How to cite: Kaya, Y.Z., Demirci, M., Varçin, H., Turhan, E. (2023) Monthly Trend Investıgatıon of the Dıscharge of a Stream in Cache County. Utah. *2023 "Air And Water – Components of the Environment" Conference Proceedings*, Cluj-Napoca, Romania, p. 85-94, DOI: 10.24193/AWC2023_09.

MONTHLY TREND INVESTIGATION OF THE DISCHARGE OF A STREAM IN CACHE COUNTY. UTAH

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DOI: 10.24193/AWC2023_09

Abstract. Discharge values of streams are critical for planning the water resources of basins. Discharge values of streams may change due to many reasons such as climatological effects or human-related issues. It is essential to make estimations about the discharge values' trends for more feasible constructions on streams. In this study, discharge monitoring station records of USGS were used to determine the trends over 50 years. The data set is belonging to the Logan River Above State Dam, Near Logan. UT station and it starts in 1971 and ends in 2020. Traditional Mann Kendall Spearman's Rho and Sen's slope statistical tests were used to determine the monthly trends. Additionally, a yearly investigation was performed by using the same statistical approaches. According to the obtained results, any significant trends were not detected in the yearly evaluation. However, in the monthly evaluation trends were detected for August and September.

Keywords: Trend Investigation, Discharge, Mann Kendall Test Sen's Slope

1. INTRODUCTION

The discharge of streams is an important parameter for well-planned water resources management. The discharge of the streams can change over time due to the various direct and indirect effects. The direct effects are generally human-based effects such as the construction of river channels to transfer the water from one basin to another one. The indirect effects can be generalized as meteorological and hydrological. Regardless of the reason for the change in the discharge of a stream, it is crucial to determine the trends of the discharge over time to make reliable future water plans in a basin or subbasin. A true determination of the discharge trends may help to prepare feasibility plans for construction on streams such as dams or irrigation systems.

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Trend investigation methods have recently been used for different hydrological and meteorological cases. Cherinet et al.. (2019) have used Mann-Kendall and Sen's slope estimator for the Abbay River Basin streamflow trend investigation. They investigated the annual temperature, river discharge, and precipitation variability. According to the results they obtained, they have underlined that the mean temperature increased, and the river discharge sharply decreased for the study area which is stated in Ethiopia. Hu et al. (2019) used the Mann-Kendall test for hydro climatological trend investigation of the Kamo River Basin, Japan. They investigated the river discharge, precipitation, temperature, and potential evapotranspiration parameters starting from 1962 to 2017. By using the Mann-Kendall test and Sen's estimator they found an annual decreasing trend for river discharge. However, on seasonal scale, they did not detect any significant trends for the 95% confidence interval. Finally, they suggested that the results obtained can be useful for water-related plan makers. Ali & Abubaker, (2019) published a flow trend investigation review for the Yangtze river basin. China. They used the Innovative Şen Trend test in addition to the Mann-Kendall traditional method.

The authors of the study emphasized that the results can be helpful for stakeholders or water resources managers to determine the risks and vulnerability due to climate change in the region. Forootan, (2019) used the non-parametric test to analyze the hydrologic and climatologic trends, he investigated the six parameters including discharge and found that at an annual scale the evaporation was increasing, and the river discharge was decreasing. Srinivas et al., (2020) underlined how climatic changes have dramatic effects on river regimes. This is why they used an advanced spatiotemporal approach to define the river discharge and seasonal trends. They used 117 yearly data set for investigating the 11 parameters by using statistical R software. They performed both parametric and non-parametric models for analysis. The study area was in the Ganges River basin of India. They found gradually decreasing trends in precipitation and significantly decreasing trends for river discharge. Mallick et al., (2021) performed a trend investigation study for the Asir region of Saudi Arabia. They applied detrended fluctuation analysis in addition to the traditional approaches. They concluded that 23 stations have declining future rainfall trends based on records. Leone et al., (2021) investigated the spring discharge trends of Caposole which is located in South Italy. The time series was including 100 years of records. They used Mann Kendall and Sen's Slope trend detection test for trend investigation. While they did not detect any statistically significant trends for precipitation, they detect a decreasing trend for spring discharge. Üneş & Kaya., (2021) published a trend investigation paper for Amik plain, Hatay. They used Mann Kendall, Spearman's Rho, Regression test, and the Innovative Şen Trend approach to determine the temperature, precipitation, and river flow trends. According to the analysis they performed, they have seen a significantly increasing trend of air temperature and decreasing trend of total precipitation in the study area. Some of the additional studies about trend investigation of the hydrologic or climatologic parameters can be found in (Bastiancich et al., 2022; Das et al., 2021; Das & Banerjee., 2021; Das & Scaringi., 2021; Shah & Kiran., 2021).

Table 1. Definitive statistics of the used data set

	Min.	Max.	Mean	Std.	Skewness Coeff.
January	63.10	164.50	107.87	27.05	0.50
February	61.60	229.60	107.93	32.10	1.68
March	78.90	405.30	135.10	60.63	3.21
April	108.60	615.40	250.93	107.98	1.40
May	130.80	1072.00	550.69	246.47	0.42
June	113.40	1413.00	625.62	368.12	0.48
July	77.90	1047.00	301.44	207.19	1.35
August	63.60	405.50	166.16	81.43	0.99
September	61.10	267.10	135.85	57.11	0.78
October	67.40	247.10	132.73	48.27	0.84
November	71.90	220.60	127.99	38.82	0.79
December	69.00	186.40	114.22	31.31	0.72
Yearly	92.43	454.38	229.71	96.71	0.65

- The unit of the discharge is cubic feet per second.

In this study, authors applied different trend investigation methods to the discharge values of a stream located in Cache County, UTAH. They used namely Mann Kendall, Spearman's Rho, and Sen's Slope tests. They showed the differences between approaches and how the direction of the trend can differ in order to use non-modified classical methods.

2. METHODOLOGY

A discharge data set of the stream was downloaded from USGS (United States Geological Survey) website. The data set is starting in 1971 and it is ending in 2020 (including). The data set was chosen as mean monthly statistics. The data set is belonging to the Logan River Above State Dam, Near Logan, UT gauge station. The station number is 10109000. The location of the stream and the gauge station is given in figure 1.

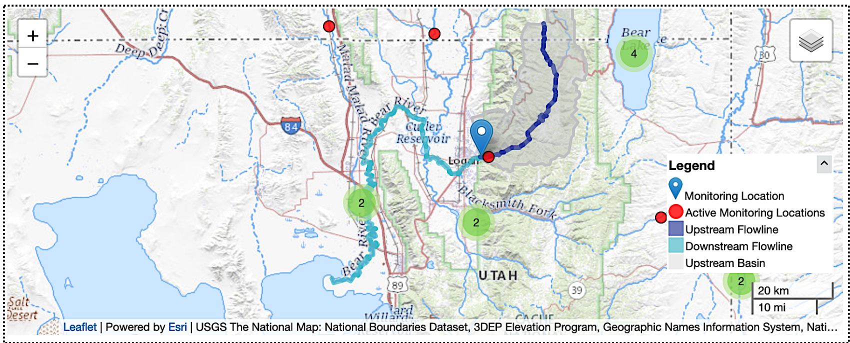

Fig. 1. ***Location of the gauge station (USGS)***

In figure 1, it is possible to see monitoring location, upstream and downstream of the river, and upstream basin. The figure is also downloaded from the USGS website. The map style was chosen as USGS Topo and Hydro.

The definitive statistics were calculated and shared in Table 1. Monthly and yearly scale minimum, maximum, mean, standard deviations, and skewness coefficients were given to show the fluctuations of the data over years. The Microsoft excel software was used for analysis. An open-source tool namely Real Statistics Resource Pack was added to the excel to perform the trend investigations.

When Table 1. is examined it will be seen that the lower value of the "Min" stats is 61.1 and it is belonging to September. The highest value of the "Max" stats is 1413 and it is belonging to June. Max. standard deviation was calculated for June and the lowest value for January. The Highest skewness coefficient was calculated for March and the lowest for May.

2.1. Mann Kendall Test

It is a non-parametric test that is in use for trend detection. The Mann Kendall stat must be calculated first to decide if is there a trend or not within a certain confidence interval. This approach uses the magnitude of each time step for calculation (Kendall, 1975; Mann, 1945). Formulation of the Mann Kendall stat (S) is given by equation 1&2 as follows,

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

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

where x_i and x_j are the data at the times i and j respectively. And "n" is the length of the time series.

If the calculated "S" is a negative value, then the direction of the trend is negative. Otherwise, if the calculated "S" is positive then the direction of the trend is positive.

To make a decision about the trend (If there is a trend or not) the null hypothesis is used. For this purpose, the Z stat must be calculated to compare with the critical Z value. In this study alpha was accepted as 0.05, therefore the confidence interval is taken as 95%. Calculation of the Z stat by using "S" is given by equation 3.

$$Z = \begin{cases} \frac{S-1}{\sigma} \ if \ S > 0 \\ 0 \ if \ S = 0 \\ \frac{S+1}{\sigma} \ if \ S < 0 \end{cases} \quad (3)$$

In equation 3. "σ" is the variance of the slope value. The calculated Z value must be compared with the critical Z value for the decision of the trend.

2.2. Spearman's Rho Test

This approach is based on the rank of the investigation values. It has a similar evaluation method to the Mann-Kendall classical test. In this method, the null hypothesis defines the "no trend" the same as the Mann-Kendall approach. Spearman's rho test is generally in use to determine the cases that have no trend (Dahmen & Hall, 1990). The formulation of Spearman's rho is shared by equation 4 & 5.

$$D = 1 - \frac{6\sum_{i=1}^{n}(R_i - i)^2}{n(n^2-1)} \tag{4}$$

$$Z_{SR} = D\sqrt{\frac{(n-2)}{(1-D^2)}} \tag{5}$$

where at equation 4 „R_i" is the i_{th} rank of observation and „n" is the length of the time series. At equation 5 Z_{SR} is the Z stat calculated according to Spearman's rho value. If the calculated Z stat is positive, it means the trend direction is positive. If it is negative, then it means the trend direction is negative.

2.3. Sen's Slope

Sen's slope was calculated to define the magnitude of the trend. The calculation of Sen's slope is given by equation 6.

$$\beta = median\left\{\frac{x_j - x_i}{j-i}\right\} \quad i<j \tag{6}$$

Equation 6 x_j and x_i shows the value of the time series in the j_{th} and i_{th} time steps (Sen, 1968).

3. RESULTS AND DISCUSSIONS

In this section Mann Kendall test, Spearman's Rho test, and Sen's slope values of the discharge of Logan River were calculated and shared. Both the Mann Kendall and Spearman's rho tests were applied within the 95% confidence interval.

Monthly and yearly evaluation of the Mann-Kendall test is given in Table 2. According to the results of the Mann-Kendall test, a significant trend was not detected for the yearly scale. However, on a monthly scale, trends were detected for august and September within the 95% confidence interval.

As all calculated Mann-Kendall test values (MK stat) have negative values, the detected trend directions were considered declining trends according to the Mann-Kendall approach.

Table 2. Mann Kendall test results of Logan River discharge.

Time Interval	*Alpha*	*MK Stat*	*Z Stat*	*Critical Z*	*Trend*
January	0.05	-158	-1.31	(+.-)1.96	No
February		-146	-1.21		No
March		-128	-1.06		No
April		-45	-0.37		No
May		-127	-1.05		No
June		-150	-1.25		No
July		-221	-1.84		No
August		-290	-2.42		Yes
September		-285	-2.38		Yes
October		-153	-1.27		No
November		-132	-1.10		No
December		-128	-1.06		No
Yearly		-141	-1.17		No

In the second part of the study, Spearman's rho test was applied to the same data set. Spearman's rho results showed that there is a trend in monthly evaluation same as the Mann-Kendall test. However, surprisingly the trend directions of august and September were calculated as positive by using Spearman's rho approach. Results belonging to Spearman's rho method are given in Table 3.

As it is suggested by Dahmen & Hall, (1990) Spearman's rho test is generally in use to detect whether there is a trend or not. In this case, within the identified confidence interval it is possible to see that Spearman's rho detected the same months as the trend months.

The direction differences between both approaches lead to authors making an additional calculation to decide the trend's final direction. In order to do that, the authors thought Sen's slope will be helpful. Therefore, Sen's slope was calculated and shared in Table 4.

Table 3. Spearman's rho test results of Logan River discharge.

Time Series	**α**	**Critical Z Value**	**Calculated Z Value**	**Trend**
January	0.05	+1.96 -1.96	1.40	No
February			1.19	No
March			1.12	No
April			0.45	No
May			1.20	No
June			1.45	No
July			1.92	No
August			2.56	Positive
September			2.56	Positive
October			1.45	No
November			1.15	No
December			1.16	No
Yearly			1.47	No

As it is shared in Table 4. every time the steps negative Sen's slopes were calculated. Sen's slope was only calculated to support the findings of the Mann-Kendall or Spearman's rho tests. Since every MK stat and Sen' slope has negative values, it is seen that Sen's slope results support the Mann-Kendall results. However, it is also seen that by using Sen's slope more sharp slopes were calculated for May, June, and July than the other trend-detected months (August and September).

Table 4. Sen's Slope calculations of the discharge time series.

Time Step	I	II	III	IV	V	VI	VII	**VIII**	**IX**	X	XI	XII	Yearly
Sen's slope	-0,30	-0,22	-0,26	-0,29	-2,83	-4,80	-2,80	**-1,53**	**-1,19**	-0,66	-0,44	-0,33	-1,07

The yearly mean discharge distribution graph for August is given in Figure 2. According to the slope of the regression line, it is possible to see that the trend direction is also negative.

The yearly mean discharge distribution graph for the September is given in Figure 3. The slope of the regression line is negative as it was negative for August too. August and September were investigated especially because these two months were detected as the months which has trends in Mann-Kendall and Spearman's rho tests.

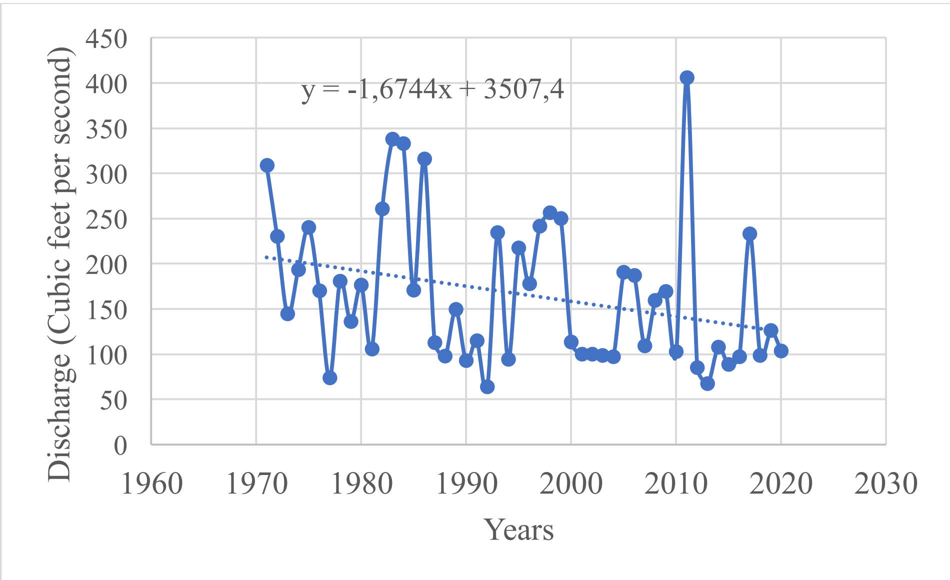

Fig. 2. ***Mean Discharge of the August over years***

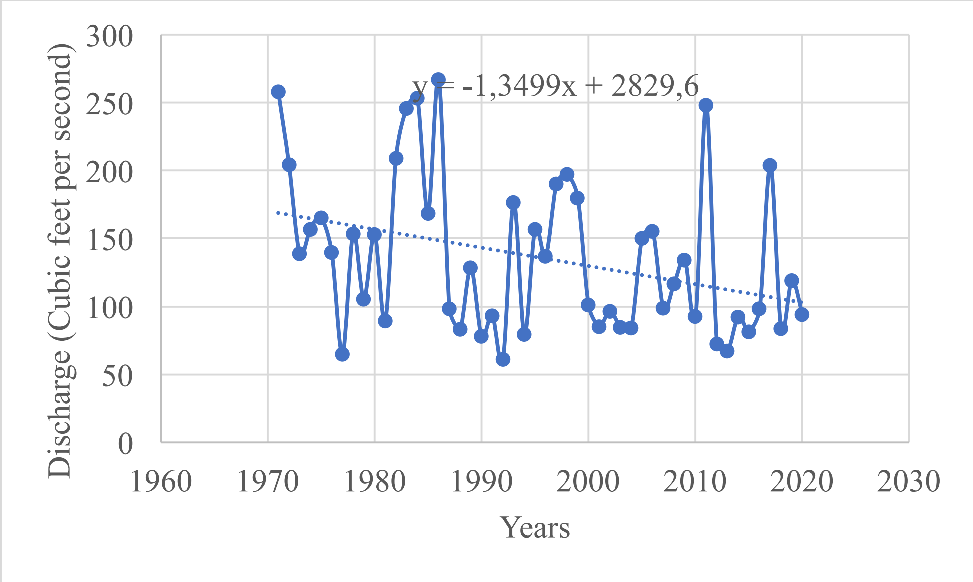

Fig. 3. ***Mean Discharge of the September over years***

4. CONCLUSION

In this study, the monthly mean discharge of Logan River Above State Dam, Near Logan, UT gauge station trends were investigated by using traditional statistical approaches. The Mann-Kendall test and Spearman's rho test were applied to the same data within the same time scales. According to both methods results trends were detected for August and September. However, the directions of the trends were opposite in both methods. In order to make a final decision about the direction of the trend, additional calculations were made by using Sen's slope. Sen's slope values were calculated as negative for all time steps, and it is seen that the results supported the Mann-Kendall results.

According to traditional approaches, It is understood that there is a decreasing mean discharge trend in August and September. Also, the Mann Kendall test is more appropriate to detect the trends and the trend directions in case of discharge evaluation. Additionally, it is seen that the trend analysis must be checked with more statistical approaches such as slope to be able to make a final decision.

ACKNOWLEDGEMENT

The authors would like to thank the staffs and administrators of the United States Geological Survey (USGS) for collecting and sharing the data set.

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