Streamflow Regionalization: Case Study of Turkey

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Abstract: Homogeneous streamflow regions in Turkey were identified using a multivariate statistical tool, namely, principal components analysis (PCA) with a varimax orthogonal rotation. The rotated PCA was applied to monthly streamflow records of 78 gauging stations during the period 1964–1994. The first seven rotated components were found significant at the 0.05 or lower levels. All accounted for 68% of the total variance of the original data assembly. The different groups of highly intercorrelated streams were defined by the pattern of map drawn for the rotated components loadings. Furthermore, an annual cycle analysis was applied to the same monthly streamflow data. Harmonic vectors extracted from a series of 12 monthly means at each station were marked over a map to readily keep track of streamflow seasonal variations across the study domain. The basic statistical characteristics of streamflow were also investigated within the identified regions; thus, some similarities and dissimilarities between the regions were documented. The identified streamflow regions were shown to be consistent with climate zones in Turkey defined by a recent study based on cluster analysis of temperature and precipitation data.


CE Database subject headings: Turkey; Streamflow; Homogeneity; Rotation; Case reports

Introduction

As one of the most important water resources for society, streamflow and its low frequency temporal and regional variations have been of considerable interest to hydrologists and water-resource managers (Lins 1997). Streamflow conditions over a region can conveniently be displayed by plotting maps that reveal some particular areas of normal, above or below normal flow. This, in turn, reflects the spatial and temporal characteristics of climatic anomalies (Burklein 1982). Streamflow variability, however, deserves special interest since streamflow has been recognized as an integral form of land and atmospheric processes. Most previous studies have examined the spatial modes of meteorological variations. One common technique used to explore the variability of earth system variables over large regions is principal components analysis (PCA) (Maurer et al. 2004), also known as empirical orthogonal function analysis or eigenvector analysis. PCA is a multivariate statistical analysis method frequently used in the geophysical sciences (i.e., meteorology and oceanography) (Preisendorfer 1988; Emery and Thomson 1997); particularly in climate studies, which aim to explain correlations in a large set of variables in terms of a reduced number of underlying independent components (von Storch and Zwiers 1999). These components describe the most extensive and influential patterns of variability and their calculations are based on eigenvalues derived from a correlation matrix (Davis 1973; Cayya et al. 2001). In general, PCA allows us to represent the spatial and temporal variability of climate variables as a number of empirical modes (Mettas-Nunez 2000). Cluster analysis is also known as an effective tool for the same purpose and widely used in climatic studies. For example, Rovell and Fovell (1993) attempted to develop a regionalization for climatic variables over the US using monthly temperature means and precipitation accumulations from 344 climate divisions. Gaffen and Joshi (1999) applied a modified version of eight-cluster solution to analyze trends in US temperature and humidity.

The North Atlantic oscillation (NAO) is one of the major modes of variability of the northern hemisphere atmosphere. Since it exerts a strong control on the climate of the northern hemisphere, especially during winter, any issue related to climate or hydrologic variability over Turkey should be linked to the NAO and the extreme events of the southern oscillation (SO). Recent studies (Price et al. 1998, Karaçu et al. 2000, Cullen and deMenocal 2000; Nazemosadat and Corderoy 2009) showed the relations between the El Niño events and climate variables in the Middle East sector. Kahya and Karabörk (2001) and Karabörk and Kahya (2003) documented the influences of the SO extreme events on both streamflow and precipitation patterns of Turkey in terms of consistent and coherent signal region. More recently, Karabörk et al. (2005, 2007) analyzed Turkish surface climate variables (precipitation, streamflow, and maximum and minimum temperatures) in association with both the SO and NAO. In addition, Tayag and Tortes (1999), who were first to link the local climate effects in Turkey to the global climate change, pointed out that there is a shift towards the warmer side in the frequency distributions of daily minimum and 21:00 h temperature difference series in four cities in Turkey, indicating urban heat island effect.

No comprehensive research has been undertaken to characterize streamflow regionalization using a nationwide data set in Turkey to date (Kalayci 2003). Following the pioneering studies...
Data and Methodology

Data

A monthly mean streamflow data set containing 78 gauging stations, which are more or less uniformly distributed in 26 river basins of various sizes, was used in this study. It was obtained from the electrical power resources survey and development administration (abbreviated as EFS). Each streamflow time series has a length of 31 years, spanning from October 1964 to September 1994. The locations of streamflow stations with corresponding identification numbers are shown in Fig. 1. The homogeneity of each streamflow time series in our data set was already discussed by Kahya and Karabörk (2001) in detail. A completely homogeneous data set has rarely been encountered in many hydroclimatic studies due to scarcity. In this case, a suggested common practice is to define reasonable criteria to verify the homogeneity of observations. For example, Lins (1985b) logically included streamflow stations on watercourses where diversion amounts have been less than 10% of the mean flow and storage capacity amounted to less than 10% of the mean annual runoff. To satisfy the homogeneity condition, a total of 78 streamflow gauging stations where there was no reported regulation or diversion have been selected among more than 300 stations.

Preliminary Data Transformation

The PCA does not require normalized data sets as long as the data are not excessively skewed; however, data transformation may result in an improved ability to interpret the principal components (Wayland et al. 2003). In general, large disparities in the means and variances of most streamflow stations exist both in individual streams and in different months of the year. Therefore, the monthly mean values were subjected to first a logarithmic transformation and second, seasonally standardization in this study. At each individual station, each logarithmically transformed monthly value was expressed in units of standard deviation by subtracting the appropriate monthly mean from that value and then dividing the result by the appropriate monthly standard deviation. Thus, the standardized records have a mean of zero and a standard deviation of 1 and no longer contain a seasonal cycle. In this case, the principal components resulting from those standardized values define basic streamflow anomaly patterns.

Principal Components Analysis and Varimax Rotation

PCA is briefly described here in accordance with Bartlein (1982). The description of its historical developments and other methodological details shall not be presented; however, readers are referred to a comprehensive book by Preisendorfer (1988). In general, PCA produces a minimum number of uncorrelated variables, which are linear combinations or transformations of the original variables. The time-dependent coefficients of these fields in the linear combination are called principal components (PCs). Each observation in the $12 \times N$ ($N$: the number of years) monthly streamflow series is a seasonally standardized value.

Emphasis is given here to the spatial patterns of streamflow anomalies; hence, PCA is used to condense 372 streamflow anomaly maps into a smaller number of patterns of the anomaly fields. In this context, the spatial pattern of the first principal component (PC1) reveals the maximum possible simultaneous resemblance to the 372 observed maps. In other words, PC1 is considered as the dominant mode of variability of the sample of data fields in such a way as to present maximization of the explained variance. All PCs explain independently some portion of the total variance of all stations. The PC1 accounts for as much of the total variance in the data as possible, the PC2 accounts for as much of the remaining variance as possible, and so forth (Hsuin 1977). All significant PCs efficiently represent the spatially arrayed data set by a set of independent basic anomaly patterns or empirical modes.

The tendency of the empirical modes to extract scantily representative commonality among subdomains of large datasets may
be remedied by grouping the variance by means of procedure based on rotation (Mestas-Núñez 2000). The aim of rotation is usually to obtain a structure that requires that each variable of the correlation matrix should substantially load only on one common component (von Storch 1995). In other words; it is to redefine the components in order to make sharper distinctions (Peterson and Zett 1999). Various methods for component rotation have been proposed, which generally fall into two categories: (i) Orthogonal rotations, which preserve independent axes; and (ii) oblique rotations, which allow the axes to be correlated to some extent. VariMAX rotation, yielding statistically more stable patterns than the conventional PCA, is the most commonly used orthogonal method (von Storch 1995; Mestas-Núñez 2000; Schwerizer 2001; Cayan et al. 2001; Tadesse and Bekele 2001; Villarini et al. 2003; Wayland et al. 2003). It results in stronger component loadings denoting regions of maximum correlation between the variables and the components.

In most applications, the rotation is used to simplify the spatial structure by isolating regions with similar temporal variations (Hurt 1981; Bannister and Livecy 1987; Mestas-Núñez and Enfield 1999). The resulting rotated space patterns are generally more robust than their unrotated counterparts. The applications concerning the use of the varimax rotation method when the PCs are physically not interpretable or when the interpretation of the PC's needs to be simplified are well presented by Bartlein (1982) and Links (1985a, b, 1997). In a series of studies, Links applied rotated PCA (RPCA) to streamflow in the conterminous United States and described regional anomaly cores and the hydroclimatology of the United States and denoted usefulness of this method for characterizing regional streamflow variability. The rotated principal components (RPCs) expose sub-regions arising from highly intercorrelated streams that reflect homogeneously varied regimes (Richman 1986; White et al. 1991). In this study, we used the varimax orthogonal rotation method to determine homogeneous streamflow regions in Turkey.

### Annual Cycle Analysis

Regional and global scale studies concerning annual cycle characteristic of a surface climate variable using harmonic analysis dated back to the 1970s and focused on precipitation (Hsu and Wallace 1976). In this study we first attempted to document a nationwide picture of streamflow annual cycle behaviors across Turkey. The annual cycle analysis of streamflow data at each station was also carried out as a supplementary approach to identify homogeneous streamflow regions. At this point, we aimed to identify regions of similar streamflow according to the oscillations of long-term monthly means using a 12-month period. In order to practically visualize the oscillations of long-term monthly means, the first harmonic fits, which have only one maximum and one minimum during the 12-month period, were calculated at each station. A mathematical description of the method is summarized in the Appendix. The information embedded in the first harmonic curve could be summarized by the following three parameters: (1) amplitude (maximum departure from a mean value); (2) phase shift (the time of the maximum of the first harmonic within a 12-month period); and (3) the percentage of variance explained by the first harmonic. The first harmonic curve can be represented by a harmonic vector for plotting purposes. After converting the phase shifts to angles on a harmonic dial, the direction of a harmonic vector indicates the phase angle (time of maximum), whereas the size (magnitude) of a vector shows the amplitude.

### Table 1. Comparison of the Percentages of Variance Explained by the First 12 PCs as Calculated for Unrotated (PCs) and Orthogonally Rotated (RPCs) Solutions

<table>
<thead>
<tr>
<th>Principal component</th>
<th>Unrotated (PCs)</th>
<th>Rotated (varimax) (RPCs)</th>
<th>Principal component</th>
<th>Unrotated (PCs)</th>
<th>Rotated (varimax) (RPCs)</th>
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<tr>
<td>1</td>
<td>38.17</td>
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<td>1.92</td>
<td>2.91</td>
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<tr>
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<td>9.71</td>
<td>9</td>
<td>1.92</td>
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<tr>
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<td>5.70</td>
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<td>2.31</td>
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<td>5.28</td>
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<td>1.53</td>
</tr>
<tr>
<td>Σ</td>
<td>79.78</td>
<td>79.78</td>
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</tr>
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</table>

### Analysis of Streamflow Climatology in the Homogeneous Regions

In order to document different features of streamflow climatology among the homogeneous streamflow regions, a series of simple statistical analyses were performed. First, we plotted annual cycles of regional streamflow in the same diagram to make a comparison. In this analysis, original monthly streamflows were expressed in terms of the monthly percentages of annual streamflow volumes at each station. All stations were then spatially averaged to compute monthly means for the 12 months of a year within a region. Second, interannual variability of monthly streamflow was shown by the plots of monthly coefficient of variation. The coefficient of variation for each month is defined as a ratio of the corresponding standard deviation to mean. All the coefficients of variation were calculated at each station, and then regionally averaged. Third, monthly maximum streamflows were also plotted in the annual cycle fashion. In this analysis, monthly maximum streamflow values at each station were divided by the annual mean streamflow to standardize the data. In addition to these various cyclic streamflow features, annual and monthly lag-1 serial correlation coefficients were computed to document the regional streamflow persistence.

### Results and Discussion

#### Rotated Principal Components Analysis

The first 12 PCs with eigenvalues greater than 1 were adapted from Karayla and Kaaya (2006) and orthogonally rotated by the varimax method. They accounted for nearly 80% of the total variance and are given in the second column of Table 1. The number of significant PCs that is 12 in this study was determined using the dominant variance criterion described by Preisendorfer (1988). The percentages of explained variances by the first 12 RPCs are presented in Table 1.

The percentages of the total variances explained by the first 12 PCs and RPCs with both eigenvalues greater than 1 are the same (79.78%), implying that there is no difference between the two sets according to overall variance. However, the differences between variances explained by successive components decline. For example, the difference between the PC1 and PC2 is approximately 25% for the unrotated PC and 6% for the rotated counterparts. The RPC1 reproduces more than one-fifth of the total...
variance and the first two significant RPCs together account for more than one-third of the total variance. The first seven RPCs, which are relatively more important than the remaining five RPCs, cumulatively explain 68% of the overall streamflow variance. After rotating the PCs, some correlation values between streamflow values and the component scores increase in absolute magnitude (even approaching to ±1), while some dramatically decrease (even so close to 0).

In general, the positive correlation values in the map patterns of the rotated components in comparison to their unrotated counterparts [shown elsewhere: Kahya and Kahya (2002) and Kahya (2003)] also increase as the negative values decrease in magnitude. We have taken only the first four patterns into consideration to briefly explain and afterwards tried to describe homogeneous streamflow regions. The map pattern of the RPC1 in Fig. 2 exhibits positive values all over the country, except the small regions in northeastern, eastern, and southeastern Turkey. It is clear that stations located in western Turkey have the highest
values. The map pattern of the RPC2 is similar to the RPC1, revealing positive values across the country except a fairly small region in northern Turkey (Fig. 2).

For RPC3, the core area of the highest correlations moves further to eastern Turkey. Once again, the characteristic of having the same sign of anomalies throughout the entire domain remains almost unchanged. This feature still manifests itself clearly in the map pattern of the RPC4 with a somewhat split-shaped feature occurring mainly in western and southern Turkey. The location of the core area of the highest correlations is now changed to the northwestern Black Sea coast. It is worth noting that the direction regarding the location of the core area of the highest correlations starting from west for the RPC1 ending up to north for the RPC4 is said to be counterclockwise. An overall noticeable improvement for all PCs due to the rotation is that the anomaly maps of the first four rotated components have fairly less busy patterns in comparison to their counterparts presented in Kahya and Kayalý (2002) and Kayalý (2003). This feature expectedly enables us to uncover the extents of some regions where streamflow anomalies are assumed to be consistent.

Consequently, the following three scenarios were used to identify the distribution of homogeneous streamflow regions:

1. The correlation values equal or greater than 0.7 in the map patterns of the first seven RPCs in Fig. 2;
2. The components having the highest correlation values (among 12 possible ones) between each station data and the first 12 rotated components; and
3. the components having the highest correlation values (among 78 possible ones) between each station data and all rotated components.

For the selected threshold level of Scenario (1), it should be noted that Kuhnle et al. (1990) have used a lower threshold level ($r \geq 0.6$) in identification of homogeneous streamflow regions. Englehart and Douglas (1995) also used correlation values with $r \geq 0.6$ to determine similar precipitation regimes in America for each season. It is noteworthy that despite having discussed only the first four RPCs earlier, the reason to consider all significant RPCs (up to 12) in the analysis is not to overlook a possible influence of remaining higher RPCs over the final picture.

**Evaluation of Scenario 1.** In this case, the boundary of each area in Fig. 3(a) is determined by the geographic extents of extremely high correlation values (that is, $r \geq 0.70$ at the 99.9% confidence level) in the map patterns of the first seven RPCs in Fig. 2. These areas in which the region numbers define the RPC5 display streamflow anomaly core areas that are formed by stations having coherent modes. The consistent behaviors of 17 stations in Fig. 3(a) form the largest region (Region 1) in western Turkey. A total of seven homogeneous streamflow regions are outlined, being scattered around the country without any regional indication in the southeastern part of Turkey. The stations numbers included in these regions are 17, 9, 6, 6, 3, 1, and 3, respectively. The homogeneous regions shown in Fig. 3(a) are compared with the climatic zones in Turkey defined by Ural et al. (2003). Using cluster analysis, they redeline climate zones by using monthly temperature and precipitation data, spanning from 1951 to 1998, at 113 climate stations and found seven main clusters. They named these clusters as the Mediterranean, Black Sea, Central Anatolian, Eastern Anatolian, Southeastern Anatolian, and Eastern Mediterranean regions (symbolized by A, B, C, D, E, F, and G zones, respectively, in Fig. 4).

These are noticeable similarities between Regions 1, 2, 3, and 4 (Fig. 3(a)) and B, C, E, and G climate zones, respectively. The geographical extents of both Region 4 and Region 5 in the western and eastern Black Sea coast correspond to C climate zone. Furthermore, the Region 5 has relatively smaller extents than D climate zone.

**Evaluation of Scenario 2.** Each of the regions in Fig. 3(b) was defined by which of the first 12 RPCs have the highest cor-
relation with the streamflow time series at each of the 78 stations. Special care was given to the consistency between the real basin topographic boundaries shown in Fig. 1 and those of the regions in Fig. 3(b). It is noteworthy that Bartlein (1982) used 24 significant components rotated by the varimax method to determine homogeneous hydrologic regions in the USA and southern Canada. Having indicated the number of RPCs between the two studies, it is self-evident that the characteristics of streamflow variation are less complex in our case.

In this scenario, there are 27 streamflow stations having the highest correlation values with the RPC1 in the region designated by 1s in Fig. 3(b). The largest region associated with the RPC2 is identified by 21 stations. In general, as the component number increases, the number of the stations included in the regions decreases. In this context, the numbers of stations corresponding to the third and higher components are 7, 3, 5, 2, 3, 2, and 2, respectively. Thus, the station numbers in the regions bounded by the third and the other components are 7, 3, 5, 2, 3, 2, and 2, respectively [Fig. 3(b)].

The homogeneous streamflow regions in Fig. 3(b) appear to be more extensive and dispersed compared to those in Fig. 3(a). Region 1 in Fig. 3(b) is in part of the western Black Sea coast, southern Marmara, all over the Aegean coast, and partially the western Mediterranean and northwestern central Anatolian. Although Region 2 comprises fewer stations than Region 1, it extends to further locations, including those areas designated as Region 1 and Region 3 in Fig. 3(a). Having determined the boundary of major streamflow homogeneous regions, the extents of Region 1 and Region 4 fairly resemble those of climate zones of B and F, respectively. Similarly, Region 2 and Region 7 match the climate zones of E, G, and partly D and F zones, respectively.

The similarities between the homogeneous streamflow regions of Fig. 3(b) and El Niño related core regions of Turkey detected by Kahya and Karabörk (2001) are also noticeable. Kahya and Karabörk (2001) analyzed the influence of El Niño on streamflow patterns of Turkey and revealed two core regions (western Anatolia and eastern Anatolia regions, see their Fig. 3) in which streamflow have coherent and consistent wet El Niño signals. Geographical extents of Region 1 and Region 3 fairly coincide with the El Niño related western Anatolia region. Regions 4, 6, 8, and 10 are located within the El Niño related eastern Anatolia region whereas only the eastern stations of Region 2 are in the borders of eastern Anatolia region.

**Evaluation of Scenario 3.** The varimax rotation applied to 78 stations in the streamflow network reveals 10 distinct homogeneous regions in the final scenario. Special care was given to the overlap between the real basin topographic boundaries shown in Fig. 1 and those in Fig. 3(c). The rotated components having the highest loadings are the first component at 20 stations in western Turkey and the second component at 12 stations in southern and interior parts of Turkey. Following these, the third component was a cluster of seven stations in western Black Sea. In addition to the three large regions, seven more relatively small regions are also marked in the same map [Fig. 3(c)].

**General Evaluation of the Scenarios.** The pattern in Fig. 3(a) somehow lacks inclusion of an important region in mid-southern Turkey, as opposed to those in Figs. 3(b) and c. Our hydroclimatologic evaluations between the last two scenarios concluded that the pattern of homogeneous streamflow regions resulting from 12 significant RPCs is the logical choice. Consequently, our decision is made upon the one depicted in Fig. 3(b) as the main pattern to represent a typical picture of hydrologically homogeneous regions.

A striking feature of Fig. 3 is the similarity among the outcomes of three scenarios. This implies that the number and location of potential homogeneous regions are more or less stable. Identifiable clusters could be summarized as (1) a stable large region in the west; (2) a large region in the middle extending to the east; (3) a stable small region in the northwest; (4) a stable small region in the south confined by the two large regions; and finally (5) a stable small region in the far northeast and southeast.

**Annual Cycle Analysis**

First harmonics curves were fitted to the annual cycles of long-term averages of monthly streamflow at each station. After
calculating the amplitudes and phases of the first harmonics at
each station, a vectorial map was plotted and presented in Fig. 5.
The first harmonics accounted for more than 50% of the variance
of individual streamflow data at every station in the study domain.
Therefore, the first harmonic, in general, represents a dominant
cyclic variation mode that is to imply that one maximum and
minimum exist in a year at each station) across Turkey.

Streamflow in the western coastal zones of Turkey is charac-
terized by a peak within the season of January–February. Moving
into the interior regions, a phase shift in the timing of peak is
notable. A large portion of the country, extending from midwest to
further east, reveals a maximum streamflow around March and
April. In the elevated areas of the northeast, the timing of peak
flow is in May or June, due to spring snow melt.

When the map in Fig. 5 is compared with those in Fig. 3, there
are some striking resemblances. More specifically, Region 1 in
all scenarios in Fig. 3 appeared to match with the area described
by the January–February peak in Fig. 5. Region 2 of Fig. 3(b)
seems to represent major parts of the area described by the April
peak. Similar relations exist between the March–April peak and
Regions 3, 6, 8, and 10. The distinct behavior of streamflow
within the area described by the May–June peak in Fig. 5 is also
noticeable in all scenarios in Fig. 3.

Being aware of the fact that the maps of RPCs are based on
streamflow anomalies, whereas the map of annual cycle is based
on streamflow monthly means, we were curious about comparison
of the two different maps in terms of geographical extent. It
can be said that the resemblance of an annual cycle map to those
of the RPCs is evident in RPC 5 to higher components. In
particular, distinct spatial grouping of streamflow stations over
Aegean region, northern, and southern coastal zones, and a large
interior region is readily identifiable on the relevant diagrams
[Figs. 2(a–g) and Fig. 5]. We conclude that streamflow anomaly
characteristics in the form of spatial variability mode and stream-
flow deterministic characteristics in the form of seasonality seem
to be in phase within the aforementioned regions.

Streamflow Climatology in the Identified
Homogeneous Streamflow Regions

The analyses of streamflow climatology were performed on the
basis of homogeneous streamflow regions depicted in Fig. 3(b).
The regions were referred to according to the RPC numbers. That
is, Region 1 describes the region that includes the stations having
the highest correlations between the streamflow data and first
RPC; Region 2 describes the region that includes the stations
having the highest correlations between the streamflow data and
second RPC; and so on. Among the regions depicted in Fig. 3(b),
only the regions having more than two stations were taken into
the consideration.

Fig. 6 shows the annual cycles of spatially averaged stream-
flow. As seen in Fig. 6, except for Region 1 and Region 5, the
peaks of the annual cycles occur in April. The timings of the
maximum flows are March and May for Region 1 and Region 5,
respectively. In general, except for Region 1 and Region 5, all of
the annual cycles have similar patterns with a unimodal annual
cycle. This pattern confirms the adequacy of the use of first har-
monic curves to represent the oscillation of annual cycles for
Turkey. Unlike the other regions, Region 5 has a direct period of
December–February on the annual cycle. This unique driest period and late occurrence of annual peak are likely due to the precipitation regime of the region since the geographic extent of Region 5 overlap the areas of strongest orographic precipitation regime in Turkey. For Region 1, the strong increase during the November–March period in the annual cycle can be considered as an absence of snow-melt contribution to streamflow for the region. It should be noted that Region 1 has a lower topography with respect to other regions.

Fig. 7 shows the interannual variability of the monthly streamflow on the basis of calculated coefficients of variation. It is seen that Region 5 has the minimum interannual variability among the identified regions. For Region 8 and Region 2, there is also not any considerable fluctuation in the interannual monthly variations during the annual cycle. Except for these two regions, the identified homogeneous streamflow regions are characterized by comparatively low interannual variability during high streamflow months. The monthly variability of Region 3, Region 4, and Region 7 are almost the same during the February–June season.

Fig. 8 shows the regionally averaged annual cycles of monthly maximum volumes divided by the long-term mean annual flow. As a general evaluation of Fig. 8, similarities are evident when comparing Fig. 6 with Fig. 8. The earliest and latest rises in the annual cycles are observed in Region 1 and Region 5, respectively. This difference mainly resulted from topographic and climatic conditions. The river basins located in northeastern Turkey (Region 5) are highly elevated, leading precipitation in the form of long-lasting snow during winter. The annual behavior of the annual cycles of maximum monthly flows, which is consistent with those in Fig. 6, may be interpreted as a consequence of regular depression-prone winter and spring precipitations across Turkey. It is also noticeable in Fig. 8 that except for the December–March season, maximum monthly flows are comparable for all of the regions in terms of percentages of long-term mean annual flow.

The most prominent parameter of persistence characteristics of a hydrological time series, lag-1 annual autocorrelation coefficients ($r_1$), was calculated at each station. Table 2 lists the number of streamflow stations that have significant autocorrelations beyond 95% and 99% confidence limits for each region. According to the Anderson's limits (Salas et al. 1980), 95% and 99% confidence intervals for the lag-1 autocorrelation coefficients were calculated as [0.318; -0.385] and [0.384; -0.451], respectively. As seen in Table 2, Region 1, Region 2, and Region 7 appear to have strong year-to-year persistence since in these regions more than 90% of the stations have showed significant autocorrelations beyond 95% confidence levels. It should also be noted that all of the computed significant autocorrelations are positive in sign. This situation can be considered as a reflection of significant groundwater storage capacity for these regions, which yields a time series of streamflow with a positive time dependence structure.

In order to reveal month-to-month persistence structure of the identified homogeneous streamflow regions, cross-correlation coefficients between consecutive months were also computed at each station and regionally averaged values were obtained. Fig. 9 shows the averaged results for each region. A close look at Fig. 9 reveals that except for Region 1, there is an annual signal in the month-to-month correlations, with high flow months tending to have comparatively weak correlations. This can be explained by a streamflow response to the interannual variations in the timing of strong winter and spring precipitations. For the first half of the water year, the results of Fig. 9 are valid. For the second half of the water year, the month-to-month correlations of Regions 1, 2, 4, and 7 are similar and comparatively higher than those of Region 3 and Region 5.

The relation between the NAO and various climate variables in Turkey have been a recent concern in the study of Karabik et al. (2005), who documented a number of significant negative correlations with respect to the NAO index using precipitation, streamflow, maximum temperature, and minimum temperature data. Their conclusions showed noticeable relationships between Turkish temperature patterns and the SO and less sensitive temperature patterns to the NAO. On the other hand, the SO index

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of significant lag-1 autocorrelation coefficients</th>
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<tr>
<td>1</td>
<td>16</td>
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<tr>
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series was negatively correlated with both Turkish precipitation and streamflow patterns. Karabörk et al. (2005) reviewed some linkages between the SO and the NAO together with their earlier SO-related findings and discussed the possible mechanisms based on mainly the rearrangements of Hadley Circulation. They noted that the Atlantic sector can play an important role in transmitting El Niño signals to midlatitudes by means of a feedback mechanism. Cullen and deMenocal (2000) pointed out that secondary cyclogenesis in the eastern Mediterranean provides a physical linkage between the NAO (as a key provider of precipitation to the Middle East) and climatic surface variables in Turkey.

Conclusions

In this study, the determination of hydrologically homogeneous regions is performed using three scenarios based on the principal components analysis with the varimax rotation. The rotated principal components analysis was carried out using 78 streamflow gauging stations. The first component reproduced greater than one-fifth of the total variance as the first two components reproduced greater than one-third. The first seven components cumulatively explain 68% of the total streamflow variance over the study domain.

The homogeneous streamflow region identified by the three approaches were found to be similar to each other. At the same time, the streamflow regions were compared with the climate zones, which were recently redefined by Unal et al. (2003) using both temperature and total precipitation data. This comparison indicated that the homogeneous streamflow regions resembled the climate zones in Turkey from the standpoint of geographical extent.

As a rough approach of regionalisation for Turkish streamflow, the annual cycle analysis (first harmonic fitting) was applied to a 12-month long-term mean series at each station. Consequently, three large regions were identified considering the phase angle of the first harmonics. The designated regions were compared with the previously identified homogeneous streamflow regions by the rotated principal components analysis, and resemblances were noted. Furthermore, a series of statistical characteristic-based analyses were performed for streamflow, and some considerable differences between the streamflow behaviors of the identified homogeneous regions were documented.

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Appendix

Harmonic Analysis

In general, harmonic analysis is a convenient method to observe regional variations of climate variables (Kirkby and Hamed 1989). The first harmonic fitted to the monthly long-term mean series is calculated from Eq. (1) when \( k \) (the harmonic number) is equal to 1:

\[
X = X_0 + \sum_{i=0}^{\infty} C_i \cos \left( \frac{2\pi k}{P} (t - t_i) \right) \tag{1}
\]

where \( X \) = monthly long-term mean value at time \( t \), \( X_0 \) = arithmetic mean of the 12 months, \( P \) = fundamental period, equal to 12 months. The amplitude of the \( k \)th harmonic (defined here as the maximum departure from \( X_0 \)) can be computed by

\[
C_i = (A_i^2 + B_i^2)^{1/2} \tag{2}
\]

where \( A_i \) and \( B_i \) = Fourier coefficients, and \( t \) = time of observation \( (t = 1, 2, \ldots, P \text{ month}) \), and \( t_i \) = time at which the \( k \)th harmonic has a maximum. The term \( t_i \) represents the phase shift of the \( k \)th harmonic, expressed in months, and is given by

\[
t_i = \frac{P}{2\pi k} \arcsin \left( \frac{B_i}{C_i} \right) \tag{3}
\]

Each streamflow location has a unique phase shift value. Detailed derivations and different application of harmonic analysis can be found elsewhere (Davis 1973; Salas et al. 1986; Kahya and Drouet 1993).

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References


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