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Climatic Variability in a Kumaun Himalayan Watershed (Jatayu Ganga Watershed), Uttarakhand

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Abstract: ***Due to global warming, the climate is changing steadily. Climate change in mountainous terrain of the fragile Himalayan region necessitates thorough understanding of present and future temperature and precipitation regimes for better water resource management, hydropower generation, natural hazard risk assessment and ecosystem response. But no data on climatic variability are available for most of the Himalayan region. The fundamental objective of this paper is to define the climatic variability and its prominent impact on hydrological system and agriculture activities in a Kumaon Himalayan watershed of the Uttarakhand state, viz the Jatayu Ganga. IMD gridded data of temperature and rainfall of the four decades (i. e., 1980 to 2020) were used and the Mann-Kendall test was applied to determine the trend in annual and monthly rainfall and temperature. The results reveal that the long-term average annual temperature of the study area stands at 20.9 OC which varies in between 11.3OC in the month of January to 27.3OC in the month of June. The analysis of annual average temperature series shows a rising trend which is found significant at a confidence level of 99%. The long-term mean annual rainfall in the watershed stands at 1507.51mm. July is the month of maximum rainfall (389.52mm) and November is the month of minimum rainfall (4.32mm). During the study period the maximum rainfall occurred in the year of 2003 (2974.07mm) while the minimum rainfall was recorded in 1997 (558.09 mm). The statistical analysis shows that rainfall is decreasing but it is non-significant trend in the series of rainfall data. It is believed that, if the decreasing rainfall and rising trend of temperature continues, it will have adverse impact on the water availability for drinking water supplies and water-dependent sectors like agriculture, horticulture and tourism in the Kumaon Himalayan region.***

Keywords: Climate Variability, IMD, Mann-Kendall, Jatayu Ganga, Kumaun Himalaya

1. Introduction

Climate change is defined as a significant change in climate variables such as temperature or precipitation, that lasts for decades or longer (IPCC 2007). Main impact of climate change is the changing precipitation and temperature patterns. Changes in rainfall due to global warming will influence the hydrological cycle and the pattern of stream-flows and demands (particularly agricultural), requiring a review of hydrologic design and management practices. (Kalnay et. al 2003). The heavy rainfall leads to flood and the other season exhibits insufficiency of water to fulfil the requirement especially irrigation requirement. Trend analysis of rainfall for the period 1901-1984 at 11 stations in Himachal Pradesh indicated increasing trend in annual rainfall at 8 stations (Kumar et. al, 2005). Droughts, heavy rains, hail storms, unseasonal rains, floods and other weather-related events are increasing as a result of climate change. There is general agreement that many areas of currently high precipitation is expected to experience precipitation increases, whereas many of the areas at present with low precipitation and high evaporation, now suffering water scarcity, are expected to have rain decreases (IPCC 2007). The hydrologic effects of climate change will have an important influence on all types of watersheds. The average surface temperature of the Earth will cross 1.5°Cover pre-industrial levels in the next 20 years (By 2040) and 2°C by the middle of the century without sharp reduction of emissions (IPCC, 2021). over the last century (between 1906 and 2005), the average global temperature rose by about 0.74 0C. This has occurred in two phases, from 1910s to 1940s and more strongly from the 1970s to the present (IPCC, 2007). According to the IPCC Scientific Assessment Report, global average temperature would rise between 1.4 and 5.8°C by 2100 with the doubling of the CO2 concentration in the atmosphere. Sea level rise, change in precipitation pattern (up to ±20%) and change in other local climate conditions are expected to occur as a consequence of rising global temperature (Cubasch et al., 2001). The projected changes in climate will have direct and indirect impacts on natural environment as well as on human societies. Hydrology and water resources will be affected, since they are closely linked to climate (Arnell, 2003; Barnett, 2005). Therefore, climate change may induce major changes in hydrological conditions.

The projected changes in climate will have direct and indirect impacts on natural environment as well as on human societies. Climate change may induce major changes in hydrological conditions like; sea level rise, change in precipitation pattern, change in stream flow characteristic, groundwater recharge and availability, change in vegetation composition affecting interception process, changes in evapo-transpiration process. Climate change impacts can vary between catchments even within relatively small areas due to local climate and catchment characteristics depending on which specific watershed process and response are sensitive to change because of difference in geophysical characteristic of watersheds (Mamuye et. al 2018). In view of all above problems, the present study had done as an attempt to find out the trend of most important climatic variable rainfall and temperature. From the daily time series precipitation and temperature data (1980-2020) were derived to find out the possible changes in precipitation and temperature of one of the watersheds of the Kumaun

Himalaya viz., Jatayu Ganga watershed. Trend analysis of monthly and annual rainfall of the selected watershed is very helpful to understand the climatic variability in the region.

2. Study Area

The study area viz., the Jatayu Ganga watershed (Fig.1) is located in between 29° 34' North latitude to 29°44' North latitude and 79°49' East longitude to 79°58' East longitude and has a geographical area of about 78.81 km2 in district Almora of the Uttarakhand state. It is situated at southern edge of Kumaun Lesser Himalaya Region of Central Himalaya. The whole region is mountainous with successive mountain range and river valleys. The altitude of the watershed varies in between 569 m to 2309 m above the mean sea level. The watershed lies 48 km east of the Almora town and 412 km from Delhi.

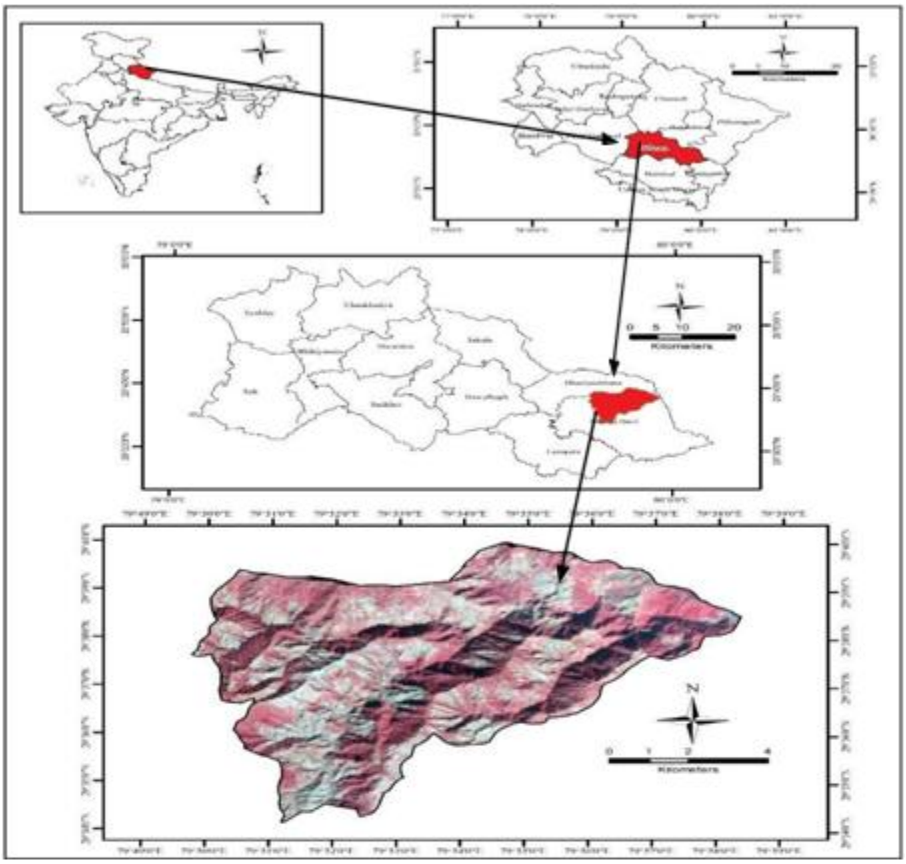


Figure 1: Location map of the Jatayu Ganga watershed, Kumaun Himalaya, Uttarakhand.

The watershed includes area of two development blocks of i. e., Bhasiyachana and Dhauladevi and includes total 55 revenue villages and 23 village Panchayats. The watershed is religious and historical impression as Jageshwar Temple lies in the watershed (Fig 1). Jageshwar Temple also referred to as Jageshwar Valley Temples, are the group of 124 ancient Hindu temples dated between 7th and 14th century. It is Hindu pilgrimage town.

3. Materials and Methods

Data Used

Climatological data, temperature and precipitation were obtained from the Indian Meteorological Department (IMD), Pune. IMD gridded rainfall product 0.250x0.250 (Pai et al., 2014) ranging from 1981 to 2020 obtained from the nearest metrological stations at (80.00 E longitude 29.50 N latitude) namely Dhauladevi for trend analysis of rainfall in the watershed. IMD gridded temperature product (10x10) Srivastava et al., (2009) ranging from 1981 to 2020 obtained from the nearest metrological stations at 79.50 E longitude 29.50 N latitude, namely Mukteshwar (Nainital) for trend analysis of temperature in the watershed.

Techniques

The data we obtained from IMD were binary gridded data. With the help of PyCharm software this binary data convert in to Csv format. The daily rainfall data was converted to annual monthly data for further use. The Mann-Kendall test and Sen's slope estimation methods are adopted to study the trend. Trend analysis of time series hydrological and meteorological data is of practical importance because of the insights it provides about its past and future variability and is generally conducted using either a parametric or a nonparametric test. Meteorological time series data are not characterized by normally distributed pattern, and therefore, nonparametric tests are considered more robust compared to their parametric counterparts (Hess et al., 2001). The Mann-Kendall test (Mann, 1945; Kendall, 1975) is one of the most widely used non-parametric tests for trend detection in hydro-meteorological time series data (Burn et al., 2010). Mann-Kendall has the advantage of the robustness against departures from any normality in data. Additionally, it is less affected by outliers because its statistic is based on the sign of differences, and not directly on the value of the random variables. The statistic S, as given in Eq. (1), is computed by comparing each value of the time series with the remaining in a sequential order. Accordingly, Mann-Kendall test was used for trend analysis in this study and the correlation between the precipitation and temperature was determined using Kendall Correlation Coefficient Zc. The significance (S) was measured at three levels of significance; 99% (S=0.01), 95% (S=0.05) and 90% (S=0.1). The test statistic S is:

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

Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S. (Eq.2).

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

X i and Xj are the sequential data values, n is the length of the data set. For samples greater than 10, the test is conducted using normal distribution (Helsel and Hirsch, 1992) with the mean (E) and variance (Var) shown in Eq. (3) and Eq. (4).

$$E[S] = 0$$

$$\text{Var}(S) = \frac{1}{18} n[(n-1)(2n+5) - \sum_{p=1}^{q} tp(tp-1)(2tp+5)$$

where, tp is the number of ties value for the pth group and q is the number of tied groups. The standardized test statistic (Zmk) is calculated in Eq. (5) by:

$$Zmk \begin{bmatrix} \frac{s-1}{\sqrt{var(s)}} if\ s > 0 \\ \frac{s+1}{\sqrt{var(s)}} if\ s < 0 \\ 0\ if\ s = 0 \end{bmatrix} \quad (5)$$

Where, the value of Zmk is the Mann-Kendall test statistic that follows standard normal distribution with mean of zero and variance of one.

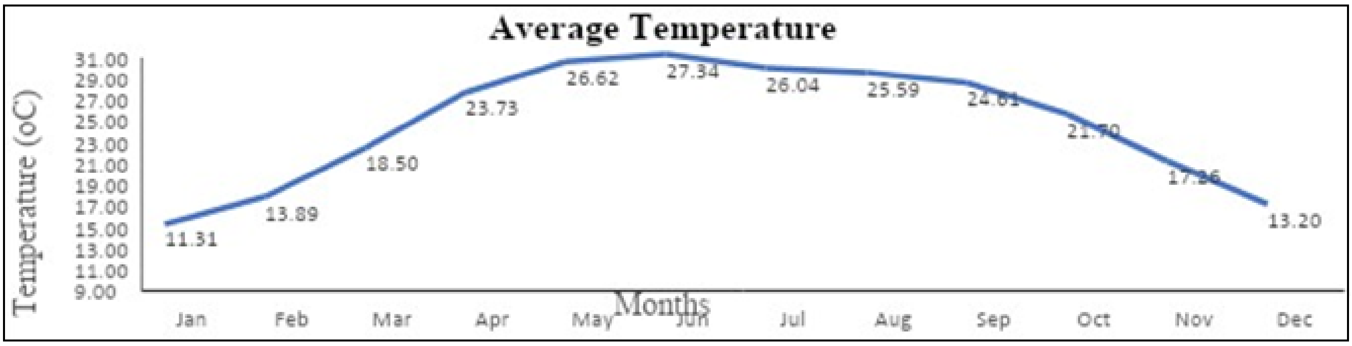
4. Results and Discussion

Temperature

The long-term (1981-2020) average annual temperature of the study area stands at 20.9OC which varies in between 11.3OC in the month of January to 27.338OC in the month of June (Fig.2, above). The analysis of annual average temperature series using Man-Kendall test shows a rising trend (Fig.2, below) which is found to be significant at a confidence level of 99%. The month wise analysis (Fig.3) suggests that that the average temperature shows maximum increasing trend in winter months and slight in summer months and very slight in the rainy season months. During the study period the maximum temperature occurred in the year of 2016 21.812 OC) while the minimum temperature was recorded in 1983 (19.834 OC).

Fig.6 shows the variation in Zc values for different months. Highest positive trend is observed during the month of June which is 0.412. The highest negative trend (-0.204) is shown in the month of January. These are the implications of the effect of South West monsoon.

Table 1 showed the Sen's slope estimation factor and Kendall test statistics (Zc) for the study period for individual months. There is negative trend in the month of February, May and August and the other months showed the positive trend. The positive trend of rainfall is due to the onset of S-W monsoon and N-E monsoon in Kerala especially in the month of June



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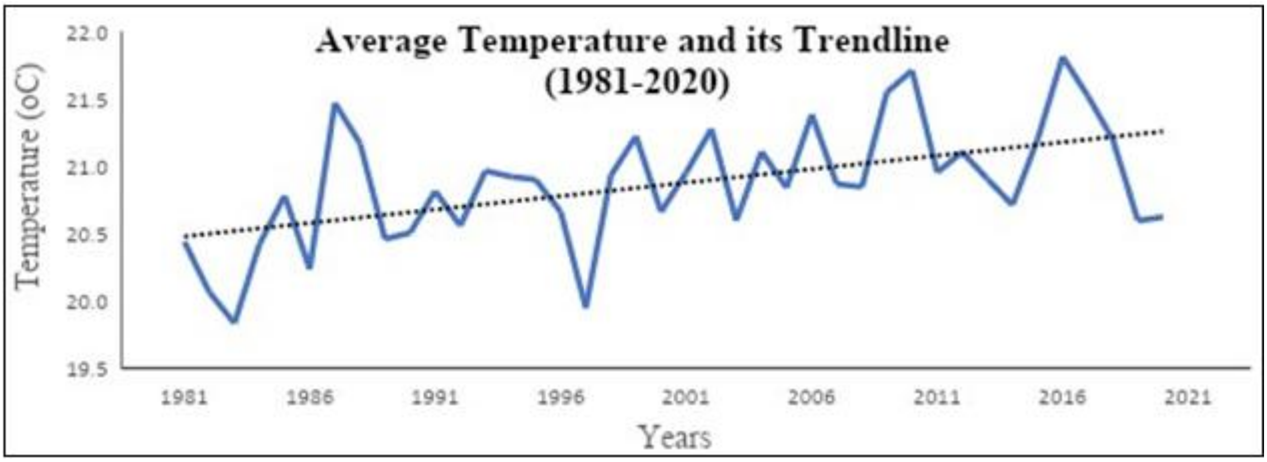
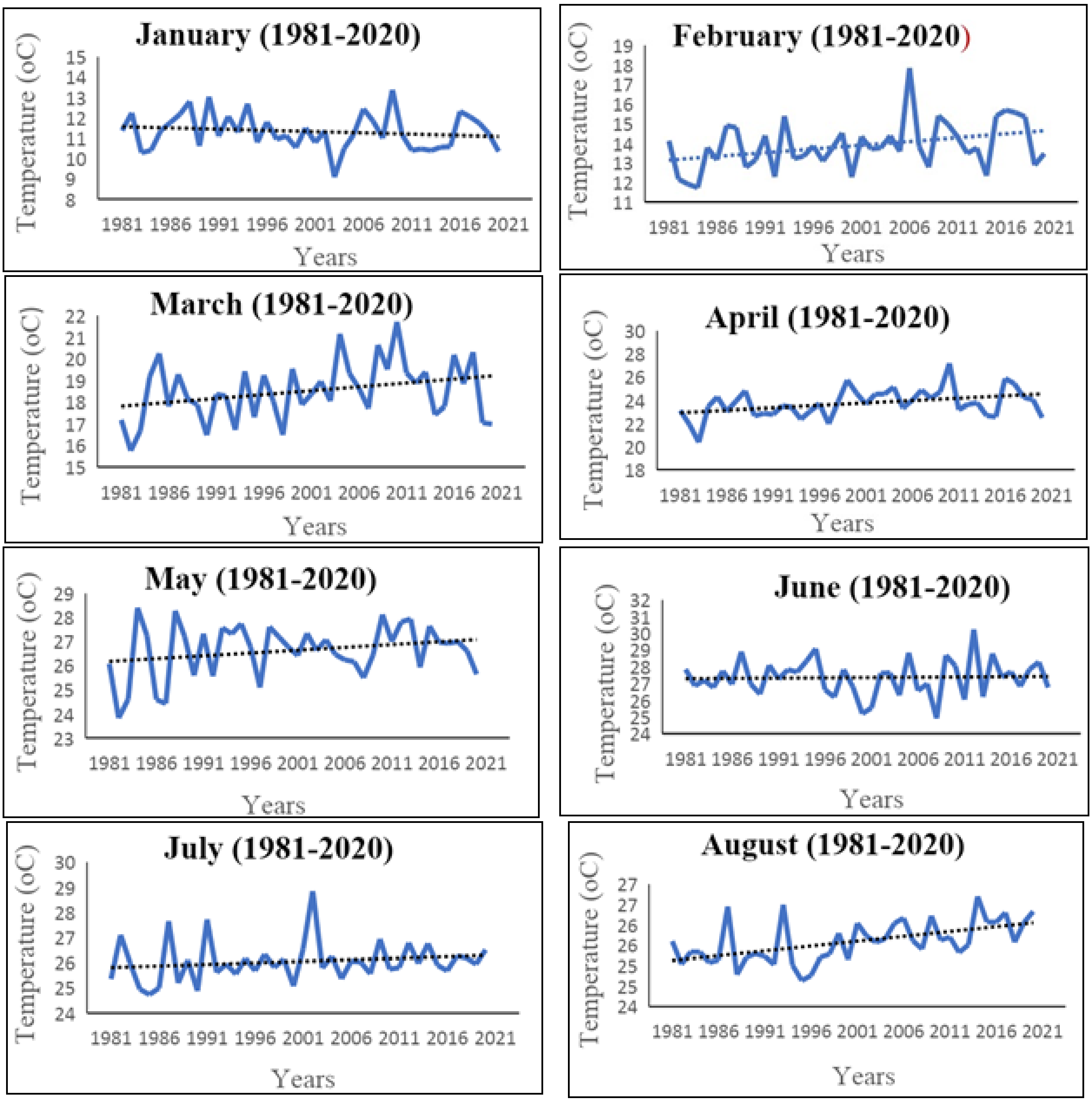


Figure 2: Mean monthly (1981-2020) average temperature (above) and annual mean temperature trend (below)



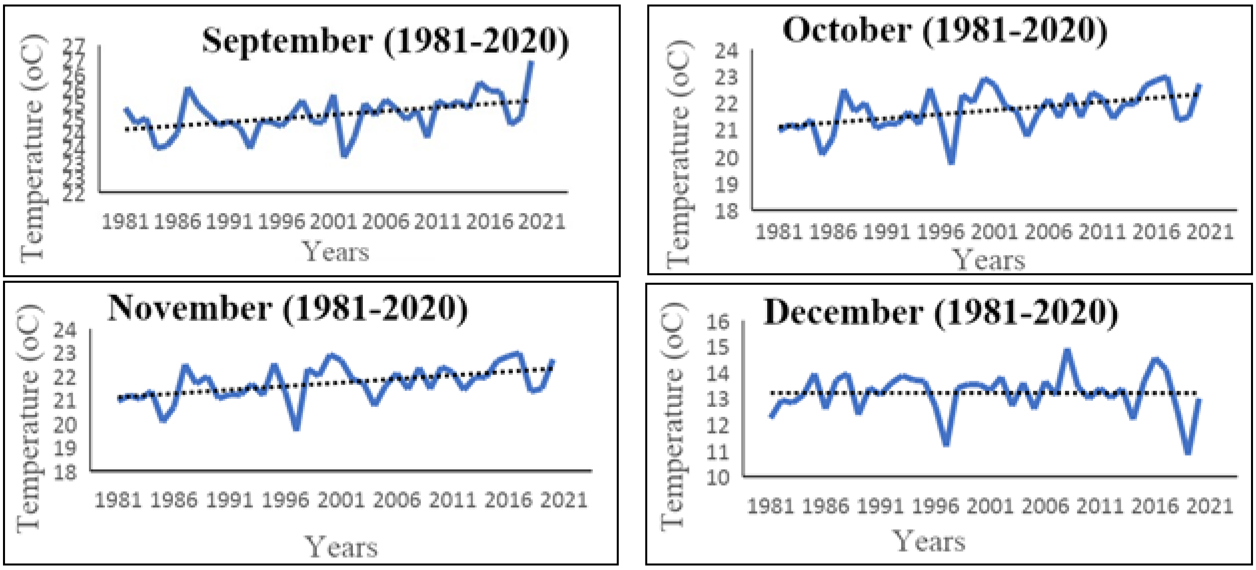


Figure 3: Long term trend of average temperature of all the months in the Jatayu Ganga watershed

The further month wise scanning of long-term temperature data reveal that although the overall annual temperature has significant trend at a confidence level of 99%. Out of twelve the ten months have shown increasing trend of temperature (Fig 3.0). These months are February, March, April, May, June, July, August, September, October and November. The months in which the temperature is found having decreasing trend are January and December.

Table 1: Estimated Sen's Slope and Kendall's test statistics (Zc) values of Temperature from 1981to 2020

Name of test	Temperature of Jatayu Ganga Watershed						
	Months	Mean	Std. deviation	Kendall's test statistics (Zc)	Sen's slope	p-valu e	Result
Man Kendall Test	Jan	11.314	0.891	-0.136	-0.014	0.221	NS
	Feb	13.885	1.241	0.226	0.039	0.041	S (0.05)
	Mar	18.498	1.360	0.200	0.037	0.071	S (0.1)
	Apr	23.727	1.236	0.241	0.038	0.029	S (0.05)
	May	26.622	1.103	0.059	0.012	0.600	NS
	Jun	27.338	1.098	0.005	0.000	0.972	NS
	Jul	26.044	0.816	0.197	0.018	0.075	S (0.1)
	Aug	25.586	0.516	0.387	0.024	0.000	S (0.01)
	Sep	24.612	0.661	0.292	0.026	0.008	S (0.01)
	Oct	21.703	0.755	0.362	0.032	0.001	S (0.01)
	Nov	17.257	0.630	0.241	0.022	0.029	S (0.05)
	Dec	13.204	0.781	-0.018	-0.001	0.880	NS
	Annual Average	20.868	0.451	0.367	0.020	0.001	S (0.01)

Fig.2 shows the annual total rainfall variation and it is shown that the maximum rainfall of 2321.5 mm occurred in 2006 and minimum rainfall occurred in 2012 of 1142.3 mm. The year 2006 is referred as 'wet year' and 2012 'dry year' among the study period

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The Zc (Kendall correlation) statistics revealed the trend of the series for 40 years for individual 12 months from January to December which are-0.136, 0.226, 0.200, 0.241, 0.059, 0.005, 0.197, 0.387, 0.292, 0.362, 0.241 and-0.018 respectively (Table 1.0). Highest positive trend is observed during the month of August which is 0.387 and the highest negative trend (-0.136) is shown in the month of January (Fig.4.0).

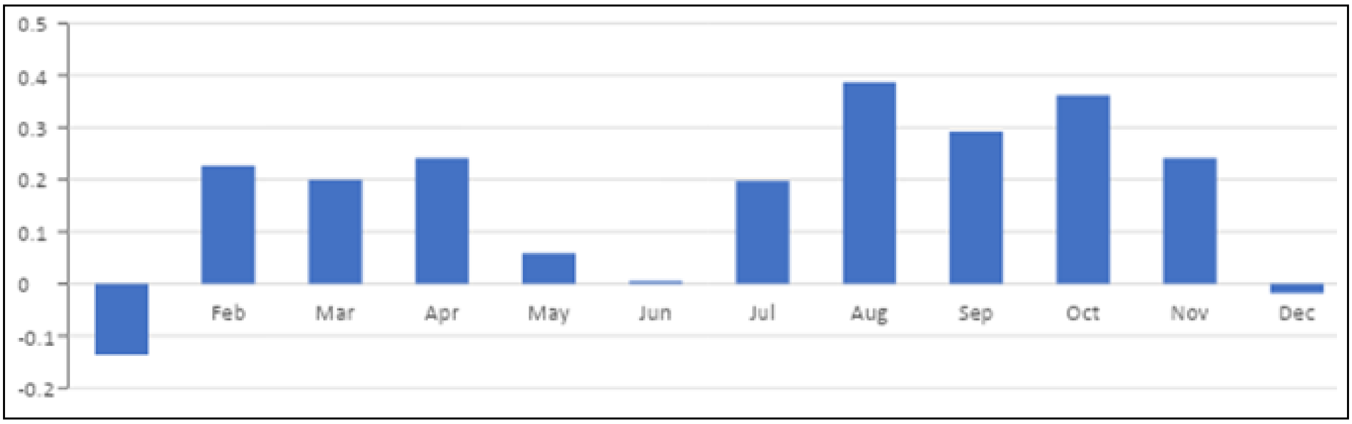

Figure 4: MK Trend of Zc values for individual Average Temperature months over 40 years (1981to 2020) in the Jatayu Ganga watershed

4.2 Rainfall

The long-term (1981-2020) mean annual rainfall in the watershed stands at ~1507.51mm. July is the month of maximum rainfall (~389.517mm) and November is the month of minimum rainfall (~4.317mm) (Fig.5, above). The rainfall time series data (Fig.5, below) depicts the distribution of amount of rainfall in different years and its trend by the Man Kendall Test. During the study period the maximum rainfall occurred in the year of 2003 (~2974.07mm) while the minimum rainfall was recorded in 1997 (~558.09mm). Month wise scanning of long-term rainfall data reveal that although the annual rainfall has non-significant trend but overall, the annual rainfall has decreasing trend (Fig.5, below). Out of twelve the eleven months have shown decreasing rainfall. These months are January, February, March, May, June, July, august, September, October, November and December. The months in which the rainfall is found having increasing trend is April (Fig.6).

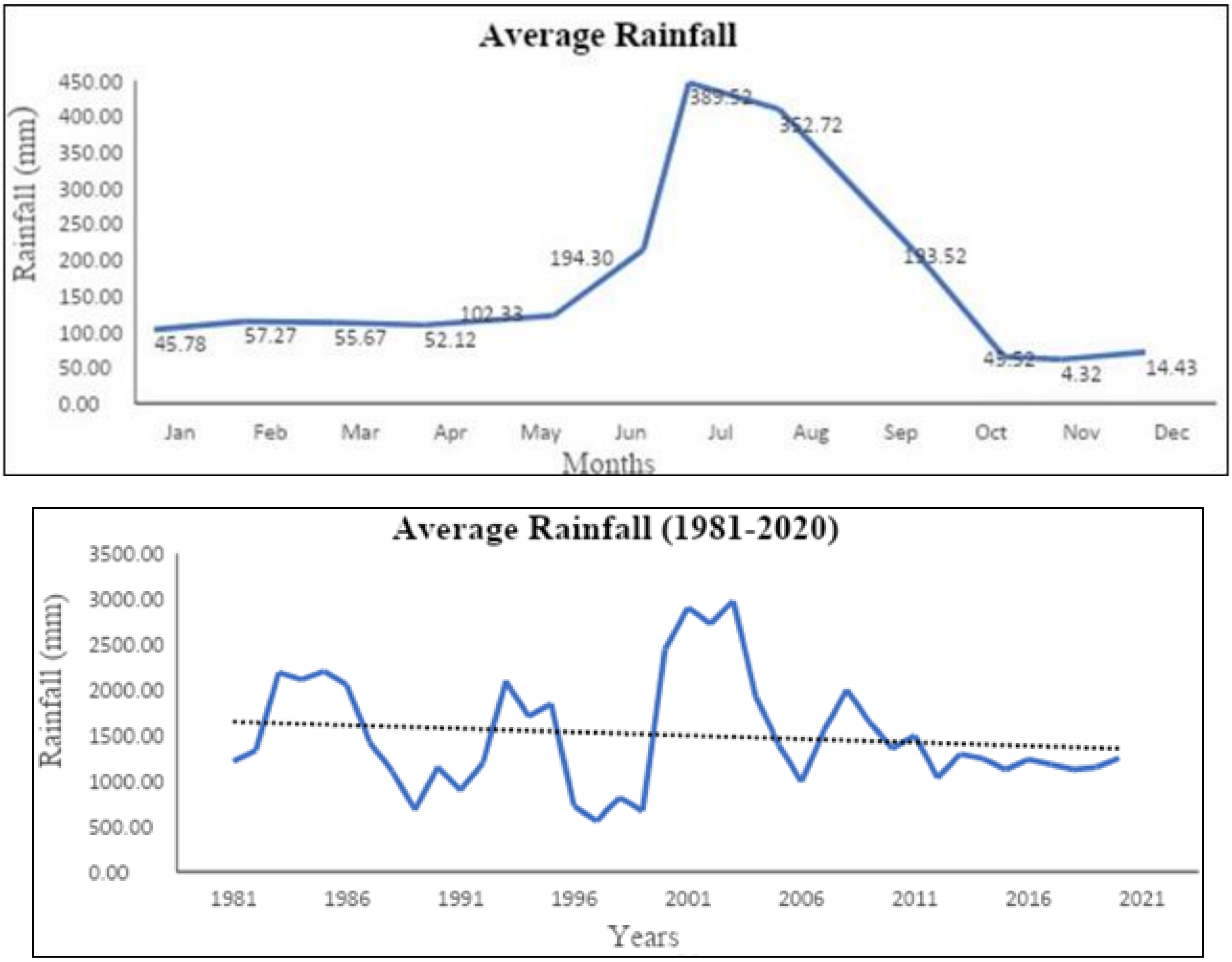

Figure 5: Average (1981-2020) annual monthly rainfall (above) and Rainfall trend (below) in the Jatayu Ganga watershed

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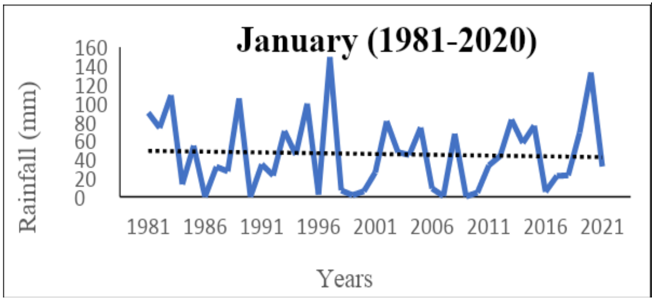
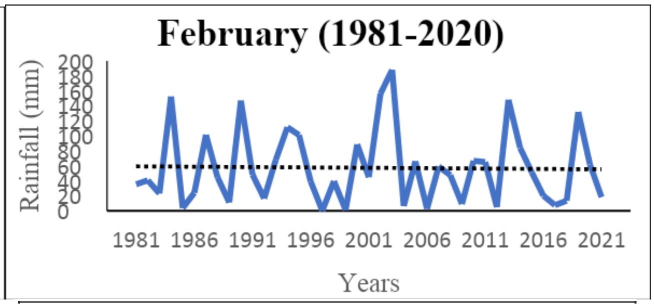
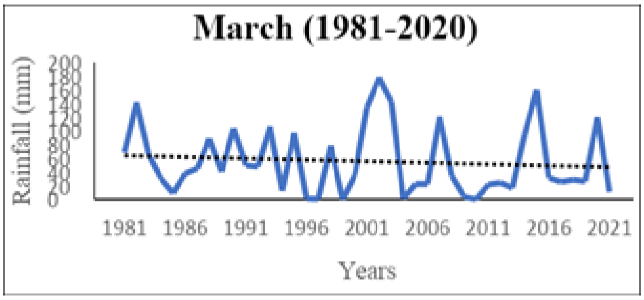
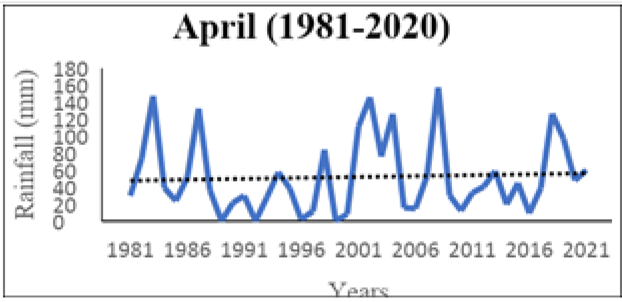
Table 2: Estimated Sen's Slope and Kendall's test statistics (Zc) values of Rainfall from 1981 to 2020

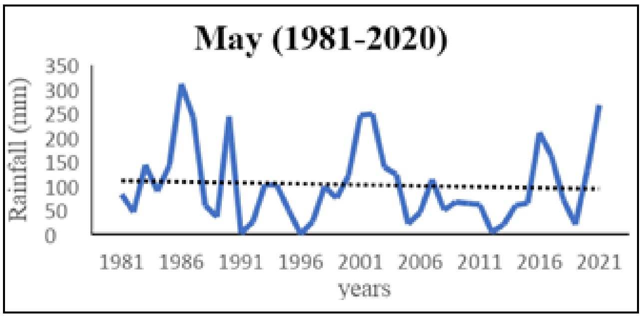
Name of test	Rainfall at Jatayu Ganga Watershed						
	Months	Mean	Std. deviation	Kendall's tau (Zc)	Sen's slope	p-valu e	Result
Man Kendall Test	Jan	45.781	39.208	-0.021	-0.086	0.857	NS
	Feb	57.274	50.437	0.002	0.036	0.991	NS
	Mar	55.671	50.195	-0.106	-0.529	0.334	NS
	Apr	52.119	44.818	0.088	0.370	0.425	NS
	May	102.327	81.165	-0.029	-0.308	0.832	NS
	Jun	194.305	128.919	-0.010	-0.208	0.937	NS
	Jul	389.517	190.891	-0.049	-0.968	0.661	NS
	Aug	352.724	207.969	-0.094	-2.681	0.393	NS
	Sep	193.524	145.279	-0.088	-0.987	0.356	NS
	Oct	45.520	108.060	-0.105	-0.165	0.344	NS
	Nov	4.317	7.372	-0.123	0.000	0.290	NS
	Dec	14.429	23.343	-0.075	-0.092	0.500	NS
	Grand Total	1507.509	604.419	-0.102	-7.698	0.255	NS

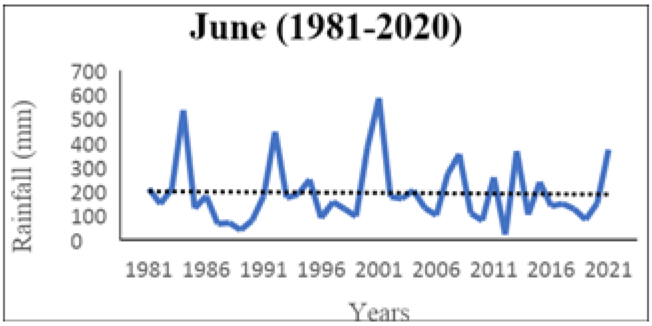


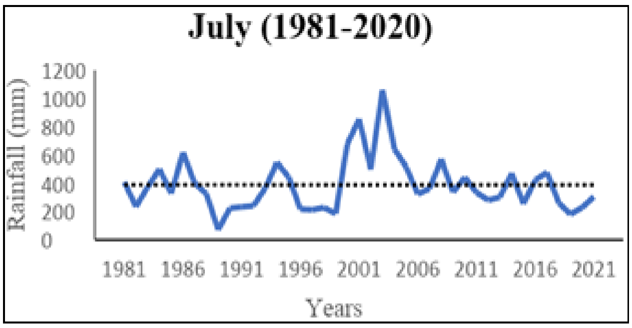


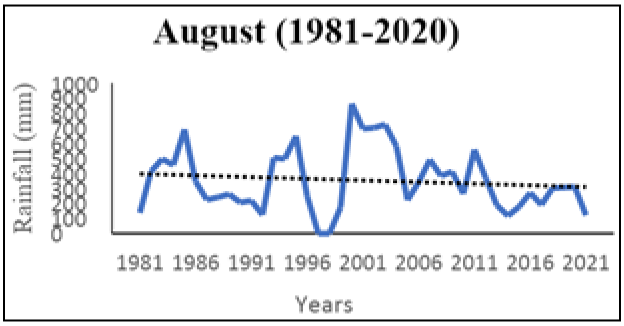












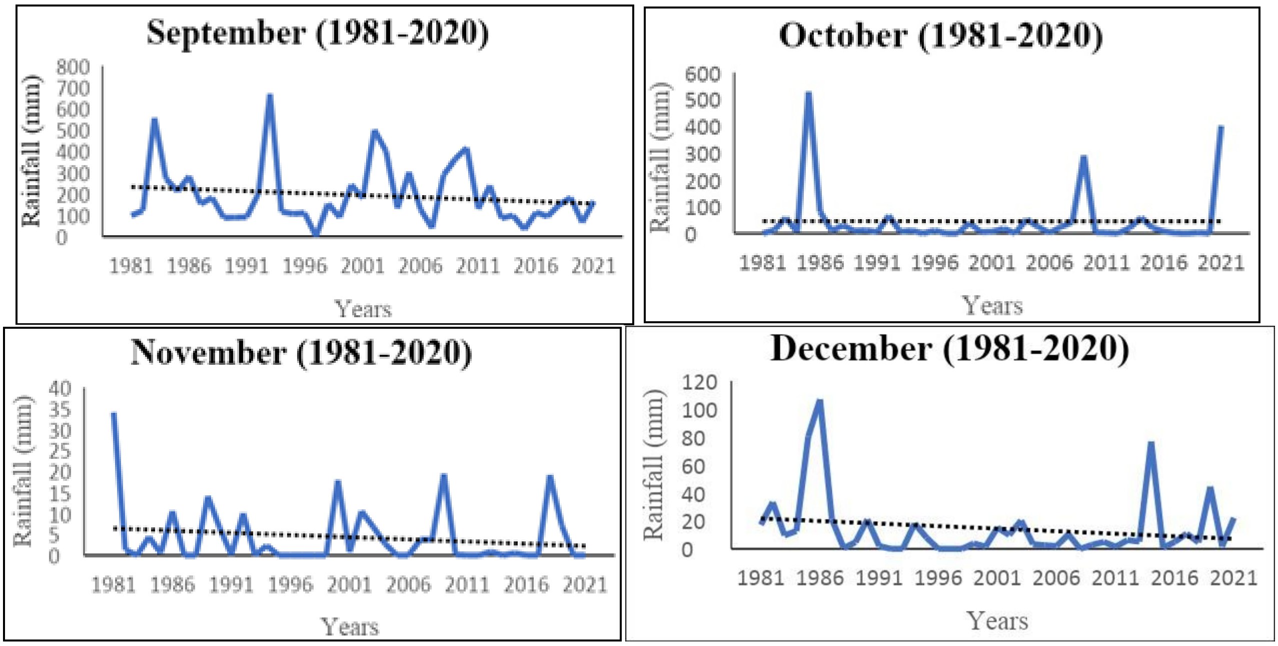


Figure 6: Long term trend of Rainfall of all months in the Jatayu Ganga watershed.

The Zc statistics revealed the trend of the series for 40 years for individual 12 months from January to December which are-0.021, 0.002,-0.106, 0.088,-0.029. -0.010,-0.049, -0.094,-0.088,-0.105,-0.123 and-0.075, respectively (Table 2). Highest positive trend is observed during the month of April which is 0.088 and the highest negative trend (-0.123) is shown in the month of November (Fig.7)

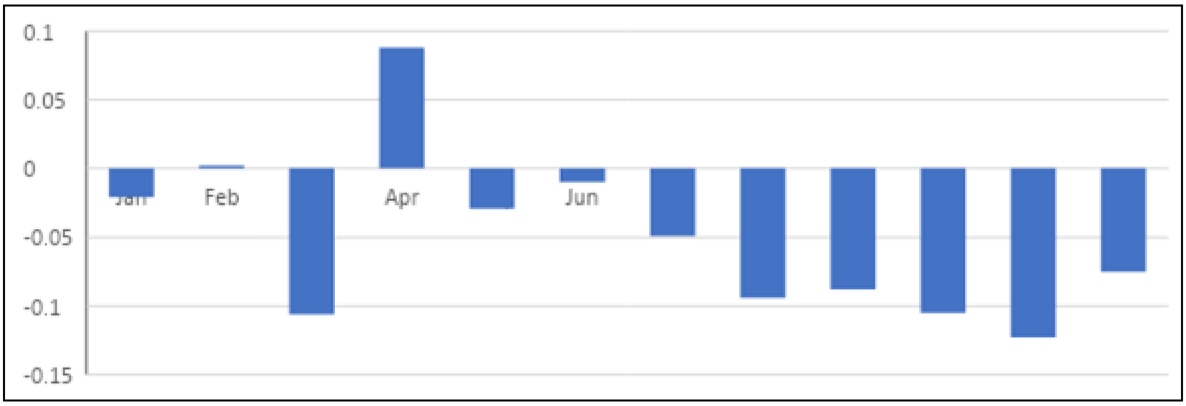


Figure 7: MK Trend of Zc values for individual rainfall months over 40 years (1981to 2020) in the Jatayu Ganga watershed.

5. Conclusion

The statistical analyses of the metrological data in Jatayu Ganga Watershed from 1981-2020 showed an overall significant increase in the annual temperature particularly during spring and winter seasons with variable. The rainfall is decreasing but it is non-significant trend in the series of rainfall data. The decreasing precipitation and increase temperature will have significant impact on the agriculture, water availability for drinking water supplies, energy generation, winter tourism and flooding in the Kumaun region in the near future. The government should plan to combat the impact of climate change in the region

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