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Climatic Variability Analysis of a Garhwal Himalayan Watershed, Uttarakhand

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Abstract: ***Climate change is the most serious threat confronting the globe today, and it is predicted to have its impacts on different sectors. A study of climate changeability, trend and estimate for better water resource management and planning in a watershed is very significance. The present study focuses on the study trend analysis of the temperature and precipitation of a central Himalayan watershed viz., the Mathugad in district Chamoli of Uttarakhand state. For this purpose, IMD Gridded daily data over the time period of 40 years (1981–2020) have been used. Statistical trend analysis techniques, namely the Mann–Kendall test and Sen's Slope estimation have been done to examine trends. The results indicate that the average annual temperature shows a significant increase which has found significant at 95% confidence level no marked change were notice in the average annual rainfall but the rhythm of the rainfall has changed significantly. Due to temperature rise and change in rainfall rhythm the hydrological system and agriculture is being adversely affected in the region. The present study also attempts to define the impact of temperature rise and change in rainfall rhythm in springs, streams and river.***

Keywords: Climate Change Impact, Hydrological Cycle, Trend Analysis, Mathugad Watershed, Uttarakhand

1. Introduction

The term climate 'refers to a statistical description of weather in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 - 35 years) and of the related conditions of oceans, land surfaces including human perturbations and ice sheets. The atmosphere, land surface, snow and ice, seas, other bodies of water, and living creatures all play their role in determining the climate of any given place. The climate system evolves over time as a result of its own internal and external dynamics, which are referred to as 'forcing.' (Schneider, 2001). Climate change is a science that has been a matter of research for a long time. Humankind has learned a lot about Earth's environment long before we arrived according to the fossil records. We currently live in a unique era in which our scientific abilities have not only provided us but also taken us to new heights, an age not only of the planet but of the entire universe. However, there are many things we don't know, and some of the unanswered questions could have a major impact on the quality of our lives in the future. As our modern civilization witnesses an unmistakable period of global warming the nature of this change continues to be a source of debate among scientists, planners, administrators and the general public.

Climate change variability is the biggest challenge facing the world today and is expected to make an impact. Hydrological processes such as precipitation and evapotranspiration. Second, it can have a direct impact on flow and groundwater recharge. Possible impacts of projected climate change on water resources, as a result Impact of global warming due to rising greenhouse gas concentrations in the atmosphere, it's a serious decision-making problem maker around the world. The terms "climate change" and "global warming" are sometimes used interchangeably. 'Warming' and 'change' are used similarly, but they have specific meanings in the sense that 'warming' is simply one phase of the wider climate system on Earth that is always changing.

Physical evidence from Earth and space has helped scientists to understand that a variety of causes can contribute to long-term climate change on the planet.Climate change has many facets, global warming being just one. Heating temperatures, drought, flooding, storms, increasing sea levels, consequences on food production, and infectious diseases are only a few indications of larger changes. (Pant and Kumar, 1997) "It has been discovered that seasonally and annually temperatures of the atmosphere have been expanding at an annual rate of 0.57 °C per 100 years (1881 to 1997) in India". These activities include in particular the use of petroleum-derived substances and deforestation, both of which result in the emission of GHGs like methane (CH_4) and nitrous oxide (N_2O), as well as carbon dioxide (CO_2), the primary gas responsible for environmental change. Land use changes, of which tropical deforestation is the most obvious, can be responsible for up to 25% of all global GHG emissions. The consequences of what has already transpired will last for many more years, even if outflows end today. Recent research indicates that several climate change-induced eco-hydro-meteorological phenomena in the northwestern Himalaya are already active (Arnell, N. and C. Liu, 2001; Tambe et al., 2012; Pande et al., 2014).

The Mann-Kendall trend test is less susceptible to outliers because it is based on the rankings of the observations rather than their actual values, which are unaffected by the data's true distribution. Basistha et al. (2009) reported a decline in precipitation over the Himalayan region over the past 20 years (1965–80). Rajeevan et al. (2008) report on the frequency of extreme rainfall events over India, significant inter-annual and inter-decadal variability, as well as a statistically significant long-term trend of 6% per decade. Therefore, the significance of continual rainfall research has to be stressed for the long-term planning and management of water resources. The primary goal of the present study work is to look at variations and trends in rainfall and average temperature, over the time periods 1981–2020 in Grahwal Himalayan watershed viz., Muthugad watershed.

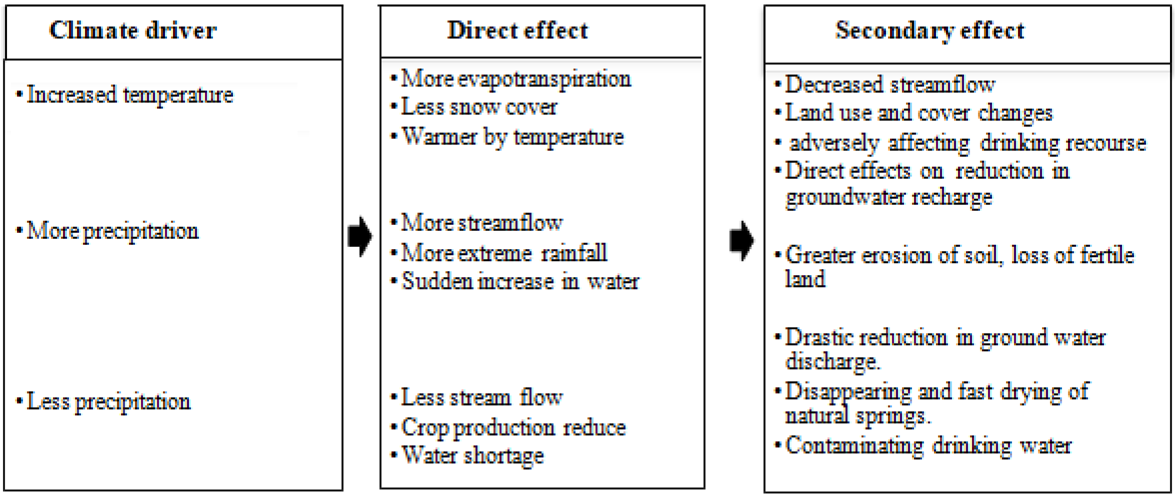

Chart 1: Causes and effects of climatic variability

2. Study Area

The study area Viz. the watershed lies in between $30^{0}1'02''$ N and $30^{0}6'3''$ N latitudes and $79^{0}12'15''$ E and $79^{0}19'04''$ E longitudes in the district Chamoli of the Uttarakhand state (Fig-1) encompasses a total area of about 77.12 sq.km and the watershed lies on the lesser Himalaya Genetic region of the central Himalaya in including the elevation from the sea level varying in between 1533m to 3119m there are 33 villages in the watershed having a total population of 5775 male and 6153 female persons.. The river Mathugad originates from the foothills of charorakhal dhar and total length of Mathugad river 11.4 km river is about the Mathugad is a tributary of Western Ramganga. The watershed is totally under hilly terrain. The Mathugad river that flows through the watershed is among the hundreds of first -order perennial streams of the non-glacial -fed western Ramganga river system in lesser Himalayan terrain. Geographically, the study area is very important because it has a political impression it is falls under summer capital (Gairsain) of the Uttarakhand State.

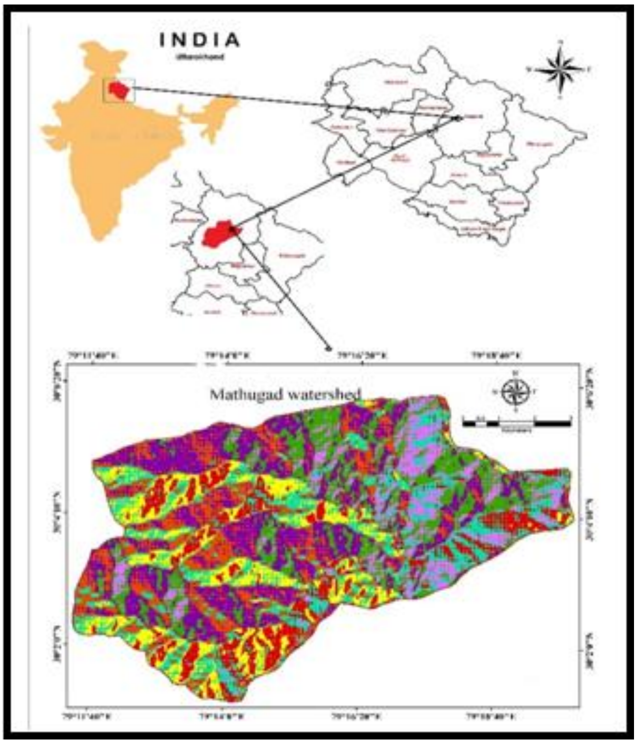

Figure 1: Location map of the Mathugad Watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand

3. Materials and Methods

Data used

The daily and monthly rainfall and temperature data were obtained from Indian Meteorological Department (IMD), Pune. The data were converted and rearranged into a form by using QGIS (2.18.24) and Python by using PyCharm software (2021.3.3). The processed data were then organized into monthly and annual series.Gridded data sets of rainfall and temperature have been used in many hydrological and climatological studies worldwide (Tozer et al., 2012; Dash et al., 2013). Therefore, in the present study the data of rainfall obtained from IMD remotely sense station which is district rainfall monitoring scheme (DRMS) stations. the nearest station located in Karnaprayag district Chamoli these data sets have obtained in Longitude 79.5 E Latitude 29.5 N. in resolution 0.25° × 0.25° (Pai et al.,2014).Temperature data 1° × 1° (Rajeevan M. 2008; Srivastava et al., 2008) resolution Longitude 29.5 E Latitude 78.75 N. Gridded data sets of daily rainfall and temperature for the period 1981 to 2020 were used for the spatial and temporal analyses for the present study.

Techniques

Once the data had been processed, it was rearranged into monthly and annual series (1981–2020). The pattern was defined using the mean monthly data, and the trend of the meteorological parameters was examined using the mean yearly data. The monthly and annual variability of temperature and rainfall trends in the research area throughout the 40-year period of 1981–2020 was examined using statistical methods. In this study, trends in meteorological parameters are found using non-parametric Mann-Kendall and Sen slope estimators (Mann, 1945; Kendall, 1975; Sen, 1968).The pattern and variance of the trend have been calculated using the linear regression technique. In order to find significant trends in climatological time series, the data must be completely autonomous and normally distributed. Non-parametric tests can be employed to evaluate the importance of monotonic trends (either linear or non-linear) (Thakur et al.,2016).

The non-parametric Mann Kendall test is a tool for identifying trends in variables in hydro-meteorological disciplines. The MK test compares the alternative hypothesis of an existing trend a rising or declining trend to the null hypothesis, which is that there is no trend. A specific application of Kendall's test for correlation known as the Mann-Kendall test, proposed by Mann in 1945, is a nonparametric test for unpredictability against time (Kendall 1962).Sen's slope estimation can be used to estimate the trend's magnitude in conjunction with the statistical significance trend discovered using a non-parametric model, such as the Mann-Kendall (MK) test. This test has been widely used by researchers to assess the importance of trends in hydrometeorological time series data, including water quality, stream flow, temperature, and precipitation, and it has established itself as a highly effective method for trend detection.

The Kendall tests the statics (s) can be defined as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sig}\left(X_j - X_i\right) \quad (1)$$

Where, N is the number of data points. Assuming (xj – xi) = θ, the value of sgn(θ) is computed as follows:

$$sgn\left(X_j - X_i\right) = \begin{cases} +1 \; if \left(X_j - X_i\right) > 0 \\ 0 \;\; if \left(X_j - X_i\right) = 0 \\ -1 \; if \left(X_j - X_i\right) < 0, \end{cases} \quad (2)$$

This statistic represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N > 8), the test is conducted using a normal distribution, with mean and variance as follows:

E[S] = 0

$$\operatorname{Var}(S) = \frac{1}{18} n\left[(n-1)(2n+5) - \sum_{p=1}^{q} tp(tp-1)(2tp+5)\right] \quad (3)$$

Where, n is the number of tied (zero difference between compared values) groups and t_k the number of data points in the k_{th} tied group. The standard normal deviate (Z-statistics) is then computed as follows:

$$Zmk \begin{bmatrix} \frac{s-1}{\sqrt{var(s)}} if\ s > 0 \\ \frac{s+1}{\sqrt{var(s)}} if\ s < 0 \\ 0\ if\ s = 0 \end{bmatrix} \quad (4)$$

If $\pm Z_{mk} \leq Z_{\alpha/2}$ (here α = 0.1), then the null hypothesis for no trend is accepted in a two-sided test for trend, and the null hypothesis for the no trend is rejected If the computed value of $Z_{mk} > Z_{\alpha/2}$, the null hypothesis (H0) is rejected at α level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level. Failing to reject H0 (i.e., null hypothesis) does not mean that there is no trend. Rather, it is a statement that the evidence available is not sufficient to conclude if there is a trend (Helsel and Hirsch, 2002). The significance levels (p-values) for each trend test can be obtained from the relationship given as (Coulibalyand Shi, 2005):

$$P = 0{:}5 - \varphi\left(|Z|\right) \quad (5)$$

Where, φ () denotes the cumulative distribution function (CDF) of a standard normal variate at a significance level of 0.1, if p ≤ 0.1 then the existing trend is considered to be statistically significant.

Sen Slope estimator-If a linear trend is present in a time series, then the true slope of the trend is estimated using a simple non-parametric procedure (Theil, 1950; Sen, 1968), which is given by:

$$Q_i = \operatorname{median}\left(\frac{X_j - X_k}{j-k}\right) \quad \forall k \leq j \quad (6)$$

Where, x_j and x_k are data values at times j and k (j > k), respectively. The median of N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by $Q_{med} = Q_{(N+1)/2}$ and if N is even, then Sen's estimator is computed by $Q_{med} = [Q_N/2 + Q_{(N+2)/2}]/2$. Finally, Q_{med} is tested by a two-sided test at 100(1 - α) % confidence interval, and the true slope is obtained by a non-parametric test.

4. Result and Discussion

Temperature variability analysis

The average temperature variability over the last 40 years in individual months from January to December (1981-2020) is diagrammatically illustrated in Fig-2 the average annual temperature of the study area stands at 20.9^{0}C. It is observed that the January is the coldest average temperature month when the average temperature is 11.13^{0}C and the June is hottest month when the temperature risen up is 27.53^{0}C (Fig.3, above). The annual average temperature variation over the time period of 40 years for each 12 months shows that the highest rise in annual average temperature with trend in the months of June which stand at 27.53^{0}C during the study period maximum temperature occurred in the years 2006 (22.41 ^{0}C) while minimum temperature was recorded in the year 1983(19.8^{0}C) (Fig.3, below). Month wise analysis (Fig.4) denote average month wise temperature which displays that the maximum increasing trend in winter months and minor in summers months very insignificant in rainy season months.

Figure5 shows a summary and illustration of the results from Table 1's MK trend analysis test and Sen's slope estimation. These data show the Zc statics value, which revealed the trend of the 40-year time series for the specific months from January to December presented. The statistical analysis of the average temperature for the year suggests an increasing trend, which has been observed to be significant at a confidence level of 99%. The strongest upward trend in mean temperature was seen in the month of August (0.367), while the highest negative trend was seen in the month of January (0.087). This is due to the south-west monsoon's effects, which are what caused these trends to occur.

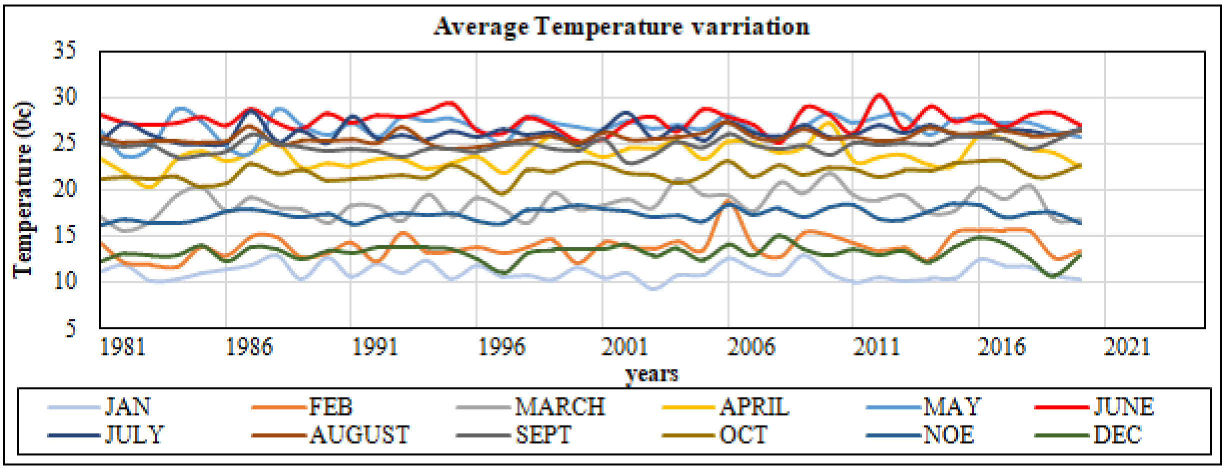

Figure 2: Average temperature variation over 40 years in individual months Jan to Dec (1981-2020) in the Mathugad Watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand

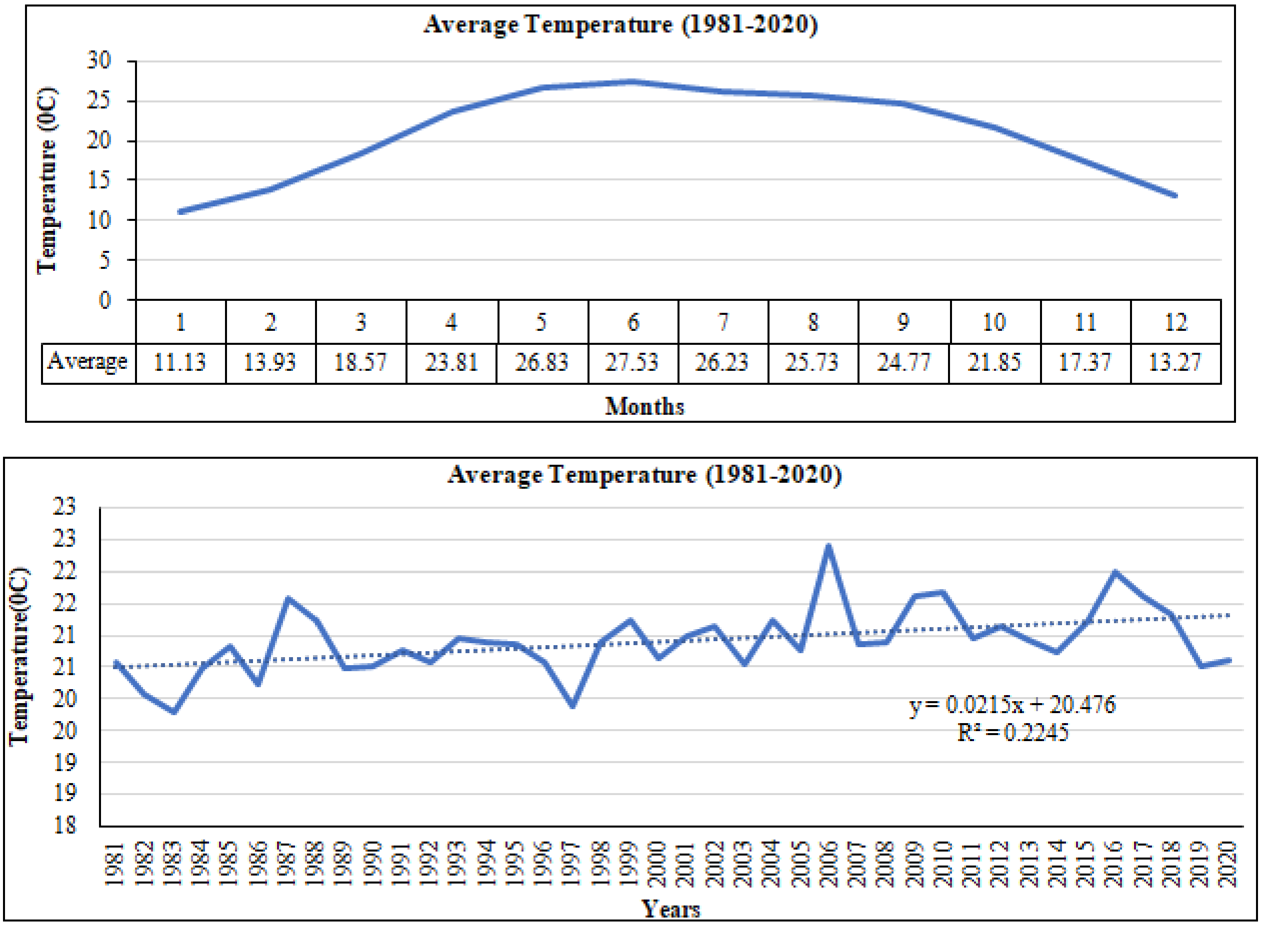

Figure 3: Mean monthly (1981-2020) average temperature (above) and average annual temperature and its trend (belove) in the Mathugad watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand

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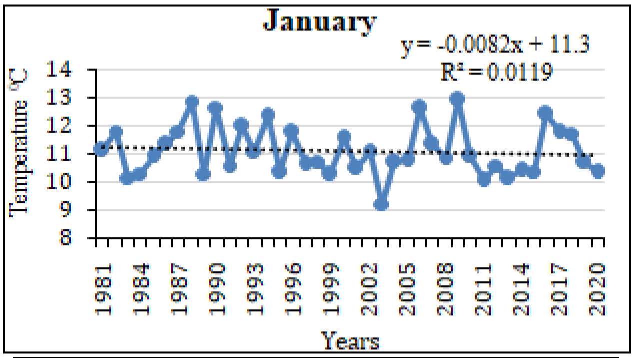
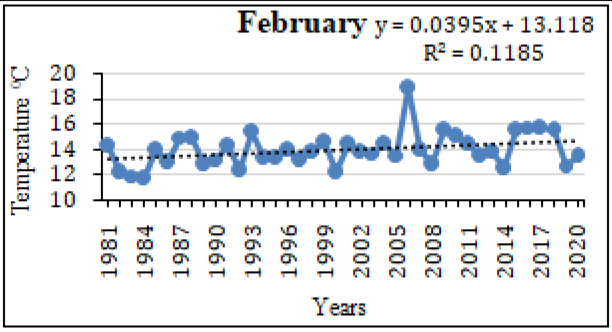
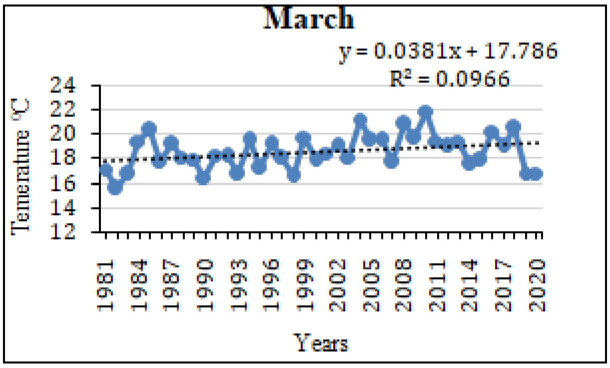
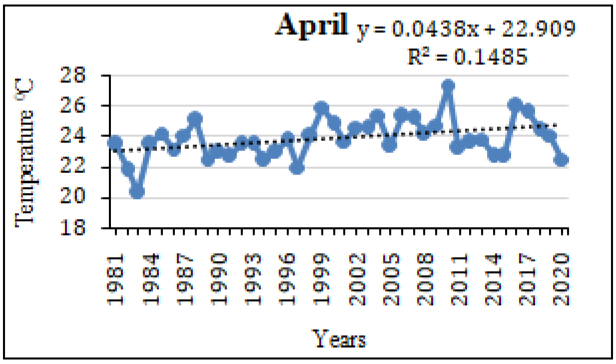
Table 1: Annual average temperature Estimated Sen's Slope and Kendall's test statistics (Zc) values from 1981 to 2020 in the Mathugad watershed, Grahwal Himalaya, Uttarakhand

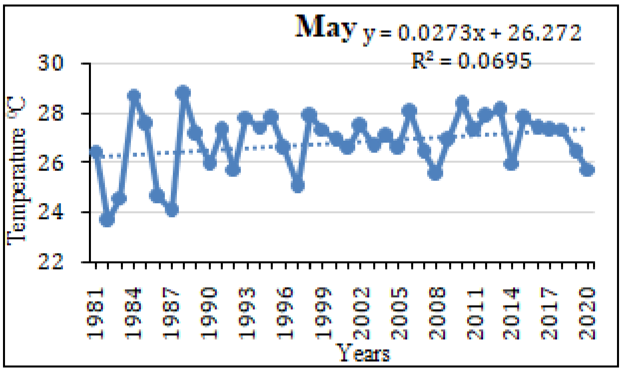
Months	Minimum	Maximum	Average	Std. deviation	Kendall's test Zc statistics	Sen's slope	p-value	Results
January	9.26	12.95	11.132	0.880	-0.087	-0.008	0.442	NS
February	11.72	18.8	13.929	1.343	0.241	0.041	0.029	S (0.05)
March	15.58	21.87	18.566	1.431	0.192	0.040	0.085	S (0.1)
April	20.32	27.35	23.807	1.328	0.228	0.042	0.038	S (0.05)
May	23.69	28.77	26.831	1.211	0.108	0.020	0.339	NS
June	25.1	30.32	27.532	1.108	0.026	0.003	0.807	NS
July	24.93	28.53	26.227	0.884	0.215	0.023	0.050	S (0.1)
August	24.55	27.37	25.727	0.64	0.367	0.025	0.001	S (0.01)
September	22.98	26.64	24.766	0.744	0.277	0.027	0.012	S(0.01)
October	19.65	23.24	21.854	0.804	0.344	0.029	0.002	S (0.01)
November	16.15	18.55	17.372	0.651	0.241	0.022	0.028	S (0.05)
December	10.76	15.09	13.266	0.845	0.026	0.002	0.843	NS
Average	18.720	23.290	20.910	0.980	0.180	0.020	0.001	S (0.01)

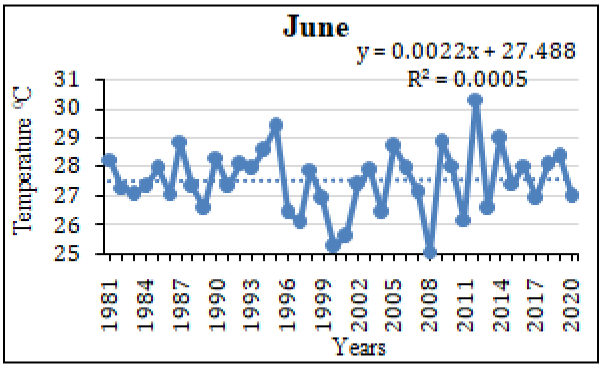


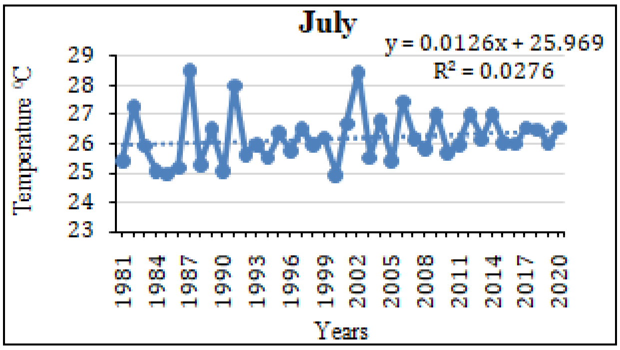


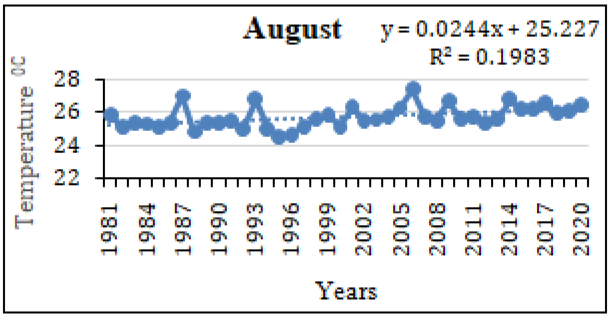












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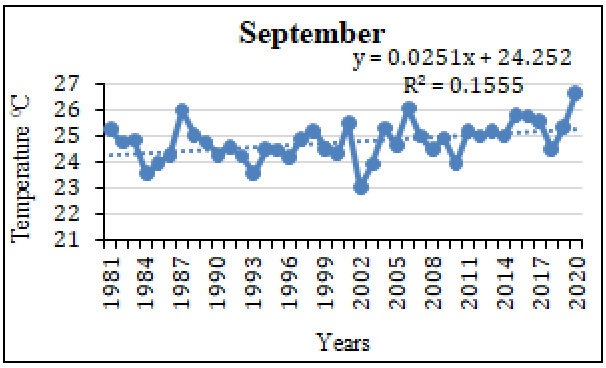
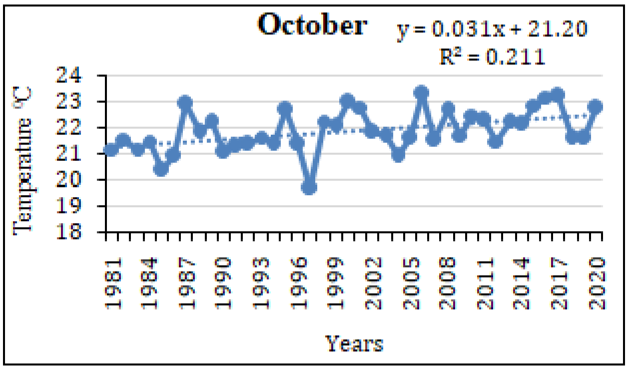
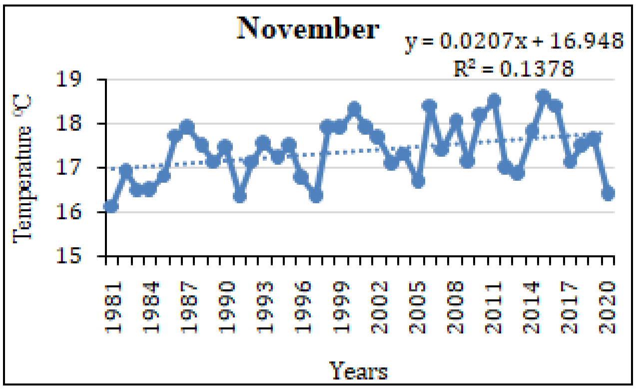






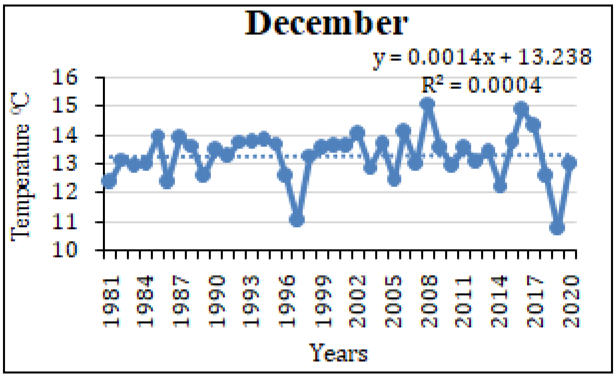


Figure 4: Average Temperature pattern and trend (1981-2020) of all the months from January to December in the Mathugad watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand

It has been noted that the months with the lowest average temperatures are January (11.13^{0}C) and the months with the highest average temperatures are June (27.53^{0}C). These numbers show the Zc statics values of 0.087, 0.241, 0.192, 0.228, 0.108, 0.026, 0.215, 0.367, 0.277, 0.344, and 0.026, respectively, which demonstrated the trend of the time series over 40 years for the separate months from January to December. The highest positive trend, which was noticed in the month of January, was -0.087, while the highest negative trend, which was reported in the month of August, was 0.367. (Fig.5)

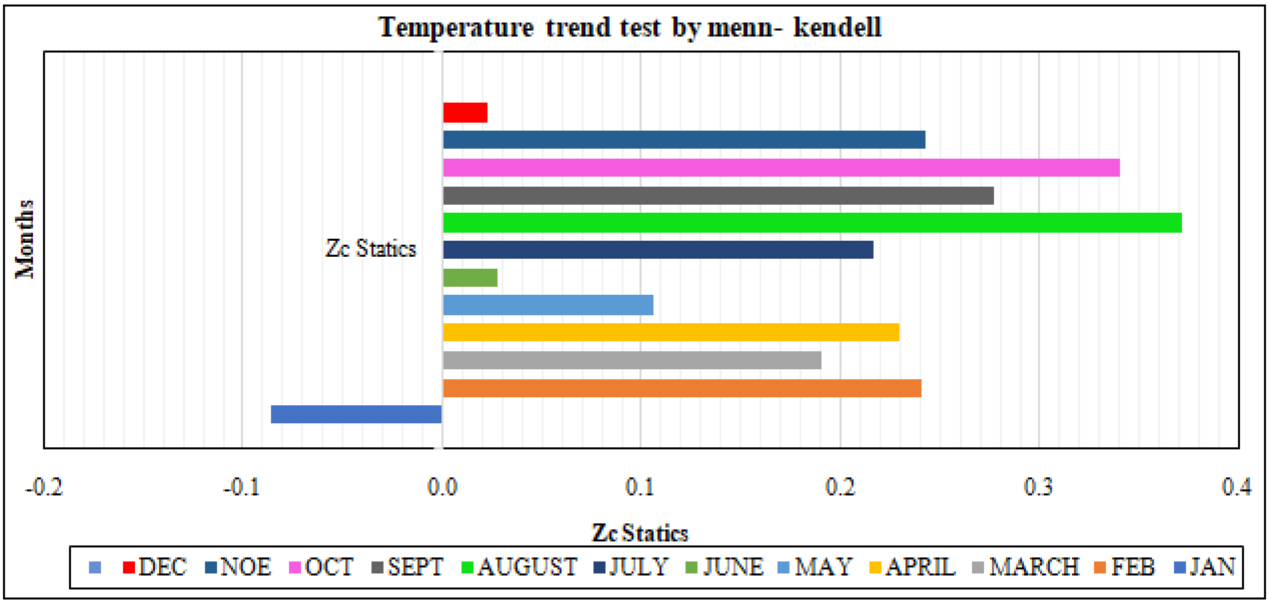


Figure 5: Mk Trend of Zc for Individual average temperature Months for 40 Years (1981-2020). in the Mathugad Watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand.

Rainfall variability analysis

The average rainfall variability over the last 40 years of individual months from January to December (1981-2020) is diagrammatically illustrated in Fig-6.The long-term Mean annual rainfall in the watershed stands at ~1103.38mmIt is also shown that July is the month of maximum average rainfall (~291.593) mm and November is the month of minimum average rainfall (~4.328) mm (Fig.7, above). During the study period maximum rainfall occurred in the years of 1990 which is ~1690.35 while the minimum rainfall occurred in the year of 2008 which is ~482.68mm. The year 1990 referred as 'wet year' and 2008 'dry year' Among the study period. (Fig.7, below).

The long-term linear trend line of the rainfall data has indicated slightly possible trend. Figure 8 shows the month wise analysis of long-term rainfall data reveal that the out of 12 the 8 months shows decreasing rainfall. These months are January, February, March, April, May, October, November December remains months in which rainfall is found cumulative trend in the month January.

Table 2: contains the Sen's slope estimation value and Kendall test statics and diagrammatically illustrated (Fig.9) (Zc) for the study time series for particular months. The rainfall records reveal that there is positive trend in the month of June, July, august and September and remaining months showed the negative trend.

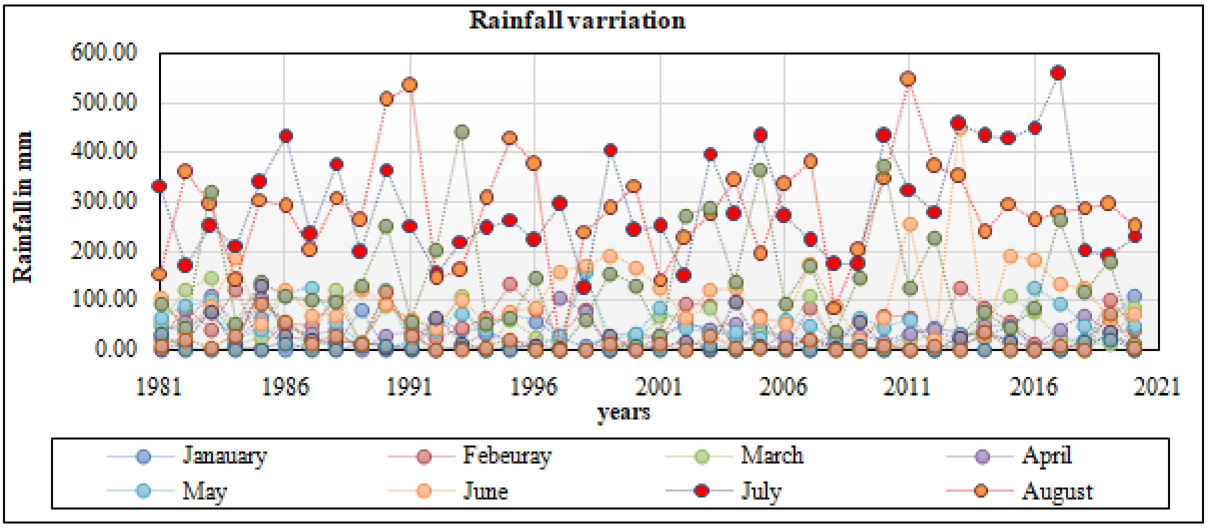
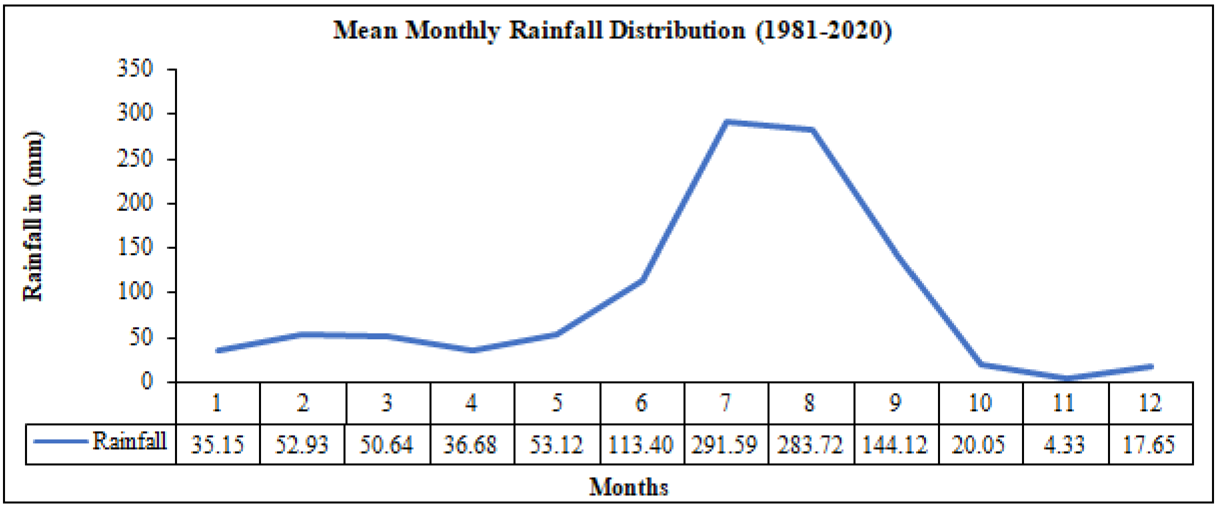


Figure 6: Rainfall variation over 40 years in individual months Jan to Dec (1981-2020) in the Mathugad Watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand.



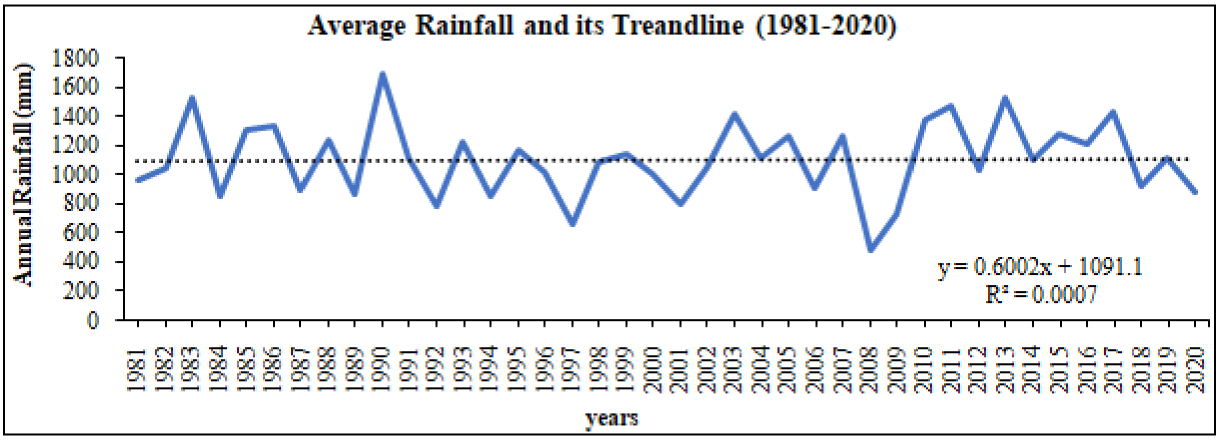
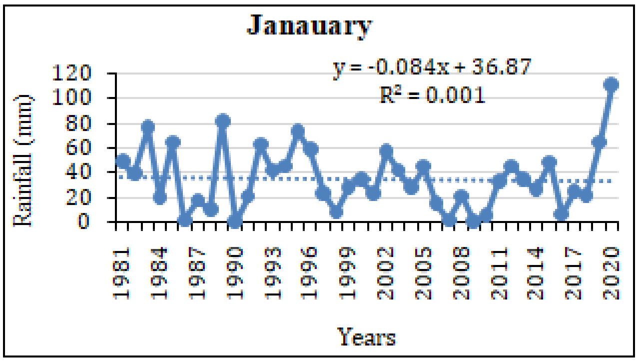
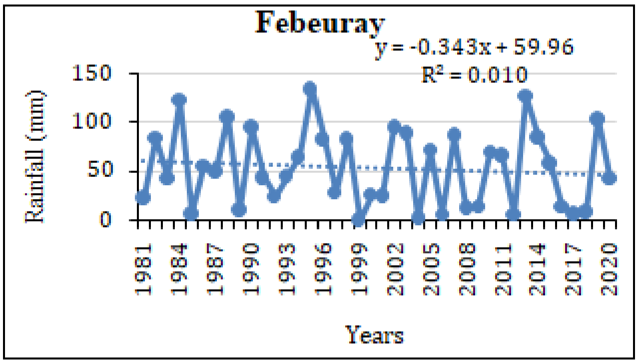


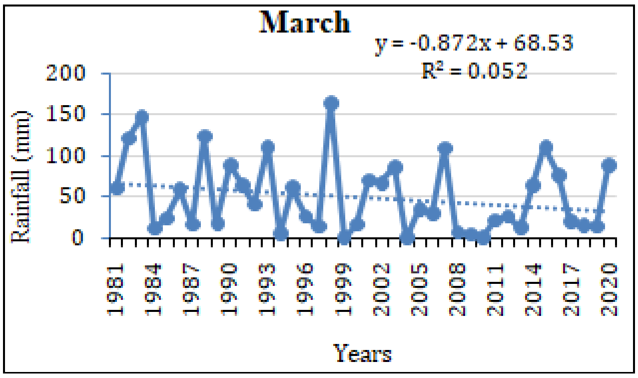
Figure 7: Rainfall Average monthly (above) and Average annual rainfall (below) (1981-2020) and its trend in the month of the Mathugad watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand.

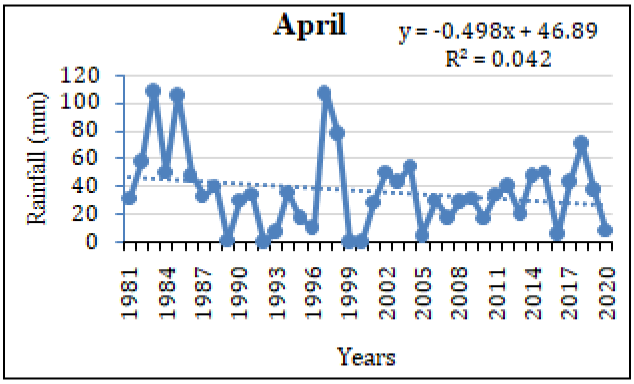
Table 2: Rainfall Estimated Sen's Slope and Kendall's test statistics (Zc) values from 1981 to 2020 in the Mathugad watershed, Grahwal Himalaya Uttarakhand.

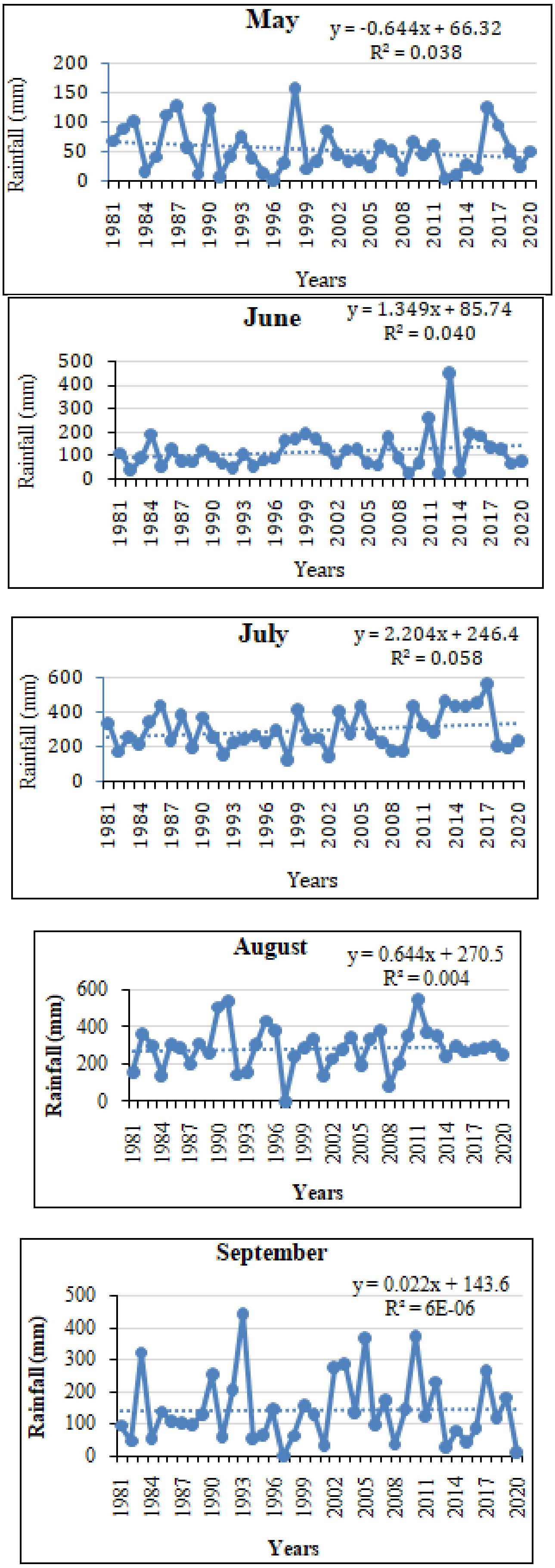
Months	Mean	Standard deviation	Kendall's test Zc statistics	Sen's slope	p-value	Results
JANUARY	35.149	25.515	-0.049	-0.182	0.666	NS
FEBRUARY	52.93	39.268	-0.072	-0.417	0.522	NS
MARCH	50.644	44.712	-0.13	-0.675	0.248	NS
APRIL	36.678	28.152	-0.083	-0.225	0.456	NS
MAY	53.118	38.506	-0.092	-0.528	0.408	NS
JUNE	113.402	77.974	0.082	0.594	0.463	NS
JULY	291.593	106.449	0.146	2.109	0.188	NS
AUGUST	283.718	112.809	0.049	0.668	0.425	NS
SEPTEMBER	144.119	107.516	0.010	0.381	0.938	NS
OCTOBER	20.051	29.152	-0.151	-0.219	0.176	NS
NOVEMBER	4.328	7.027	-0.15	-0.021	0.005	S (0.01)
DECEMBER	17.653	26.871	-0.162	-0.269	0.148	NS
AVERAGE	91.95	53.66	0.044	1.251	0.701	NS











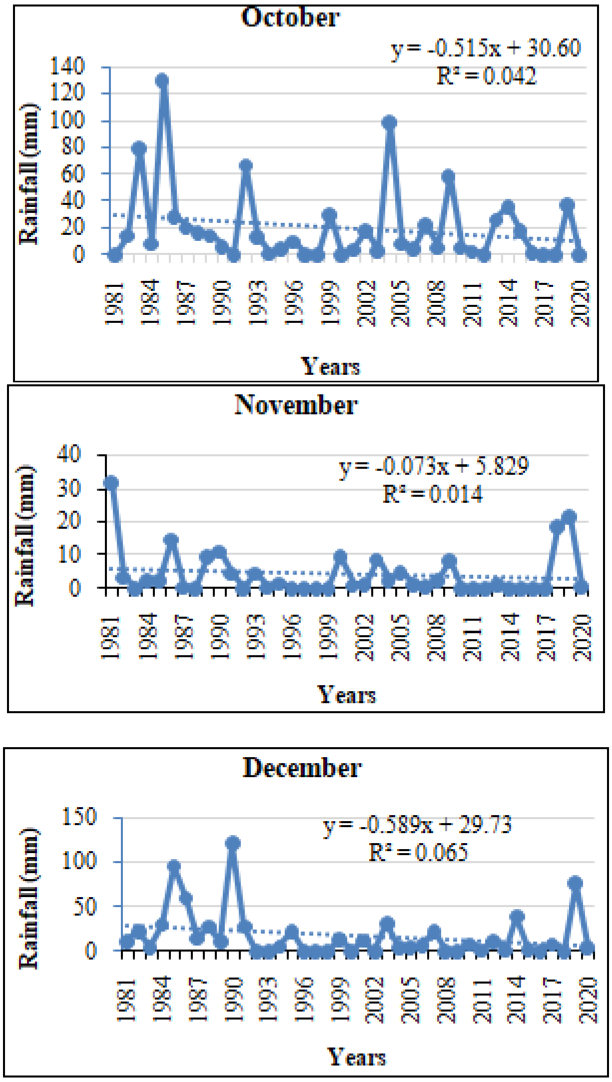


Figure 8: Average Temperature pattern and trend (1981-2020) of all the months from January to December in the Mathugad watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand.

According to the men Kendall test trend of precipitation for the year 1981- 2020 from January to December it has been considered for each month separately together with the Sen's slope magnitude of slope (Q) the results shows that the Zc statics revealed the trend of the time series for 40 years for individual 12 months from January to December which are -0.049, -0.072, -0.130, -0.083, -0.092, 0.082, 0.146, 0.049, 0.010, -0.151, -0.150, and -0.162 respectively. Table-1 depict the Sen's slope estimation value and Kendall test statics (Zc) for the study time series for particular months. And the records reveal that there is positive trend in the month of June, July, august and September and remaining months showed the negative trend. And the positive trend of rainfall is due to onset of South-Western monsoon especially in the months of July.

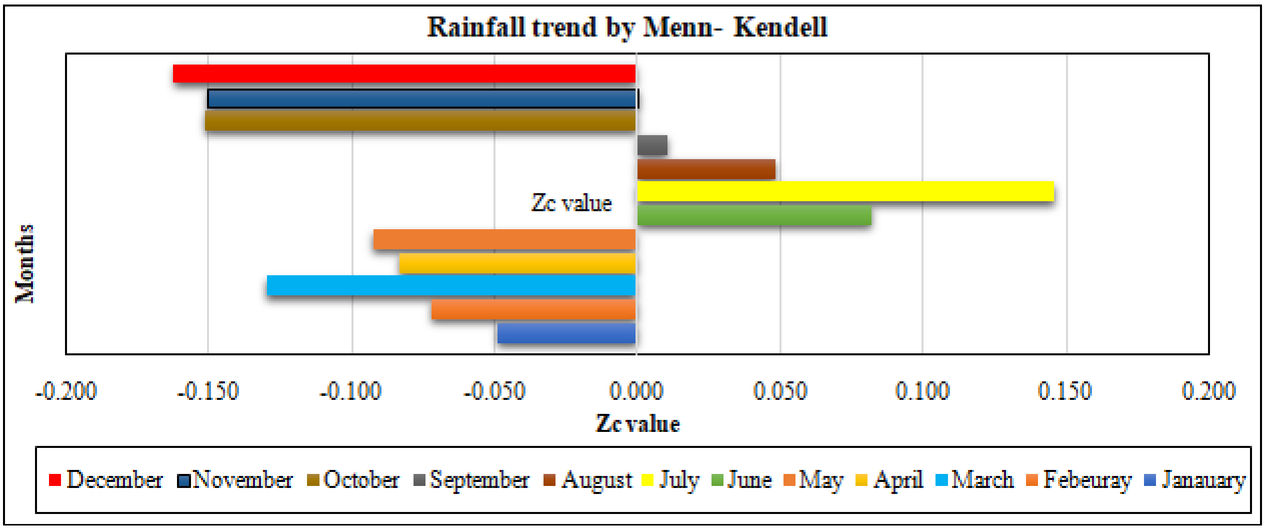


Figure 9: Mk Trend of Zc for Individual rainfall of all Months for 40 Years (1981-2020) in the Mathugad Watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand.

5. Conclusion and Recommendation

The current experimental study which is based on historical data of meteorological parameters of one of the experimental micro-watersheds from the Lesser Himalayan terrain of the Uttarakhand state, reveals that the temperature has a significant rising trend while the rainfall has significantly showed no trend. Findings show that an increase in temperature will trigger a higher demand for water for evapotranspiration by crops and natural vegetation which will lead to more rapid depletion of soil moisture. The study shows that the area is witnessing changes in temperature and precipitation regime, both duration and amount of rainfall having change significantly. It poses threat for Himalayan ecology, change in temperature and rainfall not only disturbed the water table but also adversely impact the biodiversity of Himalaya. The integration of local indigenous knowledge and customs, regional cooperation, and coordinated group activities are crucial for coping with and adjusting to the watershed's increasing hydro-climatic variability. Policymakers, hydrologists, and water resource planners dealing with the effects of climate change should find utility in the study's conclusion.

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