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Variation of Seasonal and Annual Rainfall Series over Southeastern Anatolian Project Area

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ABSTRACT

Aims In this study, variation in annual and seasonal rainfalls in Southeastern Anatolian Project (GAP) area was analyzed using the non-parametric and parametric approaches.
Materials & Methods According to the aim of the study, the data sets of the seasonal and annual timescales, based on monthly rainfalls in the GAP area, including 9 rain gauges operated by Turkish State Meteorological Service, were considered in the study. Mann–Kendall (MK) and unit root test to detect the direction of an available monotonic trend in any given data were used while obtaining the magnitude of the variation with Theil–Sen slope estimator.
Findings Based on the MK test, decreasing trend in four of the seven different time scales was observed, whereas there was an upward trend in the only two (P-III and P-IV) of the all time scales while none of the stations in the P-II period showed a monotonic trend. However, the parametric unit root test detected the existence of variation in the period III for Sanliurfa station and the period V for Sirnak station.
Conclusion The percentage change calculated by considering the MK varied between 19 and 57%.

Keywords Mann–Kendall, Southeastern Anatolian Project; Unit Root Test

CITATION LINKS

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Introduction

The increased concentrations of greenhouse gases caused by human activities would alter the magnitude and seasonal variations in temperature and precipitation patterns in many parts of the globe (Intergovernmental Panel on Climate Change (IPCC]).[1] According to IPCC,[2] in the last half of the 20th century, there has been an upward trend in the number of heavy precipitation events in many parts of the word. Giorgi[3] emphasized that Mediterranean Basin was among the most sensitive regions in terms of the future precipitation extreme conditions. Unal *et al*.[4] reported that a dominating trend in decreasing annual precipitation existed throughout Anatolia, including west and southwest sections, while an increased trend in annual precipitation was observed only in northeast Black Sea region of Turkey. Onyutha *et al.*[5] evaluated trends from long-term and short-term rainfall data selected over different time periods at 39 locations in Nile River Basin. For the equatorial region, there was the significant increasing trend in annual rainfall, and in contrast, a decreasing trend was detected in the annual rainfall of Sudan, Ethiopia, and Egypt. Bari *et al*.[6] used Mann–Kendall (MK) test and Theil–Sen slope estimator to determine magnitude and direction of monotonic trend in annual and seasonal precipitation series belonging to Northern Bangladesh over 50 years (1964–2013), and they applied the sequential version of rank statistic (sequential version of MK) test to define any fluctuations in the trends over time and to detect the approximate starting point of change in the rainfall series. Pre-monsoon and post-monsoon rainfall had an increase in most of the rainfall stations. However, they found that monsoon rainfall showed a downward trend in the majority of the study area. Seyhun and Akıntug[7] investigated the existence of a linear trend in annual and monthly rainfall series during 1978–2009 in North Cyprus using MK rank correlation method. They found that there was any variation in annual rainfall data sequences while being determined an increasing trend for September rainfall and decreasing trend for March rainfall. Gajbhiye *et al*.[8] studied to detect whether there is a trend in monthly, seasonal, and annual rainfall data set from 8 rainfall stations across Sindh river basin, India, over the period 1901–2002 and 1942–2002 using the conventional MK test, Sen's–slope estimator, and the modified MK test, respectively. The upward trend in annual and seasonal rainfall series during 1901–2002 was detected. Nafarzadegan *et al.*[9] studied on trend in some climatic variables as well as seasonal and annual reference evapotranspiration (ETo) data sequences during 1966–2005 at 10 stations in southern Iran. The results from the tests (MK, Spearman's rho, Pearson correlation, and linear regression) used in the study indicated that the data sets of some stations had a decreasing trend, but many of trend values were statistically insignificant in most of the 10 stations. They implied that compatible results were recovered from all tests with each other. Gautam and Regmi[10] analyzed variation in the onset and withdrawal dates and the duration of summer monsoon of Nepal over the period of past 63 years (1951–2013). The analysis results revealed that there was a large interannual variation on both the onset and withdrawal of summer monsoon in recent years.

Due to the foregoing described facts, the analysis of long-term variation of seasonal and annual rainfall in Southeastern Anatolian Project (GAP) region, planned in the boundaries of the upper Euphrates and Tigris river basin, is very crucial owing to the inherent climate characteristic in the GAP area. The GAP project is the largest investment in terms of regional development throughout the history of Turkish Republic and the fourth largest irrigation project in the world. The development of the GAP region was originally deliberated on its water and land resources. Therefore, a probable drought event would cause the failure of the GAP. The foresight is removed due to the water resources development program associated with the GAP which consists of 13 groups of irrigation and energy projects, seven of which are on the Euphrates River. The two of seven is the largest and comprehensive project called as Atatürk Dam and Urfa Tunnels.[11, 12] The main objectives of this study were to make up new data set to be analyzed by summing up monthly precipitation of the stations in the study area and to apply MK, Theil-Sen Slope estimator's tests, and unit root test to new data set to detect the direction and magnitude of a trend.

Materials and Methods

The Euphrates–Tigris basin is largely fed from snow precipitation over the uplands of north and eastern Turkey, Iraq, and Iran. Precipitation in the basin largely falls during the winter months from October to April. A large proportion of precipitation in this period occurs as snow on the uplands and it remains in solid form until temperatures increase up to the spring or early summer. Thereupon, snow melt is decisive on the flow characteristics of both the Euphrates and Tigris. A substantial amount of precipitation which converts to runoff or groundwater in the basin takes place over Turkey.[13] In the GAP region, including nine provinces, monthly rainfall amounts from 9 rain gauges (site) operated by Turkish State Meteorological Service were used in the analysis. The geographical locations, characteristic information, and data availability of the nine stations in the GAP are presented in Figure 1 and Table 1. The data quality control of monthly rainfall series was performed in the context of the missing data and homogeneity. Each station performed the homogeneity condition according to Mann–Whitney U-test.

In the analysis, the monthly data sets of the 9 stations were arranged at seven different categorical data sets, namely, period one (from January to March), period two (from April to June), period three (from July to September), period four (from October to December), period five (from January to June), period six (from January to September), and period seven (from January to December). Monthly precipitation time series were summed up to obtain the data set to be analyzed for each station at time scales of interest.

Analysis of change in the data

Variation in meteorological variables has been tested using both parametric and non-parametric approaches.[14-18] The non-parametric approaches have some advantages over the parametric. The most attractive one is the assumption that values have any distribution form for non-parametric approaches, and the requirement is the normally distributed variables.[19, 20] The MK method is the most popularized non-parametric method to define variation in hydrologic variables. The null hypothesis (H_0) of the MK test assumes that time series values are independent, and identically distributed while alternative hypothesis (H_1) is that there is a monotonic trend in the data set. Mathematical formulation of this test is given as follows:

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}\left(x_j-x_i\right)\operatorname{sgn}\left(x_j-x_i\right)=\begin{cases}+1 & \text{if}\left(x_j-x_i\right)>0\\ 0 & \text{if}\left(x_j-x_i\right)=0\\ -1 & \text{if}\left(x_j-x_i\right)<0\end{cases} \tag{1}$$

According to Eq. (1), a positive or negative S value indicates upward and downward monotonic trend in the data, respectively. It is assumed that the statistic S is approximately normally distributed with the mean zero, and in case where the sample size n > 10, its variance and the MK test statistics (ZMK) are calculated by the equations 2 and 3.

$$\sigma_S^2=18^{-1}\left[\begin{array}{l}n\left(n-1\right)\left(2n+5\right)-\\ \sum_{i=1}^{m}t_i\left(t_i-1\right)\left(2t_i+5\right)\end{array}\right] \tag{2}$$

$$Z_{MK}=\left\{\begin{array}{l}\frac{S-1}{\sqrt{\sigma_S^2}}\quad \text{if}\ \ S>0,\ 0\\ \text{if}\ \ S=0,\ \frac{S+1}{\sqrt{\sigma_S^2}}\quad \text{if}\ \ S<0\end{array}\right\} \tag{3}$$

The Z_{MK} test statistic here follows a standard normal distribution. This value calculated

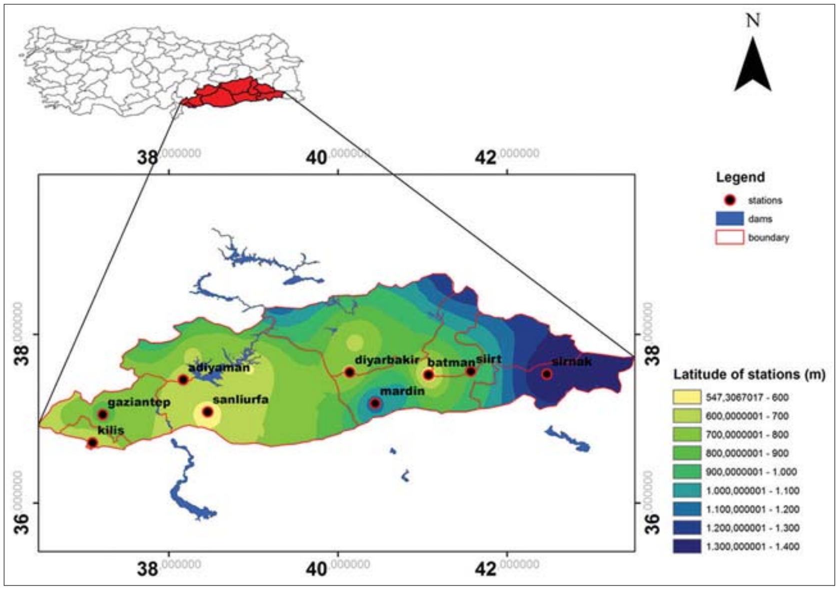

Figure 1: Rainfall stations in Southeastern Anatolian Project region

Table 1: Characteristics of the sites in the GAP area

Gauging stations	Longitude (E)	Latitude (N)	Elevation (m)	Mean annual precipitation (mm)	Data period
Gaziantep	37°22'	37°05'	840	554	1940–2013
Kilis	37°05'	36°44'	680	498	1960–2013
Adiyaman	38°17'	37°46'	669	713	1963–2013
Sanliurfa	38°46'	37°08'	547	453	1929–2013
Mardin	40°44'	37°18'	1150	678	1940–2013
Diyarbakir	40°14'	37°55'	677	487	1929–2008
Batman	41°07'	37°52'	550	492	1952–2013
Sirnak	42°47'	37°53'	1350	673	1970–2013
Siirt	41°57'	37°56'	895	718	1938–2013

GAP: Southeastern Anatolian Project

from the Eq. (3) is compared to the value of $Z_{1-\alpha/2}$ from standard normal distribution table at 5% significance level. The null hypothesis associated with no trend is accepted if the Z_{MK} test statistic is smaller than the critical value of the standard normal distribution at the significance level of α. The Z_{MK} test statistic having a positive or negative value signifies an increasing or decreasing trend.

Theil–Sen's estimator (TSE) (Q_{med})[21, 22] has been substantially considered in specifying the magnitude and direction of the trend in hydrologic variables. The brief descriptions of the statistical method are in Yurekli.[23] To directly apply the MK test to the raw data, there should be no serial correlation among the observations; otherwise, the presence of serial correlation in the raw data would lead to misinterpretation over trend.[24] According to Yue and Wang,[25] the existence of serial correlation in any data set would result in a significant positive trend. To avoid the undesirable situation, Yue and Pilon[26] suggested a new modified technique called as a trend-free pre-whitening (TFPW) and was used in the study. A detailed description related to the above methods is available in Yurekli.[23]

The percent change related to the seasonal and annual rainfall data set with monotonic trend was found by the following equation as given by Petrow and Merz.[27]

$$\Delta x_R = (x_{end} - x_{start}) \times (\bar{x})^{-1} \quad (4)$$

In Equation 4, X_{end} and x_{start} are the values associated with the trend line at the end and at the start of observation period. $\bar{x}$ is the mean of observations. In this study, parametric unit root test was also applied to data sequences.

Findings

In the first attempt, the Q(*r*) statistic suggested by Ljung and Box[28] was applied to all of the series to detect the presence of serial correlation among the observations. For this purpose, the statistic for every data was calculated for lag one and was compared to critical value of the χ^2_{Table} at 5% significant level. This statistic value was shown in bold characteristic when this value was greater than critical value of the reference table (Table 2). The TFPW method was applied to the data found statistically significant in terms of serial dependence.

MK test using one-sided hypothesis at 5% significance level was applied to the seasonal and annual rainfall data sets. The results of this test are presented in Table 3. As can be seen in the table, monotonic trend was detected for the rainfall series of five provinces in the GAP region. The seasonal and annual rainfall series belonging to Kilis, Mardin, and Siirt Provinces showed downward trend while the rainfall series in PIII and PIV periods for Gaziantep and Sirnak Provinces have significant upward trend.

The MK test for the PIII period of Sanliurfa ve Mardin sites could not be carried out due to many years with no precipitation. TSE results of five stations having monotonic trend are shown in Table 4. In Table 4, the highest and lowest values of the TSE at 99% confidence level were also given. The TSE values were located between the highest and lowest values.

Surprisingly, the results of parametric unit root test were quite different from that of MK test. The unit root test found to be monotonic trend in the period III of Sanliurfa site and the period V of Sirnak site, while there was no trend for the other data sets. Onoz and Bayazıt[29] stated that the assumption in the parametric tests was required that the random variable was normally distributed and constant variance (homoscedastic), whereas there was no obligation to comply with any probability distribution for the MK test. The difference between the results from these methods is probably due to the above specialty. Hirsch *et al*.[30] reported that parametric tests were more powerful in case of a given data set having a normal probability distribution, and in circumstances where the variable with high coefficient of skewness, the non-parametric tests (especially MK test) were more suitable for trend analysis.

Table 2: Q (r) statistics at lag one of each station in the GAP area (Yurekli, 2015)

Gauging stations	Q (r) value							χ^2-table *P*>0.05
	P-I	P-II	P-III	P-IV	P-V	P-VI	P-VII	
Gaziantep	0.71	0.11	2.34	0.27	0.70	0.57	0.85	0.13–0.70
Kilis	1.66	0.01	0.48	0.18	1.61	1.91	0.44	0.17–0.92
Adiyaman	0.38	0.01	2.26	0.14	0.48	0.48	0.02	0.13–0.96
Sanliurfa	2.79	1.52	1.75	0.10	4.67	6.12	0.34	0.01–0.75
Mardin	2.69	3.16	7.10	0.00	0.00	0.00	2.38	0.01–1.00
Diyarbakir	1.04	6.11	0.13	2.05	4.82	4.98	1.97	0.01–0.72
Batman	0.15	0.97	0.10	0.33	0.00	0.00	0.77	0.32–0.99
Sirnak	1.57	0.88	1.21	1.24	0.01	0.04	1.32	0.21–0.92
Siirt	4.48	1.99	2.81	0.03	0.40	0.39	5.88	0.02–0.87

Table 3: The results of Mann–Kendall test for each station in the study area (Yurekli, 2015)

Gauging stations	Z_{MK} test statistic						
	P-I	P-II	P-III	P-IV	P-V	P-VI	P-VII
Gaziantep	−1.12	0.60	1.13	1.77++	−0.27	−0.04	0.79
Kilis	−1.98**	−1.00	1.64	−0.12	−2.39**	−2.05**	−1.77**
Adiyaman	−0.41	−0.64	0.51	0.06	−0.68	−0.63	−0.33
Sanliurfa	−1.43	−0.33	***	0.16	−1.30	−1.20	−0.72
Mardin	−2.10**	−0.76	***	−0.71	−2.03**	−1.99**	−2.11**
Diyarbakir	−0.47	−0.41	−0.67	0.30	−0.37	−0.39	−0.47
Batman	−1.44	−0.92	−0.47	−0.50	−1.30	−1.47	−1.47
Sirnak	1.33	−0.85	2.96++	1.92++	1.19	1.36	1.56
Siirt	−2.38**	−0.79	0.89	−0.63	−1.42	−1.30	−1.66**

The "++, **" shows increasing and decreasing monotonic trend in the data of interest

Table 4: The TSE results in quantifying the slope of the trend line (Yurekli, 2015)

Gauging stations	Q_{med}						
	P-I	P-II	P-III	P-IV	P-V	P-VI	P-VII
Gaziantep	s			0.71			
Kilis	−1.19				−1.82	−1.55	−1.79
Mardin	−1.31				−1.56	−1.54	−2.36
Sirnak			0.13	2.51			
Siirt	−1.01						−1.65
Q_{min}	−2.94	−0.26	−0.13	−5.74	−4.19	−3.88	−5.34
Q_{max}	0.45	1.41	1.69	6.11	0.48	0.58	0.97

TSE: Theil–Sen's estimator

For the sites with monotonic trend in Table 3, percentage change varied between 19 and 57%. The highest percentage change was in the period III for Sirnak site, while the lowest percentage change was in the period VII for Kilis site.

Discussion

The main findings of trend analysis in the context of GAP were summarized. The most comprehensive attempt to the date has been achieved by Turkish Republic with GAP, which is the largest investment for regional development in the history of Turkey and the fourth largest irrigation project in the world. In this sense, having information on rainfall variation in the region with dominant arid and semi-arid climate characteristic are crucial in terms of a sustainable water resources management. Especially, the decrease in precipitation would affect the failure of the GAP because the water resource development program in the GAP is composed of 13 groups of irrigation and energy project.

With respect to the critical value (±1.645) from the standard normal distribution at 5% significance level, the MK test results belonging to 9 rain gauge stations in the GAP region indicated that there was significant upward and downward trend of the summed rainfall data at the seven time scales. The monotonic trend was found at 56% of the stations (5 of 9 stations) for the considered time scales. In three stations for P-I and P-VII periods and in two stations for P-V and P-VI periods, there was statistically significant decreasing trend while being determined very notable increasing trend for P-III (in one station) and P-IV (in two stations) periods. The stations in the P-II period had no monotonic trend. According to the findings from the parametric unit root test, its results were very inconsistent with the MK test. Trend was identified in the two time scales (P-III and P-V periods) of only two stations (Sanliurfa and Sirnak). The results from TSE for five stations having monotonic trend at 6 time scales (except P-II period) were between −2.36 mm per year and 2.51 mm per year. The percent change ranged between 19 and 57%.

When considering the results obtained for all time periods in the stations of the region, 75% of the test values from the MK was negative. However, all of these values were not statistically significant. This implies that rainfall in the study area shows a downward trend. Karabulut and Cosun[31] reported that the Mediterranean and Southeastern regions have been vulnerable area to climate variability. The recent studies on changes and variability of precipitation occurred over Turkey exposed considerable spatial and temporal changes in the precipitation.[32-34]

Conclusion

The current study is on variability of precipitation in Southeastern Anatolian Project Area (GAP). The achievement of this project is depend on the reliable development and operation of water resources in the region. The region has a semiarid characteristic. Due to this feature, it is inevitable to take advantage of the precipitation falling in the region in the most efficient manner. The success of projects related to the development of water resources is directly associated with the reliable acquisition of selected project values due to rainfall since the amount of water resources depends on falling rainfall.

The change in precipitation should be considered to ensure the highest level of benefit from the existing projects and the projects planned to be performed in the region by reference to the results of existing and similar studies. The success and utility of the GAP project is precisely depend on protecting the natural course of rainfall more than anything else.

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Ethical Permissions

None declared by authors.

Conflicts of Interest

The corresponding author has no conflict of interest.

Authors’ Contributions

The corresponding author contributed extensively to detecting variability of precipitation in the studied area in this paper.

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