Analysis of trends of hydrologic and climatic variables

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Abstract: Assessing trends of hydrologic variables related to both hydrologic processes facilitates accurate water resources forecasting, especially in arid and semiarid regions with high evaporation and low rainfall volume. In this study, spatial and temporal trends of six hydrologic and climatic variables, viz. rainfall, evaporation, streamflow discharge, temperature, wind speed and relative humidity and also the ratio of annual potential evaporation to precipitation (E/P) were analysed at a monthly and annual scale. Moreover, the relationship of relative humidity, temperature, rainfall and wind speed trends with evaporation trend was investigated. Results of the study revealed the absence of significant temporal trend in precipitation, temperature and wind velocity for the majority of months, and the presence of upward trends in relative humidity and evaporation values as well as downward trend in streamflow discharge in some months. At an annual scale increasing evaporation and decreasing stream flow discharge trends were observed at most stations, which means that the region will be confronted with more severe drought conditions in future. Also, the result of Spearman's rank coefficient revealed that the temporal evaporation trend is not related to wind speed, temperature, relative humidity and rainfall trend. Moreover, the spatial trend of climatic and hydrologic variables indicated the similarity of evaporation and relative humidity trend as well as wind speed and rainfall trend.

Keywords: aridity index; nonparametric test; streamflow; watershed

Planning for water resources management projects depends on observational and historical hydrologic and climatic data (CHEN et al. 2007) as well as powerful analysis techniques necessary to identify hydrological behaviour of watersheds. In this regard, assessing trends of hydrologic variables related to both hydrologic processes facilitates accurate water resources forecasting (ISTANBULLUOGLU et al. 2012) especially in arid and semiarid regions with high evaporation and low rainfall volume. Concerns about climate change impacts (IPCC 2007) on the behaviour of hydrologic variables tend to extensive studies to specify trends of hydrologic and climate variables (Burn et al. 2002; Partal & Kahya 2006; Xu et al. 2007; Gocic & Trajkovic 2013; Dimkić 2017; Şen 2017). For instance; analysing the streamflow trend in some parts of the world explained a significant or insignificant trend (DOUGLAS et al. 2000; LINS & SLACK 2005; Petrow & Merz 2009; Stewardson & Chiew 2009; Stahl et al. 2010, 2012; Niazi et al. 2014; Chen & Grasby 2014; Zhang et al. 2016; My-

RONIDIS et al. 2018) and identifying the trend of climatic variables such as precipitation, temperature, evaporation indicated an increasing or decreasing status or non-existence of climate change in each region (Partal & Kahya 2006; Modarres & Silva 2007; MILLER & PIECHOTA 2008; KUMAR et al. 2009; Xu et al. 2010; Wang et al. 2012; Jhajharia et al. 2014; Sharma & Walter 2014; Gajbhiye et al. 2016; YANG et al. 2017; TORIDE et al. 2018). Assessment of a trend in any system variable for investigating the water budget system is a necessity (ISTANBULLUOGLU et al. 2012). Moreover, evaluating hydrologic trends in man-made conditions such as urban catchments revealed a land use change and effects of climatic variables simultaneously (BRAUD et al. 2013; SUN et al. 2016). The trend tests are classified into parametric and nonparametric, and mixed types. Parametric tests are powerful and more sensitive to detect significant trends than nonparametric tests, especially for small sample numbers (MEALS et al. 2011). The assumption of normal distribution for parametric statistics does

not exist in most cases. Therefore, a nonparametric test such as Mann-Kendall statistical test (Mann 1945; Kendall 1975) has been applied to assess the importance of a trend (Douglas *et al.* 2000; Yue & Pilon 2004; Bouza-Deaño *et al.* 2008; Drápela & Drápelová 2011; Şen 2013) and the significant positive autocorrelation of Mann-Kendall result has been removed by applying the theoretical relationship (Hamed & Rao 1998; Hamed 2008). This test has been applied to detect trends for environmental, meteorological, and hydrologic variables (Liang *et al.* 2011; Gajbhiye *et al.* 2016; Sarita *et al.* 2016; Yang *et al.* 2017).

Human activities and climate change may affect the hydrological behaviour of the watershed and this study highlights climate variables and hydrologic trend of the region for this purpose. In spite of many researches on trends of climatic and hydrologic variables such as rainfall, temperature, and streamflow discharge, the trend of relative humidity and wind speed was studied in few researches (Kousari & Asadizarch 2011; Şimşek 2013; Tabari & Talaee 2013; Eymen & Köylü 2018) and their relationship with evaporation trend has not been investigated in arid regions. In this study, spatial and temporal trends of six hydrologic and climatic variables viz. rainfall, evaporation,

streamflow discharge, temperature, wind speed and relative humidity and also ratio of annual potential evaporation to precipitation (E/P) were analysed at a monthly and annual scale and finally the relationship of relative humidity, rainfall, temperature and wind speed trend with evaporation trend were investigated.

MATERIAL AND METHODS

Study area. The studied watershed is bounded by latitude 33°30' to 35°30'N and longitude 49°30' to 51°30'E with a total area of 2 755 673 hectares located in the central part of Iran in Qom Province, Iran. The studied watershed has five climate stations viz. Salarie, Aghalak, Veshnaveh, Koohesefid and 15 Khordad Dam(Figure 1). In this research, data from four stations were analysed because one of them did not have enough data (Veshnaveh station). Based on the De Marton climate categorization, this watershed was classified as an arid region with the average annual rainfall volume of 162.79 mm and annual rainfall volume variation from 41.5 to 225 mm.

Also, there are 12 hydrometer stations in this area, whereas 8 stations (Aghalak, Emamzadeh Esmaeel, Emamzadeh Abdollah, Sanjegan, Shadabad, Ghom-

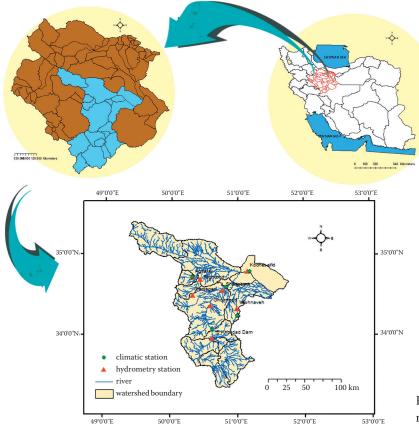


Figure 1. Location of climatic and hydrologic stations in the study area

Table 1. Annual Mann-Kendall test *P*-values for climatic variables

Station	Wind speed	Temperature	Evaporation	Relative humidity	Rainfall	Evaporation to rainfall ratio
15 Khordad Dam	0.138	0.279	0.023	0.038	0.592	0.711
Aghalak	0.012	0.451	0.034	0.064	0.373	0.070
Koohesefid	0.133	0.928	0.020	0.005	0.897	0.009
Salarieh	0.188	0.000	0.006	0.106	0.180	0.054

rood, Toghrood, 15 Khordad Dam) with enough data were employed for trend detection. Datasets of 144 months and 12 years (from 2001 to 2013) were obtained from the region water department of Qom province.

Statistical analysis. In this study, modified Mann-Kendall (MMK) test was employed to analyse the temporal monthly and annual trend of rainfall, streamflow discharge, evaporation, temperature, relative humidity and wind speed whereas the trend of the annual ratio of evaporation to precipitation, the aridity index described by Вируко (1974), was applied to describe the spatial and temporal trend of runoff production in the region. In Budyko's aridity index, runoff occurs when the ratio of E/P < 1. Moreover, the annual spatial distribution of runoff potential and other variables were obtained by Arc-GIS (Ver. 10.2, 2013). Also, Spearman's correlation coefficients were applied to investigate the relationship between evaporation and other climatic variables such as temperature, rainfall, wind speed and relative humidity.

RESULTS AND DISCUSSION

Temporal trend. For rainfall, on a monthly basis, a declining trend can be seen in May and April at the 15 Khordad Dam station and for Aghalak station such a trend is observed in May and December. Also,

there is a declining trend at Koohesefid station in February and October whereas Salarieh station has a decreasing trend in September and August (Figure 2). On an annual basis, all stations are without trend (Table1).

Streamflow discharge at Aghalak station has a decreasing trend in May, August and September while Emamzadeh Esmaeel station shows a downward trend in May, April, March, January and December. At Emamzadeh Abdollah station, there is a trend of decline except for February, January and December whereas at Sanjegan station a decreasing trend can be observed in May, April, January, March and December. At Shadabad station, there is a decreasing trend in all months except for October while at Ghomrood station the declining trend exists in June, May, February, January, December and November. Toghrood station has a decreasing trend for all months except for two months of October and September and also at 15 Khordad Dam station, the downturn trend can be seen in July, June, May, February, November, September and October (Figure 3). At an annual scale, the declining trend can be seen at five stations viz. Emamzadeh Esmaeel, Emamzadeh Abdollah, Sanjegan, Shadabad and Toghrood (Table2).

As can be seen in Figure 4, investigating the evaporation trend at a monthly scale revealed that 15 Khordad Dam station has a downward status in August, March, January, November and October

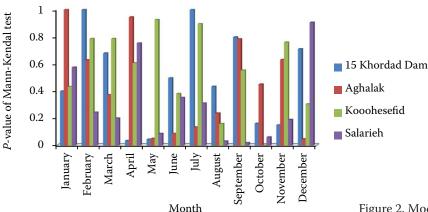
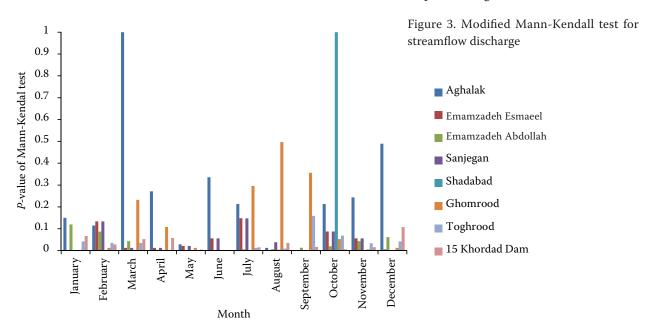


Figure 2. Modified Mann-Kendall test for rainfall



whereas Aghalak station has an upward trend in five months viz. in May, January, December, November and September. At Koohesefid station an increasing trend can be observed in March, February, December, January and November while at Salarieh station, there is an increasing trend in two months of August and November and a decreasing trend in two months of February and January. On an annual basis, Salarieh station does not show any trend; Aghalak and Koohesefid stations have an increasing trend while 15 Khordad Dam station has a decreasing trend (Table 1).

Figure 5 shows the results of the relative humidity trend on a monthly basis. At 15 Khordad Dam station, there is an increasing trend in August, April, March, February, January, December, November, October and September while at Aghalak station an increasing trend can be seen in January and September. At Koohesefid station, there is an increasing trend

Table 2. Annual Mann-Kendall test *P*-values for hydrologic variables

Station	
Aghalak	1.000
Emamzadeh Esmaeel	0.038
Emamzadeh Abdollah	0.004
Sanjegan	0.038
Shadabad	0.000
Ghomrood	0.202
Toghrood	0.024
15 Khordad Dam	0.184

in all months except for January, March, December and September while at Salarieh station there is an increasing trend in four months of September, August, December and October. The annual trend analysis

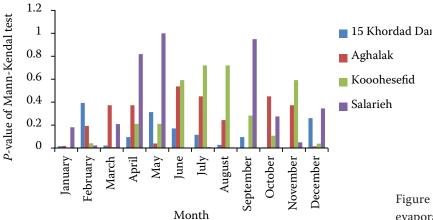
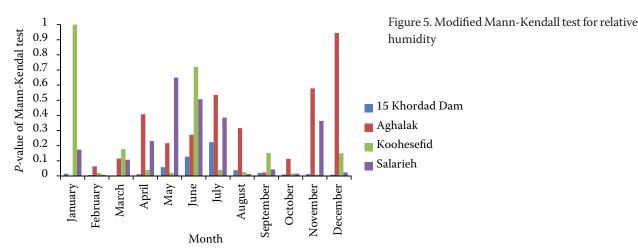


Figure 4. Modified Mann-Kendall test for evaporation



revealed that 15 Khordad Dam station and Koohesefid station have an increasing trend while Aghalak and Salarieh stations are without trend (Table1).

Analysis of the trend of temperature (Figure 6) at a monthly scale at 15 Khordad Dam station revealed an increasing status in June and May while no trend can be seen at Aghalak and Koohesefid stations. At Salarieh station, there is an increasing trend except for the months of April, December, November and October. At an annual scale, the increasing trend can be seen only at Salarieh station (Table 1). Also, the wind speed on a monthly basis has a decreasing trend at 15 Khordad Dam station in August, July, June and November while at Aghalak a decreasing trend can be observed in August (Figure 7). At Koohesefid and Salarieh stations there is no trend whereas: at an annual scale, a decreasing trend exists except for Aghalak (Table1). In the study area, the value of the annual evaporation to precipitation ratio (E/P) does not show any trend at 3 stations, viz. 15 Khordad Dam, Aghalak, Salarieh whereas only one station named as Koohesefid has an upward trend (Table 1). **Spatial trend**. The values of the spatial mean annual evaporation trend show that a decreasing evaporation trend from northwest to southeast is similar to the relative humidity trend. As can be seen in Figure 8, relative humidity and rainfall trends vary from northwest to southeast similar to each other. Moreover, wind speed and rainfall trends are similar to each other while a decreasing spatial temperature trend was revealed from northeast to southwest. Also the values of streamflow discharge trend are increasing from west to east and the trend of annual evaporation to rainfall ratio is decreasing from south to north.

Relationship between temperature, relative humidity, wind speed, rainfall and evaporation. Spearman's rank correlation coefficient was used to study the relations of evaporation with climate factors such as temperature, wind speed, relative humidity and rainfall. The results indicate that the relationship between the evaporation trend and four factors such as rainfall, relative humidity, wind speed and temperature is not significant (Table 3).

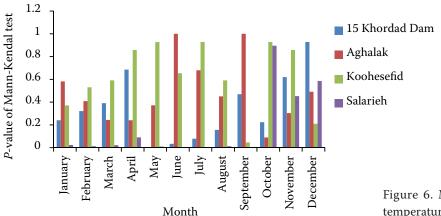


Figure 6. Modified Mann-Kendall test for temperature

1.200 P-value of Mann-Kendal test 1.000 0.800 0.600 15 Khoradad Dam Aghalak 0.400 Koohesefid 0.200 Salarieh 0.000 June October November August September March May December February

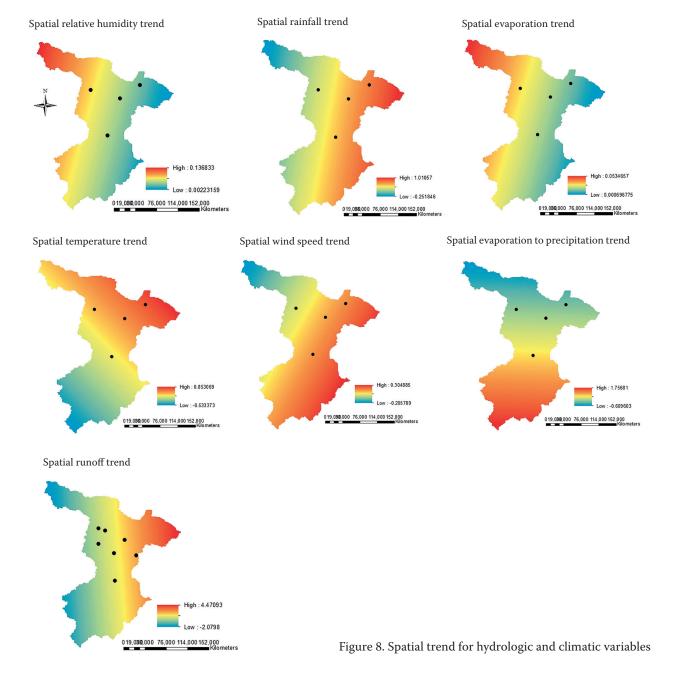
Figure 7. Modified Mann-Kendall test for wind speed

Changes in hydrologic and climatic datasets could be assessed by statistical significance testing (Liu et al. 2008; Hannaford & Buys 2012; Sayemuzzaman & Jна 2014). Results of this study revealed a temporal decreasing trend in rainfall at a monthly scale whereas no such trend exists at an annual scale. The evaporation trend analysis on a monthly basis verified that all stations except for one station (15 Khordad Dam) have an upward trend. Moreover, on an annual basis, two stations have an increasing trend and 15 Khordad Dam station has a decreasing trend again. As described before, all climatic stations were located in a nonhumid environment. As a result, the decreasing trend of evaporation at 15 Khordad Dam station was not a good index for potential evaporation and may explain a powerful signal of increasing terrestrial evaporation (Brutsaert & Parlange 1998). The increasing trend emphasizes the necessity of implementations for reducing an evaporation rate in the region. The analysis of temperature trend shows that two stations are without trend while others have an upward trend at a monthly scale in some months. Moreover, at an annual scale one station has an upward trend. The difference in temperature and evaporation trend verified that the evaporation rate is not controlled only by temperature (DIBALDASSARRE & MONTANARI 2009) and the existing upward trend of temperature at some stations could not necessarily explain a significant increase in the evaporation trend. The investigation of relative humidity trend verified an increasing trend at all stations at a monthly scale whereas two stations were observed with increasing status and the rest showed no trend at an annual scale. A decreasing trend of wind speed was observed in half of the stations and the other stations were without trend at a monthly scale whereas at an annual scale a downward trend existed except for one station. The increasing relative humidity trend and decreasing wind speed at some stations agreed with EYMEN and KÖYLÜ (2018) results. Applying Spearman's coefficient for realizing evaporation trend relationship with other climatic variables trend resulted in the P-value of more than α (0.05) which verified that the relation of temperature, wind speed and relative humidity trends with evaporation trend was insignificant at the level of 0.95. As changes in water availability that originated from changes in precipitation may affect an evaporation trend (MAO $et\ al.\ 2015$), in this study the relation of precipitation and evaporation trend was investigated at the significance level of 0.05 which revealed that there is no relation between precipitation and evaporation trend.

Detection of the streamflow discharge trend indicated a declining trend at all stations at a monthly scale and in five of the eight stations at an annual scale. In most cases an increasing evaporation trend corresponds with a decreasing streamflow discharge trend, which highlights the effect of climate factors on hydrologic variables. In the majority of cases the non-existence of temporal trend for the evaporation to precipitation ratio also revealed the variability of runoff production in the region. The investigation of spatial trend verified that an evaporation trend is the same as relative humidity and is not similar to the

Table 3. Spearman's rank coefficient between evaporation and other climatic variables

Variable	Sig. (2-tailed)
Relative humidity	0.108
Temperature	0.226
Wind speed	0.120
Rainfall	0.226



temperature and wind speed trend. Also, rainfall is correspondent with wind speed, which emphasizes their same trend direction significance in the study area. Moreover, the evaporation to rainfall ratio and streamflow discharge trend are not the same, which revealed that produced surface runoff in the region

CONCLUSION

does not affect streamflow discharge.

Using the Mann-Kendall test the present study analysed spatial and temporal trends at an annual

and monthly scale in wind speed, relative humidity, temperature, evaporation, rainfall and flow discharge in the study area located in Qom province. The results revealed the absence of significant temporal trend in precipitation, temperature and wind velocity for the majority of months, and the presence of upward trends in relative humidity and evaporation values as well as downward trend in streamflow discharge in some months. At an annual scale increasing evaporation and decreasing streamflow discharge trends were observed at most stations, which means that the region will be confronted with more severe drought

conditions in future and emphasizes the attention to climate change and water resources management. As a result, anthropogenic activities such as land use change and groundwater overexploitation which may affect streamflow discharge and evaporation rates should be paid attention. Also, the result of Spearman's rank coefficient revealed that the temporal evaporation trend is not correlated with wind speed, temperature, relative humidity and rainfall trend. Moreover, the spatial trend of climatic and hydrologic variables indicated the similarity of evaporation and relative humidity trend as well as wind speed and rainfall trend.

References

- Bouza-Deaño R., Ternero-Rodríguez M., Fernández-Espinosa A.J. (2008): Trend study and assessment of surface water quality in the Ebro River (Spain). Journal of Hydrology, 361: 227–239.
- Braud I., Breil P., Thollet F., Lagouy M., Branger F., Jacqueminet C., Michel K. (2013): Evidence of the impact of urbanization on the hydrological regime of a medium-sized periurban catchment in France. Journal of Hydrology, 485: 5–23.
- Brutsaert W., Parlange M.B. (1998): Hydrologic cycle explains the evaporation paradox. Nature, 396: 1–30.
- Budyko M.I. (1974): Climate and Life. San Diego, Academic Press.
- Burn D.H., Hag Elnur M.A. (2002): Detection of hydrologic trends and variability. Journal of Hydrology, 255: 107–122.
- Chen Z., Grasby S.E. (2014): Reconstructing river discharge trends from climate variables and prediction of future trends. Journal of Hydrology, 511: 267–278.
- Chen H., Guo S., Xu C., Singh V.P. (2007): Historical temporal trends of hydro-climatic variables and stream flow discharge response to climate variability and their relevance in water resource management in the Hanjiang basin. Journal of Hydrology, 344: 171–184.
- DiBaldassarre G., Montanari A. (2009): Uncertainty in river flow discharge observations: a quantitative analysis. Hydrology and Earth System Sciences, 13: 913–921.
- Dimkić D. (2017): Present and future mean hydrologic trends in Serbia as a function of climate trends. Desalination and Water Treatment, 99: 10–17.
- Douglas E.M., Vogel R.M., Kroll C.N. (2000): Trends in floods and low flows in the United States: impact of spatial correlation. Journal of Hydrology, 240: 90–105.
- Drápela K., Drápelová I. (2011): Application of Mann-Kendall test and the Sen's slope estimates for trend detection in deposition data from Bílý Kříž (Beskydy Mts., the Czech Republic) 1997–2010. Beskydy, 4: 133–146.

- Eymen A., Köylü Ü. (2018): Seasonal trend analysis and ARIMA modeling of relative humidity and wind speed time series around Yamula Dam. Meteorology and Atmospheric Physics, 2018: 1–12.
- Gajbhiye S., Meshram C.M., Mirabbasi R., Sharma S.K. (2016): Trend analysis of rainfall time series for Sindh river watershed in India. Theoretical and Applied Climatology, 125: 593–608.
- Gocic M., Trajkovic S. (2013): Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. Global and Planetary Change, 100: 172–182.
- Hamed K.H. (2008): Trend detection in hydrologic data: the Mann–Kendall trend test under the scaling hypothesis. Journal of Hydrology, 349: 350–363.
- Hamed K.H., Rao A.R. (1998): A modified Mann-Kendall trend test for auto correlated data. Journal of Hydrology, 204: 182–196.
- Hannaford J., Buys G. (2012): Trends in seasonal river flow regimes in the UK. Journal of Hydrology, 475: 158–174.
- IPCC (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press.
- Istanbulluoglu E., Wang T., Wright O.M., Lenters J.D. (2012): Interpretation of hydrologic trends from a water balance perspective: The role of groundwater storage in the Budyko hypothesis. Water Resources Research, 48: 1–22.
- Jhajharia D., Dinpashoh Y., Kahya E., Choudhary R.R., Singh V.P. (2014): Trends in temperature over Godavari river watershed in southern peninsular India. International Journal of Climatology, 34: 1369–1384.
- Kendall M.G. (1975): Rank Correlation Measures. London, Charles Griffin Book Series.
- Kousari M.R., AsadiZarch M.A. (2011): Minimum, maximum, and mean annual temperatures, relative humidity, and precipitation trends in arid and semi-arid regions of Iran. Arabian Journal of Geosciences, 4: 907–914.
- Kumar S., Merwade V., Kam J., Thurner K. (2009): Streamflow trends in Indiana: Effects of long term persistence, precipitation and subsurface drains. Journal of Hydrology, 374: 171–183.
- Liang L., Li L., Liu Q. (2011): Precipitation variability in Northeast China from 1961 to 2008. Journal of Hydrology, 404: 67–76.
- Lins H.F., Slack J.R. (2005): Seasonal and regional characteristics of US stream flow trends in the United States from 1940 to 1999. Physical Geography, 26: 489–501.
- Liu Q., Yang Z.F., Cui B.S. (2008): Spatial and temporal variability of annual precipitation during 1961–2006 in Yellow River Watershed, China. Journal of Hydrology, 361: 330–338.

- Mann H.B. (1945): Non-parametric test against trend. Econometrica, 13: 245-259.
- Mao J.F., Fu W.T., Shi X.Y., Ricciuto D.M., Fisher J.B., Dickinson R.E., Wei Y.X., Shem W., Piao S.L., Wang K.C., Schwalm C.R., Tian H.Q., Mu M.Q., Arain A., Ciais P., Cook R., Dai Y.J., Hayes D., Hoffman F.M., Huang M.Y., Huang S., Huntzinger D.N., Ito A., Jain A., King A.W., Lei H.M., Lu C.Q., Michalak A.M., Parazoo N., Peng C.H., Peng S.S., Poulter B., Schaefer K., Jafarov E., Thornton P.E., Wang W.L., Zeng N., Zeng Z.Z., Zhao F., Zhu Q.A., Zhu Z.C. (2015): Disentangling climatic and anthropogenic controls on global terrestrial evapotranspiration trends. Environmental Research Letters, 10: 10.1088/1748-9326/10/9/094008.
- Meals D.W., Spooner J., Dressing S.A., Harcum J.B. (2011): Statistical Analysis for Monotonic Trends. Tech Notes 6, Fairfax, Tetra Tech.
- Miller W.P., Piechota T.C. (2008): Regional analysis of trend and step changes observed in hydroclimate variables around the Colorado River basin. Journal of Hydrometeorology, 9: 1020–1034.
- Modarres V., Silva R. (2007): Rainfall trends in arid and semi-arid regions of Iran. Journal of Arid Environments, 70: 344–355.
- Myronidis D., Ioannou K., Fotakis D., Dörflinger G. (2018): Streamflow and hydrological drought trend analysis and forecasting in Cyprus. Water Resources Management, 32: 1759–1776.
- Niazi F., Mofid H., FazelModares N. (2014): Trend analysis of temporal changes of flow discharge and water quality parameters of Ajichay River in four recent decades. Water Quality, Exposure and Health, 6: 89–95.
- Partal T., Kahya E. (2006): Trend analysis in Turkish precipitation data. Hydrological Processes, 20: 2011–2026.
- Petrow T., Merz B. (2009): Trends in flood magnitude, frequency and seasonality in Germany in the period 1951–2002. Journal of Hydrology, 371: 129–141.
- Sarita G., Meshram C., Mirrabasi R., Sharma S.K. (2016): Trend analysis of rainfall trend series for Sindh river watershed in India. Theoretical and Applied Climatology, 125: 593–608.
- Sayemuzzaman M., Jha M.K. (2014): Seasonal and annual precipitation time series trend analysis in North Carolina, United States. Atmospheric Research, 137: 183–194.
- Şen Z. (2013): Trend identification simulation and application. Journal of Hydrologic Engineering, 19: 635–642
- Şen Z. (2017): Hydrological trend analysis with innovative and over-whitening procedures. Hydrological Sciences Journal, 62: 294–305.
- Sharma A.N., Walter M.T. (2014): Estimating long-term changes in actual evapotranspiration and water storage using a one-parameter model. Journal of Hydrology, 519: 2312–2317.

- Şimşek O. (2013): Trend analysis of some meteorological data in Hatay. SDU International Technologic Science, 5: 132–144.
- Stahl K., Hisdal H., Hannaford J., Tallaksen L.M., van Lanen H.A.J., Sauquet E., Demuth S., Fendekova M., Jódar J. (2010): Streamflow trends in Europe: evidence from a dataset of near natural catchments. Hydrology and Earth System Sciences, 14: 2367–2382.
- Stahl K., Tallaksen L.M., Hannaford J., van Lanen H.A.J. (2012): Filling the white space on maps of European stream flow discharge trends: estimates from a multi-model ensemble. Hydrology and Earth System Sciences, 16: 2035–2047.
- Stewardson M.J., Chiew F. (2009): A comparison of recent trends in gauged stream flows with climate change predictions in southeast Australia. In: 18th World IMACS/MODSIM Congr., Cairns , July 13–17, 2009. Available at http://mssanz.org.au/modsim09/
- Sun S., Barraud S., Branger F., Braud I., Castebrunet H. (2016): Urban hydrologic trend analysis based on rainfall and stream flow discharge data analysis and conceptual model calibration. Hydrological Processes, 31: 1349–1359.
- Tabari H., Talaee P.H. (2013): Moisture index for Iran: spatial and temporal analyses. Global and Planetary Change, 100: 11–19.
- Toride K., Cawthorne D.L., Ishida K., Kavvas M.L., Anderson M.L. (2018): Long-term trend analysis on total and extreme precipitation over Shasta Dam watershed. Science of the Total Environment, 626: 244–254.
- Wang Q.X., Fan X.H., Qin Z.D., Wang M.B. (2012): Change trends of temperature and precipitation in the Loess Plateau Region of China, 1961–2010. Global and Planetary Change, 92: 138–147.
- Xu K., Milliman J.D., Xu H. (2010): Temporal trend of rainfall and precipitation in major Chinese Rivers since 1951. Global and Planetary Change, 73: 3–4.
- Xu Z., Li J., Liu C. (2007): Long-term trend analysis for major climate variables in the Yellow River watershed. Hydrological Processes, 21: 219–232.
- Yang P., Xia L., Zhang Y., Hong S. (2017): Temporal and spatial variations of precipitation in Northwest China during 1960–2013. Atmospheric Research, 183: 283–295.
- Yue S., Pilon P. (2004): A comparison of the power of the t test, Mann-Kendall and bootstrap for trend detection. Hydrological Sciences Journal, 49: 21–37.
- Zhang X.S., Amirthanathan G.E., Bari M.A., Laugesen R.M., Shin D., Kent D.M., MacDonald A.M., Turner M.E., Tuteja N.K. (2016): How stream flow has changed across Australia since the 1950s: evidence from the network of hydrologic reference stations. Hydrology and Earth System Sciences, 20: 3947–3965.

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