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Time-series Analysis of Long-term Variations in Stream-flow Data of Some Stream-flow Stations over the Gediz Basin and in Precipitation of the Akhisar Station

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Abstract: Analyses of time series were carried out for stream-flow-precipitation relationship by using flow measurements in the 4 observation stations in Gediz watershed and precipitation measurements in Akhisar meteorological station. Analyses of seasonal stream-flow and precipitation anomaly series showed that flow and precipitation series were mainly homogenous. Additionally, the value of experimental sampling value u(r) estimated by serial correlation coefficient of Wald-Wolfowitz was positive and significant at the p = 0,05 level of significance. These suggested a serial correlation among observation series for 36 years (1964-1999). Mann-Kendall and EKKDR tests for 36 years revealed that there was a decreasing trend or at least beginning of this trend in most of the flow series excluding Akhisar precipitation series. This trend was especially pronounced in the summer season when the man uses of water were significantly high. On the other hand, there was no significant trend for the precipitation of Akhisar in all seasons but winter. A statistically significant and positive linear relationship was also found between variations of precipitation of Akhisar and variations flows of four stations in winter and spring. Unfortunately, there were no statistically significant relationships between flow and precipitation in summer and fall because of excessive man uses of water in the seasons with the exception of Deliniş and Selendi creeks.

Key words: The Gediz Basin, precipitation, stream-flow, time-series analysis, stream flow-precipitation relationship

INTRODUCTION

The globe is continuously warming up and climatical models show signs of important climate changes for the current century which we are right at the beginning. These changes will give raise to negative results and will constitute big difficulties in front of the development (Turkes, 2001a-c).

Within the third annual evaluation report (TAR) of Intergovernmental Panel on Climate Change (IPCC) envisage increases in all release scenarios and projections, atmospheric carbon dioxide accumulations, surface temperatures and see level during the 21st century and also envisage a decrease in terrestrial and sea glaciers and the areas and volumes of glaciers (IPCC, 2000; IPCC, 2001).

In general, based on global model assimilation and several scenarios, average global water vapor accumulation and the amount of precipitation will increase during the 21st century. Until the second half of the 21st century, precipitation will increase in middle and high latitudes and Antarctica during the winter. On the other hand, both regional increase and decreases in precipitation will be expected in terrestrial areas of low latitudes. In many areas where increases are expected in average precipitation, annual changes in precipitation will be higher.

Model calculations revealed that as the global warming increases evaporation will increase and an increase also will occur in the amount of average global precipitation and in the frequency of severe precipitation events. It was also envisaged that some regions will have increases and some will have decreases in precipitation. Moreover, flows and soil moisture may decrease because of the increased evaporation in the areas with increased precipitation.

It was projected that seasonal shifts in precipitation may occur. Generally, precipitation in high latitudes will increase both in summer and winter. It was also projected that precipitation will increase in middle latitudes, tropical Africa and Antarctica during winter; and in south and east Asia during summer. A continuous decrease is expected for winter precipitation in Australia, Central America and South Africa. Although it was not mentioned about an important change in precipitation for Mediterranean climate, based on Hadley Centre climate models (UKMO. and DETR., 1999) and the results of the other models important decreases in precipitation, water resources and flows for the 21st century are expected for especially East Mediterranean and Middle East Climate. On the other hand, model reliabilities for precipitation projections is relatively weak for many regions of the world.

A long time is needed to minimize the changes in climate system and projected antropogenous climate changes. That is why, concerning to projected climate change models expected scenarios in every region has to be determined in great detail and necessary protective measures suitable to these scenarios has to be taken.

In this study, time series analysis of the flow values of four stations (numbered as 509, 510, 514 and 515) operated by EIEI in Gediz watershed and precipitation values of Akhisar meteorological station were carried out and stream flow-precipitation relations were determined (Fig. 1 and Table 1). Gediz watershed is located in Mediterranean precipitation regime region dominated by humid and semi-humid subtropical climatical conditions and characterized with warm and highly precipitated winters and hot and dry summers (Turkes, 1996, 1998).

Results of the performed analysis were interpreted and presented in a Table. Statistical analysis results can provide a scientific contribution to take the long term changes in flow and precipitation series into consideration in water resources planning works to be carried out in this region.

MATERIALS AND METHODS

Gediz river, originated from southeast of Gediz Town in Central Anatolian Part of Aegean Region, is fed by several side branches and pour into Gulf of Izmir. Since 1962, the smallest discharge recorded in Manisa Observation Station located in upstream side of Gediz and operated by General Directorate of State Hydraulic Works (DSI) is 3.8 m^3 s^{-1}, average discharge is 60.48 m^3 s^{-1}, maximum discharge is 812 m^3 s^{-1}. Arable land area of watershed is 2.82 million hectares.

In this study, stream flow values were taken from EIEI and precipitation values taken as monthly from the General Directorate of State Meteorological Works (DMI). Stream flows were rearranged as average stream flow (m^3 s^{-1}) and precipitation values were rearranged as seasonal total precipitation (mm).

It is desired that observation duration of flow stations the data of which to be used in time series analysis should be equal or as close to each other as possible (Turkes, 2002). Since the starting date of observations of the stations are different from each other, the year 1964 was selected as the common start date and precipitation observation values of Akhisar station were taken with this dated taken as basis.

In this study, statistical time series methods theory of which is located in details in Sneyers (1990) and Turkes (2002) and most of which are non parametrical and applied by Turkes *et al.* (2002a, b) in their very new study were taken as basis. Following statistical methods were used in time series analysis of 36 years (1964-1999) of flow and precipitation data.

Kruskall-Wallis (K-W) homogeneity test was applied to determine the homogeneity of means and variances. This method is an effective homogeneity test without a universal value.

Runs test was applied to determine whether the observations randomized or not. Each of consecutive observation groups running above and below the median value determined for observation series was taken as a run and the numbers of runs were determined just by adding them together.

A parametric correlation test, Wald-Wolfowitz (W-W) serial relationship test, was used to evaluate if there is a relationship between the subsequent observations of observation series or there is a serial dependence. This test generally depends on the assumptions that being nonrandomized in observation series could be defined or explained changes with low frequencies (long term fluctuations) (Turkes, 2002).

Mann-Kendal (M-K) serial relationship coefficient was applied to determine significant humid and dry periods and to determine non-linear long term tendencies and change points in flow and precipitation series. With

Table 1: EIE Stream Flow Stations and DMI Meteorology Station

Stations	Place	Altitude (m)	Coordinate	Precipitation Area (km^2)	Observation start date	Measure of level
Medar Çayı- Kayalıoğlu (509)	Akhisar-Manisa highway 7th km	77	27 46' 07"D 38 53' 26" K	901,6	10.11.1951	Scale Lymnigraph
Kumçay- Killik (510)	Akhisar-Manisa highway 30th km	55	27 40' 58" D 38 47' 36" K	3184,8	11.05.1951	Scale
Selendi Çayı- Dereköy (514)	Selendi-Manisa highway 15th km	345	28 42' 01" D 38 41' 57" K	689,6	12.04.1960	Scale
Deliniş Deresi- Topuzdamları (515)	Selendi-Manisa highway 20th km	375	25 33' 15" D 38 43' 27" K	739,6	14.04.1960	Scale
Akhisar Meteorological Station	Akhisar Centre	93	28 85' 05" D 38 92' 15" K	Large Climatical Station		

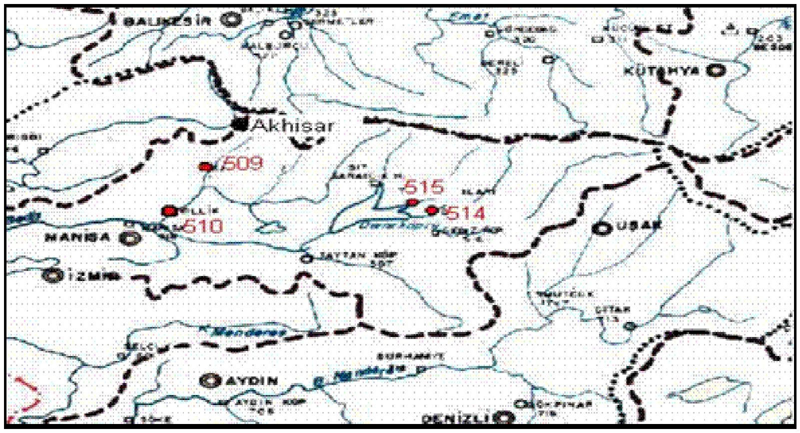

Fig. 1: Position of stream flow and precipitation stations (EIE, 1990)

subsequent analysis of this method, linear tendencies were determined graphically. To determine the linear tendencies, Student's-t test for (β) meaningfulness of X coefficient, obtained from least squares linear regression (EKKDR) calculations, was used. Changibility in observation series between years were regulated with a 9 point Gauss filter.

Pearson relationship coefficient r was calculated to determine the possible relations between year to year changes in flow and precipitation series, then the meaningfulness of r was evaluated with Student's-t test.

RESULTS AND DISCUSSION

Results of statistical time series analysis applied on seasonal average flow series of 4 flow stations in Gediz watershed and on seasonal total precipitation series of Akhisar station and significance levels were given in Table 2; and relationship coefficients calculated for possible relationships between seasonal flows and precipitation values of Akhisar station were given in Table 3.

Non homogeneity observed in some flow series was possible caused by decreases started in the middle of 1980s, reached to the smallest value in 1989 and continued in the following years. Excessive water use forced by dry conditions was also effective on this non homogeneity. In fact, an evident decreasing tendency especially with 1970s was identified in annual especially winter precipitation and annual drought index series for this region (Turkes, 1996, 1998, 1999; Erlat, 2002). The year 1989 was among the driest years in long term records.

Based on the runs and Wald-Wolfowitz tests, rejection of null hypothesis reveals that samples are not randomized. The decreasing tendencies in these series and the above mentioned excessive water use can be thought to reduce the number of runs and as a main reason spoiling the randomization. This situation especially observed in Kumçay Station can be interpreted in a way that this station was the most effected one from the excessive water use dry conditions.

Rejection of null hypothesis of Wald-Wolfowitz test states that observations exhibit a serial relationship. Existence of serial relation in observation series at 5% significance level, calculated positive values of u(r) identifies the existence of a significant serial dependence.

u(t) and $u'(t)$ values obtained from subsequent analysis on M-K test assumed to show direction of tendency of u(t) curve as a basic rule in interpretations based on time series drawings; the point at which u(t) and $u'(t)$ curves intersect and separate each other was identified as an significant change point or as a starting point of a significant tendency (Sneyers, 1990; Turkes, 1999; Turkes, 2002; Turkes *et al.*, 2002b). Following such a change point, based on the two tail figure of normal distribution of u(t) curve, the parts left out of 95% confidence interval (here left out of critical value of ±1.96) were identified as significant increase (decrease) periods (Turkes, 1999; Turkes *et al.*, 2002b). For example, when the precipitation series are used in this evaluation, it was defined as a significant precipitated or humid (low precipitation or dry) period.

Seasonal flow and precipitation observation series mostly exhibit a decreasing tendency. Based on Mann-Kendall tendency test results, decreasing tendencies observed in Medar creek summer, Kumçay winter, spring, summer and autumn, Selendi spring, summer and autumn and Deliniş Creek summer and autumn flows are significant at 5% significance level (Table 2). A great consistency exists between the signs (nature or direction of tendency) of the M-K and EKKDR results; similar consistency also exists between magnitudes (significance

Table 2: Results of time series analysis

Station-Season	K-W Xk/χ_{kr}	RUNS z/α_1	W-W U(r)/ α_1	M-K u(t)/ α_1	EKK t/ t_α
Medar Çayı Winter	4,19/7,81 homogeneous	-2,37/0,0089 randomized	1,25/0,1056 serial correlation not exist	-1,88/0,06 a statistically significant tendency not exist	-1,97/|2,032| a statistically significant tendency not exist
Medar Çayı Spring	4,27/7,81 homogeneous	1,01/0,1562 randomized	0,31/0,3783 serial correlation not exist	-1,74/0,08 a statistically significant tendency not exist	-2,41/|2,032| a statistically significant decreasing tendency exists
Medar Çayı Summer	12,59/7,81 nonhomogeneous	-1,352/0,089 randomized	2,43/0,0075 serial correlation exists	-3,24/0,001 a statistically significant decreasing tendency exists	-3,59/|2,032| a statistically significant decreasing tendency exists
Medar Çayı Autumn	3,23/7,81 homogeneous	-1,69/0,0455 nonrandomized	2,03/0,0212 serial correlation exists	-1,09/0,28 a statistically significant tendency not exist	-0,52/|2,032| a statistically significant tendency not exist
Kumçay Winter	8,83/7,81 nonhomogeneous	-0,04/0,0012 nonrandomized	3,01/0,0013 serial correlation exists	-2,72/0,007 a statistically significant decreasing tendency exists	-2,56/|2,032| a statistically significant decreasing tendency exists
Kumçay Spring	11,56/7,81 nonhomogeneous	-2,03/0,0212 nonrandomized	2,52/0,0059 serial correlation exists	-3,11/0,002 a statistically significant decreasing tendency exists	-3,39/|2,032| a statistically significant decreasing tendency exists
Kumçay Summer	21,61/7,81 nonhomogeneous	-3,72/0,0001 nonrandomized	4,35/~ 0,000 serial correlation exists	-4,83/~ 0,00 a statistically significant decreasing tendency exists	-5,85/|2,032| a statistically significant decreasing tendency exists
Kumçay Autumn	18,92/7,81 nonhomogeneous	-4,40/0,0001 nonrandomized	4,70/~ 0,000 serial correlation exists	-4,49/~ 0,00 a statistically significant decreasing tendency exists	-6,21/|2,032| a statistically significant decreasing tendency exists
Selendi Winter	7,19/7,81 homogeneous	-1,69/0,0455 nonrandomized	2,53/0,0057 serial correlation exists	-1,83/0,07 a statistically significant tendency not exist	-1,89/|2,032| a statistically significant tendency not exist
Selendi Spring	6,39/7,81 homogeneous	-1,352/0,089 randomized	1,14/0,1271 serial correlation not exist	-2,19/0,03 a statistically significant decreasing tendency exists	-3,078/|2,032| a statistically significant decreasing tendency exists
Selendi Summer	16,50/7,81 nonhomogeneous	-3,043/0,0012 nonrandomized	4,34/~ 0,000 serial correlation exists	-4,07/~ 0,00 a statistically significant decreasing tendency exists	-4,17/|2,032| a statistically significant decreasing tendency exists
Selendi Autumn	11,86/7,81 nonhomogeneous	-1,352/0,089 randomized	1,35/0,0885 serial correlation not exist	-2,67/0,012 a statistically significant decreasing tendency exists	-2,43/|2,032| a statistically significant decreasing tendency exists
Deliniş Deresi Winter	3,07/7,81 homogeneous	-1,69/0,0455 nonrandomized	1,31/0,0951 serial correlation not exist	-1,12/0,26 a statistically significant tendency not exist	-1,12/|2,032| a statistically significant tendency not exist
Deliniş Deresi Spring	3,80/7,81 homogeneous	-0,338/0,3707 randomized	0,28/0,3897 serial correlation not exist	-1,06/0,29 a statistically significant tendency not exist	-0,81/|2,032| a statistically significant tendency not exist
Deliniş Deresi Summer	8,87/7,81 nonhomogeneous	-1,014/0,1562 randomized	2,24/0,0125 serial correlation exists	-2,62/0,01 a statistically significant decreasing tendency exists	-2,71/|2,032| a statistically significant decreasing tendency exists
Deliniş Deresi Autumn	10,54/7,81 nonhomogeneous	-1,69/0,0455 nonrandomized	1,47/0,0708 serial correlation not exist	-2,67/0,01 a statistically significant decreasing tendency exists	-2,18/|2,032| a statistically significant decreasing tendency exists
Akhisar Winter	3,38/7,81 homogeneous	-1,014/0,1562 randomized	1,179/0,119 serial correlation not exist	-1,72/0,09 a statistically significant tendency not exist	-1,87/|2,032| a statistically significant tendency not exist
Akhisar Spring	2,23/7,81 homogeneous	3,042/0,0012 nonrandomized	-1,67/0,0475 serial correlation exists	0,35/0,73 a statistically significant tendency not exist	-0,60/|2,032| a statistically significant tendency not exist
Akhisar Summer	2,66/7,81 homogeneous	-1,69/0,0455 nonrandomized	0,47/0,3192 serial correlation not exist	-1,23/0,22 a statistically significant tendency not exist	-1,52/|2,032| a statistically significant tendency not exist
Akhisar Autumn	4,43/7,81 homogeneous	0,00/0,500 randomized	1,29/0,0985 serial correlation not exist	1,39/0,17 a statistically significant tendency not exist	1,38/|2,032| a statistically significant tendency not exist

Table 3: Correlation coefficients between flow and precipitation series

r / t ($t_{0,05}$ = 2,032)

Istasyonlar	Winter	Spring	Summer	Autumn
Medar Çayı	0,8558/9,645**	0,6823/5,443**	0,0443/0,259	0,3200/1,969
Kumçay	0,7847/7,381**	0,6117/4,509**	-0,0617/-0,361	0,1996/1,188
Selendi Çayı	0,7219/6,083**	0,5017/3,382**	0,2531/1,525	0,5311/3,655**
Deliniş Deresi	0,7546/6,706**	0,4333/2,803**	0,4764/3,159**	0,3269/2,017

(*) Statistically significant at 5% significance level for two-tail Student's *t* distribution;
(**)Statistically significant at 1% significance level for two-tail Student's *t* distribution

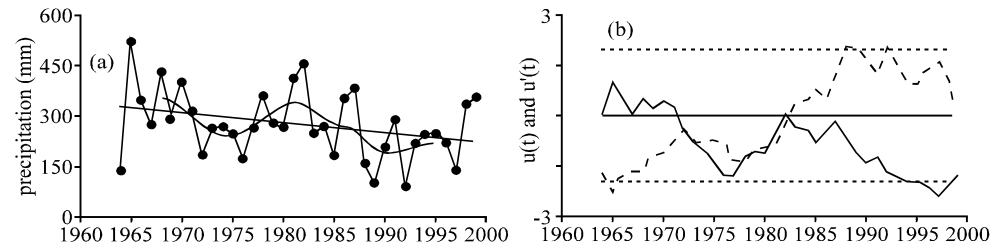

Fig. 2: Change and Tendency of Winter Precipitation for Akhisar Station
(a) (- - -), regression line fitted to winter precipitation of Akhisar precipitation station based on the smallest squares lineer regression equation. (▬), The series was regulated with 9 point Gauss, filter to suppress the fluctuation with less than 10 years in precipitation series.
(b) Tendency in winter series of Akhisar precipitation station shows a critical value of ± 1,96 at 0,05 significance level based on u(t) (—) and u'(t) (----) obtained from Mann-Kendall subsequent analysis

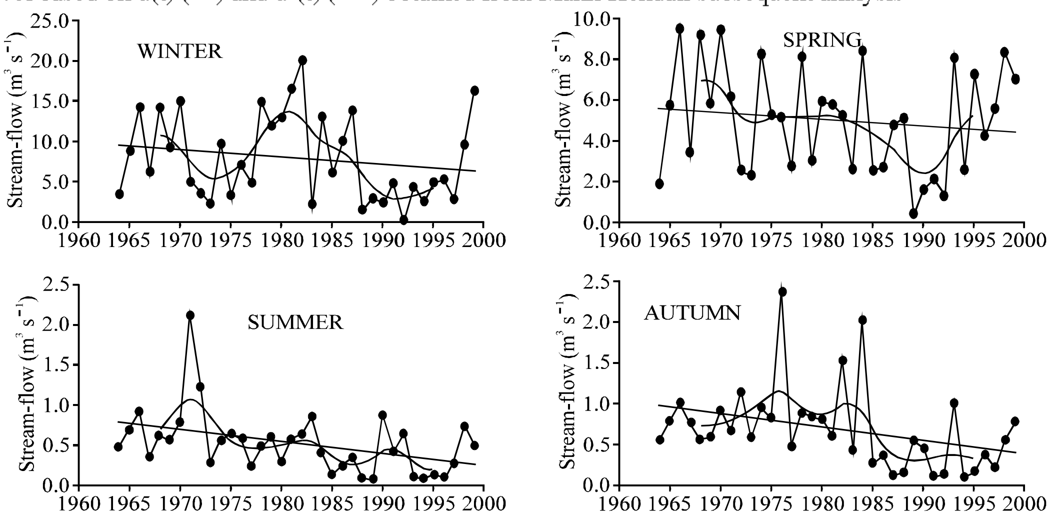

Fig. 3: Change in seasonal series of Deliniş creek flow station. (- - -), regression line fitted to seasonal flows of Deliniş creek flow station based on the least squares linear regression equation. (▬), The series was regulated with 9 point Gauss, filter to suppress the fluctuation with less than 10 years in precipitation series

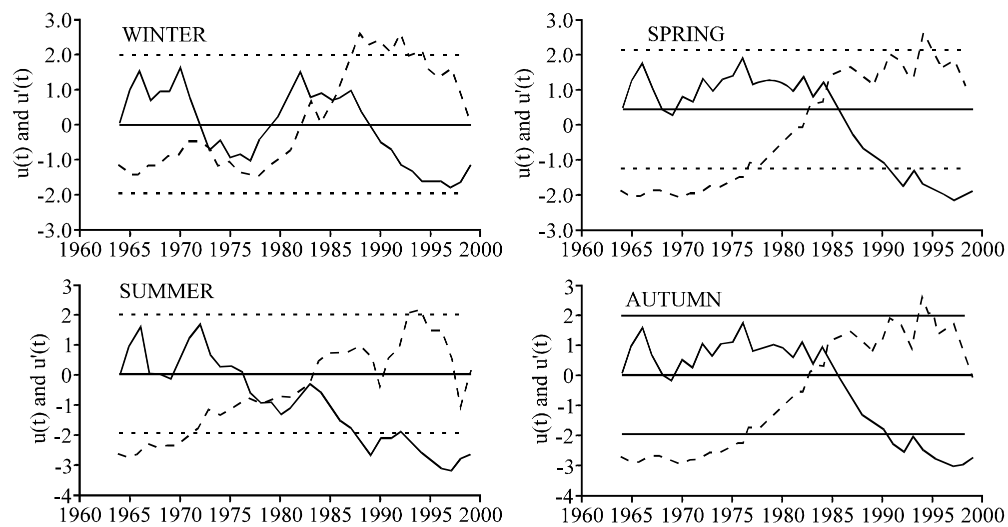

Fig. 4: Tendency in seasonal series of Deliniş creek flow station (----) shows a critical value of ± 1,96 at 0,05 significance level based on u(t) (—) and u'(t) (----) obtained from Mann-Kendall subsequent analysis

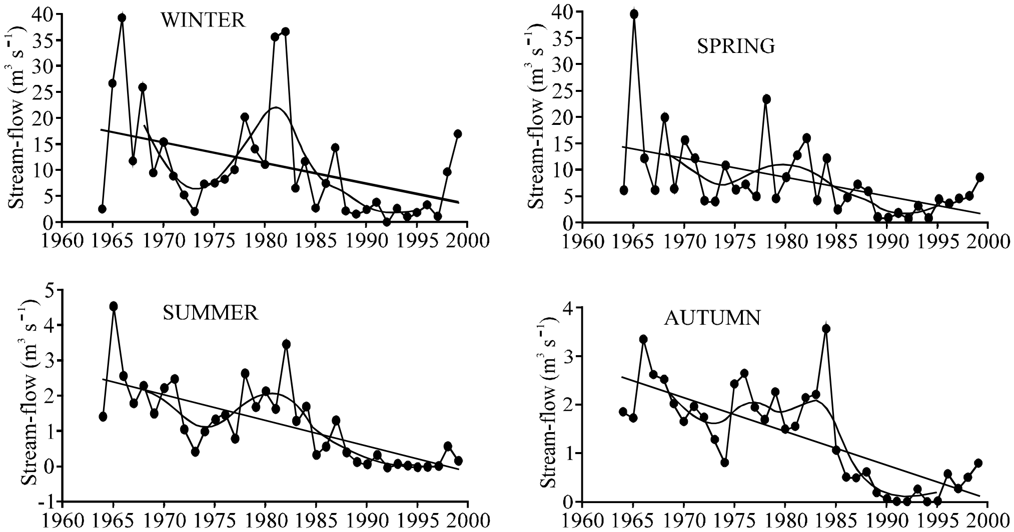

Fig. 5: Change in seasonal series of Kumçay flow station. (- - -), regression line fitted to seasonal flows of Kumçay flow station based on the least squares linear regression equation. (▬), The series was regulated with 9 point Gauss, filter to suppress the fluctuation with less than 10 years in precipitation series

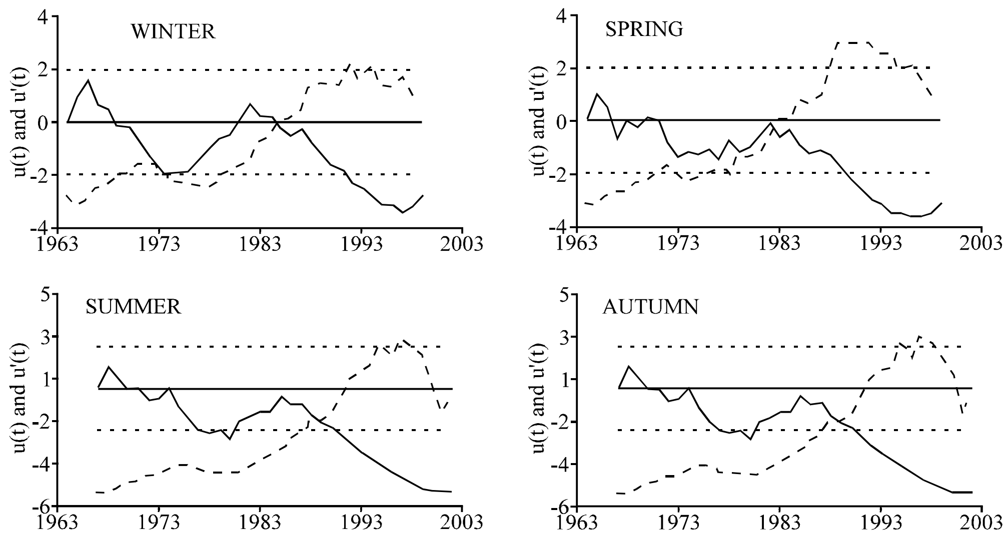

Fig. 6: Tendency in seasonal series of Kumçay flow station (----) shows a critical value of ± 1,96 at 0,05 significance level based on u(t) (—) and u'(t) (----) obtained from Mann-Kendall subsequent analysis

levels), except spring results of Medar Creek. Although it wasn't significant, a clear decreasing tendency (Fig. 2) in winter and a weak decreasing tendency (Table 2) in summer and autumn were identified in Akhisar precipitation series.

When seasonal time series graphics the u(t) and u′(t) values, obtained from subsequent analysis of M-K sequence relation coefficient for seasonal flow values, were evaluated, it was seen that u(t) curves in most of the stations are declining and u(t) and u′(t) are separated from each other after intersection (for example Fig. 3, 4, 5 and 6). These results indicates the existence of a systematic decreasing tendency in flows during the 36 years study period and decreasing tendency is strengthened especially starting from the beginning and middle of 1980s.

A statistically significant positive linear relation exists at 1% significance level between the flow changes of 4 observation station and Akhisar precipitation changes in winter and spring seasons. This identified strong flow-precipitation relation is an expected result for Mediterranean precipitation regime region under natural flow and precipitation conditions.

Except Deliniş summer and Selendi autumn seasons, there isn't any statistically significant relation between flows and precipitation. It was thought that especially in summer's low levels of precipitation in rivers' basins, high levels agricultural irrigation practices and in turn non natural changes in flows of the years have significant effect on this result. On the other hand, even though they were not found to be statistically significant, Medar Creek and Deliniş Creek autumn flow-precipitation relation was found to be close at 5% significance level.

In fact, low-precipitation relations were expected to be high in autumns. However, continuing water demand for irrigation or other purposes under late precipitation conditions (in autumn droughts) in this region may cause more powerful relations not to occur. A significant positive relation between flow values of Deliniş Creek observation station and changes in precipitation can be explained by low levels of human practices around Deliniş Creek flow station and by different regional conditions of this station from the other stations for the precipitation formation.

Based on the time series analysis of 36 years (1964-1999) flow and precipitation data, it was determined that most of the series are homogeneous. It was found that randomization in flow series are spoiled due to decrease in the number of runs as a natural result of strong decreasing tendencies observed in series. Existence of statistically significant positive serial relation coefficients (u(r)) reveals the existence of a serial dependence or insistence in these series. Tendency test results showed that most of the seasonal flow series has a decreasing tangency and the dry seasons strengthened from the beginning and middle of 1980s. Most of the decreasing tendencies in seasonal flows are statistically significant. Except the clear but statistically not significant decrease in winter, any clear and statistically significant tendency in Akhisar precipitation were not found.

A statistically significant positive linear relation at mostly 1% significant level were found between flow changes and precipitation changes of winter and autumn seasons. A strong flow-precipitation relation is an expected result for Mediterranean precipitation regime region under natural flow and precipitation conditions. There isn't any statistically significant relation between flows and precipitation except in autumn seasons of Selendi and in summer seasons of Deliniş. It was thought that especially in summer's low levels of precipitation in rivers' basins, high levels agricultural irrigation practices and in turn non natural changes in flows of the years have significant effects on this result.

REFERENCES

Erlat, E., 2002. Turkiye'de yagis anomalileri ve Kuzey Atlantik Salinimi ile iliskisi. Prof. Dr. Sirri Erinc Anisina Klimatoloji Calistayi 2002, Bildiriler Kitabi. Ege Universitesi Cografya Bolumu, 11-13 Nisan 2002, I zmir, (Baskida).

IPCC., 2000. Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK., ISBN-13: 9780521804936, Pages: 599.

IPCC., 2001. Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK., ISBN-13: 978-0521014953, Pages: 881.

Sneyers, R., 1990. On the Statistical Analysis of Series of Observations. World Meteorological Organization, Geneva, Switzerland, ISBN-13: 9789263104151, Pages: 192.

Turkes, M., 1996. Spatial and temporal analysis of annual rainfall variations in Turkey. Int. J. Climatol., 16: 1057-1076.

Turkes, M., 1998. Influence of geopotential heights, cyclone frequency and southern oscillation on rainfall variations in Turkey. Int. J. Climatol., 18: 649-680.

Turkes, M., 1999. Vulnerability of Turkey to desertification with respect to precipitation and aridity conditions. Turk. J. Eng. Environ. Sci., 23: 363-380.

Turkes, M., 2001a. Kuresel iklim degisikligi: Tarim ve su kaynaklari uzerindeki olasi etkiler. Iklim Degisikliklerinin Tarim Uzerine Etkileri Paneli, Bildiriler Kitabi, 91-128, Tarim ve Koy Isleri Bakanligi, KKGM, Ankara.

Turkes, M., 2001b. Kuresel iklimin korunmasi, iklim degisikligi cerceve sozlesmesi ve turkiye. Tesisat Muhendisligi TMMOB Makina Muhendisleri Odasi Sureli Teknik Yayin Organi Istanbul, 61: 14-29.

Turkes M., 2001c. Bonn anlasmasi ve kuresel isinmaninonlenmesindeki rolu. TMMOB Turkiye III. Enerji Sempozyumu: Kuresellesmenin Enerji Sektorunde Yapisal Degisim Programive Ulusal Enerji Politikalari, 5-7 Aralik 2001, Bildiriler Kitabi, pp: 339-353.

Turkes, M., 2002. Iklimsel ve atmosferik verilerin iklim degisimleri acisindan analizi. Hacettepe Universitesi Fen Bilimleri Enstitusu (Cevre Bilimleri Anabilim Dali), 2001-2002 Egitim ve Ogretim Yili Yayimlanmamis Ders Notlari, Ankara.

Turkes, M., U.M. Sumer and I. Demir, 2002a. Turkiye'nin gunluk ortalama, maksimum ve minimum hava sicaklari ile sicaklik genisligindeki egilimler ve degisiklikler. Prof. Dr. Sirri Erinc Anisina Klimatoloji Calistayi 2002, Bildiriler Kitabi. Ege Universitesi Cografya Bolumu, 11-13 Nisan 2002, Izmir, (Baskida)

Turkes, M., U.M. Sumer and I. Demir, 2002b. Re-evaluation of trends and changes in mean, maximum and minimum temperatures of Turkey for the period 1929-1999. Int. J. Climatol., 22: 947-977.

UKMO. and DETR., 1999. Climate change and its impacts, stabilisation of CO in the atmosphere. United Kingdom Meteorological Office and Department of the Environment, Transport and the Regions (UKMO/DETR), the Hadley Centre for Climate Prediction and Research, Bracknell.