

## **Do El Niño events modulate the statistical characteristics of Turkish streamflow?**

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**Abstract.** The objective of this study is to investigate whether or not the basic statistical characteristics of a streamflow time series that is assumed to be affected by the warm phases of the Southern Oscillation (El Niño events). In order to achieve this intended goal, we considered a hypothetical series, so-called generated series, which can be obtained from the historical series at hand by first assuming non-occurrence of El Niño events in the past. The historical monthly precipitation data during the El Niño years were simulated by the Radial Based Artificial Neural Network (RBANN) method. The differences in the basic statistical characteristics between the generated and original historical series were tested by various statistical hypothesis testing methods for four different cases. Consequently if significant differences were determined between the two series in terms of variance, mean and autocorrelation parameters, then it can be inferred that the El Niño events modulate the major statistical characteristics of streamflow series. This type of result (related to a question of “how”) may be conceived as the subsequent phase of the previously documented results concerning the determination of El Niño signal (related to a question of “is there”). The outcomes of this study were in agreement with the previous studies and may be taken into consideration by the hydrologist for the long-term irrigation, hydropower and environmental planning.

### **1. Introduction**

El Niño Southern Oscillation (ENSO) is a sporadic, intensive and extensive climatic phenomenon occurring due to the changes in the usual atmospheric pressure patterns and in the sea surface temperature at some parts of the Pacific Ocean. Despite its irregular repetition, El Niño occurs approximately every four years on average. El Niño/La Niña and Southern Oscillation are respectively the oceanic and atmospheric components of the phenomenon affecting the climatic characteristics of the world in terms of temperature, rainfall, streamflow, evaporation, etc. Regional and global hydrologic and climatologic influences of ENSO events have been extensively studied (i.e., Redmond and Koch, 1991; Kahya and Dracup, 1993; 1994).

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In earlier works, the relations between the extreme phases of the Southern Oscillation (SO) and surface climate variables (i.e., streamflow, precipitation and temperature) in Turkey were well documented (Kahya and Karabörk, 2001; Karabörk and Kahya, 2003; Karabörk et al., 2005). No study had a concern to search an answer to the question of this paper.

The objective of this study is to determine whether ENSO affects the streamflow records of Turkey or not. The procedure that will be described in further sections will be applied to streamflow data in Turkey. Furthermore, the results of this study are compared with the results of Karabörk and Kahya (2001) in which two large regions in the western and eastern parts of Turkey and corresponding signal seasons were determined in association with ENSO.

## **2. Data**

The mean monthly streamflow values of 78 streamflow observation stations with more or less uniformly distribution around Turkey were used in this study for the time period 1962-2000. This streamflow data set was previously used in Karabörk and Kahya (2001). The selection criteria of the stations included: (i) homogeneous distribution; (ii) without a missing record; (iii) no upstream interference. Homogeneity condition of the data network was discussed in detail by Karabörk and Kahya (2001). In simulation phase the following ENSO years were taken into consideration: 1963, 1965, 1969, 1972, 1976, 1982, 1987, 1991, 1993, and 1997.

## **3. Methodology**

### **3.1 Simulation of mean monthly streamflow records**

The simulation of mean monthly streamflow records corresponding to El Niño years was performed using the Radial Based Artificial Neural Network (RBANN) model. It was first introduced by Govindaraju and Ramachandra Rao (2000) and further used in many generation studies.

In order to determine the synthetic streamflow data by the RBANN model, the input variables were taken as the first and second years' mean monthly records ( $X_{i,t-1}$ ;  $X_{i,t-2}$ ) and the mean monthly value of that month ( $X_i$ ) ( $i$ : year,  $t$ : month) not involving any record of El Niño year. The reason for taking the data of first two years as the input variables is due to their considerable correlation with the data of the estimated year. When the third and the fourth values of that month's mean monthly data were taken as the input variables; the data set becomes so small, and thus the training performance of ANN decreases. The mean value of each month was calculated considering non-El Niño years of the data set. The RBANN model was formed by an input unit, a hidden unit and an output unit (Table 1). The synthetic data generation with the RBANN was executed by MATLAB computer program.

**Table 1.** The characteristics of the RBANN model.

Input Layer Data	Propagation parameter	Output Layer Data	Training Period	Testing Period
$\bar{X}_i; X_{i,t-1}; X_{i,t-2}$	$S = 0.15$	$X_{i,t}$	Mean monthly streamflow data except El Niño years	Mean monthly streamflow data of El Niño years

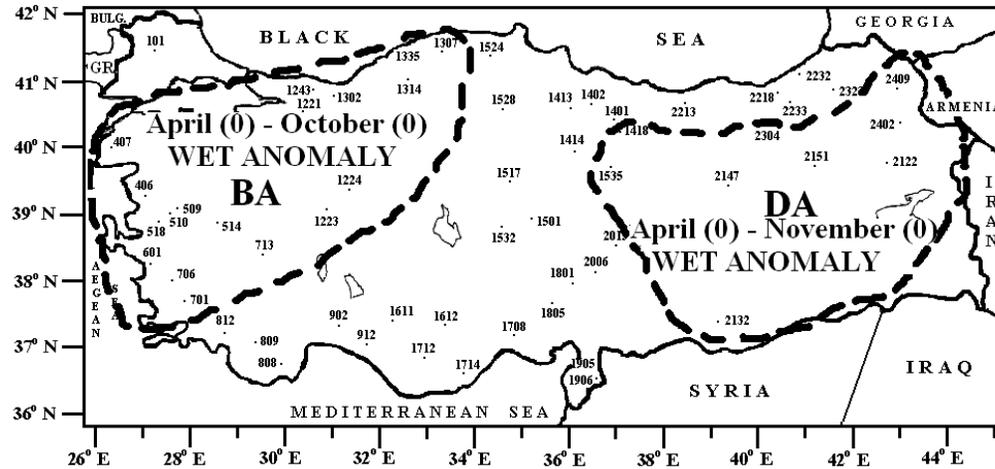
As a consequence, we have two time series at hand at each station: the original (historical) and the synthetic (whose historical data during El Niño year were replaced by generated data).

### 3.2 Test Conditions

The analyses were carried out considering the stations within Western Anatolia (marked by BA) and Eastern Anatolia (marked by DA) regions (Figure 1) and their corresponding seasons determined by Karabörk and Kahya (2001). Four different testing conditions were formed with the data sets:

**Condition A:** This involves two time series: the original mean annual streamflow records of 39 years and the hypothetical time series whose El Niño years were filled with the synthetic data generated by the RBANN.

**Condition B:** This involves two time series: the original mean annual streamflow records of 39 years and the hypothetical time series whose values comprised of the mean values of the ENSO signal seasons specified for the stations existing in the BA and DA regions.



**Figure 1.** The regions and seasons affected from ENSO in Turkey (adapted from Karabörk and Kahya, 2001).

### 3.3 Hypothesis Testing

#### a- Testing variances

The *F*-test was used to test the variances of the original and synthetic series for both A and B test conditions. The details of *F*-test can be found elsewhere (i.e., Haan, 1977).

**b- Testing means**

The *t*-test was used to test the mean values of the two data sets. The details of the *t*-test can be found elsewhere (i.e., Haan, 1977).

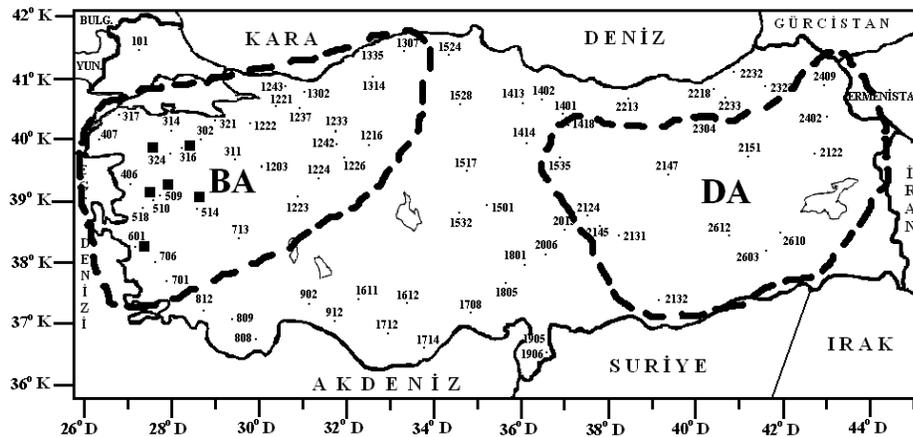
**c- Testing the autocorrelations**

The historical and hypothetical streamflow series were analyzed to see whether El Niño events have changed the autocorrelation structures of the observed series, or not. The existence of statistically significant positive lag-1 autocorrelation coefficient ( $r_1$ ) is the important indication of the persistence characteristic of a streamflow time series.

**4. Results and Conclusions**

**a- Variances**

The F-test results are given in Figure 2 for the stations included in the BA and DA regions defined by Karabörk and Kahya (2001). There are no detected variance difference in the both regions BA and DA for Condition A.



**Figure 2.** Differences in the variances of the simulated and original streamflow data for (a) Condition B. Solid squares represent the 95% significance level.

**b- Means**

The results of the *t*-test analyzing the differences between the means of the generated and original data are given in Figure 3.

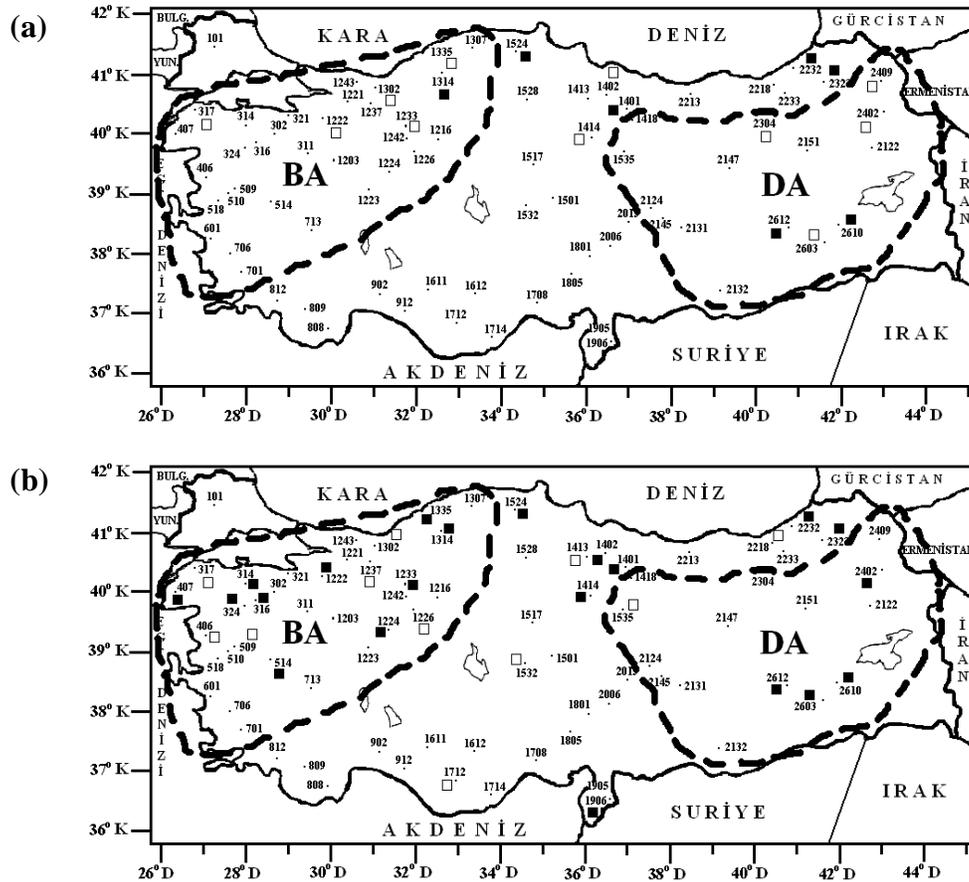
**c- Autocorrelations**

The possible changes occurring in the autocorrelation structure of the streamflow data in Turkey due the tropical El Niño events were analyzed for A and B testing conditions as described earlier (Table 2).

The differences in terms of variance, mean, and autocorrelation characteristics of the simulated and original streamflow time series were determined by using the various tests.

**a- Variances**

While the simulated and original time series did not differ statistically in terms of Condition A for both the BA and DA regions, they presented significant differences for Condition B at three (six) stations in the BA region at the 90% (95%) significance level. On the other hand stations in the region DA did not exhibit any difference for Condition B.



**Figure 3.** Differences in the means of the simulated and original streamflow data for (a) condition A, (b) condition B. Solid (open) squares represent the 95% (90%) significance level.

**b- Means**

The t-values for Conditions A and B were determined considering the positive correlation between the simulated and historical series. The significance of the t-values was evaluated based on the two-tailed t-distribution and the maps in Figure 3 were formed considering the 90% and 95% significance levels. Except a few stations, the observed streamflow values in El Niño years were greater than the ones generated by the RBANN (i.e., wet anomaly responses to El Niño event was confirmed in most of the stations). In Condition A, the DA region had six stations (35% of the total stations in DA) having a significant difference in the means with two at the 95% significance level.

**Table 2.** Lag-1 autocorrelation results for the simulated and original streamflow data for the regions BA and DA.

"BA" REGION									
Station	Test Condition (DA)				Station	Test Condition (DA)			
	A		B			A		B	
	Obs.	ANN	Obs.	ANN		Obs.	ANN	Obs.	ANN
1413	+■	-	-	-	2147	+■	+■	+■	-
1418	+■	-	-	-■	2151	+■	-	-	+■
1535	-	-	-	-	2304	+■	-	+■	-
1801	+■	+■	+■	-	2402	+■	-	-	-
2122	-	-	-	-	2409	-	-	-	-
2124	+■	-	+■	-	2603	+■	+■	-	-
2131	+■	-	+■	-	2610	+■	+■	-	-
2132	+■	+■	-	-	2612	-	-	-	-
2145	+■	-	+■	-					

"DA" REGION									
302	+■	-	-	-	713	+■	+■	+■	+■
311	+■	+■	+■	+■	1203	+■	+■	+■	+■
314	-	-	-	-	1216	+■	+■	+■	-
316	+■	-	-	-	1221	+■	+■	+■	-
317	+■	-	+■	-	1222	+■	-	-	-
321	+■	+■	+■	-	1223	+■	+■	+■	+■
324	+■	-	-	-■	1224	+■	+■	+■	+■
406	+■	-	-	-	1226	+■	-	-	-
407	+■	-	-	-	1233	+■	+■	-	-
509	+■	-	-	-	1237	+■	-	-	-
510	+■	-	-	-	1242	+■	+■	+■	+■
514	+■	+■	+■	-	1243	+■	+■	+■	-
518	+■	+■	+■	+■	1302	+■	-	-	-
601	+■	-	+■	+■	1307	-	-■	-	-
701	+■	+■	+■	+■	1314	+■	-	-	-
706	+■	+■	+■	+■	1335	-	-	-	-

- Autocorrelation values are not significant at 95% level.  
 ■ Autocorrelation values are significant at 95% level.

The BA region also showed six stations (19% of the total stations in BA) having statistically significant difference in the means with one at the 95% significance level (Figure 3b). The results of Condition B presented more stations having significant t-values because of the consideration of ENSO signal season. For Condition B, the DA region had the same number of significant stations (35%) as in Condition A, but the portion of the stations with significant difference in the BA region is 50 percent.

**c- Autocorrelations**

The important component of the autocorrelation structure of a hydrologic time series is the  $r_1$  autocorrelation coefficient which was calculated for the mean monthly streamflow time series in the DA and BA regions for Conditions A and B. The 95% significance level was selected for the evaluation of the  $r_1$  values as suggested by Salas et al. (1980). The results of autocorrelation calculations are given in Table 2.

The following four situations related to the calculated  $r_1$  values were determined:

- i) When the  $r_1$  values of both the simulated and original series emerge within the 95% confidence interval; this means that the series has no dependency property and, that is, El Niño events has no influences on the internal dependency of the original streamflow series. Four stations in the DA region and two stations in the BA region resulted in this conclusion for Conditions A and B.
- ii) When the  $r_1$  values are not significant in the original series, they exhibit significance at the 95% level in the simulated series; this means that El Niño events modify the autocorrelation structure of streamflow series. This situation was not observed in the region of DA, but at 1307 station (Table 2).
- iii) The  $r_1$  values of the original series had significance while the simulated series had no significant  $r_1$  value. This case has occurred for eight stations of DA and fourteen stations of BA according to Condition A. Six stations for both the BA and DA regions showed a significant difference at the 95% significance level according to Condition B (Table 2). For these stations, it can be said that El Niño events change the autocorrelation structure of the series, increasing the dependency of the series.
- iv) The final case regards the difference in  $r_1$  coefficients exceeding the 95% confidence intervals. For Condition A, five stations in the BA region and fifteen stations in the DA region had  $r_1$  values out of the confidence intervals. For Condition B, only ten stations in region BA and none in region DA presented this situation. The original streamflow values of these stations can be construed as El Niño events do not have any effect on the streamflow records of these stations.

The situations explained in (ii) and (iii) contradict each other. This implies that El Niño changes the autocorrelation structure of the streamflow series of the relevant stations. Therefore, it is seen that El Niño events caused modification in the persistency characteristic of Turkish streamflow patterns.

The statistical tests performed in this study indicated that El Niño events have influences on the streamflow values of Turkey. The large-scale atmospheric oscillation patterns like the North Atlantic Oscillation and the Southern Oscillation should be taken into consideration for the planning and managing purposes of Turkey's water resources studies.

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