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INVESTIGATION OF PRECIPITATION TREND IN REGIONAL SCALE BASED ON THE STATISTICAL APPROACH

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ABSTRACT. In recent years, hydrological trend analysis had become very popular due to global warming and climate change issues. Knowledge of the trend changes of hydrological series helps designers, engineers, and plan makers about future projections of all water related problems such as irrigation systems, water distribution systems, etc. Statistical approaches are historically very crucial for determining the trend. In this study, authors focused on determining total precipitation trend change monthly, seasonally, and annually on a regional scale. Non-parametric Mann Kendall test, Spearman's Rho test, and Sen's Slope test are used for the determination of the precipitation trend. Additionally, the total annual precipitation trend is investigated with the linear regression trend analysis method. Detailed results of each method are shared separately.

Keywords: Precipitation, Trend, Mann Kendall test, Sen's slope test, Spearman's Rho test

1. INTRODUCTION

Global warming, climate change issues make hydrological and meteorological problems more important day by day. Climate change effects make difference in different areas on a regional scale. Therefore, it is essential to estimate the changing trends of hydrological parameters in a specific area for handling unexpected future changes. One of the most important parameters in the hydrologic cycle is precipitation from the point of water management view. It is critical to know the changing trends of precipitation for making future water management plans such as water distribution systems, irrigation systems and even developing flood protection strategies, etc. However, the determination of a trend, calculation, or estimation of a hydrological problem is generally very complicated because of the direct and indirect effects on the hydrological process. This is why, recently data mining techniques, artificial intelligence, soft computing approaches are developed and used for the estimation of different hydrological processes because of the abilities of the mentioned models. (Demirci & Kaya, 2019; Demirci et al., 2018; Mamak et al., 2017; Üneş et al., 2018a; Üneş et al., 2019; Üneş et al., 2018b; Kisi, 2008, 2015; Shiri et al., 2012; Zhao et al., 2013, Üneş et al.,2017). Specifically, trend analyses are used recently for streamflow, precipitation, evaporation cases. Bacanlı &

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Tanrıkulu, (2017) used Mann Kendall and Sen's Test to evaluate the evaporation trend in the Aegean region, Turkey. Ercan & Yüce, (2018) searched for the trend of precipitation and temperature using weather station-based records between 1975-2016. Mahmood et al., (2019) investigated the climate variability and trend change of Chad basin, Africa. Serencam, (2019), used an innovative trend analysis method to make a trend analysis on total rainfall and temperature variability as a case study of the Yeşilırmak region. Tosunoğlu, (2017) evaluated the daily maximum rainfall Series in Çoruh Basin, trend variability using Mann Kendall test, Modified Mann Kendall test, Sequential Mann Kendall test, and Theil-Sen test. Fukushima et al., (2019) investigated the regionality of long-term trends and interannual variation of seasonal precipitation over India during two different periods. Kahya & Kalaycı (2004) used 31 year period streamflow data belonging to 26 basins over Tukey to determine the trend of streamflow. They used the Mann Kendall test, Spearman Rho test, Sen's t-test, Seasonal Kendall approaches for trend investigation. Partal & Kahya (2005) aim to investigate the long-term annual mean and monthly total precipitation by using the Mann Kendall test and Sen's T-test. Fathian, F., et al, (2015) Mann Kendall, Spearman Rho, Sen's T methods for investigation of the trends in the annual and seasonal time series of temperature, precipitation, and streamflow over the Urmia Lake basin, Iran.

In this study, precipitation-based trend change analyses are generated using the most popular trend analyzing methods namely Mann Kendall, Spearman's Rho tests, Linear Regression trend test, and the magnitude of the trend is investigated by Sen's Slope method.

1.1. Study area

A weather station daily precipitation record belonging to United States Geological Survey (USGS) is used for the trend investigation. Daily records of precipitation are for 16 years between 2002-2017. The station is located in Middlesex County, USA and the given hydrologic unit of the station by USGS is 01090001. The drainage area of the station is 17.77 km^2. The location of the station is marked as it is in Fig.1.

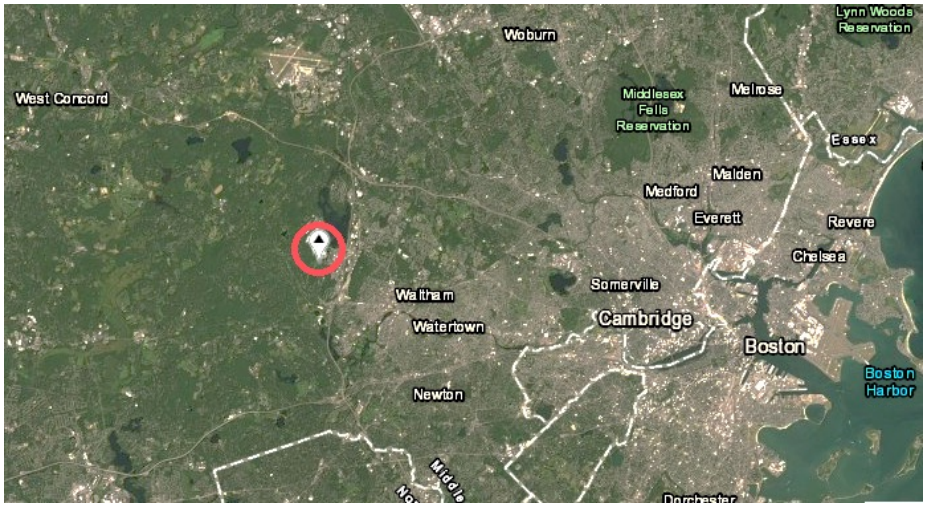

Fig. 1. ***Location of the weather station***

Monthly Seasonally and Annual Maximum total precipitation (mm), minimum total precipitation (mm), Mean total precipitation (mm), standard deviation (Sx), and Skewness (Csx) statistics are calculated and given with Table 1.

Table 1. ***Used data set statistics***

Time Interval (Total)	Max (mm)	Min (mm)	Mean (mm)	Sx	Csx
January	134.87	21.84	78.59	31.72	-0.09
February	227.08	13.21	87.73	50.43	1.13
March	432.56	15.75	114.84	89.20	3.03
April	226.06	46.23	110.40	49.42	0.89
May	257.81	38.86	97.16	53.87	1.85
June	226.57	38.35	109.06	54.03	0.83
July	243.08	24.89	103.59	62.99	1.07
August	276.86	17.53	97.37	62.00	1.54
September	202.69	39.88	93.22	50.85	0.91
October	261.37	20.32	118.65	58.91	0.59
November	236.98	24.13	100.52	50.32	1.20
December	177.04	60.45	117.83	34.73	0.08
Spring	562.61	159.26	322.40	100.40	0.60
Summer	454.66	105.16	310.01	96.42	-0.24
Fall	520.45	169.16	312.39	92.16	0.65
Winter	437.13	188.47	284.32	66.60	0.55
Annual	1593.34	829.06	1228.96	217.36	-0.26

2. DATA AND METHODS

The Mann Kendall test which is used for the trend analysis in this study is a non-parametric method. This is why a detailed definition of the data set is essential to evaluate and understand the outputs of the study. For this purpose, monthly, seasonally, and annually distribution of the precipitation data is drawn as Fig. 2, 3, 4, 5 and 6. It is also important to know the distribution for a better understanding of the hydrological situation of the study area.

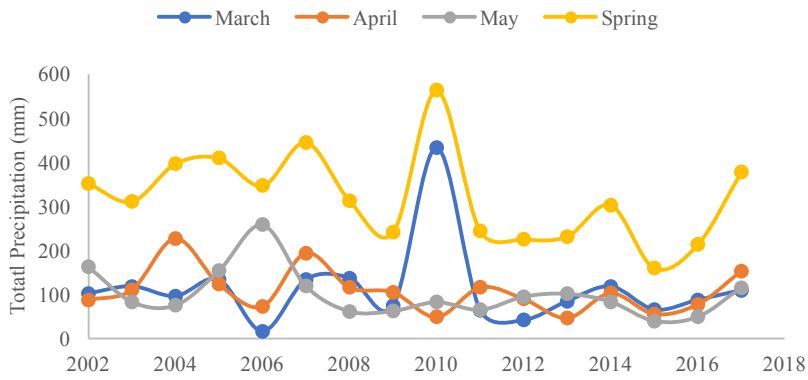

Fig. 2. ***Precipitation distribution during spring***

Fig. 2. shows that maximum and minimum records are belonging to march during the springtime. And, the maximum total precipitation is recorded in March 2010 as an extreme event.

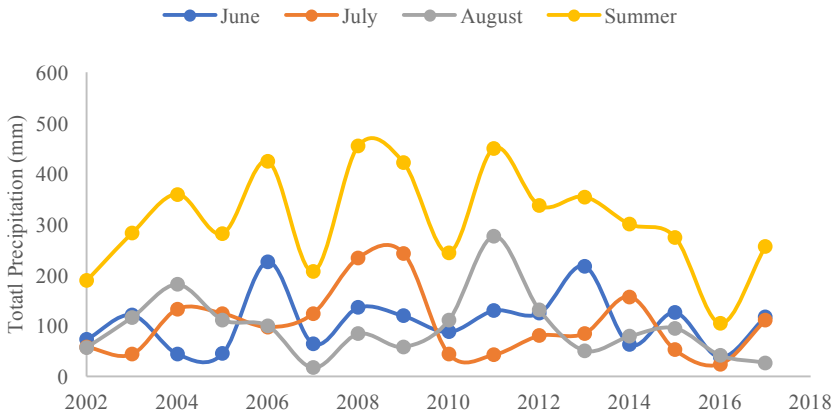

Fig. 3. ***Precipitation distribution during summer***

Fig. 3. shows that maximum and minimum records are belonging to august during the summer season. And, the maximum total precipitation is recorded as 454.66 mm in 2008 as the sum of summertime.

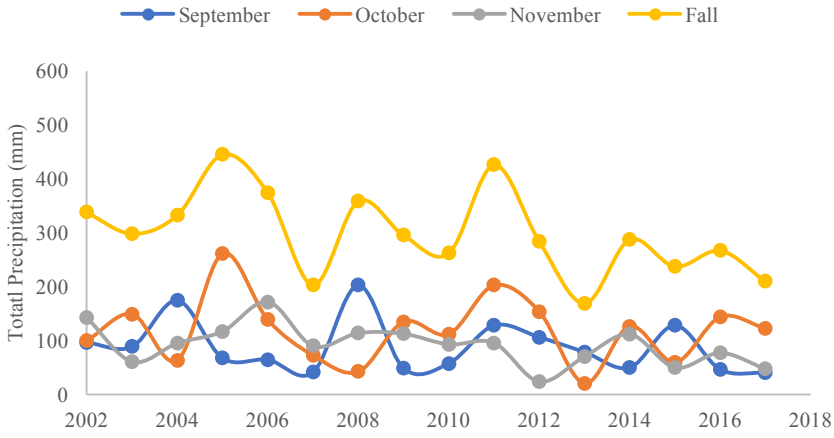

Fig. 4. ***Precipitation distribution during fall***

Fig. 4. indicates that maximum and minimum records are belonging to October during the fall season. And, the maximum total precipitation is recorded as 445.52 mm in 2005 as the sum of the fall season.

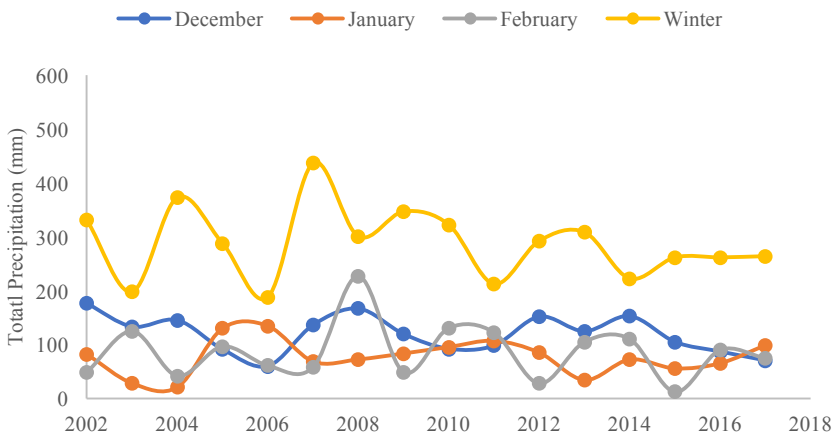

Fig. 5. ***Precipitation distribution during wintertime***

Fig. 5. indicates that maximum and minimum records are belonging to February during the fall season. And, the maximum total precipitation is recorded as 437.13 mm in 2007 as the sum of the fall season.

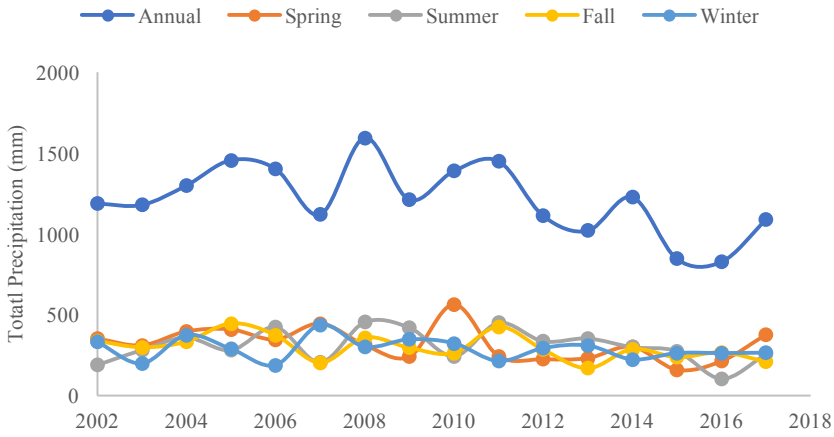

Fig. 6. ***Annual and Seasonal distribution of the sum of precipitation***

The maximum annual total precipitation is 1593.34 mm belonging the 2008 year and the minimum is belonging to 2016 as 829.06 mm.

2.1. Mann Kendall Trend Analysis Method

The Mann Kendall test is a non-parametric test that is used often for analyzing hydro climatologic data and for determining trend series. This method is a special application of Kendall's Tau test. Non-parametric tests are not related to the distribution of the data directly, it is more about the relationship between each time step numerical magnitude against one another (Mann, 1945; Kendall, 1975). The

evaluation of the trend is based on the acceptance or rejection of the null hypothesis (H_0). Calculation of Mann Kendall test and evaluation is given as follows,

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (1)$$

"S" is the Mann Kendall statistic and the calculation of "*sgn(x_j-x_k)*" is given with the formula (2).

$$sgn(x_j - x_k) = \begin{cases} +1; & if \ (x_j - x_k) > 0 \\ 0; & if \ (x_j - x_k) = 0 \\ -1; & if \ (x_j - x_k) < 0 \end{cases} \quad (2)$$

The mean of E[S] = 0 and the variance σ^2 is,

$$\sigma^2 = \frac{\left(n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5)\right)}{18} \quad (3)$$

$$z = \begin{cases} \frac{S-1}{\sigma} \ if \ S > 0 \\ 0 \ if \ S = 0 \\ \frac{S+1}{\sigma} if \ S < 0 \end{cases} \quad (4)$$

2.2. Sen's Slope Method

Calculation of a set of linear slopes is as follow,

$$d_k = \frac{X_j - X_i}{j - i} \quad (5)$$

at equation 5 „n" is the number of the data, i and j are indices, X defines variable, d is slope for $1 \leq i \leq j \leq n$.

And according to the median of all slopes, Sen's slope can be calculated. Where the b = median d_k , intercepts computation of each time step „t" is given by equation 6.

$$a_t = X_t - b * t \quad (6)$$

The median of all intercepts gives the corresponding intercept (Pohlert T., 2018).

2.3. Spearman's Rho Test

Spearman's Rho test is a similar test with the Mann Kendall test which allows users to identify non-parametric linear or non-linear trends. This method generally defines the situations that have no trend (Dahmen and Hall, 1990). The similarity of this method with the Mann Kendall method is based on the acceptation or rejection of the null hypothesis. If the H_0 hypothesis is accepted for a time series then it means there is no trend. But if the H_0 is rejected then it can be released there is an increasing or decreasing trend (Yue, et al., 2002). The test statistics (D) calculation step of this method is given with equations 7 and 8.

$$D = 1 - \frac{6 \sum_{i=1}^{n} (R_i - i)^2}{n(n^2-1)} \quad (7)$$

$$Z_{SR} = D \sqrt{\frac{(n-2)}{(1-D^2)}} \quad (8)$$

at equation 7 „R_i" is the *i*th rank of observation and „n" is the length of the time series. If the calculated Z_{SR} value is positive then the trend is being positive, the oppositely, if the Z_{SR} value is negative then the trend is being negative.

2.4. Linear Regression Analysis Method

The linear regression trend investigation method is in use for the calculation of the single variable series trends. If the average trend line has a positive slope then there is an increasing trend, oppositely, if the slope of the regression line is negative then the trend is accepted as decreasing. The numerical size of the slope gives researchers an idea about the magnitude of the trend (Dabanlı, 2017).

3. RESULTS AND DISCUSSIONS

In this study, the precipitation trend of Middlesex County, USA is investigated using the Mann Kendall test, Spearman's rho test, linear regression trend analysis, and Sen's slope methods during 2002-2017 based on the one weather station records. Monthly, seasonally and annual evaluation is performed for the given time scale. Results of the Mann Kendall test and Sen's slope values are given in Table 2.

Table 2. ***Mann Kendall test results of each period***

Time Step	Mann Kendall Results					Sen's Slope	
	alpha	MK-stat	z-stat	p-value	trend	alpha	slope
January	0.05	2	0.05	0.96	no	0.05	0.26
February	0.05	-6	-0.23	0.82	no	0.05	-1.53
March	0.05	-10	-0.41	0.69	no	0.05	-1.40
April	0.05	-26	-1.13	0.26	no	0.05	-2.78
May	0.05	-32	-1.40	0.16	no	0.05	-3.22
June	0.05	6	0.23	0.82	no	0.05	0.68
July	0.05	-12	-0.50	0.62	no	0.05	-1.51
August	0.05	-32	-1.40	0.16	no	0.05	-3.50
September	0.05	-32	-1.40	0.16	no	0.05	-2.39
October	0.05	-8	-0.32	0.75	no	0.05	-1.36
November	**0.05**	**-50**	**-2.21**	**0.03**	**yes**	**0.05**	**-4.41**
December	0.05	-30	-1.31	0.19	no	0.05	-3.02
Spring	0.05	-44	-1.94	0.05	no	0.05	-10.43
Summer	0.05	-14	-0.59	0.56	no	0.05	-1.99
Fall	**0.05**	**-50**	**-2.21**	**0.03**	**yes**	**0.05**	**-7.73**
Winter	0.05	-21	-0.90	0.37	no	0.05	-4.56
Annual	0.05	-44	-1.94	0.05	no	0.05	-22.57

Aforementioned before, acceptance or rejection of the null hypothesis determines the trend according to the Mann Kendall approach. And Sen's slope method gives the magnitude of the trend. After the decision of the trend, negative values of the Mann Kendall test results indicate the direction of the trend as negative and the

positive values of the Mann Kendall test show it as positive. The decision of acceptance of the H_0 is made for the 95 confidence interval. According to the Mann Kendall trend test results presented in Table 2. only two trends are detected. "z"-stats are calculated as -2.21 for November and Fall time scales. Since mentioned z-stats are numerically lower than -1.96 (95% confidence interval), trend directions of November and Fall are determined as negative. No more total precipitation trends are detected by using the Mann Kendall test.

The same evaluation for total precipitation is generated with Spearman's Rho test and results are shared with Table 3.

Table 3. ***Spearman's Rho test results of each period***

Spearman's Rho test results					
Time Scale	α	Critical Z value	Calculated Z value	Trend	Trend Direction
January			-0.08	No	-
February			0.00	No	-
March			0.92	No	-
April			1.14	No	-
May			1.73	No	-
June			-0.28	No	-
July			0.64	No	-
August			1.37	No	-
September	0.05	1.96	1.29	No	-
October			0.25	No	-
November			2.54	Yes	Positive
December			1.34	No	-
Spring			2.32	Yes	Positive
Summer			0.51	No	-
Fall			2.72	Yes	Positive
Winter			0.99	No	-
Annual			2.33	Yes	Positive

Spearman's rho test was applied to the data set based on the 95 % confidence interval (alpha=0.05). As the critical Z value for 0.05 alpha is +- 1.96 then the null hypothesis is accepted or rejected due to the comparison of calculated Z_{SR} and critical Z value. For monthly, seasonally, and annual evaluation of Spearman's Rho test, results are presented with Table 3. According to the results obtained, four positive trends are determined. Z_{SR} values are calculated as 2.54, 2.32, 2.72, and 2.33 for November, Spring, Fall, Annual time scales respectively. According to the

Spearman's Rho test results, It is seen that there is an increasing total precipitation trend in November, Spring, Fall, Annual during the 16 years period. No more trends were detected by using Spearman's Rho test for total precipitation.

The results of the regression trend investigation method are shared in Table 4.

Table 4. ***Linear Regression analysis trend test results of each period***

Linear Regression Approach	
Time Scale	Slope of the regression line
January	0.00
February	0.00
March	0.00
April	-0.03
May	-0.04
June	0.01
July	-0.01
August	-0.01
September	-0.03
October	-0.01
November	-0.07
December	-0.05
Spring	-0.02
Summer	-0.01
Fall	-0.03
Winter	-0.02
Annual	-0.01

According to the linear regression trend investigation approach, any positive trends were not detected. And, only one significant trend is detected as negative for the November time scale. This application is done additionally for having one more trend test on the evaluation of the results based on the comparison of the Mann Kendall test and Spearman's Rho test. As some of the results of the Mann Kendall test and Spearman's Rho test are in opposite directions, one more trend investigation application will be helpful to make a final conclusion.

5. CONCLUSIONS

Determination of the precipitation trend is an important issue for agriculturists, irrigation engineers, water planers, etc., to develop new strategies for the future.

According to the statistical analyses based on the 95 percent confidence interval, it is concluded that there is a negative trend in November for monthly evaluation within the given period for the three of the methods used namely, Mann Kendall test, Sen's Slope test, and Linear Regression trend investigation approach. Oppositely, Spearman's Rho test gave a positive trend result for November. It should be known that each method has different calculation steps and methodologies and they may not validate one another. Hence, each result must be evaluated separately. But, for a final conclusion on a period, the sum of the results of each method can be used. For example, if we take consider the November results, we will see we have three negative trend results and one positive. So, It can be said that there is a negative total precipitation trend for November. For the Fall season, the Mann Kendall test gave a negative trend and the magnitude calculated with Sen's slope supported this finding. Additionally, even there is not found a significant trend with the linear regression trend approach, the trend direction is detected as negative. However, Spearman's rho test gave a positive trend result for the Fall season. Similarly, for the spring season and annual evaluation Spearman's rho test has positive trends. Any trends are not detected for the Summer season and other months in any methods used. This station-based analysis is performed for Middlesex County, USA. For a more inclusive result, the authors suggest studying for more stations and for a larger time scale.

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