Discussion of "Hydrologic Regionalization of Watersheds in Turkey" by Sabahattin Isik and Vijay P. Singh

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The authors' extensive efforts on delineation of similar hydrologic regions are important in the germane research field started recently in Turkey. Their study seems to add a new dimension to the work of Demirel (2004) who first attempted to identify groups of stations having similar flow conditions on the national scale using the cluster analysis. The study of Isik and Singh (2008) included many more streamflow gauging stations in the data set and used k-means method as a nonhierarchical approach. The results were consistent with those of Demirel (2004) as six clusters were determined for Turkish river basins.

The discussers have the following suggestions to improve the author's systematic investigation on cluster analysis:

1. Cluster analysis does not require a priori knowledge on data structure such as normality condition as required in other statistical tests (Everitt 1993). On the other hand, if there is a gap in the data set, the construction of distance matrix will not be possible. The number of stations and the span of the years in Isik and Singh (2008) seem in question as their data set unnecessarily comprises many stations (i.e., 1,400 stations), most with a short record length as low as five years. Demirel (2004) examined 257 streamflow gauging stations by using high-resolution (100000:1 or 25000:1) maps of Turkey in terms of regulation, diversion, and such human interventions in accordance with homogeneity concerns raised by Kahya and Karabörk (2001). After this rigorous inspection it was then decided to limit the total number of stations to 80, each having 31-year records, to be included for the analysis. We believe that 5-year data are not sufficient to represent the flow patterns sought; hence, a sufficiently large data set should be implemented. Moreover, the data span in terms of years should be given in the manuscript. A simple gridding process prior to the analysis could be advisable and practical to arrange a vast number of stations spread across the study domain. In this case each grid can be represented by either an averaged series or some chosen numbers of stations (i.e., 1, or 2). Thus this procedure is expected to prevent biased cluster formations as more or less equally weighted contributions from each grid to the entire picture come into play.
2. Streamflow patterns are much more affected by the precipitation spatiotemporal patterns and the hydrogeological settings among other factors. The geographic position of each station is significant in defining homogeneous regions; therefore, there is a topologic relationship among stations in a given watershed.

   For the aforementioned reasons, it would be reasonable to include watershed borders on Fig. 6 of Isik and Singh (2008) to analyze the spatial distribution of the defined cluster within each watershed. This simple task allows exploring relationships such as the association between station's altitude and specific streamflow. Therefore, it is suggested in further investigations to include additional information about both station position (e.g., altitude) and hydrogeological characteristics (e.g., soil type), in addition to monthly streamflows. A good reference on this matter and the use of topology preserving methods, such as self-organizing maps, is Lin and Wang (2006).
3. In the clustering scheme, the selection of similarity/dissimilarity measures and linkage methods used for clustering may indeed significantly affect the results of analysis (Anderberg 1973; Demirel 2004; Everitt 1993).

   In the paper by Isik and Singh (2008), the authors used the Euclidean distance as similarity measure and applied it on standardized data. Both manipulations create smaller scale values so that the objects will tend to be very close to each other in Cartesian coordinates, which later will be difficult to delineate distinctive clusters. To avoid this shortcoming, Ward's algorithm and squared Euclidean metric can be selected because this linkage method, which is considerably more complex than the others, aims to join entities or cases into clusters such that the variance within a cluster is minimized. In addition the squared distance results in clusters more detectable.
4. Arabie et al.(1996) compared seven different standardization techniques and concluded that "The only standardization procedures that were in the superior group in every condition were those methods that standardized by range, namely z_4 and z_5." These relations are expressed here in Eqs. (1) and (2), respectively.

   For streamflow S_{it} for station i in year t, the streamflow index, Z_{it} is computed by

   $$Z_{it} = \frac{S_{it}}{\max(S_{it}) - \min(S_{it})} \tag{1}$$

   $$Z_{it} = \frac{S_{it} - \min(S_{it})}{\max(S_{it}) - \min(S_{it})} \tag{2}$$

   It would be plausible if the authors applied one of these standardization techniques instead of classical approach.
5. There are several techniques to choose the best number of clusters such as cubic clustering criterion (CCC), the pseudo F and pseudo t^2 and dendrogram (Fovell and Fovell 1993; Sarle 1983). The authors preferred the visual evaluation of the dendrogram, RMSSTD, RSQ, and SPRSQ statistics;

however, it would be worthwhile to justify the use of the Ward's clustering method and particularly RMSSTD test. Ward's minimum variance method uses the error sum of squares to reach the iteration number to terminate the clustering process (Bacher 2002; Everitt 1993) (the authors already mentioned "Ward's minimum variance" in the article). Therefore the use of the RMSSTD test, which minimizes the within-cluster variance for the purpose of result affirmation seems unnecessary. If applicable, the pseudotests or CCC would provide more explicit information regarding the number of clusters (Sarle 1983).

6. The test of stability phase in the cluster analysis is crucial to validate the results. Demirel (2004) used a simple method of dividing the data set into two parts and applied the cluster analysis for each part to observe consistency in cluster memberships. We would like to strongly encourage the researchers in the field to consider the book by Bacher (2002) for fruitful germane explanations. The replication schemes for clustering are also available in Breckenridge (2000). Finally, it would be useful to explain why it was not necessary to validate the cluster memberships while the authors were convinced by the coefficients of determination.

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The authors have proposed the mixture of three well-known techniques to classify Turkish runoff measurements at a set of stations scattered all over the country. All of these methods suffer from the consideration of spatial variability, which is a very important component in hydro-meteorological classification studies (Şen and Habib 1998). The authors also rightly state in their introduction that "this way of grouping does not generally work if there is a large amount of spatial variability." Perhaps their approach may be a preliminary mechanical regionalization but recently there is a trend in hydrology literature to use regionalized variables (ReV) approach for spatial feature detection for the purpose of classification into homogeneous regions. The following additional points may help the authors for further reconsideration of their work.

1. The methodology section provides a very simple formulation that is used even by practical hydrologists for many years. Eq. (3) is a logical conclusion without a hydrological background, referred to as area proportionality technique. Further, Eq. (2) is almost one century old (Şen, 2008). Classical specific discharge definition in Eq. (5) already assumes homogenization if there are more than one measurement station in a drainage area. To avoid such an implied assumption would not it be better to consider, for instance, a dimensionless stream flow, $q_d = Q/\bar{Q}$, where $\bar{Q}$ is the average flow of the same station?
2. In Eq. (15) the data has been transformed into a dimensionless form by considering mean and standard deviation value of all available data again with an implied categorization, because in this manner, station-based data are intermingled with all data, which cause loss of station individuality characteristics. Would it be acceptable to use such a standardization station-based mean and standard deviation values?
3. The analysis and results section has rather artificial methodology applications and misconceptions, which can be summarized as follows:
   - In the second paragraph of this section concerning interpretations of graphs in Fig. 2(b-d) of the original paper, the authors do not consider sampling errors and state that "curves decrease after six clusters up to eight clusters and then increase." The reverse is shown in Fig. (2c) of the original paper. Is it not possible that these rather minor fluctuations are due to sampling errors because as the number of clusters increase the number of stations decrease (Table 4)?
   - It is not clear why the authors resort to relative error and coefficient of variation (not coefficient of variance). Eq. (17) is another way of rendering the overall data into dimensionless form. The statement "Since the values of COVs and REs are better in the k-means method than the hierarchical method, it is concluded that the number of stations in the k-means method is better distributed" can be acceptable if the two methods have the same footings. However, they have different assumptions and besides COV variation, the domain for both methods are practically the same, say for instance the lower limits 0.455 and 0.439 are different from each other without 5% relative error, which is acceptable in any hydrological study.
   - The curve fitting (not modeling) in graphs of Fig. (3) of the original paper is subjective and does not have any use in practical applications. Why should they all be of sixth-degree polynomials (coincidence with the number of clusters)? First glance at the graphs on the left-hand side in Fig. (3) practically indicates exponential decrease, which is more practical than sixth-order polynomials. Further, the

authors have R^2 values almost equal to 1 not because of practicality or on physical grounds but to obtain mechanically the best result.
- Only the eastern Black Sea coast is generally rainy throughout the year. Although some parts of the Mediterranean Basin are allocated to the sixth cluster as having highest flows, there are also high flow regions in other parts (Black Sea) of Turkey that do not fall into the same category.

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The writers appreciate the discussion by Sen. The discusser misinterpreted what we wrote in the introduction by saying, "this way of grouping does not generally work if there is a large amount of spatial variability." The previous paragraph states: "Delineation of regions has traditionally been based on geographic, political, administrative, or physiographic boundaries. These regions are then grouped into homogeneous regions in terms of hydrologic response, but this way of grouping does not generally work if there is a large amount of spatial variability in the physiographic or hydrologic characteristics of the catchments in the region (Burn et al. 1997)." We clearly state that traditional delineation does not work in this case and therefore this study was implemented.

The discusser makes three points. First, he argues that the methodology section in the article provides a very simple formulation and he comments on Eq. (2), Eq. (3), and Eq. (5). Eq. (3) and Eq. (5) are derived from Eq. (2). These simple formulations are basic equations in hydrology, and q=average monthly specific streamflow $m^3/s/km^2$ in Eq. (5) is used as input in the study. What the discusser suggests is to use $q_d = Q/\bar{Q}$ for homogeneous regionalization instead of whole study. The problem is: How does one decide on the measurement stations in the same homogeneous region without using a cluster analysis technique? There are more than 100 river gauging stations in some basins. Can one consider all of them in the same homogenous region or how can one separate them if one does not use any cluster analysis technique? Therefore, the suggestion does not practical.

Table 1. Number of Stations versus Record Length in Turkey Watersheds

Length of record (years)	Number of stations
5–9	289
10–14	306
15–19	238
20–24	163
25–29	124
30–34	126
35–39	95
40–49	49
50–64	20

Second, the discusser comments on Eq. (15) by saying. "the data has been transformed into a dimensionless form by considering mean and standard deviation value of all available data again with an implied categorization, because in this manner, station based data is intermingled with all data, which cause loose of station individuality characteristics." It is true that individual station characteristics can be masked by standardizing data but it assumed that all basin boundaries are removed and mean and standard deviation values of all data are used to determine homogeneous regions.

Answers for the third comment are given below:

1. Methods for the optimum cluster determination, given in Fig. 2 (a–d), are commonly used. See, for example, Stahl and Demuth (1999), Everitt et al. (2001), Halkidi, et al. (2002), Chiang et al. (2002), and Unal et al. (2003), among others. Some of the fluctuations can be attributed to sampling errors but the increase in the number of clusters when the number of stations decreases does not necessarily imply sampling errors, because the way this method works is that stations are grouped from the largest to the smallest. As a result, all tests except one indicate the optimum number of clusters as six.
2. The discusser's question is answered in the same section. COV is the degree to which a set of data points varies. Since the aim of both methods is to minimize the sum of squares of variance, COV and RE were used to compare the methods.
3. The paper aims to obtain the best curve fitting in Fig. 3 using computer technology. If one uses a calculator and hand graphing, it is practical to use exponential functions. When one used exponential functions instead of a sixth-degree polynomials for fitting, R^2 decreased from 0.9979 to 0.909 in Fig. 3. The question is: Why should n't one use sixth-degree polynomials if one can get a 9.8% better estimate?
4. There are only 22 stations in the sixth cluster, whereas 35 and 120 stations are in the fifth cluster and the fourth cluster, respectively. It may be not clear in the black and white map but one can see the sixth cluster in the Black Sea coast. Most of the eastern Black Sea area falls into fourth and fifth clusters.

The writers also wish to thank the discussers for their comments and interest in the subject presented in our paper. The authors added a large data set of 1.410 stations to the study to represent geographically the entire country, even though some of the stations have limited length of records, as the discusser argues. The record length is given in Table 1. The length of record of 290 and 525 stations is between 30–64 years and 15–29 years, respectively, whereas the length of record of 595 stations is between 5–14 years. Since q values of data that have limited time span are generally smaller, their effects are also limited, compared to data that have larger record length.

The authors appreciate the discussers for their suggestions to improve the study.

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Discussion of "Validity of Regional Rainfall Spatial Distribution Methods in Mountainous Areas" by Bahram Saghafian and Sima Rahimi Bondarabadi

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The authors have shown that the validity of spatial rainfall distribution models is not reliable for rainfall estimations in mountainous areas. They have mentioned the drawbacks of different methods and suggest the use of Kriging approach in mountainous areas. However, even this method cannot yield reliable estimations of rainfall in mountainous areas because it is based on global semivariogram (SV) model. A more refined approach can be obtained by applying a point cumulative semivariogram (PCSV) approach, which yields different SVs for each station rather than a single regional SV. Conventional areal precipitation assessment methods such as Theissen polygons, isohyets, and alike, though simple and handy, yield physically implausible and accordingly inaccurate results, as the authors state in their paper. It is observed by the authors that the Theissen method provides unrealistic rainfall maps with discontinuity and does not allow incorporation of other factors, such as topography. A detailed account of Theissen polygons and similar methods is presented by Şen (1995) with the suggestion of percentage weighted polygon method, which subdivides the area into polygons by taking into consideration the precipitation records at the measurement sites in addition to the station configuration. Its application is given by Bayraktar et al. (2005) for precipitation measurements in Turkey. Inverse distance method is among the geometrical formulation of the regional dependence, which does not take into account again the rainfall amounts at each site. However, a cumulative semivariogram (CSV) method is proposed as an optimum analysis technique for producing gridded fields of meteorological regional variables that are sampled at irregular sites as sparse data (Şen, 1997). This approach considers the station configuration and the rainfall amounts at these stations for depicting the areal dependence. The experimental CSVs are obtained from monthly rainfall data for northwestern Turkey. Following the interpretation of these experimental CSVs, they are converted into experimental weighting functions necessary for optimum analysis. Comparison of these experimental functions is made on an individual monthly basis with other mathematically simple but geometric weighting functions that are available in the meteorology literature. It is observed that none of the available geometric weighting functions represents completely the regional variation within one month. However, the experimental CSV weighting functions represent regional variability and remain within the domain of various available geometric models. Finally, the rainfall contour maps are produced by using the experimental CSV weighting functions for each month for northwestern Turkey.

The regional distribution of precipitation amounts around each station is presented by Şen and Habib (2000) in relation to station elevation. The extent of orographic mechanism around any station is evaluated by the PCSV) method, which has already been used for the regional precipitation variability modeling of many natural events and recently for the estimation of average areal precipitation by Şen and Habib (1998) and Şen (1989). However, in the cases of two variables with different units, it is necessary to use the standard PCSV (SPCSV) as first suggested by Şen (1992). The comparisons of the elevation and precipitation SPCSVs provide basic data for the orographic and spatial rainfall distribution interpretations. This methodology is helpful for interpretation of the regional and elevation variations in the extent of especially orographic precipitation generating mechanisms such as in mountainous regions. For the application of simple Kriging the authors may use PSCV concept for the clustering of station groups into almost similar behavior groups. Such a grouping is based on the precipitation amounts of each station with its surrounding stations and station configuration. It is hoped that the results will improve significantly.

Fig. 7 in the original paper indicates the scatter of observed and interpolated rainfall (by regression, TPSS 2, and co-Kriging approaches) with elevation, where it is not possible to state that annual rainfall is consistently underestimated in this elevation zone by trends because there is no trend in this scatter diagram. Due to extrapolation none of the methods is capable of estimating rainfall at higher elevations. Such a scattered data can be grouped into a set of similar categories by PCSV approach as suggested by Şen and Habib (1998).

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The discusser promotes the application of point cumulative semivariogram (PCSV) for clustering of rainfall stations and the cumulative semivariogram (CSV) method for producing gridded fields of regional variables measures at irregular sites. It is stated by the discusser that application of such methods could improve mapping of annual rainfall in our case study region.

For this, we must restate the main objective of our paper, which was to study the validity of several interpolation methods—geostatistical methods in particular—in a mountainous region. The study was directed to focus not only on the methods, but also on two distinct regions (i.e., interpolation and extrapolation regions). Rainfall stations are located in the former region, while the latter region is bounded by the stations at lower elevation. Extrapolation remains a major challenge encountered in mapping of rainfall in almost all basins. Since there are numerous interpolation methods and their variants, we had to limit ourselves to a number of methods, thus setting a few criteria in selection of the methods. Besides being known to the engineering community, an important criteria was usability within the existing GIS software. Geostatistical methods are among interpolation techniques that are favored in many engineering studies since they consider spatial structure of data points. Another vital issue was the ability of at least one of the methods to incorporate a covariate in the procedure to examine whether this could result in more accuracy in the extrapolation region. The cokriging method, with elevation as the covariate, was therefore included as an extension of ordinary kriging. While regular cross validation was chosen to determine the accuracy of each method in the interpolation region, a variation of cross validation was performed for the extrapolation region. Visual inspection of scatter plots as well as cumulative distribution functions were also employed to better assess the performance of each method. The latter tool has been well practiced in other engineering fields (Issaks and Srivastava 1989). Another minor objective was to assess the effect of excessive data generation on the accuracy of interpolation.

The results of our studies confirmed the existence of nonstationarity in the rainfall field. This led us to group the region on the basis of Ward's cluster analysis which proved sufficient to secure stationarity in each homogeneous zone. Evaluation of other clustering methods, to include PCSV, requires a detailed study in regions with different characteristics. This was beyond our objectives. Moreover, the density of the stations in the interpolation region was not a major problem in our case study to justify the use of PCSV. We do not think that this method could provide a substantial improvement in the extrapolation region where no station exists.

The results further indicated that TPSS was slightly superior in the interpolation region according to the cross validation error. However, it was shown that TPSS lacked consistency in the extrapolation region. Overall, cokriging performed better, but not sufficiently accurate, in the extrapolation region due its use of elevation as the covariate. This selection was on the basis of cross validation and consideration of the characteristics of the region. Comparison of our selected methods with the CSV, as recommended by the discusser, was not possible via common GIS software. It is believed that the evaluation of other interpolation methods such as CSV would most likely be case study dependent. Furthermore, we found no evidence in the literature that CSV approach is superior in mapping rainfall fields in the extrapolation regions. We generally think that involvement of covariates is required for improvement in extrapolation when using the methods originally developed for interpolation.

We agree with the discusser that Thiessen and simple linear and/or inverse distance methods are unable to provide acceptable rainfall maps, particularly for extrapolating region.

Referring to Fig. 7 (Saghafian and Rahimi 2008), the pattern marks a generally increasing trend of rainfall with the elevation, as indicated by circles in the figure. The interpolated points are underestimated, particularly by TPSS. The use of this figure was simply to facilitate a qualitative assessment of different methods in interpolation and extrapolation regions and discuss drawbacks and under/overestimation of the methods. It was concluded that although cokriging was more consistent with the changes in the region, none of the methods was capable of estimating rainfall at higher elevations.

Last, the suggestions by the discusser to include and compare other clustering and interpolation methods in two will require further works and access to the corresponding software.

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