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A COMPREHENSIVE STUDY OF THE DYNAMICS OF THE CLIMATE BHAGIRATHI-ALAKNANDA BASIN OF UTTARAKHAND HIMALAYA

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ABSTRACT

The complex topography of Uttarakhand Himalaya has caused several microclimates in the region. These microclimates are substantially sensitive to the present context of global climate variability. Though the climate dynamism in those micro-climatic locales is difficult to comprehend, it is a significant part of global climate research, especially to grasp the influences of global change on the socio-ecological frameworks of the Himalayas and to appraise the versatile limit of the adaptive capacity of the community networks. This paper explores the dynamics of the regional climate in the Garhwal Himalaya in reference to the meteorological records of the last six decades (1956-2015) at observatories in the Bhagirathi-Alaknanda Basin. The findings illustrate that the climates of the basin are changing, with variable rates across the observatories situated at different eco-hydrological zones.

KEYWORDS: Uttarakhand Himalaya & Climate Bhagirathi-Alaknanda Basin

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Original Article

INTRODUCTION

Uttarakhand Himalaya is substantially vulnerable to climate interceded risks. The gross economy is portrayed by low economic development joined with high paces of populace development. The livelihoods are completely founded on natural resources - water, woodland, agribusiness, and so on. Around three-fourths of the state's populace is provincial and all rely upon farming. The travel industry and Animal farming are different types of revenue. With north of 15 significant waterways and over scores of dynamic glacial masses, Uttarakhand is an important freshwater hold. A huge piece of the state is under woodlands. Climate change might seriously affect livelihoods as the vast majority of the financial sector is vulnerable to the effects of climate change. Several investigations have documented a striking temperature rise over the regions, particularly in the rugged mountains, and attribute recent natural calamities and outrageous climate events like subsiding glacial masses and upwardly moving snowline, depleting natural resources, erratic precipitation, sporadic winter downpours, progressing cropping seasons, fluctuations in the blooming of plants, shifting of cultivation zones of apple and different yields, decrease in snow in winter, increasing intensity and recurrence of flash floods, evaporating of perennial streams, and so forth to this warming.

The complex topography of the Himalaya has come about in incalculable microclimatic areas. These microclimates are sensitive to the current setting of global climate inconstancy. Literature showed that warming in the Greater Himalayas was astoundingly higher than in some other regions on the planet (Shrestha et al., 1999; Chaulagain, 2006; ICCP, 2007a; NRC, 2012; Shrestha et al., 2012). Sort of a high pace of warming in the Himalaya has effectively brought about a quick dissolving of the Himalayan ice sheets (Xu et al., 2007; Prasad et al., 2009;

Sveinbjörnsson and Björnsson, 2011; NRC, 2012). Glaciers supply around 12.3%, 9.1% and 44.8% of water for major Himalayan Rivers - Brahmaputra, Ganges, and Indus individually. The portions of the glacial mass melts in these waterways are ascribed to increment until the 2050s and decay from there on (Xu et al., 2009). Diminished portion of meltwater has brought about decreased water accessibility for the rice fields of Nepal, India, Bangladesh, and Pakistan (Lal, 2011). This change results in a serious impact on South Asian socio-agro-economy and livelihood.

Rise in precipitation is likewise anticipated due to increasing temperature. Wentz et al. (2007) detailed a 7% increment in worldwide mean rainfall by per °C expansion in temperature. Numerous researchers have concentrated on monsoon behavior and observed that the monsoon attributes are changing (Kripalani et al., 2007; Turner and Slingo, 2009; Cherchi et al., 2011; Schewe et al., 2011). literature additionally announced expanded outrageous precipitation episodes, and the monsoon of the area has set off intemperate (IPCC, 2007a; UNDP and DFID, 2007). By the by, spatial varieties in the pace of warming and in the pace of the dynamics of precipitation inside the Himalaya have likewise been accounted for (Shrestha et al., 1999; Shrestha et al., 2000; Chaulagain, 2006; Manandhar et al. 2011; Gentle and Maraseni, 2012; Rawat et al., 2012).

Climate variability studies in the Himalaya have not focused on such little clusters of microclimatic zones yet. This study was directed in light of the assumption that the microclimates of the Himalaya are reacting to global climate variability in an unexpected way, so the generalization made through the restricted investigations in the Himalaya may not address what is going on in climate and micro-climate elements in the Himalaya. The aim of the study is to trace out the dynamic spatial variety of the local climate across the Alaknanda-Bhagirathi basin.

THE STUDY AREA

The area of concern is the Garhwal Himalaya which is located from 29.5^0 N to 31.5^0 N latitude and 77^0 E to 80^0 E longitudes and comprises an area of 32450 km^2 (Figure 1). This locale has primarily three seasons in a year, warm summer (March to June), moist warm summer (July to June), and winter season (November to February). The climatic states of the Garhwal Himalayan region vary from the glacial to the tropical cover zone. Based on temperature, precipitation and altitude, Garhwal Himalaya can be divided into seven unique climatic zones from south to north: tropical (< 300 m), subtropical (301-800 m), warm calm (801-1600 m), cool mild (1601-2400 m), cold mild (2401-3200 m), sub-elevated (3201-4000), and frosty cover (> 4000 m) (Kaushik, 1962).

The elevation ranges from 474m (Devaprayag) to 3892m (Gomukh ice sheet, CWC, 2020). The gross number of ice sheets distinguished in Ganga basin is 968 with the glacial covered area coming to around 2,850 km^2, which is nearly 8% of the overall basin region. The largest number of glacial masses totalling 407-has been distinguished in the Alaknanda basin involves 1,230 km^2, which represents practically 11% of the total basin volume (Glacier Atlas of India, GSI, 2017). The land under cultivation is 644.22 km^2, which is 5.9 percent of the overall geological region while just 64.8 km^2 (0.6%) land is under agricultural yields (Sati VP, 2008). Around 60% of the basin is under the agrarian movement (standard harvest groupings that fuse wheat, maize, rice, sugarcane, bajra and potato), while 20% is roofed by woodlands, by and large inside the higher mountains; generally 2% in the mountain tops is forever covered with the snow. The yearly typical precipitation inside this basin ranges somewhere in the range of 550 and 2500 millimetre (Shukla et al., 2014), and a significant part of the precipitation is contributed by the south-westerly monsoon that prevails from July to late September. The geological area and elective nuances of the review locale of Alaknanda-Bhagirathi basin are given in Figure 1

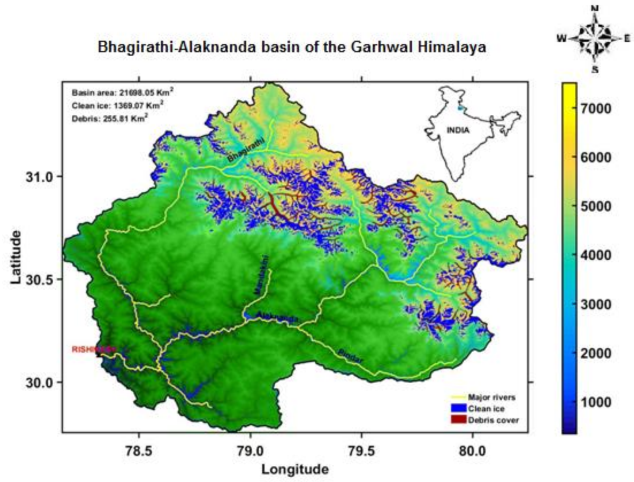

Figure 1: Elevation of the Bhagirathi-Alaknanda Basin of the Garhwal Himalayas.

RESULT AND DISCUSSIONS

Joshimath

On a yearly premise, the precipitation pattern results show the rising trend with no level of significance. Besides, the pre-monsoon series have an increasing trend on the seasonal scale with 90% degree of certainty while a diminishing pattern has been observed in the monsoon series with 99.9% certainty of level. Autumn and winter manifest the rising tendency with non-significance levels. On a monthly premise, the long stretch of July manifests the diminishing pattern of 95% degree of certainty; August exhibits the diminishing pattern with 99.9% confidence level and the month of November manifests an increasing pattern with 90% confidence level.

Haridwar

On the annual premise, precipitation pattern results show the rising tendency with no level of significance. On the other hand, the seasonal premise the pre-monsoon series exhibits the rising tendency with close to 99% degree of certainty and the monsoon series manifests the increasing tendency with level of non-significance. Post monsoon and winter series exhibit the expanding pattern with level of non-importance. On a month to month premise, the long stretch of May exhibits the expanding pattern with 95% degree of certainty.

Srinagar-Garhwal

On annual sector, precipitation pattern results show the rising tendency with no level of significance. On the seasonal premise the pre-monsoon series exhibits the rising tendency with nearly 99.9% degree of certainty and the monsoon series manifests the increasing tendency with level of non-significance. Autumn and winter series exhibit the expanding pattern with non-importance level. On a month to month premise, May manifests the rising pattern with 95% confidence level.

Karnaprayag

On annual basis, the precipitation pattern results show the rising trend with no level of significance. On the other side, in seasonal premise the pre-monsoon series manifests rising tendency with 90% degree of certainty and the monsoon exhibits the diminishing pattern with 95% confidence level. Post monsoon exhibits the increasing tendency with level of non-importance and winter series manifests the diminishing pattern with level of non-importance. On monthly premise, the period of August shows the decreasing trend with 99% degree of certainty and November exhibits expanding pattern with 90% confidence level.

Devprayag

On yearly premise, the precipitation pattern results show the rising tendency with no level of significance. Besides, in the seasonal premise, the pre-monsoon series exhibits the rising tendency with almost 99% degree of certainty and the monsoon manifests the diminishing pattern with 95% level of confidence. Post monsoon and winter series exhibit the expanding pattern with level of non-significance. On month to month premise, the period of March shows the expanding pattern with 90% level of confidence, the long stretch of May shows the expanding pattern with 95% confidence level, August shows the diminishing pattern with 99% level of confidence and November show rising tendency with 99% degree of certainty.

Uttarkashi

On yearly basis, the rainfall pattern results show the rising tendency with no level of significance. On the other side, in seasonal premise, pre-monsoon series manifests the expanding pattern with 95% degree of certainty and monsoon series manifests the diminishing pattern with 90% level of confidence. Autumn and winter series exhibit the rising tendency with non-significance level. On the monthly premise, August shows the diminishing pattern with 95% degree of certainty and November show expanding pattern with 90% confidence level.

Table 1: Values of Serial Correlation, T-Stat Value, P-Value and Skewness Coefficient after Pre-whiting the Rainfall Series.

S. No.	City	Latitude	Longitude		Annual	Pre-Monsoon	Monsoon	Post-Monsoon
1	Joshimath	30.55	79.56	variance	43239.7	2075.5	51792.27	1489.15
				covariance	216.08	201.31	4079.14	10.93
				serial correlation	0	0.097	0.078	0.007
2	Haridwar	29.956	78.17	variance	43239.7	474.31	26771.65	231.78
				covariance	216.08	108.23	-2218.45	6.23
				serial correlation	0	0.23	-0.082	0.026
3	Srinagar-Garhwal	0.22	78.79	variance	43239.7	1297.17	98324.67	894.62
				covariance	216.08	401.86	12435.24	-12.43
				serial correlation	0	0.31	0.126	-0.013
4	Karnprayag	30.26	79.22	variance	43239.7	1716.77	48703.27	1108.24
				covariance	216.08	181.32	1354.15	21.16
				serial correlation	0	0.105	0.027	0.02
5	Devprayag	30.15	78.60	variance	43239.7	988.14	41294.21	577.18
				covariance	216.08	253.06	-394.12	15.93
				serial correlation	0	0.256	-0.009	0.027
7	Uttarkashi	30.73	78.45	variance	43239.7	1577.84	39838.76	462.37
				covariance	216.08	172.28	-317.39	29.56
				serial correlation	0	0.11	-0.008	0.063

Table 2: Rainfall Trend in the Bhagirathi basin Station Wise (1956–2015)

Time series	Haridwar			Devprayag			Uttarkashi		
	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q
JAN	*-1.18*		*-0.074*	*-0.96*		*-0.058*	*-1.32*		*-0.092*
FEB	0.41		0.028	1.21		0.076	0.86		0.059
MAR	1.36		0.098	1.88	+	0.085	1.52		0.099
APR	0.27		0.023	1.54		0.062	0.84		0.042
MAY	1.24		0.089	2.12	*	0.128	1.34		0.091
JUN	-1.43		-0.284	-0.91		-0.146	-1.37		-0.242
JUL	-1.06		-0.371	-1.04		-0.366	-0.71		-0.215
AUG	-2.75	**	-0.814	-2.56	**	-0.747	-2.52	*	-0.699
SEP	-0.69		-0.151	-0.04		-0.008	-0.34		-0.089
OCT	0.09		0.007	0.51		0.022	0.49		0.024
NOV	1.68	+	0.027	2.03	*	0.024	1.65	+	0.027
DEC	-0.23		-0.012	-0.05		-0.003	-0.27		-0.004
Annual	0.92		0.597	0.92		0.597	0.92		0.597
Pre-monsoon (Mar-May)	1.67	+	0.189	2.94	**	0.265	2.12	*	0.224
Monsoon (June-Sept)	-2.36	*	-1.721	-2.08	*	-1.338	-1.83	+	-1.214
Post-monsoon (Oct-Nov)	0.25		0.021	0.68		0.047	0.61		0.041
Winter (Dec-Feb)	-0.16		-0.026	0.42		0.052	0.04		0.006

Table 3: Rainfall Trend in the Alakananda basin Station Wise (1956–2015)

Time series	Joshimath			Karnaprayag			Srinagar-Garhwal		
	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q
JAN	-0.51		-0.037	-1.37		-0.066	-0.18		-0.010
FEB	0.74		0.059	1.20		0.055	0.97		0.058
MAR	1.47		0.093	1.46		0.047	2.13	*	0.088
APR	0.12		0.017	0.72		0.017	0.32		0.010
MAY	1.18		0.089	2.06	*	0.080	2.56	*	0.150
JUN	-1.29		-0.297	0.51		0.068	1.00		0.195
JUL	-2.31	*	-0.592	1.38		0.351	0.48		0.174
AUG	-3.19	***	-1.136	-0.96		-0.232	0.04		0.017
SEP	-0.62		-0.124	0.88		0.211	0.64		0.182
OCT	0.26		0.016	0.34		0.009	0.48		0.017
NOV	1.68	+	0.027	-0.33		-0.006	-0.48		-0.004
DEC	0.21		0.008	-1.25		-0.025	0.01		0.000
Annual	0.92		0.597	0.92		0.597	0.92		0.597
Pre- monsoon (Mar-May)	1.84	+	0.215	2.54	*	0.209	2.85	**	0.181
Monsoon (June-Sept)	-3.19	***	-2.277	-0.58		-0.334	0.58		0.287
Post- monsoon (Oct-Nov)	0.49		0.041	1.39		0.079	0.30		0.019
Winter (Dec-Feb)	0.63		0.089	1.08		0.098	0.21		0.017

Now the monthly, annual and seasonal statistics have been calculated from IMD gridded rainfall data of spatial resolution of 0.25° X 0.25° for the period of 1956-2015 for both river basins. Daily rainfall occurring on each day of each month of the year is summed to get Monthly Rainfall (MR) of that particular grid point. This process is followed for every year and for each of the 37 points for Bhagirathi basin.

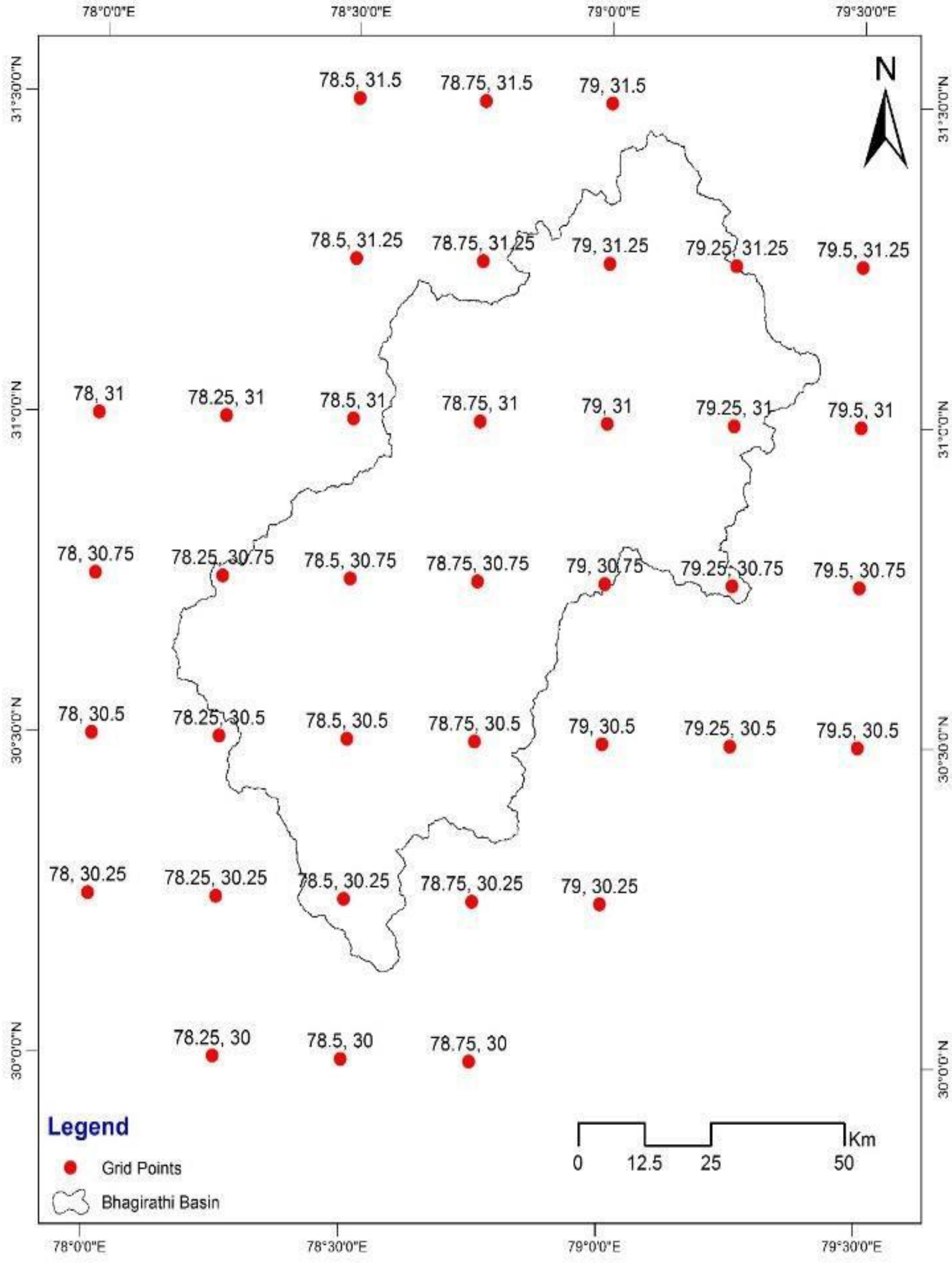

Figure 2: Grid Points in and Around Bhagirathi Basin Considered for Analysis.

Table 4: Monthly, Annual and Seasonal Rainfall Statistics of Bhagirathi Basin (1956-2015)

Month/Season	Rainfall(mm)	Standard deviation	Coefficient of variance(%)	%Contribution to annual RF
Jan	57.24	6.05	10.15	5.08
Feb	69.18	10.17	13.80	6.09
Mar	71.23	18.36	25.82	6.11
Apr	39.28	9.32	22.58	3.53
May	53.68	4.91	8.97	4.68
Jun	119.32	13.17	11.41	10.43
Jul	267.73	25.12	9.22	23.82
Aug	277.30	23.31	8.46	23.16
Sep	130.26	6.93	5.34	11.23
Oct	32.22	1.47	4.47	2.90
Nov	8.56	2.94	32.54	0.73
Dec	27.32	3.06	11.74	2.30
Month/Season	**Rainfall(mm)**	**Standard deviation**	**Coefficient of variance(%)**	**%Contribution to annual RF**
Pre Monsoon	292.51	42.22	14.14	24.98
Monsoon	799.11	67.41	8.41	68.89
Post Monsoon	69.80	6.66	9.68	6.13
Annual	1158.43	44.92	3.84	100.00

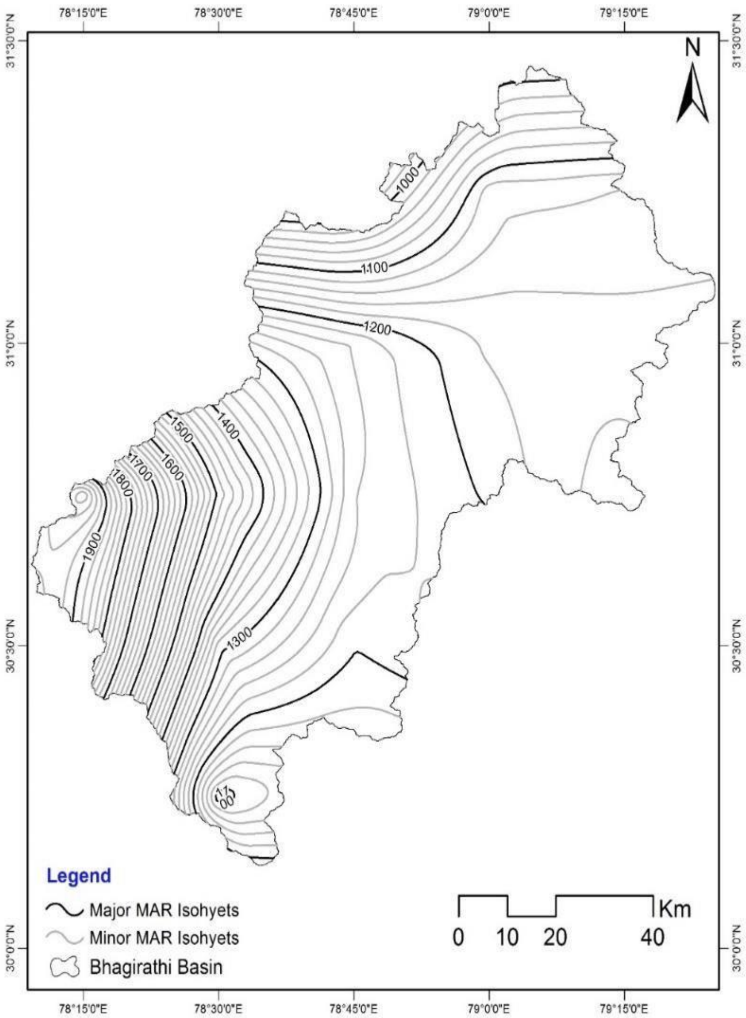

Figure 3: Isohyets of Mean Annual Rainfall in Bhagirathi Basin.

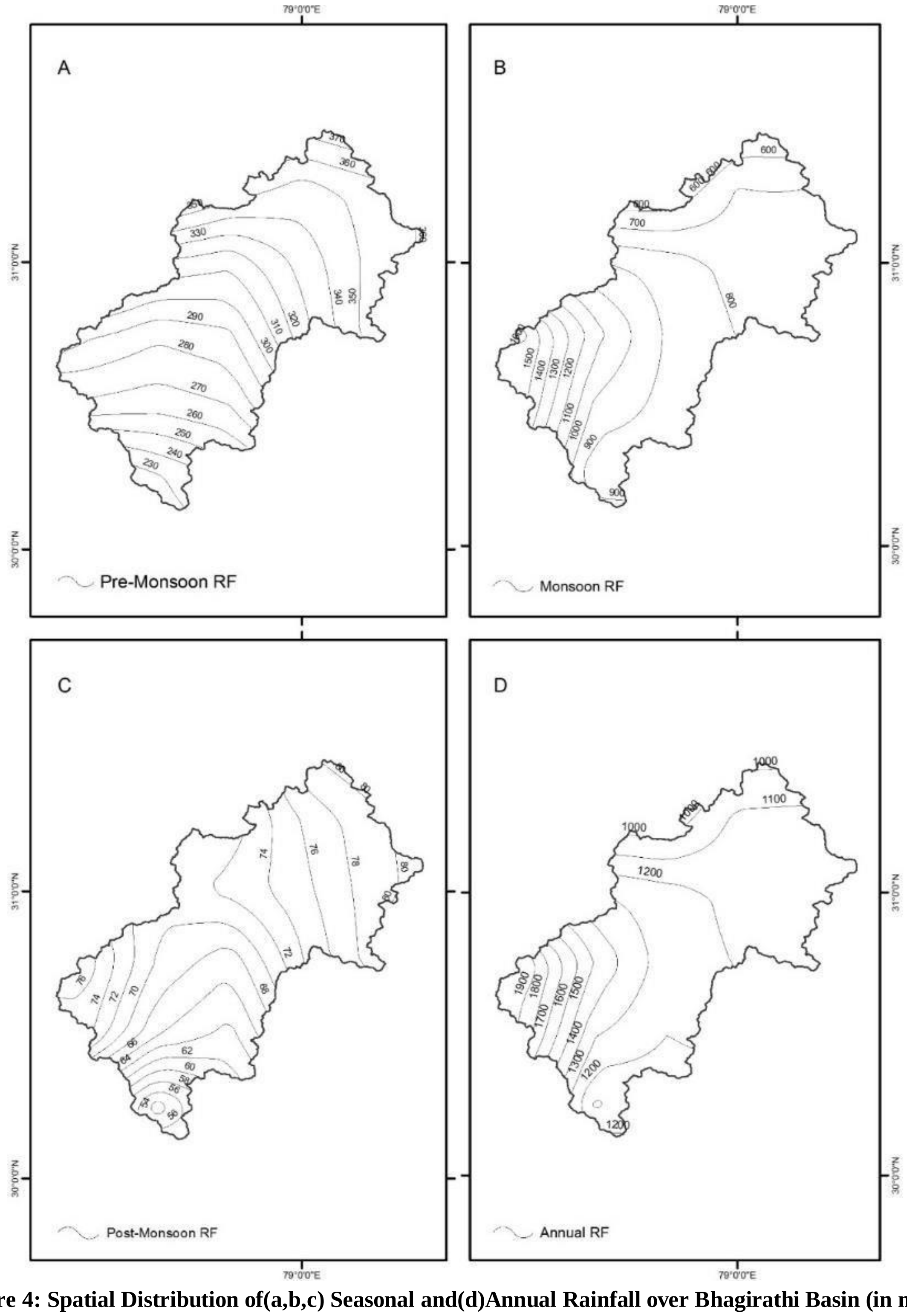

Figure 4: Spatial Distribution of(a,b,c) Seasonal and(d)Annual Rainfall over Bhagirathi Basin (in mm).

Similar rainfall statistics have been calculated for Alaknanda basin. Annual, Monthly and seasonal rainfall has been derived for each of the 38 points for Alaknanda basin.

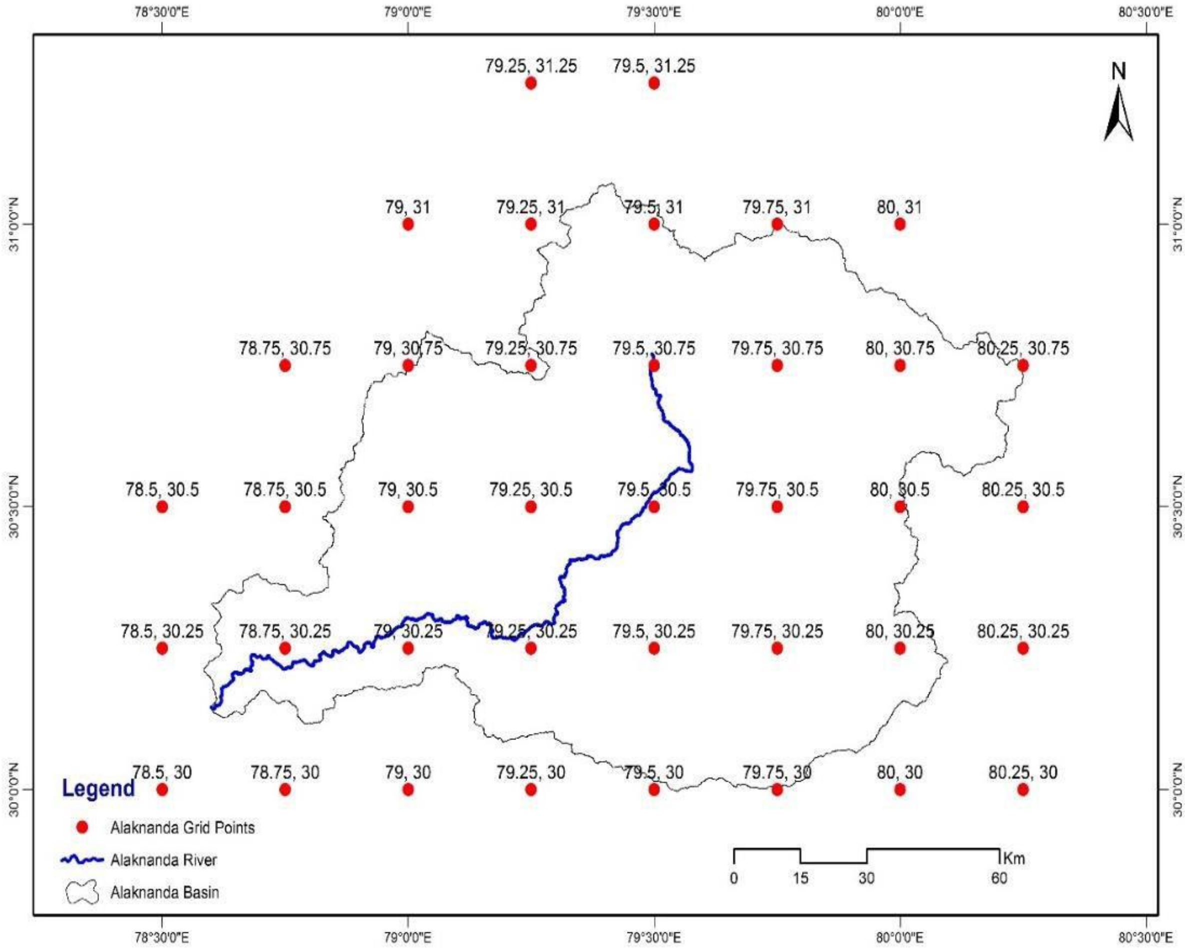

Figure 5: Grid Points in and Around Alaknanda Basin Considered for Analysis.

Table 5: Monthly, Annual and Seasonal Rainfall Statistics of Alaknanda Basin(1956-2015)

Month/Season	Rainfall(mm)	Standard Deviation	Coefficient of Variance(%)	%Contribution to annual RF
Jan	65.38	9.01	13.78	4.94
Feb	76.94	11.50	14.95	5.81
Mar	79.21	19.50	24.62	5.99
Apr	48.54	14.26	29.39	3.67
May	58.68	11.44	19.49	4.43
Jun	141.50	45.42	32.10	10.69
Jul	315.69	81.37	25.78	23.86
Aug	308.10	79.82	25.91	23.28
Sep	154.72	37.51	24.24	11.69
Oct	38.01	6.46	16.99	2.87
Nov	10.45	2.90	27.73	0.79
Dec	27.53	4.01	14.56	2.08
Pre-Monsoon	327.20	51.73	15.81	24.73
Monsoon	920.02	243.19	26.43	69.53
PostMonsoon	75.99	9.92	13.06	5.74
Annual	1323.21	263.34	19.90	100.00

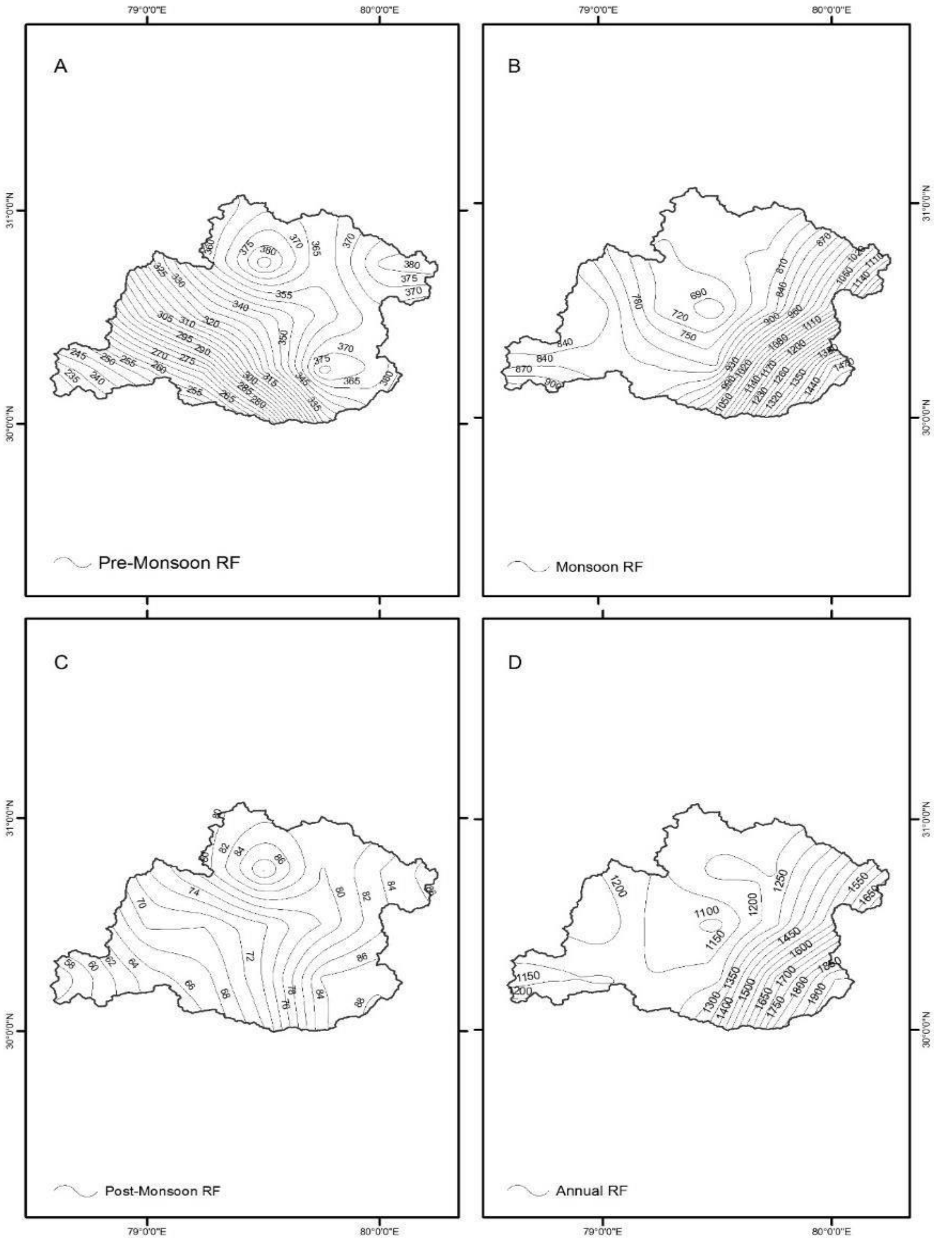

Figure 6: Spatial Distribution of Seasonal and Annual Rainfall over Alaknanda Basin (in mm).

Table 6: Statistical Summary of Monthly Mean Temperatures in Bhagirathi Basin

Month	Mean	SD	CV%	R^2
January	11.45	1.40	12.30	0.044
February	14.83	2.18	13.96	0.078
March	20.87	2.72	12.64	0.358
April	23.96	2.04	8.47	0.212
May	25.94	2.23	9.03	0.072
June	27.67	2.41	9.24	0.064
July	27.93	2.08	7.57	0.012
August	27.72	1.36	4.62	0.002
September	26.10	1.77	5.82	0.452
October	21.07	2.17	10.43	0.554
November	16.56	1.45	10.18	0.028
December	11.86	1.23	10.76	0.676

Similarly, it is evident from the above table that, for all the months, monthly mean temperatures of Bhagirathi basin have increased significantly. The extreme of 27.93 °C has been observed in July, followed by 27.72 °C in the month of August and 27.67 °C in the month of June, while the minimum temperature 11.45 °C was observed in January followed by 11.86 °C in December. The statistical summary of maximum temperature for all months is shown in Table 6. Coefficient of variation for mean temperature for Alaknanda Valley is most elevated in the period of February and it is seen as 13.96% though it is least in the long stretch of August and it is 4.62%. This implies that mean temperature is most steady in the long stretch of August and least steady in the period of February.

Table 7: Statistical Summary of Monthly mean Temperatures in Alaknanda Basin

Month	Mean	SD	CV%	R^2
January	12.30	1.30	13.20	0.042
February	15.36	2.24	13.82	0.084
March	21.08	2.67	12.97	0.372
April	24.74	2.09	8.73	0.206
May	26.98	2.38	9.12	0.062
June	27.68	2.47	9.16	0.056
July	27.87	2.14	7.46	0.008
August	27.67	1.31	4.76	0.001
September	26.25	1.63	5.94	0.489
October	21.43	2.27	10.57	0.578
November	17.12	1.68	10.07	0.030
December	12.23	1.28	11.05	0.664

Likewise from Table-7, it is discernible that for all the months, monthly mean temperatures for Alaknanda basin have increased significantly. The maximum of 27.87 °C was observed in July, followed by 27.68 °C in June and 27.67 °C in August, while the minimum temperature 12.30 °C was observed in the month of January followed by 12.23 °C in December. Coefficient of variation for mean temperature for Alaknanda Valley is at its peak in the month of February with a value of 13.82% whereas it is lowest in August with a value of 4.76%. This implies that the mean temperature is most steady in the stretch of August and least stable in the stretch of February.

CONCLUSIONS

Multiple climate variables (mean, maximum, and minimum temperature; rainfall)procured from different data sources (observation stations, gridded datasets) were used together with survey data on community perceptions to understand and assess the climate dynamics of the Bhagirathi and Alaknanda basin of Garhwal Himalaya. The analyses of meteorological data demonstrated the rise in temperatures and increase in erratic rainfall events in the Basin in general. However, there exists variability among the studied sites.

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