



Flood and Hydrological Water Discharge in Rishikesh City Assessment of Flood and Hydrological Water Discharge in Rishikesh City

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Abstract: The rivers are life line for human being and these are also a disaster for human as well in monsoon season rivers become disaster in India. The study is focused on occurrence of flash flood in Rishikesh city with rainfall data and water discharge level data of Ganga River. The climate data was processed with the help of Mann Kendall test to observe the trend of surge in water level which is potential threat of flash flood in the city. There was increasing trend in the rainfall of the months of July (0.21), August (1.11), September (0.98) and October (2.21) for last 44 years which was more than significant value. The flood frequency analysis method was used to observe the frequency of occurrence of flash flood in the city. The study shows that 448 occurrence of surge is observed in last 44 years. There was 13 occurrence of flash flood events observed in last 448 surges. The river's normal flash floods is occur at 28177 m³/s, with an arrival time of around every three years, as shown by the flood peak data. The data analysis shows that the most extreme flood was recorded in 2013.

Keywords: Himalaya, Rishikesh, Flood occurrence, Flood frequency, Hydrological-system

The risks of climate change and extreme climatic events such as droughts and floods impact on economy and natural systems (Saha and Malkar 2024). The mountains are more vulnerable than the other places in the world (Dimri et al 2021). The rapid urban growth of the past three decades and resulting increased flooding problem are common in many cities, especially in humid areas (Rawat et al 2017). Hydroelectric power plants are being studied as a possible contributor to the Himalayan flood threats and consequences intensifying (Vishwanath and Tomaszewski 2018). Mountain environments are susceptible to climate change because small changes in winter precipitation, summer solar radiation receipts, and summer air temperatures can have major effects on glacier mass balance, dynamics and geometry (Elalem and Pal 2015). The implications of global change on the tropical montane ecosystem, in particular the composition of the angiosperm and vertebrate communities is widespread (Gupta et al 2022). The type of soil, large river networks, and high elevations have all contributed to the increased intensity of flash floods (Payra et al 2022). Global climate change has an impact on water resources through changes in rainfall, temperature and energy balance (Kundzewicz et al 2014). Increasing trend of rainfall can be resulted as increase in floods and could thereby affect water quality (Tabari et al 2011). Himalayan Mountain are facing the most disastrous events worldwide and the concern for sustainability has emerged. The cities which are built in the mountains have weak hydrology and improper management of water resources (Chauhan et al 2021). Climate change

has great impact on the Indian sub-continent because its economic performance and social progress are dependent on rainfall and climate change is likely to affect rainfall. India possesses a great variety and diversity of climate, varying from extremely hot to extremely cold, from extremely arid regions to extremely humid regions and drought-prone areas to flood-prone areas (Roy et al 2021). Climatic conditions govern to a great extent the operation of water resources in the country. A one percent rise in floods can cause a 2.7% decrease in economic growth (Ayog et al 2021). The study assess impact of climate change on hydrological system and flood occurrence with changes in temperature, rainfall and evaporation.

MATERIAL AND METHODS

Study area: Rishikesh city is situated at 30° 10' 33" N latitude and 78° 29' 47" E longitude with average height of 442 meters (1,745 feet) (Statistical Abstract of Dehradun, 2016). Rishikesh city is one of the mountain city which lies along the bank of river Ganga (Fig. 1).

Methodology

Data source: The climate data such as rainfall, temperature, humidity, evapotranspiration. was collected from India Meteorological Department (IMD) for last 44 years has been collected from 1980 to 2024 .

Data Analysis

Mann Kendall method: The Mann-Kendall Test used to detect monotonic trends in series of environmental data, climate data or hydrological data. Each data value is

compared to all subsequent data values. Let $x_1, x_2, x_3, \dots, x_n$ represent n data points where x_j represents the data point at time j . Then the Mann-Kendall statistic (S) is given by (Kendall 1975):

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

Where,

$$\text{sgn}(x_i - x_k) = \begin{cases} +1 & \text{if } (x_i - x_k) > 0 \\ 0 & \text{if } (x_i - x_k) = 0 \\ -1 & \text{if } (x_i - x_k) < 0 \end{cases}$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. It is necessary to compute the probability associated with S and the sample size, n , to statistically quantify the significance of the trend. If n is at least 10, the normal approximation test is used. However, if there are several tied values (i.e. equal values) in the time series, it may reduce the validity of the normal approximation when the number of data values is close to 10. First the variance of S is computed by the following equation which takes into account that ties may be present:

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

Where q is the number of tied groups and tp is the number

of data values in the p th group. The values of S and $VAR(S)$ are used to compute the test statistic Z as follows:

$$Z_s = \frac{S-1}{[VAR(S)]^{1/2}} \text{ If } S > 0$$

$$Z_s = 0 \text{ If } S = 0$$

$$Z_s = \frac{S+1}{[VAR(S)]^{1/2}} \text{ If } S < 0$$

Probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following equation:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}}$$

The trend is said to be decreasing if Z is negative and the computed probability is greater than the level of significance. The trend is said to be increasing if Z is positive and the computed probability is less than the level of significance. If the computed probability is less than the level of significance, there is no trend.

The Mann-Kendall test has two parameters that are of importance to trend detection. These parameters are the significance level that indicates the trend's strength and the slope magnitude estimate that indicates the direction as well as the magnitude of the trend. In MAKESENS the tested significant levels are 0.001, 0.01, 0.05 and 0.1. For the four tested significant levels, the symbols used in the trend statistics worksheet are:

- *** if trend at $\alpha = 0.001$ level of significance, ** if trend at $\alpha = 0.010$ level of significance,
- * if trend at $\alpha = 0.050$ level of significance, and + if trend at $\alpha = 0.100$ level of significance.

If the cell is blank, the significance level is greater than 0.1. The presence of a statistically significant trend is evaluated using the Z value. A positive value of Z indicates an upward trend and a negative value of Z indicates a downward trend.

Probability -Flood frequency analysis: The main purpose of probability frequency analysis is to obtain a relation between the magnitude of flood or storm and its probability of occurrence.

This analysis is done through empirical Gumble's method (1958):

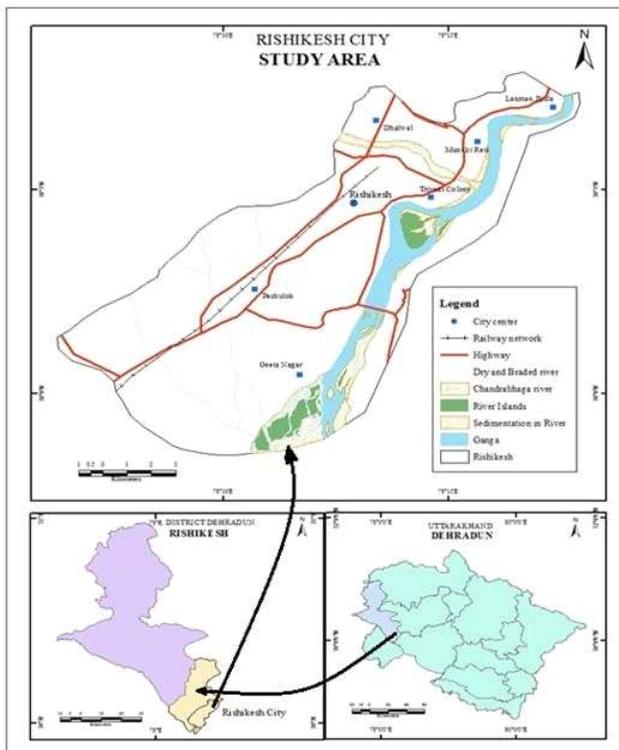
and
Whereas, $p =$ Probability exceedance

$$p = i/T$$

$$T = N+1/m$$

$T =$ Recurrence interval or Frequency or return period

$m =$ Ranking of flood



Source: Census of India, 2011

Fig. 1. Location of study area

The Maya Kund station (30°10'53" and 78°30'02") annual peak flood data from 1980 to 2024 is presented in descending order, and each flood event is given a ranking number (m). Thus, the flash flood that was most catastrophic ranked first and placed at the top and second flash flood was ranked second and smallest level of peak flow was positioned last. Equation $T = N+1/m$ is then used to determine the frequency (T), or return $N + 1$ period, and a graph is shown between m frequencies and flood discharge. If needed, the graph can be expanded to extrapolate the flood magnitude value corresponding to any high frequency value.

RESULTS AND DISCUSSION

Mann-Kendall trend analysis of rainfall: The overall annual and non-monsoon trends was not significant as per Mann Kendall trend analysis of 44 years of climate data of Rishikesh city. The rainfall data of annual, monsoon season and non-monsoon season were reflecting the increasing trend in rainfall with Z of 0.62, 0.06 and 1.44 respectively which was showing that the rainfall in monsoon season was significant with 0.06 value. An increasing trend in the rainfall of the months of July, August, September and October was significant (Table 1). An increasing trend for the annual rainfall was seen where as a decreasing trend for the rainfall of February (-0.95) and December (-.88) was also observed, both at a significance level of 0.10 and in June (-.71) at 0.50 significance level.

There was an increase of 90% in rainfall in Rishikesh city during the pre-monsoon season, which follows an increasing pattern. The annual rainfall is trending upward and is increasing partially. The monsoon season has shown a rising trend in rainfall, which is significant since it provides the basis for the yearly increase in total rainfall. The decreasing trend is shown in the post-monsoon season. Although there is not much rain throughout the winter, but some rainfall took place in this area because to western disturbances. Since winter rainfall makes up a very small portion of the overall growing trend in annual rainfall, it does not indicate a significant trend; the annual trend of rainfall describes the increasing trend at level 0.05 and it is annual rainfall increasing trend with significant seasonal declining trend of rainfall (Table 2).

Mann-Kendall trend analysis of maximum and minimum temperature: Increasing trends was observed for maximum temperature at Rishikesh city and decreasing trends for minimum temperature. The computed Mann-Kendall for Tmax, during winter, was significant, while for annual, North-eastern Monsoon, and summer, and was insignificant. These statistics indicated that there was an increasing trend in Tmax for winter, while the decreasing trend in Tmax during the South-west Monsoon season was observed. The Tmin,

during summer season, was insignificant and during annual and winter, was significant, whereas during South-west Monsoon and North-eastern Monsoon was insignificant (Table 3).

The Tmean during winter, summer, and annual were significant whereas the NEM was not significance.

Flood frequency and return period: There is an increase in water levels in Rishikesh city of more than 50% ($R^2=0.52$). On the basis of returning period data, the tendency of flash flood very feasible. The occurrence data of 448 surges in river Ganga observed in last 44 years is extremely valuable for building water management purposes to prevent the loss caused by flash flood (Izinyon and Igbinoba 2011). The present study comprises various aspect of measurement of surges in the river basins such as length, shape, and cross profile, and rainfall in the catchment area. The catchment area explain over 50 percent of the variation in surge extent. There was 13 occurrence of flash flood events observed in last 448 surges. The Gumbel method is used in this study

Table 1. Mann-Kendall trend statistics for rainfall

Time series	No. of years	Test Z	Significance levels
January	44	0.18	
February	44	-.95	+
March	44	0.16	
April	44	0.13	
May	44	0.48	*
June	44	-.71	*
July	44	0.21	
August	44	1.11	*
September	44	0.98	*
October	44	2.21	*
November	44	0.17	
December	44	-.88	+
Annual	44	1.74	+
Monsoon	44	1.23	
Non-monsoon	44	1.38	

+: significance level: 0.1; *: significance level: 0.05

Table 2. Mann Kendall Trend Statistics (Z) Rainfall in Rishikesh city

Seasons	Trends
Annual	↑*
Pre-Monsoon (Mar-May)	↑+
Monsoon (June-Sept)	↑*
Post-Monsoon (Oct-Nov)	↓
Winter (Dec-Feb)	↑

Where, (↑) shows increasing trend; (↓) shows decreasing trend; * 0.05 level of significance; + 0.1 level of significance

Source: Calculated by Researcher

because the distribution of the extremes events, each selected from a set of occurrences, exponentially approaches the Gumbel distribution as r approaches infinity.

The result of analyses of monthly time series of discharge at Maya Kund gauge station in annual, winter and summer time period with the hydrological years 1980-2024 have been presented in Figure 2. The results describe various aspects such as in between 1990 to 1996 there were trend of extreme water discharge and occurrence of floods this water discharge is nearby 1.5 lakh cusec which was highest ever discharge in this trend of discharge data. There is probability of occurrence of highest discharge once in last thirty years except year 2013 which is part of another thirty years of trend at that time discharge level was 2.5 lakh cusec. The probability of highest discharge reflects the increasing trend of highest discharge with increasing total discharge in the

year. This is the result of highest probability analysis in which the total number of event has been divided by number of highest discharge level. The probability of occurrence of flood is 0.03 throughout the months in the duration of 44 years. The plotting position method has been used to describe the probability of occurrence of flood.

The maximum river flow of 233 m³/s was at Mayakund in 1980, 1992 and 2013 while minimum of 8.83 m³/s was in 1998. The 44 year mean average peak river was 75.05 m³/s the most extreme flood of 246893 m³/s was recorded in 2013 while the least river flow of 5182 m³/s was in 1983. The 44 year mean rapid river flow is 28177 m³/s with a less fluctuation in water flow. The Gumbel dispersion capacity's remarkable ability to predict the amount the flood flows (Fig. 3). Estimated R^2 of 0.9543 indicates that Gumbel's dispersion technique is predicting the expected flood in the river and that

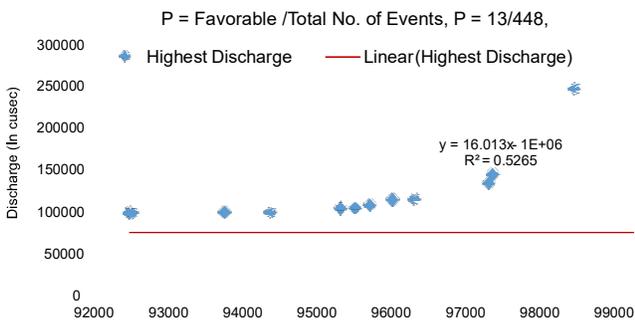


Fig. 2. Probability of flood in Rishikesh City

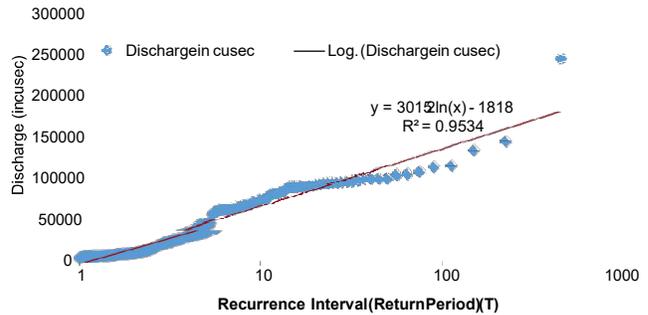


Fig. 3. Frequency curve and return period of flood in Rishikesh city

Table 3. Mann-Kendall trend statistics for maximum and minimum temperature

Time series	N	Maximum temperature		Minimum temperature	
		Test Z	Significance	Test Z	Significance
January	44	2.83	+	-.84	+
February	44	2.22	*	-2.09	*
March	44	3.14		-1.48	*
April	44	0.29	*	-2.43	*
May	44	2.04	*	-3.06	
June	44	2.12	*	-2.19	
July	44	1.21		-2.25	*
August	44	2.16	*	-1.41	+
September	44	1.75	+	-3.42	*
October	44	2.14	*	-1.87	*
November	44	0.31	*	-2.87	
December	44	0.47	+	-2.16	*
Annual	44	1.40		-2.17	*
Monsoon	44	1.01	*	-2.57	+
Non-monsoon	44	2.07	+	-2.21	*

+: significance level: 0.10; *: significance level: 0.05

the example of the dispersion is limited. Furthermore, the river's normal flash floods occur at 28177 m³/s, with an arrival time of around every three years, as shown by the flood peak data. This indicates that the basin's flood forecast is somewhat precise. The planning of important pressure-driven structures and additions in the river reach can be done using this flood forecast. The flash flood prediction is accurate in Rishikesh city. This forecast of flood can be used in the planning of critical pressure driven structures and extensions in the river reach.

CONCLUSION

The Mann Kendall shows an increasing trend in the rainfall was significant of the months of July, August, September and October. An increasing trend for the annual rainfall was seen where as a decreasing trend for the rainfall of February and December was observed. The catchment area explain over 50 percent of the variation in surge number. There was thirteen occurrence of flash flood events observed whole period of time. From 1990 to 1996, trend of extreme water discharge and occurrence of floods was very high with exceptional value of water discharge level. There was probability of occurrence of extreme flash flood once in thirty years. The river's normal flash floods occur at water level of 28177 m³/s, with an arrival time of around every three years, as shown by the flood peak data.

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