

Climatic characteristics of temperature and precipitation of Bhutan

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सार – भूटान 26°70' – 28°35' उत्तरी अक्षांशों और 88°50' – 92°30' पूर्वी देशांतरों के बीच पूर्वी हिमालय के दक्षिणी ढाल में स्थित स्थल से घिरा एक पर्वतीय देश है। भूटान के विभिन्न स्थानों में विभिन्न प्रकार की जलवायु मिलती है जैसे कि उष्णकटिबंधीय मैदानी क्षेत्र, शीतल शीत ऋतु और गर्म ग्रीष्म ऋतु वाली मध्य घाटियाँ तथा कड़ाके की शीत ऋतु और शीतल ग्रीष्म ऋतु वाले पर्वतीय क्षेत्र। भूटान की स्थलाकृति के अत्यधिक असमान होने के कारण वहाँ की जलवायु अत्यंत मिश्रित प्रकार की है। इसके अलावा भूटान बहि-उष्णकटिबंधीय परिसंचरण और एषियाई मानसून परिसंचरण की परिधि के क्रमशः उत्तर और दक्षिण में स्थित है। ये सभी स्थितियाँ भूटान की जलवायु को बहुत मिश्रित बना देती हैं। इस शोध-पत्र में 1990-1999 तक के वर्षों में 44 केन्द्रों के तापमान और वर्षा के आँकड़ों का उपयोग करके भूटान की जलवायु की विशेषताओं का अध्ययन करने का प्रयास किया गया है। मासिक न्यूनतम और अधिकतम तापमान के वार्षिक प्रोफाइल से भूटान के अधिकांश केन्द्रों में जुलाई में अधिकतम और जनवरी में न्यूनतम तापमान की यूनोमोडल विशेषता का पता चला है। दक्षिण-पश्चिमी भूटान के फंटर्षोलिंग में तापमान सबसे अधिक 37.2° से. रहा और पश्चिमी मध्य भूटान के ड्रकजेल जाँग में तापमान सबसे कम -8.2° से. रहा। तापमान के स्थानिक वितरण से भूटान के मध्यवर्ती, पश्चिमी मध्यवर्ती और उत्तरी भागों के पर्वतीय क्षेत्रों में कम तापमान की तथा दक्षिणी घाटियों में अधिक तापमान होने की विशेषता का पता चला है। मासिक वर्षा के वार्षिक प्रोफाइल से इसकी यूनोमोडल विशेषता का पता चला है जो अधिकांशतः जुलाई में अधिकतम और जनवरी में न्यूनतम रही। सिपसू में अधिकतम वार्षिक वर्षा 5866 मि.मी. हुई और गिडाकॉम में सबसे कम 628 मि.मी. वर्षा हुई। भूटान के मध्यवर्ती भागों और उत्तरी भाग में अपेक्षाकृत कम वर्षा हुई। देश की औसत वर्षा से पता चला है कि भूटान में 1679.4 मि.मी. वर्षा हुई जिसमें से 70 प्रतिशत वर्षा मानसून ऋतु में और 19.9 प्रतिशत वर्षा मानसून ऋतु से पूर्व हुई। देश में हुई 10 वर्षों की औसत मानसून वर्षा की वार्षिक समयश्रृंखला से 3-4 वर्षों की परिवर्तनशीलता का पता चला है जिसमें परिवर्तन का गुणांक (सी. वी.) 5.5 प्रतिशत रहा। अखिल भारतीय मानसून वर्षा (ए. आई. एम. पी.) और भूटान में हुई मानसून की वर्षा की तुलना से पता चला है कि ए. आई. एम. पी. की तुलना में भूटान में परिवर्तन की अवस्था लगभग विपरीत रही। सहसंबंध विप्लेषण से नकारात्मक सहसंबंध का पता चला है जिसमें सहसंबंध गुणांक -0.64 रहा जो 0.05 स्तरों पर पाया गया है।

ABSTRACT. Bhutan is a land locked mountainous country situated on the southern slopes of the eastern Himalayas between 26° 70' - 28° 35' N Latitudes and 88° 50' - 92° 30' E Longitudes. Bhutan has a spatially diversified climate- tropical in southern plains, cool winter and hot summer in central valleys and severe winter and cool summer in the mountains. Extremely non-uniform topography makes the climate of Bhutan very complex. More over, Bhutan is situated in the periphery of the extra-tropical circulation and Asian monsoon circulation in the north and south respectively. These situations make the climate of Bhutan more complex. An attempt has been made to study the characteristics of the climate of Bhutan using the data of temperature and precipitation of 44 stations for the years 1990-1999. Annual profile of monthly minimum and maximum temperature shows the unimodal character attaining maximum in July and minimum in January for most of the stations of Bhutan. Extreme highest temperature was 37.2° C at Phuntsholing in the southwest Bhutan and extreme lowest temperature is -8.2° C at Drukgyel Dzong in the west central Bhutan. Spatial distribution of temperature shows that the mountainous areas of the central, west central and northern part of Bhutan are characterized by low temperature and the southern valleys by high temperature. Annual profile of monthly precipitation manifests the unimodal nature attaining maximum mostly in July and minimum in January. The highest annual precipitation was 5866 mm at Sipsoo and lowest annual precipitation of 628 mm at Gidakom. The central and northern part of Bhutan has relatively low precipitation. The country average precipitation shows that Bhutan gets 1679.4 mm of annual precipitation of which about 70 % occurs in the monsoon season and 19.9% in the pre-monsoon season. The yearly time series of country average monsoon precipitation for 10 years shows a variation with timescale of 3-4 years with a coefficient of variation (CV) of 5.5%. Comparison of monsoon precipitation of Bhutan with All India Monsoon Precipitation (AIMP) shows that the former undergoes more or less opposite phase of variations with respect to AIMP. The correlation analysis shows negative correlation with correlation coefficient of -0.64 which is significant at 0.05 levels.

Key words – Climatic characteristics, Bhutan, Temperature, Precipitation, Monsoon variability.

1. Introduction

Bhutan is situated on the southern slope of the eastern Himalayas, between 26° 70' - 28° 35' N Latitudes and 88° 50' - 92° 30' E Longitudes. The topography of Bhutan is extremely inhomogeneous with elevation within the range from 97 m (the lowest point at Dragme Chu) to 7553 m (the highest point at Kangri). Elevation of the country increases from south to north. The population of Bhutan is about 7, 50,000 ([http](http://www.bhutan.gov.bt), 2004) and the total land area is approximately 38,500 km² (Department of Energy, 2005). Economy of the country is based on agriculture and forestry (Ministry of Agriculture, 2002). Bhutan has a spatially diversified climate: tropical in the southern plains, cool winter and hot summer in central valleys and severe winter and cool summer in the mountains. The local severe storms, cold waves, landslides and land erosions are the major disastrous events. Bhutan has extremely complex characteristics of climate because of its location in the mountains of Himalayas with extremely non-uniform topography. Moreover, the country is influenced by both the extra-tropical and monsoon systems. The country as a whole has three climatic zones: (i) the Duars plain has a subtropical climate characterized by high humidity and heavy rainfall, (ii) the central belt of flat valleys is characterized by cool winter and hot summer with moderate rainfall and (iii) the high valleys have cold winter and cool summer. Over 5000 m the land is permanently covered with snow and glaciers ([http](http://www.bhutan.gov.bt), 2004).

In this study the mean climatic characteristics have been investigated for Bhutan using the maximum and minimum temperature and precipitation for the period 1990 to 1999 for 44 stations. The country average precipitation and coefficient of variation on monthly, seasonal and annual basis have been calculated. The inter-annual variability of monsoon precipitation of Bhutan with respect to All India Monsoon Precipitation (AIMP) has also been investigated.

2. Data used and methods of analysis

In this study climatological data of monthly minimum and maximum temperature and precipitation of 44 stations of Bhutan for the maximum period of 10 years 1990-1999 have been considered (Fig. 1). The data were received from Meteorology Section, Department of Energy, Ministry of Trade & Industry, Royal Government of Bhutan. The database was subjected to rigorous quality checking and cleaning operations to get rid of the erroneous data. Severe data gaps have also been noticed for many stations. Thus, for generating the time series of the country average precipitation, data of 22 stations (shown as parabolic symbols in Fig. 1) having better temporal coverage was used. The data gaps were filled up

through spatial interpolation of the data of the above mentioned 44 stations. The annual profiles of the mean monthly minimum and maximum temperature and precipitation have been prepared and analyzed. Spatial distribution of minimum temperature of winter, maximum temperature of southwest monsoon season and annual precipitation has also been presented. Besides, the country average mean monthly, seasonal and annual precipitation and coefficient of variation (CV %) have been calculated. The four seasons considered in this study are winter (December-January), pre-monsoon (February-May), monsoon (June-September) and post-monsoon (October-November). For estimating the total or average of a parameter for the winter of one year, the data of January and February of that year and December of the previous year is used. The time series of the country average monsoon precipitation of Bhutan has been analyzed with respect to AIMP using temporal plots and statistical correlation analysis. For comparison, the precipitations of Bhutan and AIMP were expressed as percentage departure from long term normal. The AIMP data were obtained from electronic site of Indian Institute of Tropical Meteorology (IITM).

3. Results and discussion

The results of the analysis of temperature and precipitation have been discussed in the following subsections.

3.1. Thermal characteristics

The Fig. 2 shows the profiles of maximum and minimum temperature for 6 selected stations. The figure indicates that both maximum and minimum temperature follows unimodal variation with minimum in January and maximum in July. In fact the high temperature prevails from April-October. The temperature curve is very flat from May-September both for maximum and minimum temperature profiles. The amplitude of annual variation is found to be low for the maximum temperature compared to minimum temperature. Very high amplitude of annual profile of minimum temperature (16-20° C) and that of the maximum temperature (10-14.5° C) are obtained over the mountainous areas of the central and west-central parts of Bhutan where very cold temperatures prevail. The southwestern and south-central parts of Bhutan have relatively low amplitude of the annual variation for both minimum and maximum temperature.

Fig. 2 shows that the diurnal variation is stronger in winter than in summer. Very high amplitude of diurnal variation (14-16° C) is observed over the high mountains of the central, central-western and northern Bhutan. The

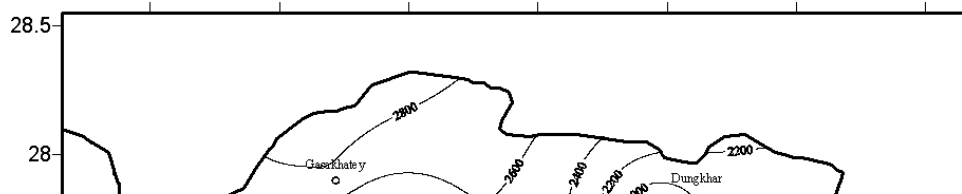


Fig. 1. The map showing the location of 44 climatological stations of Bhutan. The contour shows the lines of equal elevations in meters based on the elevation of the stations. 22 stations which are represented by open circles have been used for generating the time series of country average precipitation

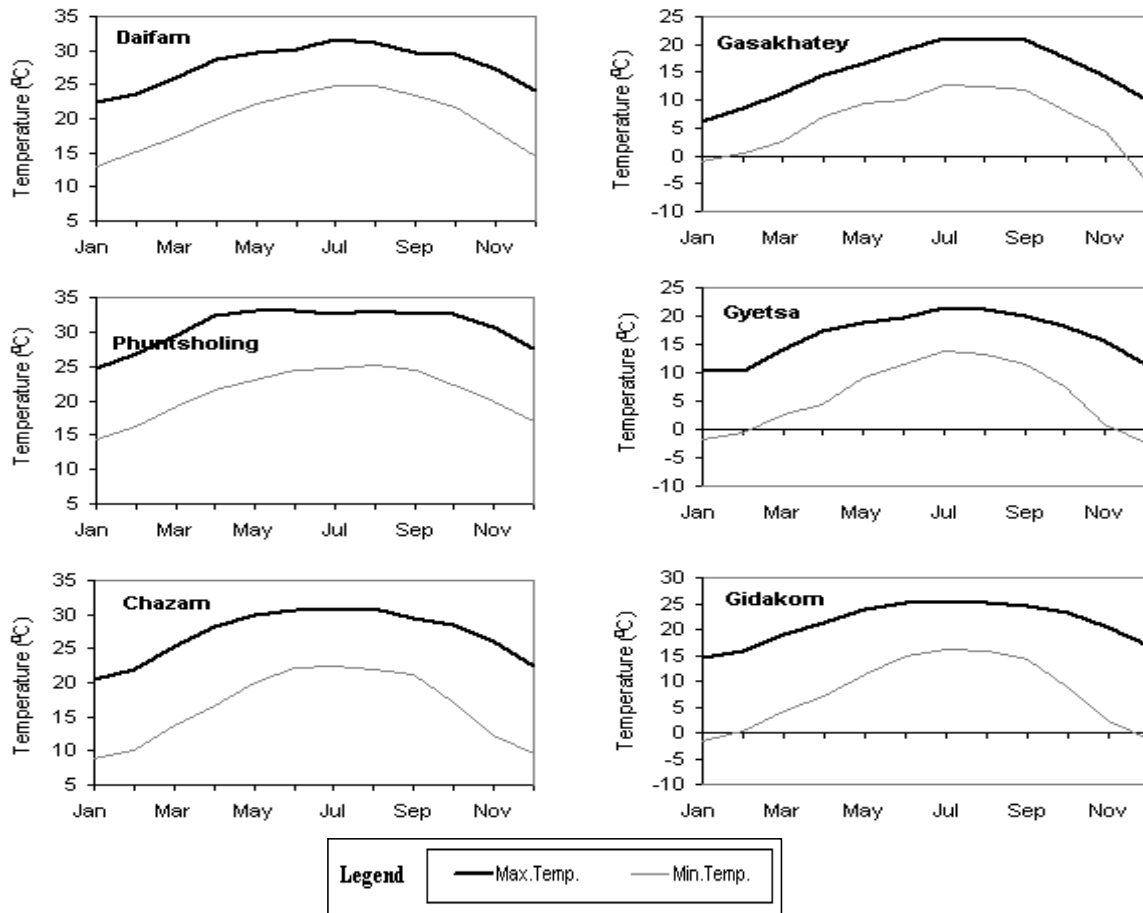
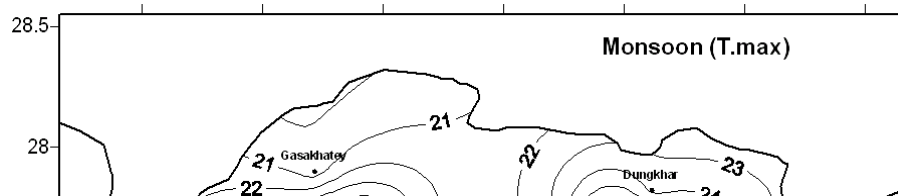
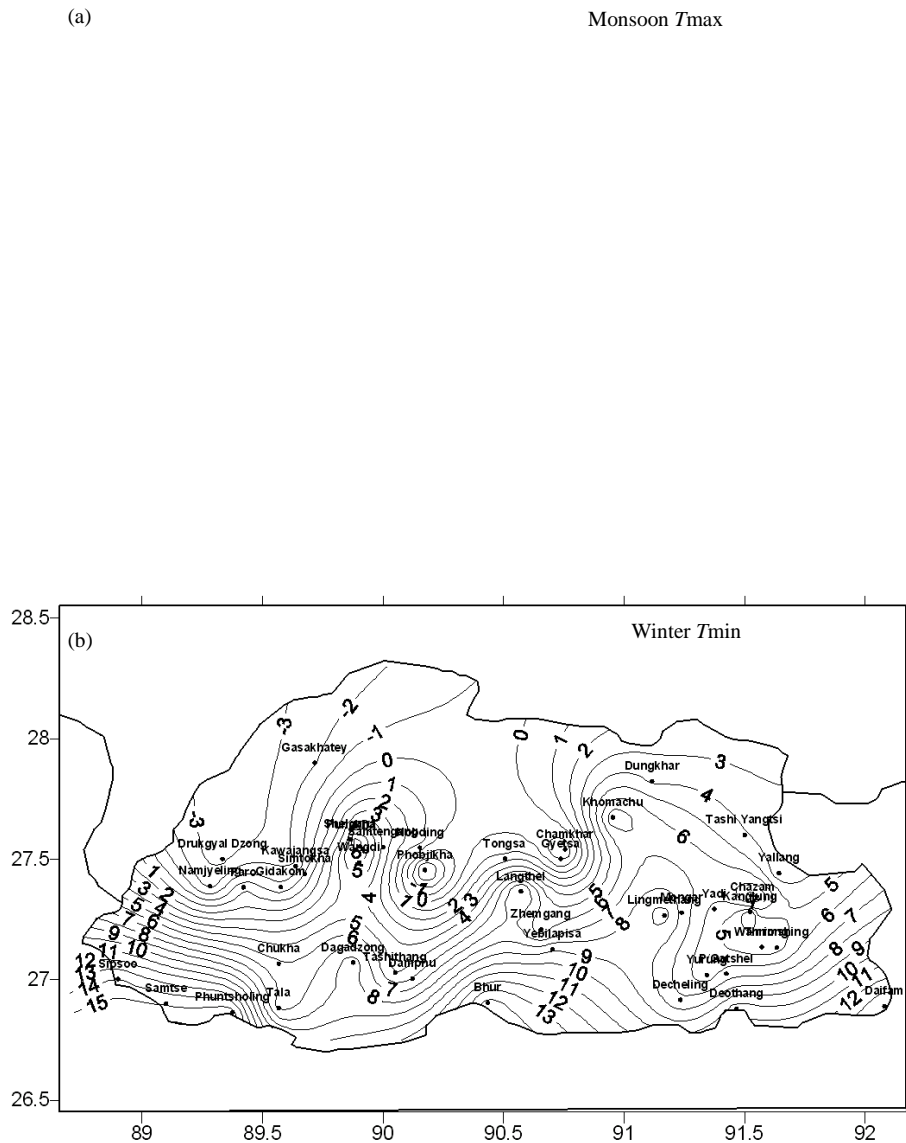


Fig. 2. Annual profile of monthly maximum and minimum temperature for 6 geographically distributed stations of Bhutan





Figs. 3(a&b). Spatial distribution of (a) summer maximum and (b) winter minimum temperature ($^{\circ}\text{C}$) of Bhutan

stations situated over southern Bhutan exhibit very low diurnal variations with amplitudes around $6\text{-}10^{\circ}\text{C}$.

The spatial distribution of average winter minimum and monsoon maximum temperature [Figs. 3(a&b)] and the records of extreme temperature during the period 1990-1999 show that average highest maximum temperature occurs over the southwestern and southern Bhutan. The extreme highest monthly maximum temperature of 37.2°C was observed at Phuntsholing. Very low average minimum temperature below freezing

level (-1 to -5.6°C) was found in the central, west-central and northwestern mountainous areas of Bhutan. The extreme lowest minimum temperature was recorded as -8.2°C at Drukgyel Dzong which is located at the west-central Bhutan. The above analysis depicts that southern part of Bhutan with low elevation has relatively warmer climate and the central, northern and northwestern mountainous areas have cold climate. The meteorological observations over the inaccessible high mountains and peaks do not exist; as a result the paper cannot highlight the climatic characteristics for those areas.

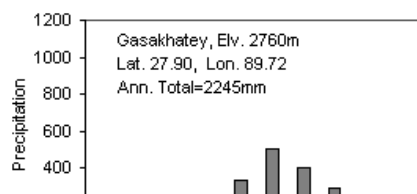
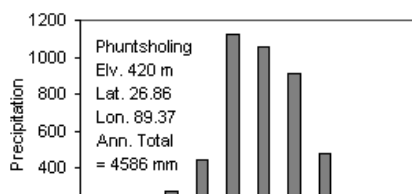


Fig. 4. Annual profile of monthly precipitation (mm) for 6 geographically distributed stations of Bhutan

3.2. *Precipitation characteristics*

3.2.1. *Annual profile of monthly total precipitation*

The annual profile of the average monthly total precipitation for 6 geographically distributed stations of Bhutan (Fig. 4) shows that the precipitation of Bhutan manifests monsoonal characteristics and exhibits unimodal variation with lowest in January and highest in the month of July for most parts of the country except a few stations in the southern parts where the highest occurs in the month of June. Very high precipitation between 500 - 1263 mm/month occurs in the monsoon months (June to September) over the southern valley of Bhutan with highest amounts realized in the southwestern part. The rapid increase of precipitation from May to June indicates that monsoon onset over Bhutan takes place in the month of June. The lowest monthly mean precipitation from 0.0 - 5.0 mm is observed over the central and northern mountains (Gidakom and Khomachu) during the months November – February.

3.2.2. *Spatial distribution of annual precipitation*

The spatial distribution of annual precipitation (Fig. 5) shows that the southern valley of Bhutan receives high annual precipitation ranging from 2500 – 5866 mm with highest in the western side of the valley. The precipitation was found to decrease from west to east over the valley. Relatively lower amount of precipitation in the range from around 1000 – 2500 mm occurs along the northern parts of the southern valley of Bhutan on the foot of the mountains. Very low precipitation occurs in the central Bhutan situated over the high mountains where the annual precipitation is below 1000 mm but mostly concentrate around 700 mm. The lowest annual precipitation of 628 mm was observed at Gidakom. As compared to Central Bhutan relatively high precipitation occurs in northern Bhutan with highest occurring over the northwestern Bhutan (2245mm at Gasakhatey). This is due to the fact that these areas are likely to receive some precipitation from the sub-tropical westerly disturbances. The distribution of monsoon precipitation and topographic

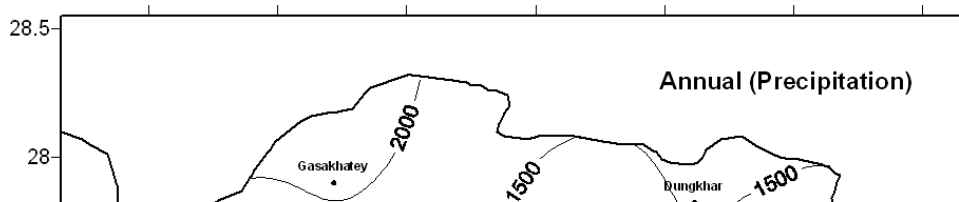




Fig. 5. Spatial distribution of annual precipitation (mm) of Bhutan

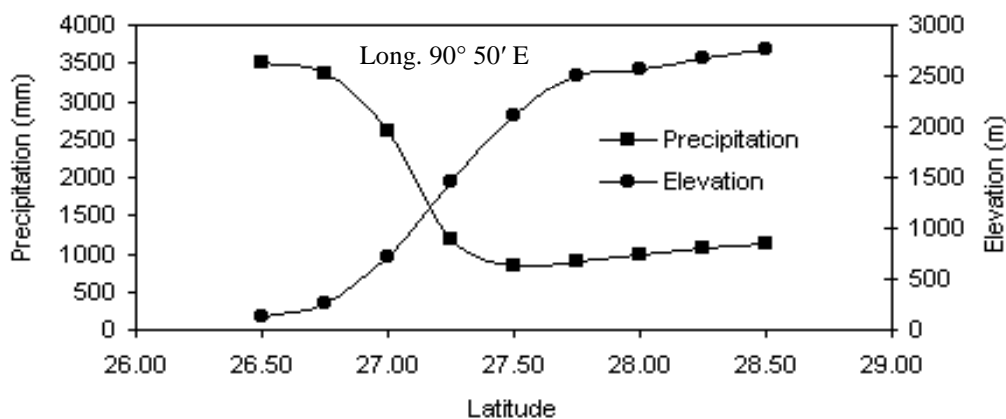


Fig. 6. Distribution of monsoon precipitation (mm) and elevation (m) along longitude 90° 50' E as function of latitudes

height (elevation) along a north-south transect through the longitude of 90° 05' E (Fig. 6) demonstrates that the monsoon precipitation rapidly decreases from south to north with the increase of elevation up to 27° 5' N in the upper slope of the high mountains. Thereafter, the precipitation has shown slight increase over the northern Bhutan.

3.2.3. *Characteristics of country average precipitation*

The 10 year's mean country average monthly, seasonal and annual precipitation of Bhutan has been shown in Table 1 along with the coefficient of variation

(CV %). The annual profile has been drawn using the monthly country average precipitation (Fig. 7), which again indicates that high rainfall occurs in the monsoon months with maximum in July. The country average mean annual rainfall of Bhutan was found to be 1679.4 mm. The country average precipitation of winter, pre-monsoon, monsoon and post-monsoon are 63.5, 334.2, 1175.3 and 106.4 mm respectively. The percent distribution shows that 70.0 % of the annual total precipitation is received in the monsoon season and 19.9 % in pre-monsoon. The post-monsoon and winter contribute to 6.3 and 3.8 % respectively. High CV of 37.6 and 39.9 % are observed in post-monsoon and winter compared to 5.5 and 10.0% in the monsoon and pre-monsoon seasons respectively.

TABLE 1

Statistics of monthly and seasonal country average precipitation (mm) of Bhutan

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	21.6	30.6	53.1	102.8	178.4	306.2	364.3	307.6	197.2	88.1	18.3	11.3
CV (%)	64.7	57.0	34.5	24.8	16.4	13.4	14.1	13.3	8.0	44.2	91.8	75.5
Seasons	Winter			Pre-monsoon			Monsoon		Post-monsoon		Annual	
Mean	63.5			334.2			1175.3		106.4		1679.4	
CV(%)	39.9			10.0			5.5		37.6		4.7	

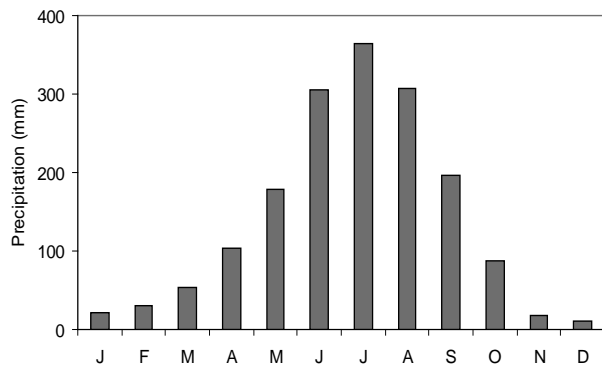


Fig. 7. Annual profile of country average precipitation of Bhutan in mm

The inter-annual variability of country average monsoon precipitation of Bhutan has been studied in comparison with AIMP. The time series of the precipitation of Bhutan and AIMP expressed in percentage departure from normal has been presented in Fig. 8. The figure clearly depicts that the monsoon precipitation of Bhutan and AIMP undergoes variations in the timescale of 3-4 years with CV of 5.5 and 6.4% respectively. The figure illustrates that the monsoon activities of Bhutan are more or less in opposite phase with respect to AIMP; however, there is no one to one relationship. The correlation coefficient between AIMP and Bhutan precipitation is -0.64 which is significant at the 0.05 level (2-tailed). This implies that the monsoon is strong over Bhutan when it is weak over India as a whole and *vice versa*.

4. Conclusions

The study has the following conclusions.

(i) The annual profile of monthly minimum and maximum temperature of Bhutan has unimodal pattern

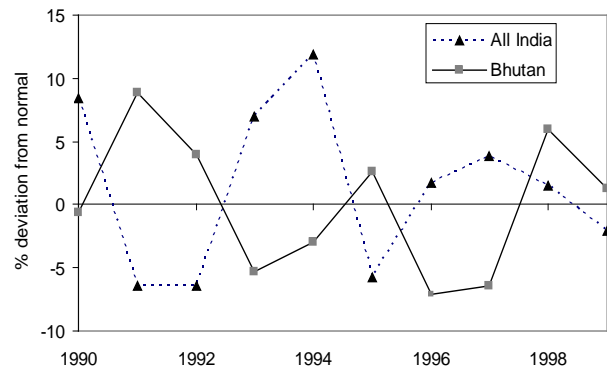


Fig. 8. Comparison of monsoon precipitation of Bhutan (solid line) and All India Monsoon Precipitation (AIMP) (dotted line) expressed as percentage deviation from normal. The normal for AIMP is 838.3 mm for the period 1971-2000 and that of Bhutan is 1175.28 mm estimated for the period 1990-1999

attaining maximum in July and minimum in January. The amplitudes of annual temperature profile have wide spatial variations. High amplitude variations are observed over the mountainous areas of the west-central, central and northern Bhutan where cold temperature prevails. The amplitude of diurnal variation varies from season to season and place to place. The diurnal variation of temperature is strong in winter. The high amplitudes of the diurnal variation (14-16° C) occur in the west-central, central and northern parts of Bhutan.

(ii) The spatial distribution of temperature shows that the south-western and southern valleys are the warmest zones of Bhutan. The cold regions are situated over the central, west-central and northern mountains with temperature below freezing in the winter.

(iii) The station wise annual profile of precipitation shows that Bhutan manifests unimodal variation of precipitation with lowest in January and highest in July for

most parts of the country except for a few stations in the southern parts where the highest occurs in June. High precipitation continues from June to September. The precipitation is governed by the southwest monsoon circulation. The winter is very dry over Bhutan.

(iv) The southern valley receives relatively high annual precipitation from 2500-5866 mm. The western part of the southern valley receives the highest precipitation. The precipitation in the northern part of the southern valley in the foot hills of the mountains lies within the range 1000-2500 mm. Very low precipitation occurs in the central Bhutan ranging from 700-1000 mm. The northern Bhutan receives relatively higher rainfall compared to the central Bhutan with maximum in the northwestern Bhutan. The north-south transects of monsoon precipitation and elevation along 90° 5' E longitude show that the monsoon precipitation decreases from south to north up to 27° 75' N with the increase of the topographic height; thereafter, it shows slight increase.

(v) The country average monthly precipitation shows that maximum occurs in July. The country average annual precipitation as obtained from 10 year data (1990-1999) is 1679.4 mm and the monsoon precipitation is 1175.3 mm. The latter constitutes 70% of the annual precipitation. The pre-monsoon precipitation constitutes about 19.9 % while post-monsoon and winter contribute to 6.3 and 3.8% respectively.

(vi) The study of inter-annual variability of monsoon precipitation of Bhutan with respect to AIMP shows that the variation of Bhutan precipitation occurs more or less in opposite phase with AIMP. The correlation coefficient of AIMP and Bhutan precipitation is -0.64. Which indicates the negative relationship between the two monsoons.

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