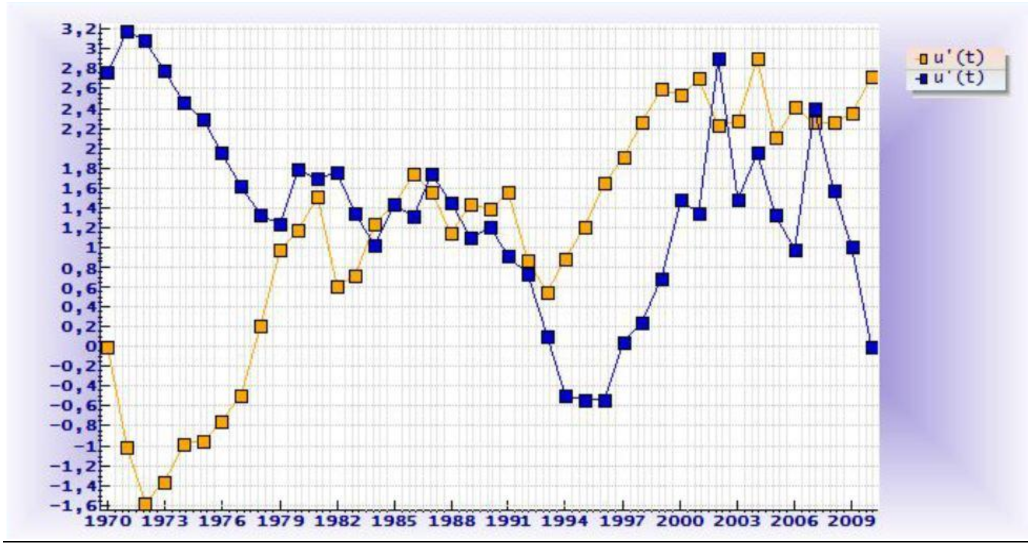


Figure 32. Sequential Mann Kendall test u(t) - u'(t) graph for annual average temperature data of Agri

Agri station's precipitation time series show that, although the annual average precipitation value has no trend, total precipitation in accumulation period decreased significantly. This trend is proved by Mann-Kendall and Spearman's Rho tests results. Test results are -1.85 and -2.23 respectively. Sequential Mann-Kendall test also shows the trend and the year 2000 can be declared as the starting year of this significant trend (Figure 33).

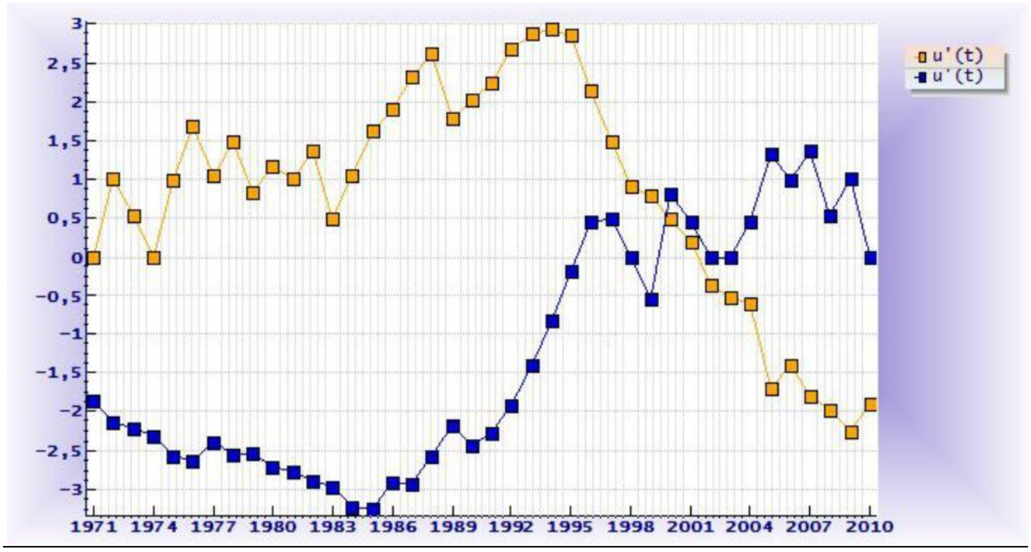


Figure 33. Sequential Mann Kendall test u(t) - u'(t) graph for annual total precipitation from November to February from 1970 to 2010

According to cumulative deviation line of Agri station, the wet period started from 1983 was ended in 1995 and the dry period was started on 1995 and continued up to 2008.

Monthly average streamflow graph for 2402 station (Appendix D) shows that, the streamflow values of the melting period were increased for last 20 years period. This can be a result of the wet period started on 1995. This result can be seen on average streamflow for melting period analysis. Mann-Kendall and Spearman's Rho test results are +2.20 and +1.60 for this analysis. This significant trend is also shown on Sequential Mann-Kendall test result (Figure 34). Although the lines did not intersect each other, the year 1985 can be referred as the starting year of the trend, because after this year, the lines move away and trend becomes more obvious.

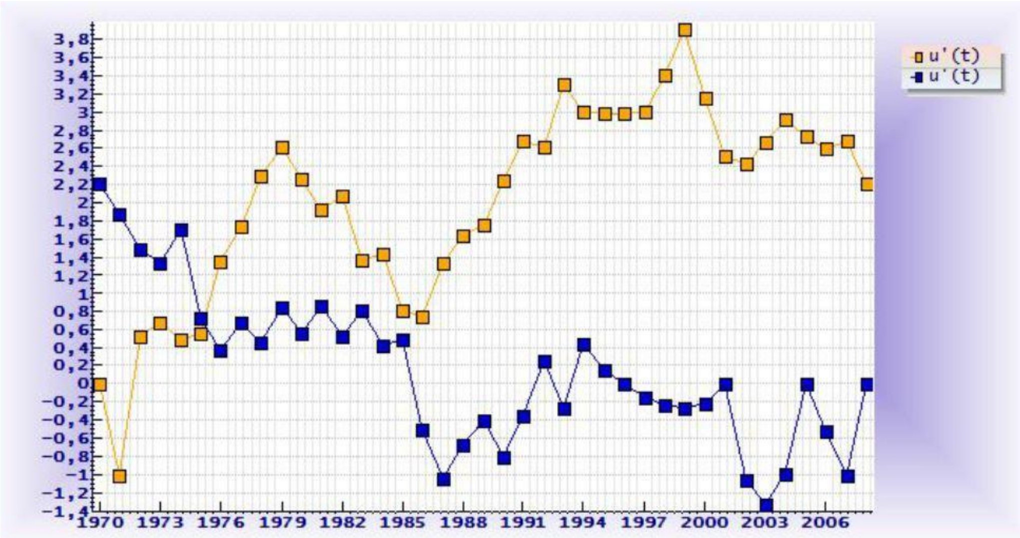


Figure 34. Sequential Mann Kendall test u(t) - u'(t) graph for average streamflow for melting period from 1970 to 2010

Annual average streamflow trends are also significantly positive with trend analysis results as +1.70 and +0.82 for Mann-Kendall and Spearman's Rho tests respectively. The number of days below freezing decreased significantly from1970 to 2010. This is proved by Mann-Kendall and Spearman's Rho tests. Test results are -2.81 and -2.82 respectively. This strong trend can be seen on Sequential Mann-Kendall test result in Figure 35. According to this Figure, the decreasing trend is obvious, but to point the starting year is not clear because, between the years 1980-1995 the trend was strayed from the path.

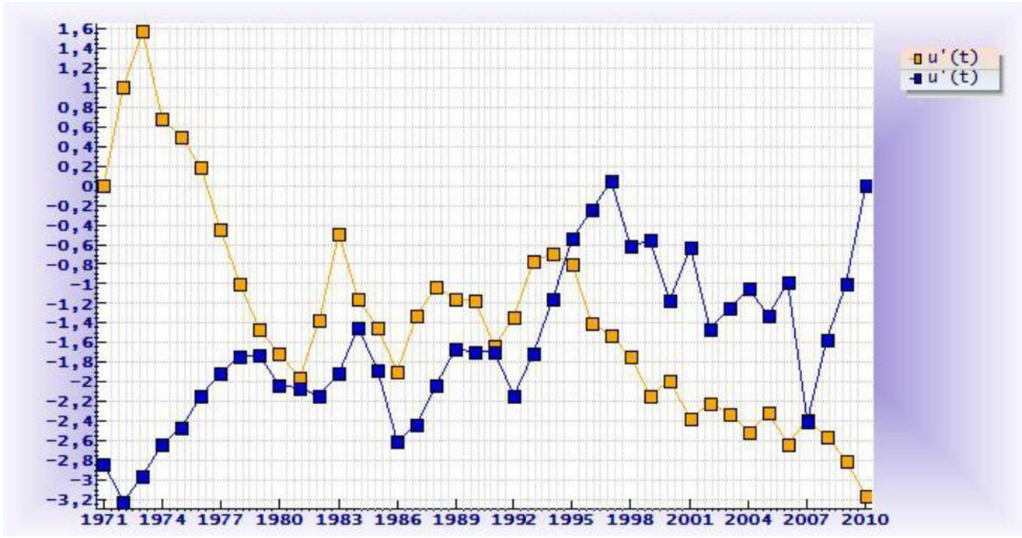


Figure 35. Sequential Mann Kendall test u(t) - u'(t) graph for number of days smaller than 0oC daily average temperature, from 1st of October to CT of 2402-Agri station pair

The number of wet days below freezing trend is again statistically significant according to trend analysis results. These trend results are -2.34 and -2.80 for Mann-Kendall and Spearman's Rho test results respectively. Sequential Mann-Kendall test results are also shown in Figure 36. This graph indicates the year 1997 as the start of significant decreasing trend. This can also be inferred from the graph that, after the year 1995, decreasing trend is very strong.

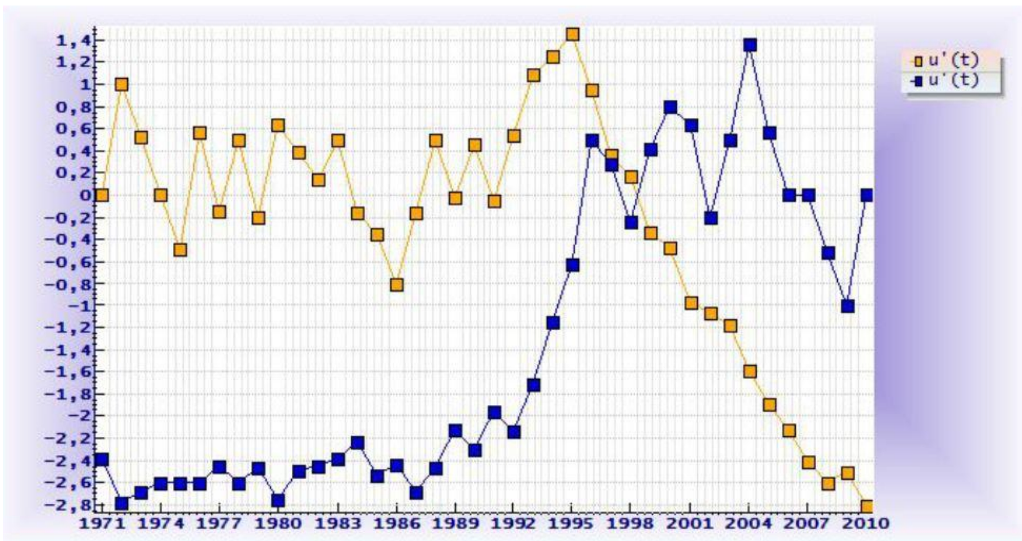


Figure 36. Sequential Mann Kendall test u(t) - u'(t) graph for total number of wet days smaller than 0^{o}C daily average temperature, from 1st of October to CT of 2402-Agri station pair

Statistical trend analysis tests are applied on total precipitation quantity for these wet days. According to results of these Mann-Kendall and Spearman's Rho tests, the total quantity of snow for these days decreased significantly with test results of -2.95 and -3.13 respectively. This analysis is shown on Sequential Mann-Kendall graph in Figure 37. This analysis shows the year 2004 as the start of significant trend. However, similar to total number of wet days below freezing analysis u(t)-u'(t) graph, this graph also shows that, after the year 1995, the trend became more obvious.

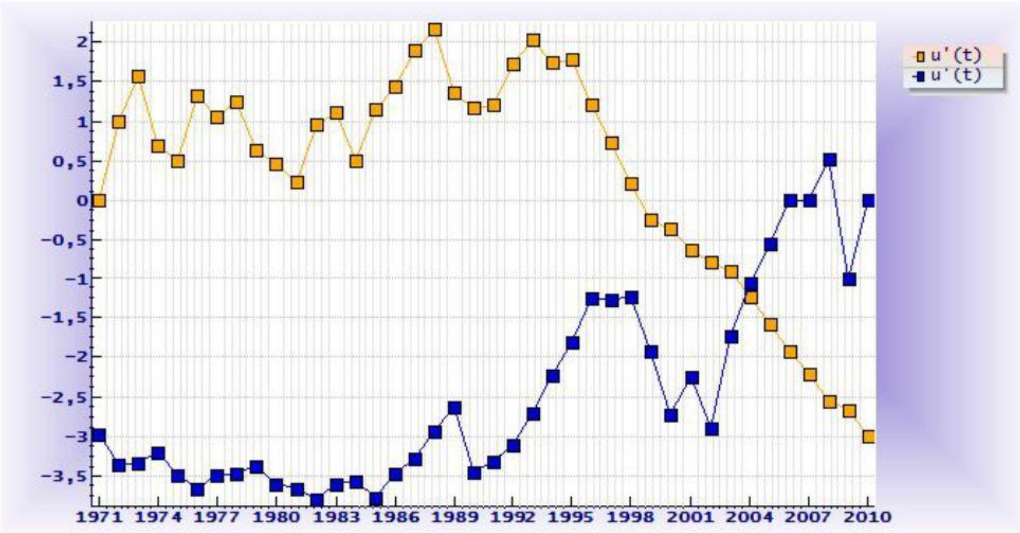


Figure 37. Sequential Mann Kendall test u(t) - u'(t) graph for cumulative precipitation value of the wet days smaller than 0°C daily average temperature, from 1st of October to CT of 2402-Agri station pair

Although, decreases in precipitation in accumulation period (November to February) may affect the quantity of snow in a negative manner, the number of wet days below freezing can not be clarified with decrease in precipitation. The decrease in number of wet days may be explained by the increase in temperature significantly. And due to this increase, the type of precipitation may be changed from snow to rain. As a result, the melting of snow shifted to earlier times. Although, the precipitation quantities in melting period increased very little (Table 4), the change in precipitation phase makes additional impact on increases in melting period streamflow due to effect of early melting. In other words, precipitation has fallen as rain, rather than snow, and therefore has reached rivers more rapidly than before.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Trend analyses of 15 streamflow stations from 1970 to 2010 (40 years) in Eastern regions of Turkey are investigated in this study. In conjunctions to the streamflow trend analyses, for the same period temperature and precipitation trend analyses are performed using 10 meteorological stations nearest to these stream gauge stations. In order to determine the significance of trends in these stations non-parametric Mann-Kendall and Spearman's Rho tests are used. In addition to significance of the trends, the start of the meaningful trends is also determined by Sequential Mann-Kendall test.

By several different measures, long-term shifts in the timing of streamflow have been observed for snowmelt dominated basins throughout eastern mountainous region of Turkey since the year 1970. Significant CT shifts are associated with either no change in annual streamflow or decrease in annual streamflow as a consequence of warming effect. These results are summarized in Figure 38.

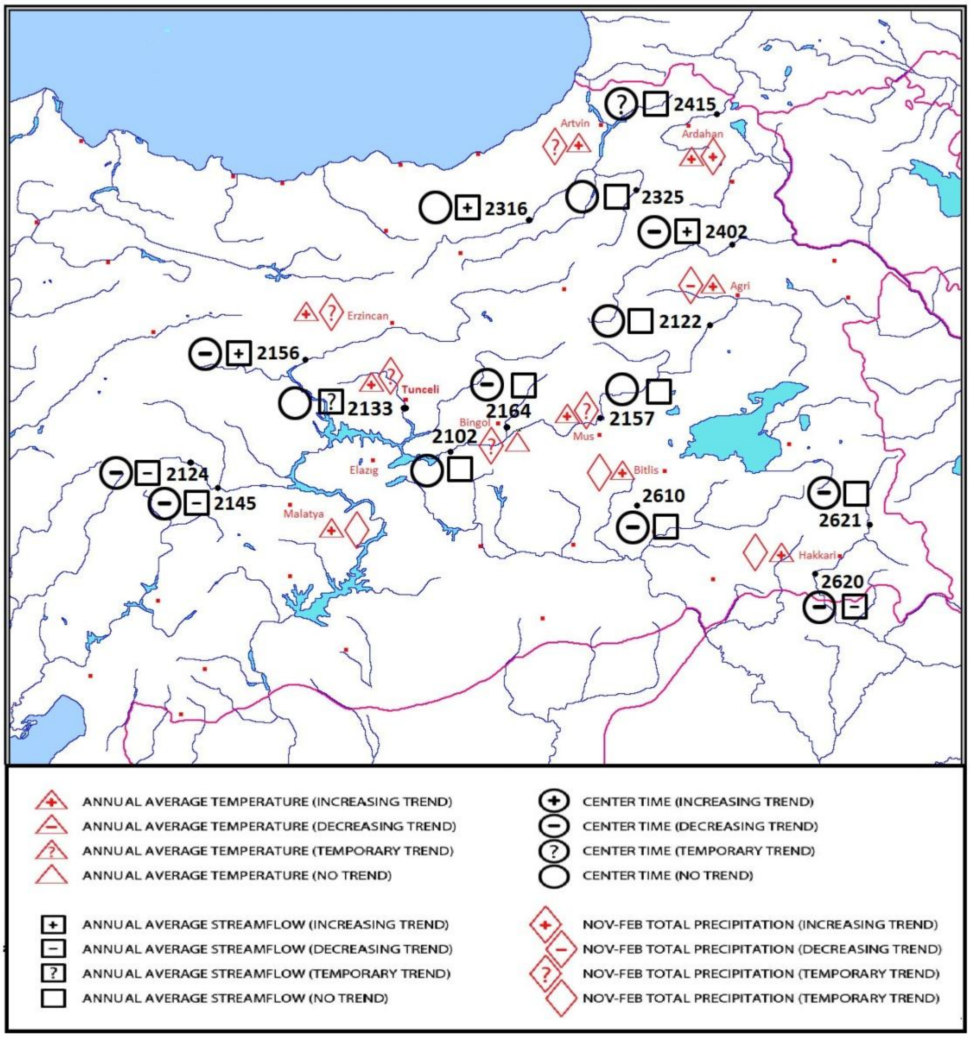


Figure 38. Mann-Kendall and Spearman's Rho test trend analysis results for selected streamflow and meteorological stations on Turkey map.

The following conclusions can be drawn from the present study:

1. Analysis of temperature time series in the Eastern part of the Turkey, revealed that the temperature exhibited an obvious increasing trend during the past 40 years. The daily average temperature for the period 1970-2010 was increased by almost 1.5 ^{0}C. Both the results of the Mann-Kendall test and of the Spearman's Rho test indicated that the long-term monotonic trend in daily average temperature was strong over time and statistically significant. This increase in temperature advances the timing of snowmelt and generally a shift in the center time of the streamflow.

2. The test results for the long-term trend of precipitation showed that, although there was a slight increase in November-February period precipitation analysis, the change in annual average precipitation was not statistically significant. Analysis of the precipitation time series during the past 40 years revealed that there was no significant interannual variability. Cumulative deviation lines (Figure 10) identify the wet and dry years along with data period from 1970 to 2010. In these graphs, three stations (Malatya, Ağrı, Bitlis) showed a dry period while the rest of the stations showed a wet period towards the end of the evaluation period from 1970 to 2010.

3. Spring streamflow during the last 40 years has shifted to earlier times so that the major March–June streamflow peak now arrives one or more weeks earlier, resulting in declining fractions of spring and early summer river discharge. Importantly, as yet, there has been little concurrent change in the total annual discharge and only 2 of the selected streamflow stations (2124 and 2145) show evidence for decreasing March–June streamflow volumes. (Table 9). This is also evident in monthly streamflow comparison between 1970-1990 and 1990-2010 (Figure 12).

4. 7 of the 15 selected stations show significant decreasing trend in the number of wet days below freezing and this precipitation amount was strongly decreased in 4 of these stations (Table 12 and Table 13). Observed winter warming causes an increased fraction of the precipitation to fall as rain, resulting in a reduced snowpack and an earlier melt.

5. As a consequence of warming effect appears throughout the eastern Turkey in Figure 38, the mass of snowmelt runoffs are shifted to earlier times on basins of Euphrates, Tigris and Aras on the region. For the Tigris basin, although there is no any significant trend in streamflow changes, the shifts in CT are statistically meaningful. This means that, the shifts are mainly due to the warming effect. This is also the case for the middle parts of the Euphrates basin. For the lower parts of the Euphrates basin, the CT shifts to earlier times are more pronounced than the shifts in the upper parts of the basin. These are mostly due to the fact that, the streamflow values of these stations are also decreased significantly from 1970 to 2010, whereas there is no any significant change in precipitation for this region. For Tigris and Aras basins the shifts are statistically significant. However, for the Çoruh basin, the shifts exist but these are not statistically significant with 90% confidence level. In addition to these results, since there is no significant trend in precipitation regionally, warming effect may result in changes in type and intensity/duration of precipitation in this region.

These results are important in hydrologic regimes of river systems available in mountainous region of eastern Turkey. The effects of shifts in melting of snow should be considered in planning of dam reservoirs in order to sustain the effective storage and effective use of water. These results should be used in Turkey's water policies to be followed in the future and could provide support for research and decision making in the science and policy-making arenas.

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APPENDIX A

TABLES OF STREAM GAUGE STATIONS IN EUPHRATES, TIGRIS, ARAS AND ÇORUH BASINS

Table A. Stream gauge stations in Euphrates, Tigris, Aras And Çoruh basins

21 - Euphrates Basin						
NUMBER	**STATION**			**OPENING DATE**	**CLOSING DATE**	**ELEVATION (m)**
2101	**Fırat Nehri**	**-**	**Kadıköy**	26.07.1936	11.07.1945	625
2102	**Murat Suyu**	**-**	**Palu**	26.07.1936		852
2103	**Fırat Nehri**	**-**	**Keban**	03.08.1936		681
2104	**Fırat Nehri**	**-**	**Bakırhan**	08.10.1936	30.11.1938	600
2105	**Fırat Nehri**	**-**	**Karakaya (Karakilise)**	13.10.1936	01.01.1983	540
2106	**Fırat Nehri**	**-**	**Sarsap**	16.10.1936	30.11.1938	500
2107	**Murat Nehri**	**-**	**Ardişen**	30.10.1936	21.05.1943	1300
2108	**Murat Nehri**	**-**	**Pertek**	07.11.1936	30.04.1941	740
2109	**Fırat Nehri**	**-**	**Kemaliye**	11.11.1936	15.03.1975	810
2110	**Fırat Nehri**	**-**	**Kömürhan**	10.12.1938	16.01.1971	628
2111	**Derme Suyu**	**-**	**Pınarbaşı**	11.02.1943	22.12.1950	1225
2112	**Gökpınar**	**-**	**Yelkenköy**	04.11.1945	21.07.1953	1450
2113	**Girlevik Deresi**	**-**	**Kalecik**	22.07.1947	01.09.1953	1463
2114	**Fırat Nehri**	**-**	**Birecik**	23.12.1947	16.01.1998	337
2115	**Göksu**	**-**	**Malpınar**	15.02.1953		390
2116	**Munzur Suyu**	**-**	**Kalender**	31.07.1953	23.07.1957	810
2117	**Fırat Nehri**	**-**	**Mezra**	17.08.1953	24.03.1963	525
2118	**Tohma Suyu**	**-**	**Kırkgöz**	23.08.1953	01.10.1967	653
2119	**Fırat Nehri**	**-**	**Kemah Boğazı**	04.09.1953		1123
2120	**Fırat Nehri**	**-**	**Kötür Köp.**	05.09.1953	31.01.1972	1375
2121	**Fırat Nehri**	**-**	**Sansa Boğazı**	05.09.1953	01.08.1967	1205
2122	**Murat Nehri**	**-**	**Tutak**	09.09.1953		1552
2123	**Çağ Çağ Suyu**	**-**	**Çınarköy (Nusaybin)**	27.11.1953	31.01.1994	560
2124	**Tohma Suyu**	**-**	**Yazıköy**	01.09.1954		1193

Table A (continued)

2125	**Sultansuyu**	**-**	**Suçatı**	01.09.1954	30.09.1976	995
2126	**Tohma Suyu**	**-**	**Ayvalı**	04.09.1954	01.02.1962	1125
2127	**Tohma Suyu**	**-**	**Samah**	05.09.1954	30.06.1962	825
2128	**Cimin Deresi**	**-**	**Cimin**	03.06.1955	10.12.1965	1467
2129	**Sakaltutan Suyu**	**-**	**Erkenek**	20.08.1955	24.12.1965	1220
2130	**Pülür Çayı**	**-**	**Sakalıkesik**	09.08.1956	31.10.1968	1050
2131	**Bey Deresi**	**-**	**Kılayık**	07.09.1956		892
2132	**Culap Suyu**	**-**	**İncirli**	10.09.1956	31.10.2001	470
2133	**Munzur Suyu**	**-**	**Melekbahçe**	31.07.1953	01.09.2009	875
2134	**Abdulharap Göl Ayağı**	**-**	**Şerefhan**	10.07.1959	01.10.1967	1371
2135	**Bulam Çayı**	**-**	**Fatopaşa**	28.09.1957		1252
2136	**Pülk Çayı**	**-**	**Koşmaşat**	06.10.1958	12.12.1965	1900
2138	**Büyükçay**	**-**	**Gülebağdi**	28.10.1959	01.10.1971	1760
2139	**Mercan Deresi**	**-**	**Arklarbaşı**	11.03.1961	31.10.1968	1385
2140	**Fırat Nehri**	**-**	**Dutluca**	21.04.1961	31.01.2002	386
2141	**Peri Suyu**	**-**	**Korudibi**	20.11.1961	12.09.1997	1035
2142	**Murat Nehri**	**-**	**Gülüşkür Köp.**	06.05.1962	01.09.1968	817
2143	**Munzur Suyu**	**-**	**Lazvan**	09.05.1962	01.09.1968	890
2144	**Peri Suyu**	**-**	**Seyitli**	15.05.1962	01.11.1968	838
2145	**Tohma Suyu**	**-**	**Hisarcık**	30.06.1962		933
2146	**Murat Nehri**	**-**	**Aşvan Köp.**	09.11.1962	01.10.1968	710
2147	**Munzur Suyu**	**-**	**Dedikuşağı**	07.11.1962	01.10.1997	1195
2148	**Pülümür Çayı**	**-**	**Pah Köp.**	18.01.1963	30.09.1974	905
2149	**Munzur Suyu**	**-**	**Miskisağ**	17.01.1963		900
2150	**Çaltı Suyu**	**-**	**Çaltı**	28.09.1963	30.08.1968	845
2151	**Fırat Nehri**	**-**	**Demirkapı D.D.Y. (Sansa Boğazı)**	13.06.1963		1355
2152	**Murat Nehri**	**-**	**Muş**	01.10.1967	30.09.1983	1241
2153	**Fırat Nehri**	**-**	**Fırat D.D.Y. Köp.**	08.11.1967	01.08.1986	640
2154	**Karasu**	**-**	**Aşağı Kağdariç**	01.10.1968		1675
2155	**Tuzla Deresi**	**-**	**Tercan Köp.**	01.10.1968	31.08.1990	1415
2156	**Fırat Nehri**	**-**	**Bağıştaş**	01.10.1968		865
2157	**Karasu**	**-**	**Karaköprü**	15.11.1968	03.10.2007	1250
2158	**Bingöl Çayı**	**-**	**Abdurrahmanpaşa K.**	19.11.1968		1310

Table A (continued)

2159	**Çam Deresi**	**-**	**Hacıkamil Köp.**	17.12.1968	04.02.1993	525
2160	**Nizip Çayı**	**-**	**Danaoğlu**	16.12.1968	25.04.1989	365
2161	**Habur Çayı**	**-**	**Ceylanpınar**	01.07.1969	25.10.1972	345
2162	**Fırat Nehri**	**-**	**Eriç**	09.07.2003		1000
2163	**Kahta Çayı**	**-**	**Kahta**	01.10.1969	01.10.1974	480
2164	**Göynük Çayı**	**-**	**Çayağzı**	07.11.1968		990
2165	**Zerkan Çayı**	**-**	**Hocaköy**	23.11.1968	30.11.1998	445
2166	**Peri Suyu**	**-**	**Loğmar**	01.11.1968		845
2167	**Çaltı Suyu**	**-**	**Dazlak**	21.10.1967	07.04.1997	890
2168	**Dumlu Suyu**	**-**	**Yeşildere**	01.10.1972	03.06.1997	2000
2169	**Fırat Nehri**	**-**	**Tilla Köp.**	25.10.1972	14.02.1975	430
2170	**Fırat Nehri**	**-**	**Belkısköy**	01.07.1973	01.10.1999	340
2171	**Uludere**	**-**	**Hasançelebi**	01.05.1976	13.04.1993	1188
2172	**Pülümür Çayı**	**-**	**Batman Köp.**	14.11.1977	01.12.2009	886
2173	**Sultan Suyu**	**-**	**Dedeköy**	01.06.1976	14.01.1993	943
2174	**Murat Nehri**	**-**	**Akkonak**	01.10.1979		1285
2175	**Fırat Nehri**	**-**	**Hindibaba**	24.10.1982	12.11.1990	523
2176	**Tacik Deresi**	**-**	**Mutuboğazı**	01.03.1983		1225
2177	**Hınıs Çayı**	**-**	**Adıvar**	28.05.1985		1452
2178	**Göynük Çayı**	**-**	**Devecik Köp.**	01.07.1986	04.11.1992	1579
2179	**Kop Suyu**	**-**	**Pırnakapan**	04.10.1996		1780
2180	**Dumlu Suyu**	**-**	**Yeşildere**	03.06.1997		1935
2181	**Arabalı Dere**	**-**	**Tutak**	17.06.1997		1615
2182	**Ulıçay**	**-**	**Kurtdere**	12.12.1998	31.10.2001	875
2183	**Pamukçayı**	**-**	**Koçali**	18.12.1998		1057
2184	**Kapıkaya Deresi**	**-**	**Kapıkaya**	20.02.1999	31.10.2001	805
2190	**Tavuk Çayı**	**-**	**Çaltı**	26.10.2004		960
2191	**Atma Çayı**	**-**	**Atma**	27.10.2004		1155
2192	**Türk Çayı**	**-**	**Kesme**	09.11.2004		1050
2193	**Eriç Çayı**	**-**	**Oğuz**	17.05.2005		1165
2194	**Değirmendere**	**-**	**Çanakcı**	19.07.2005		444
2195	**Karasu Çayı**	**-**	**Gümüşpınar**	23.09.2005		408
2196	**Karasu**	**-**	**Sungu**	26.08.2008		1262
2197	**Ayvalı Deresi**	**-**	**Ayvalı**	01.11.2008		1242

Table A (continued)

26 - Tigris Basin						
NUMBER	**STATION**			**OPENING DATE**	**CLOSING DATE**	**ELEVATION (m)**
2601	**Dicle Nehri**	**-**	**Şerbetin**	27.09.1940	26.03.1951	590
2602	**Batman Çayı**	**-**	**Sinan**	27.10.1945	15.11.1968	518
2603	**Garzan Çayı**	**-**	**Beşiri**	01.11.1945	30.09.2002	545
2604	**Botan Çayı**	**-**	**Billoris**	07.11.1945	01.10.1971	465
2605	**Dicle Nehri**	**-**	**Diyarbakır**	13.11.1945	15.11.2002	570
2606	**Dicle Nehri**	**-**	**Cizre**	27.11.1945		370
2607	**Behramaz Çayı**	**-**	**Hatunköy**	07.07.1950	10.09.1960	1075
2608	**Hazar Göl Ayağı**	**-**	**Gezin**	07.07.1950	30.11.1960	1350
2609	**Çatak Deresi**	**-**	**Çatak**	12.09.1954	22.02.1972	1625
2610	**Bitlis Çayı**	**-**	**Baykan**	14.09.1954		698
2611	**Dicle Nehri**	**-**	**Rezuk**	01.03.1955	07.03.1975	427
2612	**Batman Çayı**	**-**	**Malabadi**	06.02.1957		597
2613	**Batman Çayı**	**-**	**Hüseyinkan**	01.03.1959	26.06.1966	650
2614	**Sortkin Suyu**	**-**	**Çatak**	18.10.1963	22.02.1972	1615
2615	**Müküs Çayı**	**-**	**Beğendik**	11.08.1964	01.02.1973	1250
2616	**Bitlis Çayı**	**-**	**Karınca**	22.09.1964	01.02.1971	1145
2617	**Dicle Nehri**	**-**	**Çayönü**	31.11.1968	01.12.1997	695
2618	**Ambar Çayı**	**-**	**Köprübaşı**	01.11.1968	01.10.1998	595
2619	**Göksu Çayı**	**-**	**Çınarköprü**	22.11.1968	25.05.1988	657
2620	**Zap Suyu**	**-**	**Üzümcü**	12.11.1968		1072
2621	**Zap Suyu**	**-**	**Musahan**	13.11.1968		1725
2622	**Nehil Çayı**	**-**	**Konak**	19.08.1988		1694
2623	**Dicle Nehri**	**-**	**Ilısu**	24.03.1970	30.09.1978	400
2624	**Kezer Çayı**	**-**	**Pınarca**	01.10.1971		530
2625	**Hezil Çayı**	**-**	**Girikhan**	01.10.1971		780
2626	**Botan Çayı**	**-**	**Billoris**	01.10.1971	03.10.1996	457
2627	**Zap Suyu**	**-**	**Narlı**	01.10.1977		775
2628	**Cemilkatlı Deresi**	**-**	**Kamışlı**	01.08.1982	01.10.1993	1620
2629	**Şemdinli Çayı**	**-**	**Yeşilöz**	22.12.1984	07.01.1998	1627
2630	**Zap Suyu**	**-**	**Teknisyenler**	15.08.1985		1412
2631	**Çatak Suyu (Deresi)**	**-**	**Tüliran**	08.07.1987		1482
2632	**Berkilin Çayı**	**-**	**Çayüstü**	16.09.1988	13.01.1998	689
2633	**Botan Çayı**	**-**	**Billoris**	03.10.1996		465
2634	**Garzan Çayı**	**-**	**Kozluk (Köprübaşı)**	29.09.1999		630
2635	**Dicle Nehri**	**-**	**Kalender Köp.**	30.10.2001		843
2636	**Şemdinli Çayı**	**-**	**Şemdinli**	11.10.2001	13.03.2006	1290

Table A (continued)

2637	**Habur Çayı - Habur II**	17.06.2002		935
2638	**Dicle Nehri - Ziyaret**	01.04.2006		563
2639	**Şemdinli Çayı - Olgunlar**	14.03.2006		1340

23 - Çoruh Basin				
NUMBER	**STATION**	**OPENING DATE**	**CLOSING DATE**	**ELEVATION (m)**
2301	**Murgul Çayı - Murgul**	09.02.1938	31.01.1939	380
2302	**Tortum Çayı - Tev Köp.**	27.07.1940	19.08.1969	960
2303	**Tortum Çayı - Azort**	28.07.1940	10.09.1957	1070
2304	**Çoruh Nehri - Bayburt**	03.09.1941		1545
2305	**Çoruh Nehri - Peterek**	11.09.1941		654
2306	**Aralık Deresi - Aralık**	27.05.1944	15.12.1960	90
2307	**Deviskel Deresi - Deviskel**	06.09.1944	15.12.1960	98
2308	**Çoruh Nehri - Borçka**	18.07.1952	11.01.1966	95
2309	**Oltu S. - Tivasor**	03.09.1953	13.07.1958	640
2310	**Çoruh Nehri - Kan**	05.09.1953	28.09.1964	1430
2311	**Tortum Çayı - Dikkale**	10.09.1957	30.09.1969	1140
2312	**Murgul Çayı - Murgul**	08.06.1958	30.09.1963	569
2313	**Oltu Suyu - Gülpaşagöllüğü**	13.07.1958	07.12.1962	610
2314	**Tortum Çayı - Çatak Köp.**	07.12.1962	01.10.1969	610
2315	**Çoruh Nehri - Karşıköy**	26.06.1964	15.07.2002	57
2316	**Çoruh Nehri - İspir Köp.**	01.10.1964		1170
2317	**Arduça Deresi - Damar**	28.07.1967	01.11.1968	980
2318	**Berta Çayı - Ardala**	01.10.1968	01.10.1971	245
2319	**Tortum Çayı - Uluboga**	10.07.1969	01.01.1975	775
2320	**Çoruh Nehri - Laleli**	31.07.1970		1365
2321	**Parhal Deresi - Dutdere**	26.06.1971		705
2322	**Çoruh Nehri - Altınsu**	01.10.1971	01.10.2001	201
2323	**Oltu Suyu - İşhan Köp.**	07.12.1962		572
2324	**Oltu Suyu - Oltu**	01.10.1972	30.09.1973	1270
2325	**Oltu Suyu - Aşağı Kumlu**	01.10.1973		1129
2326	**Meydancık Deresi - Dutlu**	20.10.1981		875
2327	**Berta Suyu - Çiftehanlar**	21.10.1981	01.10.1998	570
2328	**Ardanuc Deresi - Ferhatlı**	22.10.1981		365
2329	**Oltu Suyu - Çoşkunlar**	19.11.1981		1004
2330	**Çamlıkaya Deresi - Çamlıkaya**	19.11.1981		995
2331	**Deviskel Deresi - Gündoğdu**	17.09.1987	30.06.2001	560
2332	**Çoruh Nehri - Borçka**	01.01.1989	11.01.2002	97
2333	**Mansurat Deresi - Şavşat**	01.01.1989		830
2334	**Berta Suyu - Bağlık**	01.01.1989		366
2335	**Çoruh Nehri - İnanlı**	01.01.1989		435
2336	**Parhal Suyu (Deresi) - İkizkavak**	01.01.1989	30.09.2007	805

Table A (continued)

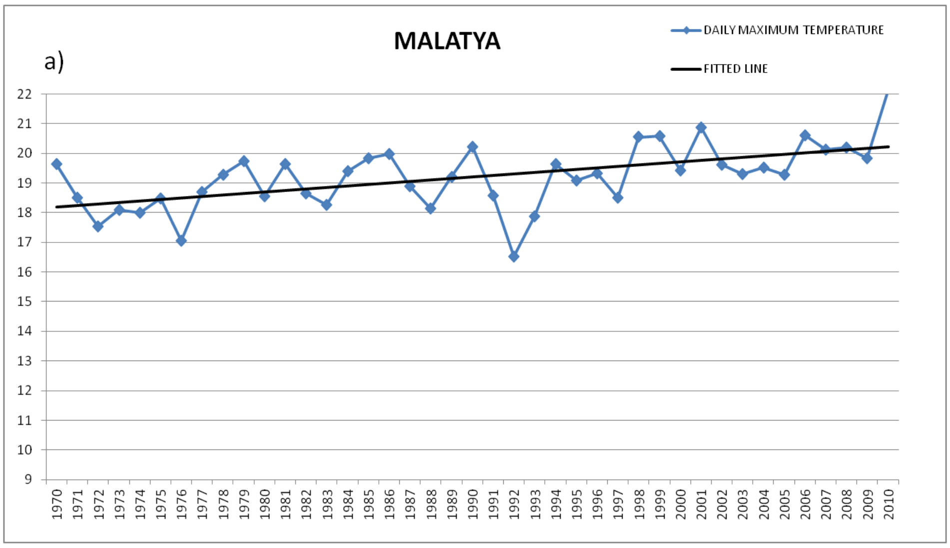
2337	**Çoruh Nehri - Çamlıkaya**	01.12.1988		892
2338	**Çoruh Nehri - Pazaryolu**	01.12.1988		1265
2339	**Murgul Çayı - Erenköy**	01.06.1989	10.05.2001	213
2340	**Öğdem Deresi - Uysallar**	12.12.1990		682
2341	**Arcıvan Deresi - Esendal**	01.12.1991	01.10.1998	1150
2342	**Parhal Deresi - Altıparmak**	01.01.1992		1122
2344	**Deviskel Deresi - Borçka**	05.07.2004		110
2345	**Hüngemekdere - Cala**	12.06.2005		860
2346	**Karçkal Deresi - Verenibağları**	13.11.2008		523
2347	**Çoruh Çayı - Taş Köprü**	12.07.2008		1584

24 - Aras Basin

NUMBER	STATION	OPENING DATE	CLOSING DATE	ELEVATION (m)
2401	**Aras Nehri - Horasan**	06.08.1953	01.10.1971	1520
2402	**Aras Nehri - Kağızman**	06.08.1953		1140
2403	**Aras Nehri - Çüllü Köp.**	07.10.1955	01.10.1971	1760
2404	**Çağlıkhan Deresi - Çağlıkhan**	07.10.1955	01.10.1971	1790
2405	**Sarısu - Kanikök**	15.08.1956	01.12.1992	1491
2406	**Sarısu - Gülveren**	22.08.1956	15.11.1972	1450
2407	**Çıldır Göl Ayağı - Taşbaşı**	25.08.1956	25.06.1969	1955
2408	**Sarısu - Nonak Köp.**	19.09.1957		1685
2409	**Kars Çayı - Güvercinkaya**	02.11.1959		1670
2410	**Kars Çayı - Geçitköy**	05.12.1959	01.10.1969	1525
2411	**Çıldır Suyu - Çıldır**	12.06.1961	31.10.1968	1800
2412	**Hacıkotu Deresi - Arpaçay**	01.07.1961	31.10.1968	1687
2414	**Kars Çayı - Dikme**	01.03.1969	15.11.1972	1790
2415	**Kura Nehri - Ur Köp.**	01.02.1969		1750
2416	**Aras Nehri - Çobandede Köp.**	01.10.1971	01.04.1981	1580
2417	**Aras Nehri - Mescitli**	01.10.1971	01.10.1998	1735
2418	**Kars Çayı - Şahnalar**	01.10.1969		1495
2419	**Çıldır Göl Ayağı - Telek**	01.10.1972	01.04.1982	1690
2420	**Kura Nehri - Doğankaya**	25.07.1977	30.12.1983	1630
2421	**Kura Nehri - Akkiraz**	23.11.1978	01.10.1998	1380
2422	**Ölçek Çayı - Ölçek**	01.08.1997		1715
2428	**Aras Nehri - Meşecik**	03.10.2006		1512

APPENDIX B

FIGURES OF DAILY MAXIMUM TEMPERATURES (a-c-e-g-j-k-m-o-q-s) AND DAILY MINIMUM TEMPERATURES (b-d-f-h-j-l-n-p-r-t) OF METEOROLOGICAL STATIONS



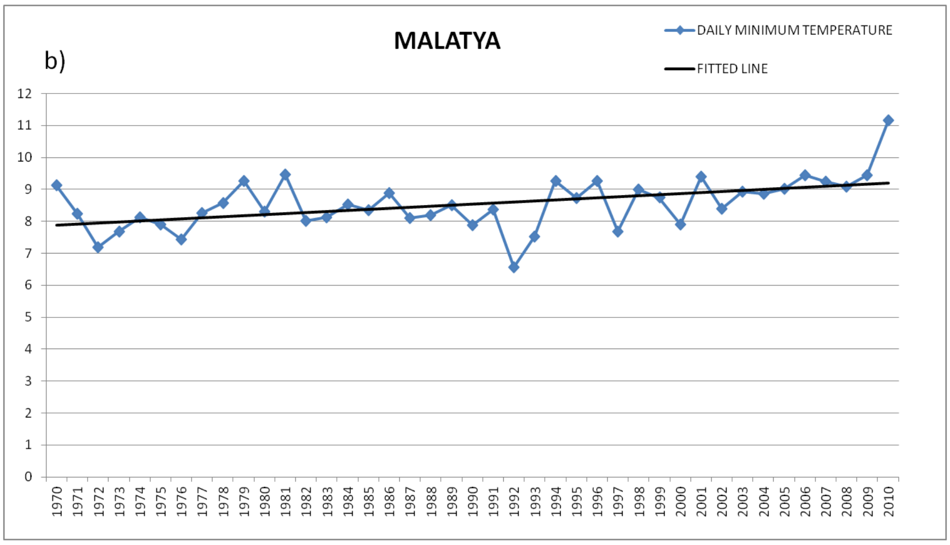
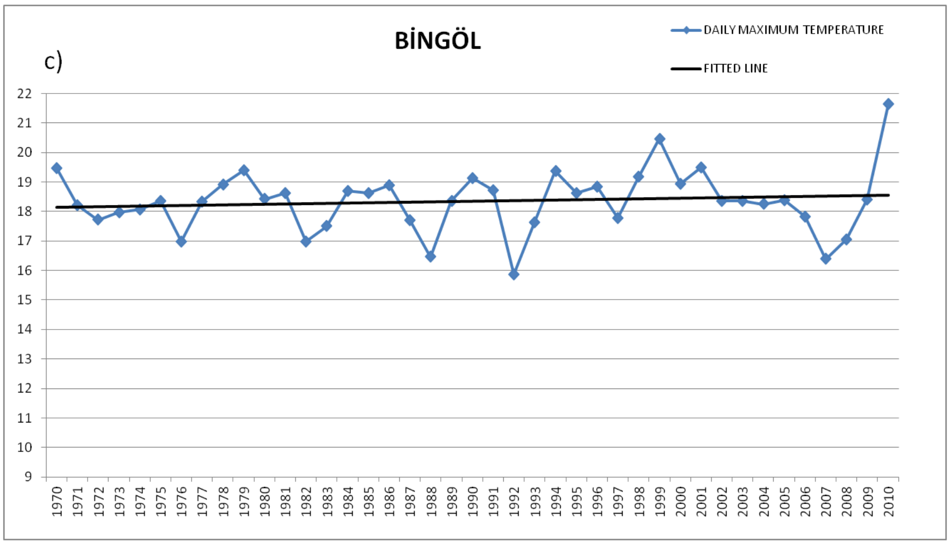
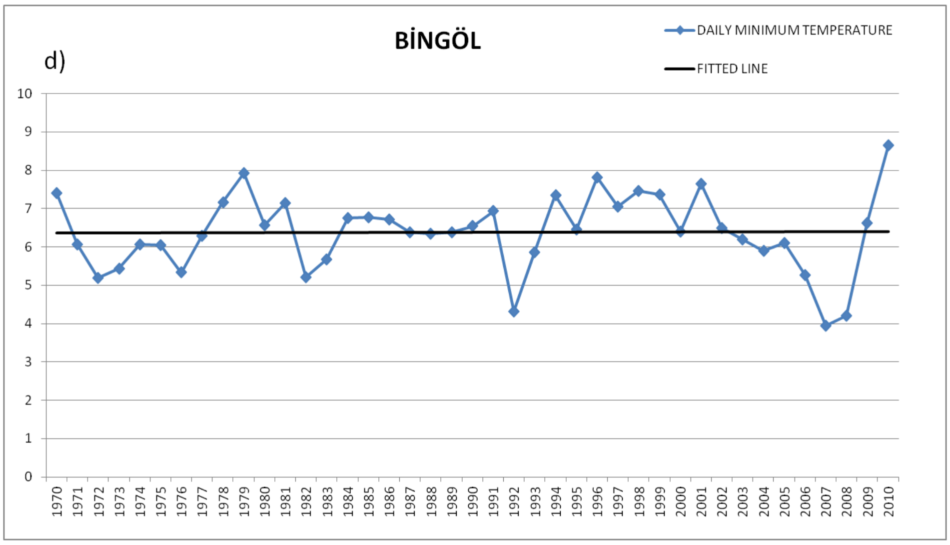


Figure B. Daily maximum temperatures (a-c-e-g-j-k-m-o-q-s) and daily minimum temperatures (b-d-f-h-j-l-n-p-r-t) of meteorological stations





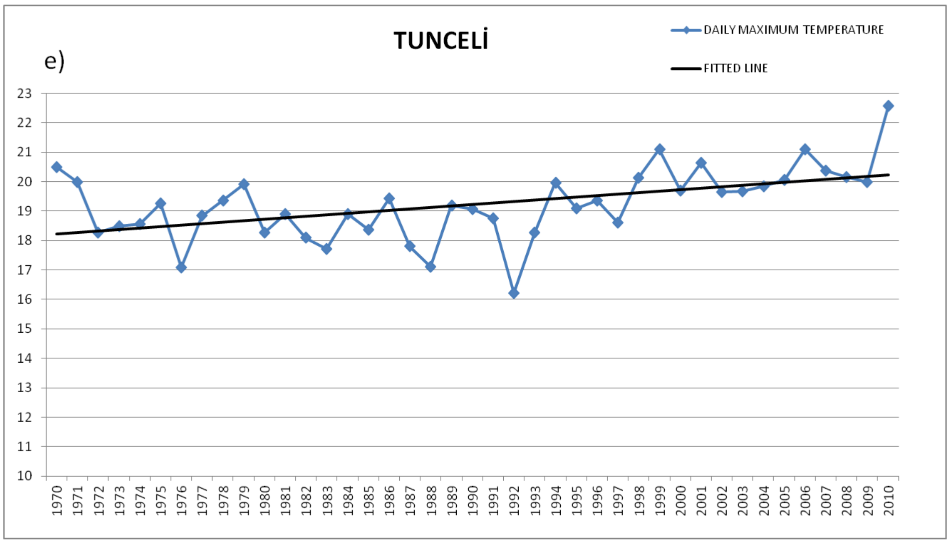
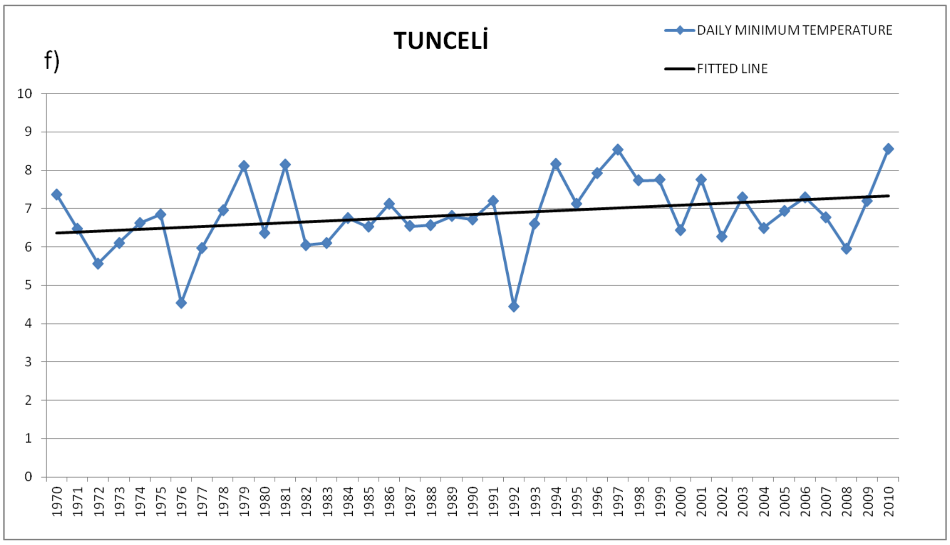
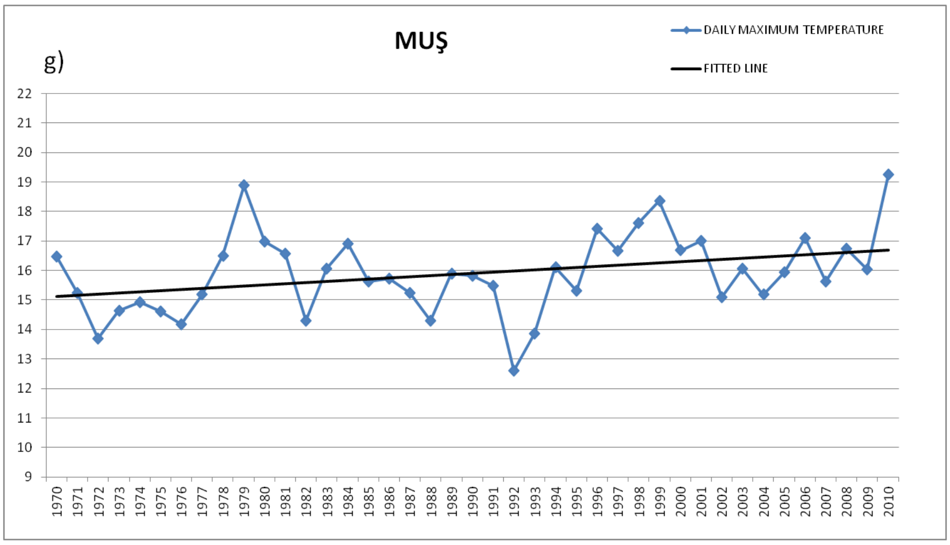


Figure B (continued)





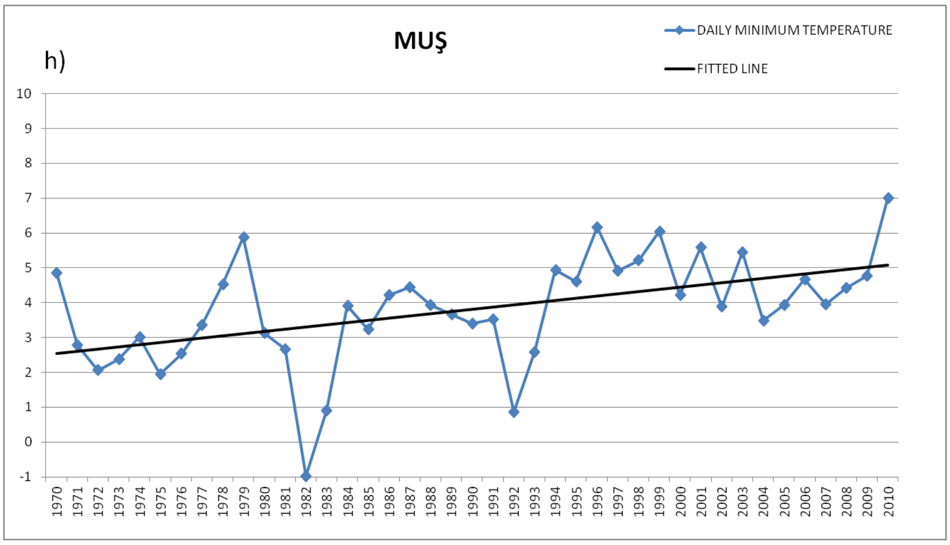


Figure B (continued)

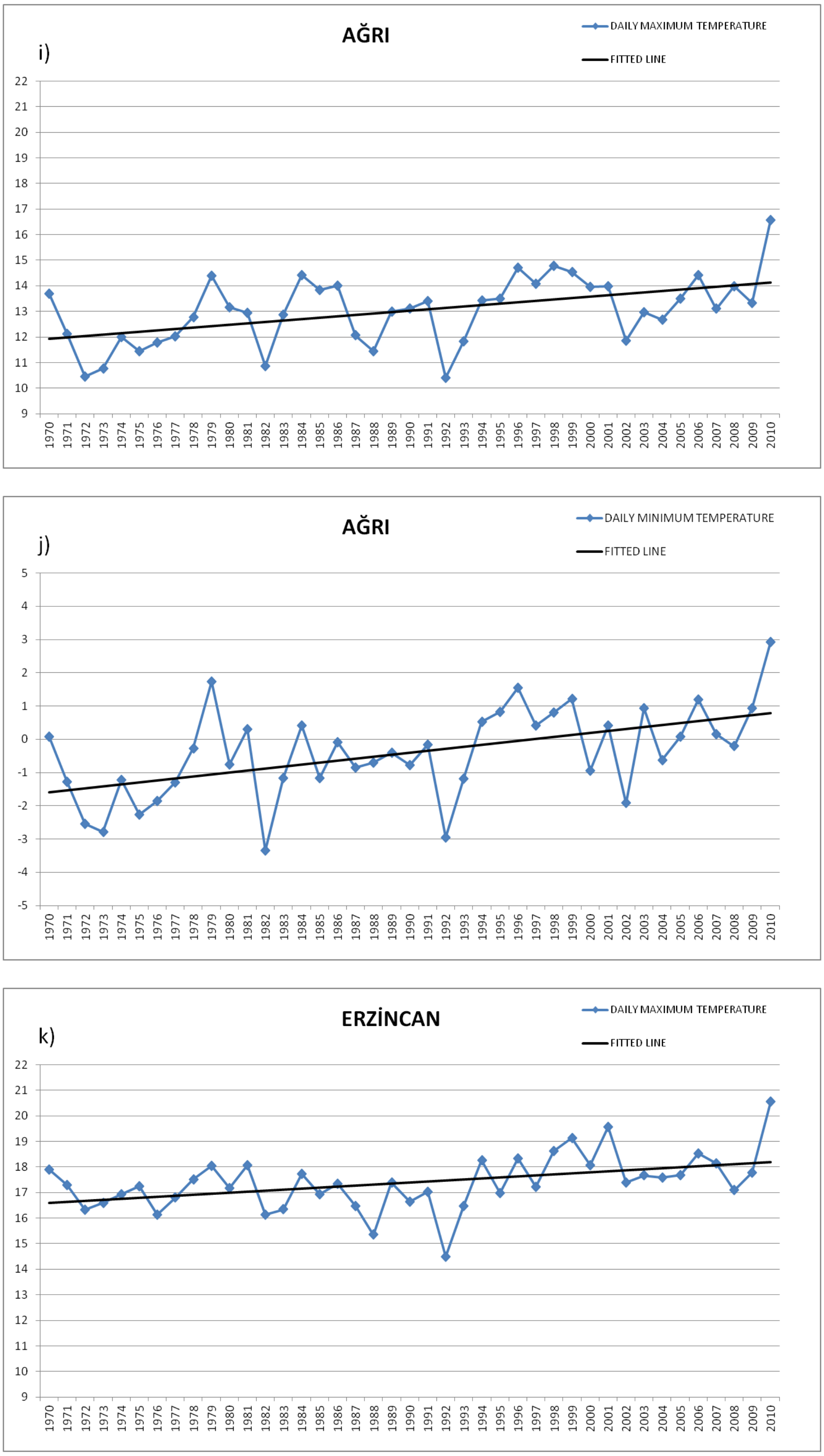
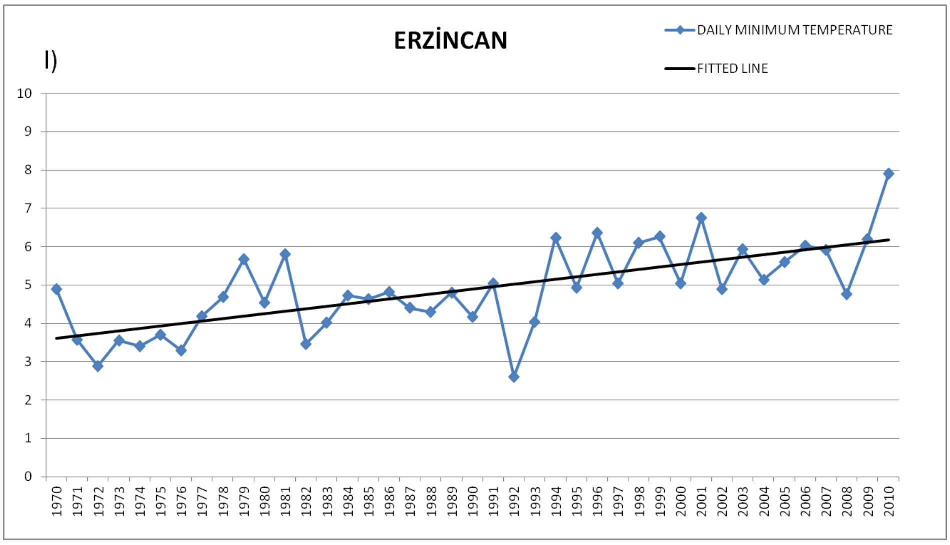
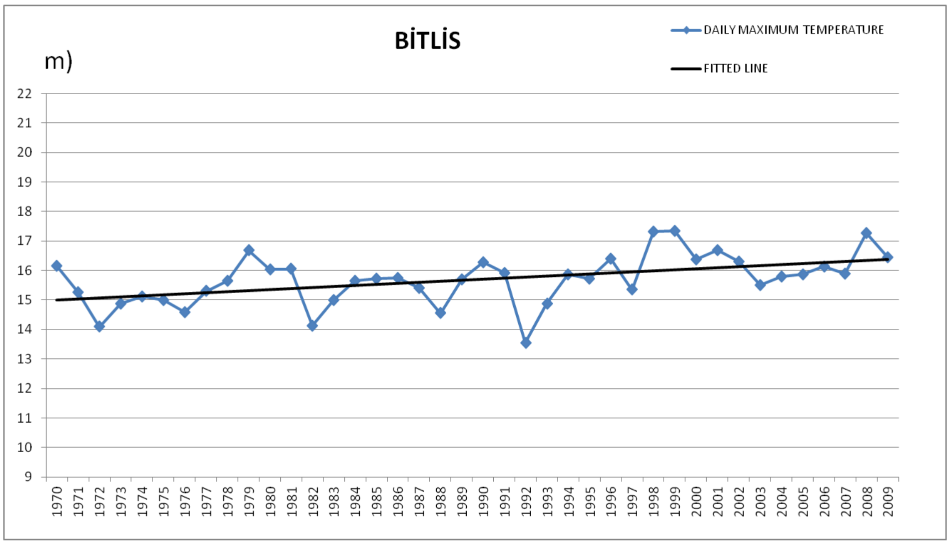


Figure B (continued)





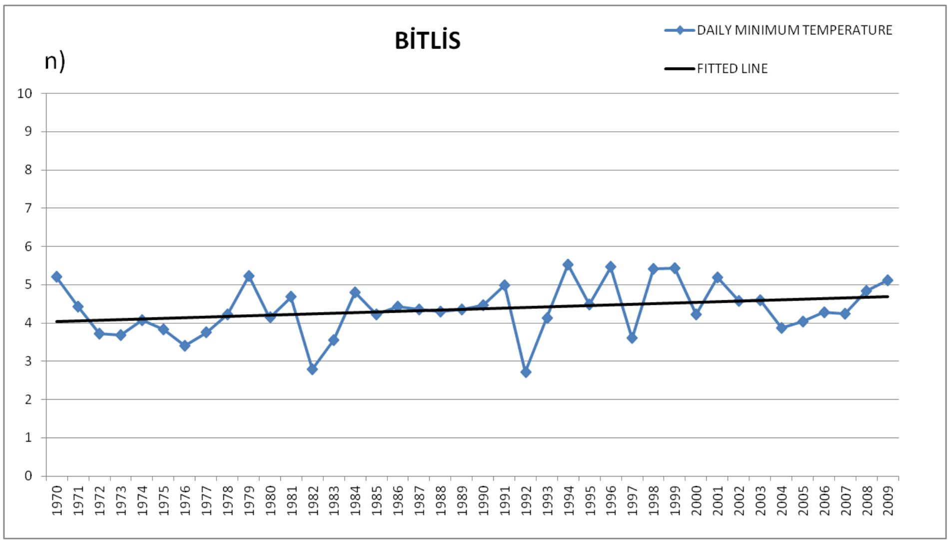
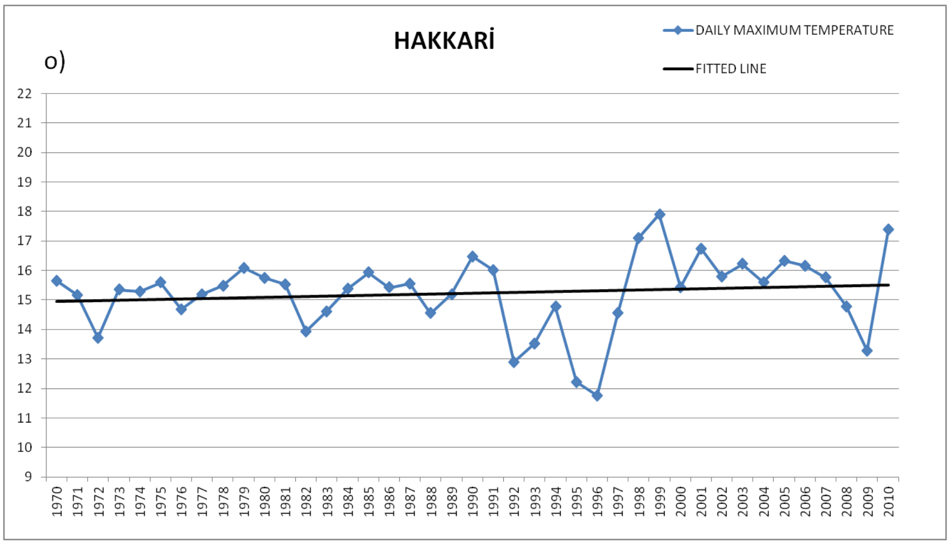
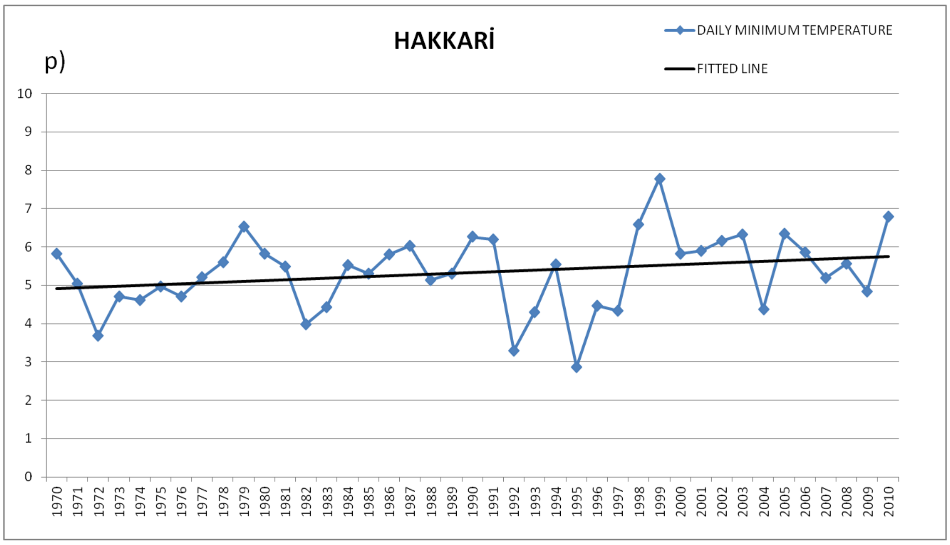


Figure B (continued)





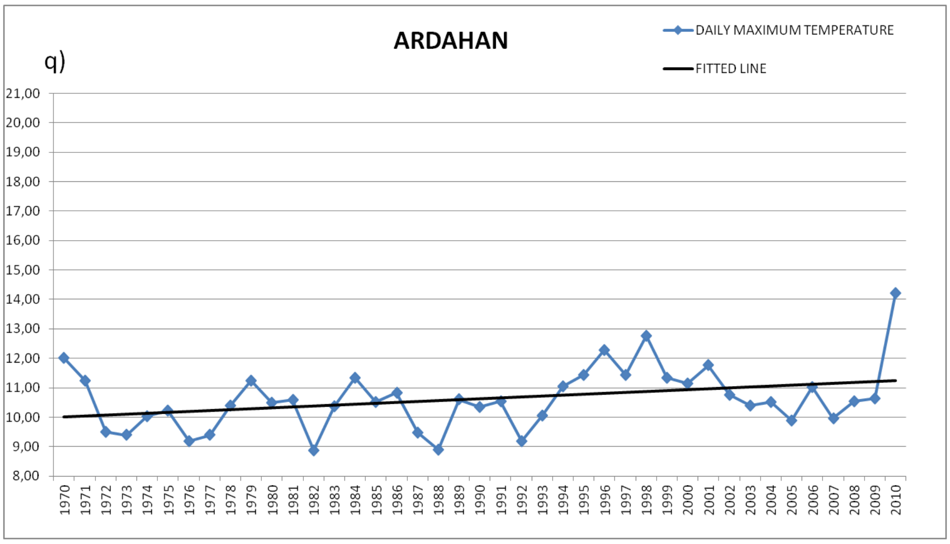
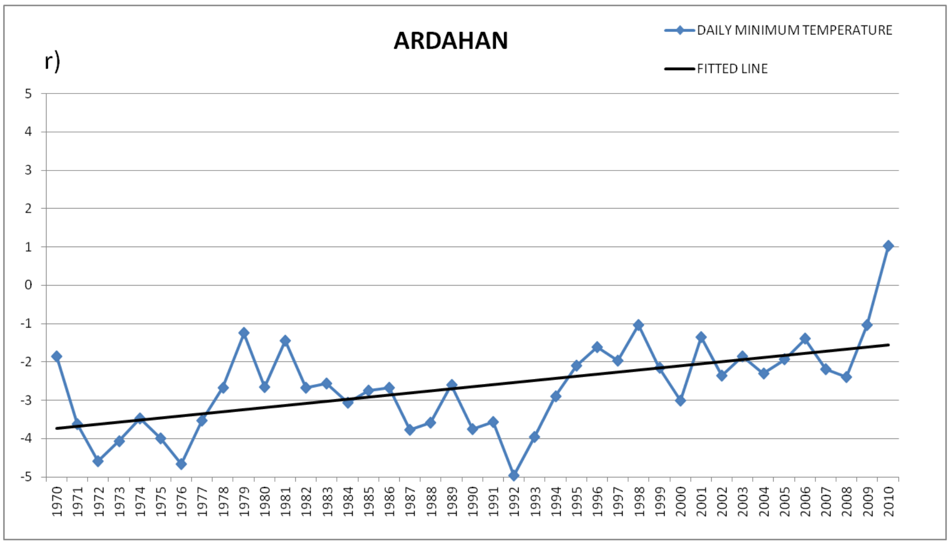
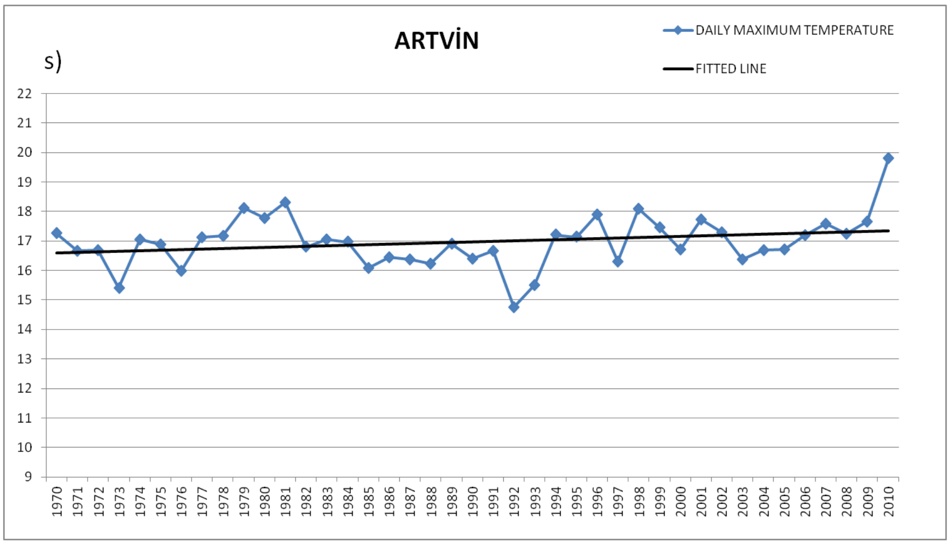


Figure B (continued)





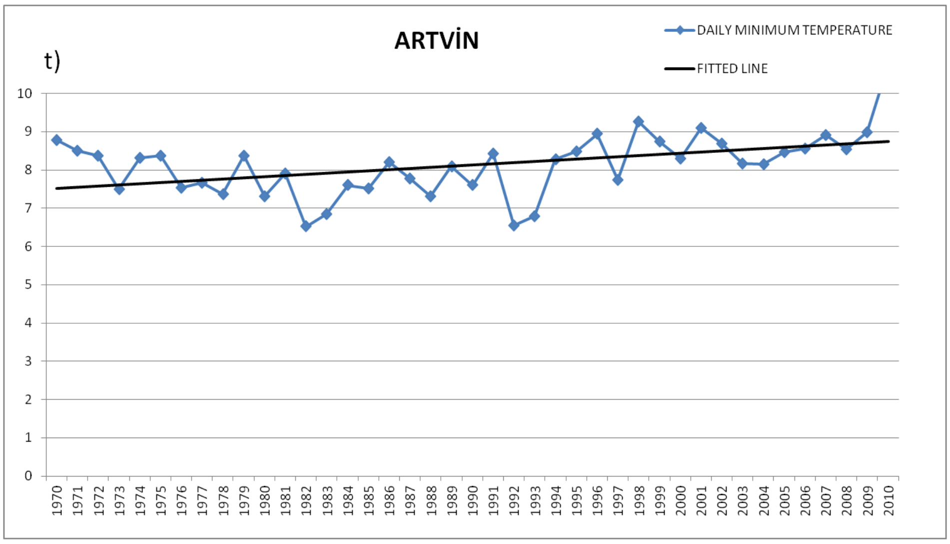
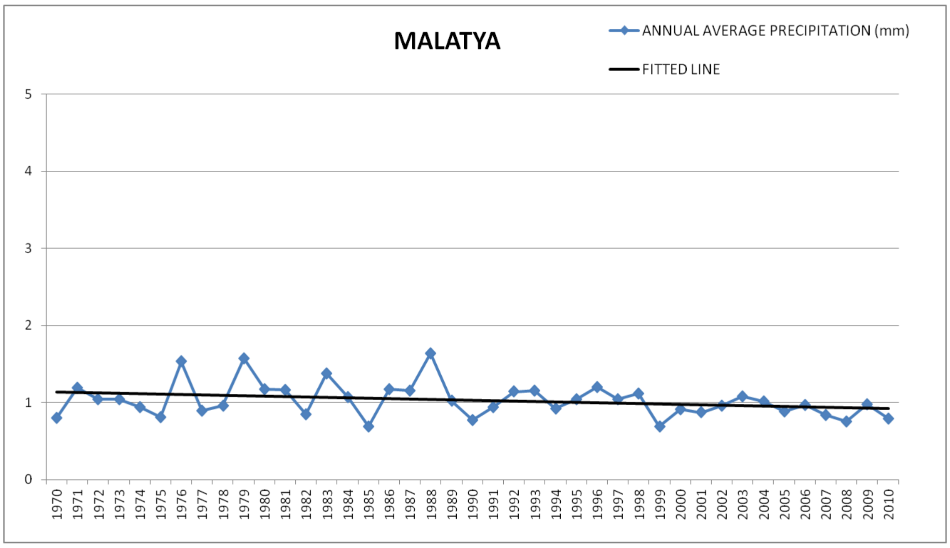


Figure B (continued)

APPENDIX C

FIGURES OF ANNUAL AVERAGE PRECIPITATIONS OF METEOROLOGICAL STATIONS



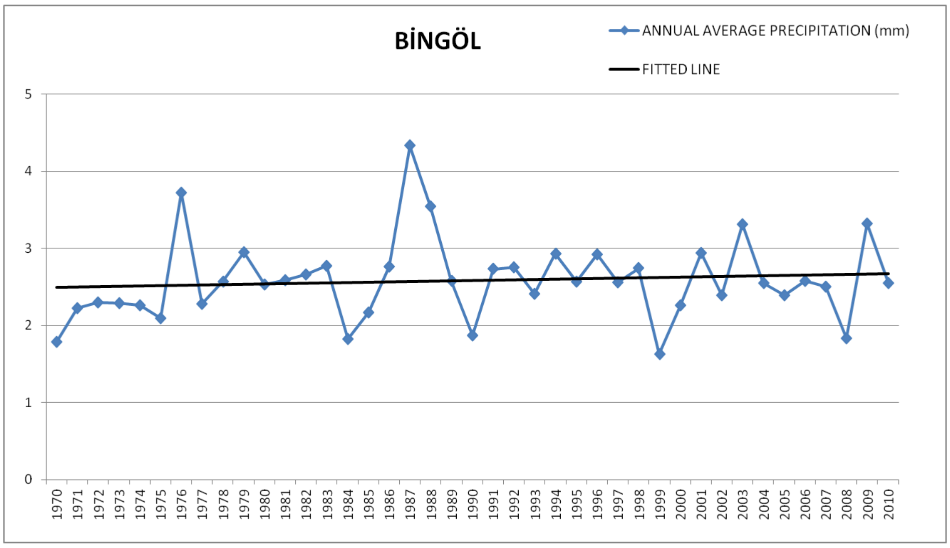
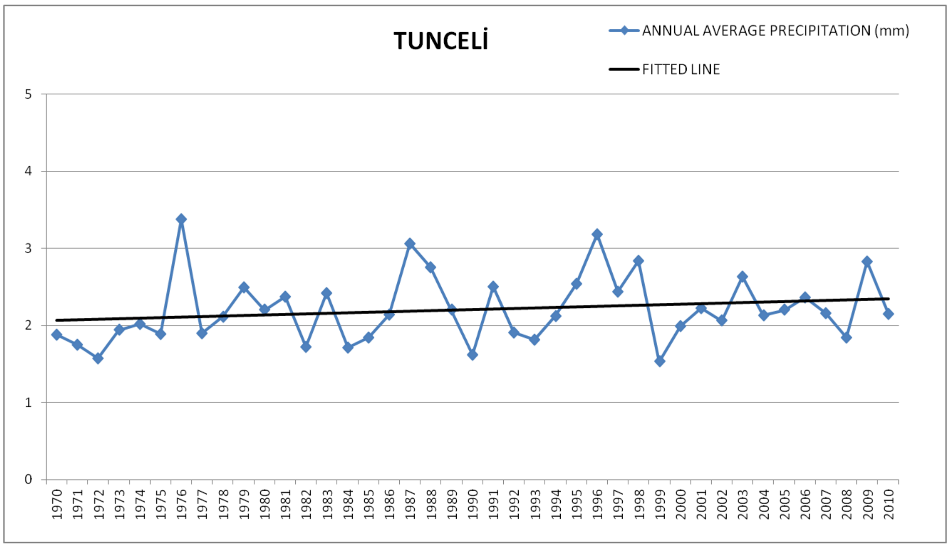
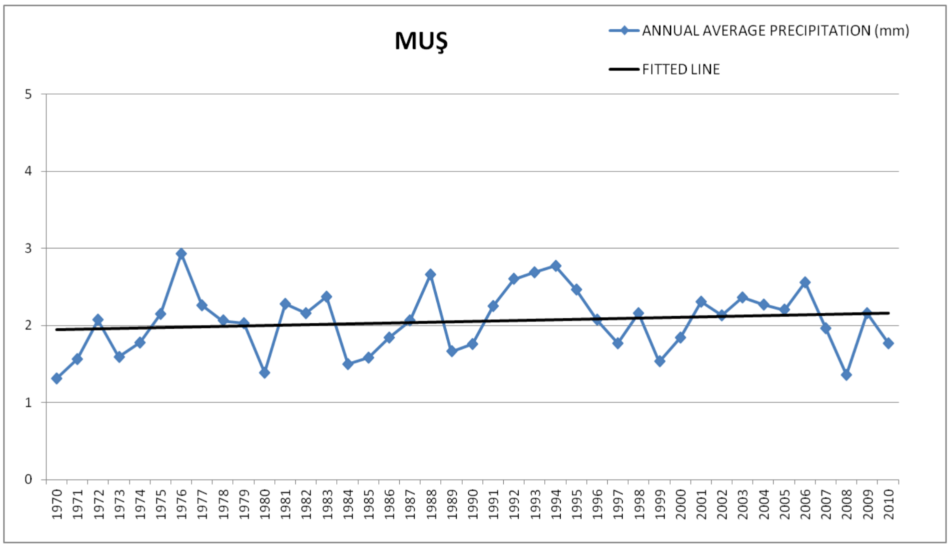


Figure C. Annual average precipitations of meteorological stations





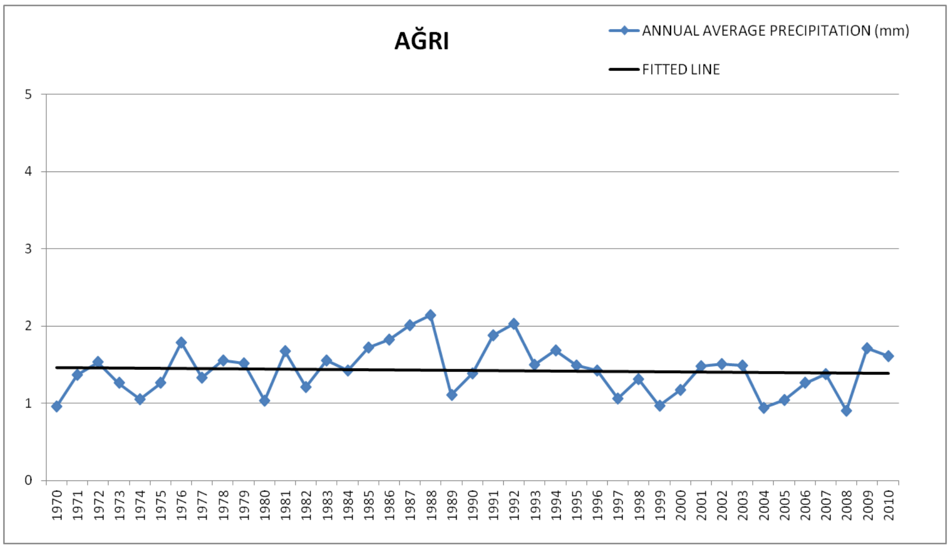
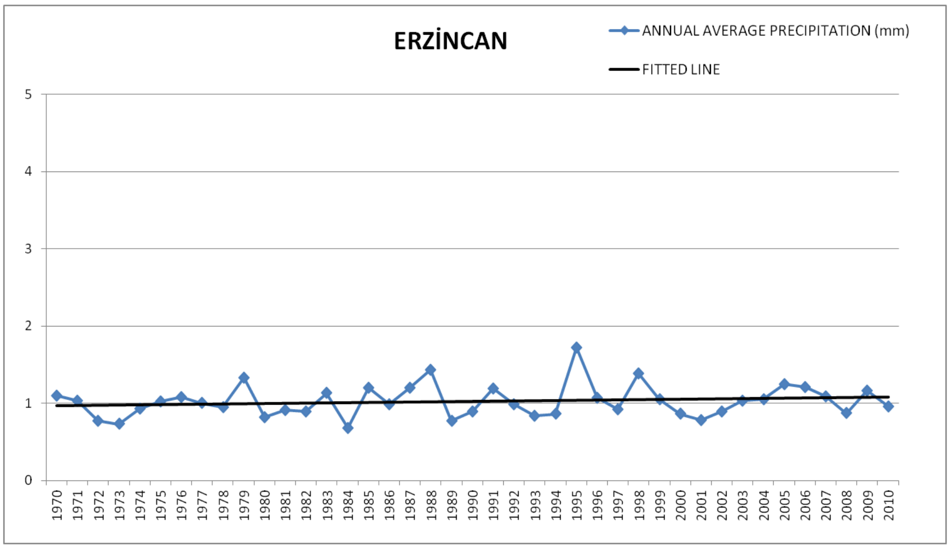
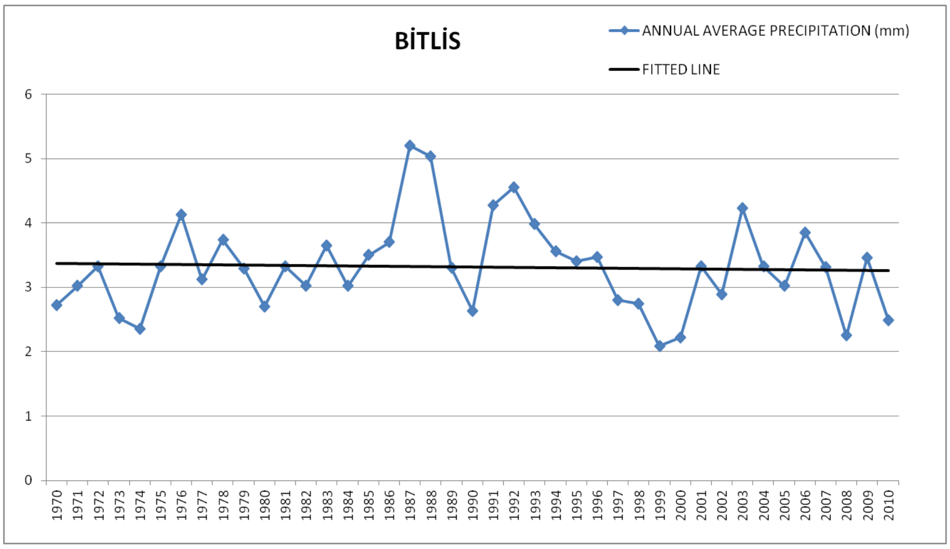


Figure C (continued)





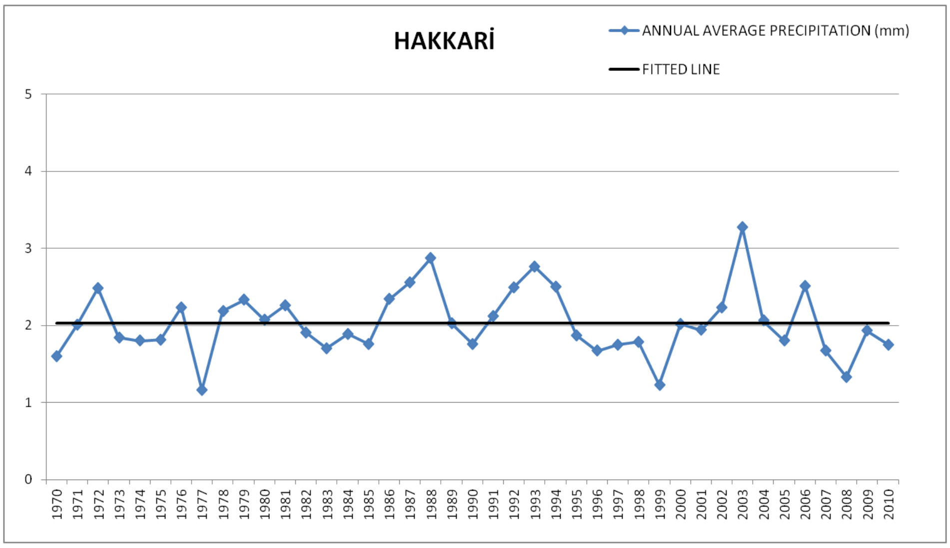
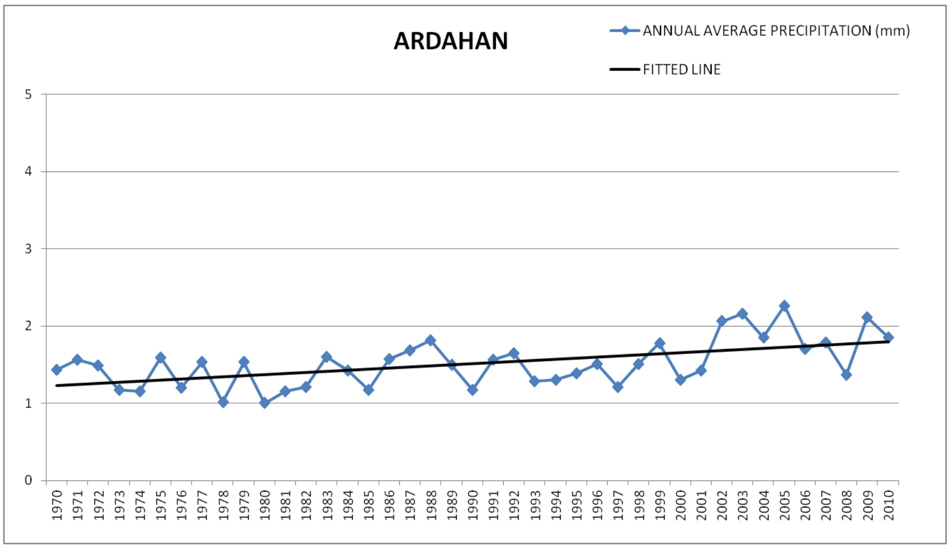


Figure C (continued)



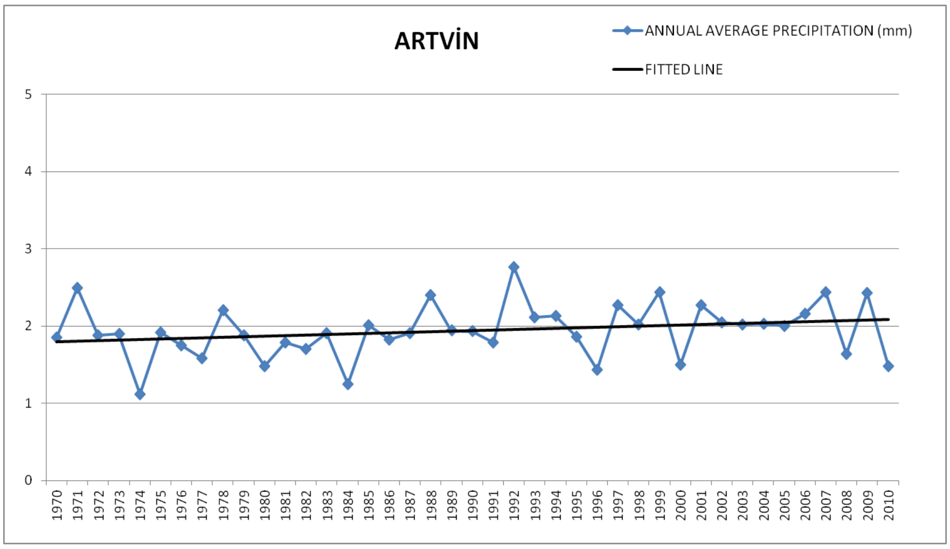
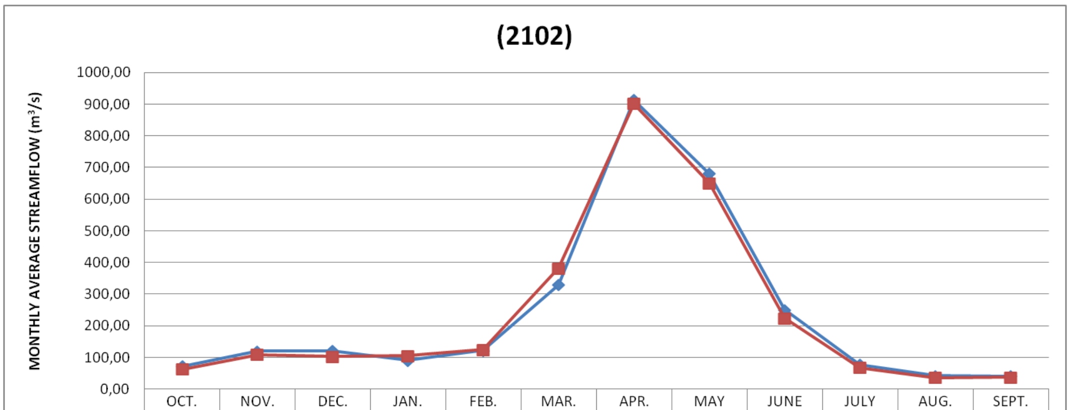


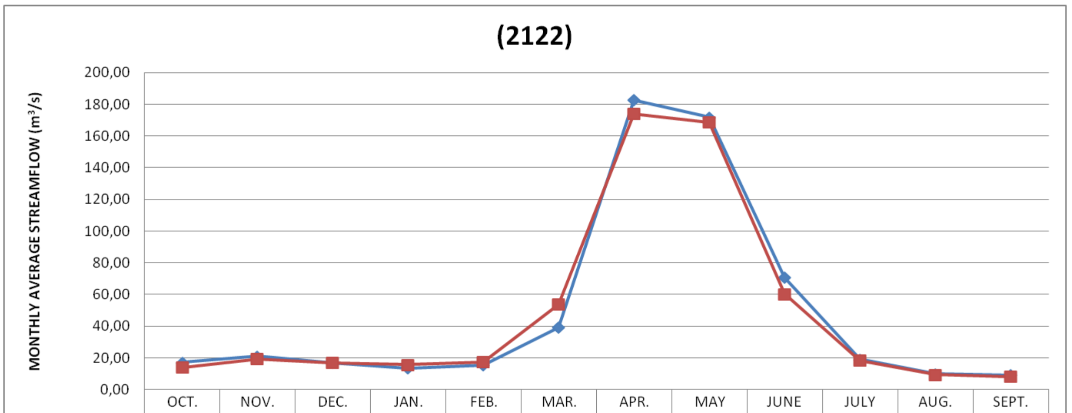
Figure C (continued)

APPENDIX D

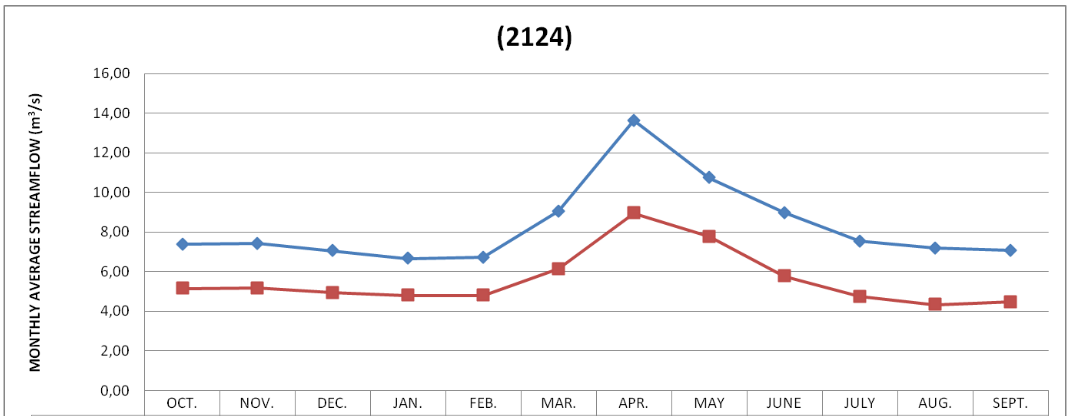
FIGURES OF MONTHLY AVERAGE STREAMFLOWS FOR THE PERIODS 1970-1990 AND 1991-2010



	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	72,95	119,82	121,10	90,64	121,65	329,48	913,76	680,86	250,78	76,63	42,09	40,86
1991-2010	62,92	108,07	102,99	104,92	124,66	381,45	901,50	651,05	223,62	67,98	36,67	36,87



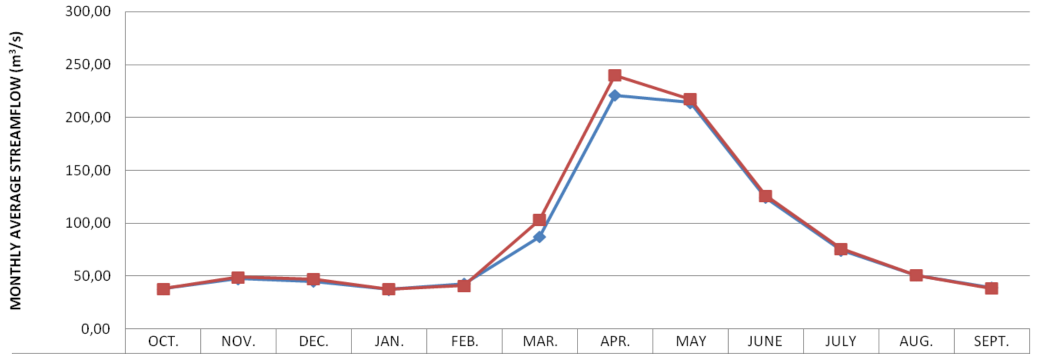
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	17,18	20,95	16,96	13,62	15,34	39,12	182,75	171,91	70,71	19,12	9,83	9,17
1991-2010	14,03	19,21	16,84	15,75	17,44	53,70	174,15	168,75	60,38	18,25	9,40	8,15



	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	7,38	7,43	7,05	6,66	6,73	9,05	13,63	10,73	8,97	7,55	7,18	7,07
1991-2010	5,15	5,16	4,94	4,80	4,80	6,14	8,95	7,76	5,77	4,75	4,33	4,47

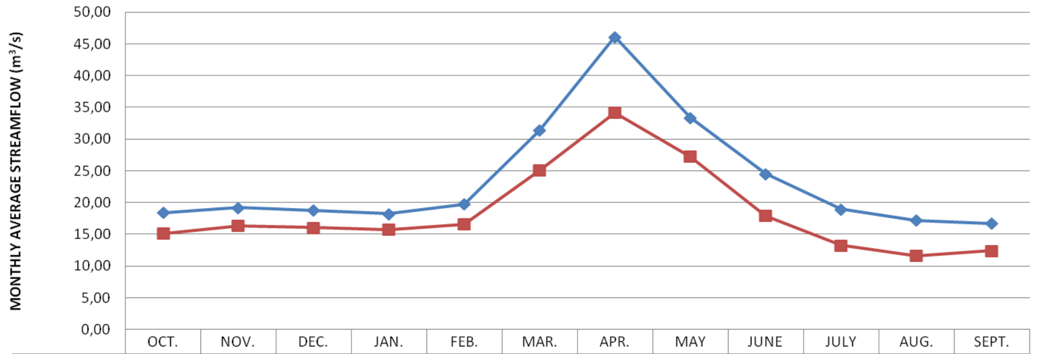
Figure D. Monthly average streamflows for the periods 1970-1990 and 1991-2010

(2133)



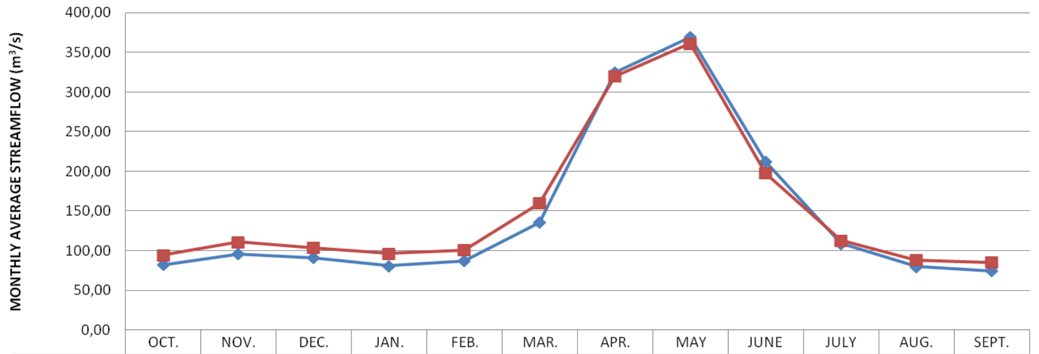
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	38,14	47,51	44,86	37,45	42,85	87,35	221,25	214,05	124,07	74,49	50,75	39,34
1991-2010	38,11	49,09	47,22	37,71	41,06	103,15	240,00	217,40	126,04	75,90	50,62	38,46

(2145)



	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	18,45	19,19	18,77	18,25	19,76	31,37	46,12	33,37	24,55	18,96	17,16	16,69
1991-2010	15,12	16,34	16,07	15,75	16,63	25,06	34,16	27,27	17,89	13,27	11,61	12,40

(2156)



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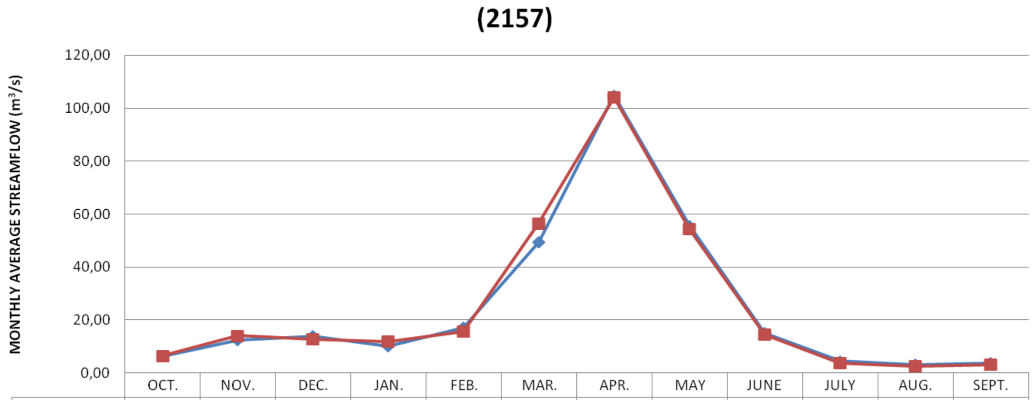
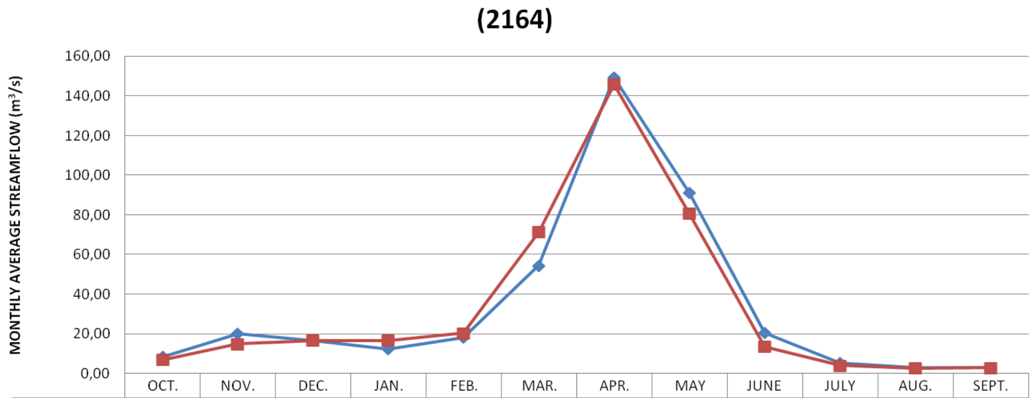
1970-1990	82,39	95,84	91,03	80,94	87,02	135,74	325,05	369,70	212,00	108,77	79,98	74,45
1991-2010	94,40	110,86	103,85	96,31	100,49	159,72	320,10	361,00	197,60	113,00	88,33	85,28

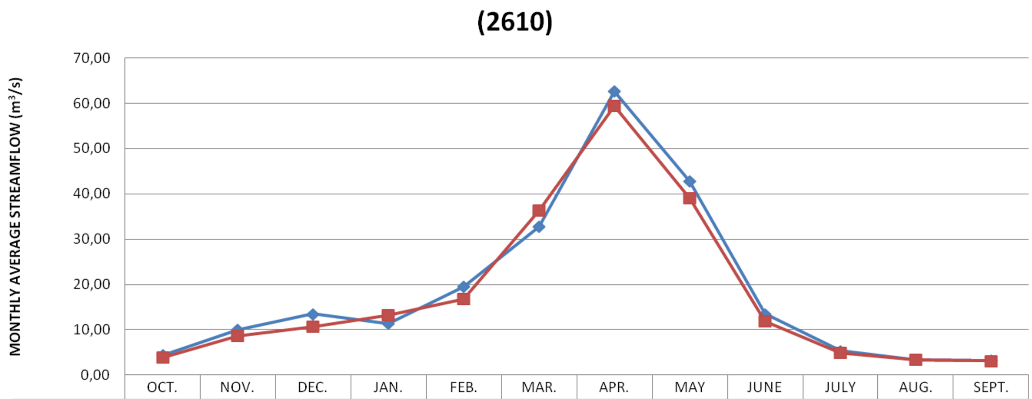
Figure D (continued)



	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	6,34	12,37	13,83	10,10	17,07	49,41	104,85	55,64	15,08	4,47	3,08	3,74
1991-2010	6,48	14,02	12,71	11,82	15,74	56,58	104,11	54,44	14,57	3,80	2,49	3,19

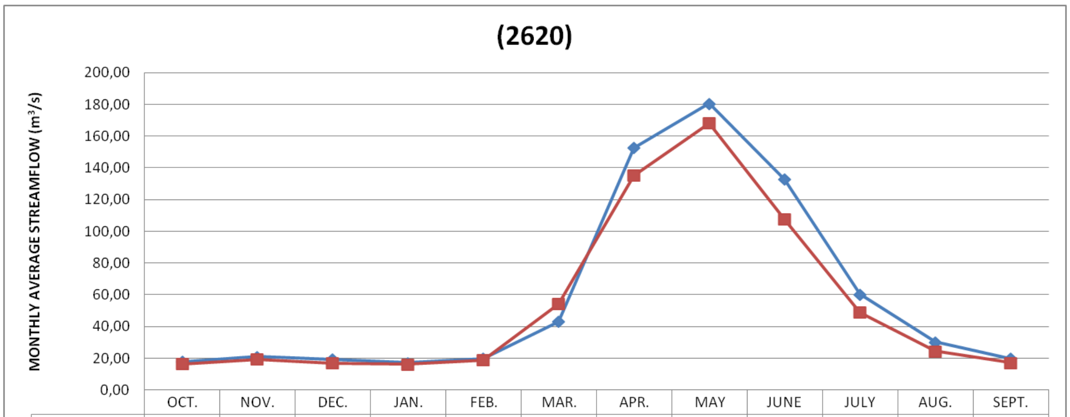


	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	8,35	20,02	16,57	12,39	18,27	54,46	149,30	91,13	20,40	5,29	2,83	2,84
1991-2010	7,01	14,85	16,73	16,65	20,25	71,44	145,71	80,54	13,39	4,04	2,63	2,89

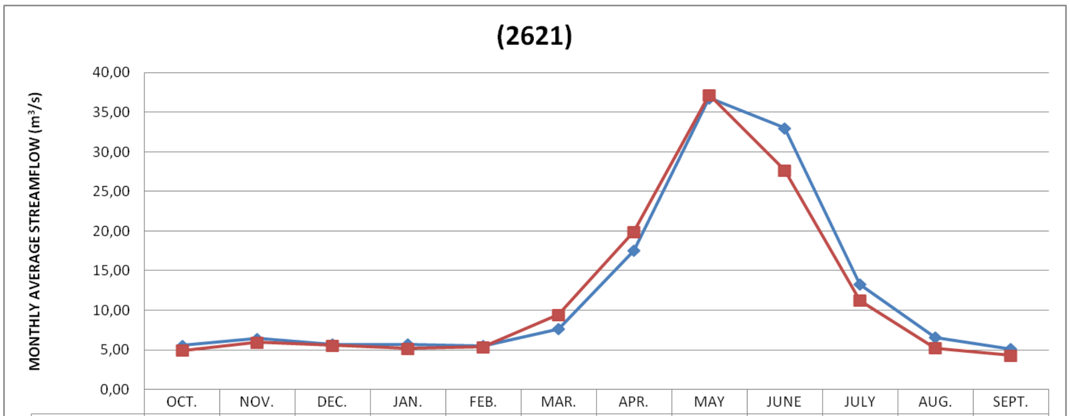


	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	4,39	10,05	13,49	11,34	19,52	32,77	62,58	42,81	13,49	5,33	3,44	3,14
1991-2010	3,88	8,62	10,66	13,23	16,81	36,34	59,44	39,01	11,93	4,93	3,37	3,13

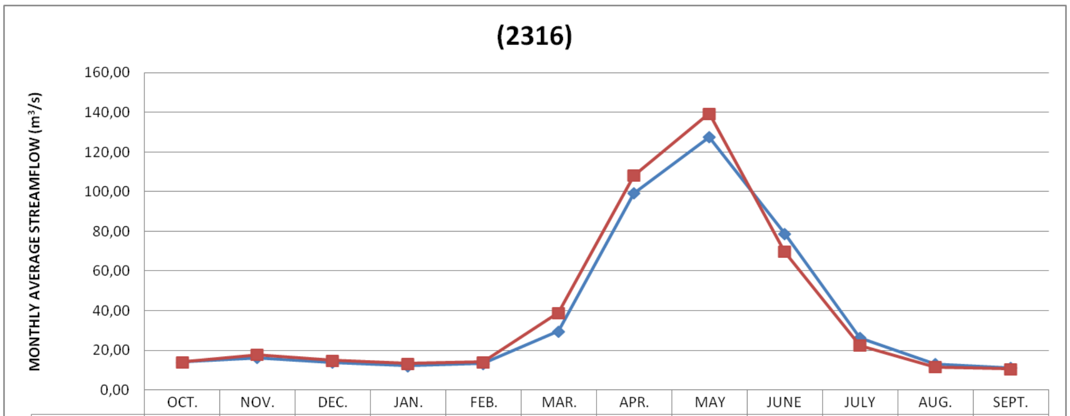
Figure D (continued)



	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	17,88	21,03	19,17	17,22	19,89	42,99	152,63	180,59	132,90	60,33	30,14	19,65
1991-2010	16,41	19,39	16,82	16,20	18,75	54,19	135,22	168,31	107,49	48,96	24,33	17,16

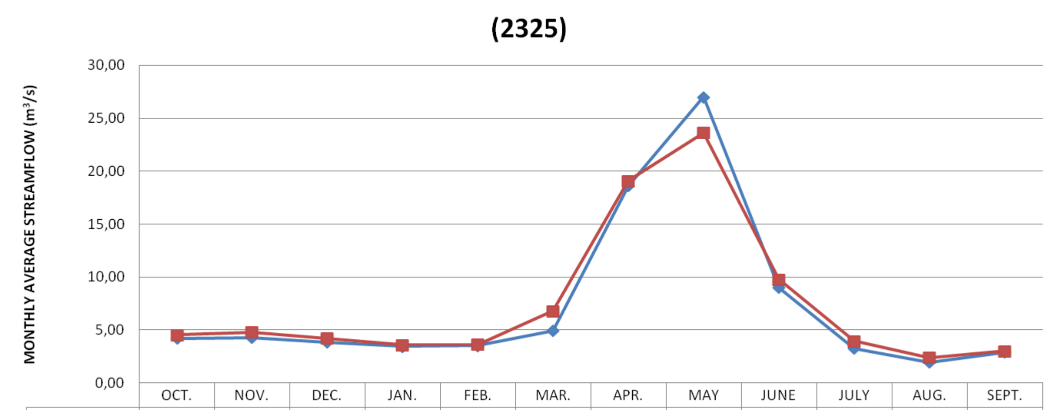


	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	5,57	6,45	5,70	5,68	5,54	7,67	17,52	36,79	33,01	13,24	6,58	5,10
1991-2010	4,90	5,94	5,56	5,19	5,38	9,45	19,91	37,17	27,67	11,22	5,21	4,30

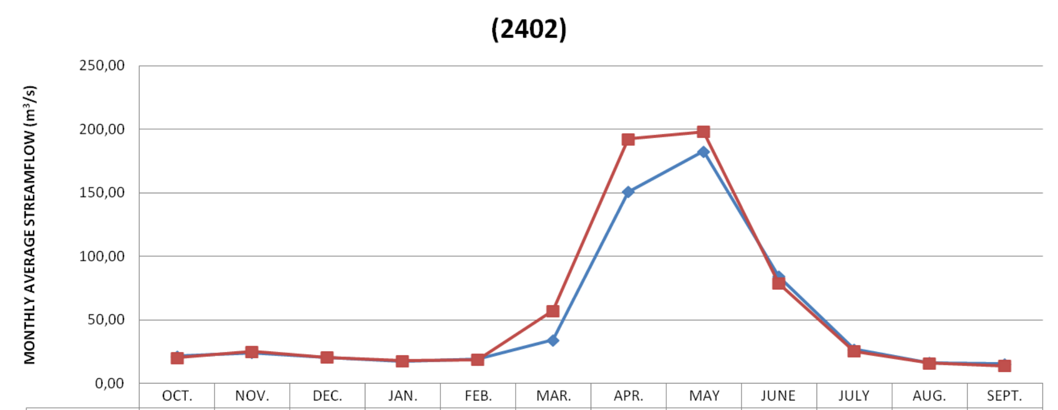


	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	14,11	16,28	13,96	12,14	13,37	29,57	99,35	127,69	78,96	26,25	13,00	11,20
1991-2010	14,14	17,88	14,84	13,27	14,12	38,87	108,23	139,41	69,82	22,51	11,56	10,52

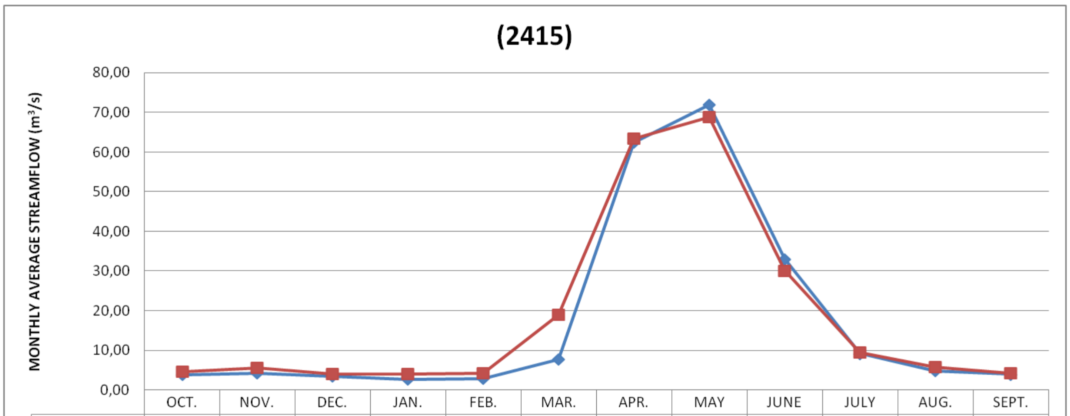
Figure D (continued)



	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	4,19	4,29	3,84	3,44	3,51	4,95	18,61	27,01	9,01	3,26	1,95	2,89
1991-2010	4,53	4,80	4,20	3,57	3,63	6,80	19,08	23,64	9,77	3,95	2,39	3,02



	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	21,47	24,11	20,33	17,65	19,09	34,22	150,81	182,61	84,24	26,87	16,11	15,29
1991-2010	20,18	25,02	20,41	17,74	18,75	57,21	192,36	198,13	78,88	25,16	16,05	13,94

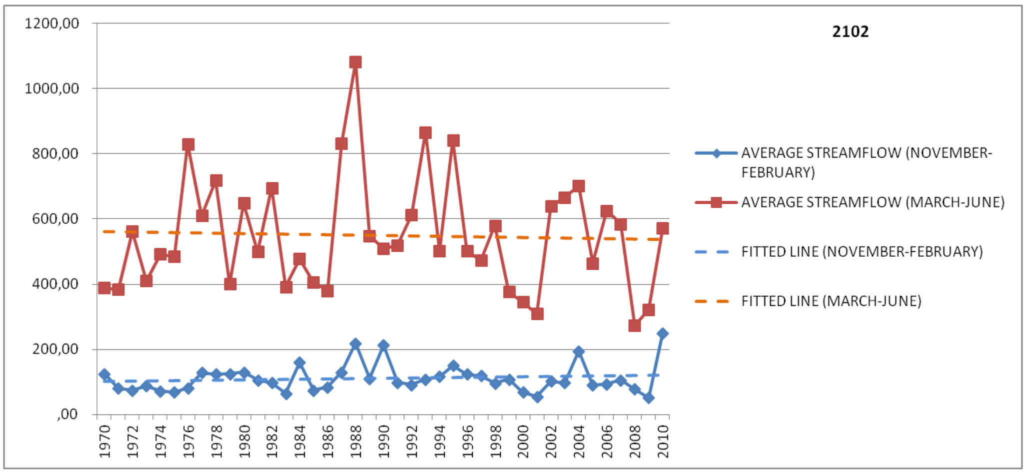


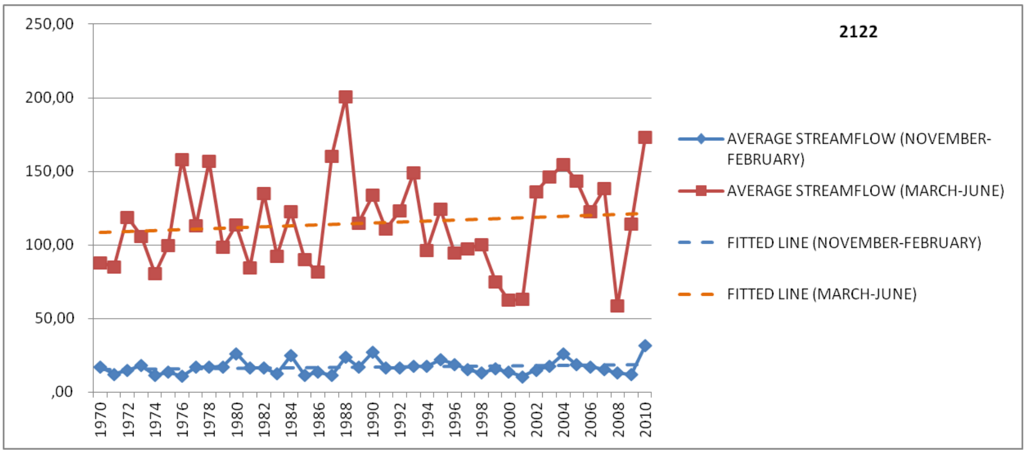
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1970-1990	3,87	4,24	3,47	2,72	2,89	7,73	62,43	71,97	33,04	9,20	4,80	3,94
1991-2010	4,63	5,64	4,09	3,98	4,27	18,93	63,43	68,87	30,16	9,48	5,74	4,26

Figure D (continued)

APPENDIX E

FIGURES OF AVERAGE STREAMFLOW FOR SNOW ACCUMULATION PERIOD AND MELTING PERIOD BETWEEN THE YEARS 1970-2010





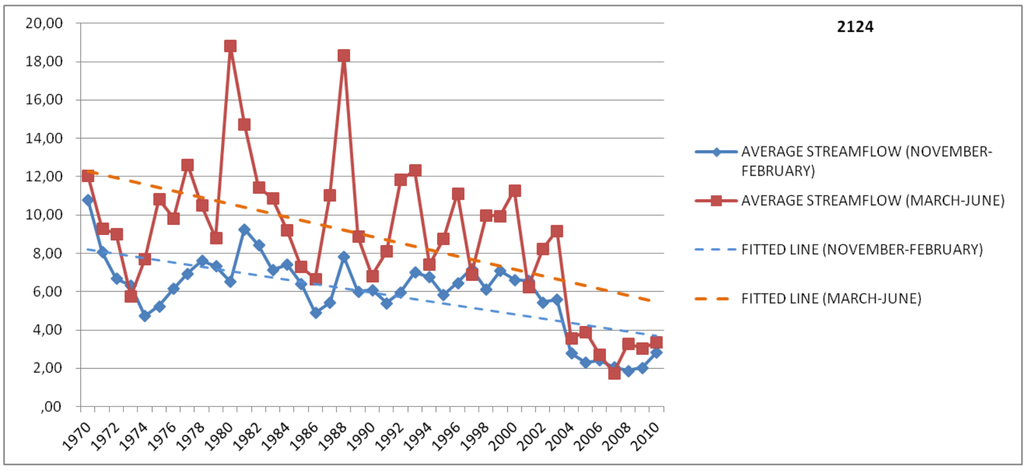
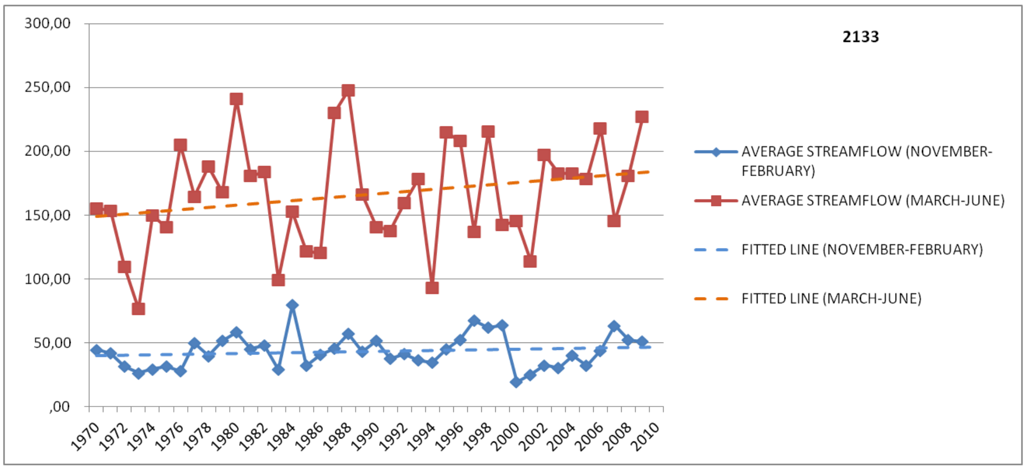
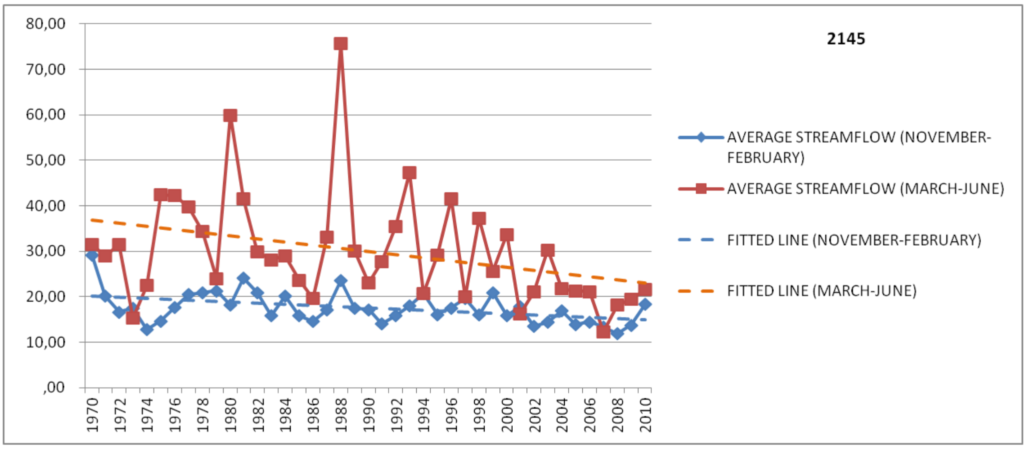


Figure E. average streamflow for snow accumulation period and melting period between the years 1970-2010





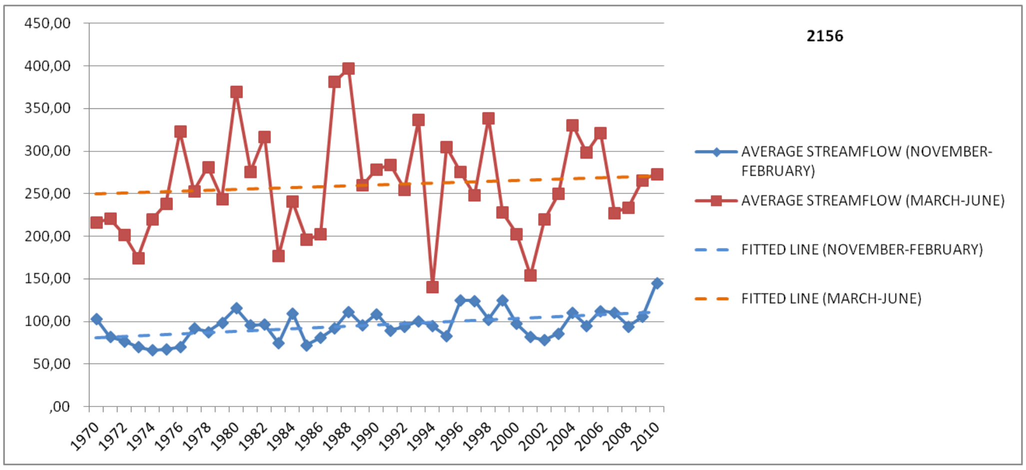
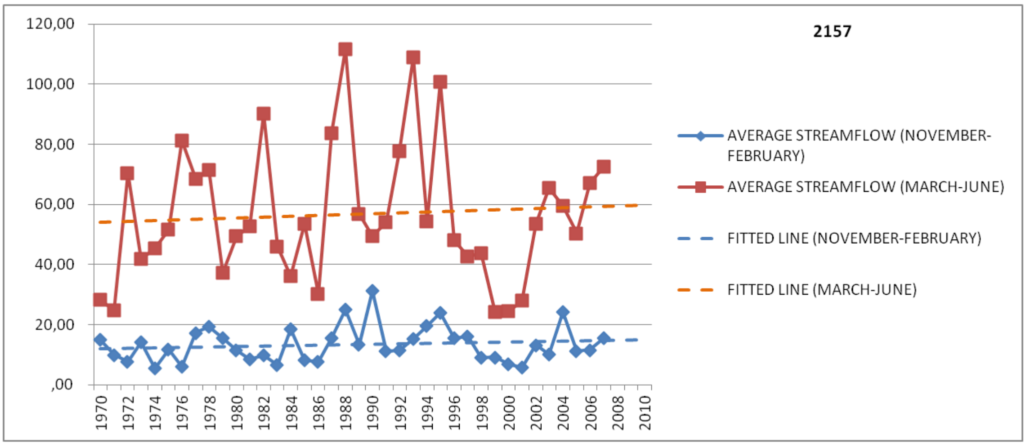
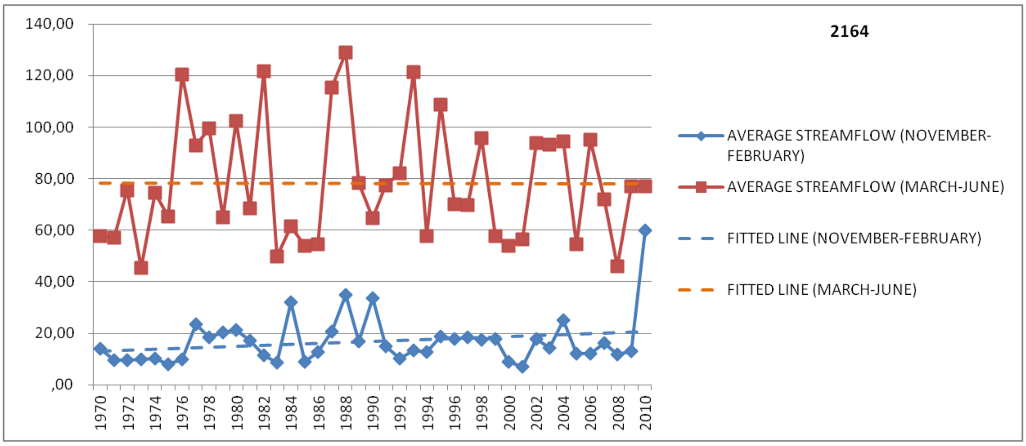


Figure E (continued)





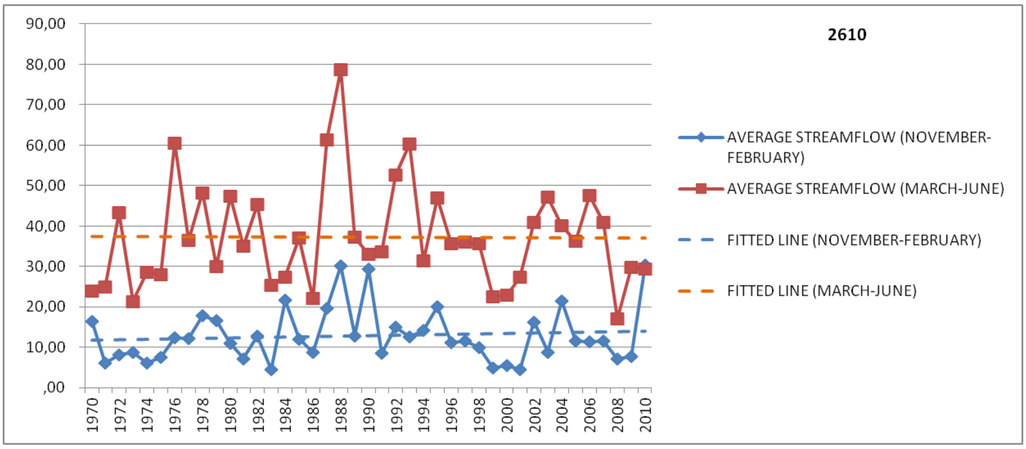
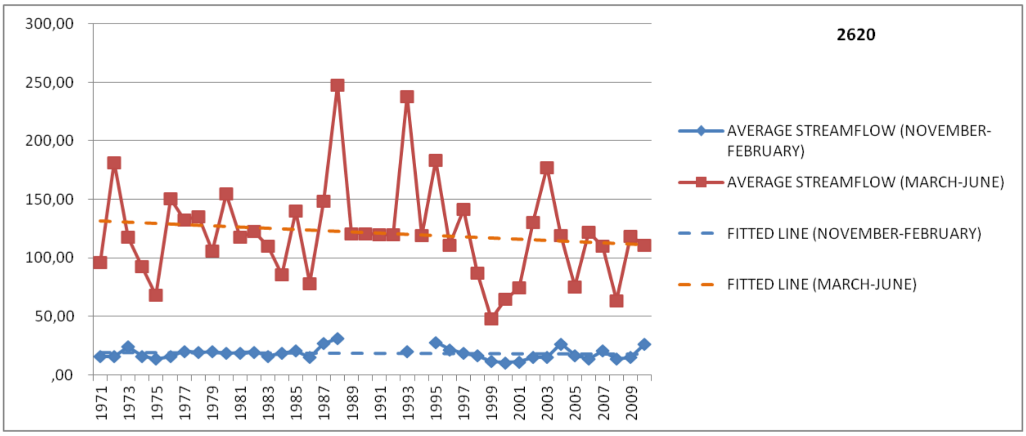
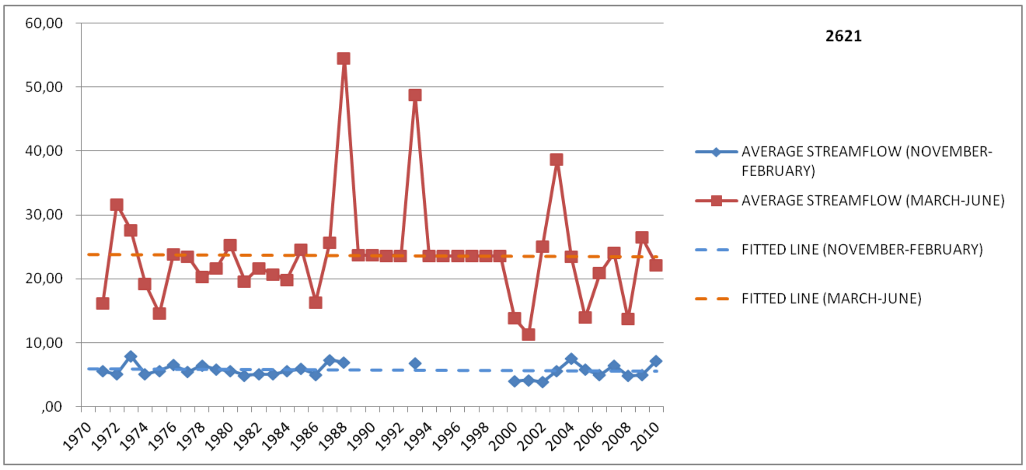


Figure E (continued)





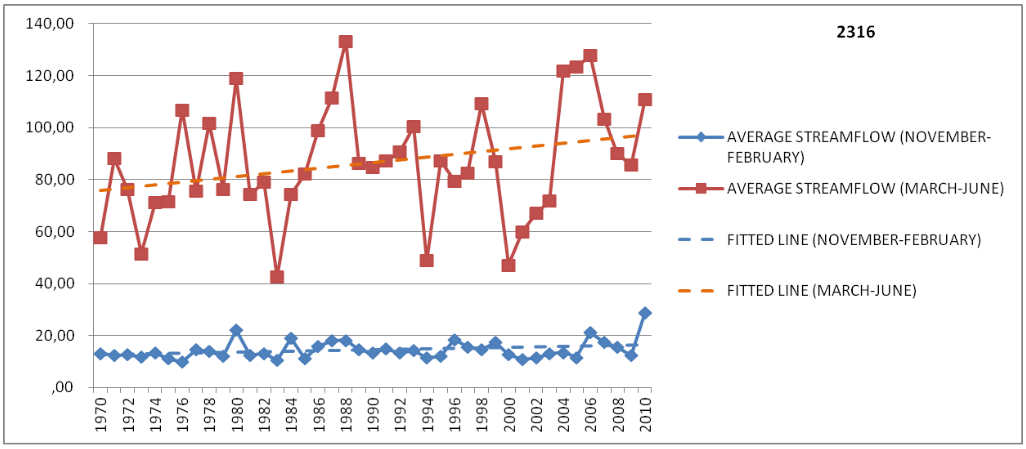
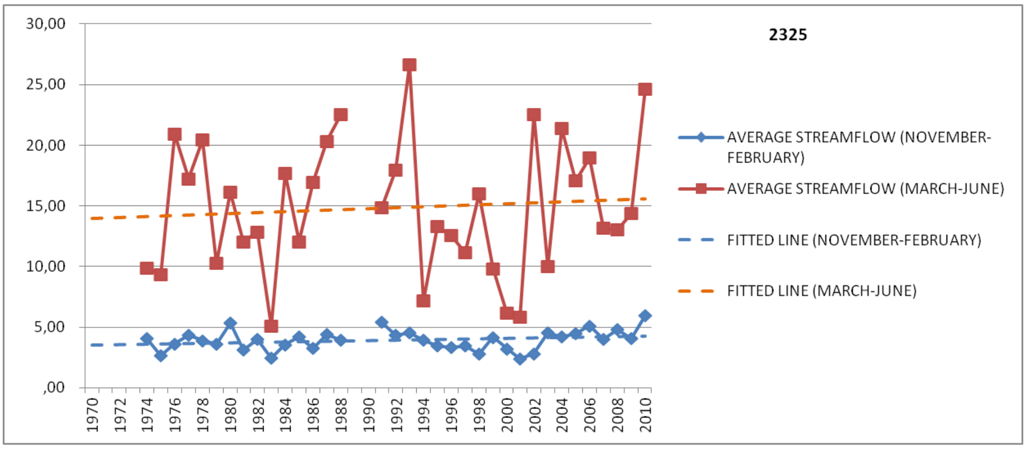
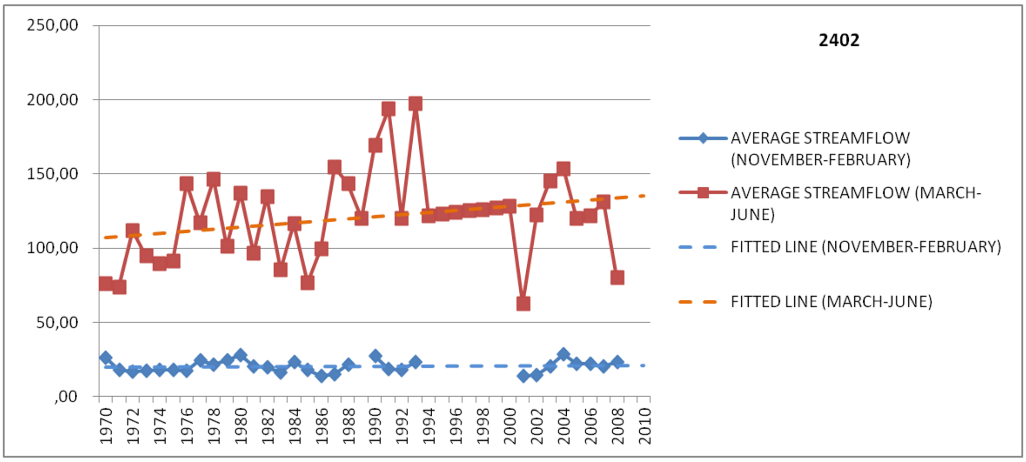


Figure E (continued)





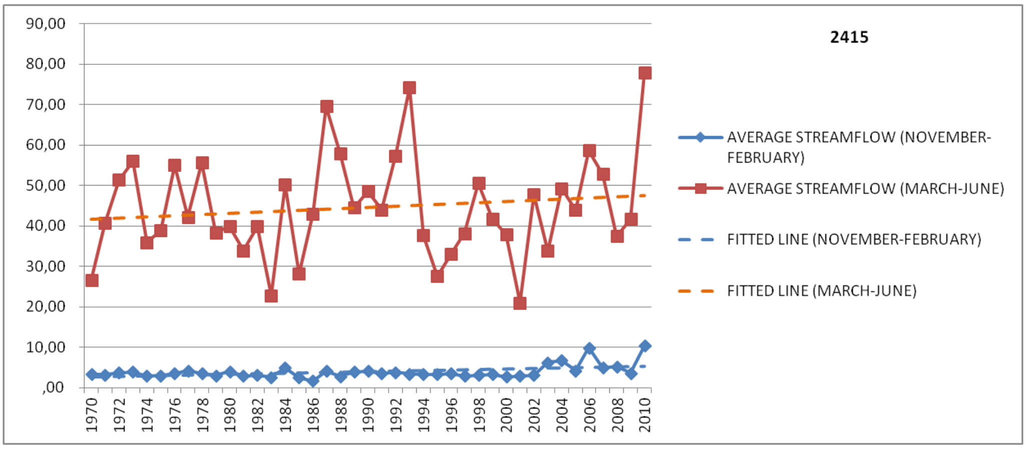


Figure E (continued)