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RAINFALL TREND ANALYSIS USING MANN-KENDALL AND SEN'S SLOPE ESTIMATOR TEST

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Abstract: This study aims to analyze trends, being a very useful analytical tool for managing water resources. The Mann-Kendall test is frequently used by researchers to determine trends in temperature, evapotranspiration, and precipitation on monthly, seasonal, and annual scales. The purpose of this study is to analyze the rainfall trends in the Petrosani area, using long time series data and establish a hydrological model. In addition, this study is conducted to assess the significance of rainfall trends over the chosen study area using the Mann-Kendall Test and Sen's Slope.

Keywords: trend, precipitation, time series,

1. INTRODUCTION

The appearance of the trend in a time series is due to the non-homogeneity of the series of observations; this being actually considered a long-term deviation in the analyzed data series [2]. Changes in precipitation trends are directly related to climate change. Floods are increasingly common in our country, but also globally.

This study aims to analyze trends, being a very useful analytical tool for managing water resources.

In this paper, Mann-Kendall test and Sen's slope methods are used, which are more suitable than parametric methods to deal with non-normally distributed data in hydrometeorology.

The Mann-Kendall test is frequently used by researchers to determine trends in temperature, evapotranspiration, and precipitation on monthly, seasonal, and annual scales.

2. METHODOLOGY

The area study is Petroșani City (Figure 1), that is located in Hunedoara County, Romania and at an altitude of 615–620 m in the Petroșani Depression. The relief is specific to the mountainous area (Figure 1), the maximum altitude being the peak of Parângul Mare at 2,519 m. Through Petroșani passes the Jiul de Est and its four tributaries: Maleia, Staicului, Slatinioara and Salatruc. Due to the abundant precipitation, there are many underground waters and springs on the surface of Petroșani.

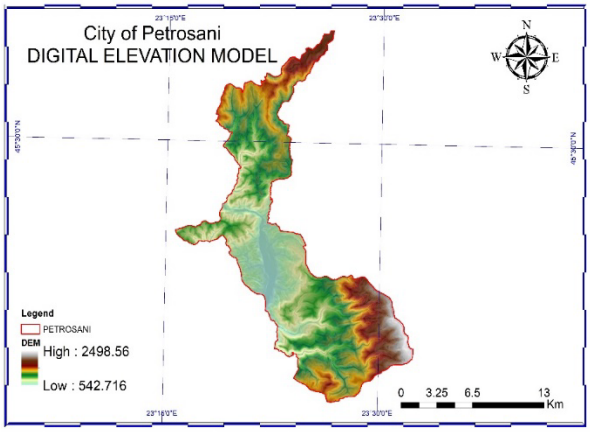

Figure1. Location map of the study area

The climate of the area is mountainous, the average annual temperature is 6.8 ºC, and the average annual precipitation is 700–800 mm/year (Figure 2).

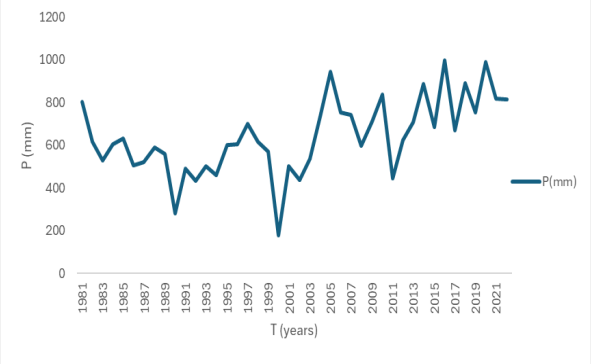

Figure 2. The annual precipitations variation

The purpose of this study is to analyze the rainfall trends in the Petrosani area, using long time series data and establish a hydrological model. In addition, this study is conducted to assess the significance of rainfall trends over the chosen study area using the Mann-Kendall Test and Sen's Slope.

The test statistic S is:

$$S = \sum_{1}^{n-1}[\sum_{j=i+1}^{n} sgn(x_j - x_i)] \quad (1)$$

Where: x_j and x_i represent the value of sequence j and i (j > i) which express the time indices associated with individual time series and n is the data length.

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The Mann - Kendall test is used to perceive statistically significant decreasing or increasing trends in long-term temporal data [3].

sgn(x) = 1 for x > 0
sgn(x) = 0 for x = 0
sgn(x) =-1 for x < 0

Sen's Slope Estimator Test was developed by Sen for the performance of checking the statistical linear relationships. It is used to calculate the magnitude of trends in the long-term temporal data [5].
In this study, Sen's slope is applied to calculate the magnitude of the trend for temperature and rainfall data. The equation below is used to estimate each individual slope (Qi):

$$Q_{ij} = \frac{y_{j-}\ y_i}{j-i} \qquad (2)$$

Where:
i=1 to n-1, j=2 to n
y_j and y_i are data value at time j and i , and j > i.
If the time series, there are n values of y_j, estimate of the slope will be:

$$N = \frac{n(n-2)}{2} \qquad (3)$$

The Sen's slope is:

$$Q_{ij} = \begin{cases} \frac{y_{j-}\ y_i}{j-i} & \text{if n is odd} \\ \frac{1}{2}(Q_{\frac{N}{2}} + Q[\frac{N+2}{2}]) & \text{if n is even} \end{cases} \qquad (4)$$

The positive value of Q_i indicates an increasing trend, and the negative value tell us that there is a negative trend [5].

3. RESULTS AND CONCLUSIONS.

The results of statistical analysis of the rainfall data for the study area for the period 1981 – 2022 are discussed in this section (table 2, 3 and 4).
Results presented in this study are based on observed data at Petrosani for the period of annual rainfall from 1981 to 2022.

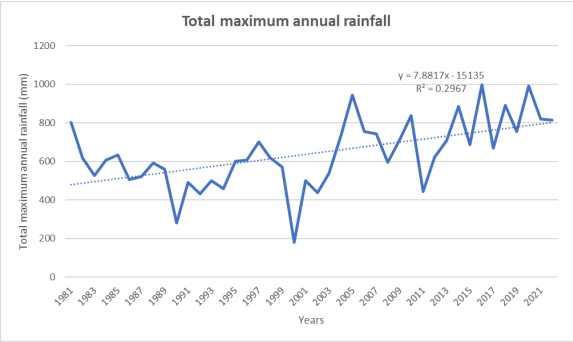

Figure 3. Total maximum annual rainfall.

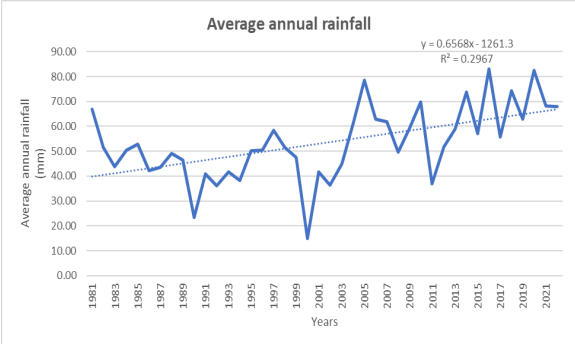

Figure 4. Average annual rainfall

In table 1 were determined the necessary parameters using excel - The Mann-Kendall test statistic (S), the normal Z test statistic and the variance of the rainfall (var S). A positive S value indicates an upward trend, while a negative value indicates a downward trend [1].

Table 1. Parameters of Mann _ Kendall test

Year	*Average*	*Annual Rainfall*	*RANK*	*S*
	66.80	801.55	34	-25
1982	51.42	616.98	21	0
1983	43.94	527.33	12	17
1984	50.54	606.43	19	4
1985	52.74	632.82	24	-3
1986	42.19	506.24	10	18
1987	43.50	522.05	11	17
1988	49.22	590.63	16	10
1989	46.58	558.98	14	13
1990	23.29	279.49	2	30
1991	40.87	490.42	7	21
1992	36.04	432.43	3	28
1993	41.75	500.97	9	19
1994	38.23	458.78	6	22
1995	50.10	601.16	18	13
1996	50.54	606.45	20	12
1997	58.45	701.37	27	3
1998	51.42	617.01	22	10
1999	47.46	569.53	15	13
2000	14.94	179.28	1	22
2001	41.75	500.96	8	17
2002	36.47	437.69	4	20
2003	44.83	537.9	13	17
2004	61.08	733	30	4
2005	78.66	943.95	40	-13
2006	62.84	754.11	33	-2
2007	61.96	743.56	31	1
2008	49.66	595.91	17	12
2009	59.33	711.92	29	3
2010	69.87	838.46	37	-4

2011	36.91	442.95	5	11
2012	51.86	622.26	23	10
2013	58.89	706.63	28	5
2014	73.83	885.94	38	-2
2015	57.13	685.53	26	5
2016	83.06	996.66	42	-6
2017	55.81	669.71	25	5
2018	74.27	891.2	39	-2
2019	62.84	754.1	32	3
2020	82.62	991.39	41	-2
2021	68.33	819.95	36	-1
2022	67.93	815.19	35	0

Significance level (%): 5
Continuity correction: No
Confidence interval (%) (Sen's slope): 5

Table 2. Mann-Kendall trend test

Kendall's tau	0.377
S	325
Var(S)	8514.333
p-value (one-tailed)	0.000
alpha	0.05

Test interpretation:

H_0: There is no trend in the series
H_a: There is a positive trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis H_a

Table 3. Sen`s slope test

Sen's slope:	*Value*	*Lower bound (5%)*	*Upper bound (5%)*
Slope	7.764	7.617	7.910
Intercept	Value	Lower bound (5%)	Upper bound (5%)
Slope	7.764	7.617	7.910
Intercept	-14889.136	-15034.905	-14742.712

Table 4. Summary statistics

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
annual	42	0	42	179.280	996.660	639.973	177.512

Summary:

Series\Test	Kendall's tau	p-value	Sen's slope
annual	0.377	**0.000**	7.764

Figure 4 shows the linear regression analysis for annual data, the linear regression slope is positive and equal to 7.8817 mm/year, which ensures the annual trend of increasing precipitation similar to the precipitation trends found at the hydrometric station. The non-parametric Mann-Kendall test is frequently used to detect trends in a series of climate data or hydrological data.

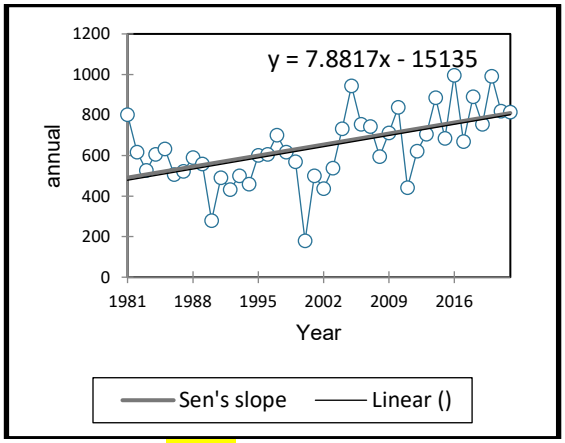

Figure 4. Sen `s slope

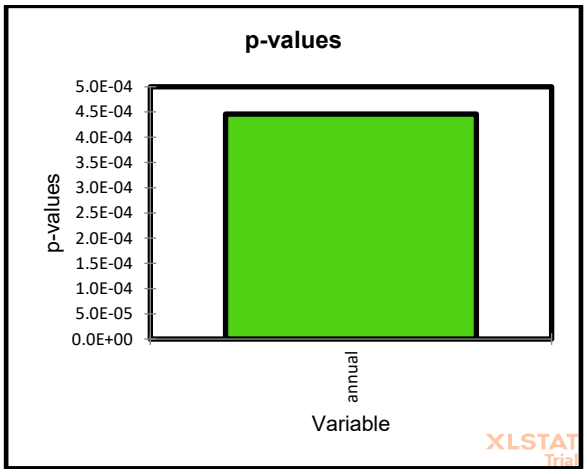

Figure 5. p – values

The Mann-Kendall trend, its statistical significance along with magnitude of Sen's slope for 1982-to-2022-year rainfall data is shown in above Tables.

Table 5. Mann-Kendall trend test for average rainfall

Kendall's tau	*0.377*
Kendall's tau	0.377
S	325
Var(S)	**8514.333**
p-value (Two-tailed)	**0.000**
alpha	0.05

Table 5 presented the magnitude of average rainfall patterns obtained from the Mann-Kendall test, the slope estimator from Sen and the linear regression. From table 5, the average data trend is increasing as both the slope estimator of the Sen and the tau (Z) values of Kendall were positive.

	Value	Lower bound (5%)	Upper bound (5%)
Slope	Value	Lower bound (5%)	Upper bound (5%)
Slope	0.647	0.635	0.659
Intercept	-1240.761	-1252.909	-1228.559

Figure 6 shows the linear regression analysis for annual data, the linear regression slope is positive and equal to 0.658 mm/year, which ensures the annual trend of increasing precipitation similar to the precipitation trends found at the hydrometric station.

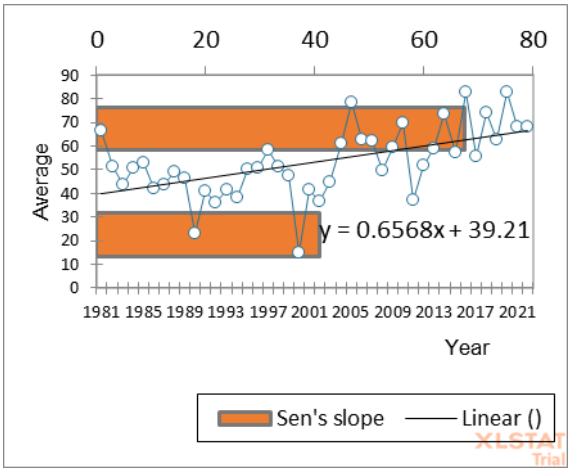

Figure 6. Sen `s slope for average rainfall

In this study, Sen's slope estimator, non-parametric Mann-Kendall test, and linear regression test were investigating trends of average and annual rainfall for Petrosani city. The trend of the annual rainfall increasing rate was equal to 7.88 mm/year. The results of analysis the average rainfall trend revealed an increasing trend also.

REFERENCES

[1] Fawaz Kh. Aswad, Ali A. Yousif And Sayran A. Ibrahim, (2020), Trend Analysis Using Mann-kendall And Sen's Slope Estimator Test for Annual And Monthly Rainfall for Sinjar District, Iraq , The Journal of The University of Duhok 23(2):501-508

[2]. A. Serban, 2001, Modelarea seriilor temporale, Ed. HGA, Bucuretsi

[3]. Mallick et al. 2021, Analysing the trend of rainfall in Asir region of Saudi Arabia using the family of Mann-Kendall tests, innovative trend analysis, and detrended fluctuation analysis, Theoretical and Applied Climatology, 143(3)

[4] Sunny Agarwal, A.S. Suchithra and Surendra Pal Singh, (2021), Analysis and Interpretation of Rainfall Trend using Mann-Kendall's and Sen's Slope Method, Indian Journal of Ecology (2021) 48(2): 453-457

[5] Agarwal, S., Suchithra, A. & Singh, S. P., (2021), Analysis and interpretation of rainfall trend using Mann-Kendall's and Sen's slope method. Indian Journal of Ecology 48 (2), 453–457