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HYDROLOGIC HOMOGENEOUS REGIONS USING MONTHLY STREAMFLOW IN TURKEY

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ABSTRACT

Cluster analysis of gauged streamflow records into homogeneous and robust regions is an important tool for the characterization of hydrologic systems. In this paper we applied the hierarchical cluster analysis to the task of objectively classifying streamflow data into regions encompassing similar streamflow patterns over Turkey. The performance of three standardization techniques was also tested, and standardizing by range was found better than standardizing with zero mean and unit variance. Clustering was carried out using Ward's minimum variance method which became prominent in managing water resources with squared Euclidean dissimilarity measures on 80 streamflow stations. The stations have natural flow regimes where no intensive river regulation had occurred. A general conclusion drawn is that the zones having similar streamflow pattern were not be overlapped well with the conventional climate zones of Turkey; however, they are coherent with the climate zones of Turkey recently redefined by the cluster analysis to total precipitation data as well as homogenous streamflow zones of Turkey determined by the rotated principal component analysis. The regional streamflow information in this study can significantly improve the accuracy of flow predictions in ungauged watersheds.

***Key words*:** Cluster analysis, Ward's method, streamflow, homogeneous region, regionalization, Turkey

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RESUMEN

El análisis de nidos de registros de flujos de corrientes calibrados en regiones homogéneas y robustas es un instrumento importante para la caracterización de sistemas hidrológicos. En este artículo hemos aplicado este análisis para clasificar objetivamente datos de flujos de corrientes en una región que comprende patrones similares en Turquía. El desempeño de las tres técnicas de estandarización probado y estandarizado por rangos, fue mejor que la estandarización con media cero y varianza 1. El anidamiento se llevó a cabo utilizando el método de mínima varianza de Ward el cual se torna prominente en el manejo de recursos acuíferos con medidas de dis-similaridad cuadráticas euclidianas sobre 80 estaciones de flujos de corriente. Las estaciones poseen regímenes de flujos donde no ha ocurrida regulación intensiva sobre los ríos. Una conclusión general es que las zonas que tienen patrones similares de flujos de corriente, no fueron bien cubiertas con las zonas climáticas convencionales de Turquía.

Palabras clave: Análisis racimo, Método de Ward, Flujo de corriente, Región homogénea, regionalización, Turquía.

1. Introduction

Streamflow characteristics provide information needed in design of structures built in or along stream channels, for avoiding flood hazards, for defining the available water supply and in the large scale provides a useful tool for extrapolation of hydrological variables and for the identification of natural flow regimes where intensive river regulation has occurred. Because climate factors, such as precipitation, temperature, sunshine, humidity, and wind, all affect streamflow but topography, soil characteristics, precipitation and temperature account for major differences among the river catchments (Haines 1988; Riggs 1985). For instance high temperature variability generally leads to more potential evaporation so that the water cycle turns in a warmer environment. Hence the higher content of water vapour in a warmer atmosphere will increase precipitation. But in summer, the streamflow will be decreased by higher temperatures and higher evapotranspiration (Stahl 2001).

It is important to document climatic and hydrologic regionalization in planning water resources systems. This requires similar pattern and clustering characteristics. In this context, Fovell (1993) was among the first pioneering studies which attempted to develop a regionalization for climatic variables over the US using monthly temperature means and precipitation accumulations from 344 climate divisions. Gaffen and Ross (1999) applied a modified version of eight-cluster solution to analyze trends in US temperature and humidity.

Stahl (2001) correlated the monthly averages of the Regional Streamflow Deficiency Index (RDI) series of the 19 European clusters with the NAO index and noted weak relations. However seasonal correlations were much higher except for the summer season in northern Europe. In Europe, most rivers show a strong seasonal regime; therefore, seasonal variability is important to assess the impact of climate changes on the complex hydrological system (Stahl 2001).

The seasonality of streamflow varies widely from stream to stream and is influenced mostly by the local distribution of precipitation, local seasonal cycle of evaporation demand, timing of snowmelt, travel times of water from runoff source areas through surface and subsurface reservoirs and channels to stream gauge, and human management (Chiang 1996). Dettinger and Diaz (2000) worked with the global dataset of monthly streamflow series and pointed out that the timing and amplitude of streamflow seasonality depends on the local month of maximum precipitation and the extent to which precipitation is trapped in snow and ice at most gauges. Acreman (1986) classified 168 basins in Scotland using Normix multivariate clustering algorithm. They used logarithmically transformed basin characteristics; area, stream length, channel slope, stream density, rainfall, soil moisture deficit, soil type, and lake storage.

In cluster analysis, the choice of variables, clustering technique and dissimilarity measure significantly influence the results (Fovell 1993; Stooksbury and Micheals 1991). The final groups may or may not be geographically contiguous. If robust clustering is done, strong relationship in streamflow properties (e.g., mean, standard deviation, and correlation of monthly streamflow) and river basin characteristics can be determined. These links can be utilized to develop useful streamflow information at ungauged watersheds featuring similar patterns (Chiang 1996).

Using temperature and precipitation data, some climate classifications to delineate regions with similar climate conditions in Turkey were previously presented by Türkeş (1996) and Ünal *et al*., (2003). The former applied a common approach (Thornthwaite classification method) as a priori definition of a set of climate types or rules that were then used to classify climate of Turkey. The latter applied cluster analysis for the same purpose. Since streamflow is an integrated variable of atmospheric and land processes, it would be wise to explore clustering schemes from the hydrological standpoint using nation wide streamflow network in Turkey. In this study we carry out the cluster procedures for delineating the geographical zones having similar monthly streamflow variations.

2. Data and methodology

2.1 Streamflow Data

Our study domain includes 26 river basins across Turkey (Figure 1). Because of unreliable records we, however, had to eliminate the basins 2, 10, 11, and 25 from the analysis. Table 1 presents gauging stations and their basins used in this study. Most of the drainage basins are medium to large size (>1000 km) and are located in an elevated area (>500m). The maximum flow per unit area can be observed in Antalya basin as the Eastern Black Sea basin has the highest precipitation measurements. Turkey is located in semiarid zone where precipitation is mainly characterized by high spatial and temporal variability. Readers are referred to Ünal *et al*., (2003) and Karaca

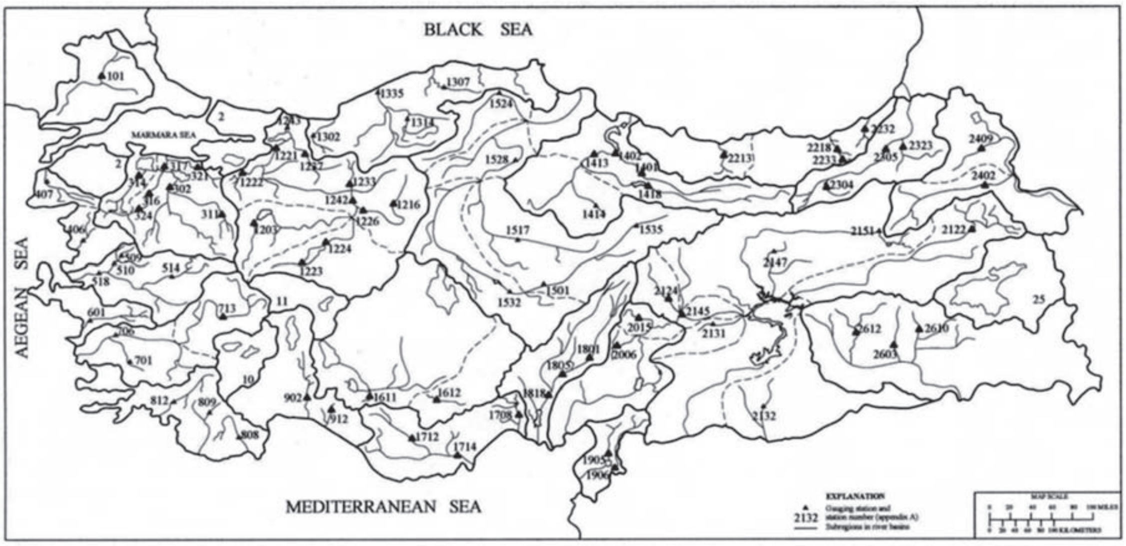

Figure 1. Locations of streamflow gauging stations used in this study. The boundaries of river basins are shown along with station ID numbers.

et al. (2000) for a recent review of the general climate features in Turkey. Monthly streamflow recorded at 80 stations used in this study are compiled by General Directorate of Electrical Power Resources Survey and Development Administration (abbreviated as EIE). Each streamflow station contains a 31-year period spanning from 1964 to 1994. Karabörk and Kahya (1999) and Kahya and Karabörk (2001) showed that the data set used in this study fulfils the homogeneity condition at a desirable confidence.

Following suggestion of Arabie *et al*. (1996), original streamflow data first were standardized by the following equation prior to the cluster analysis.

Table 1. Gauging stations used in this study and their locations

Basin No	Name of River Basin	Number of the Gauging Stations’
1	Maritza (Meriç)	101
2	Marmara	-
3	Susurluk	302, 311, 314, 316, 317, 321, 324
4	Northern Aegean	406, 407
5	Gediz	509, 510, 514, 518
6	Small Menderes	601
7	Big Menderes	701, 706, 713
8	Western Mediterranean	808, 809, 812
9	Antalya	902, 912
10	Burdur Lake	-
11	Akarçay	-
12	Sakarya	1203, 1216, 1221, 1222, 1223, 1224, 1226, 1233, 1237, 1242, 1243
13	Western Black Sea	1302, 1307, 1314, 1335
14	Yeþilýrmak	1401, 1402, 1413, 1414, 1418
15	Kýzýlýrmak	1501, 1517, 1524, 1528, 1532, 1535
16	Konya Closed.	1611, 1612
17	Eastern Mediterranean	1708, 1712, 1714
18	Seyhan	1801, 1805, 1818
19	Orontes (Asi)	1905, 1906
20	Ceyhan	2006, 2015
21	Euphrates (Fýrat)	2122, 2124, 2131, 2132, 2145, 2147, 2151
22	Eastern Black Sea	2213, 2218, 2232, 2233
23	Chorokhi (Çoruh)	2304, 2305, 2323
24	Arax (Aras)	2402, 2409
25	Van Lake	-
26	Tigris(Dicle)	2603, 2610, 2612

$$Z_{it} = \frac{S_{it} - \min(S_{it})}{\max(S_{it}) - (S_{it})} \quad \text{Eq. (1)}$$

where Z_{it}: streamflow index and S_{it}: monthly streamflow value at station *i* in year *t* (*i* = 1,..., 80 and *t* = 1,2,..., 31).

2.2 Cluster Analysis

Cluster analysis is an unsupervised learning procedure that group names and number of groups are not known in priori. Classification differs from clustering since it is a supervised learning procedure in which group names and numbers of groups are known. Since the purpose of cluster analysis is to organize observed data into meaningful structures, it combines data objects into groups (clusters) such that objects belonging to the same cluster are similar as those belonging to different clusters are dissimilar (Anderberg 1973; Everitt 1993; Karaca *et al*. 2000).

To measure the distance between two stations *x* and *y*, the Euclidean distance function, d is frequently used (Chiang 1996; Gong and Richman 1995) and expressed as

$$d = |x - y| = \sqrt{\sum_{i=1}^{n} |x_i - y_i|^2} \quad \text{Eq. (2)}$$

where x and y is the station pair and n is the number of months. Although there are many other distance metrics, the Euclidean distance is the most commonly used dissimilarity measure in the clustering algorithms. A literature review provided by Gong and Richman shows that the majority of investigators (i.e., 85%) applied this metric in their study. The Ward's algorithm and squared Euclidean metric were selected in this study because this linkage method aims to join entities or cases into clusters such that the variance within a cluster is minimized (Everitt, 1993). To be more precise; each case begins as its own cluster then two clusters are merged if this merger results in a minimum increase in the error sum of squares. Readers are referred to Everitt (1993) and Romesburg (1984) for further details concerning cluster analysis.

Determination of the appropriate number of clusters to retain is considered as one of the major unresolved issues in the cluster analysis. In this study, we applied an informal method which includes an examination of the differences between a conjunction level in the dendrogram and cutting the dendrogram when large changes are observed (Everitt, 1993). It is then possible to define different cluster numbers by moving the dashed horizontal line up and down in the graph of dendrogram until achieving a desirable result. Moreover, we applied two other statistics to decide an appropriate number of clusters i.e. root-mean-square standard deviations (RMSSTD), pseudo *F* statistic (Sarle 1983).

4. Results and discussion

A group of 80 stations was analyzed using the hierarchical clustering method described in the preceding section. An agglomerative clustering method show which stations or clusters are being clustered together at each step of the analysis procedure. This requires a total of 79 (80-1) steps to converge to one single cluster. The Ward's minimum variance method was applied to the distance matrix constructed from the standardized monthly mean variables. For each variable, the analysis process was stopped at the 60^{th} (calculated as 80-20) step to detect variation in the cluster memberships and to get more consistent clusters. At the beginning of the analysis, we carried out the cluster procedures up to 20 steps using both standardized and original variables to see which type of variables seems to be proper for the analysis. The 20 steps was the possible reasonable largest number of cluster (hereafter abbreviated as NCL). If it was a larger number, it would not be practical to handle the analysis outcomes.

The results for the monthly streamflow variables were presented in a mapping fashion for the cluster level of 6 which was selected among possible 20 different cluster levels. This cluster level seemed to account more for compact and reasonable solutions in a manageable manner and is consistent that of Ünal *et al*. (2003). Different colours for each cluster will be used to demonstrate the analysis results on the maps afterward.

In addition, we calculated the RMSSTDs and pseudo *F* statistics to decide an appropriate number of clusters and presented their results together with those of dendrogram in Table 2 for each month. As a result, all three different techniques suggested us more or less same number. We considered single digit for the number of clusters, namely 6, for each month.

Figure 2 illustrates 6 distinctive clusters, each showing a hydrologically homogeneous region across Turkey. For January, four clusters appeared to be prevailing, mainly having a stripe-like shape extending from north to south. For the coastal areas of Mediterranean Sea, two clusters come out not only in this month but also in the February and March, dividing the entire coastal area into the west and east parts. For February, six clusters emerged almost equally in size, and each extending more or less from west to east. In this month, the patterns of streamflow variation in the Marmara and Aegean areas differs each other as opposed to the case in January in which the both areas were confined in Region A (Figure 2a). The entire Black Sea coast lines were represented by a single cluster, namely Region B. Southern part of Kizilirmak basin and Konya Closed basin together were identified by Region C in February, representing the boundary of characteristic mid Turkey hydroclimatology. For March, the overall pattern seems somewhere in-between those of January and February, resembling to the latter's map for the west side and to the map of the former for the east side. Region C of March cluster solution remains unchanged but its designation was changed to Region E in February solution. Region F includes Konya Plateau in all monthly analysis except January and February months where annual rainfall frequently is less than 300 mm. In this region, May is generally the wettest month and July and August are the driest season.

Similar detailed evaluations can be made for the remaining months (figures 3, 4 and 5); however, we will introduce common and striking features of the map patterns after this point. There is immense similarity between cluster solutions of January and April, both belonging to different season. In the same context, the map pattern of May, in general, is said to be a replication of that of May and April, implying that spring months demonstrate nearly common cluster pattern. Region F in the cluster solution of April is often appears in most months, composing of the basins 16, 17, 18 and 20, and the stations 2124, 2145 and 2131. This cluster region was also noted by (Kahya and Kalaycı 2002; Kahya *et al.,* 2008). They used an alternative approach that is the

Table 2. Examination of the number of clusters in monthly domain

	January		February		March		April		May		June	
	Suggested	Selected	Suggested	Selected	Suggested	Selected	Suggested	Selected	Suggested	Selected	Suggested	Selected
RMSSTD	6		7		7		4		6		8	
Pseudo F	5	8	8	8	8	8	6	8	7	8	5	8
Dendrogram	6		6		6		6		6		6	

	July		August		September		October		November		December	
	Suggested	Selected	Suggested	Selected	Suggested	Selected	Suggested	Selected	Suggested	Selected	Suggested	Selected
RMSSTD	6		4		5		6		5		4	
Pseudo F	4	8	5	8	5	8	7	8	5	8	6	8
Dendrogram	6		6		6		6		6		6	

Figure 2. Homogeneous streamflow regions for the months: (a) January, (b) February, and (c) March

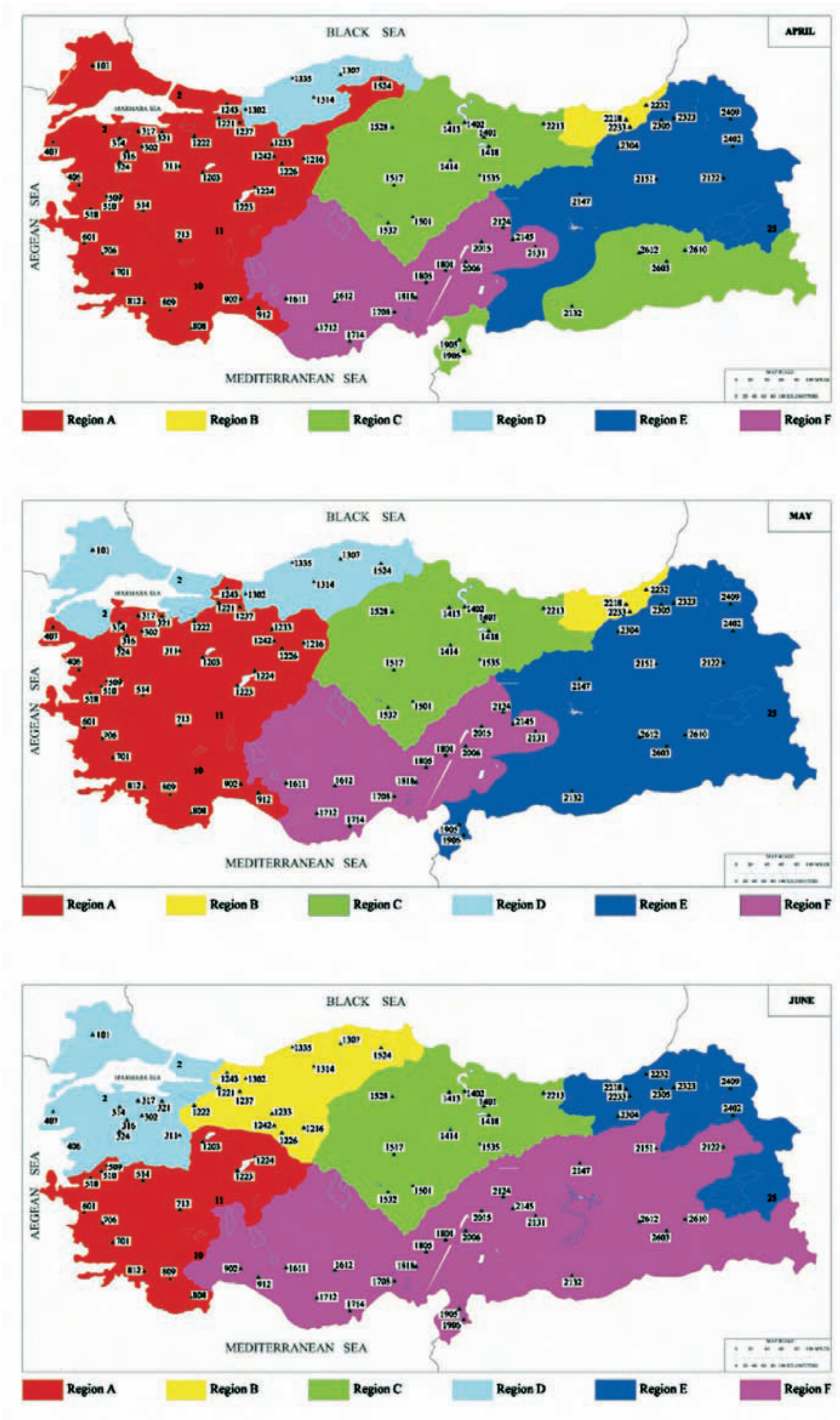

Figure 3: Homogeneous streamflow regions for the months: (a) April, (b) May, and (c) June

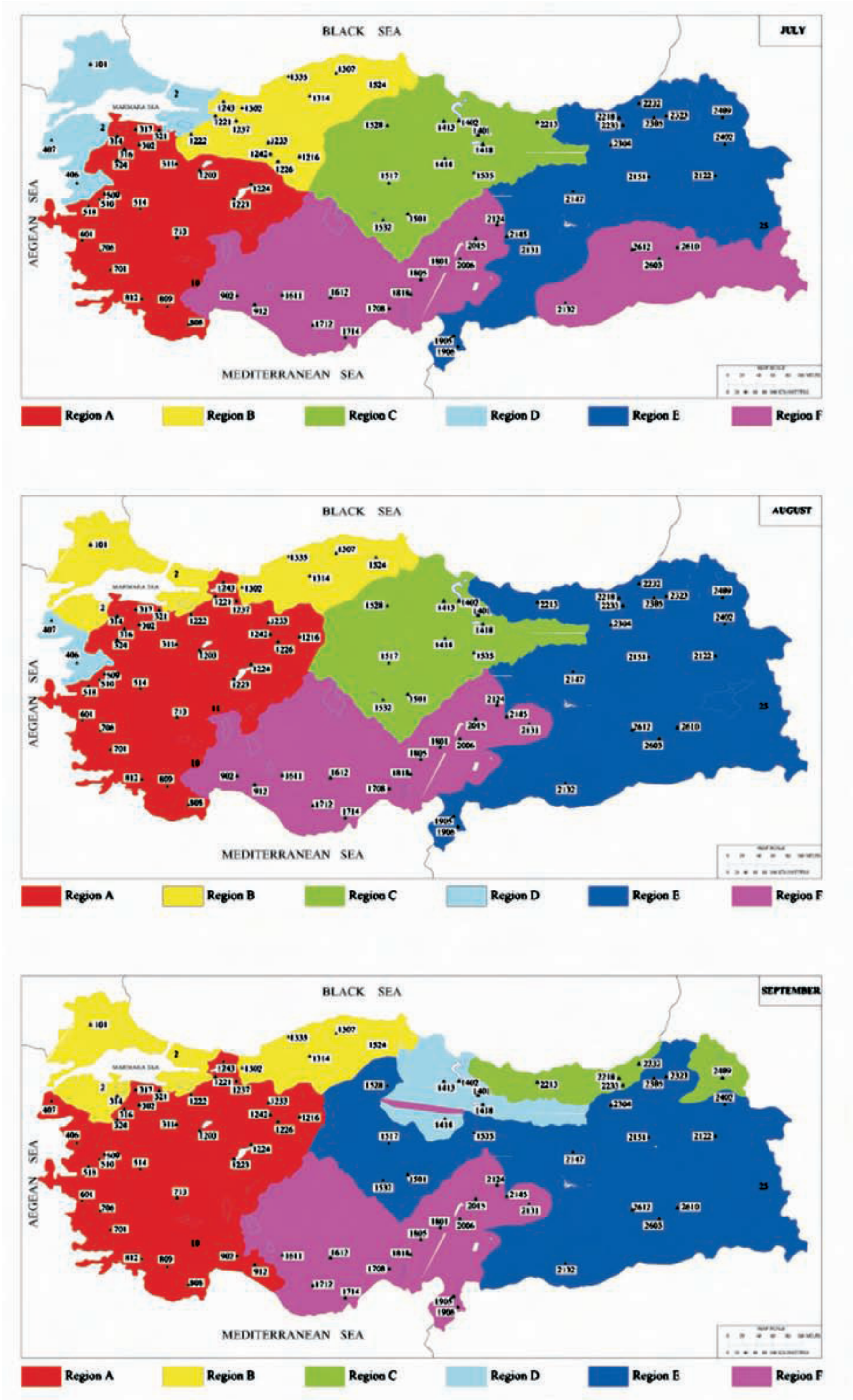

Figure 4. Homogeneous streamflow regions for the months: (a) July, (b) August, and (c) September

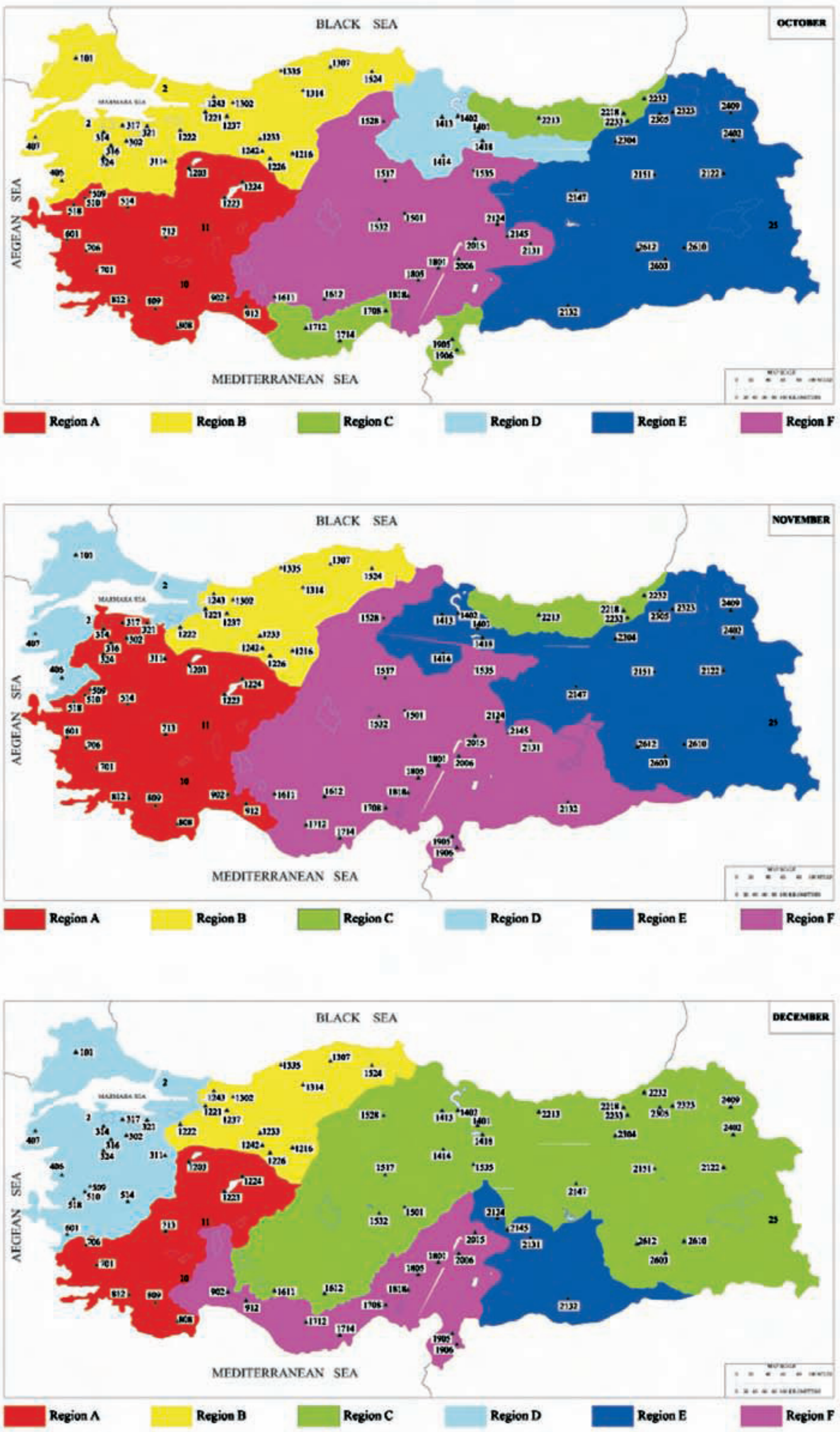

Figure 5: Homogeneous streamflow regions for the months: (a) October, (b) November, and (c) December

rotated principal component analysis. Region E (Figure 3b) is another spatially widespread cluster covering eastern Turkey.

The comparison of all twelve monthly cluster patterns together led us to draw the following features for hydrologic regionalization of Turkish streamflow patterns.

(i) Region C in the cluster solution of October may be the most disaggregated scheme which includes the basins 17, 19 and 22.

(ii) Figure 4 designates that there is no significant change in the map patterns of July, August, and even September.

(iii) The eastern Black Sea basin where current national energy politics mainly rely on this basin was divided into two sub-regions in the analysis of the following months: January, April, May, June and July.

(iv) In two monthly patterns (i.e., June and December), there exists a single cluster (i.e., Region F in Figure 3 and Region C in Figure 4, respectively) occupying almost half of the entire country.

(v) In particular during the months January and April, streamflow stations in the Marmara and Aegean area (marked as Region A in the both cases) reveal common variation modes. For the remaining months, the both regions were included by separate clusters.

(vi) The area described by Region C cluster during the months March, April, May, June, July, and August sequentially appears to delineate the same geographical extent (referring Kizilirmak and Yesilirmak basins), indicating a noticeable temporal persistency as well.

(vii) The cluster defined by Region F constantly emerges with almost same geographical extent (referring Antalya, Konya Closed, Eastern Mediterranean, Ceyhan, and some parts of Firat basins) during the months March, April, May, July, August, and September. It should be noted that this cluster also comes out during the months January, June, and November with a large size. It might be concluded that it is very stable throughout the year.

(viii) The geographical extent defined by the Region E cluster in Figure 2c shows a temporal consistency during the months March, partially in June, July, August, and with much larger area coverage in December.

(ix) The cluster Region D defined in Figure 3b, implying similar streamflow variation mode in the Marmara and western Black Sea areas, appears during the months may, August, September, and with little larger area in October. This cluster includes the basins Meric, Western Black Sea, and some parts of Kizilirmak basins.

Isik and Singh (2008) also applied cluster analysis to the same domain to demonstrate hydrologic regionalization. They included 1410 stations from 26 river basins having at least 5 year data. They used flow duration curves in the analysis to estimate streamflow values at desired ungagued sites after the homogeneous regions were defined by cluster analysis methods. The number of clusters was chosen by hierarchical methods and homogenous regions were delineated by k-means method. They used standard Euclidean distance instead of squared Euclidean that we used in our application as a measure of dissimilarity. Our results for the number of cluster is consistent with those of Isik and Singh (2008). Readers are referred to our recent discussions regarding methodological aspects of the cluster analysis (Demirel *et al.*, 2008a; Demirel *et al.*, 2008b).

Explanations concerning climatological reasoning are out of the scope of this investigation. However, it is very important to document the patterns of monthly precipitation and temperature variables in similar manner, and to relate to the results presented here.

5. Conclusions

Within a river basin, hydrologic processes are integrated into streamflow characteristics; thus, streamflow data provide a natural filter for precipitation data (Piechota *et al.*, 1997) and was preferred unique study-variable in this study. We then set the goals of this investigation as to determine streamflow zones of Turkey, as objectively as possible, and evaluate the stability of solutions based on the feedbacks obtained from variable pre-processing, choosing the best algorithm, and NCL. We specifically considered two measures: the Euclidean and squared Euclidean. Ward's minimum variance method was decided to yield acceptable results in our solutions. Ünal *et al.*, (2003) redefined 7 climatic zones for Turkey as quite different boundaries than conventional classification. Hence in this paper, the number of homogenous cluster is chosen as 6 for month domain according to visual inspection of the dendrogram and two statistics of clusters.

The initial data consisted of monthly average streamflow resulting in a data matrix of 80-station x 31-variable.

(a) The Ward's method with squared Euclidean was found more effective in producing homogenous cluster schemes when comparing to the other HCA methods.

(b) Using monthly patterns seem to be favourable in regard to defining streamflow regions.

(c) Standardization by range is superior to the other techniques.

The outcomes of this study were in a good agreement and relation with earlier studies conducted for, in general, Turkish hydrologic and climatological surface variables. For example, precipitation and streamflow variables showed some significant downward trends in western Turkey (Partal and Kahya 2006; Kahya and Kalayci 2002; Kahya and Kalayci 2004) where we usually assigned Region A in this study. Ünal *et al.*, (2003) who developed a regionalization of climate in Turkey using cluster analysis, pointed out eight regions of similar climate pattern. Some of their regions are quite similar to those found here. However the zones having similar streamflow pattern appeared not overlapped well with the conventional climate zones of Turkey. Although river drainage basins were not a major impetus for the climate divisions in Turkey, which are based primarily on political boundaries with limited attention given to topography and other factors, streamflow variable is strongly recommended for inclusion in the dataset used for climate clustering studies.

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