Discussion of "Rainfall Trend Analysis of Hydrological Subbasins in Western Iran" by Mahsa Farhangi, Majid Kholghi, and Seyyed Ali Chavoshian

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The discussers would like to thank the authors for their study on the trend analysis of rainfall in arid and semiarid regions. They applied the Thom and cumulative summation (CUSUM) tests for investigating, respectively, homogeneity and inconsistencies in the rainfall time series. As the main goal, they used the Mann-Kendall (MK) test for monthly and annual rainfall trend analysis. The work by the authors is really appreciated. The discussers, however, would like to add a few points.

Different parametric (distribution-dependent) and nonparametric (distribution-free) methods, such as covariance analysis, regression, Sen's *T* test, Spearman's rho test and the MK test, are available for analyzing trends of different kinds of data such as annual, monthly, and seasonal time series in the field of water engineering (e.g., Timbadiya et al. 2013; Kisi and Ay 2014). The MK test, which was used in the original paper, can be only used to assess the significance of monotonic trends, and the time series is assumed not to have serial correlation, while almost all the natural hydrometeorological records do not have such features (Kisi and Ay 2014; Şen 2017). Recently, the innovative trend analysis (ITA) technique was introduced by Şen (2012). Innovative trend analysis shows many advantages, such as graphical results with its low, medium, and high values for identifying monotonic and nonmonotonic trends. In ITA, the used data can be normally or nonnormally distributed and can have skewness. There is not any process on data before applying the technique. Furthermore, the ITA technique does not depend on the restrictions in the aforesaid methods, such as serial correlation and size of sample.

In the ITA technique, the given time series are subdivided into two portions with respect to time and then their ascending order series are compared with each other. Taking the first half on the horizontal axis and the second half on the vertical axis, the scatter plot of data can be drawn with a 45° (1:1) line in a Cartesian coordinate system. The same scale should be considered for the ordinate and abscissa axes with the same length. While any deviation from the 1:1 line indicates trend existence, this line corresponds to a trend-free case. The upper and lower triangular areas of the Cartesian coordinate system correspond to increasing and decreasing trend regions, respectively. There is a monotonic trend in the time series if the scatter plot of data appears along a straight line parallel to a 1:1 line. A composition of various trends or trend-free portions in the time series yields a nonmonotonic trend.

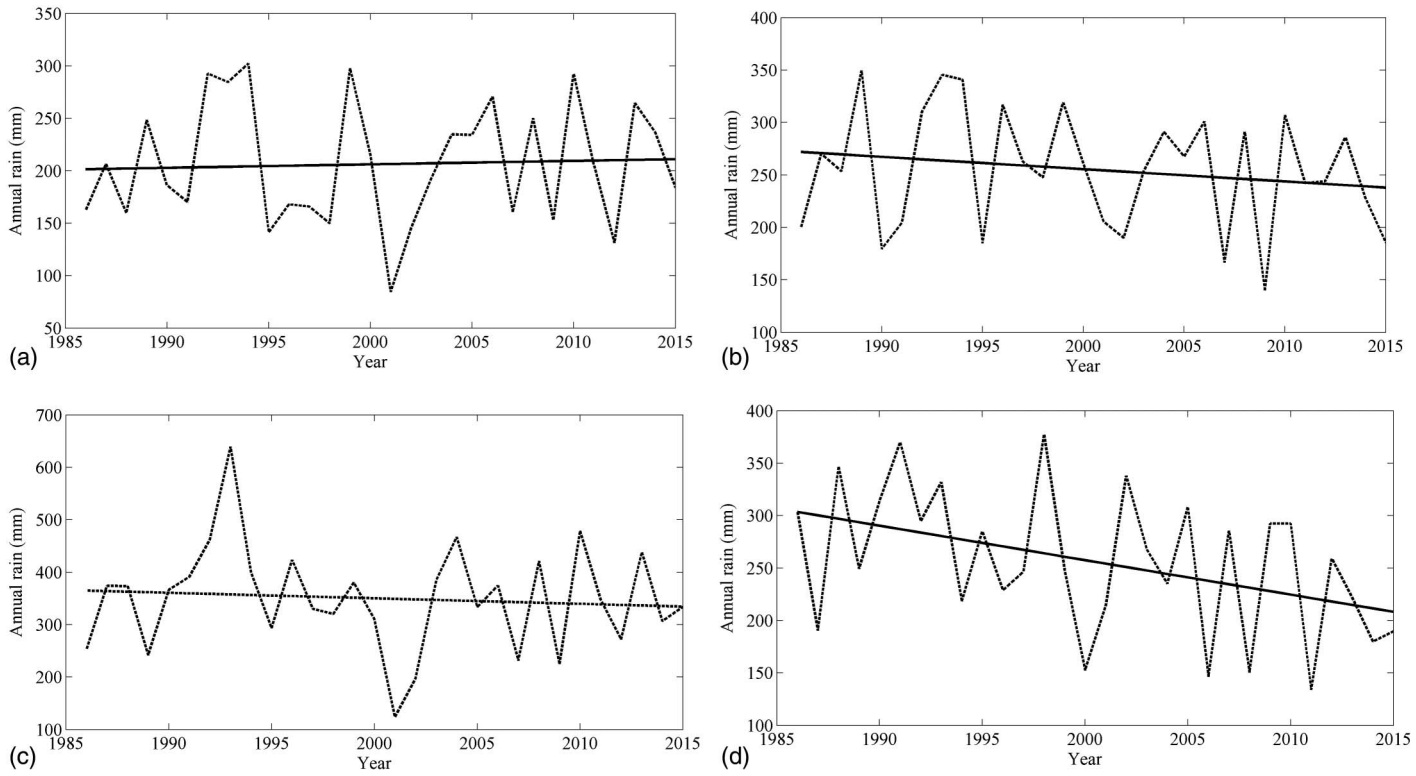

Fig. 1. Time series of annual rains (in millimeters) at the (a) Mashhad, (b) Ardak, (c) Zoshk, and (d) Kardeh gauge stations

Moreover, the segmentation of the scatter plot of data into three clusters as low, medium, and high can be considered to give detailed information of the internal trend structure of the time series.

For the comparison of the performance of the MK test and the ITA technique, four rain gauge stations (Mashhad, Ardak, Zoshk, and Kardeh with average rainfall 206, 255, 350, and 256 mm, respectively) in the Mashhad subbasin of Iran with a cold and semidry climate, which is part of the country of the study area of the original paper, are selected. For analyzing the trend of annual rainfall in the stations, a plot of time series of annual rainfalls will be investigated, as well as the MK test and the ITA technique. Annual rainfalls from 1986 to 2015 have been analyzed. Before the application of trend analysis methods, all the data are checked for homogeneity, and the results indicate there is no artificial effects such as hydraulic structures.

Time series of annual rainfalls (mm) at the four considered stations are depicted in Fig. 1. From the figure, it can be seen that the trends of annual rainfalls are gradually decreasing in the Ardak and Zoshk stations and gradually increasing in the Mashhad station with the passage of time. The trend line of the Kardeh station shows rapidly decreasing annual rainfall.

The Mann-Kendall statistic (Z) for average annual rainfall time series of the Mashhad, Ardak, Zoshk, and Kardeh stations, respectively, are 0.18, −1.08, −0.21, and −2.27. Therefore, based on the MK test, the three former stations do not have significant trend at the 95% confidence level, while the latter one indicates a significant decreasing trend at this confidence level.

The results of the ITA technique are shown in Fig. 2. It can be seen that the Ardak and Kardeh stations indicate a significant decreasing trend for all low, medium, and high values, whereas the Mashhad and Zoshk stations do not have a similar trend for different clusters of annual rainfalls. For the Mashhad station, low and high clusters indicate a decreasing trend, while the medium cluster shows an increasing trend. For the Zoshk station, the medium cluster does not have a significant trend, while the low and high clusters indicate a significant decreasing trend. Fig. 2(a) indicates a significant nonmonotonic trend at the Mashhad station, while Fig. 2(d) is an example of a monotonic trend at the Kardeh station.

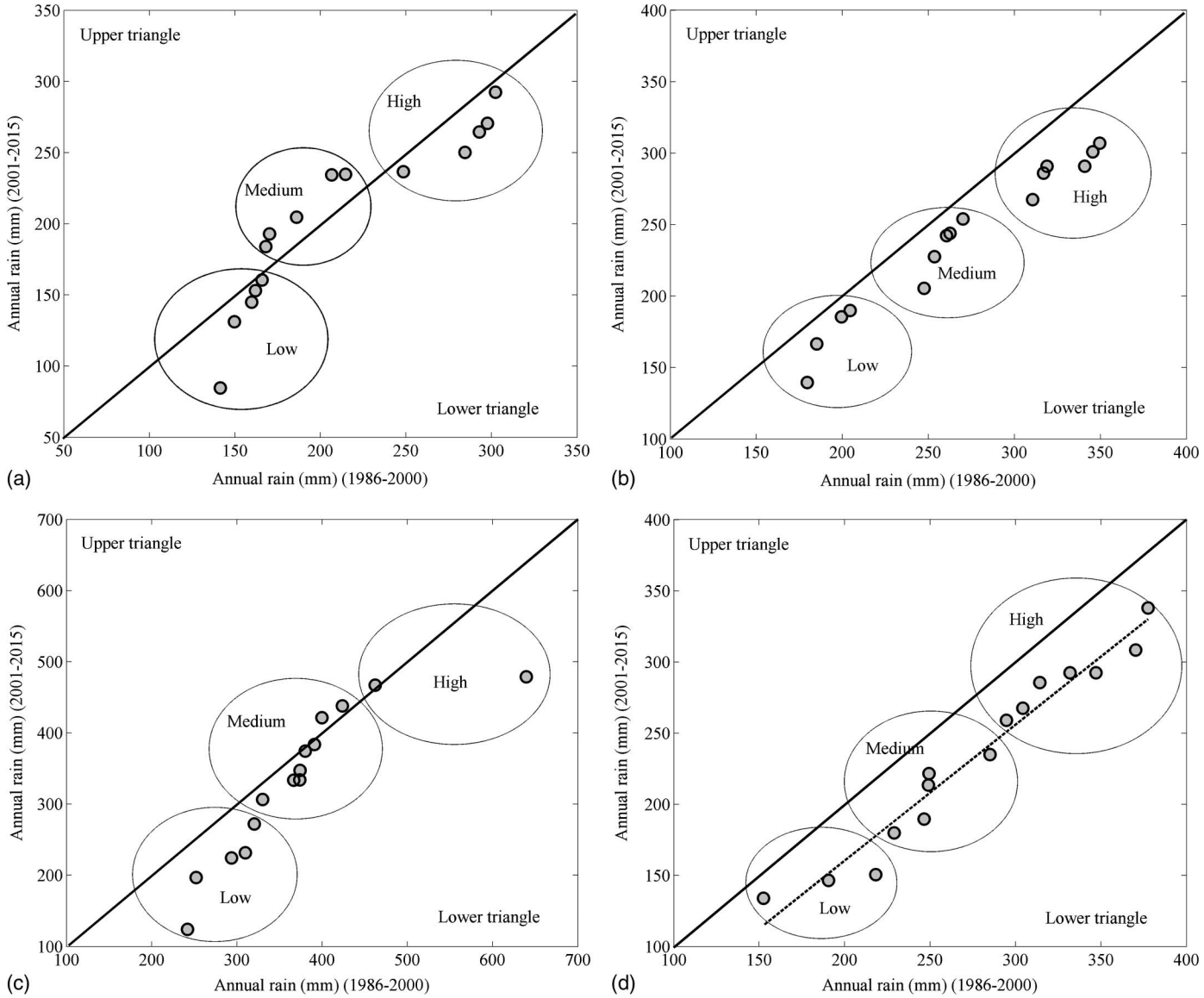

Fig. 2. Trend analysis of annual rains (in millimeters) using the ITA technique at the (a) Mashhad, (b) Ardak, (c) Zoshk, and (d) Kardeh gauge stations

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Concluding, it can be said that although there was significantly no trend in some stations according to the MK test, increasing, decreasing, or no trend were seen for the same stations with respect to the ITA technique. Moreover, based on plots of time series, the general trend of data can be observed, while the ITA technique can capture different trends (i.e., increasing, decreasing, or no trend) for three clusters (i.e., low, medium, and high clusters). Therefore, the results of the original paper are confined to the limitations of the MK test and plots of the time series analysis.

The discussers agree with the authors that the main problem in arid and semiarid regions is the high variation of the rainfall in time, space, intensity, and duration, which causes several sources of complexity for the trend analysis. The discussers hope that the use of the ITA technique can improve this analysis. The innovative feature of the technique lies in that trends of all ranges of the data (i.e., low, medium, and high records) with respect to time can be studied on the Cartesian coordinate system. Spatial trend analysis of the rainfall can also be investigated by considering low, medium, and high values. Regardless of the advantages of the ITA technique, the results of it is graphical and not quantitative, which should be considered in future studies.

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