CLIMATIC VARIABILITY IN THE CENTRAL-WESTERN HIMALAYA

Dissertation submitted to Jawaharlal Nehru University

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MASTER OF PHILOSOPHY

(Abstract)

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Climatic Variability in the Central-Western Himalaya

Climate is the long-term characteristics of the atmospheric conditions that not only affect the physical landscape but also the cultural and social landscape. In the nature, nothing is static and permanent. Each system and each unit of a system under go cyclic change over period of time. On the basis of temporal extent changes in climatic condition can be termed as climate change, climate shift and climatic variation. Climatic variation refers to the fluctuations recorded in the climatic parameters for a shorter time period, while the former two are used for the long-term (time period varies from epoch to era) climatic fluctuations and reversals. These variations in the climatic parameters suggest about the changing pattern of the climate and on that basis the future climate become predictable with much accuracy.

A large longitudinal extent, massive vertical dimension and continentality make the Himalayan region a much potential and attractive part of the world for the study of climate. This climatic study covered the Central-western Himalayan part of the massive Himalayan mountain system. The Central-Western Himalaya is the hot spot of the climate studies as the region has countless glaciers which are considered as thermometer of the Earth. That's why the current study has significant locational and situational importance. The major objectives of the study includes the analysis of temporal variations in temperature and rainfall during the study period with available data and using moving average, NADM and simple average method, recording seasonal-spatial variability in temperature and rainfall using CV method, trend analysis of temperature and rainfall using simple linear regression method and graphical representation (best fit-line method), measurement of seasonal variation in climatic extremes i.e. highest maximum and lowest minimum temperature and highest rainfall along with variation in no. of rainy days, and comparing the climatic variations of the Central-Western Himalaya and the Western Rajasthan region.

The instrumental records of rainfall and temperature were included in the study provided by the National Data Centre, Indian Meteorological Department, Pune. Study covered temporal variations analyzed with the moving average, naturalized accumulated departure from mean and simple average method, spatial variation analysis by coefficient of variation and trend analysis by simple linear regression method. A case study for the comparison of the climatic variations, experienced by the Central-Western Himalaya and the Western Rajasthan regions, was also incorporated.

The temporal-seasonal variation analysis using moving average method suggests cyclic fluctuation in rainfall and temperature regime in CWH region while the normalized accumulated departure from mean (NADM) and simple average method quantifies the variability in rainfall and temperature and also permits visual as well as statistical comparison of unlike data series. Cyclic fluctuation recorded in mean monthly maximum temperature in the region. The Central Himalayan meteorological stations recorded decrease in rainfall in almost every season while Western Himalaya reflected cyclic fluctuations. The seasonal variation analysis using simple average method provides that increasing trend in maximum temperature was more prominent at the high elevated site, Shimla while the decreasing trend in minimum temperature became more prominent at the low elevated site, Dehra Doon. A decreasing trend in rainfall recorded during winter and monsoon season in the CWH region. Spatial variation analysis using coefficient of variation method provides some interesting findings. It suggests that site with high elevation recorded relatively high variability in temperature as compared to low elevated stations. Relatively low variability in climatic parameters, such as rainfall and temperature is marked during monsoon season while relatively high variability in mean temperature is observed during winter season.

The trend analysis of rainfall and temperature regimes using simple linear regression method marked striking results. The temperature regime displayed statistically significant (at 95 % confidence level) increasing trends in Himachal Pradesh while a decreasing trend in Uttarakhand. The Western Himalaya recorded an increasing trend in maximum temperature. On the other hand, the Central Himalaya reflected decreasing trend in minimum as well as mean temperature. The monsoon and winter season temperature depicted a significant increasing trend in the Western Himalayan region. A decreasing trend in monsoon rainfall is common for all the stations (significant at 95 % confidence level) in the CWH region which consequently marked a decreasing trend in annual rainfall of the region. Uttarakhand experienced significant decreasing trend in rainfall during monsoon and post-monsoon season while Himachal Pradesh reflected decreasing trend in monsoon, winter and annual rainfall. The monthly rainy days marked a decreasing trend during monsoon and winter seasons in Himachal Pradesh.

The case study provides some significant results about the climatic variations recorded in two different physiographic regions viz. the Central-Western Himalaya and the Western Rajasthan. The maximum temperature experienced increasing trend in both the regions during 1960-90. The winter maximum temperature reflected significant increasing trend in the CWH region. The mean temperature marked increase during 1930-90 while decease during 1960-90 at the CWH stations and at Jodhpur station of the WR. Bikaner reflected persistent increase in mean temperature during 1901-2000. The rainfall regime reflected decrease in CWH region while increase in WR region in simple average analysis. Both, the CWH and the WR, regions marked relatively high inconsistency in mean temperature records during winter season while relatively high consistency during monsoon season. The Western Rajasthan marked relatively high variability in monthly rainfall compared to the Central-Western Himalaya because of less amount of rainfall received by the former during monsoon and post-monsoon season. It is perceived that rainfall in winter and post monsoon season is more inconsistent than monsoon season rainfall in both regions. Trend analysis suggests an increasing trend recorded in maximum temperature in both regions which was found significant at 95 % confidence level. The winter and monsoon season reflected statistically significant increasing trend in mean temperature in both regions. The monthly rainfall recorded increasing trend in Western Rajasthan while the Central-Western Himalaya recorded a statistically significant decreasing trend in rainfall especially in monsoon season. Both, Bikaner and Jodhpur marked an increasing trend in annual rainfall while an increasing (statistically significant) trend in monsoon rainfall recorded at Jodhpur only among all four meteorological stations.

In the concluding remarks; this study provided vital records of the climatic conditions of the Himalayan region and also experienced the data scarcity and un-availability of authentic and continuous data series for climatic elements. The maximum temperature recorded absolute increase and also reflected increasing trend in the Central-Western Himalayan region. The high elevation station Shimla marked relatively high increase in maximum temperature. Minimum temperature recorded decreasing trend in the Central Himalaya. A decrease in rainfall recorded in winter and monsoon season. Spatial variation analysis represented that monsoon season recorded lowest spatial variability in both, rainfall and temperature regime. The winter season reflected relatively high variability in temperature regime. The comparison of climatic variables between the CWH and the WR region provided very important results. The maximum temperature recorded a statistically significant increasing trend in both the regions and minimum temperature marked an increasing trend during monsoon season in the WR region. A decreasing trend in monsoon rainfall was a major concern point in the CWH region. On the other hand, the WR recorded statistically significant increasing trend in monsoon as well as annual rainfall. Therefore, it can be concluded that the Western Himalaya recorded increasing trend in temperature regime while the Central Himalaya marked statistically significant decreasing trend in rainfall. The Western Rajasthan recorded an increasing trend in temperature during winter season and importantly, marked a statistically significant increasing trend in rainfall.

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21 July 2011

CERTIFICATE

*I, **Vikas Khatik**, do hereby declare that the dissertation entitled **'Climatic Variability in the Central-Western Himalaya'** for the degree of **Master of Philosophy** is my bonafide work and may be placed before the examiners for evaluation.*

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DEDICATED

TO

MY PARENTS

AND

FRIENDS

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CONTENTS

		Page No.
Chapter One	**Introduction to the Study**	**1-14**
1.1	Introduction	
1.2	Literature Review	
1.2.1	Studies on climatic variation in Himalayan region	
1.2.2	Studies on climate change at higher elevations	
1.2.3	Studies on climatic variation in the Indian sub-continent and the world	
1.3	Objectives	
1.4	Aim of the study	
1.5	Data Base	
1.6	Methodology	
1.7	Chapterisation scheme	
1.8	Limitations of the study	
Chapter Two	**Introduction to the Study Area**	**15-26**
2.1	Introduction	
2.2	Physiography	
2.3	Geology and Tectonic Settings	
2.4	Drainage System	
2.5	Climate	
2.6	Vegetation	
2.7	Demography	
Chapter Three	**Temporal and Spatial Climatic Variability in The Central -Western Himalaya**	**27-73**
3.1	Introduction	

	3.2	Seasonal Climatic Fluctuation analysis using Moving Average method	
	3.3	Seasonal Climatic Fluctuation analysis using Normalized Accumulated Departure from Mean (NADM) method	
	3.4	Seasonal Climatic Variation analysis using Simple Average method	
	3.5	Spatial Climatic Variation analysis using Coefficient of Variation method	
	3.6	Chapter Summary and Conclusion	
Chapter Four		**Trends in the climate of the Central-Western Himalaya**	**74-102**
	4.1	Introduction	
	4.2	Trend Analysis using Simple Linear Regression method	
	4.3	Chapter summary and conclusion	
Chapter Five		**Comparison of climatic variability in the Central-Western Himalaya and the Western Rajasthan: A case study**	**103-130**
	5.1	Introduction	
	5.2	A brief introduction of the Western Rajasthan	
	5.3	Comparison of seasonal variation using Simple Average method	
	5.4	Comparison of spatial variation using Coefficient of Variation method	
	5.5	Comparison of trends in climatic variables using Simple Linear Regression method	
Chapter Six		**Summary and Conclusion**	**131-133**
		Bibliography	**134-141**

LIST OF TABLES

Table No.		Page No.
1.1	IMD Classification of Seasons in India	10
2.1	Details of meteorological stations included in the study	15
2.2	Characteristics of climate and vegetation of the Central-Western Himalaya	23
3.1	Details of meteorological stations included in Moving Average Analysis	28
3.2	Explanation for Acronyms	28
3.3	Information about the meteorological stations included in NADM analysis	49
3.4	Results of NADM analysis (span of departure; positive/ negative)	55
3.5	Information about the meteorological stations used in Simple Average Analysis	56
3.6	Seasonal climatic variation analysis using simple average method	57
3.7	Information about the meteorological stations used in Spatial Variability Analysis using CV method	66
3.8	Seasonal climatic variability using Coefficient of Variation (CV) method	67
4.1	Information about the meteorological stations used in Simple Linear Regression analysis	75
4.2	Trend analysis of mean monthly maximum, minimum and mean temperature using Simple Linear Regression method	76
4.3	Trend analysis of total monthly rainfall and monthly rainy days (MRD) using Simple Linear Regression method	85
4.4	Trend analysis of extreme events using Simple Linear Regression method	87
5.1	Information about the meteorological stations included in the case study	105
5.2	Seasonal variation in temperature regime using Simple Average method	107

5.3	Seasonal variation in temperature and rainfall regimes using Simple Average method	108
5.4	Information about the meteorological stations included in the Spatial Variation analysis using Coefficient of Variation method	117
5.5	Spatial variability in mean monthly temperature (1930-90) using Coefficient of Variation Method	118
5.6	Spatial variability in monthly rainfall (1930-90) using Coefficient of Variation Method	119
5.7	Information about the meteorological stations included in the Trend analysis using Simple Linear Regression method	121
5.8	Trend analysis in temperature and rainfall regimes using Simple Linear Regression method	122

LIST OF FIGURES

Figure No.		Page No.
2.1	Location map of the Central-Western Himalaya	16
2.2	Physiography of the Central-Western Himalaya	18
2.3	DEM and Relief Profiles of the Central-Western Himalaya	19
2.4	Aspect Map of the Central-Western Himalaya	20
2.5	Tectonic settings and Major Thrust Zones of the CWH region	21
2.6	Land use/ Land cover classification of the Central-Western Himalaya	25
3.1	Seasonal fluctuations in mean monthly maximum temperature	32
3.2	Seasonal fluctuations in mean monthly minimum temperature	33
3.3	Seasonal fluctuations in mean monthly temperature	34
3.4	Seasonal fluctuations in mean monthly rainfall	39
3.5	Seasonal fluctuations in mean monthly rainy days	40
3.6	Seasonal fluctuations in monthly highest maximum temperature	46
3.7	Seasonal fluctuations in monthly lowest minimum temperature	47
3.8	Seasonal fluctuations in total monthly highest rainfall	48
3.9	Seasonal fluctuations in mean monthly temperature (NADM method)	52
3.10	Seasonal fluctuations in total monthly rainfall (NADM method)	53
3.11	Seasonal fluctuations in monthly rainy days (NADM method)	54
3.12	Seasonal variations in mean monthly maximum temperature (Simple Average method)	59
3.13	Seasonal variations in mean monthly minimum temperature (Simple Average method)	60
3.14	Seasonal variations in mean monthly temperature (Simple Average method)	61

3.15	Seasonal variations in total monthly rainfall (Simple Average method)	63
3.16	Seasonal variations in monthly rainy days (Simple Average method)	64
3.17	Seasonal spatial variability in mean monthly temperature	68
3.18	Seasonal spatial variability in total monthly rainfall	69
3.19	Seasonal spatial variability in monthly rainy days (MRD)	70
4.1	Trend in mean monthly maximum temperature	79
4.2	Trend in mean monthly maximum temperature	80
4.3	Trend in mean monthly minimum temperature	81
4.4	Trend in mean monthly minimum temperature	82
4.5	Trend in mean monthly temperature	83
4.6	Trend in mean monthly temperature	84
4.7	Trend in total monthly rainfall	89
4.8	Trend in total monthly rainfall	90
4.9	Trend in monthly rainy days	91
4.10	Trend in monthly rainy days	92
4.11	Trend in highest monthly maximum temperature	93
4.12	Trend in highest monthly maximum temperature	94
4.13	Trend in lowest monthly minimum temperature	95
4.14	Trend in lowest monthly minimum temperature	96
4.15	Trend in highest monthly rainfall	97
4.16	Trend in highest monthly rainfall	98
5.1	Location map of the CWH and the Western Rajasthan	105
5.2	Seasonal variations in mean monthly maximum temperature	109

	(Simple Average method)	
5.3	Seasonal variations in mean monthly minimum temperature (Simple Average method)	110
5.4	Seasonal variations in mean monthly temperature (Simple Average method)	113
5.5	Seasonal variations in total monthly rainfall (Simple Average method)	114
5.6	Spatial variability in mean monthly temperature (1930-90)	118
5.7	Spatial variability in monthly rainfall (1930-90)	119
5.8	Trend analysis of mean monthly maximum temperature	124
5.9	Trend analysis of mean monthly minimum temperature	125
5.10	Trend analysis of mean monthly temperature	126
5.11	Trend analysis of total monthly rainfall	127

Chapter One

Climatic Variability in the Central -Western Himalaya

Introduction to the study

1.1 Introduction

Climate is defined as the long-term characterization of the atmospheric conditions that not only affects the physical landscape but also the anthropogenic one. In nature, nothing is static and permanent. Each system and each unit of a system under go the cyclic change. Climate, a complex mechanism of the various elements, under goes change, periodically. On the basis of temporal extent these changes can be termed as climate change, climate shift and climatic variation. Climatic variation refers to the fluctuations recorded in the climatic parameters for a shorter time period, while the former two are used for the long-term (time period varies from epoch to era) climatic fluctuations and reversals. We predict for next few days weather using the satellite images and other climatic information from weather instruments. This is a real time prediction based on real time data. Palaeo-climatologist and palaeo-ecologists put together the marine sediment core record, ice core record and pollen records to understand the past climate of the earth *(Prabhu et al., 2004; Burns et al., 2004)*. This is the analysis based on past time data. With the same integrated approach we can understand the climatic sequences and can predict for the climate also, not probably for long enough but for a substantial period. Palaeo-studies are based on the proxies like marine cores, ice cores and pollen records. As the data are retrieved from the proxies with various relative methods, so these have relatively low precision level compare to instrumental data.

The Indian Ocean and the Himalayan ranges have greater importance in the Indian climate. First one, the ocean, is the origin place of the seasonally varying monsoon, one of the prominent climatic features of the Indian subcontinent *(Duplessy, 1982)* and the second one, Himalaya is the barrier for coming monsoonal winds blocking their way towards the north. This combination has much of the responsibilities for the monsoonal climate of the subcontinent. The seasonally varying monsoon, also vary in its intensities. The intensity of the monsoonal circulation has varied greatly on time-scales of glacial–interglacial cycles and also on shorter time-scales *(Beaufort et al., 1999)*. The summer monsoon was weaker and the winter monsoon stronger during the last glacial maximum (LGM) *(Borole et al., 1982; Sarkar et al., 1990;*

Clemens et al., 1991; Rostek et al., 1997; Naidu and Shankar, 1999; Thamban et al., 2001). Palaeo-climatic and palaeo-sedimenty studies recorded, increased variability and possible weakening of the Indian and East Asian summer monsoons and continued strengthening of the East Asian winter monsoon since about 2.6Myr ago *(Zhisheng et. al., 2001).* The instrumental data recorded from the Himalaya for last century also suggest about the varying climate of the region. Significant decreasing trend in the monsoon precipitation have been recorded in last century with winter warming in the North-Western Himalaya *(Bhutiyani et. al., 2007).* Negative relationships between mean winter air temperature and snowfall amounts recorded at different meteorological stations in this period reveal strong effect of rising temperatures on the decreasing snowfall component in total winter precipitation, reducing effective duration of winter on the windward side of the Pir Panjal Himalayan Range *(Bhutiyani et. al., 2009).* Although pre-monsoon (March to May) and summer cooling have been reported in some portions of the Western Himalaya *(Yadav et al., 2004)* and Upper Indus basin *(Fowler and Archer, 2006)*, overall annual temperatures in the Himalayas have recorded significant increase in the last century *(Pant and Borgaonkar, 1984; Seko and Takahashi, 1991; Sharma et al., 2000; Bhutiyani et al., 2007).*

With temporal variations in the climate, spatial variations also recorded because climate varies greatly over short distances due to strong topographic forcing. Large-scale variations in precipitation within an area occur with changing elevation, aspect, and rain-shadowing effects *(Yadav et.al., 1997, 1999, 2002).* Temperature variation is strongly related to local altitudinal gradients *(Bonnefille et al., 1999),* although the influence of the west–east and north–south gradients is also evident *(Anupama et al., 2000).* All three gradients influence precipitation and the length of the dry season *(Barboni et al., 2003).* The Himalaya with its great topographic undulations, as Lahaul and Spiti situated at a height of 4200 m from msl, Shimla at 2196 m, Dharamshala at 1457 m, Manali at 1950 m and Bilaspur at a height of 670 m producing a ground for the great spatial temperature variations.

The greater spatial extent, massive vertical dimension and a prominent role in the subcontinents climate pattern, all these makes the Himalayan region a much potential and attractive part of the world for the study of climate.

1.2 Literature Review

1.2.1 Studies on climatic variation in the Himalayan region;

Climate is a mechanism with greater temporal extent with varying nature. The development of science and subsequently, technology leads to the study of climate for both palaeo-earth and the current time. The proxy data analysis methods like pollen analysis, sediment/ice core analysis etc. made it possible to derive the palaeo climatic data and study the variations and major shifts in the Earth's climate. Simultaneously, the development in the field of meteorological instruments made it possible to record real time climatic data and analyze the varying nature of climate. The studies on climate cover both the real time and past time climate data.

The most comprehensive study on Himalayan climate with the recorded instrumental data was credited to ***Bhutiyani at el. (2007, 2009).*** Using available instrumental records, study examined the variation of precipitation from 1866 to 2006 in the northwestern Himalaya (NWH). The study revealed no change in the winter precipitation but significant decreasing trend in the monsoon precipitation during the study period. Analysis of the temperature data show significant increasing trends in annual temperature in the NWH during the study period. Warming effect is particularly noteworthy during the winter season. Negative relationships between mean winter air temperature and snowfall amounts recorded at different meteorological stations in this period, reveal strong effect of rising temperatures on the decreasing snowfall component in total winter precipitation, reducing effective duration of winter on the windward side of the Pir Panjal Himalayan Range. The study confirms episodes of strong warming and cooling in the NWH in the last century. ***Fowlar and Archar (2005)*** have pursued a climatic study based on the instrumental temperature data of Karakoram and Hindu Kush Mountains of the Upper Indus Basin (UIB). They analyzed the seasonal and annual trends over the period 1961–2000 and compared with neighboring mountain regions and the Indian subcontinent. The study revealed strong contrasts between the behavior of winter and summer temperatures and between maximum and minimum temperatures. Winter mean and maximum temperature show significant increase while mean and minimum summer temperatures show consistent decline. Increase in diurnal temperature range (DTR) is consistently observed in all seasons and the annual dataset, a pattern shared by much of the Indian subcontinent but in direct contrast to both GCM projections and the narrowing of DTR seen worldwide. This divergence commenced around the middle of the twentieth century and is thought to result from changes in large-scale circulation patterns and feedback processes associated with the Indian monsoon. The observed downward trend in summer temperature and runoff is consistent with the observed thickening and expansion of Karakoram glaciers, in contrast to widespread decay and retreat in the eastern Himalayas. This suggests that the Western Himalayas are showing a different response to global warming than other parts of the globe.

Before this study, a work by ***Yadav at el. (2004)*** suggests the same trends but with a different methodology and with different data sets. This work included observational records and reconstructions from tree rings that reflect pre-monsoon (March to May) temperature cooling in the western Himalaya during the latter part of the 20th century. A rapid decrease of minimum temperatures at around three times higher rate, as compared to the rate of increase in maximum temperatures found in local climate records is responsible for the cooling trend in mean pre-monsoon temperature. The increase of the diurnal temperature range is attributed to large scale deforestation and land degradation in the area and shows the higher influence of local forcing factors on climate in contrast to the general trend found in higher latitudes of the northern Hemisphere.

Tree ring analysis or Dendrochronology and Pollen analysis are the major proxies used to estimate the climatic variations happened in the past time. ***Yadav and Borgaonkar (2007, 2008)*** are the major contributors to the tree-ring analysis and revealed temperature pattern over the past four centuries in the North-Western Himalayan region. In the study a network of 12 tree-ring width chronologies of Himalayan cedar (*Cedrus deodara*) from the western Himalayan region has been used to reconstruct mean spring (March–May) temperature variations back to A.D. 1600. The most conspicuous feature of the temperature reconstruction is the long-term cooling trend since the late 17th century that ended early in the 20th century. The warmest 30-yr mean for the 20th century was recorded during 1945–1974. However, this warming, in the context of the past four centuries is well within the range of natural variability, since warmer springs of greater magnitude occurred in the later part of the 17th century (1662–1691).

Pollen records suggest about the vegetation cover of the past time. On the basis of classification of vegetation in dry-period vegetation and wet-period vegetation and the amount of pollens found in a particular layer of sediment core, suggests the contemporary climatic conditions in which the particular vegetation grew-up. In this way the ice and sediment cores and also the loess deposits provide very important and vital records of the past climate. A study of Pollens from Alpine peat by ***Phadtare (2007)*** suggests a sharp decrease in Summer Monsoon Strength 4000–3500 cal yr B.P in Central higher Himalaya. About 7800 cal yr B.P., dominance of evergreen oak (*Quercus semecarpifolia*), alder (*Alnus*), and grasses in the pollen record reflect a cold, wet climate with moderate monsoon precipitation. From 7800 to 5000 cal yr B.P., vegetation was progressively dominated by conifers, indicating ameliorated climate with a stronger monsoon. A warm, humid climate, with highest monsoon intensity, from 6000–4500 cal yr B.P. represents the mid-Holocene climatic optimum. Study also suggests about the correlation between cold/dry events revealed with the events reconstructed with the help of proxy data from other localities of the Indian subcontinent, Arabian Sea, and western Tibet. A study of loess deposits of Central Himalaya, carried out by ***Yadav and Pant (2005)***, reconstruct 20 ka climate records. The occurrence of loess deposits suggests contemporary prevalence of cold and dry northwesterly winds. Field stratigraphy, geochemistry, mineral magnetism, infrared stimulated luminescence (IRSL) and radio carbon dating has enabled reconstruction of an event chronology during the past 20□ka.

Not only the instrumental and proxy data are the major tools of climate study, but the perception of the local people is also used as the parameter to measure climatic variation in the region. Study undertook by ***Vedwan and Rhoades (2001)*** examines how apple farmers in the Western Himalayas perceive climatic changes. This is done by comparing the locally idealized traditional weather cycle with climate change as perceived by the farmers of the region. They used snowfall and rainfall data from 1962–1996 to measure the accuracy of perceptions. Although climate change is usually described by farmers as the temporal displacement of the weather cycle, the changes themselves still are not perceived as altering the idealized weather calendar. Most importantly, perception of climate change is structured by knowledge of crop-climate interaction and by differential apple performance outcomes associated with the changed conditions.

1.2.2 Studies on climate change at higher elevations;

Mountains cover 25 per cents of the global land surface, providing home and living space for 26 per cents of the world's population. In arid and semi-arid areas, where water is critical, mountains provide as much as 90–100 per cents of the freshwater resources for drinking, irrigation, and industrial supply in the surrounding lowlands (Meybeck et al., 2001). Mountains have also been shown to be hotspots of biodiversity. All these make more important the study of higher riches of the world with the view point of climate change. Differential temperature changes with altitude can shed light on the relative importance of natural versus anthropogenic climatic change. There has been increased interest in this subject recently due to the finding that high-elevation tropical glaciers have been retreating and that significant melting from even the highest alpine regions has occurred in some areas during the past 20 years or so, as recorded in ice core records, which do not reveal any similar period during previous centuries to millennia ***Diaz and Bradley (1997).*** In this study major mountain tops of the world were included but special emphasis was paid on the European Alps. Study suggests evidence for appreciable differences in mean temperature changes with elevation during the last several decades of instrumental records. The signal appears to be more closely related to increase in daily minimum temperature than changes in the daily maximum. The changes in surface temperature vary spatially, with Europe (particularly western Europe), and parts of Asia displaying the strongest high altitude warming during the period of record.

Beniston (2007) put forward a paper with the comprehensive study of possible impacts of climate change in mountain regions of the world. The hydrological cycle and consumption of water resource, natural ecosystems and tourism were taken as the major thrust areas of the study.

1.2.3 Studies on climatic variation in the Indian sub-continent and the world;

At the global level, many studies with the help of instrumental and proxy data sets and climate-modeling reconstruct the past climate with much more accuracy and acceptability. ***Crowley (2000)*** counted the major causes for global climate change over the past 1000 years. This study included Comparisons of observations with simulations from an energy balance climate model indicate that as much as 41 to 64 per cents of pre-anthropogenic (pre-1850) decadal-scale temperature variations was due to changes in solar irradiance and volcanism. The combination of a unique level of temperature increase in the late 20th century and improved constraints on the role of natural variability provides further evidence that the greenhouse effect has already established itself above the level of natural variability in the climate system. Global surface temperature analysis by ***Easterling, et al. (1997)*** suggests long-term trends for the maximum and minimum temperature. It is found that temperature increase is due, at least in part, to differential changes in daily maximum and minimum temperatures, resulting in a narrowing of the diurnal temperature range (DTR). The analysis, using station metadata and improved areal coverage for much of the Southern Hemisphere landmass, indicates that the DTR is continuing to decrease in most parts of the world, that urban effect on globally and hemispherically averaged time series are negligible, and that circulation variations in parts of the Northern Hemisphere appear to be related to the DTR. Atmospheric aerosol loading in the Southern Hemisphere is much less than that in the Northern Hemisphere, suggesting that there are likely a number of factors, such as increases in cloudiness, contributing to the decrease in DTR.

A 200-ka pollen and oxygen-isotopic record was reconstructed by ***Prabhu at el. (2004)*** from two sediment cores extracted from the eastern Arabian Sea. This pollen record demarcates a boundary between marine isotopic stages (MIS) 7 and 6. Pollen, oxygen-isotopic composition and organic carbon have been examined for two sediment cores from the eastern Arabian Sea (15802VN and 71841VE, 13816VN and 71800VE), to reconstruct the long-term palaeo-climate and palaeo-vegetation of the Indian subcontinent. Oxygen-isotope data suggest that these glacial periods (MIS 2, 4 and 6) are characterized by low precipitation because of a weak southwest monsoon and a strong northeast monsoon. In contrast, interglacial periods (MIS 1, 3 and 5) are marked by high fresh water input resulting from a strong southwest monsoon. During the last glacial–interglacial cycle, sea-surface temperature and surface salinity changed as a result of variations in the evaporation–precipitation (E–P) balance. Throughout the core, the dominant pollen types are Poaceae and Chenopodiaceae and/ or Amaranthaceae (N50%). Their dominance during glacial periods (MIS 2, 4 and 6) suggests that the climate was cold and dry. This dominance is also suggestive of salinity-tolerant vegetation colonizing large areas near seashore due to lower sea level or high E–P conditions. During interglacial periods (MIS 1, 3 and 5) when there was high precipitation, the arid taxa were sparse, whereas Poaceae and Piperaceae were abundant. Hence, Chenopodiaceae and/or Amaranthaceae and Artemisia are suggestive of cold and arid/semi-arid climate, and Poaceae and Piperaceae of warm and wet conditions. Mangrove pollen is not well represented in the cores. Study by ***Thompson at el. (2000)*** revealed that Tibet has been sensitive to fluctuations in the intensity of the South Asian Monsoon. Study incorporated the ice cores from Dasuopu, Tibet. Reductions in monsoonal intensity are recorded by dust and chloride concentrations. The deeper, older sections of the Dasuopu cores suggest many periods of drought in this region, but none have been of greater intensity than the greatest recorded drought, during 1790 to 1796 A.D. of the last millennium. The 20th century increase in anthropogenic activity in India and Nepal, upwind from this site, is recorded by a doubling of chloride concentrations and a fourfold increase in dust. Like other ice cores from the Tibetan Plateau, Dasuopu suggests a large-scale, plateau-wide 20th-century warming trend that appears to be amplified at higher elevations.

The work of ***Pal and Al-Tabbaa (2009)*** provided the pattern of long-term changes and variability of monthly extreme temperatures in India. This study investigated the long-term trends and variations of the monthly maximum and minimum temperatures and their effects on seasonal fluctuations in various climatological regions in India. The results showed that the monthly maximum temperature increased, though unevenly, over the last century. Minimum temperature changes were more variable than maximum temperature changes, both temporally and spatially, with results of lesser significance.

1.3 Objectives

The **objectives** of the study are follows;

- To analyse the temporal variations in temperature and rainfall during the study period with available data and using moving average, NADM and simple average method.
- Recording seasonal-spatial variations in temperature and rainfall by dividing the meteorological data in IMD guide lined 4 seasons of the country as Winter (January-February), Pre-Monsoon (March-May) Summer, Monsoon (June-September) and Post-Monsoon (October-December) and using CV method.

- Trend analysis of temperature and rainfall using simple linear regression method and graphical representation (best fit-line method).
- Measurement of seasonal variation in climatic extremes i.e. highest maximum and lowest minimum temperature and highest rainfall along with variation in no. of rainy days.
- Comparison between climatic variations of Central-Western Himalaya and Western Rajasthan (*Shimla and Dehra Doon; Jodhpur and Bikaner).*

1.4 Aim of the study

- The **aim** of the study is to detect any major variation recorded in the climate of the region during the study period (1901-2000).

1.5 Data Base

In this study mainly instrumental data like temperature (in ^{0}C) and rainfall (in mm) are used. The sources of data are follows;

- **National Data Centre (NDC), IMD, Pune** provided monthly data for
  (1) Mean Maximum Temperature (MMAX),
  (2) Highest Maximum Temperature (HMAX),
  (3) Mean Minimum Temperature (MMIN),
  (4) Lowest Minimum Temperature (LMIN),
  (5) Total Monthly Rainfall (TMRF),
  (6) Highest Monthly Rainfall (HMRF),
  (7) No. of Rainy Days (RD)
  (8) Mean Monthly temperature (MMT), calculated by taking average of the mean monthly maximum and mean monthly minimum temperature.
- Data acquired from the literature itself i.e. Parthasarathy et al., 1994, prepared a long homogeneous rainfall series of All-India for over 100 years.
- **Indian Institute of Tropical Meteorology (IITM), Pune** also provided some meteorological data (online free available) for temperature and rainfall.

- *Data Gaps;* meteorological data provided by NDC, Pune for seven meteorological stations were not regular. The data series were having small gaps. For the analysis, these gaps have to be filled up. So, we used the temporal interpolation method for the data filling.
- *IMD Classification of the Seasons in India;* Indian Meteorological Department divided the year in four seasons. These are given in Table 1.1;-

Table 1.1 IMD Classification of Seasons in India

Season	Months
Winter	January-Fabruary
Pre-Monsoon	March-May
Monsoon	June-September
Post-Monsoon	October-December

1.6 Methodology

- **Temporal Interpolation**

Temporal interpolation method used for filling the missing data in the series. Monthly value was computed as an average of the same month for a period between ± 3 years (Mitchell et al. 1966).

- **The Moving Average**

The moving average method is widely applied to study trends in temperature and rainfall data of a long period of time. This method smoothed out fluctuations in the curves that can be plotted on either a three, a five or ten year bases (Monkhoùse and Milkenson 2003). In the study, moving average calculated for every five years.

- **Normalized Accumulated Departure from Mean (NADM)**

The normalized accumulated departure from mean (NADM) is a suitable method to analyze the temporal fluctuations and trends in temperature and rainfall. NADM permits visual as well as statistical comparison of unlike data periods characterized by above average (below average) conditions are indicated by positive (negative) slopes of the graph. The NADM permits the distinction between periods of high and low values by clearly defining the limits.

NADM = (X-Xm)/ largest number in X-Xm series

Where, X = rainfall/temperature data series

Xm = mean of rainfall/temperature data series

- **The Simple Average**

Simple average method facilitate the comparison of two climatic or base line periods and identify the variation occurred in the second period over the first one. The calculated simple average of climatic data (divided into 30 years base line period) suggests about the seasonal and temporal variation in rainfall and temperature.

- **Simple Linear Regression analysis**

The simple linear regression method was used for the trend analysis and for visual representation of climatic element the best-fit line was used. Both the techniques were applied with the help of Microsoft Excel workbook to determine the nature of trends i.e. whether positive or negative. The b-values were calculated while putting the time series data (years) as the independent variable and climatic data (temperature, rainfall etc.) as the dependent variable. The b-value in a simple linear regression model represents the slope of the regression line which explicitly indicates trend in the dependent data series. The equation for the slope of the regression line is:

$$b = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2}$$

Where, x and y are independent and dependent (in Y on X regression line i.e., y = a + bx) variables respectively.

- **F-test statistical logistics**

The results of trend analysis were scrutinized with the help of F-test. The confidence levels derived with the help of F-test, determined whether a trend is a significant or insignificant. F-test was applied with the help of SPSS computer application.

- **Line; Graphical Representation**

The seasonal-spatial variation analysis using moving average, NADM and simple average method provides many important results which were visualized using line graphs which depicts long term trend in rainfall and temperature regimes.

- **Coefficient of Variation**

Coefficient of variation is one of the best statistical method to calculate the spatial variability and it also provides data to analyze variability of two or more stations. The high value of CV implies high inconsistency or low consistency in time series data while a low value of CV indicates high consistency in data records.

- **ArcGIS application**

The study area map and other maps depicting the physical and cultural characteristics of the study area were prepared using ArcGIS computer based application package for geographical study.

- **Global Mapper**

The relief profiles, with transverse and longitudinal dimensions, and the Digital Elevation Modal (DEM) of the Central-Western Himalaya were prepared with the help of Global Mapper, a mapping application.

1.7 Chapterisation Scheme

Chapter 1: **Introduction to the study**

A brief Introduction of the study with stating its relative importance and need based on a comprehensive literature review. Aims and Objectives of the study determined after reviewing the literature. Information about the source of data procurement is given under the head of Data base. A detailed presentation of the methods and applications used in the study, given under the sub-head of Methodology. A detailed Chapterisation scheme placed which followed by the description of the limitations faced during the study.

Chapter 2: **Introduction to the study area**

A brief Introduction of the study area, the Central-Western Himalaya, was represented in this chapter. The Geology, Physiography, Drainage system, Climate, Vegetation and demographic characteristics of the CWH region were described with appropriate maps.

Chapter 3: **Temporal and seasonal climatic variation in Central-Western Himalaya**

The seasonal-temporal climatic variation analysis for rainfall and temperature was carried out using simple and moving average and normalized accumulated departure from mean methods. The calculation of seasonal variability in temperature and rainfall records was the main purpose of this chapter.

Chapter 4: **Trend analysis of temperature and rainfall for Central-Western Himalaya**

Analysis of trends in temperature and rainfall records in the CWH region using simple linear regression method and these trends were visualized by the best-fit lines. The main objective of this chapter is to mark significant trend in the time series data of the region.

Chapter 5: **Case study of comparison in climatic variation of the Central-Western Himalaya and the Western Rajasthan**

This chapter incorporates the relative comparison analysis of climatic variables i.e temperature and rainfall of two physiographically different regions viz. the Central-Western

Himalaya and the Western Rajasthan. this case study includes comparison of seasonal variations using simple average method, comparison of spatial variation using coefficient of variation method and comparison of trends using simple linear regression and best-fit line graphical method.

Chapter 6: **Summary and Conclusion**

A concise summary of the study with concluding remarks, stating major findings of the study is incorporated in this chapter.

1.8 Limitations of the study

During the persuasions of this study some limitations were faced by, these are as follows;-

- **Lack of long-term data;** except two meteorological stations, Shimla (92 years) and Dehra Doon (73 years), no other station has data for more than 40 years of period. This limited the study as the simple average method for 30 years base line periods (for each station, as anticipated earlier) was used only for Shimla and Dehra Doon.

- **All the data are not contemporary to each-other;** data provided by NDC, Pune for the stations are not belongs to the same time period i.e. Shimla (1901-1992), Dehra Doon (1928-2000), Dharamshala (1951-1998), Manali (1968-2000) etc.

- **Data gaps;** data for Dehra Doon meteorological station was provided for the period of 1901-2000, but there was a huge data gap of 15 years from 1913 to 1927 in the data series. This huge data gap could not be filled with the temporal interpolation method, as the interval was much larger. In that case, we opted not to use the data for the period of 1901-1912 in the study and all the analysis was carried out with the data range of 1928-2000 for Dehra Doon.

Chapter Two

Introduction to the study area

2.1 Introduction

The Central-Western Himalaya is a part of the 2400 km long Himalayan mountain system. The whole Himalayan system can be divided in three parts i.e. Western Himalaya including Jammu and Kashmir and Himachal Pradesh, Central Himalaya including Uttarakhand and the last Eastern Himalaya including the state of Sikkim and Arunachal Pradesh. In this study the area of interest, the Central-Western Himalaya, lies in the states of Himachal Pradesh and Uttarakhand.

Himachal Pradesh is spread over 55,673 km^2 and is bordered by the Indian states of Jammu and Kashmir on the north, Punjab on the west and south-west, Haryana and Uttar Pradesh on the south, Uttarakhand on the south-east and by the Tibet Autonomous Region on the east. The literal meaning of Himachal Pradesh is '*Region of snowy mountains.*' Four meteorological stations namely, Bilaspur, Dharamshala, Manali and Shimla were included in the study. Table 2.1 giving the basic information about the meteorological stations included in this study. The elevation range of the meteorological stations varies from 670 m to 2397 m.

Table 2.1 Details of meteorological stations included in the study

Serial No.	Meteorological Station	Height (m)	Lat/Long	Data span	Data Availability (Years)
1	Bilaspur	670	31^0 33' N / 76^0 75' E	1956-1993	37
2	Dharamshala	1457	32^0 22' N / 76^0 32' E	1951-1998	47
3	Manali	1950	32^0 27' N / 77^0 17' E	1968-2000	32
4	Shimla	2397	31^0 06' N / 77^0 10' E	1901-1992	92
5	Dehra Doon	640	30^0 32' N / 78^0 03' E	1928-2000	73
6	Joshimath (Chamoli)	960	30^0 42' N / 79^0 33' E	1959-1987	28
7	Nainital	1938	29^0 38' N / 79^0 45' E	1953-1979	26
8	Tehri Garhwal	1750	30^0 38' N / 78^0 48' E	1957-1983	26

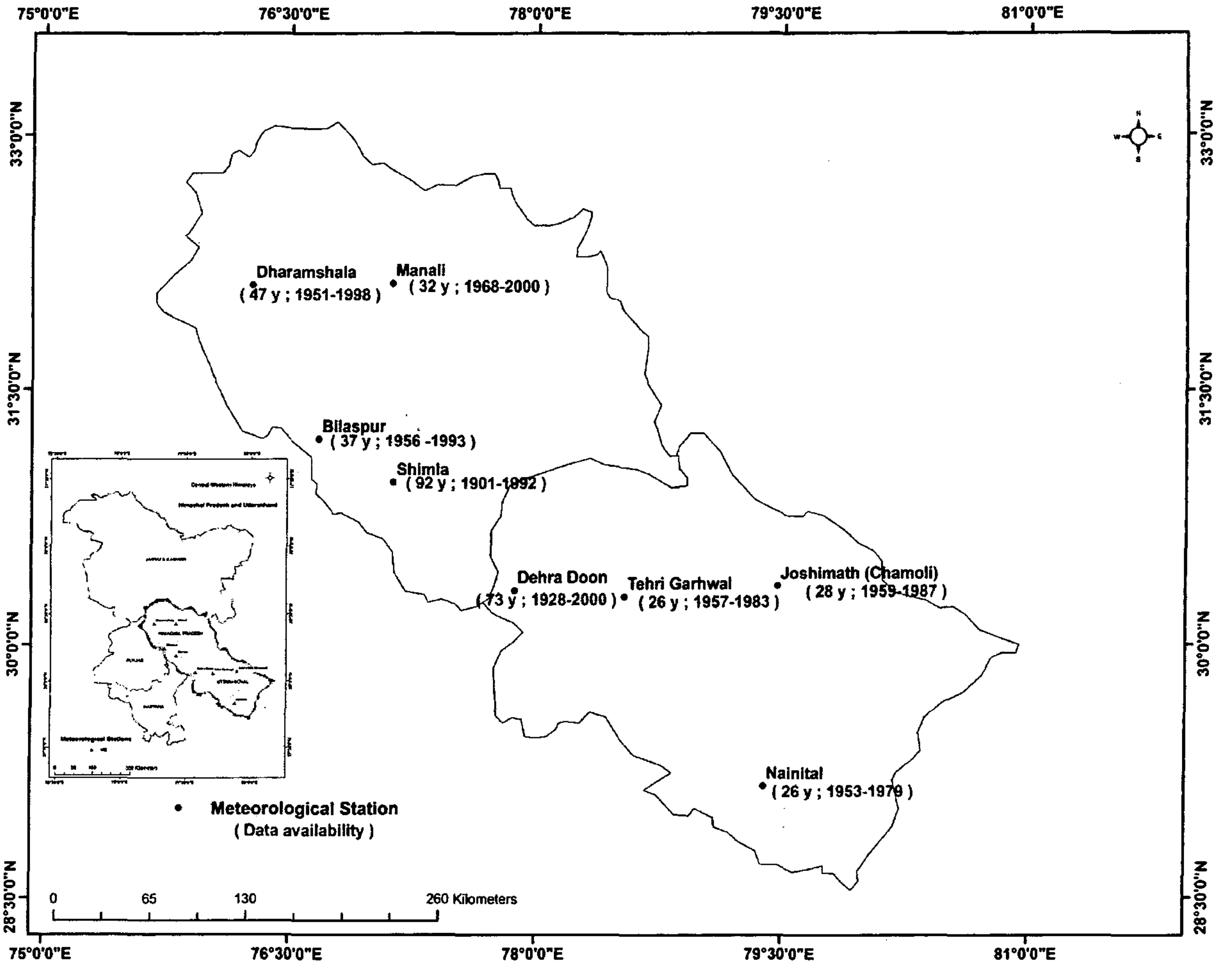


Figure 2.1 Location map of the Central-Western Himalaya.

Uttarakhand is a hilly state, adjoining of Himachal Pradesh. Uttarakhand has a total geographic area of 51,125 km^2, of which 93 per cent is mountainous and 64 per cent is covered by forest. Most of the northern parts of the state are part of Greater Himalaya ranges, covered by the high Himalayan peaks and glaciers, while the lower foothills are densely forested.

2.2 Physiography

Himachal Pradesh is a mountainous state. Elevation ranges from 450 meters to 6,500 meters (amsl). The state extends from the Shivalik range of mountains in the south to the Greater Himalayas in the north. There is a noticeable increase in elevation from west to east and from south to north. The general physiographic divisions from south to north are:

1. The Shivaliks

2. The lesser Himalayas

3. The Great Himalayas

The Shivalik range consists of lower hills (mean elevation — 600 m above sea level). The hills of the region are composed of highly unconsolidated deposits which face a high rate of erosion and deforestation.

The lesser Himalayas are spotted by a gradual increase in elevation towards the Dhauladhar and the Pir Panjal ranges. The rise is more rapid in the Shimla hills, to the south of which is the high peak of church — Chandni (3647 m). North of the river Sutlej, the rise is steady. The Kangra valley is a longitudinal trough which is at the foot of the Dhauladhar range. Dhauladhar has a mean elevation of nearly 4,550 m. It has a rapid rise of 3,600 m above the Kangra valley.

The Pir Panjal, the highest and largest of lesser Himalaya bifurcates from the Greater Himalayan range near the bank of the Sutlej. A number of glaciers exist and several passes lie across the Pir Panjal. The Rohtang Pass (4,800 m) is one of these. The Great Himalayan range (5,000 to 6,000 m) runs along the eastern boundary and is slashed across by the Sutlej. Some of the famous passes in this range are Kangla (5,248 m), Bara Lacha (4,512 m), Parang (5,548 m) and Pin Parbati (4,802 m).

The Zanskar Range, the easternmost range, separates Kinnaur and Spiti from Tibet. It has peaks rising over an elevation up to 6,500 m. Some of the well-known peaks are Shilla (7,026 m) and Riwo Phargyul (6,791 m); these are among the highest peaks in this range. There are many glaciers over the Zaskar and the Great Himalayan ranges.

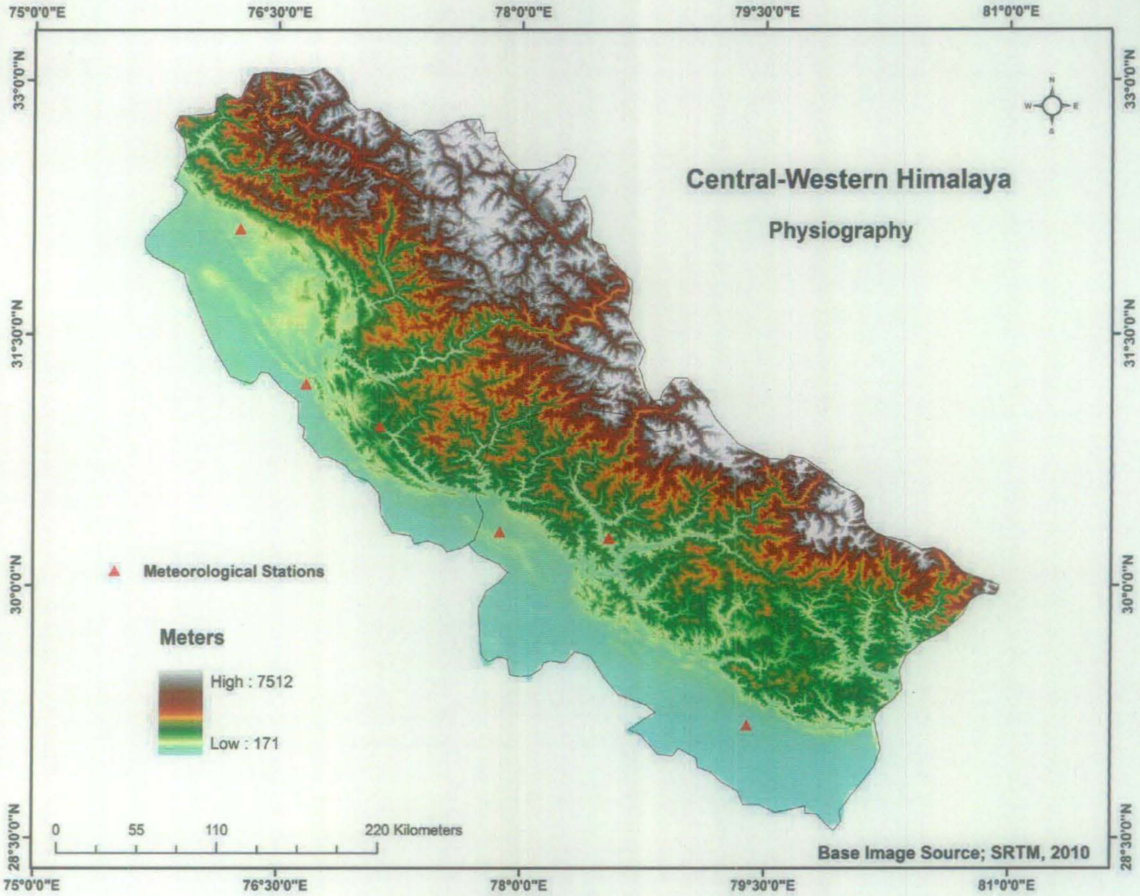


Figure 2.2 Physiography of the Central-Western Himalaya.

The unique Himalayan ecosystem plays host to a large number of animals (including bharal, snow leopards, leopards and tigers), plants and rare herbs. Two of India's mightiest rivers, the Ganges and the Yamuna are sourced from the glaciers of Uttarakhand, and are fed by glacial lakes, glacial melts and streams in the region. Figure 2.2 denotes the Physiography of the study area. South to north, elevation jumps rapidly and the extreme north is covered with the snowy peaks. The relief profiles of the region are shown in the figure 2.3 with transverse and longitudinal dimensions. These profiles and the Digital Elevation Modal (DEM) were prepared with the help of Global Mapper, a mapping application. Three profiles AB, CD and EF are showing the great undulating topography of the Central-Western Himalaya.

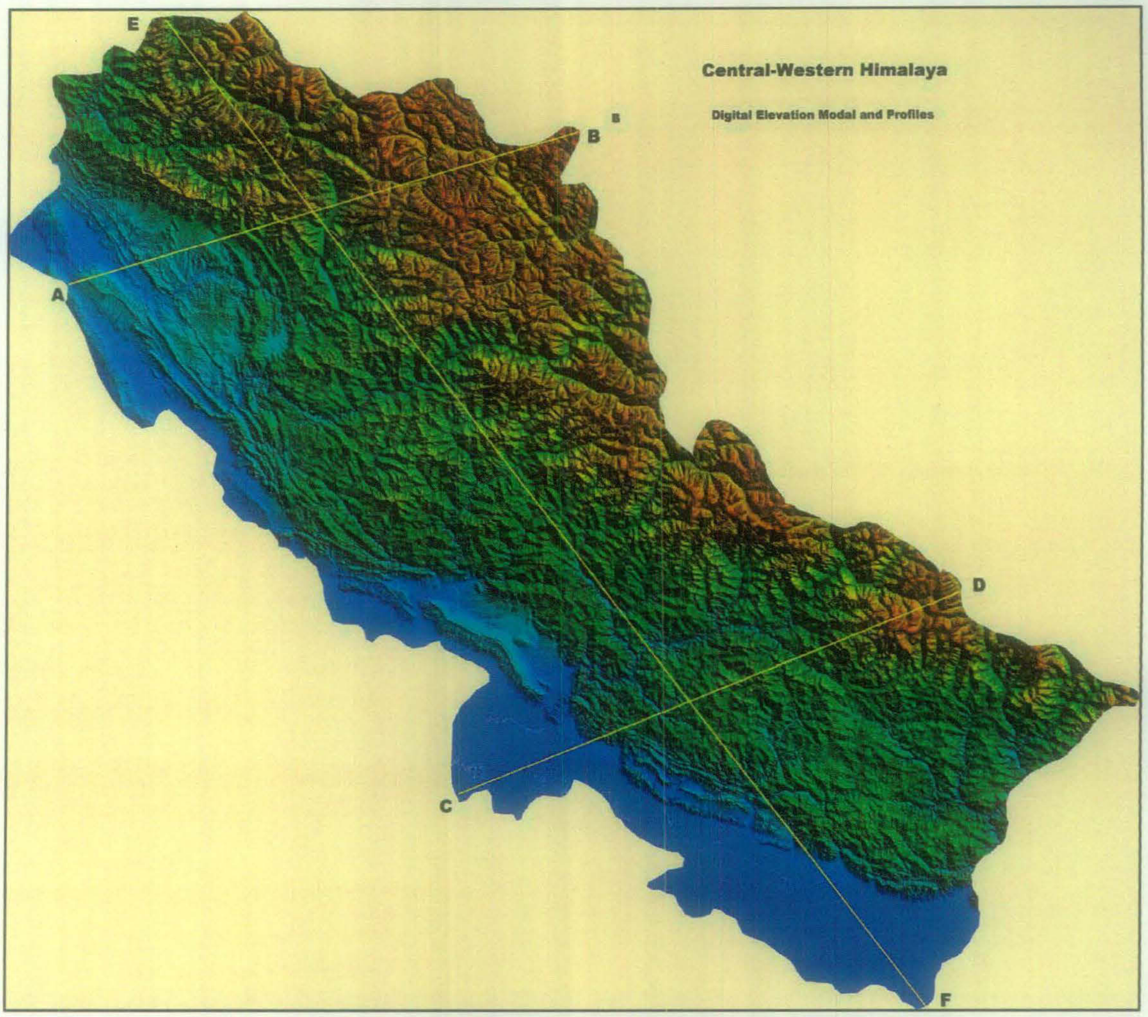
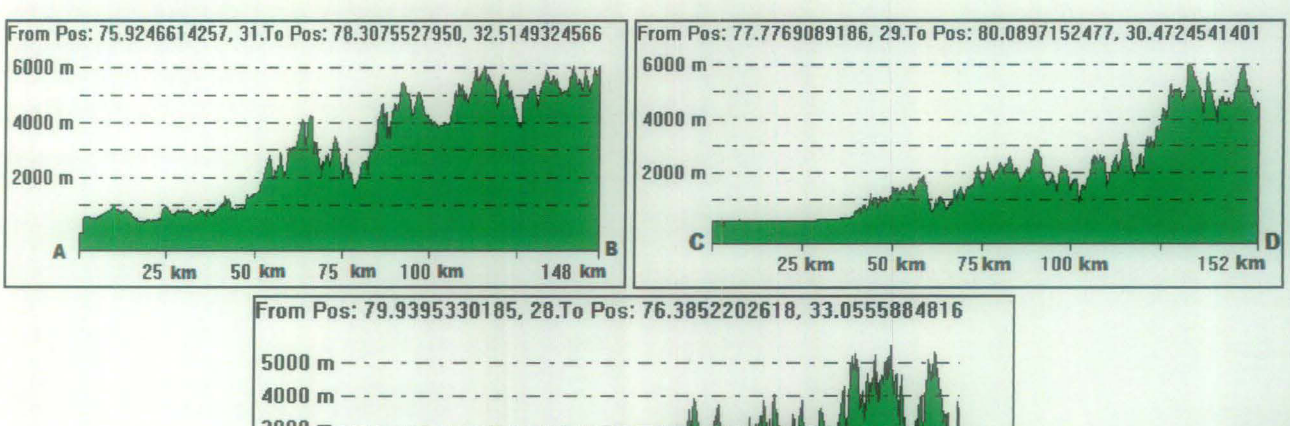


Figure 2.3 DEM and Relief Profiles of the Central-Western Himalaya; with the help of Global Mapper application.

Base Image Source; SRTM 2010



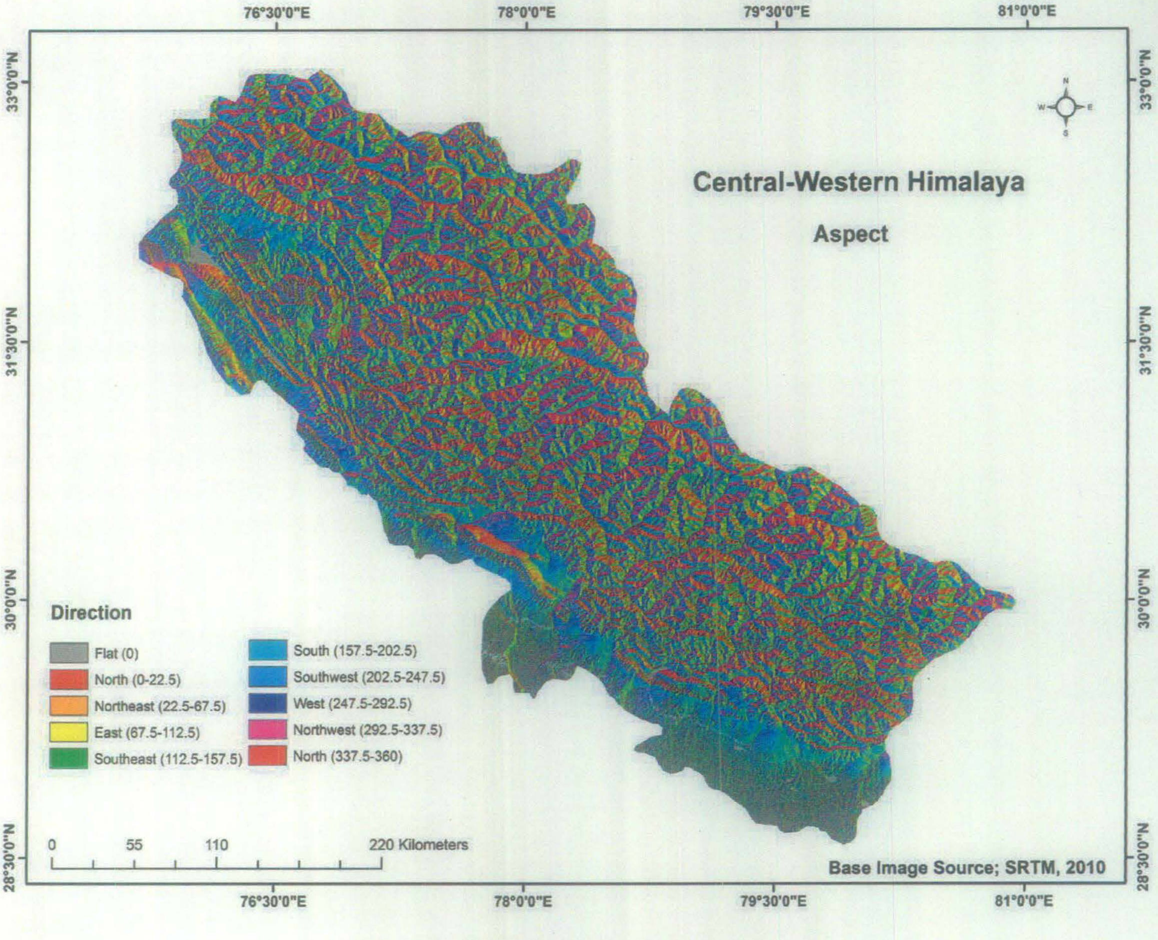


Figure 2.4 Aspect Map of the Central-Western Himalaya.

2.3 Geology and Tectonic Settings

The Himalayan mountain system is one of the youngest folded mountain systems with the continuous upliftment of the mountains. Tectonic activities are very common and regular to this part of the world. Due to the sequential convergent of Indo-Australian plate and Eurasian plate, some thrust zones developed and along these thrust zones most of the tectonic upheavals occur. Indus-Tsangpo Suture Zone (ITSZ), Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Fault (HFF) are major thrust planes along with earthquakes occur. These thrust zones play important role in the landform evolution and drainage system of the region. Figure 2.5 denotes the major tectonic thrust zones of the Himalayas and the relative locations of the meteorological stations included in the study.

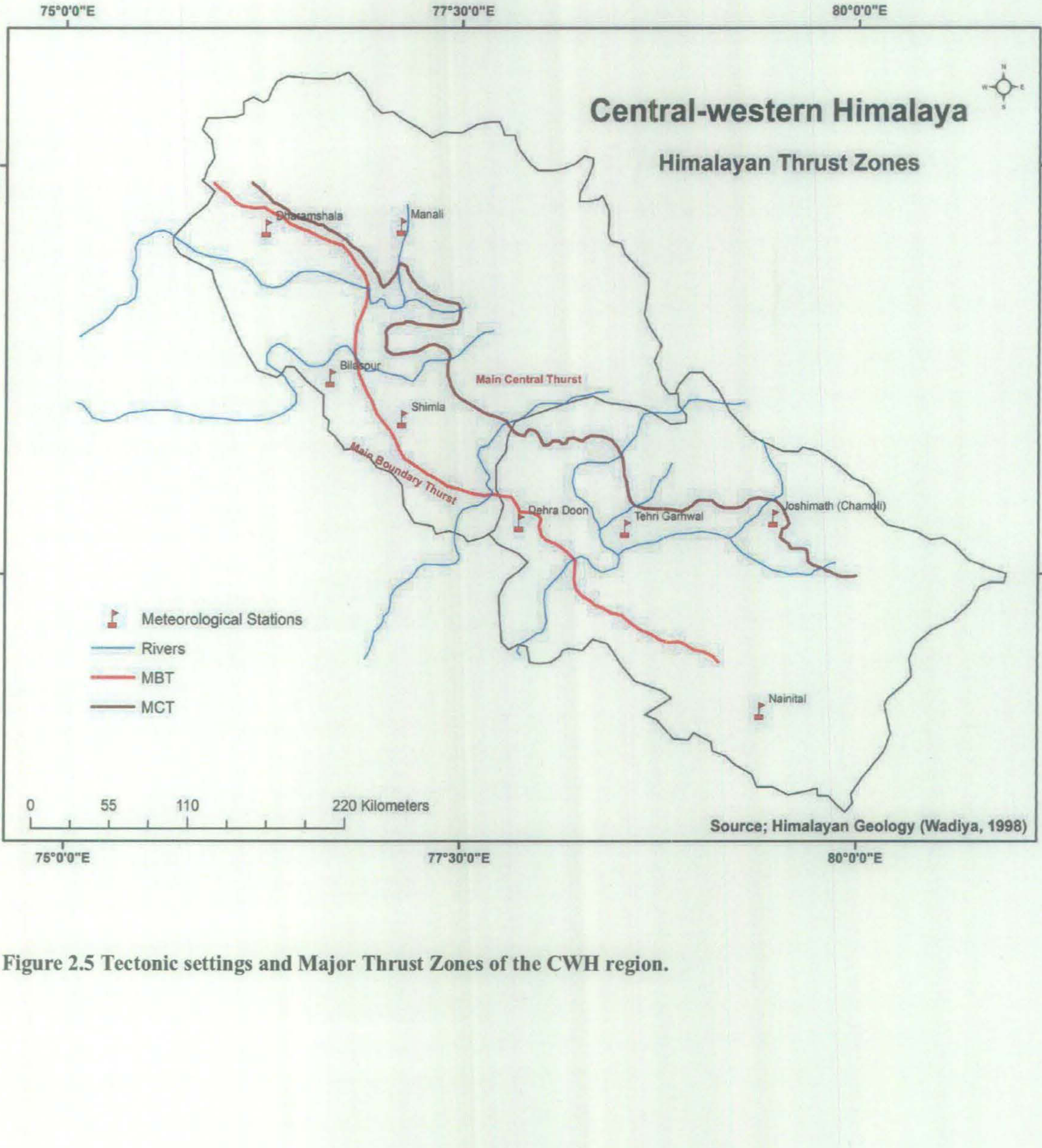


Figure 2.5 Tectonic settings and Major Thrust Zones of the CWH region.

2.4 Drainage

The drainage system of Himachal is composed both of rivers and glaciers. Himalayan rivers criss-cross the entire mountain system. In fact rivers the Indus, the Ganges, the Brahmaputra etc. are older than the mountain system. These antecedent rivers run transverse the mountain ranges. Himachal Pradesh provides water to both the Indus and Ganges basins. The drainage systems of the region are the Chandra-Bhaga or the Chenab, the Ravi, the Beas, the Sutlej and the Yamuna. These rivers are perennial and are fed by snow and rainfall. They are protected by an extensive cover of natural vegetation. Two of India's mightiest rivers, the Ganges and the Yamuna take birth in the glaciers of Uttarakhand. Because of the folded mountain system, trellised drainage pattern is much common then the other drainage patterns.

2.5 Climate

There is great variation in the climatic conditions of Himachal due to extreme variation in elevation. The climate varies from hot and sub-humid tropical in the southern tracts to cold, alpine and glacial in the northern and eastern mountain ranges with high elevation. The state has areas like Dharamshala that receive very heavy rainfall, as well as those like Lahaul and Spiti that are cold and almost rainless. Broadly Himachal experience three seasons; hot summer season, cold winter season and rainy season. Summer lasts from mid April till the end of June. During summer most of the parts become very hot (except in alpine zone which experience mild summer) with the average temperature ranging from 28 °C to 32 °C. Winter lasts from late November till mid March. Snowfall is common in alpine tracts (generally above 2200 m i.e. in the Higher and Trans-Himalayan region). During the season streams and natural springs are replenished. The heavy rains in July and August cause a lot of damage resulting into high erosion, catastrophic floods and landslides. Spiti is the driest area of the state with rainfall below 50mm. The reason is that it is enclosed by high mountains on all sides. Uttarakhand lies on the southern slope of the Himalayan ranges. There is altitudinal change in climate and vegetation regime where tops are covered by glaciers and subtropical forest at lower elevation.

Table 2.2 Characteristics of climate and vegetation of the Central-Western Himalaya

Particulars and Characteristics	Shivalik Zone	Mid-Hill Zone	High hill zone	Trance-Himalayan Zone
Altitude	Up to 800 m	800m-1,600m	1,600m-2,700m	2,700m-3,600m
Type of area	Valley areas and foothills	Hilly and mountain ranges	Alpine zone	Lahaul Spiti and Kinnaur range
Climatic conditions	Sub tropical	Slightly warm temperature	Cool temperature with humidity	Dry and extremely cold conditions
Rainfall in mm.	1,500	1,500-3000	1,000-1,500	500
% of total geographical area	30%	10%	25%	35%
% of total cultivated area	55%	30%	10%	5%

The climate in the northern part of Uttarakhand is typically Alpine. The high mountain ranges exert an appreciable extent of influence on monsoon and rainfall patterns. Within the Himalayas, climate differs depending on altitude and position. Climate ranges from subtropical in the southern foothills, averaging summer temperatures of about 30° C and winter temperatures of about 18° C. Warm temperate conditions prevail in the Middle Himalayan valleys, with summer temperatures usually hovering about the mark of 25° C and cooler winters. Cool temperate conditions dominate the higher areas of the Middle Himalayas, where the summer temperatures are usually around 15 to 18° C and winters drop below the freezing point. At altitudes over 4880 m the climate is bitterly cold with temperatures consistently below the freezing point and the area permanently shrouded in snow and ice. The eastern flanks of the Himalayan ranges are subject to heavy rainfall while the western section is relatively dry. Uttarakhand is characterized by two types of climate, sharply differentiated in the plains and the mountainous regions.

2.6 Vegetation

According to 2003 Forest Survey of India report, legally defined forest areas constitutes 66.52 per cent of the area of Himachal Pradesh, although area under tree cover is only 25.78 per cent. Vegetation in the state is dictated by elevation and precipitation. The southern part of the state, which is at the lowest elevations, has both tropical and subtropical dry broadleaf forests and tropical and subtropical moist broadleaf forests. These are represented by northwestern thorn scrub forests along the border with Haryana and Uttar Pradesh and by Upper Gangetic Plains, moist deciduous forests in the far southeast. Sal and shisham are found here. Rising into the hills, we find a mosaic of Western Himalayan broadleaf forests and Himalayan subtropical pine forests. Various deciduous and evergreen oaks in the broadleaf forests and Chir pine dominate the pine forests. Western Himalayan sub-alpine conifer forests grow near tree-line, with species that include East Himalayan Fir, West Himalayan Spruce, Deodar (State tree), and Blue pine.

In the uppermost elevations we find Western Himalayan alpine shrub and meadows in the northeast and northwestern Himalayan alpine shrub and meadows in the northwest. Trees are sturdy with a vast network of roots. Alders, birches, rhododendrons and moist alpine shrubs are there as the regional vegetation. The rhododendrons can be seen along the hillsides around Shimla from March to May. The shrub lands and meadows give way to rock and ice along the highest peaks.

Himachal is also said to be the fruit bowl of the country with orchards scattered all over the place. Meadows and pastures are also seen clinging to steep slopes. After the winter season, the hillsides and orchards bloom with wild flowers, while gladiolas, carnations, marigolds, roses, chrysanthemums, tulips and lilies are carefully cultivated. The state government is gearing up to make Himachal Pradesh as the flower basket of the world.

Uttarakhand lies on the southern slope of the Himalaya range, and the climate and vegetation vary greatly with elevation, from glaciers at the highest elevations to subtropical forests at the lower elevations. The highest elevations are covered by ice and bare rock. Below them, between 3000 and 5000 m is montane grasslands and shrub lands: the western Himalayan alpine shrub and meadows.

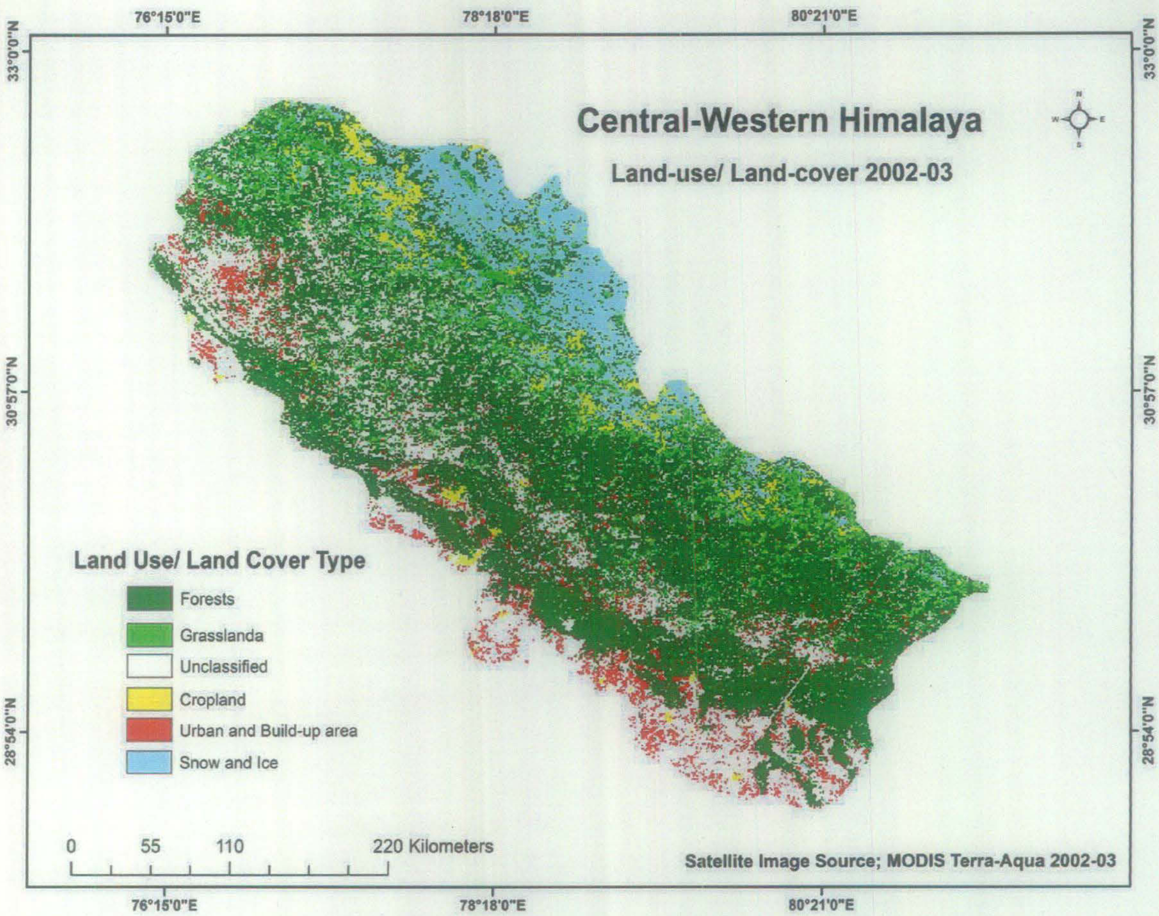


Figure 2.6 Land use/ Land cover classification 2002-03.

Temperate coniferous forests, the western Himalayan subalpine conifer forests, grow just below the tree line. At 3000 to 2600 m elevation they transition to the temperate western Himalayan broadleaf forests, which lie in a belt from 2600 to 1500 m elevation. Below 1500 m elevation lie the Himalayan subtropical pine forests. The Upper Gangetic Plains moist deciduous forests and the drier Terai-Duar savanna and grasslands cover the lowlands along the Uttar Pradesh border. This belt is locally known as Bhabhar. These lowland forests have mostly been cleared for agriculture, but a few pockets remain.

2.7 Demography

The population of Himachal Pradesh in 2001 stood at 6,077,900. The population of the State rose by 17.53 per cent between 1991 and 2001. The sex ratio was recorded as 970, which has declined from 976 in the previous census. Total literacy of the State rose to 77.13 per cent from 63.94 per cent in 1991. Himachal Pradesh has a Total Fertility Rate of 1.9, one of the lowest in India, and below the TFR, of 2.1, required to maintain a stable population. The life expectancy at birth in Himachal Pradesh is 62.8 years (higher than the national average of 57.7 years) for the period 1986–1990. The Infant Mortality Rate stood at 62 in 1999 and Crude Birth Rate has declined from 37.3 in 1971 to 22.6 in 1998, below the national average of 26.5 in 1998. The Crude Death Rate was 7.7 in 1998. Himachal Pradesh's literacy rate grew by 34.65 per cent between the period 1981 and 2001. The major spoken languages include Hindi, Punjabi, Mahasui, Kulluyi, Lahauli, Kinnauri, Chambyali, Sirmauri, Gojri (by Gujjars), Bilaspuri, Pahari, Dogri, and Kangri.

According to 2001 India census, Uttarakhand had a population of approximately 8.48 million. A population exceeding 10 million is expected by the next census of 2011. The native people of Uttarakhand are generally called either Kumaoni or Garhwali depending on their place of origin in either the Garhwal or Kumaon region. Kumaoni and Garhwali dialects of Central Pahari are spoken in Kumaon and Garhwal region respectively. Jaunsari and Bhotiya dialects are also spoken by tribal communities in the west and north respectively. The urban population however converses mostly in Hindi. Hindus form the majority of the population at 85.0%, Muslim form 10.5 per cent, Sikhs 2.5 per cent and Christians, Buddhists, Jains and others about 0.5 per cent. It has sex-ratio of 964 with literacy rate of 72 per cent. The big cities in the state include Dehra Doon (530,263), Haridwar (220,767), Haldwani (158,896), Roorkee (115,278) and Rudrapur (88,720). The state government recognizes 15,620 villages and 81 cities and urban centers.

Chapter Three

Temporal and Spatial Climatic Variability in The Central -Western Himalaya

3.1 Introduction

The high mountainous areas such as the Himalaya, Alps, Andes, Rockies etc. are ideal sites for the study of climate change. The wide range of altitudes in these regions amplifies variability in precipitation and temperature **(Liu and Chen 2000; Thompson et al., 2000).** Besides being the source of many rivers, the Himalaya provides a dominant control over the meteorological and hydrological conditions in the Indian sub-continent. Even a minor change in its climate has a potential to cause disastrous consequences on the socio-economic condition of millions of people inhabiting the Indo–Gangetic plain. The longer period of existence and large spatial extent of the Himalaya provide enormous opportunities for the climatic studies of the region. The Himalayas, which act as a mountain barrier on the earth where polar, tropical and Mediterranean influence interact, play an important role in maintaining and controlling the monsoon over Indian sub-continent. Main thrust of the current study is over the recent climatic conditions of the Himalaya and in this context study incorporated the instrumental data recorded at several meteorological stations located in the Central – Western Himalaya. The temporal-seasonal as well as spatial variability in the climatic parameters i.e. temperature, rainfall and rainy days were analyzed.

Variation analysis is divided in two parts;-

- Temporal-Seasonal Climatic Variation analysis based on,
    1. Moving Average method
    2. Normalized Accumulated Departure from Mean (NADM) method and
    3. Simple Average method.
- Spatial climatic variation analysis based on Coefficient of Variation (CV) method.

Also, on the basis of climatic parameters, the analysis is parted in two segments as,

1. Variation in temperature, rainfall and monthly rainy days.
2. Variation in extreme events such as highest maximum, lowest minimum and highest monthly rainfall.

3.2 Temporal-Seasonal Climatic Fluctuation analysis using Moving Average method

The accurate determination of trends of climate is dependent upon the availability of the reliable records over a long period of time. The moving average method is widely applied to study trends in temperature and rainfall data of a long period of time. This method smoothed out fluctuations in the curves that can be plotted on either a three, a five or ten year bases (**Monkhouse and Milkenson 2003**). In this study 5 year base is applied to calculate the moving average/ running means on the data series of selected meteorological stations located in the study area. Table 3.1 denotes the meteorological stations included with respective properties and data span. Some acronyms were used to show the seasons. These are explained in the Table 3.2.

Table 3.1 Details of meteorological stations included in the moving average analysis

Serial No.	Meteorological Station	Height (m)	Lat/Long	Data span	Data Availability (Years)
1	Bilaspur	670	31° 33' N / 76° 75' E	1956-1993	37
2	Dharamshala	1457	32° 22' N / 76° 32' E	1951-1998	47
3	Manali	1950	32° 27' N / 77° 17' E	1968-2000	32
4	Shimla	2397	31° 06' N / 77° 10' E	1901-1992	92
5	Dehra Doon	640	30° 32' N / 78° 03' E	1928-2000	73
6	Joshimath (Chamoli)	960	30° 42' N / 79° 33' E	1959-1987	28
7	Nainital	1938	29° 38' N / 79° 45' E	1953-1979	26
8	Tehri Garhwal	1750	30° 38' N / 78° 48' E	1957-1983	26

Table 3.2 Explanation for Acronyms

Symbol	Explanation	Months
MA W	Moving Average - Winter	Jan-Feb
MA PRM	Moving Average - Pre-Monsoon	March-May
MA M	Moving Average - Monsoon	June-Sep
MA POM	Moving Average - Post-Monsoon	Oct-Dec
MA A	Moving Average - Annual	

3.2.1 Trends in Mean Monthly Maximum Temperature

The seasonal variation in mean monthly maximum temperature of western and central Himalaya is depicted in Figure 3.1.

- **Winter Mean Maximum Temperature**

This indicates fluctuating nature in Western Himalaya. Bilaspur recorded increase in temperature during 1962-64 and 1985-86 while indicated decrease in 1986-90. Dharamshala recorded a sharp decrease in temperature during 1979-82 and 1993-96. Manali recorded few fluctuations in maximum temperature but Shimla experienced large variations in the temperature. From beginning, the station depicted rise in the temperature during 1908-1912 and 1964-66. There was a mild decrease in the temperature during 1982-84 but over-all increase in temperature was recorded at Shimla. The Central Himalaya depicted some identical and striking variation in maximum temperature. Both Dehra Doon and Joshimath identically showed decrease in temperature between 1982 and 1984. Such type of decrease in maximum temperature was not identical with other Central Himalayan meteorological stations due to non-availability of data for that period but the Western Himalayan meteorological stations reflected parallelism with this variation incident. However, winter temperature is showing increment over the periods but there was a decrease in the winter maximum temperature throughout the region during 1982-85.

- **Pre-Monsoon Mean Maximum Temperature**

This recorded decrease in temperature during 1982-84 in the entire region. Bilaspur, Dharamshala, Shimla, Dehra Doon and Joshimath recorded decline in pre-monsoon maximum temperature. But, Bilaspur and Shimla also experienced decline in temperature during 1962-66.

- **Monsoon Mean Maximum Temperature**

It didn't vary so much over the time. Shimla recorded decrease in temperature between 1910 and 1919 and again during 1973-75. Identical decrease in temperature depicted at Tehri between 1974 and 1975. Joshimath replicated the decreasing trend from 1982 to 1984.

- **Post-Monsoon Mean Maximum Temperature**

In Post-monsoon season variation in mean maximum temperature is similar to the winter. Dharamshala and Tehri specifically recorded decrease in temperature during 1973-81 and 1978-80, respectively.

- **Annual Mean Maximum Temperature**

It didn't experience so much variation in the region. Shimla recorded continuous increase in temperature while Dehra Doon, Joshimath, Nainital reflected decreasing trends.

Overall, mixed variations recorded for the maximum temperature in the study area. An increasing trend in winter temperature was observed at Shimla while the decreasing trend in annual mean maximum temperature recorded at Joshimath, Nainital and Dehra Doon.

3.2.2 Trends in Mean Monthly Minimum Temperature

The seasonal variation in mean monthly minimum temperature of western and central Himalaya is depicted in Figure 3.2.

- **Winter Mean Minimum Temperature**

Mean minimum temperature recorded high fluctuations at Shimla. An increase in temperature was recorded during 1907-13 while decrease during 1964-70 at the station. The thirty years period of 1960-90 recorded cyclic trends in the winter minimum temperature for the station. Dehra Doon experienced decrease in temperature during 1980-83. Tehri recorded continuous increase in temperature.

- **Pre-Monsoon Mean Minimum Temperature**

Bilaspur experienced decrease in temperature during 1960-62 and 1980-83 while increase during 1967-70. Dharamshala recorded decrease in minimum temperature during 1960-64. Sharp increase in temperature was recorded during 1919-21 while decrease during 1982-85 at Shimla. Dehra Doon experienced mild increase in temperature during 1946-53 while decrease during 1978-82. Joshimath recorded decrease in temperature during 1973-77.

- **Monsoon Mean Minimum Temperature**

Bilaspur recorded cyclic trend in monsoonal minimum temperature during 1960-68. An increase in temperature was recorded during 1959-64 and 1965-68 at the station. Dharamshala experienced decrease in temperature throughout the period. Manali experienced decrease in the temperature after 1998. Shimla recorded sharp decrease during 1964-70. Dehra Doon experienced decrease in temperature during 1960-64 and increase between 1985 and 1988.

- **Post-Monsoon Mean Minimum Temperature**

Manali experienced increase during 1973-83 and subsequent decrease in minimum temperature during 1984-88. Shimla recorded cyclic trends during 1940-55 and 1975-90. Dehra Doon recorded increase in minimum temperature during 1948-55 and decrease during 1980-84.

- **Annual Mean Minimum Temperature**

Shimla and Dehra Doon recorded cyclic trends in annual minimum temperature during 1960-90 and 1950-90 respectively.

Overall, the region recorded larger variations in the minimum temperature during the later-half of the last century. Cyclic trends in minimum temperature were recorded during 1940-55 and 1975-90 at all the meteorological stations.

3.2.3 Trends in Mean Monthly Temperature

The seasonal variation in mean monthly temperature of western and central Himalaya is depicted in Figure 3.3.

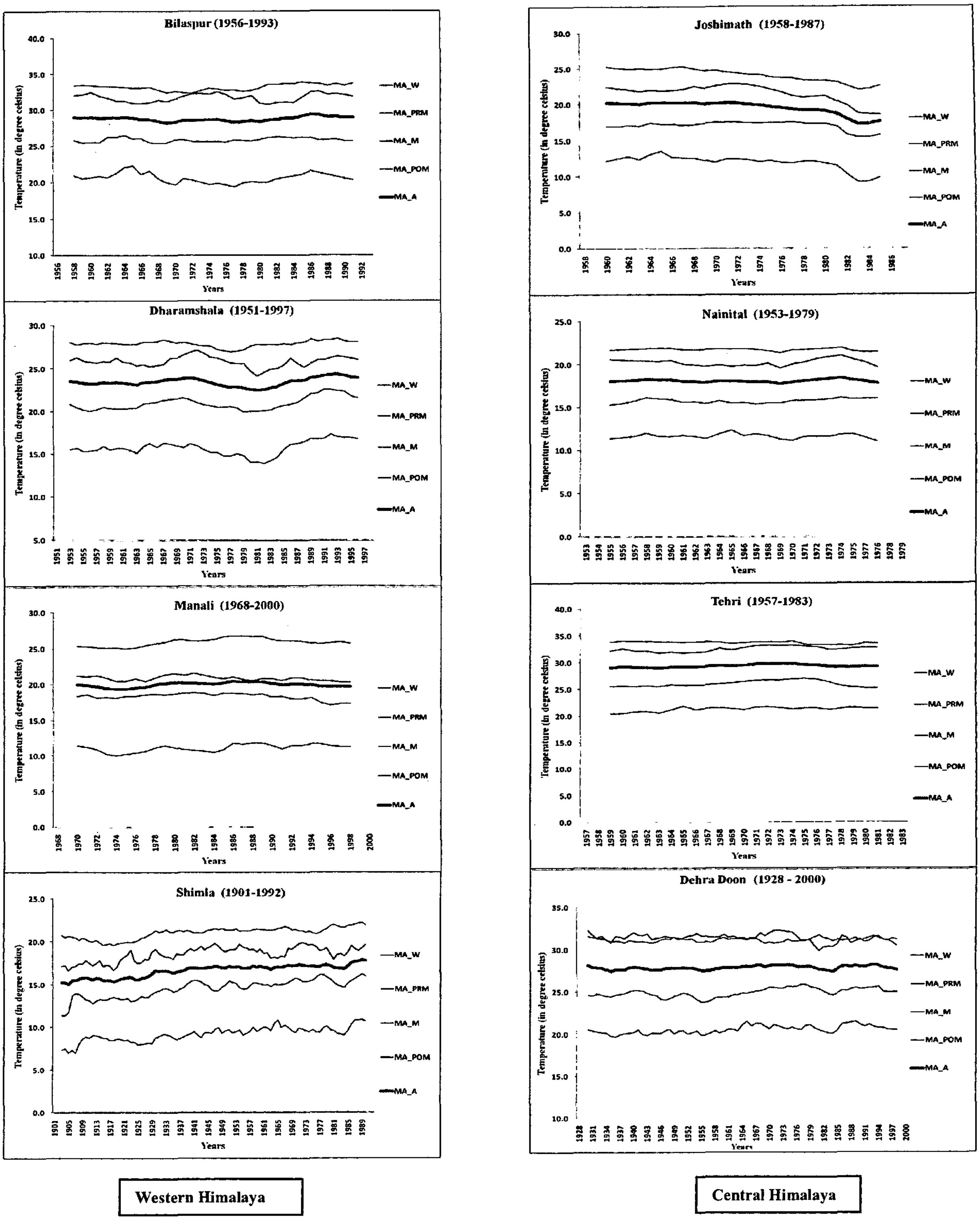
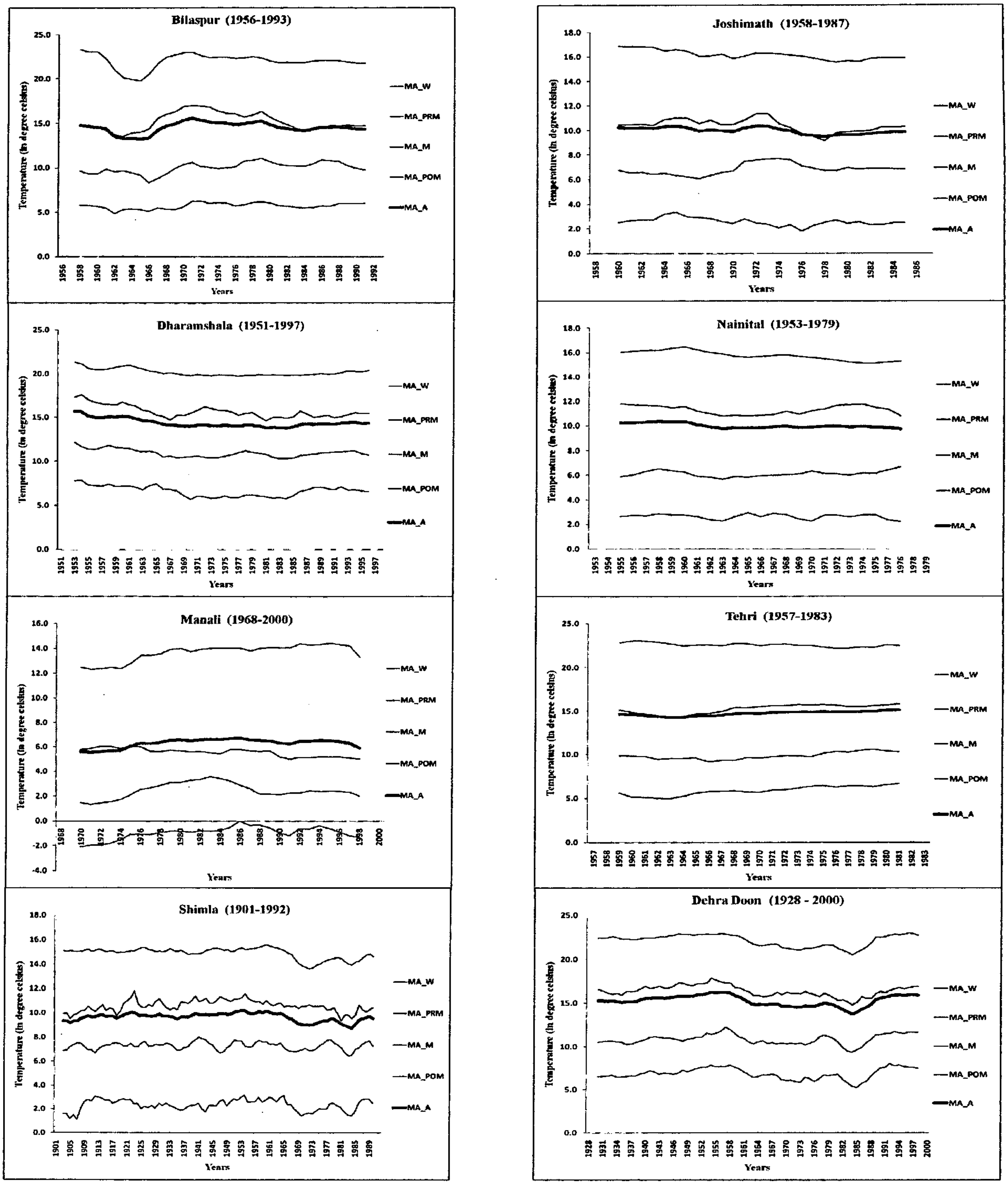


Figure 3.1: Seasonal fluctuations in mean monthly maximum temperature.

Source: National Data Centre, IMD, Pune



Western Himalaya

Central Himalaya

Figure 3.2: Seasonal fluctuations in mean monthly minimum temperature

Source: National Data Centre, IMD, Pune

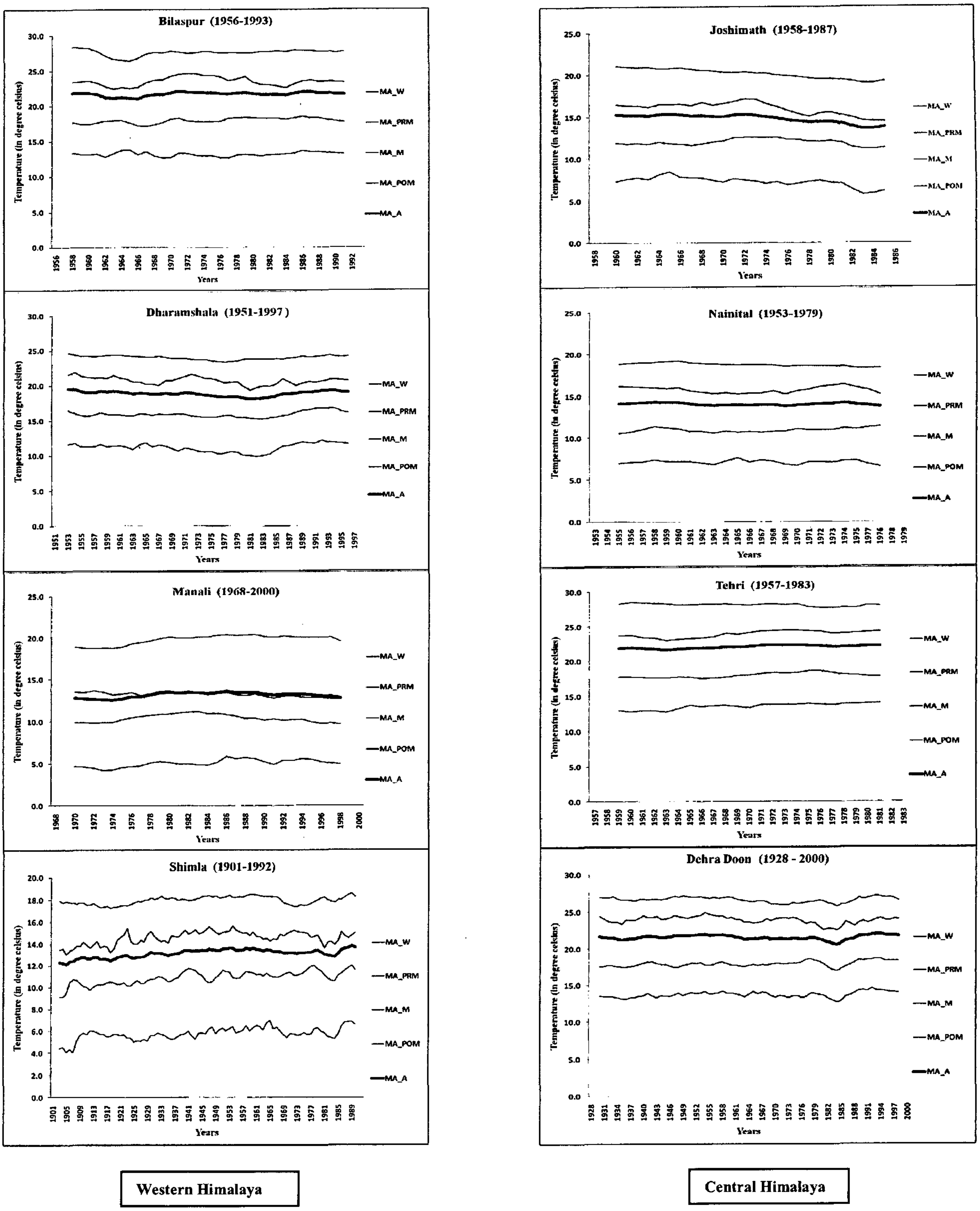


Figure 3.3: Seasonal fluctuations in mean monthly temperature.

Source: National Data Centre, IMD, Pune

- **Monsoon Mean Monthly Temperature**

The region experienced mild variations in monsoon mean monthly temperature. Manali experienced continuous increase in temperature from onward 1972-73. Shimla recorded greater cyclic trends in mean temperature during 1970-90. Joshimath recorded continuous decrease in mean temperature after 1975. The Central Himalaya recorded decrease in the monsoonal mean temperature.

- **Post-Monsoon Mean Monthly Temperature**

Manali recorded sharp increase in post monsoon mean monthly temperature after 1982. Shimla experienced cyclic trends during 1904-16, 1935-60 and 1975-90. Dehra Doon recorded decreasing trends during 1975-90. Tehri experienced sharp decline in the mean temperature after 1976.

- **Annual Mean Monthly Temperature**

Dharamshala recorded slight decline in temperature after 1980. Shimla recorded continuous increase in temperature till 1960 and after that it declined while the maximum decrease in temperature was observed from 1980 to 1985. A sharp decrease in temperature recorded at Dehra Doon during 1978-82 and increase followed that. Joshimath continued with its decreasing trends in temperature.

The last 30 years (1960-90) experienced cyclic fluctuations in the mean monthly temperature.

3.2.4 Trends in Total Monthly Rainfall

The Central and Western Himalaya receive more than 80 per cent of rainfall in monsoon season. The variations recorded in the amount of monthly rainfall are the consequent of many local physical factors and their interactions such as local topography, physical barrier to obstacle the monsoon etc. That's why variation in rainfall is more complex than variation in the temperature. Local factors affect the monsoonal rainfall at a large extent. Figure 3.4 showing the variation in the monthly rainfall regime of the region.

- **Winter Rainfall**

All the stations recorded cyclic trends in winter rainfall. Bilaspur recorded increasing trend in monthly rainfall during 1968-74 and Dharamshala during 1965-71. Manali experienced two peak times of the winter rainfall, one in 1976 and other in 1990. Shimla also recorded cyclic fluctuations during 1958-64. Dehra Doon experienced decreasing trends in rainfall during the last decade of the century. Joshimath and Nainital also recorded decrease in winter rainfall at the end part of their respective rainfall data series.

- **Pre-Monsoon Rainfall**

Cyclic fluctuations were recorded in the pre-monsoon rainfall at Bilaspur during 1980-86. Manali experienced cyclic trends in annual rainfall throughout the respective period. A sharp increase in rainfall was experienced at Manali After 1987. Shimla recorded fluctuations in rainfall during 1910-30 and 1980-90. Dehra Doon experienced cyclic trends in rainfall during 1980-2000. Joshimath recorded greater fluctuations in rainfall during 1975-87.

- **Monsoon Rainfall**

An overview of the figure 3.4 suggests that central Himalaya experienced continuous decline in the monsoon rainfall while western Himalaya experienced cyclic trends in rainfall. Bilaspur experienced peak time during 1970-72 and after that decline in rainfall experienced. Dharamshala had two peaks one in 1957-61 and another in 1976-78. Manali experienced downfall after 1976 and 1994. Shimla faced cyclic fluctuations during 1950-65. Dehra Doon recorded one peak time during 1934 but a sharp decrease in rainfall also during 1980. Joshimath also experienced decreasing trends in rainfall during 1966-67 and 1980-81. Nainital after 1974 and Tehri after 1976 experienced persistent decline in monsoon rainfall. Last 3 decades had experienced larger variations in monsoon rainfall in the region. The whole of the central Himalayan region and much of the western Himalayan region experienced sharp decline in monsoon rainfall, specifically, during 1970-80.

- **Post-Monsoon Rainfall**

Shimla experienced cyclic trends in post monsoon rainfall during 1940-60. Manali recorded a sharp decline in rainfall from 1993 to 1994. Dehra Doon recorded variations in post-monsoon rainfall during 1950-60 and again from 1980 to 2000. Joshimath experienced declining trend from 1958 but represented increase in rainfall after 1980. A continuous decline in rainfall was observed at Nainital.

- **Annual Rainfall**

A sharp decline in annual rainfall experienced at the central Himalaya. Bilaspur recorded cyclic trends in annual rainfall during 1964-78. Cyclic fluctuations in the annual rainfall were experienced at Dharamshala during 1955-80 and Shimla during 1958-64 and 1978-85. Manali faced two peak times of annual rainfall in 1976 and 1994. Dehra Doon recorded a sharp increase in annual rainfall after 1994. Declining trends in rainfall were experienced at Joshimath after 1976 and at Nainital after 1970.

This analysis revealed that central Himalaya experienced more fluctuations in rainfall than western Himalaya. The Central Himalayan stations recorded decrease in rainfall in almost every season while western Himalaya experienced cyclic fluctuations.

3.2.5 Trends in Monthly Rainy Days

Number of rainy days suggests about the wet spells of a year and also represents the intensity and performance of the monsoon. Figure 3.5 depicts trend in number of rainy days.

- **Rainy Days Winter**

A sharp increase in number of rainy days in winter was recorded at Bilaspur after 1970 and peak was recorded in 1973. Manali recorded decline in number of rainy days. Shimla recorded cyclic trends in number of rainy days during 1950-90. The year 1954 and 1965 marked with sharp decrease in number of rainy days for the station. On the other hand, Tehri recorded larger wet spells in 1974.

- **Rainy Days Pre-Monsoon**

The central Himalaya experienced increase in number of rainy days during pre-monsoon period. Tehri recorded increase in wet spells after 1974. Cyclic fluctuations in wet spells were recorded at Dehra Doon during 1980-2000 and at Bilaspur during 1978-88. Manali recorded decline in number of rainy days after 1982 while Shimla recorded increase in rainy days after 1980. Shimla experienced a sharp decreasing trend in wet spells during 1952-55.

- **Rainy Days Monsoon**

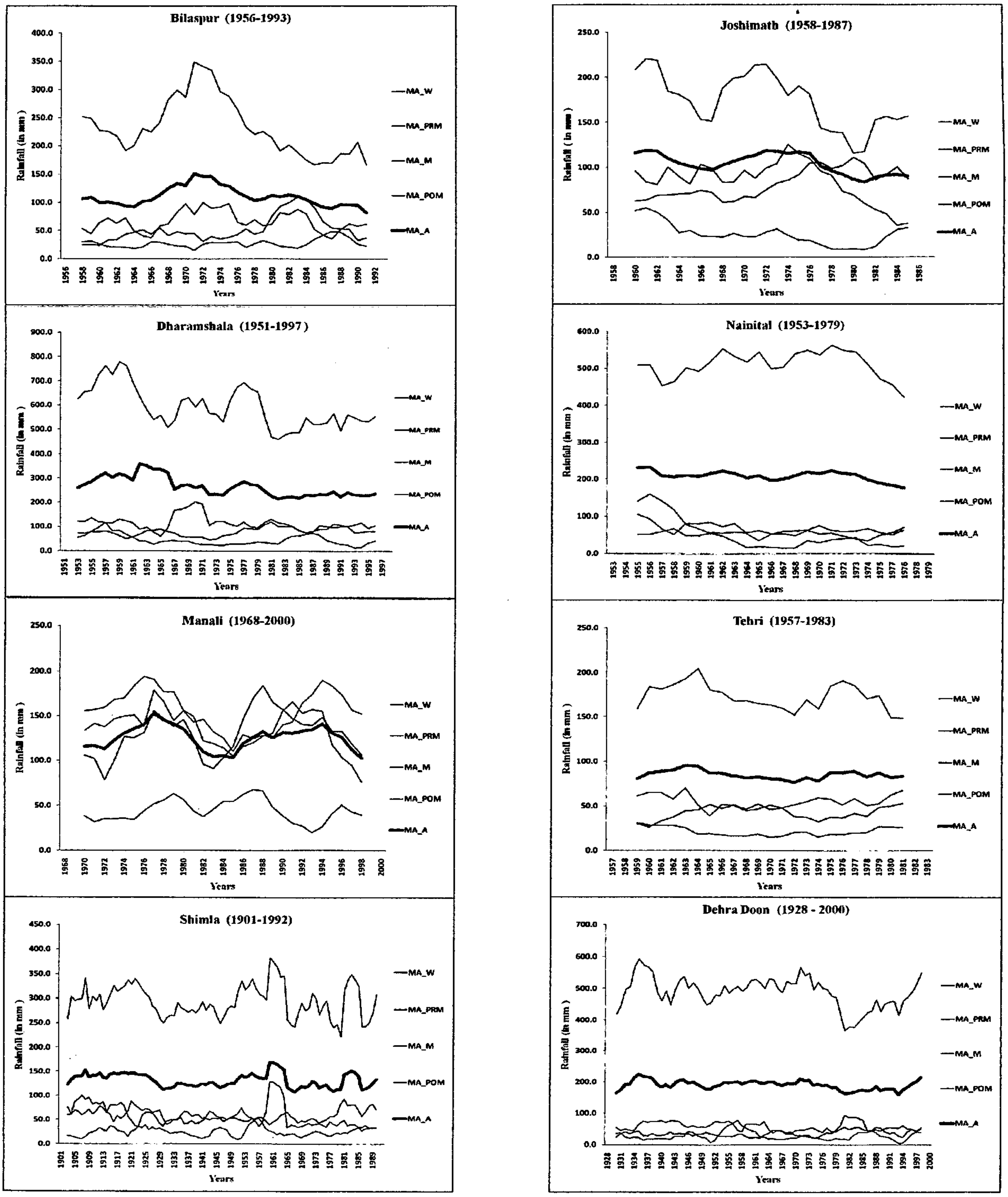
Bilaspur recorded increase in number of rainy days from 1966 to 1971 and after that a continuous decline followed. Dharamshala experienced a sharp decline in number of rainy days during 1965-67. Manali also recorded a sharp decline in rainy days during 1976-86 but had experienced increasing trend during 1989-94. Shimla experienced cyclic fluctuations in wet spells but recorded decline after 1980. Dehra Doon recorded increase in number of rainy days after 1980. Nainital recorded declining trend in the number of rainy days in monsoon season from 1962 to 1966.

- **Rainy Days Post-Monsoon**

The central Himalaya recorded more fluctuations in number of rainy days than western Himalaya in post monsoon season. Dehra Doon recorded declining trends in 1952 and 1994. Nainital recorded continuous decline in wet spells. Manali experienced decreasing trend in number of rainy days after 1988.

- **Rainy Days Annual**

Bilaspur recorded decline in number of annual rainy days after 1983. Manali also experienced declining trend during 1976-84 and again after 1994. Tehri recorded continuous increase in number of rainy days. In annual analysis not much variation were experienced by the region only some sporadic variations observed.

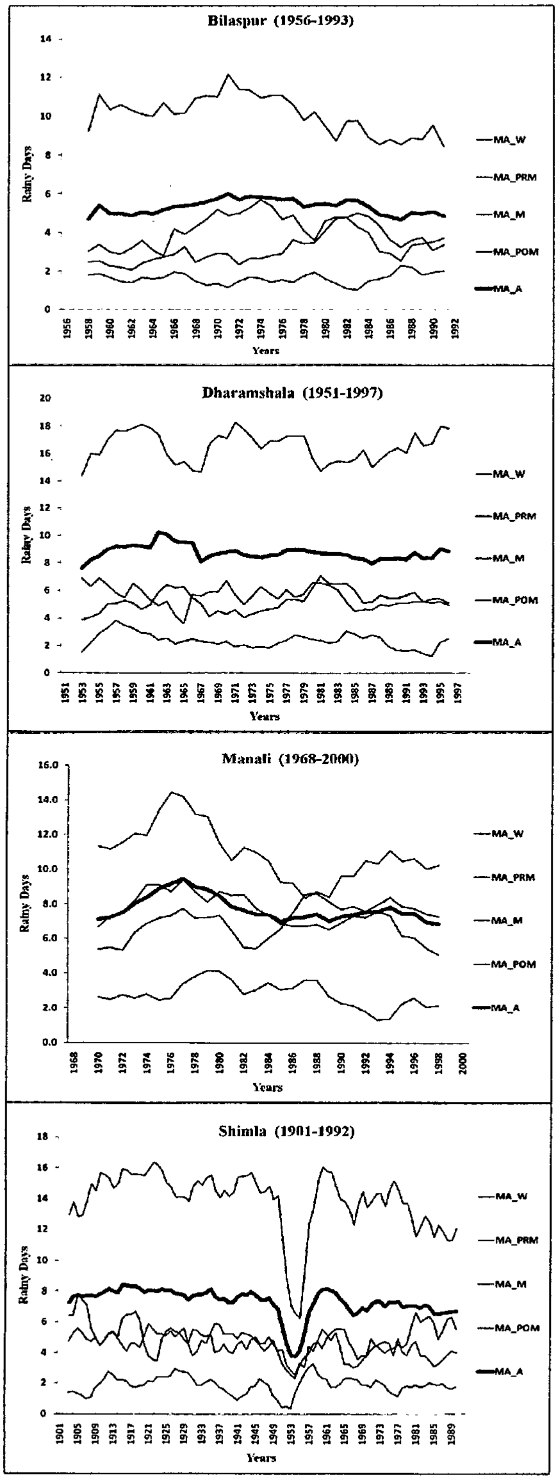


Western Himalaya

Central Himalaya

Figure 3.4: Seasonal fluctuations in mean monthly rainfall.

Source: National Data Centre, IMD, Pune



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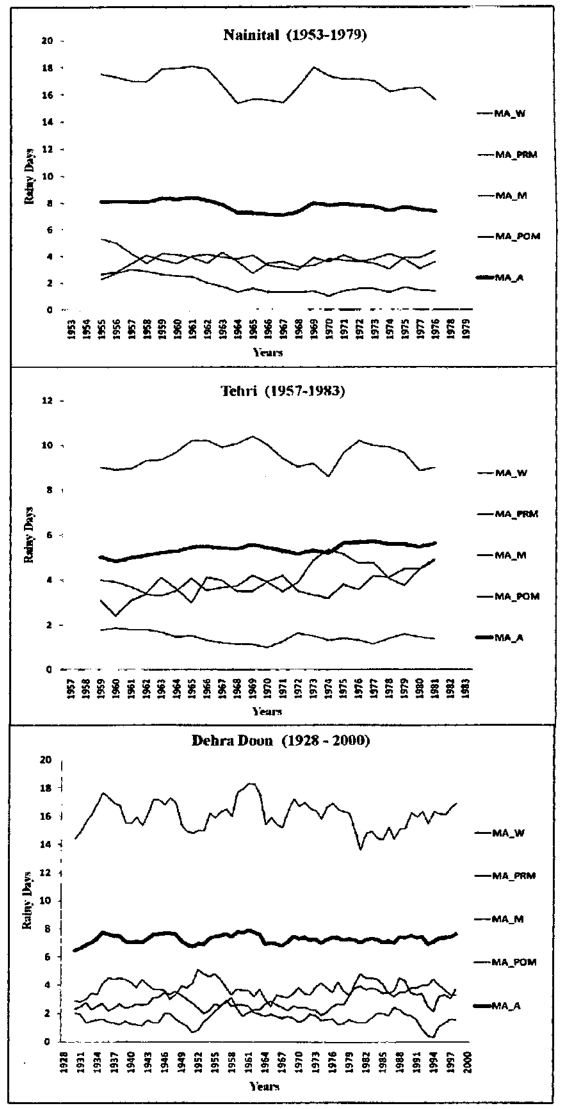


Central Himalaya

Figure 3.5: Seasonal fluctuations in mean monthly rainy days.

Source: National Data Centre, IMD, Pune

3.2.6 Temporal-seasonal variation in extreme events

Along with the basic climatic elements maximum and minimum temperature and rainfall, some of the extreme events such as highest maximum temperature, lowest minimum temperature and highest total monthly rainfall also included in the study, as they present variation in the extremity of basic elements. Joshimath meteorological station was not included in the study due to un-availability of data for extreme events.

3.2.6.1 Trends in Monthly Highest Maximum Temperature

Figure 3.6 depicts the variation in the monthly highest maximum temperature in the region.

- **Winter Highest Maximum Temperature**

A decreasing trend in the highest maximum temperature was experienced at Bilaspur during 1963-76 while increasing trend during 1986-88. Dharamshala recorded increase in highest temperature during 1971-73 and 1991-92. Shimla showed continuous increase in the records of highest maximum temperature. Dehra Doon recorded increase in the highest maximum temperature during 1985-93. Nainital experienced declining trend in highest maximum temperature after 1975.

- **Pre-Monsoon Highest Maximum Temperature**

Dharamshala recorded an increase pre-monsoon highest maximum temperature during 1971-73. Manali recorded persistent decline in temperature after 1988. Shimla recorded cyclic fluctuations in temperature during 1980-90. Dehra Doon recorded fluctuations during 1970-90. Nainital recorded increase in the highest maximum temperature after 1973.

- **Monsoon Highest Maximum Temperature**

A continuous increase in maximum temperature was recorded at Shimla especially during 1913-25. Dehra Doon recorded fluctuations in temperature during 1970-90.

- **Post-Monsoon Highest Maximum Temperature**

Dharamshala recorded increase in maximum temperature during 1969-71 and 1989-91. Manali experienced declining trend after 1988. Shimla continued with its increasing trend during 1980-90. Dehra Doon recorded cyclic trends in temperature during 1945-55. Tehri experienced declining trend in highest maximum temperature after 1977.

- **Annual Highest Maximum Temperature**

Bilaspur recorded decline in highest maximum temperature during 1964-68. Dharamshala experienced increase in temperature during 1971-74 and 1980-90. Manali recorded decline after 1988. Shimla experienced increasing trend in temperature during 1916-28. Dehra Doon recorded decline in temperature during 1975-80.

Manali and Nainital experienced decline in highest maximum temperature during their study period (1968-2000 and 1953-79, respectively) but Shimla recorded increase in temperature throughout the study period (1901-1992).

3.2.6.2 Trends in Monthly Lowest Minimum Temperature

Figure 3.7 depicts the variation in the monthly lowest minimum temperature.

- **Winter Lowest Minimum Temperature**

Bilaspur experienced cyclic trends in the lowest minimum temperature. However, the station experienced increase in the lowest minimum temperature after 1966. Dharamshala recorded sharp decline in temperature during 1968-70 while increase in temperature during 1973-88. Manali recorded increasing trend in temperature during 1972-88. Shimla experienced cyclic fluctuations in the lowest minimum temperature. It experienced sharp decline in temperature in 1905, 1931, 1951 and 1972. Dehra Doon recorded cyclic trends in temperature during 1955-85 and after 1985, it started increasing. Nainital experienced declining trend in temperature after 1965.

- **Pre-Monsoon Lowest Minimum Temperature**

Bilaspur experienced decreasing trends in lowest minimum temperature of pre-monsoon season during 1962-66 and 1972-84. Dharamshala recorded decline in temperature in 1967. Shimla experienced cyclic fluctuations in the lowest minimum temperature during the whole study period (1901-1992) of the station. Dehra Doon recorded declining trend during 1953-64 while an increase in temperature during 1982-2000.

- **Monsoon Lowest Minimum Temperature**

Bilaspur represented decreasing trend in lowest minimum temperature of monsoon season during 1958-64. Shimla experienced mild fluctuation in monsoon lowest minimum temperature than other seasons. Cyclic trends in minimum temperature were recorded during 1965-90 for the station. Dehra Doon experienced decreasing trend in temperature during 1980-85. Nainital also recorded decline in temperature during 1960-65.

- **Post-Monsoon Lowest Minimum Temperature**

Dharamshala experienced decline in post monsoon lowest temperature during a longer period of 1953-75. Manali represented increasing trend in temperature during 1972-83. Shimla again depicted cyclic fluctuations with continued rising trend of minimum temperature. Dehra Doon experienced decrease in temperature during 1980-85. Nainital recorded increase in lowest minimum temperature from 1962-1970.

- **Annual Lowest Minimum Temperature**

Bilaspur recorded increasing trend in annual lowest minimum temperature during 1964-70. Manali also experienced increase in temperature during 1992-95. Shimla experienced cyclic fluctuations in temperature during 1920-40 and 1965-90. Dehra Doon recorded cyclic trends in minimum temperature during 1955-90. Tehri experienced increasing trend in temperature during the whole study period (1957-83) of the station.

Bilaspur recorded cyclic fluctuations in the lowest minimum temperature in annual data series during 1960-66. Dehra Doon experienced the same during 1982-88. Manali, Nainital and Tehri recorded slight fluctuations in temperature while Shimla experienced larger cyclic fluctuations.

3.2.6.3 Trends in Monthly Highest Rainfall

Figure 3.8 represents the seasonal variation in monthly highest rainfall. Analysis of variation in amount of recorded highest rainfall yielded much clumsy and complex result. These results are being discussed in general instead of season wise. Bilaspur experienced cyclic fluctuation in monsoonal rainfall during 1964-88. Dharamshala depicted declining trends during 1965-75. Manali represented much complex cyclic trends in highest rainfall amount. Nainital recorded decreasing monsoonal highest rainfall but overall experienced mild fluctuations in the highest rainfall. Shimla recorded cyclic trends in rainfall with the maximum cyclic fluctuations during 1960-90. Tehri also recorded slight fluctuation but monsoonal rainfall experienced decline during 1960-65. Dehra Doon recorded mild fluctuations in the monthly highest rainfall.

3.2.7 Results and discussion

Moving average depicts the periods of high and low but not quantifies the trends as done by the simple average for a longer period study. That's why in this study moving average is used to see the trends in temperature and rainfall recorded at different meteorological stations over a period of time. Some major observations of the moving average analysis are as following;

i. Cyclic fluctuations in mean monthly maximum temperature recorded at Shimla which also represented increasing trend in winter temperature and Joshimath recorded declining trend in annual maximum temperature.

ii. Fluctuations in mean monthly minimum temperature were recorded in the later-half of the last century. The region experienced maximum cyclic fluctuations in mean monthly maximum temperature during 1940-55 and 1975-90.

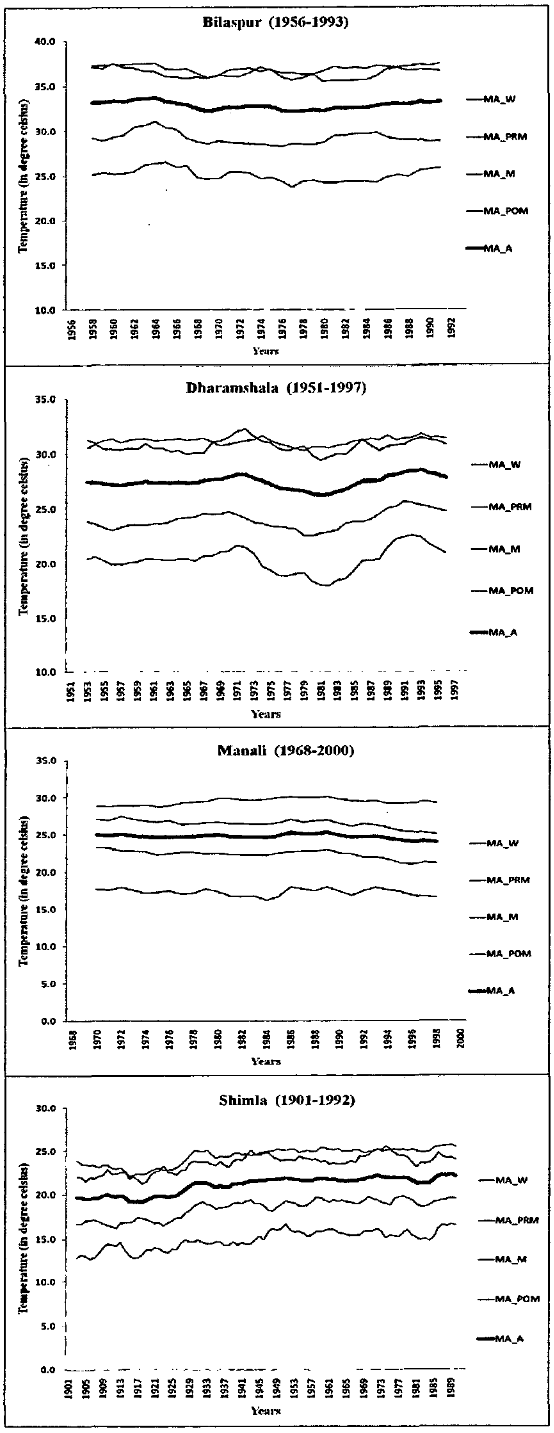
iii. The last 30 years (1960-90) experienced cyclic trends in the mean monthly temperature with 1980-90 as the most prominent part of it.

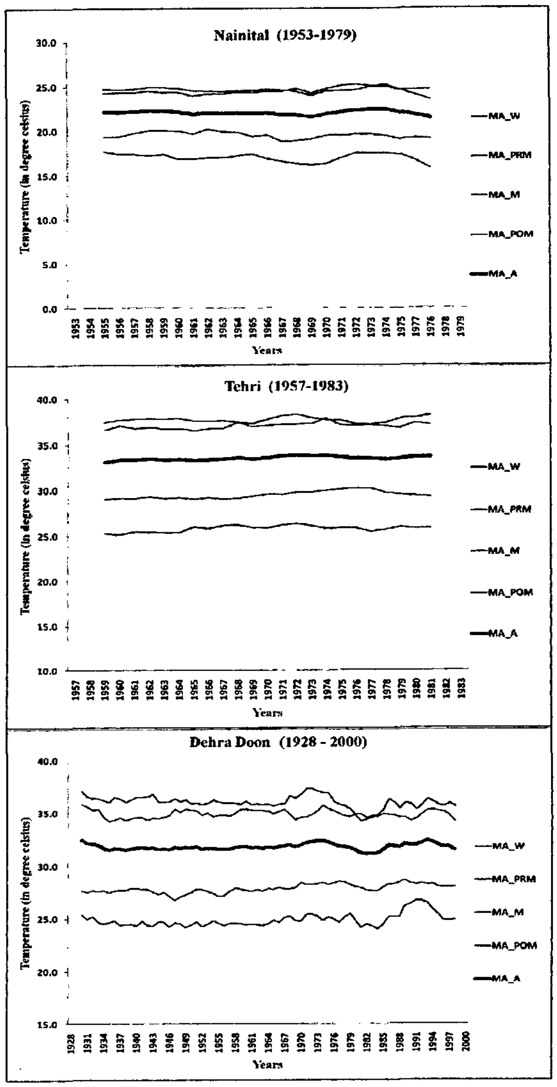
iv. The Central Himalaya experienced more fluctuations in total monthly rainfall than Western Himalaya. The Central Himalayan stations recorded decrease in rainfall in almost every season while Western Himalaya experienced cyclic fluctuations in rainfall.

v. Manali and Nainital experienced decline in the monthly highest maximum temperature during the study period of each respective station (1968-2000 and 1953-79, respectively) but Shimla recorded increase in maximum temperature throughout the study period (1901-1992) of the station.

vi. Bilaspur recorded fluctuations in annual lowest minimum temperature during 1960-66. Dehra Doon experienced the same during 1982-88. Manali, Nainital and Tehri recorded mild fluctuations while Shimla experienced cyclic fluctuations.

vii. Manali represented complex fluctuations in monthly highest rainfall amount while Shimla recorded fluctuation in monthly highest rainfall during 1960-90.



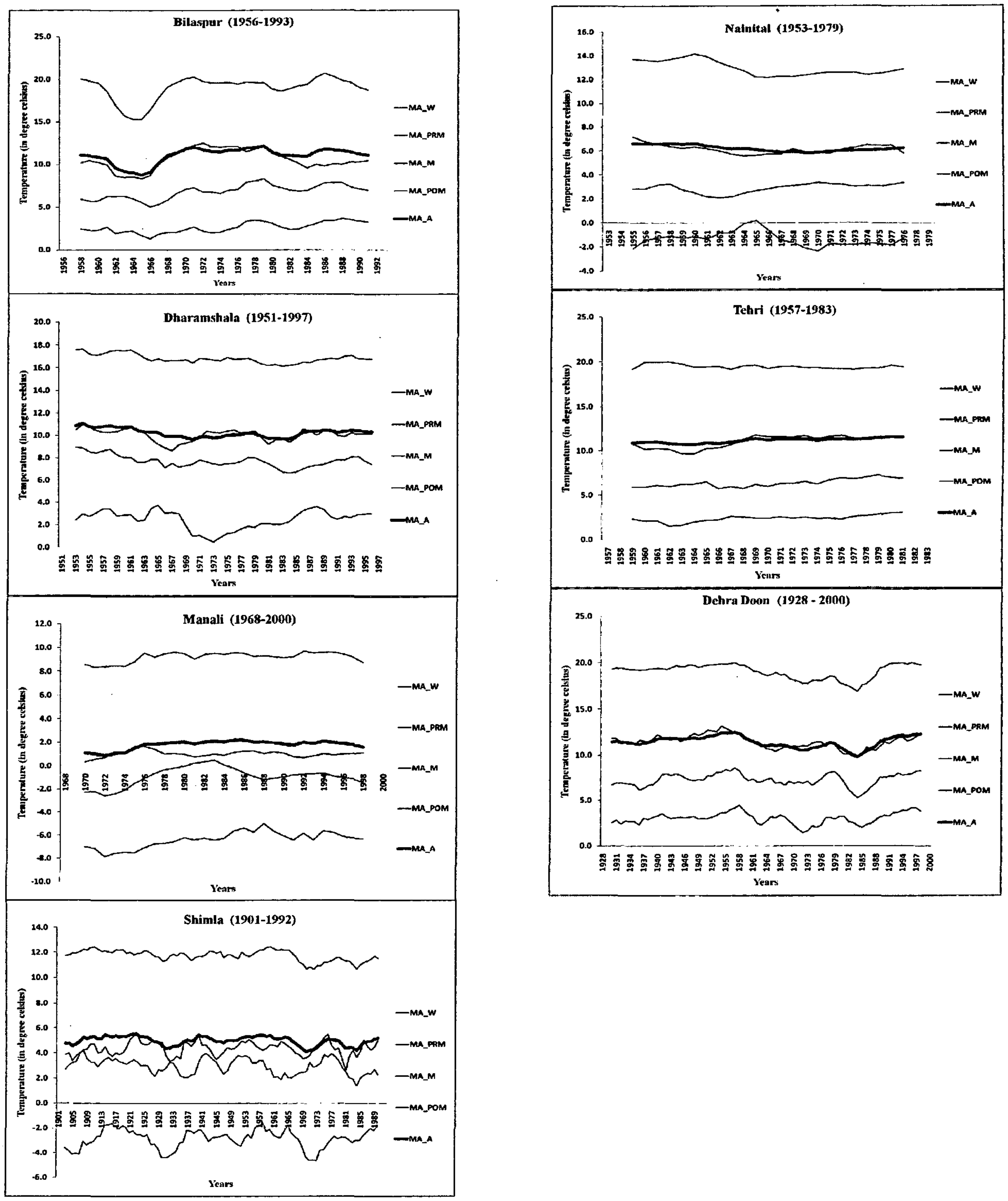


Western Himalaya

Central Himalaya

Figure 3.6: Seasonal fluctuations in monthly highest maximum temperature.

Source: National Data Centre, IMD, Pune



Western Himalaya

Central Himalaya

Figure 3.7: Seasonal fluctuations in monthly lowest minimum temperature.

Source: National Data Centre, IMD, Pune

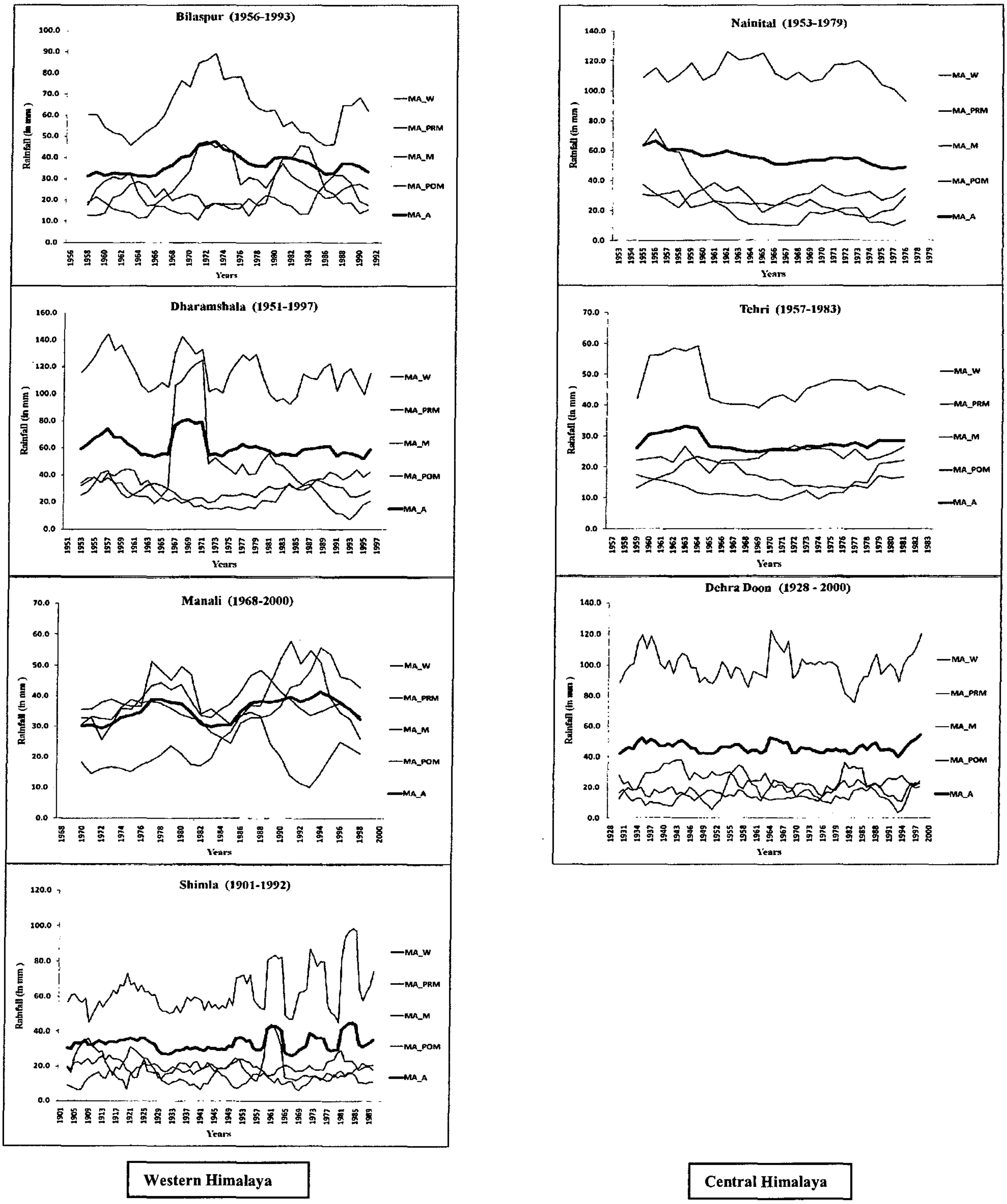


Figure 3.8: Seasonal fluctuations in total monthly highest rainfall.

Source: National Data Centre, IMD, Pune

3.3 Temporal-Seasonal Climatic Fluctuation analysis using Normalized Accumulated Departure from Mean (NADM) method

Since the time span of rainfall and temperature data record at Bilaspur, Dharamshala, Manali, Joshimath, Nainital and Tehri is very short. Therefore, the normalized accumulated departure from mean (NADM) is a suitable method to analyze the temporal fluctuations and trends in temperature and rainfall at these stations. NADM permits visual as well as statistical comparison of unlike data periods characterized by above average (below average) conditions are indicated by positive (negative) slopes of the graph. Unlike other methods, such as moving average, the NADM permits the distinction between periods of high and low values by clearly defining the limits.

Due to specific requirements and demand of the study, only three variables i.e. mean monthly temperature, total monthly rainfall and number of rainy days were included in the study and annual data series was used, as the inclusion of all the seasons' data made the interpretation difficult. Table 3.3 depicting the information about the different meteorological stations included in the study.

Table 3.3 Meteorological stations included in NADM analysis

Station	Height (in m)	Data Span	Data Availability (Years)	Variables	Seasons
Bilaspur	670	1956-1993	37	Mean Temperature	
Dharamshala	1457	1951-1998	47		
Manali	1950	1968-2000	32	Total Monthly Rainfall	Annual
Joshimath	960	1958-1987	29		
Tehri	1750	1957-1983	26	Number of Rainy Days	
Nainital	1938	1953-1979	26		

Note: Variables and seasons are common to all the stations.

3.3.1 Trends in Mean Monthly Temperature

Figure 3.9 shows the annual trends in mean monthly temperature for the selected meteorological stations of the region. The mean monthly temperature experienced positive NADM during 1957-74 and 1987-98 at Dharamshala while negative value of NADM was recorded during 1975-84. A persistent decreasing trend in mean monthly temperature was recorded at Dharamshala during 1957-84 while increasing trend was experienced during 1987-1998. Bilaspur recorded negative departure of mean temperature during 1959-67 and positive departure during 1970-1989. The station experienced static trend in mean temperature during 1956-86 and decreasing trends in temperature after 1989. A sharp increasing trend in mean temperature was recorded at Manali during 1970-92. The station represented negative departure of mean monthly temperature during 1970-76 and positive departure during 1977-92. Joshimath recorded positive departure of mean temperature during 1958-74 and negative departure during 1975-85. The station experienced static trend in mean monthly temperature but experienced increasing trends after 1986. Nainital experienced increasing trends in mean temperature during 1953-70. Positive departure from mean temperature was recorded at the station during 1953-60 while negative departure during 1961-70. A persistent increasing trend in mean temperature was experienced at Tehri during 1960-83. Tehri represented negative departure from mean during 1960-68 but showed positive departure during 1970-83.

Some striking observation of the study included the negative departure from mean recorded at Dharamshala and Joshimath during 1975-85. Negative departure of mean temperature represented at Bilaspur, Nainital and Tehri during 1960-70. Positive departure recorded at Dharamshala, Joshimath and Nainital during 1951-74. Positive departure recorded at Bilaspur and Tehri during 1970-89.

3.3.2 Trends in Total Monthly Rainfall

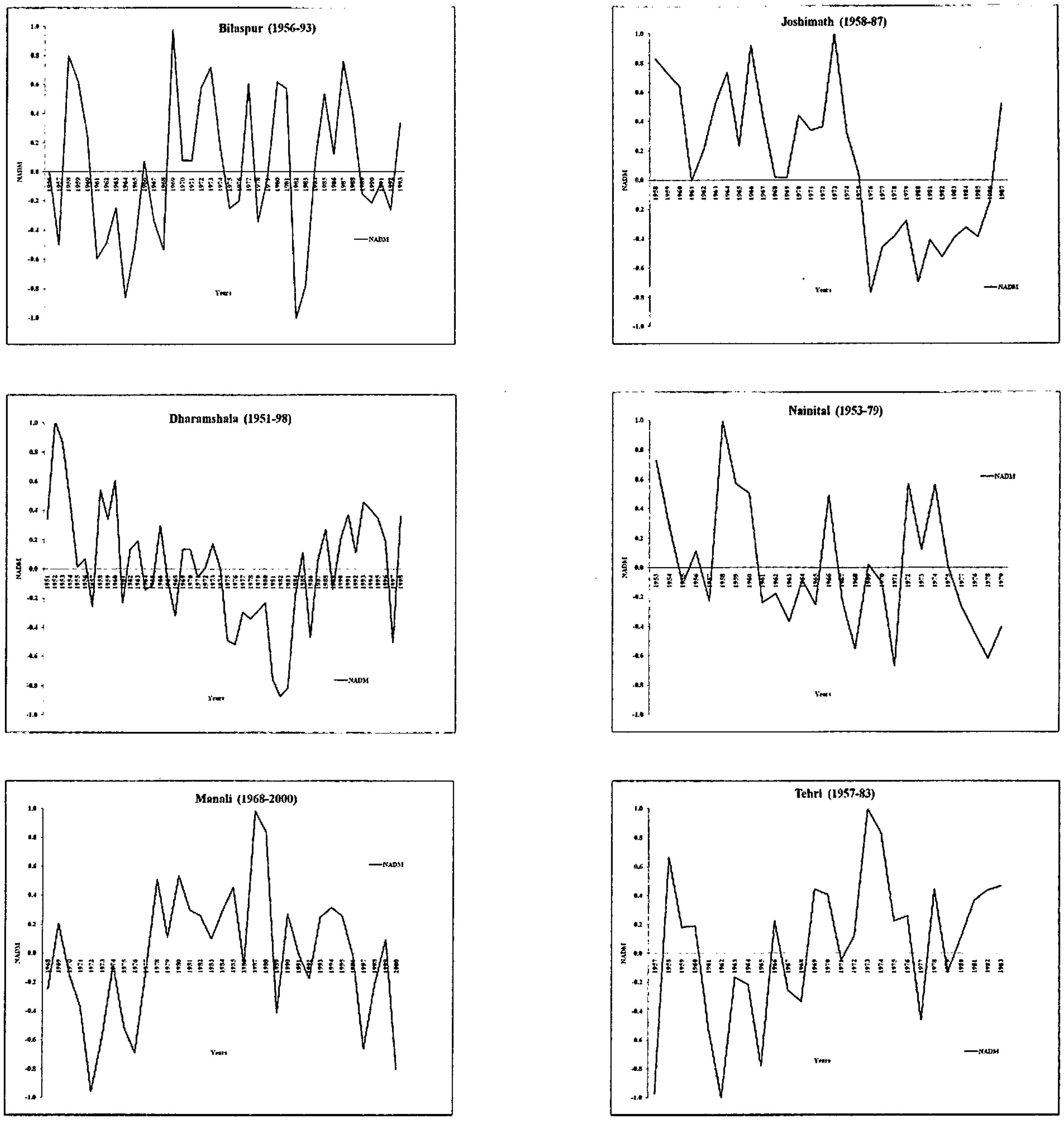
Figure 3.10 represents the trends and departure from mean monthly rainfall of selected meteorological stations of the region. Decreasing trends were experienced in mean monthly rainfall at Bilaspur during 1958-65 and 1984-93 with negative departure from mean monthly rainfall. Positive departure represented at the station during 1966-78 with increasing trends in monthly rainfall. Dharamshala experienced positive departure during 1953-64. The station recorded negative departure in mean monthly rainfall during 1966-98 with continuous decreasing trend for the same period. Joshimath recorded positive departure from mean rainfall during 1959-64 and 1969-78. Negative departure from mean rainfall recorded at the station during 1965-68 and 1979-87. Joshimath recorded continuous decreasing trend in mean rainfall after 1987. Positive departure from mean rainfall was recorded at Manali during 1975-82 and 1988-96. Negative departure was experienced at the station during 1968-74 and 1983-87. Station experienced decreasing trend in rainfall after 1997. Nainital recorded persistent decreasing trend in mean monthly rainfall during 1953-79. Positive departure from mean rainfall experienced at the station during 1954-64 and negative departure from 1973 to 1979. Tehri experienced cyclic trends of positive and negative departure in mean monthly rainfall. Negative departure recorded during 1958-60 and 1968-74 while positive departure from mean monthly rainfall recorded during 1961-66 and 1975-78. Tehri experienced decreasing trend in monthly rainfall after 1979.

3.3.3 Trends in Monthly Rainy Days

Figure 3.11 depicts the temporal fluctuations and departure from mean monthly number of rainy days at the selected stations of the region. Bilaspur experienced positive departure from mean monthly number of rainy days during 1957-84. Negative departure was recorded for the station during 1985-87. A decreasing trend in mean monthly number of rainy days was experienced at Bilaspur after 1991. A persistent negative departure from mean monthly number of rainy days was represented at Dharamshala during 1951-98. The station experienced negative departure from mean number of rainy days during 1951-60 and 1965-98. A brief period of four years (1961-64) recorded positive departure of mean monthly rainy days. Manali recorded positive departure from mean rainy days during 1975-82 while negative departure during 1965-74 and 1983-2000. Nainital recorded positive departure of mean monthly number of rainy days during 1954-61 while negative departure during 1962-1979. Tehri represented positive departure throughout the data series (1957-83). The station experienced negative departure of mean monthly number of rainy days during 1958-62 with decreasing trend in number of rainy days. The positive departure was experienced during 1963-83 with increasing trend in mean monthly number of rainy days.

3.3.4 Results and discussion

Positive departure from mean represents that recorded annual data (rainfall or temperature) was more than the normal or the average of 30/40 years data record. It shows the rise in temperature or increase in rainfall amount. Negative departure from mean depicts that

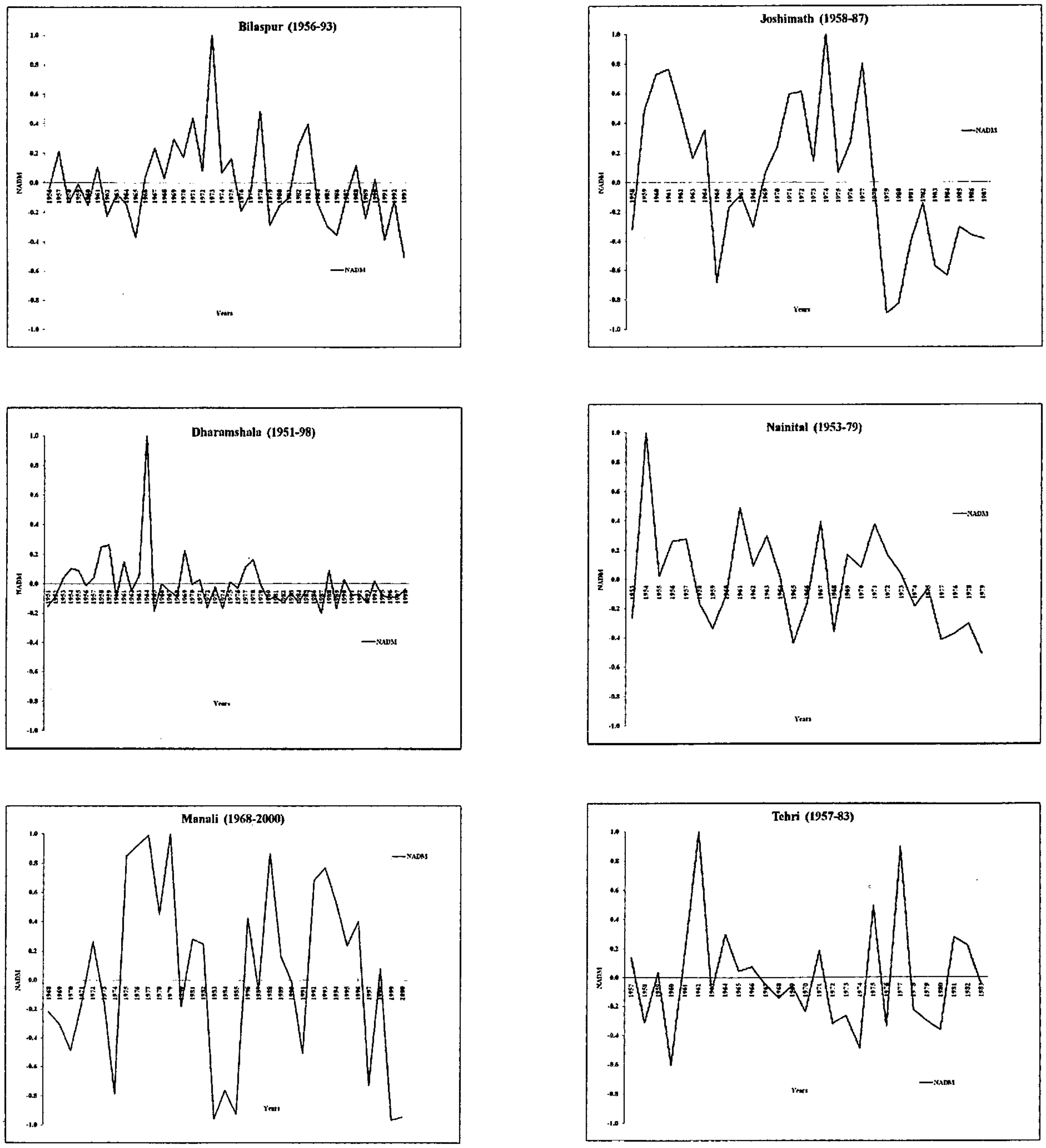


Western Himalaya

Central Himalaya

Figure 3.9: Seasonal fluctuations in mean monthly temperature (NADM method).

Source: National Data Centre, IMD, Pune

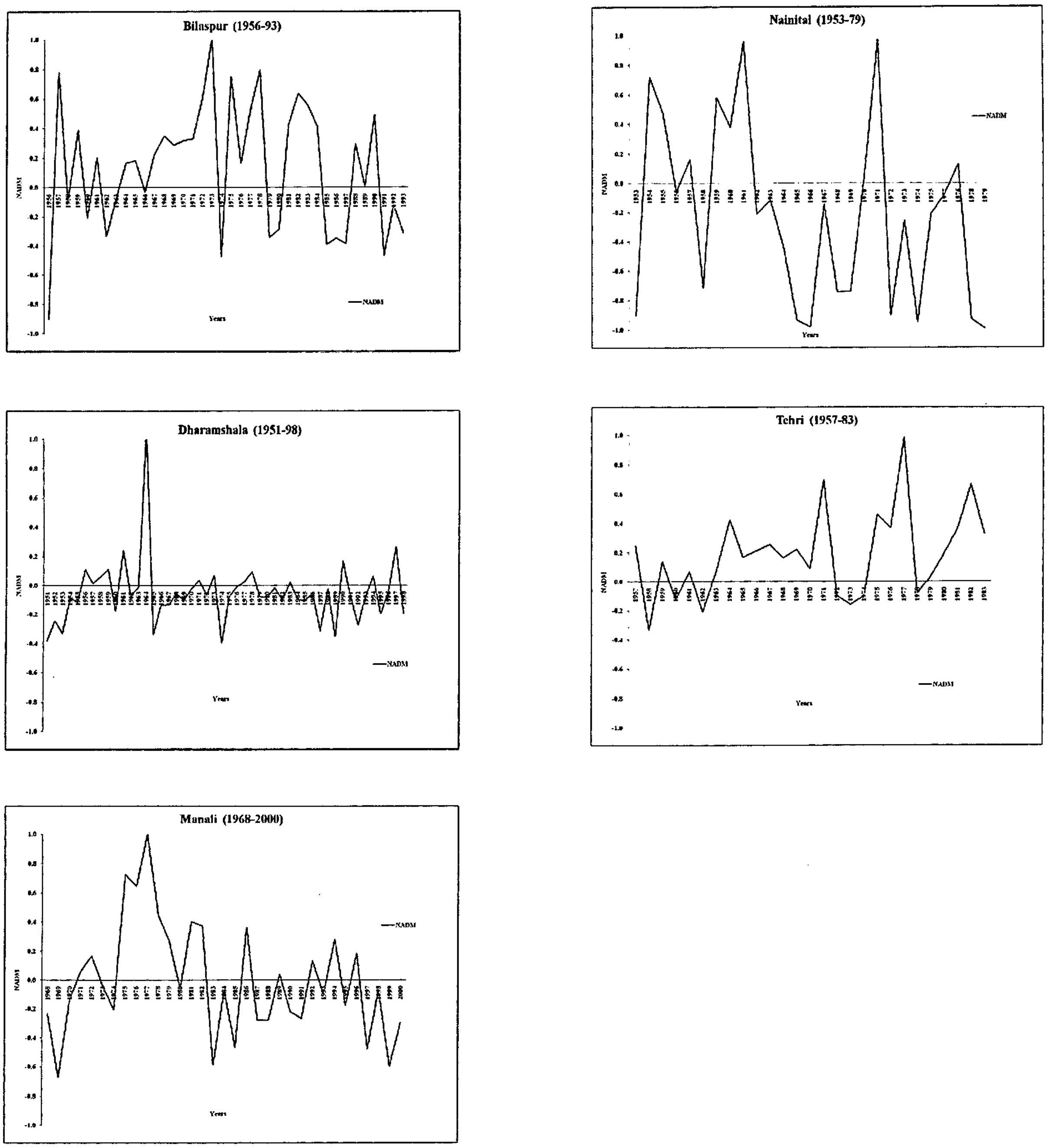


Western Himalaya

Central Himalaya

Figure 3.10: Seasonal fluctuations in total monthly rainfall (NADM method).

Source: National Data Centre, IMD, Pune



Western Himalaya

Central Himalaya

Figure 3.11: Seasonal fluctuations in monthly rainy days (NADM method).

Source: National Data Centre, IMD, Pune

Table 3.4 Results of NADM analysis (span of departure; positive/ negative)

	Variable					
Station	Mean Monthly Temperature		Monthly Rainfall		Number of Rainy Days	
	Positive Departure	*Negative Departure*	*Positive Departure*	*Negative Departure*	*Positive Departure*	*Negative Departure*
Bilaspur	1970-89	1959-67	1966-78	1958-65 & 1984-93	1957-84	1985-87
Dharamshala	1957-74 & 1987-98	1975-84	1953-64	1966-98	1961-64	1951-60 & 1965-98
Manali	1977-92	1970-76	1975-82 & 1988-96	1968-74 & 1983-87	1975-82	1968-74 & 1983-00
Joshimath	1958-74	1975-85	1959-64 & 1969-78	1965-68 & 1979-87	DNA	DNA
Nainital	1953-60	1961-70	1954-64	1973-79	1954-61	1962-79
Tehri	1970-83	1960-68	1961-66 & 1975-78	1958-60 & 1968-74	1963-83	1958-62

DNA: Data Not Available

p

recorded annual rainfall (temperature) data was less than the normal of that data series worked out for 30/40 years data record. It implies the decrease in temperature or rainfall amount over the period in comparison to the normals. Some major observations of the study are as follows;-

i. Positive departure means increase in mean monthly temperature was observed at Dharamshala, Joshimath and Nainital during 1951-74. Tehri and Bilaspur experienced increasing trend in mean temperature during 1970-90.

ii. Negative departure or decreasing trend in mean monthly temperature was recorded at Dharamshala and Joshimath during 1975-84. Nainital, Tehri and Bilaspur experienced decreasing trend in mean temperature during 1960-70.

iii. Rainfall regime represented cyclic trends for each of the station which cannot be classified in some homogeneous groups. Bilaspur, Dharamshala and Manali represented decreasing trends in mean monthly rainfall after 1995. Nainital and Tehri recorded declining trends in rainfall after 1979 while Joshimath experienced this after 1987.

iv. Departure from mean monthly number of rainy days was observed negative throughout the study period (1951-98) at Dharamshala while it remained positive for Tehri (1957-83).

v. Positive departure from mean monthly number of rainy days was observed at Bilaspur, Dharamshala, Manali and Tehri during 1960-80. Nainital experienced positive departure during 1954-61.

3.4 Temporal-Seasonal Climatic Variation analysis using Simple Average method

Simple average method facilitate the comparison of two climatic or base line periods and identify the variation occurred in the second period over the first one. As the 31 years period is generally regarded as one climatic period or base line period. Only two meteorological stations viz. Shimla and Dehra Doon had data for 92 years and 72 years respectively. Therefore, these two stations were included in the simple average analysis of the climatic variables. The detailed information about the stations, variables and seasons used in this analysis is given in table 3.5. The basic climatic variables, such as maximum, minimum and mean temperature, rainfall and number of rainy days were used in the analysis.

30 years base-line periods or climatic periods were calculated Shimla and Dehra Doon. For Dehra Doon, 1928-1930 and 1991-2000 data were not included as the climatic periods for the station demarcated as 1931-1960 and 1961-1990. Therefore, the remaining data were left out in the analysis.

Table 3.5 Meteorological stations used in the simple average analysis

Station	Data Spane	Base-line Periods	BP - Codes	Variable	Season
				Mean Maximum Temperature	Winter
		1901-1930	BP-I	Mean Minimum Temperature	Monsoon
Shimla	1901-1992	1931-1960	BP-II	Mean Temperature	Annual
		1961-1992	BP-III	Total Monthly Rainfall	
				Number of Rainy Days	
				Mean Maximum Temperature	Winter
				Mean Minimum Temperature	Monsoon
Dehra Doon	1928-2000	1931-1960	BP-II	Mean Temperature	Annual
		1961-1990	BP-III	Total Monthly Rainfall	
				Number of Rainy Days	

Note: for Dehra Doon, 1928-30 and 1991-2000 data were not used to make the periods contemporary to that of Shimla

Table 3.6 Seasonal climatic variation analysis using simple average method

Variation in Mean Monthly Maximum Temperature (in Degree Celsius)

Station	Base-line Periods	Winter			Monsoon			Annual		
		CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Shimla	(1901-1930)	16.1	8.2		3.4	20.2		3.7	15.6	
	(1931-1960)	11.9	9.4	1.1	2.0	21.3	1.1	2.6	16.9	1.3
	(1961-1992)	12.1	9.9	0.5	2.8	21.6	0.3	2.9	17.2	0.3
Dehra Doon	(1931-1960)	4.4	20.2		1.9	31.2		1.5	27.7	
	(1961-1990)	4.9	20.8	0.6	2.2	31.2	0.0	1.6	27.9	0.2

Variation in Mean Monthly Minimum Temperature (in Degree Celsius)

Station	Base-line Periods	Winter			Monsoon			Annual		
		CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Shimla	(1901-1930)	52.9	2.3		2.4	15.1		4.2	9.6	
	(1931-1960)	38.9	2.5	0.1	2.4	15.2	0.1	4.0	9.9	0.2
	(1961-1992)	44.2	2.1	-0.3	4.5	14.5	-0.7	4.9	9.4	-0.5
Dehra Doon	(1931-1960)	10.2	7.1		1.7	22.6		3.0	15.7	
	(1961-1990)	15.4	6.3	-0.8	3.7	21.5	-1.2	4.1	14.7	-1.0

Variation in Mean Monthly Temperature (in Degree Celsius)

Station	Base-line Periods	Winter			Monsoon			Annual		
		CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Shimla	(1901-1930)	24.0	5.3		2.6	17.7		3.7	12.6	
	(1931-1960)	17.3	5.9	0.6	1.9	18.2	0.5	3.1	13.4	0.8
	(1961-1992)	17.1	6.0	0.1	2.9	18.0	-0.2	3.0	13.3	-0.1
Dehra Doon	(1931-1960)	5.2	13.7		1.5	26.9		1.7	21.7	
	(1961-1990)	6.1	13.6	-0.1	2.2	26.3	-0.6	2.2	21.3	-0.4

Variation in Total Monthly Rainfall (in mm)

Station	Base-line Periods	Winter			Monsoon			Annual		
		CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Shimla	(1901-1930)	56.5	75.0		27.1	300.8		18.3	138.4	
	(1931-1960)	45.6	55.4	-19.6	19.6	289.0	-11.8	13.3	126.9	-11.5
	(1961-1992)	116.1	50.0	-5.5	46.0	292.8	3.8	34.6	129.8	2.8
Dehra Doon	(1931-1960)	51.8	60.8		19.6	503.5		14.9	195.9	
	(1961-1990)	56.5	50.6	-10.1	23.4	480.8	-22.6	16.9	188.2	-7.7

Variation in Monthly Number of Rainy Days (in number of days)

Station	Base-line Periods	Winter			Monsoon			Annual		
		CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Shimla	(1901-1930)	44.7	5		15.6	15		10.3	8	
	(1931-1960)	42.5	4	-1	30.5	13	-2	25.2	7	-1
	(1961-1992)	43.8	4	0	19.6	13	0	11.7	7	0
Dehra Doon	(1931-1960)	38.7	4		12.2	16		9.4	7	
	(1961-1990)	34.4	4	0	18.7	16	0	12.7	7	0

Source: National Data Centre, IMD, Pune

3.4.1 Mean Monthly Maximum Temperature

Figure 3.12 represents the temporal variability in mean monthly maximum temperature at Shimla and Dehra Doon. Shimla recorded gradual increase in the maximum temperature in all three seasons. Maximum variation was experienced in the winter season. Base-line Period II (BP- II) recorded 1.1 ^{0}C increase over BP- I and further BP-III recorded 0.5 ^{0}C increase in the maximum temperature. Dehra Doon's BP-III experienced 0.6 ^{0}C increase in maximum temperature which is identical to that of Shimla for the same period. Monsoon and annual maximum temperature didn't show greater variations for both of the stations. However, Shimla experienced much rise in the maximum temperature than Dehra Doon. Winter season experienced large increase in maximum temperature followed by the monsoon season.

3.4.2 Mean Monthly Minimum Temperature

Over the period, minimum temperature decreased for both of the stations. Dehra Doon experienced more decline in the minimum temperature than shimla (Figure 3.13). Form BP-II to BP-III, the minimum temperature decreased by 0.8 ^{0}C in winter and 1.2 ^{0}C in monsoon season at Dehra Doon. Annual minimum temperature also recorded decrease of 1.0 ^{0}C. Shimla experienced decrease in the minimum tempearture for the third period but experienced increase in the second period. It is quite obvious that after 1960s minimum temperature decreased for both of the stations and monsoon season experienced more decline in minimum temperature than winter. Inconsistancy in mean minimum temperature was observed at Shimla in winter season.

3.4.3 Mean Monthly Temperature

The mean monthly temperature increased from BP-I to BP-II at Shimla (Figure 3.14). But after that, it experienced decrease from BP-II to BP-III. Again winter experienced more increase in mean temperature than monsoon season in the second period. The monsoon season experieced more decrease in the third period than winter. Dehra Doon experienced decline in the mean temperature identical to Shimla but the decline is more prominent than Shimla. Overall, Dehra Doon experienced more decrease in the mean temperature than Shimla.

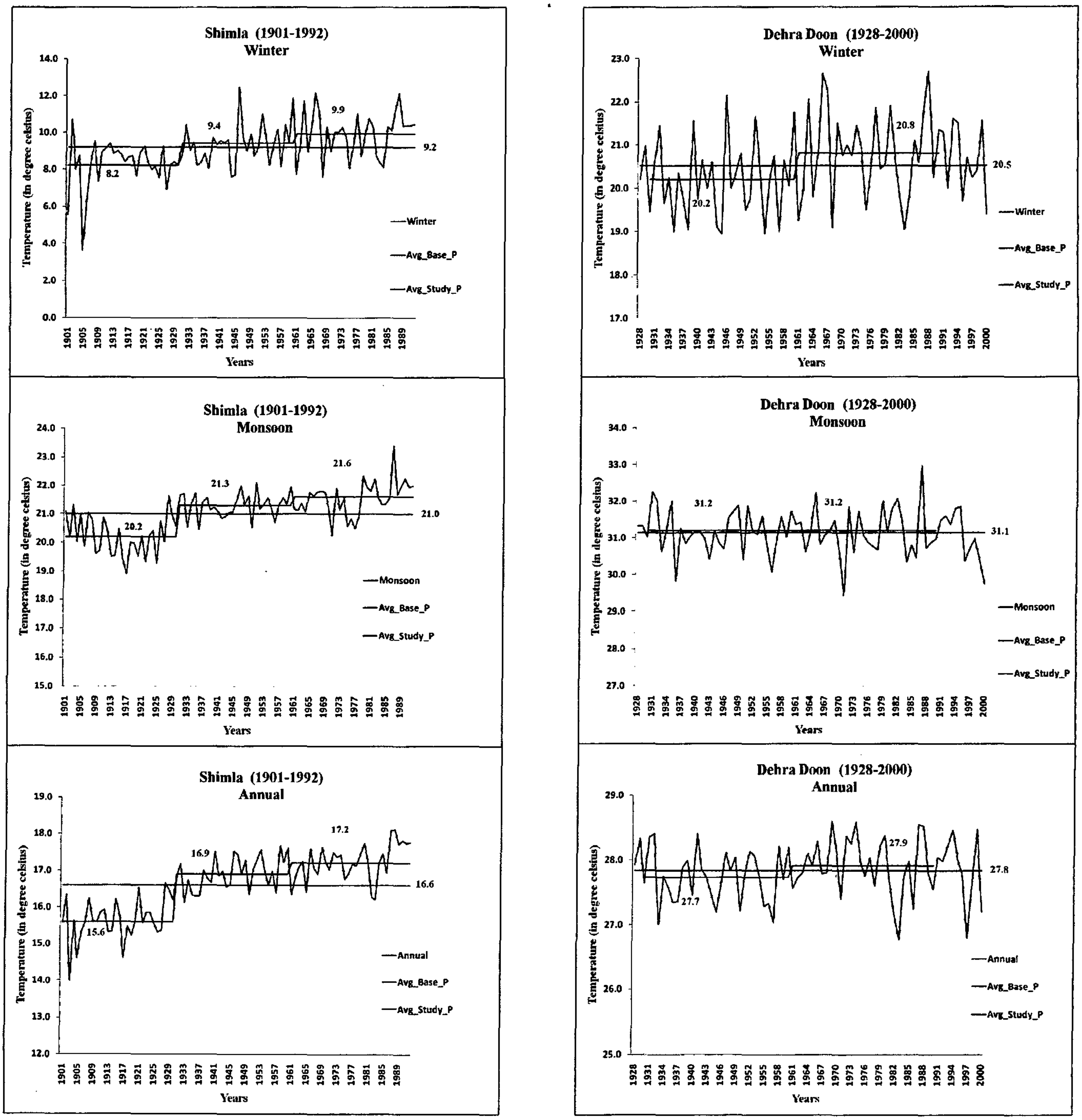


Figure 3.12: Seasonal variations in mean monthly maximum temperature.

Source: National Data Centre, IMD, Pune

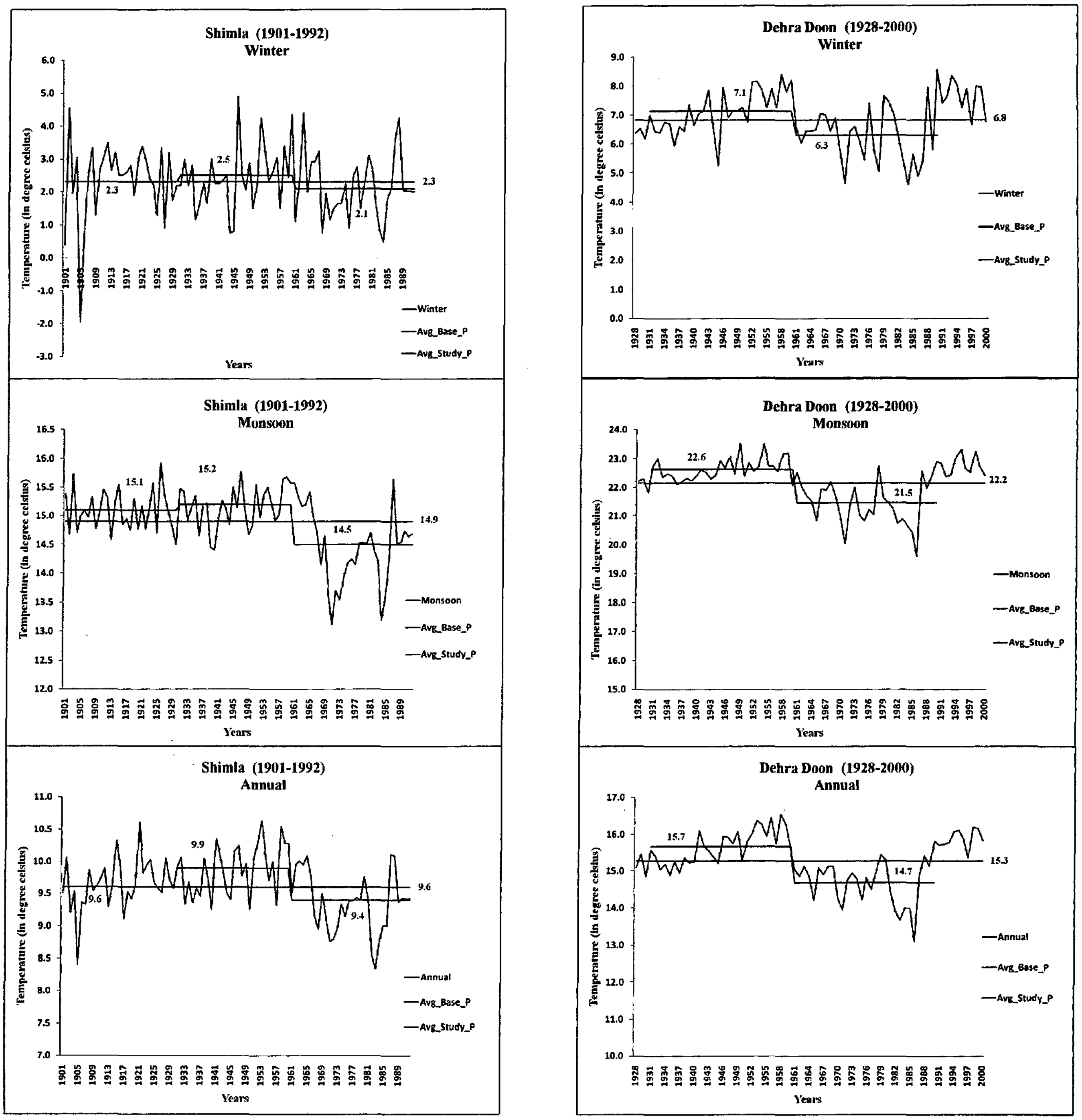


Figure 3.13: Seasonal variations in mean monthly minimum temperature.

Source: National Data Centre, IMD, Pune

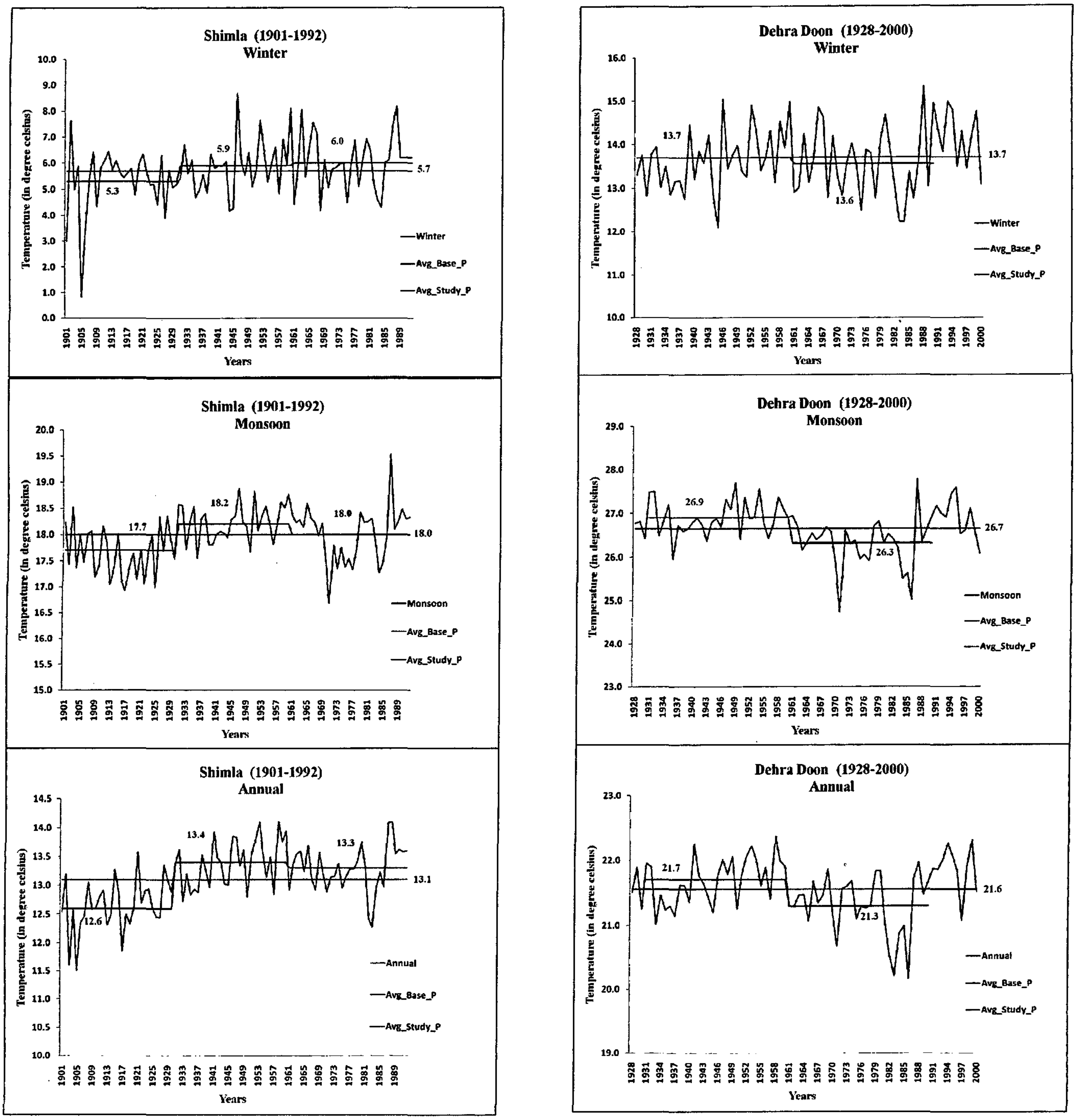


Figure 3.14: Seasonal variations in mean monthly temperature.

Source: National Data Centre, IMD, Pune

3.4.4 Total Monthly Rainfall

Winter rainfall recorded decline in all the base-line periods for both of the stations (Figure 3.15). Shimla recorded 19.6 mm and 5.5 mm decrease in rainfall for BP-II and BP-III respectively. Dehra Doon also experienced 10.1 mm decrease in monthly rainfall in the BP-III. Monsoon rainfall also reflected decline but Shimla in the BP-III experienced increase in the rainfall. It experienced 3.8 mm increase in the rainfall. Annual rainfall recorded decrease at Dehra Doon (-7.7 mm) and Shimla also reflected decline for the BP-II by -11.5 mm but it again recorded increase in the BP-III period by 2.8 mm. The overall scenario is that Shimla and Dehra Doon experienced decline in the monthly rainfall up to 1960. But, after that both the stations differed to each other. Shimla recorded increase in rainfall during 1960-90 but Dehra Doon continued with the decreasing trend for the BP-III (1960-90). Shimla experienced high inconsistency in monthly rainfall of winter season during 1930-90.

3.4.5 Monthly Rainy Days

Number of rainy days didn't experience much variation at both the stations. Shimla recorded decline in number of rainy days for the BP-II by -1 day in winter, -2 days in monsoon and -1 day in annual record. But for the next period no variation was recorded. It means that the number of rainy days didn't vary for the BP-III at both the stations.

3.4.6 Results and Discussion

i. Maximum temperature experienced increase in the study period for both the stations. But this increase was not got strengthen over the time. BP-II experienced large increase in the maximum temperature for Shimla but BP-III experienced increase with decreasing rate. It means that the increase in temperature was not continued in the next period (BP-III) with the same rate but with the reduced rate. Maximum temperature is increasing in the region but with decreasing rate of increase. Shimla located at a higher elevation (2400 m) experienced more increase in the maximum temperature than low elevation station i.e., Dehra Doon (640 m). Therefore, it can be concluded that the high elevated site is experiencing more increase in temperature than low elevated site.

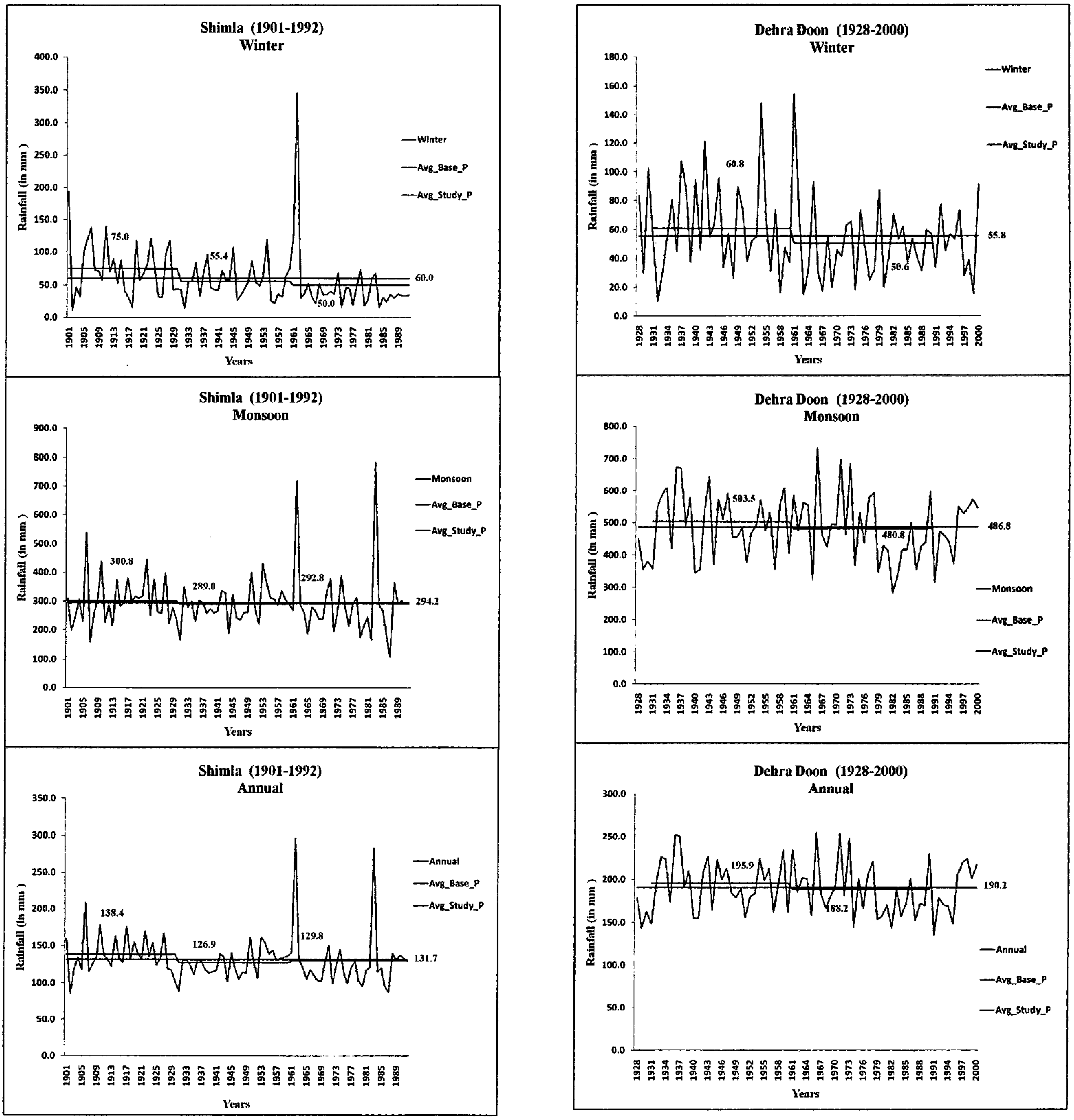


Figure 3.15: Seasonal variations in total monthly rainfall.

Source: National Data Centre, IMD, Pune

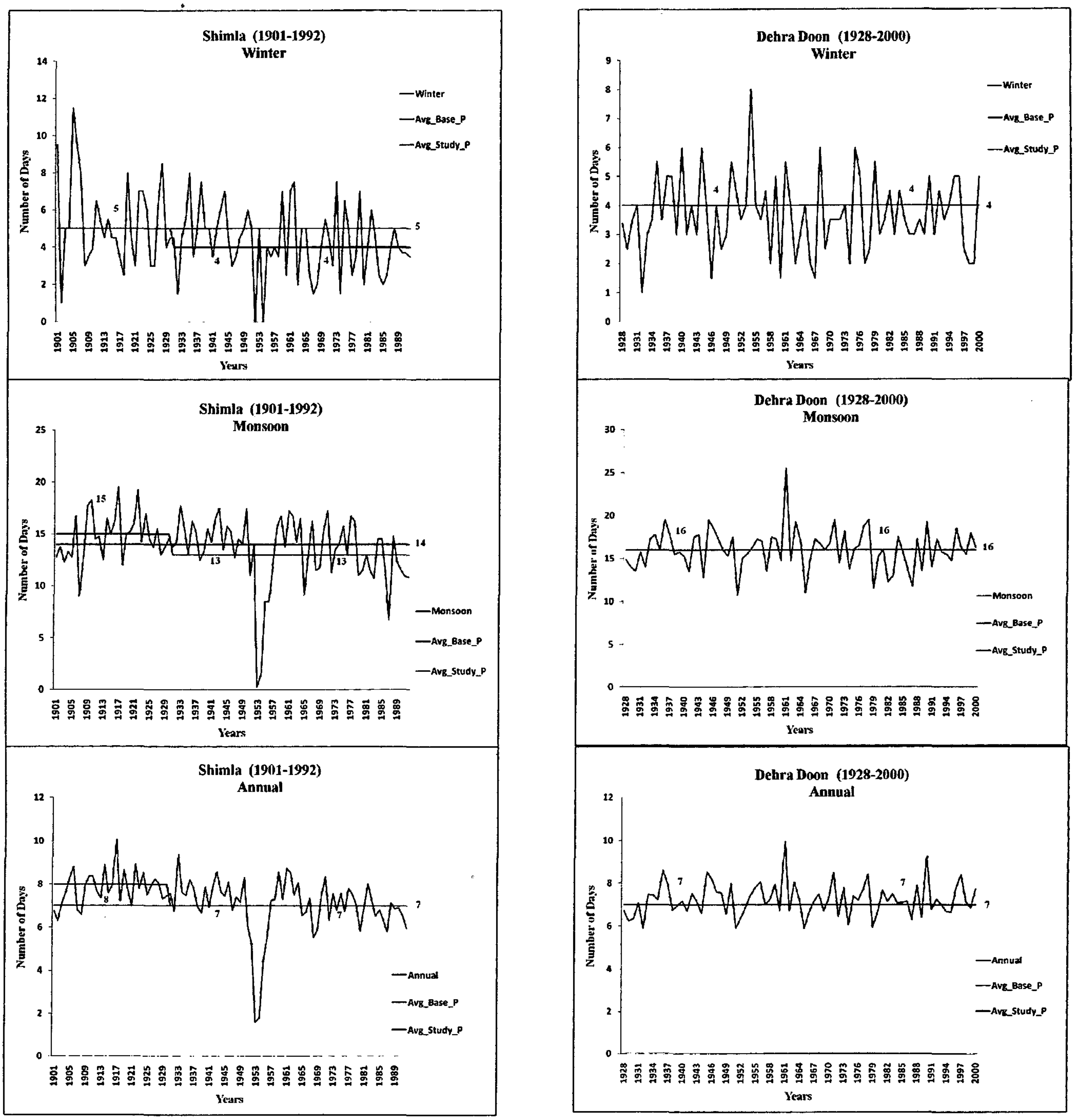


Figure 3.16: Seasonal variations in monthly rainy days.

Source: National Data Centre, IMD, Pune

i. Minimum temperature decreased at both the stations. Shimla recorded increase in minimum temperature for the BP-II period but during the next period, Shimla and Dehra Doon recorded decrease in the minimum temperature. Dehra Doon experienced more decrease in the minimum temperature than Shimla during 1960-90 (BP-III).

ii. Mean monthly temperature experienced decrease over the time. Shimla recorded increase in the mean temperature during BP-II but decrease during BP-III. Correspondingly, Dehra Doon recorded decrease in the mean temperature during BP-III. Dehra Doon experienced high decrease in the mean temperature as compared to Shimla during 1960-90.

iii. There was decrease in rainfall in the region. Shimla recorded high decrease in the rainfall during BP-II but this decreasing rate was not followed during BP-III. Shimla recorded low decrease in the rainfall as compared to Dehra Doon during 1960-90. One prominent observation is that Shimla recorded high decrease in winter season while Dehra Doon recorded high decrease in monsoon season. This was not a good sign for the later one as the monsoon rainfall is the most prominent source of the water for hilly terrain.

iv. Number of rainy days didn't vary so much. Dehra Doon hardly experienced any variation in the rainy days count during BP-III. Shimla, however, recorded decrease in the number of rainy days during BP-II. Monsoon season experienced high decrease in the number of rainy days as compared to the other seasons. BP-III didn't record any variation in number of rainy days.

Summarily, temperature regime depicted variation with the indication of decline. Increase in the maximum temperature was reflecting more prominent at the high elevated site, Shimla. Unlike this, decrease in the minimum temperature was reflecting more prominent at the low elevated site, Dehra Doon. Decrease in rainfall was recorded in the winter as well as in monsoon season. But, this decrease was not persistent one as Shimla recorded increase in the monsoon rainfall. There was no prominent change in number of rainy days at both the stations. Winter season experienced high inconsistency (high value of CV) in rainfall and temperature at Shimla. The station recorded high inconsistency in monthly minimum temperature and monthly rainfall as compared to Dehra Doon during 1930-90.

3.5 Spatial Climatic Variation analysis using Coefficient of Variation method

The climatic indicators i.e. temperature, rainfall etc. vary over the time as well as over space. The great topographic undulations and natural dividers, barriers forced these elements to vary from one place to another. The elevation is one of the most important factor behind the spatial variation recorded in the climatic parameters. Coefficient of variation is one of the best statistical method to calculate the spatial variability and it also provides data to analyze variability of two or more stations.

In this analysis all the stations were included but a common time period (1960-1990) was used as all the stations didn't have data for the same contemporary period and the time span was very short for many stations. Extrapolation for rainfall and temperature data series was done for Joshimath (1988-90), Manali (1960-67), Nainital (1980-90) and Tehri (1984-90). Three major climatic elements were included in this analysis viz. Monthly mean temperature, total monthly rainfall and monthly rainy days. Other elements inclusion was unnecessary and would make the analysis more complex and difficult to interpret. All the four seasons of a year winter, pre-monsoon, monsoon and post-monsoon were included along with the annual records. Table 3.7 systematically represents the information about the stations.

Table 3.7 Meteorological stations used in the spatial variability analysis using CV

Period	*Station*	*Variable*	*Season*
1956-1993	Bilaspur		
1950-2000	Dehra Doon	Mean Temperature	Winter
1951-1998	Dharamshala		Pre-Monsoon
1958-1987	Joshimath	Total Monthly Rainfall	Monsoon
1968-2000	Manali		Post-Monsoon
1953-1979	Nainital	Number of Rainy Days	Annual
1950-1992	Shimla		
1957-1983	Tehri		
	Note: variables and seasons are common to all the stations.		

Note: Period for each station denotes the total data availability

Table 3.8 Seasonal climatic variability using Coefficient of Variation (CV) method

Seasonal Spatial Variation in Mean Monthly Temperature

(1960-1990) (CV in Per Centages)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	7.25	4.50	2.46	4.25	2.25
Dehra Doon	5.53	4.28	2.10	3.68	2.11
Dharamshala	9.10	5.64	2.10	4.80	2.77
Joshimath	16.42	7.28	4.29	7.30	5.12
Manali	16.74	4.69	3.94	6.80	3.47
Nainital	11.57	5.63	2.02	5.62	2.52
Shimla	19.98	8.39	2.81	9.62	4.09
Tehri	5.13	3.49	2.03	3.57	1.76

Seasonal Spatial Variation in Total Monthly Rainfall

(1960-1990) (CV in Per Centages)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	57.25	76.95	36.93	65.29	28.17
Dehra Doon	52.97	84.19	21.05	92.25	16.05
Dharamshala	63.19	45.67	27.79	84.96	32.46
Joshimath	47.61	39.77	30.11	74.54	15.66
Manali	41.29	38.60	28.09	69.57	19.95
Nainital	68.28	54.51	18.56	73.44	15.24
Shimla	75.33	46.28	32.89	71.02	24.11
Tehri	48.04	42.67	25.15	52.90	16.44

Seasonal Spatial Variation in Monthly Number of Rainy Days

(1960-1990) (CV in Per Centages)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	45.14	45.15	25.68	55.26	18.86
Dehra Doon	35.78	52.47	14.80	67.19	10.77
Dharamshala	37.78	31.16	16.31	55.83	15.30
Manali	29.41	28.78	23.88	63.70	15.53
Nainital	47.16	41.47	12.90	60.19	10.85
Shimla	45.29	37.85	22.64	59.18	17.28
Tehri	39.14	38.66	16.31	41.03	11.06

Source: National Data Centre, IMD, Pune

3.5.1 Mean Monthly Temperature

Table 3.8 represents the spatial variability in climatic variables. Mean monthly average temperature recorded highest spatial variability during the winter season. Almost all the high elevated stations experienced high variability in the mean monthly temperature. Shimla, Manali and Nainital, are the stations located at a higher elevation as compared to the other stations, experienced high variability in the mean temperature. Moving from winter towards pre-monsoon and monsoon season, the variability decreases and lowest variability recorded in the monsoon season. After monsoon season once again it increases towards post-monsoon season. The annual spatial variability is quite low. Tehri and Shimla recorded minimum and maximum variability in the mean temperature, respectively. Figure 3.17 depicts the spatial variability in monthly mean temperature in the Western-Central Himalaya. Tehri is the only exception in the region situated at 1750 m (amsl) but having very low temperature variability annually and in winter season.

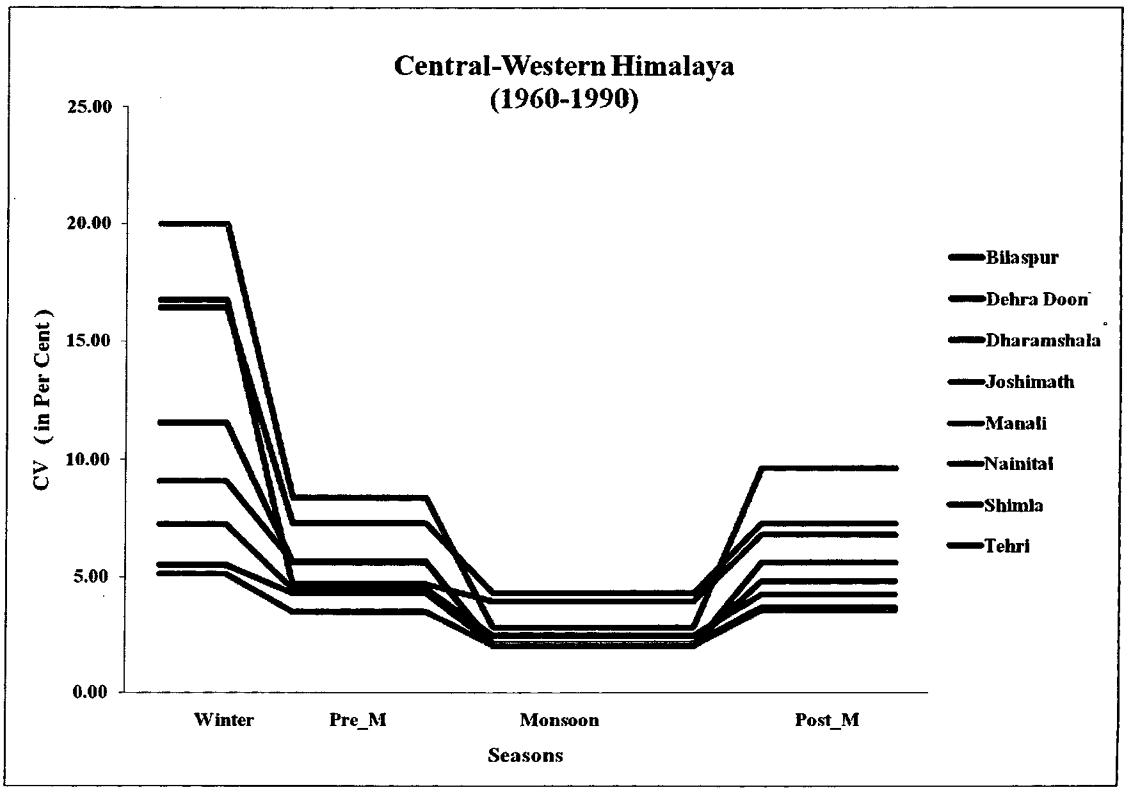


Figure 3.17: Seasonal spatial variability in mean monthly temperature.

Source: National Data Centre, IMD, Pune

3.5.2 Total Monthly Rainfall

Rainfall distribution in the Himalayan region is governed by many factors. The elevation, situation at windward or leeward side, situation in a valley or at an open space etc are some of the topographical and physiographical factors which affect the rainfall distribution or powered the variability in rainfall. Figure 3.18 represents the spatial variability in total monthly rainfall of the region. The Maximum variability recorded in the post-monsoon season. Nainital exceptionally, experienced a relatively high variability in the post-monsoon season. There was relatively very high variability in rainfall during pre-monsoon season. Dehra Doon and Bilaspur recorded exceptionally high variability in this season. Monsoon season recorded relatively lowest variability in rainfall. As the South-West monsoon commences with almost equal intensity over entire region. Therefore, variability in rainfall is very low in the monsoon season. The SW-Monsoon leads to temperature harmonizing effect which causes relatively less variability in temperature recorded during monsoon season.

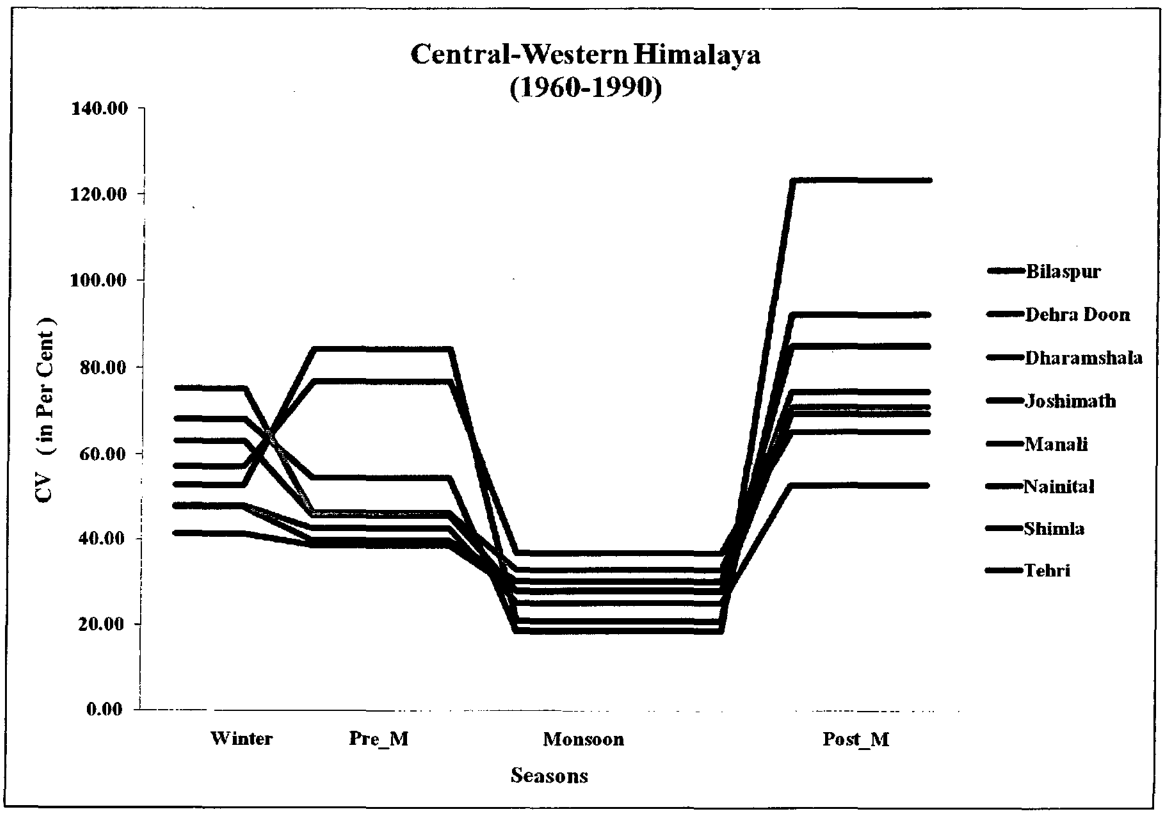


Figure 3.18: Seasonal spatial variability in total monthly rainfall.

Source: National Data Centre, IMD, Pune

3.5.3 Monthly Rainy Days (MRD)

Variability in rainy days experienced similarity with the variability in monthly rainfall. The post-monsoon season marked relatively high variability in the MRD. Tehri recorded relatively low variability in post-monsoon season. Manali recorded low variability in MRD during monsoon season. Pre-monsoon season recorded much spatial variability in MRD. Dehra Doon recorded relatively high variability in this season, followed by Bilaspur. Monsoon season experienced lowest variability in MRD. Shimla, Manali and Nainital recorded high variation as compared to other stations.

Rainfall and MRD are closely related to each other. That's why the spatial variation in rainfall and MRD were correlating to each other.

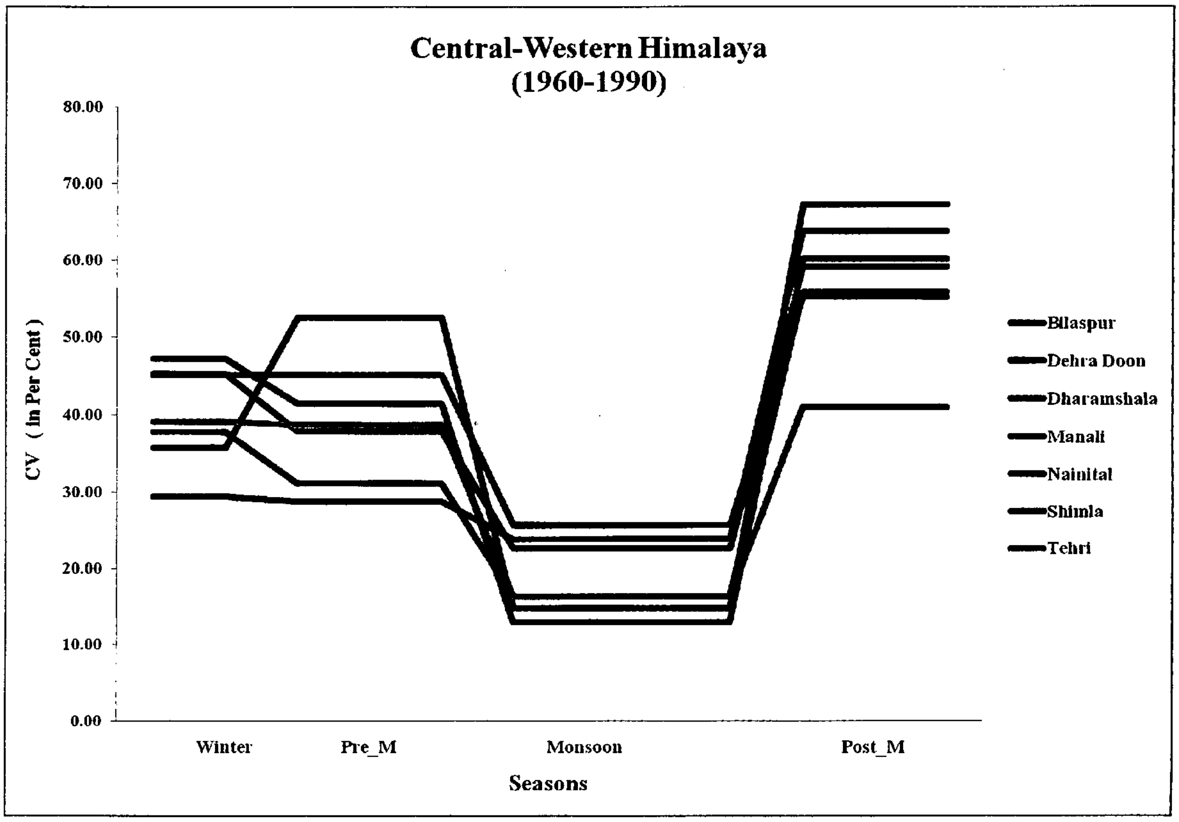


Figure 3.19: Seasonal spatial variability in monthly rainy days (MRD).

Source: National Data Centre, IMD, Pune

3.5.4 Results and Discussion

The spatial variation analysis incorporates the topographical undulations of the earth surface. Coefficient of variation, represented in the per cent form, is the best method to measure the spatial variation in the time series data. Some of the major results of the analysis are as follows;-

i. The high variation in altitude across the entire region strongly influenced the monthly mean temperature. The normal lapse rate and the situation of the site according to the windward or leeward and sun-facing and rain facing etc contributed to the evolution of variability in temperature. The stations having high elevation recorded relatively high variability as compared to the low elevated stations.

ii. Monsoon season recorded minimum variability in the mean temperature. As the South-West Monsoon proceeded towards the region, the temperature harmonizing effect leads to almost equalizing the monsoonal temperature of all the stations every year. Therefore, variability in temperature reduced from high winter to low monsoon.

iii. Rainfall is mainly influenced by the regional relief and Physiographic features. Post-monsoon rainfall experienced maximum variation in rainfall across the region followed by the winter rainfall. The western disturbance influenced rainfall led to such type of variability. Dehra Doon and Bilaspur experienced relatively high variability in rainfall during pre-monsoon season. Monsoon season marked with relatively low rainfall variability.

iv. The variability in monthly rainy days (MRD) is similar to the variability in rainfall. Relatively high variability in monthly rainfall recorded during post-monsoon season while low variability is marked in monsoon season.

v. Overall, relatively low variability in climatic parameters, such as rainfall and temperature is marked during monsoon season while the highest variability in mean monthly temperature is observed during winter season.

3.6 Chapter Summary and Conclusion

The cyclic fluctuations in climatic parameters suggest about the changing pattern of climate and on that basis the future climate become predictable with much accuracy. The Central-Western Himalaya, a part of the mighty Himalayan is the hot spot of the climate studies as the region has countless glaciers which are considered as the thermometer of the Earth. That's why the current study has immense importance.

The temporal-seasonal variation analysis is based on two methods i.e. the moving average and simple average method. Normalized Accumulated Departure from Mean (NADM) also used for the stations having short span data series. In this study moving average is used to see the variations in temperature and rainfall experienced by the meteorological stations over the period of time. Cyclic fluctuation recorded in the mean monthly maximum temperature. Shimla marked increasing trend in winter temperature while Joshimath recorded decrease in annual maximum temperature. Variation in mean monthly minimum temperature was recorded in the later-half of the last century. There were maximum fluctuations in temperature experienced by the region during 1940-55 and 1975-90. The last 30 years (1960-90) experienced relatively high variations in the mean monthly temperature with 1980-90 as the most prominent part of it. The Central Himalaya experienced relatively high variation in total monthly rainfall as compared to Western Himalaya. The Central Himalayan stations recorded decrease in rainfall in almost every season while Western Himalaya experienced cyclic fluctuations. Manali and Nainital experienced decline in monthly highest maximum temperature during the study (1968-00 and 1953-79, respectively) but Shimla recorded increasing trend throughout the study period (1901-1992). During 1960-66, Bilaspur recorded cyclic fluctuation in monthly lowest minimum temperature for all seasons. Dehra Doon experienced the same trend during 1982-88. Manali, Nainital and Tehri recorded mild fluctuations while Shimla experienced cyclic trends. Manali marked with much complex variations in highest rainfall while Shimla recorded relatively high variation in last 30 years.

Moving average filters the minor fluctuations in the time series data. The normalized accumulated departure from mean (NADM) method permits the distinction between periods of high and low values by clearly defining the limits. Beside this, the NADM curves permits visual as well as statistical comparison of unlike data series. Simple average method facilitate the comparison of two climatic or base line periods and identify the variation occurred in the second period over the first one. That's why for the variation analysis with quantified results, simple average method is much more appropriate and useful than other methods. After dividing the whole data series in two or three climatic periods or Base-line Periods (BPs); the simple average of each period compared with the next one will give absolute value of the variation in the data series. Because of unavailability of data for all the stations and for more focused analysis only two meteorological stations Shimla and Dehra Doon were included in the variation analysis by simple average method. Also less number of variables and less number of seasons were included to do more specific, rational and more productive analysis. Variation analysis highlighted some interesting results. Temperature regime marked decreasing trend. Increasing trend in maximum temperature was more prominent at the high elevated site, Shimla while the decreasing trend in minimum temperature became more prominent at the low elevated site, Dehra Doon. Decreasing trend in rainfall recorded during winter and monsoon season. But, this decrease was not persistent one as Shimla recorded increasing trend in the monsoon rainfall. Number of rainy days didn't reflect any major change.

Temporal analysis suggests about the station specific variations or trends in the data series. It doesn't compare one station to another in terms of variation faced by each one. Spatial variation analysis fulfills this quarry. The Coefficient of Variation is the method to calculate variability. It's a very rational and accurate statistical technique used for quantification of variability in time series data. The elevation is one of the most important factor behind the spatial variation recorded in the climatic parameters. Site with high elevation recorded relatively high variability in temperature as compared to low elevated stations. Monsoon season recorded minimum variability in mean temperature. As the South-West Monsoon proceeded towards the region, the temperature harmonizing effect leads to almost equalizing the monsoonal temperature of all the stations every year. Therefore, variability in temperature reduced from high winter to low monsoon. Relatively low variability in climatic parameters, such as rainfall and temperature is marked during monsoon season while the highest variability in mean monthly temperature is observed during winter season.

Chapter Four

Trends in the climate of the Central-Western Himalaya

4.1 Introduction

The analysis of temporal and spatial variations in climatic elements suggest about the things which already had taken place. This analysis covered the past or the recent past. But, it didn't look in the future for the behaviour of the climatic variables. The vital information is provided by the trend analysis carried out with the help of many non-parametric and statistical methods. The least square regression line method is the best technique for trend analysis. Mann-Kendal's nonparametric test is also used by the climatologists to assess the trends of climatic variables. The simple linear regression method was used for the trend analysis and for visual representation of climatic element, the best-fit line was used. Both the techniques were conducted with the help of Microsoft Excel workbook to determine the nature of trends i.e. whether positive or negative. The b-values were calculated while putting the time series data (years) as the independent variable and climatic data (temperature, rainfall etc.) as the dependent variable. The b-value in a simple linear regression model represents the slope of the regression line which explicitly indicates trend in the dependent data series. The equation for the slope of the regression line is:

$$b = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sum(x-\bar{x})^2}$$

Where, x and y are independent and dependent (in Y on X regression line i.e., y = a + bx) variables respectively. The results of trend analysis were scrutinized with the help of F-test. The confidence levels derived with the help of F-test, determined whether a trend is a significant or insignificant.

4.2 Trend Analysis using Simple Linear Regression method

Trend analysis provides information about the momentum of data series. Simple linear regression method is one of the best method for the trend analysis of a time series data. Trends in temperature and rainfall data of the Central-Western Himalaya can give very sound bases for the prediction of the near future climate of the Himalayan region. On the basis of climatic parameters, the analysis is divided in two parts;-

1. Trends in temperature and rainfall and number of rainy days data series.
2. Trends in extreme events such as highest maximum, lowest minimum and highest monthly rainfall.

The basic information about the meteorological stations used in this analysis is given in Table 4.1.

Table 4.1: Meteorological stations used in the Simple Linear Regression analysis

Station	Height (in m)	Data Span	Variables	Seasons	Months
Bilaspur	670	1956-1993	Maximum Temperature		
Dharamshala	1457	1951-1998	Minimum Temperature	Winter	Jan-Feb
Manali	1950	1968-2000	Mean Temperature	Pre-Monsoon	March-May
Shimla	2397	1901-1992	Highest Maximum Temperature	Monsoon	June-Sept
Dehra Doon	640	1928-2000	Lowest Minimum Temperature	Post-Monsoon	Oct-Dec
Joshimath	960	1958-1987	Total Monthly Rainfall	Annual	
Tehri	1750	1957-1983	Highest Monthly Rainfall		
Nainital	1938	1953-1979	Number of Rainy Days		

Note: Variables and seasons are common to all the stations.

4.2.1 Mean Monthly Maximum Temperature

Table 4.2 and Figure 4.1 and 4.2 show trends in mean maximum temperature of the region. With the station wise perspective, Shimla recorded increasing trends in the maximum temperature for all the four seasons (significant at 95 % confidence level). Unlike this, Joshimath recorded decreasing trends throughout all the seasons of the year (significant at 95 % confidence level). The post-monsoon season recorded increasing trend at almost all the stations except Manali and Joshimath. In Himachal Pradesh, monsoon and annual maximum temperature marked increasing trend but Manali recorded decreasing trend during pre-monsoon and post-monsoon season (significant at 95 % confidence level). Uttarakhand recorded decreasing trend in monsoon maximum temperature. Tehri recorded increasing trend in monsoon. Dehra Doon recorded increasing trend in the winter and post-monsoon season but recorded decrease in the pre-monsoon and monsoon period (significant at 95 % confidence level).

Table 4.2: Trend analysis of mean monthly maximum, minimum and mean temperature using simple linear regression method

Trend analysis of Maximum Temperature

(b-values)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	-0.009	0.008	0.019	0.007	0.008
Dharamshala	0.019	-0.002	0.002	0.024	0.008
Manali	0.021	-0.021	0.025	-0.026	0.002
Shimla	0.027	0.023	0.020	0.037	0.025
Dehra Doon	0.011	-0.009	-0.002	0.013	0.002
Joshimath	-0.082	-0.122	-0.108	-0.032	-0.090
Tehri	0.042	0.044	-0.019	0.012	0.017
Nainital	-0.019	-0.033	-0.010	0.020	-0.013

Trend analysis of Maximum Temperature

(trends)

Years	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
1956-1993	Bilaspur	670	(-)	(+)	(+)*	(+)	(+)
1951-1998	Dharamshala	1457	(+)*	(-)	(+)	(+)*	(+)
1968-2000	Manali	1950	(+)*	(-)*	(+)*	(-)*	(+)*
1901-1992	Shimla	2397	(+)*	(+)*	(+)*	(+)*	(+)*
1928-2000	Dehra Doon	640	(+)*	(-)	(-)	(+)*	(+)
1958-1987	Joshimath	960	(-)*	(-)*	(-)*	(-)*	(-)*
1957-1983	Tehri	1750	(+)*	(+)*	(-)*	(+)	(+)*
1953-1979	Nainital	1938	(-)	(-)*	(-)*	(+)*	(-)*

Trend analysis of Minimum Temperature

(b-values)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	0.012	0.005	-0.010	0.025	0.005
Dharamshala	-0.023	-0.040	-0.021	-0.025	-0.028
Manali	0.029	-0.036	0.038	0.013	0.011
Shimla	-0.0010	-0.0009	-0.0097	-0.0003	-0.0037
Dehra Doon	0.001	-0.010	-0.009	0.006	-0.004
Joshimath	-0.015	-0.027	-0.044	0.013	-0.024
Tehri	0.061	0.051	-0.014	0.026	0.027
Nainital	-0.016	-0.035	-0.048	0.023	-0.024

Trend analysis of Minimum Temperature

(trends)

Years	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
1956-1993	Bilaspur	670	(+)*	(+)	(-)	(+)*	(+)
1951-1998	Dharamshala	1457	(-)*	(-)*	(-)*	(-)*	(-)*
1968-2000	Manali	1950	(+)*	(-)*	(+)*	(+)	(+)*
1901-1992	Shimla	2397	(-)	(-)	(-)	(-)	(-)
1928-2000	Dehra Doon	640	(+)	(-)	(-)	(+)	(-)
1958-1987	Joshimath	960	(-)*	(-)*	(-)*	(+)*	(-)*
1957-1983	Tehri	1750	(+)*	(+)*	(-)	(+)*	(+)*
1953-1979	Nainital	1938	(-)*	(-)*	(-)*	(+)*	(-)*

Trend analysis of Mean Monthly Temperature

(b-values)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	0.002	0.006	0.004	0.016	0.007
Dharamshala	-0.002	-0.021	-0.010	0.000	-0.010
Manali	0.025	-0.028	0.031	-0.008	0.007
Shimla	0.013	0.011	0.005	0.019	0.011
Dehra Doon	0.006	-0.009	-0.006	0.010	-0.001
Joshimath	-0.048	-0.075	-0.076	-0.010	-0.057
Tehri	0.052	0.047	-0.017	0.019	0.022
Nainital	-0.017	-0.034	-0.029	0.022	-0.019

Trend analysis of Mean Monthly Temperature

(trends)

Years	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
1956-1993	Bilaspur	670	(+)	(+)	(+)	(+)*	(+)
1951-1998	Dharamshala	1457	(-)	(-)*	(-)*	(+)	(-)*
1968-2000	Manali	1950	(+)*	(-)*	(+)*	(-)	(+)
1901-1992	Shimla	2397	(+)*	(+)*	(+)	(+)*	(+)*
1928-2000	Dehra Doon	640	(+)	(-)	(-)	(+)*	(-)
1958-1987	Joshimath	960	(-)*	(-)*	(-)*	(-)*	(-)*
1957-1983	Tehri	1750	(+)*	(+)*	(-)*	(+)*	(+)*
1953-1979	Nainital	1938	(-)*	(-)*	(-)*	(+)*	(-)*

Source: National Data Centre, IMD, Pune

(-) increasing trend

(+) decreasing trend

* significant at 95 % confidence level

4.2.2 Mean Monthly Minimum Temperature

Uttarakhand experienced decreasing trend in monsoon mean monthly minimum temperature. Tehri had marked increasing trend in all the seasons of a year except in monsoon season (significant at 95 % confidence level). Post-monsoon season had reflected increase in the minimum temperature for all the stations. However, Himachal Pradesh experienced striking differences in trends of maximum temperature to that of minimum temperature. Manali recorded increasing trend in minimum as well as in maximum temperature (significant at 95 % confidence level). The pre-monsoon season marked decreasing trend in minimum temperature. Unexpectedly, Shimla reflected increasing trends in the maximum temperature but experienced a decreasing trend in minimum temperature for the all seasons. Although these trends didn't found much significance (insignificant at 95 % confidence level) in the F-test still they had raised some of the important questions. Why Shimla experienced the just opposite temperature regime for the maximum and minimum temperature? Why Himachal Pradesh recorded increasing trends in both maximum and minimum temperature as compared to the Uttarakhand? Monsoon season marked with dramatic changes at all stations. Himachal Pradesh recorded increasing trend in minimum temperature while Uttarakhand experienced decreasing trends at its all respective meteorological stations.

4.2.3 Mean Monthly Temperature

The same response was experienced with the mean monthly average temperature. Again, Uttarakhand recorded increasing trends in the average temperature as compared to Himachal Pradesh. Only Tehri recorded increasing trends in mean temperature in all seasons except in monsoon season. Joshimath replicated its decreasing trend in maximum temperature as well as in mean temperature. Nainital recorded increasing trend during post-monsoon season. Himachal Pradesh reflected increasing trend in mean temperature. Shimla and Bilaspur recorded positive trend in mean temperature throughout the year (significant at 95 % confidence level). Dharamshala recorded increasing trend during post-monsoon season. The monsoon mean temperature reflected almost opposite trends in Himachal Pradesh and Uttarakhand. Uttarakhand marked decreasing trend at all the stations while Himachal Pradesh, except Dharamshala, recorded increasing trends at all the stations.

Overall, the temperature regime displayed increasing trends in Himachal Pradesh and a decreasing trend in Uttarakhand in maximum and minimum temperature. Maximum and mean monthly temperature depicted significantly increasing trends in the Himachal Pradesh with Shimla and Bilaspur recorded increase during all the seasons. The monsoon and winter temperature depicted an increasing trend as compared to other seasons for the same state. Uttarakhand recorded almost reverse of these trends. Decreasing trend in mean temperature was observed in the state. Joshimath recorded decreasing trends in both maximum and mean monthly temperature regimes. Tehri recorded an increasing trend in all the seasons except in monsoon season. Dehra Doon, more or less, showed increasing trends in the maximum and mean monthly temperature regimes. The monsoon season again marked a deceasing trend at Dehra Doon. The minimum temperature showed decreasing trend in Uttarakhand while similar trend was also observed in Himachal Pradesh. The monsoon season recorded decreasing trend at all the stations of Uttarakhand but in Himachal Pradesh, Manali was the only exception in this regime, which recorded increasing trend.

4.2.4 Total Monthly Rainfall

The entire Central-Western Himalayan region recorded drastic decreasing trends in the total monthly rainfall. Monsoon and post-monsoon rainfall experienced decreasing trend. Since monsoon rainfall constitutes a major chunk of the total annual rainfall, that's why the annual rainfall also recorded decreasing trend in the region. Only pre-monsoon rainfall displayed an increasing trend for all the stations of the region (significant at 95 % confidence level). Tehri recorded positive trend in winter rainfall, which is an exception among other stations of the Uttarakhand. The decreasing trend at Dehra Doon was significant at the 95 per cent level of confidence. Himachal Pradesh recorded increasing trend rainfall during pre-monsoon (at all stations) and post-monsoon season (only at Shimla and Bilaspur). But the sharp decreasing trend in monsoon rainfall and winter rainfall, which is received from the western disturbances, caused the annual rainfall to follow a decline. The annual rainfall marked decreasing trend for the state. Decreasing trends in the monsoon rainfall is prime point of concern as not only the economy of the region but also the normal life is fully dependent on the monsoon rainfall and subsequent storage of that.

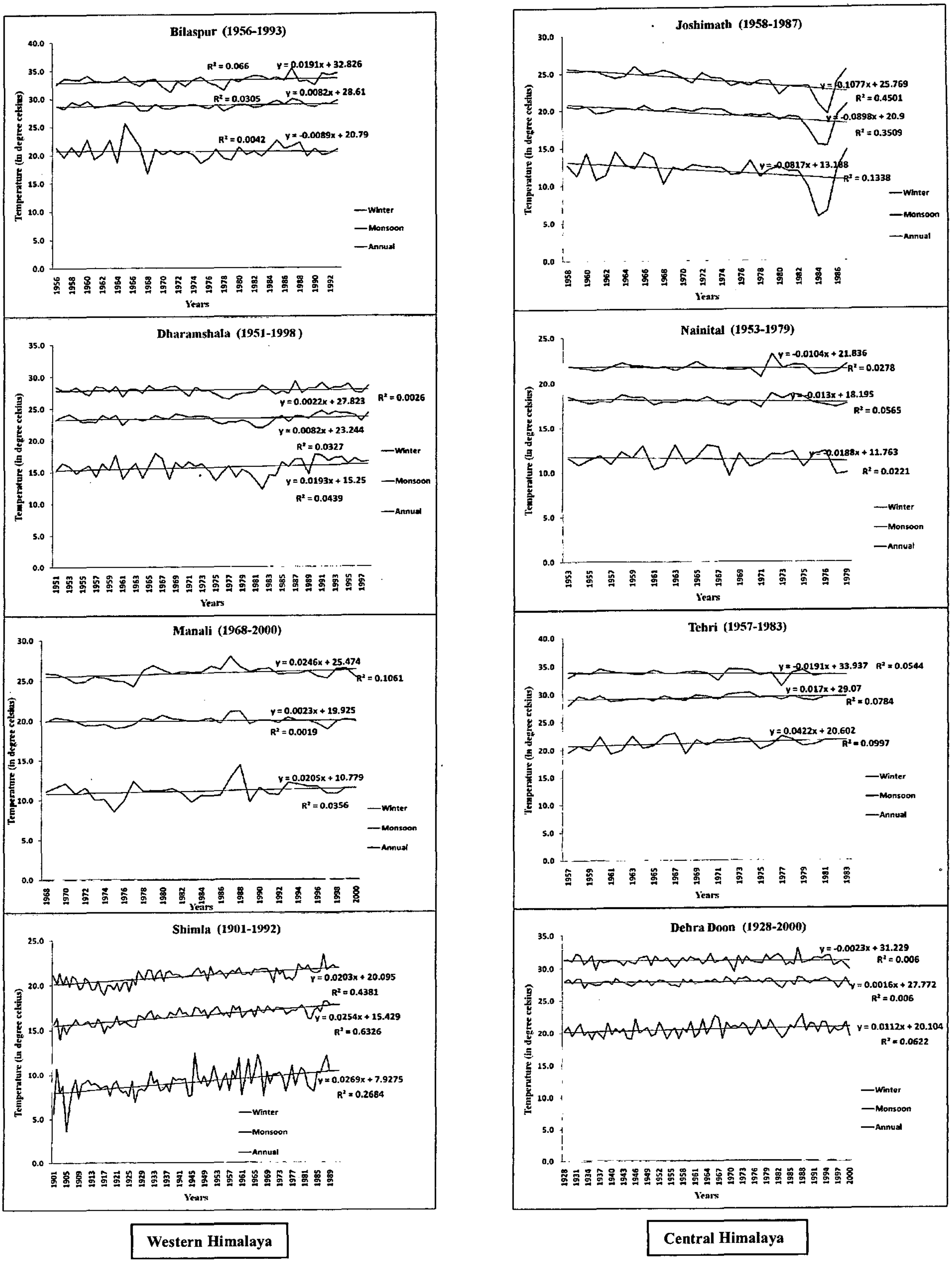
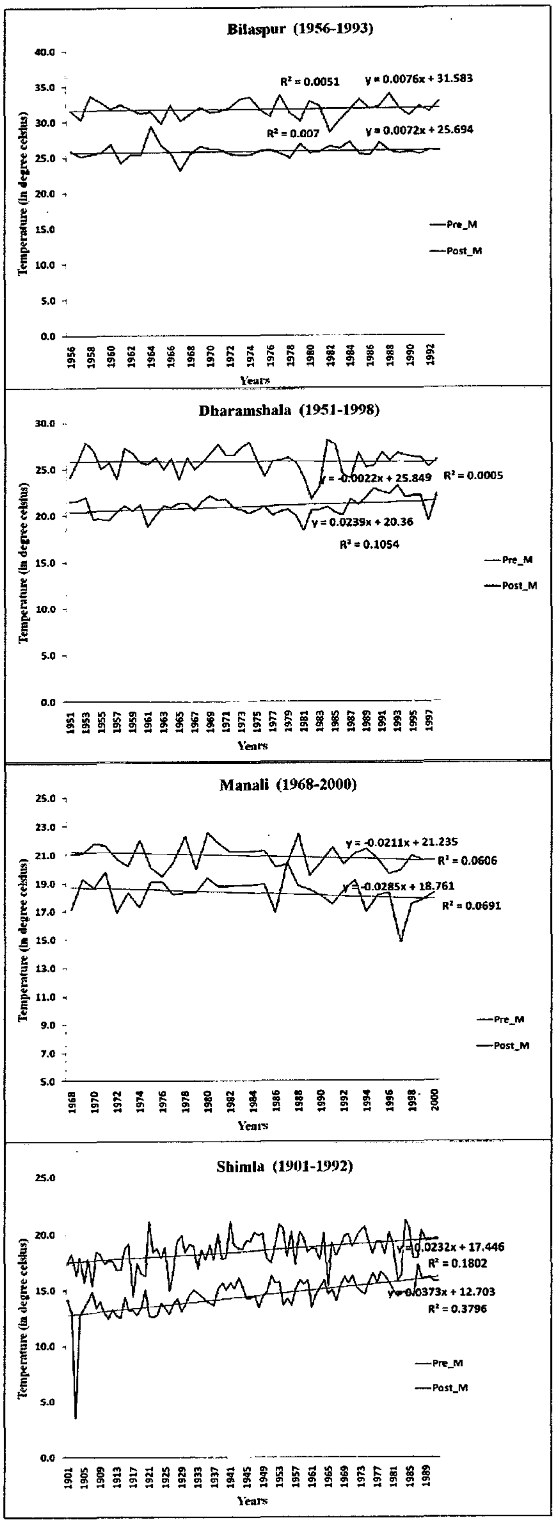
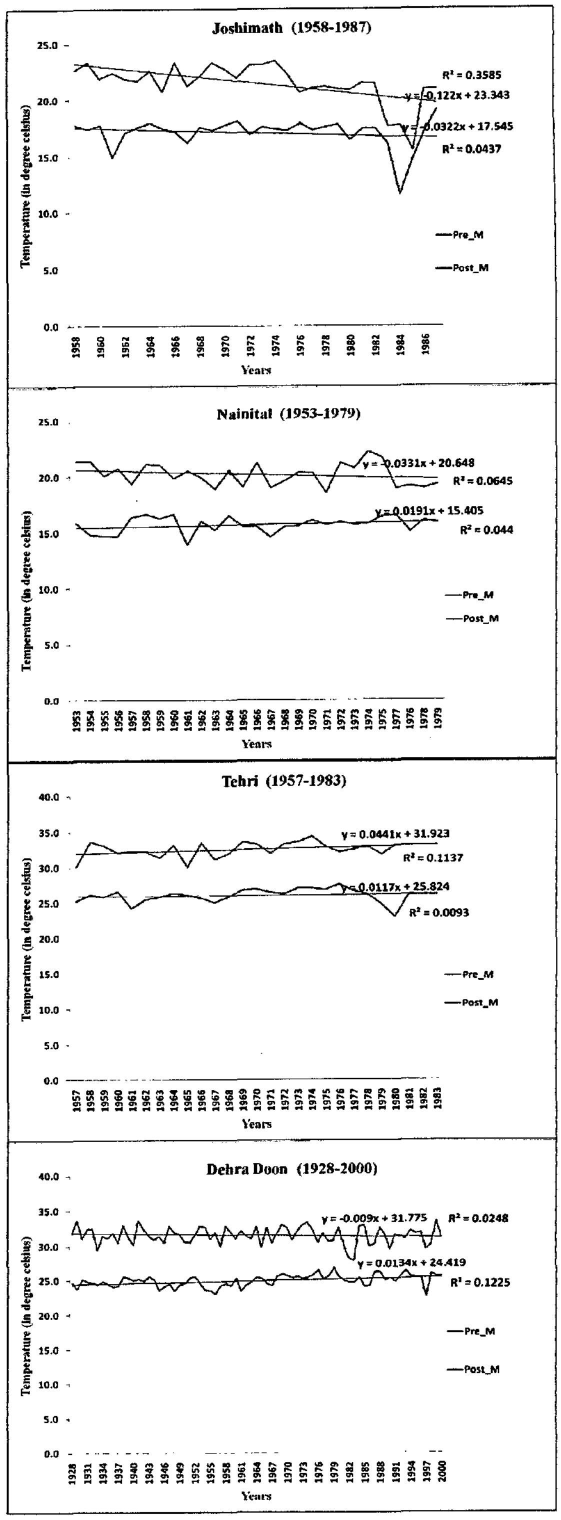


Figure 4.1: Trend in mean monthly maximum temperature.

Source: National Data Centre, IMD, Pune



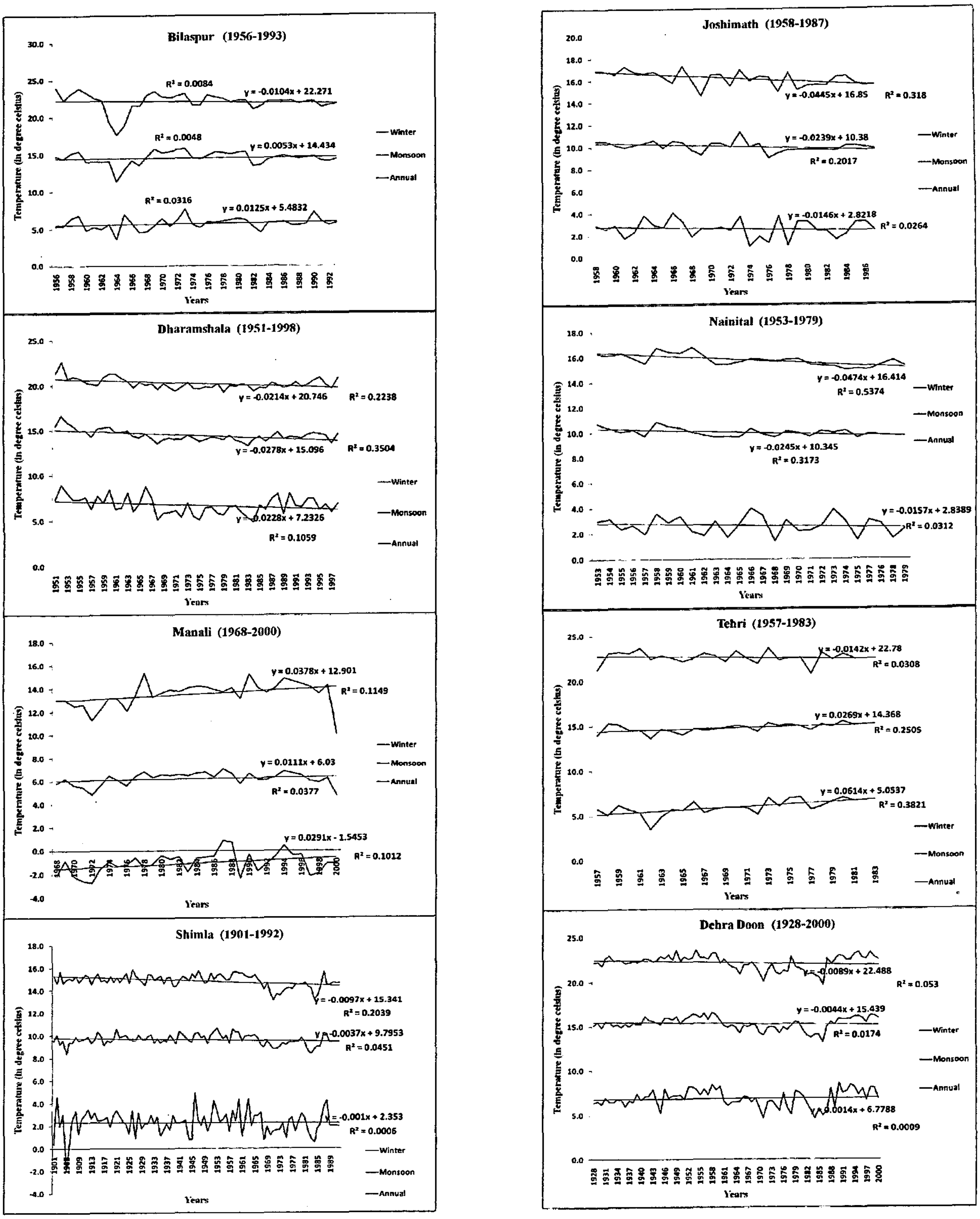
Western Himalaya



Central Himalaya

Figure 4.2: Trend in mean monthly maximum temperature.

Source: National Data Centre, IMD, Pune

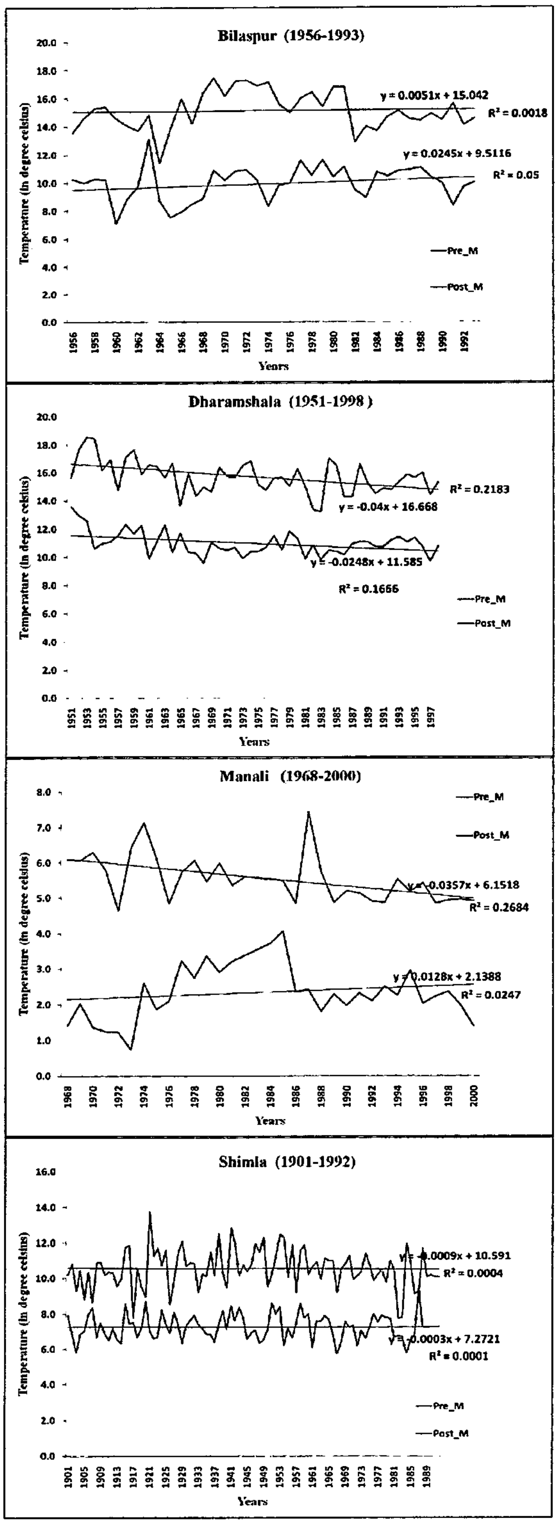


Western Himalaya

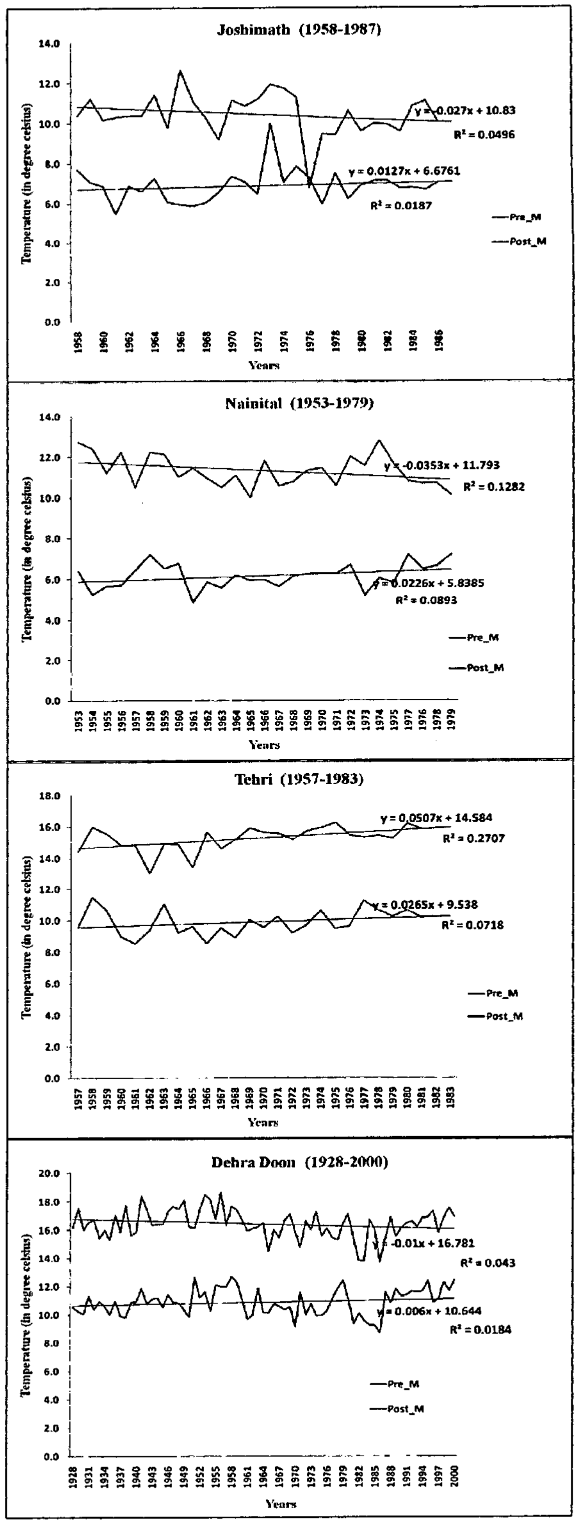
Central Himalaya

Figure 4.3: Trend in mean monthly minimum temperature.

Source: National Data Centre, IMD, Pune



Western Himalaya



Central Himalaya

Figure 4.4: Trend in mean monthly minimum temperature.

Source: National Data Centre, IMD, Pune

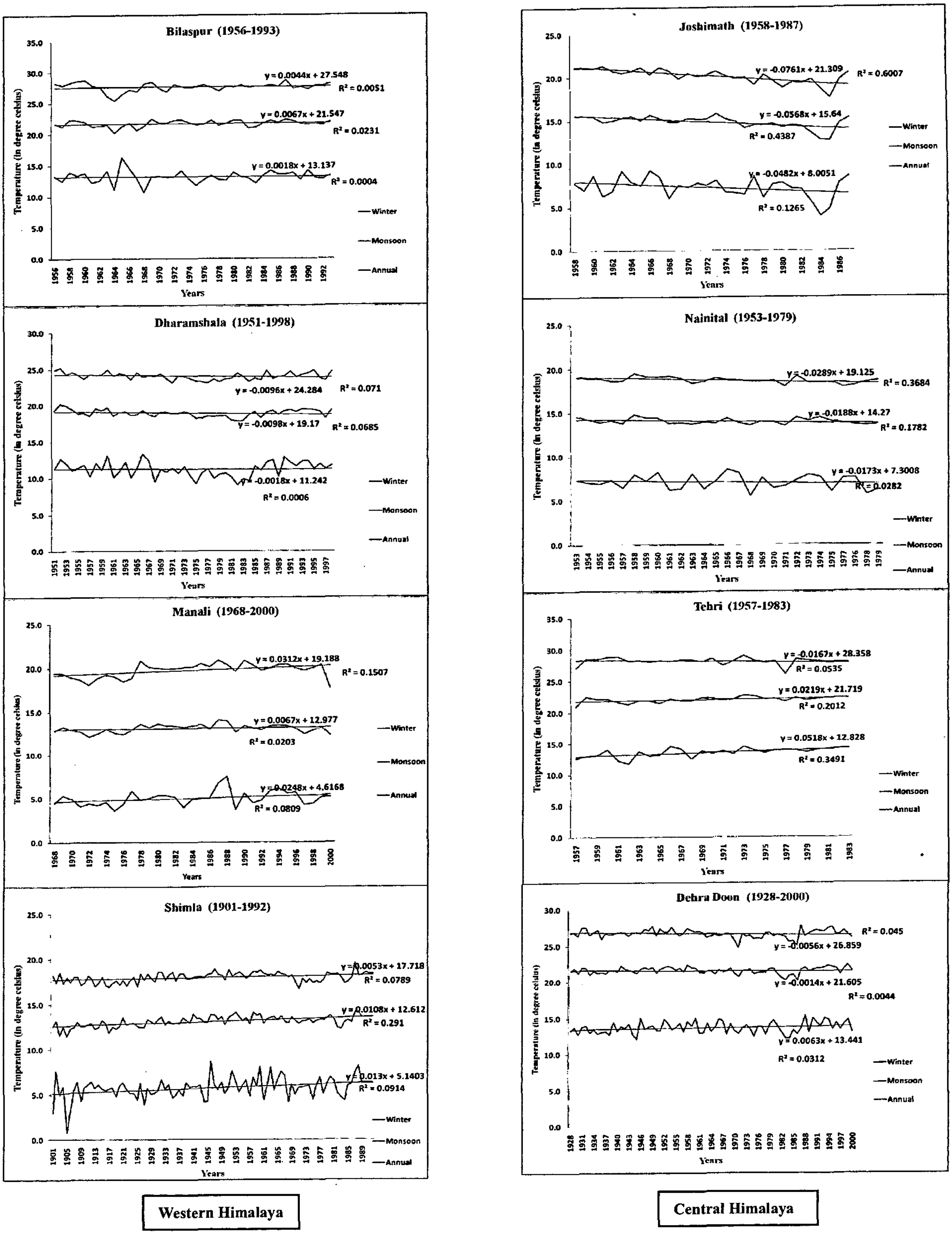
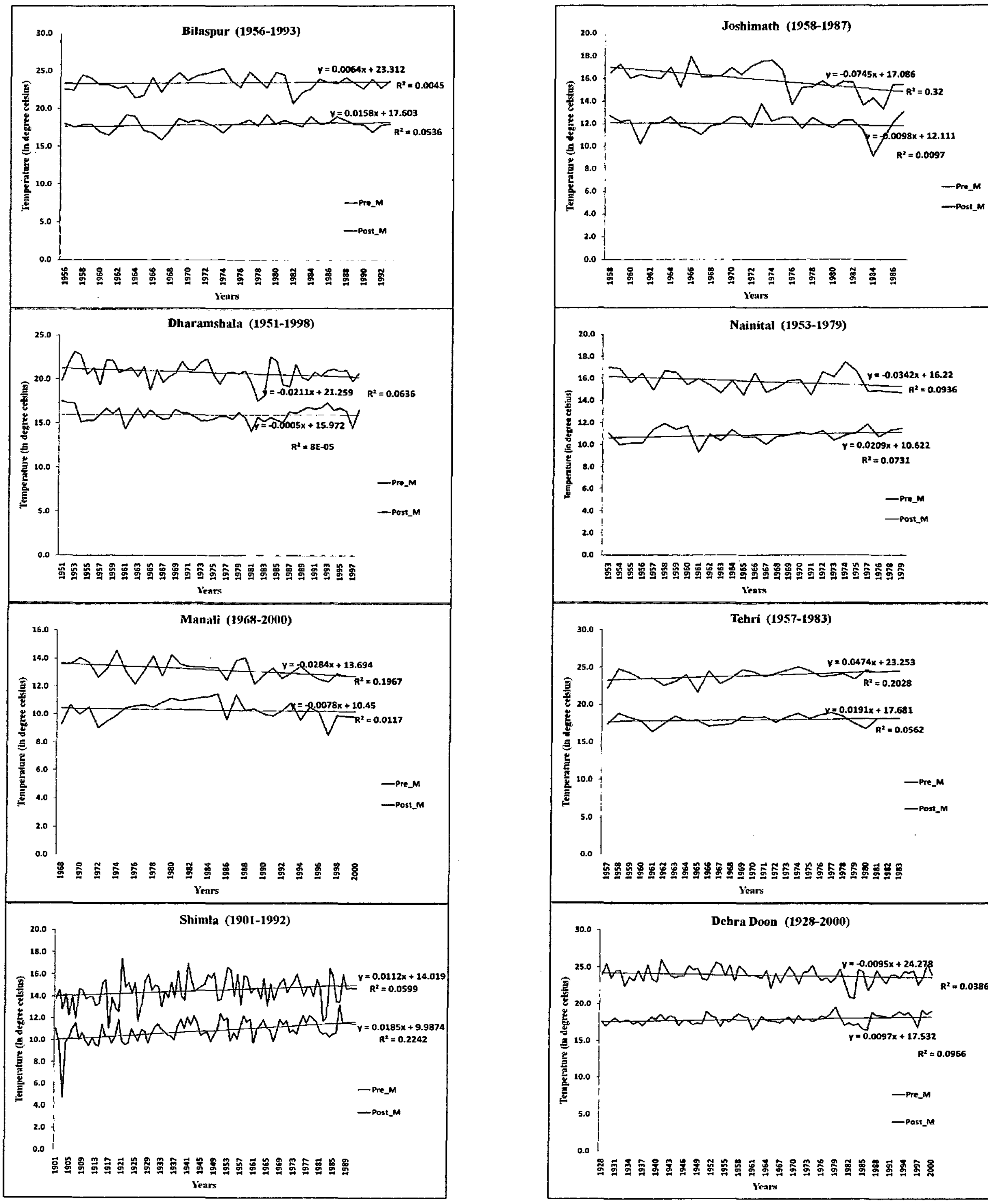


Figure 4.5: Trend in mean monthly temperature.

Source: National Data Centre, IMD, Pune



Western Himalaya

Central Himalaya

Figure 4.6: Trend in mean monthly temperature.

Source: National Data Centre, IMD, Pune

Table 4.3: Trend analysis of total monthly rainfall and monthly rainy days (MRD) using simple linear regression method

Trend analysis of Monthly Rainfall

(b-values)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	-0.022	0.976	-2.551	0.113	-0.572
Dharamshala	-0.531	0.561	-3.440	-0.456	-1.784
Manali	-0.400	0.411	-0.274	-0.075	-0.326
Shimla	-0.486	0.021	-0.084	0.054	-0.118
Dehra Doon	-0.271	0.348	-0.481	-0.054	-0.136
Joshimath	-1.772	1.637	-2.369	-0.805	-0.843
Tehri	0.221	0.632	-0.694	-0.202	-0.055
Nainital	-1.599	0.669	-2.101	-4.423	-1.661

Trend analysis of Monthly Rainfall

(trends)

Years	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
1956-1993	Bilaspur	670	(-)	(+)*	(-)*	(+)*	(-)*
1951-1998	Dharamshala	1457	(-)*	(+)*	(-)*	(-)*	(-)*
1968-2000	Manali	1950	(-)*	(+)*	(-)	(-)	(-)*
1901-1992	Shimla	2397	(-)*	(+)	(-)	(+)	(-)
1928-2000	Dehra Doon	640	(-)	(+)	(-)*	(-)	(-)
1958-1987	Joshimath	960	(-)*	(+)*	(-)*	(-)*	(-)*
1957-1983	Tehri	1750	(+)	(+)*	(-)*	(-)*	(-)
1953-1979	Nainital	1938	(-)*	(+)*	(-)*	(-)*	(-)*

Trend analysis of Monthly Rainy Days

(b-values)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	0.009	0.050	-0.041	0.001	0.002
Dharamshala	-0.026	0.021	0.020	-0.006	-0.003
Manali	-0.073	0.060	-0.080	-0.030	-0.031
Shimla	-0.024	0.001	-0.030	0.000	-0.015
Dehra Doon	-0.002	0.016	-0.002	-0.004	0.003
Joshimath	DNA	DNA	DNA	DNA	DNA
Tehri	0.043	0.069	0.012	-0.016	0.030
Nainital	-0.062	0.056	-0.093	-0.044	-0.037

Trend analysis of Monthly Rainy Days

(trends)

Years	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
1956-1993	Bilaspur	670	(+)	(+)*	(-)*	(+)	(+)
1951-1998	Dharamshala	1457	(-)*	(+)*	(+)*	(-)	(-)
1968-2000	Manali	1950	(-)*	(+)*	(-)*	(-)*	(-)*
1901-1992	Shimla	2397	(-)*	(+)	(-)*	(+)	(-)*
1928-2000	Dehra Doon	640	(-)	(+)*	(-)	(-)	(+)
1958-1987	Joshimath	960	DNA	DNA	DNA	DNA	DNA
1957-1983	Tehri	1750	(+)*	(+)*	(+)*	(-)*	(+)*
1953-1979	Nainital	1938	(-)*	(+)*	(-)*	(-)*	(-)*

Source: National Data Centre, IMD, Pune

(DNA; Data Not Available)

(-) increasing trend
(+) decreasing trend
* significant at 95 % confidence level

4.2.5 Monthly Rainy Days (MRD)

The monthly rainy days in the region displayed cyclic trends. The pre-monsoon data series depicted increasing trend in monthly rainy days. In Himachal Pradesh rainy days experienced decreasing trend and subsequently annual data series displayed the same trend during monsoon and winter seasons. Number of rainy days record was unavailable for the trend analysis at Joshimath station of Uttarakhand. The trend analysis results for Number of rainy days was much similar to that of the monthly rainfall.

The rainfall scenario is much evident in Uttarakhand than Himachal Pradesh. A decreasing trend in monsoon rainfall is common for all the stations in the region which consequently marked a decreasing trend in annual rainfall in the Central-Western Himalaya. Uttarakhand experienced decreasing trend in rainfall during monsoon and post-monsoon season. The winter season reflected a significant decreasing trend in monthly rainfall in Uttarakhand (except at Tehri). Himachal Pradesh experienced decreasing trend in monsoon, winter and annual rainfall. The pre-monsoon rainfall, interestingly, showed increasing trend at all the meteorological stations of the region (significant at 95 % confidence level). Number of rainy days is directly correlated with the monsoon rainfall. The trend analysis results of monthly rainfall and rainy days are highly similar to each-other. The monthly rainy days experienced decreasing trend during monsoon and winter seasons in the state of Himachal Pradesh while Uttarakhand reflected decreasing trend in rainy days during post-monsoon season.

4.2.6 Trend analysis of extreme events

4.2.6.1 Monthly Highest Maximum Temperature

The Western Himalaya reflected significant increasing trend in highest maximum temperature. An increasing trend in monthly highest maximum temperature recorded in Himachal Pradesh as well as in Uttarakhand. Shimla and Dharamshala recorded increasing trends for the all seasons (significant at 95 % confidence level). In Uttarakhand, Nainital recorded decreasing trends throughout the year. Tehri recorded increasing trend in highest maximum temperature during all seasons except in monsoon season. Himachal Pradesh recorded increasing trends in highest maximum temperature during monsoon season at all stations while Uttarakhand recorded decreasing trends at all stations (for Manali, Shimla and Tehri, results significant at 95 % confidence level). Overall, Himachal Pradesh experienced significant increase in the highest maximum temperature while Uttarakhand insignificant decreasing trend.

4.2.6.2 Monthly Lowest Minimum Temperature

In Himachal Pradesh, Shimla and Dharamshala recorded decreasing trend in the lowest minimum temperature. Dharamshala (except in winter season) (significant at 95 % confidence level) and Shimla (except in winter and pre-monsoon seasons) recorded significant decreasing trend in monthly lowest minimum temperature for all the seasons. An increasing trend in the lowest minimum temperature recorded during winter and pre-monsoon season at all the stations in Himachal Pradesh except Dharamshala. Manali and Bilaspur recorded increasing trend in lowest minimum temperature during all seasons (significant at 95 % confidence level). In Uttarakhand, the winter and post-monsoon season reflected increasing trend in the lowest minimum temperature. Tehri marked increasing trend in annual lowest minimum temperature (significant at 95 % confidence level). Dehra Doon and Shimla both recorded decreasing trend in monsoon lowest minimum temperature but increasing trend during winter season.

Table 4.4: Trend analysis of extreme events using simple linear regression method

Trend analysis of Highest Maximum Temperature

(b-values)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	-0.008	-0.011	0.006	-0.016	-0.006
Dharamshala	0.014	0.005	0.001	0.024	0.009
Manali	-0.013	-0.054	0.021	-0.050	-0.019
Shimla	0.034	0.028	0.030	0.035	0.031
Dehra Doon	0.012	-0.013	-0.004	0.012	-0.010
Joshimath	DNA	DNA	DNA	DNA	DNA
Tehri	0.042	0.069	-0.025	0.034	0.026
Nainital	-0.057	-0.010	-0.004	-0.015	-0.018

Trend analysis of Highest Maximum Temperature

(trends)

Years	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
1956-1993	Bilaspur	670	(-)	(-)*	(+)	(-)*	(-)
1951-1998	Dharamshala	1457	(+)*	(+)	(+)	(+)*	(+)
1968-2000	Manali	1950	(-)*	(-)*	(+)*	(-)*	(-)*
1901-1992	Shimla	2397	(+)*	(+)*	(+)*	(+)*	(+)*
1928-2000	Dehra Doon	640	(+)*	(-)*	(-)	(+)*	(-)*
1958-1987	Joshimath	960	DNA	DNA	DNA	DNA	DNA
1957-1983	Tehri	1750	(+)*	(+)*	(-)*	(+)*	(+)*
1953-1979	Nainital	1938	(-)*	(-)	(-)	(-)*	(-)*

Trend analysis of Lowest Minimum Temperature

(b-values)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	0.038	0.020	0.033	0.047	0.033
Dharamshala	0.003	-0.007	-0.020	-0.029	-0.013
Manali	0.042	0.002	0.015	0.028	0.019
Shimla	0.002	0.001	-0.009	-0.009	-0.004
Dehra Doon	0.005	-0.011	-0.010	0.006	-0.004
Joshimath	DNA	DNA	DNA	DNA	DNA
Tehri	0.035	0.067	0.009	0.043	0.037
Nainital	0.004	-0.053	-0.060	0.029	-0.029

Trend analysis of Lowest Minimum Temperature

(trends)

Years	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
1956-1993	Bilaspur	670	(+)*	(+)*	(+)*	(+)*	(+)*
1951-1998	Dharamshala	1457	(+)	(-)	(-)*	(-)*	(-)*
1968-2000	Manali	1950	(+)*	(+)	(+)*	(+)*	(+)*
1901-1992	Shimla	2397	(+)	(+)	(-)	(-)	(-)
1928-2000	Dehra Doon	640	(+)	(-)*	(-)*	(+)	(-)
1958-1987	Joshimath	960	DNA	DNA	DNA	DNA	DNA
1957-1983	Tehri	1750	(+)*	(+)*	(+)	(+)*	(+)*
1953-1979	Nainital	1938	(+)	(-)*	(-)*	(+)*	(-)*

Trend analysis of Highest Monthly Rainfall

(b-values)

Station	Winter	Pre_M	Monsoon	Post_M	Annual
Bilaspur	0.027	0.191	-0.096	0.171	0.050
Dharamshala	-0.071	-0.048	-0.292	-0.181	-0.154
Manali	-0.058	0.004	0.417	0.054	0.128
Shimla	0.002	0.001	-0.009	-0.009	-0.004
Dehra Doon	-0.138	0.094	0.016	0.016	0.003
Joshimath	DNA	DNA	DNA	DNA	DNA
Tehri	0.186	-0.075	-0.229	0.140	-0.041
Nainital	-0.134	-0.078	-0.310	-1.891	-0.482

Trend analysis of Highest Monthly Rainfall

(trends)

Years	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
1956-1993	Bilaspur	670	(+)*	(+)*	(-)*	(+)*	(+)*
1951-1998	Dharamshala	1457	(-)*	(-)*	(-)*	(-)*	(-)*
1968-2000	Manali	1950	(-)*	(+)	(+)*	(+)*	(+)*
1901-1992	Shimla	2397	(+)	(+)	(-)	(-)	(-)
1928-2000	Dehra Doon	640	(-)*	(+)*	(+)	(+)	(+)
1958-1987	Joshimath	960	DNA	DNA	DNA	DNA	DNA
1957-1983	Tehri	1750	(+)*	(-)*	(-)*	(+)*	(-)*
1953-1979	Nainital	1938	(-)*	(-)*	(-)*	(-)*	(-)*

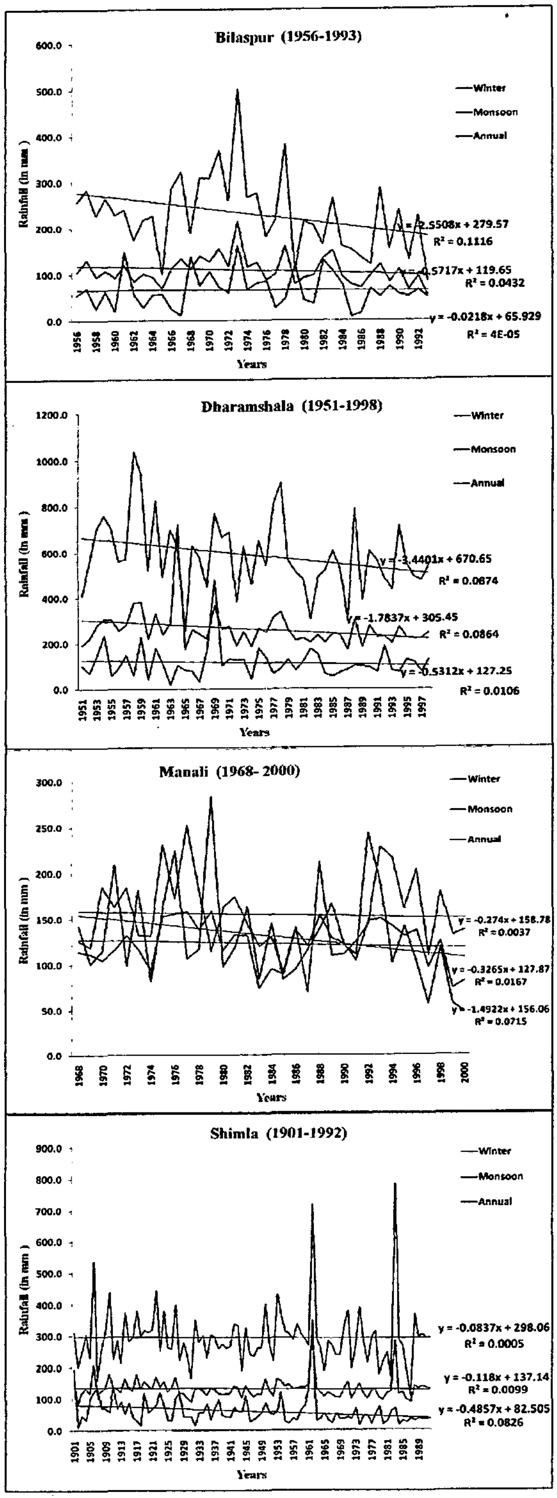
Source; National Data Centre, IMD, Pune **(DNA; Data Not Available)**

(-) increasing trend
(+) decreasing trend
* significant at 95 % confidence level

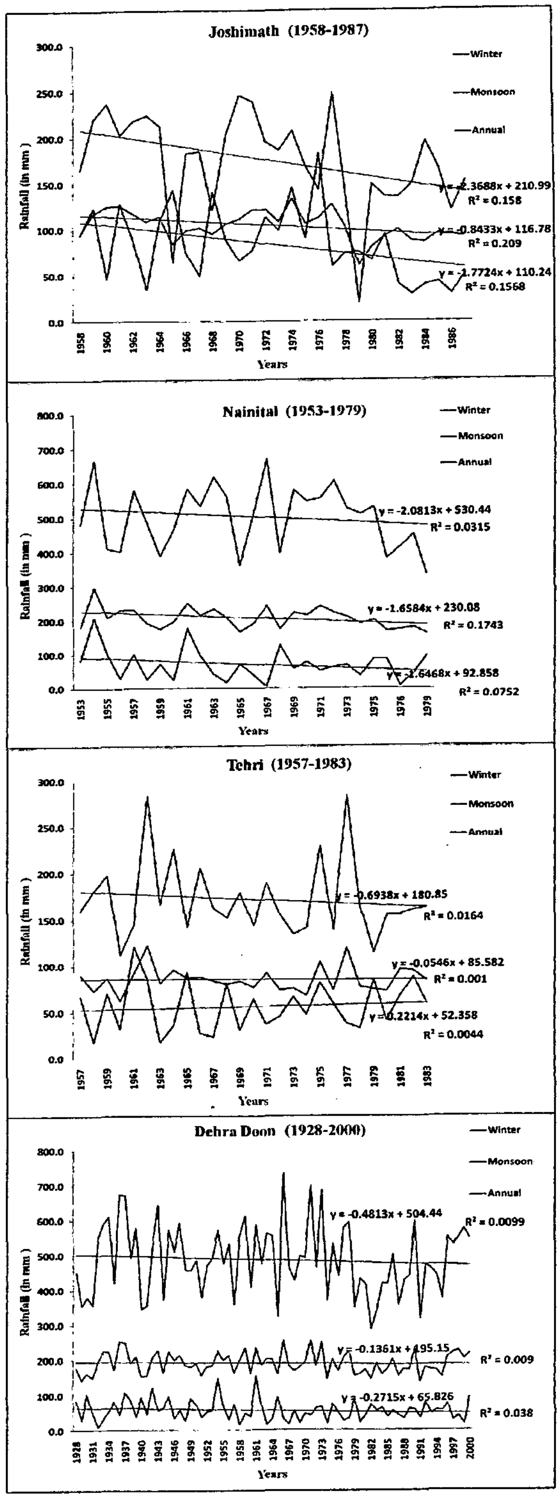
4.2.6.3 Monthly Highest Rainfall

Western Himalayan region reflected significant increasing trend in the highest monthly rainfall. Dharamshala recorded decreasing trend in annual highest rainfall (significant at 95 % confidence level). Bilaspur (except in monsoon season) and Manali (except in winter season) reflected increasing trend. Pre-monsoon season showed increasing trend at each station except Dharamshala while the monsoon season recorded decreasing trend at each station except Manali. In Uttarakhand, Nainital reflected decreasing trend in annual highest rainfall. Dehra Doon experienced increasing trend in lowest minimum temperature during all the seasons except in winter season while Shimla recorded significant positive trend in winter and pre-monsoon a decreasing trend in monsoon and post-monsoon lowest minimum temperature.

The overall scenario of the trend analysis of climatic extremes suggests that Western Himalaya recorded significant increasing trend in temperature regime. On the other hand, the Central Himalaya experienced increasing trend in temperature extremes but didn't marked a significant result like Western Himalaya. Shimla and Dharamshala recorded increasing trend in annual highest maximum temperature but Bilaspur and Manali recorded increasing trend in the lowest minimum temperature throughout the year. Uttarakhand also reflected the same trend. Nainital marked a decreasing trend in highest maximum temperature while Tehri recorded an increasing trend in annual lowest minimum temperature.



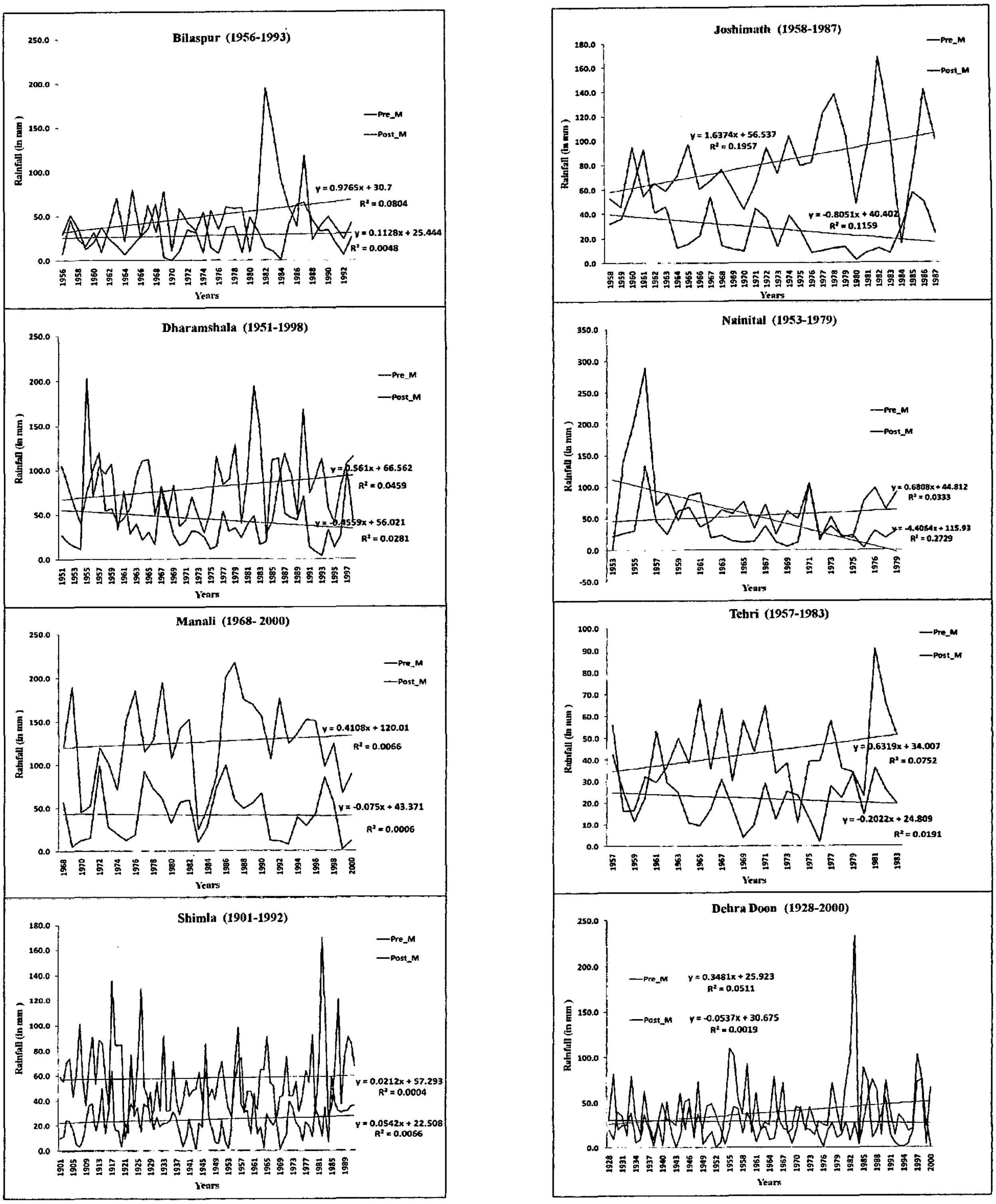
Western Himalaya



Central Himalaya

Figure 4.7: Trend in total monthly rainfall.

Source: National Data Centre, IMD, Pune

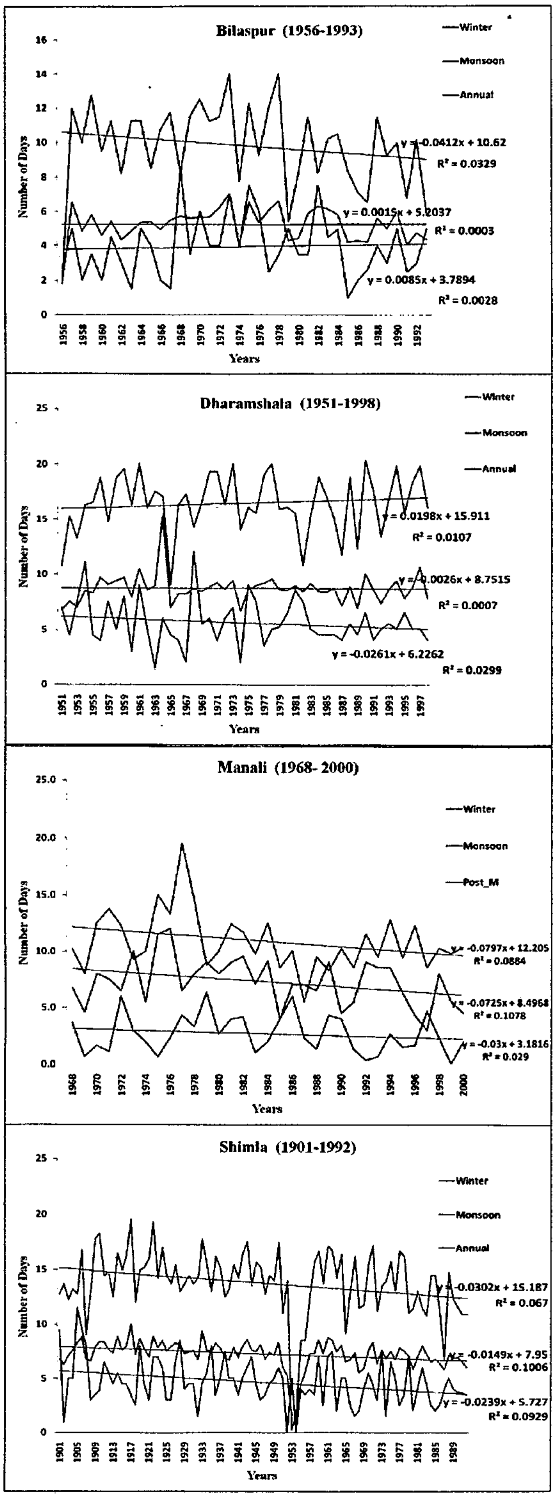


Western Himalaya

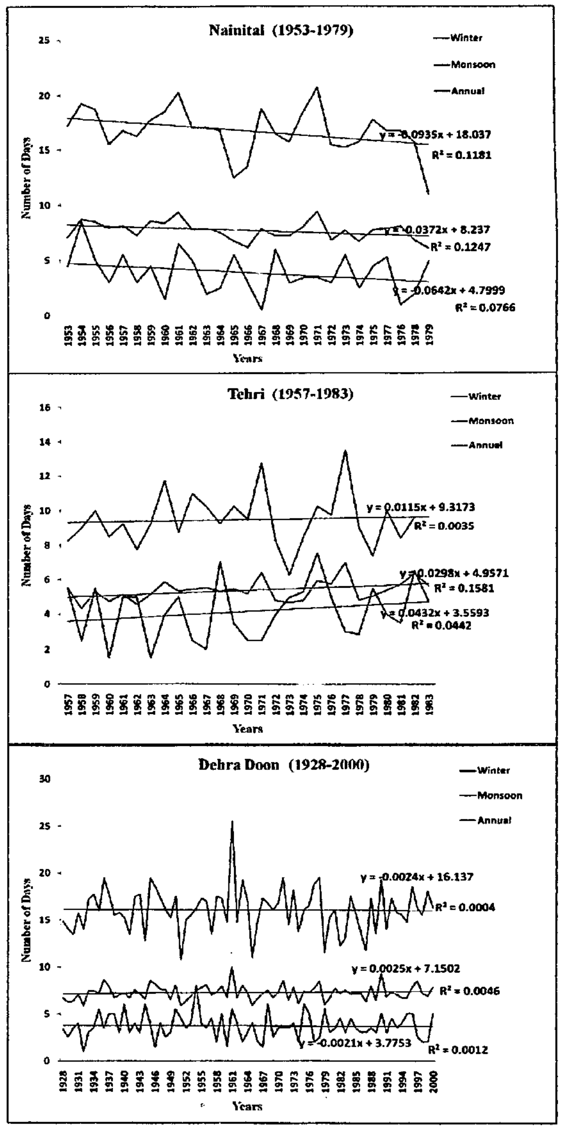
Central Himalaya

Figure 4.8: Trend in total monthly rainfall.

Source: National Data Centre, IMD, Pune



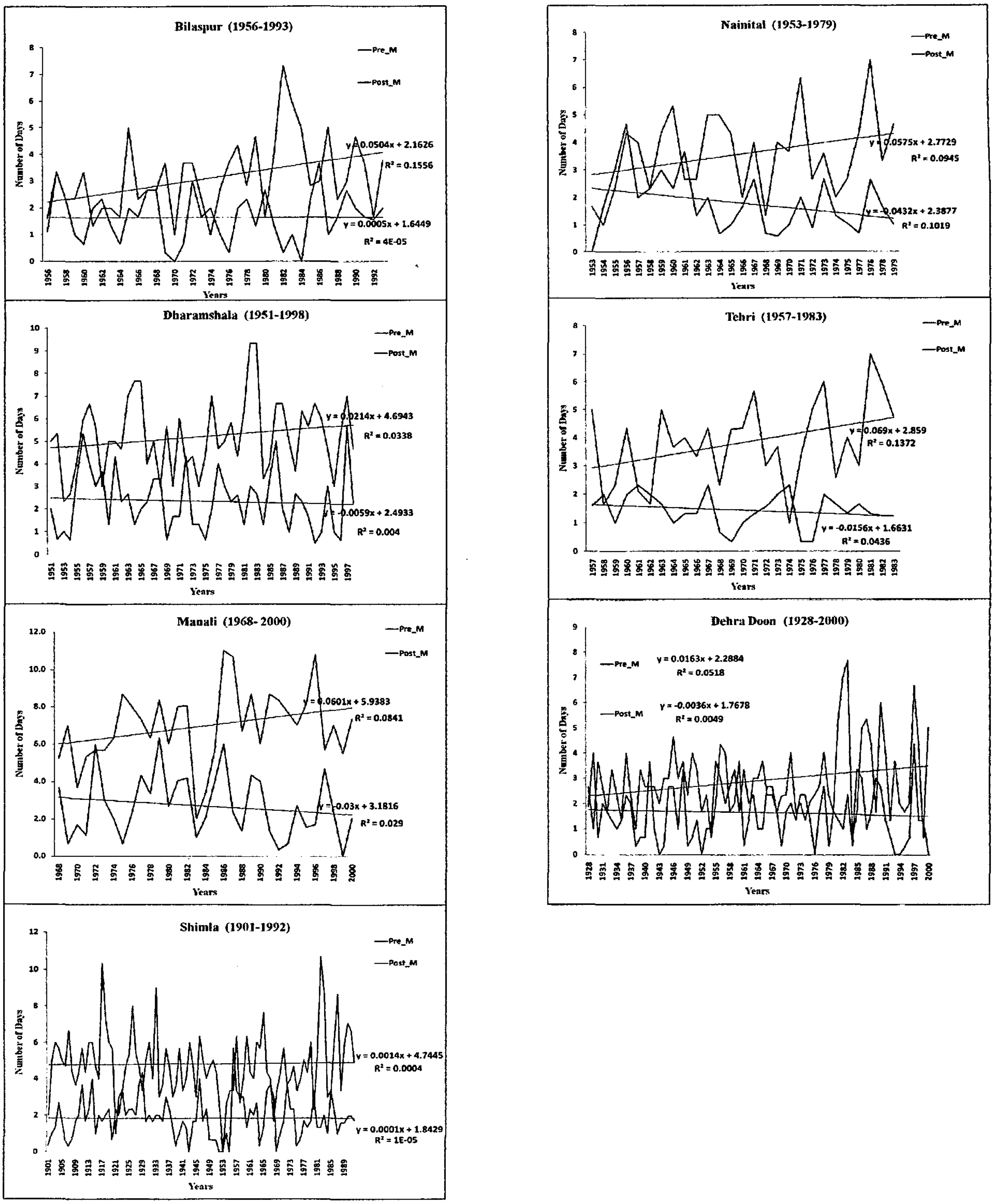
Western Himalaya



Central Himalaya

Figure 4.9: Trend in monthly rainy days.

Source: National Data Centre, IMD, Pune

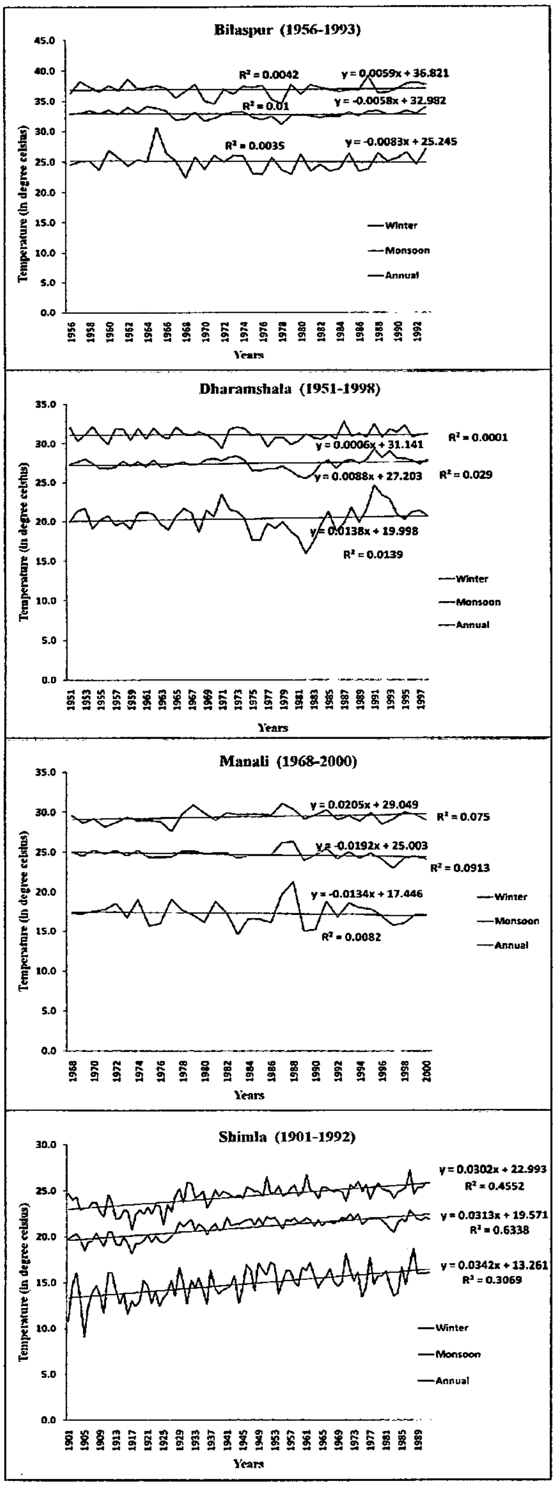


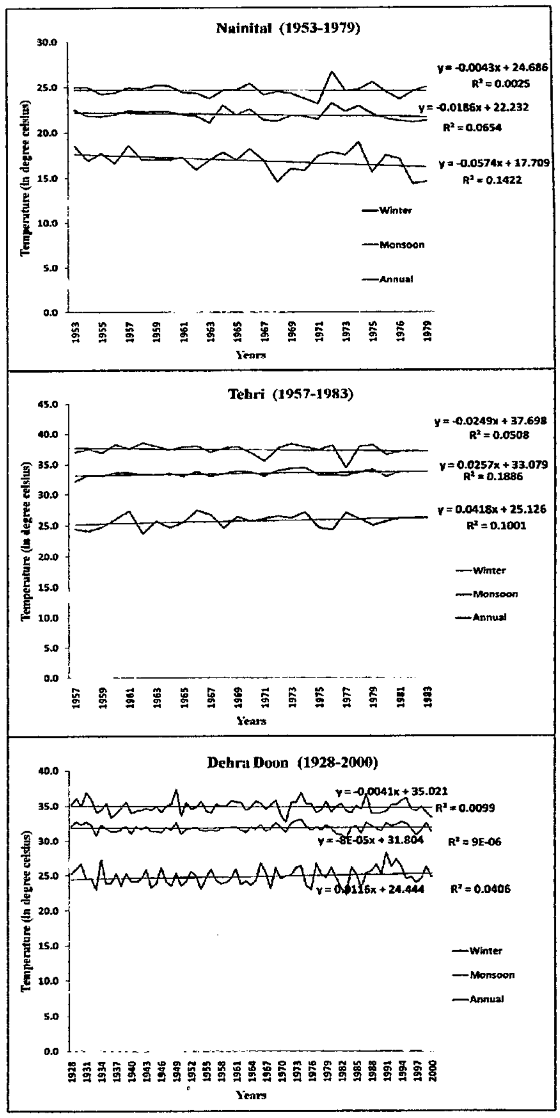
Western Himalaya

Central Himalaya

Figure 4.10: Trend in monthly rainy days.

Source: National Data Centre, IMD, Pune



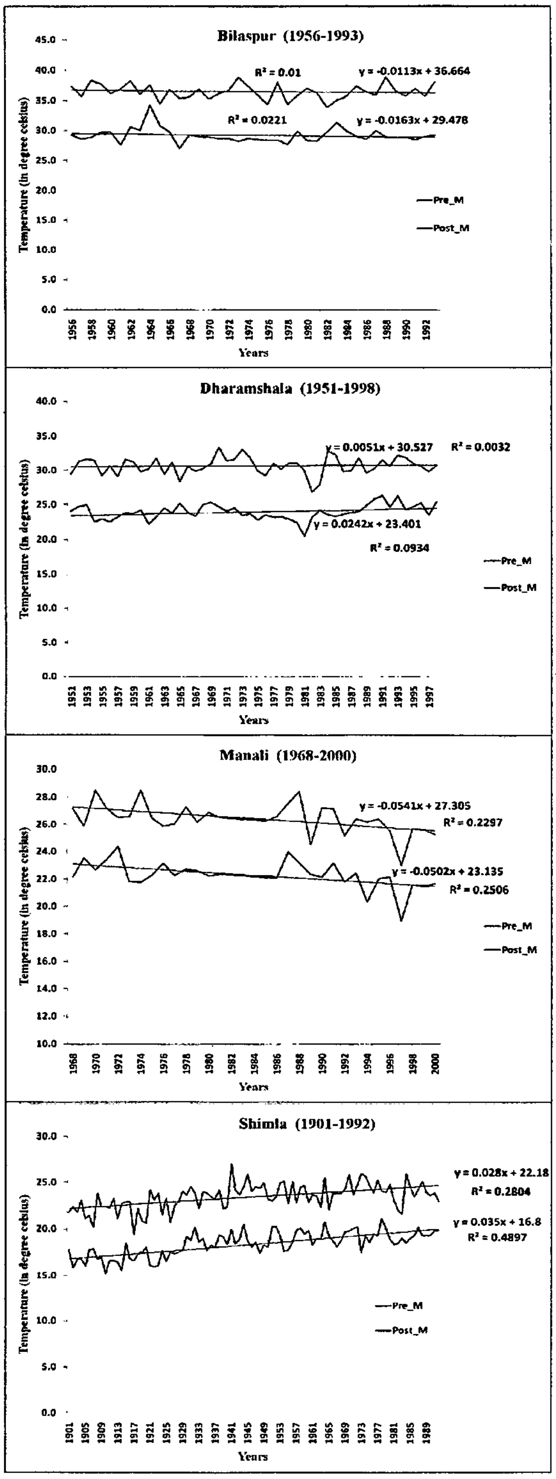


Western Himalaya

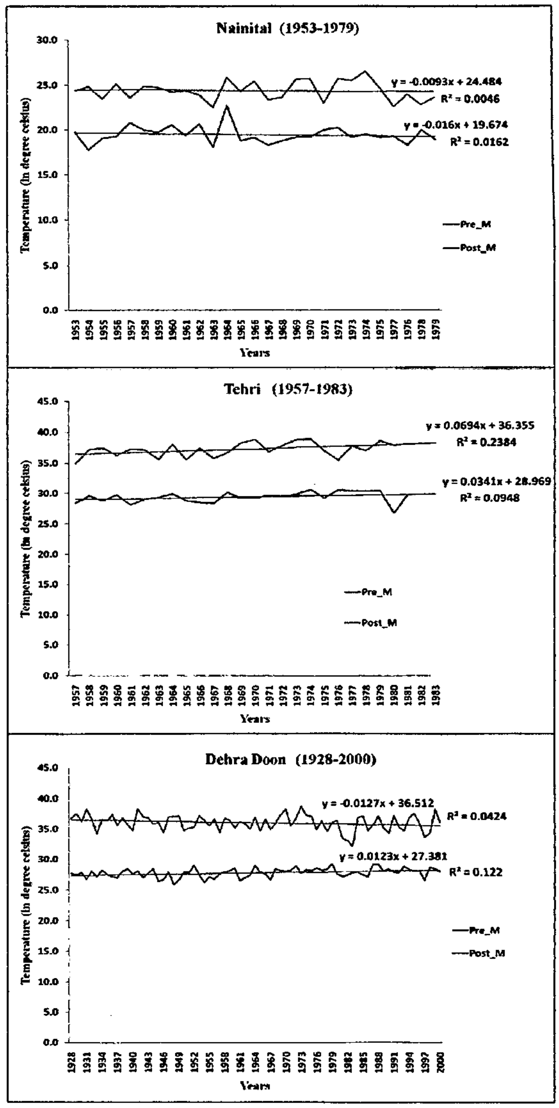
Central Himalaya

Figure 4.11: Trend in highest monthly maximum temperature.

Source: National Data Centre, IMD, Pune



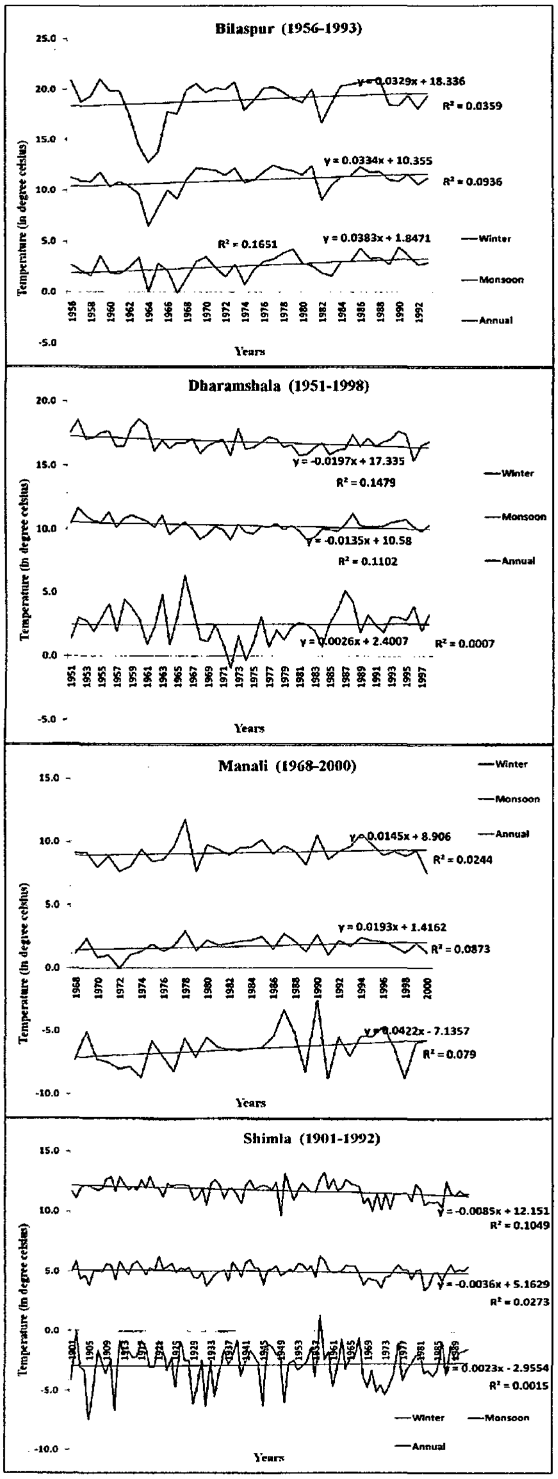
Western Himalaya



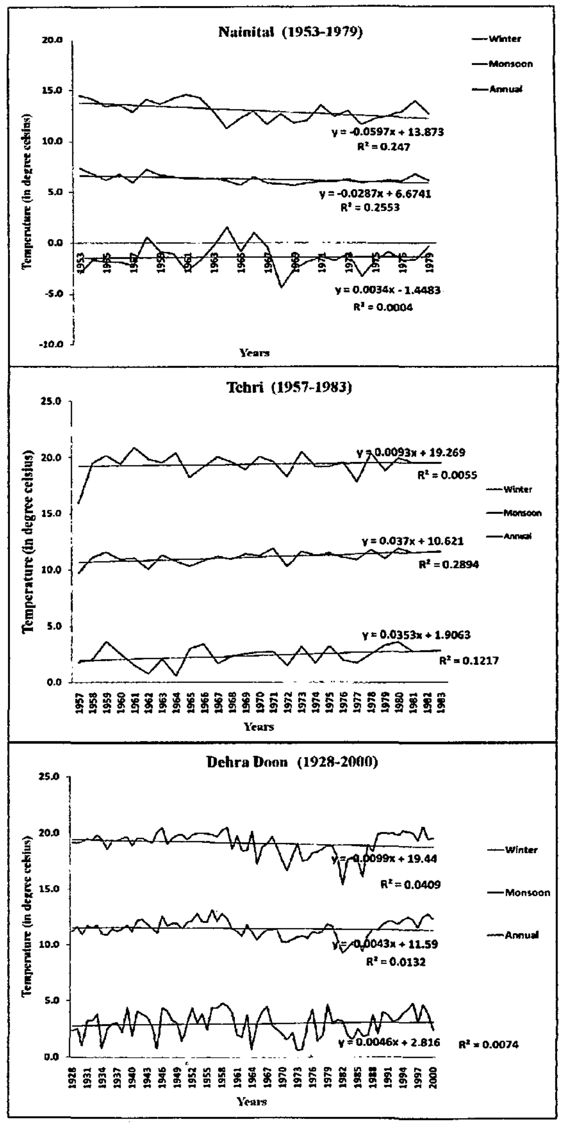
Central Himalaya

Figure 4.12: Trend in highest monthly maximum temperatu

Source: National Data Centre, IMD, Pune



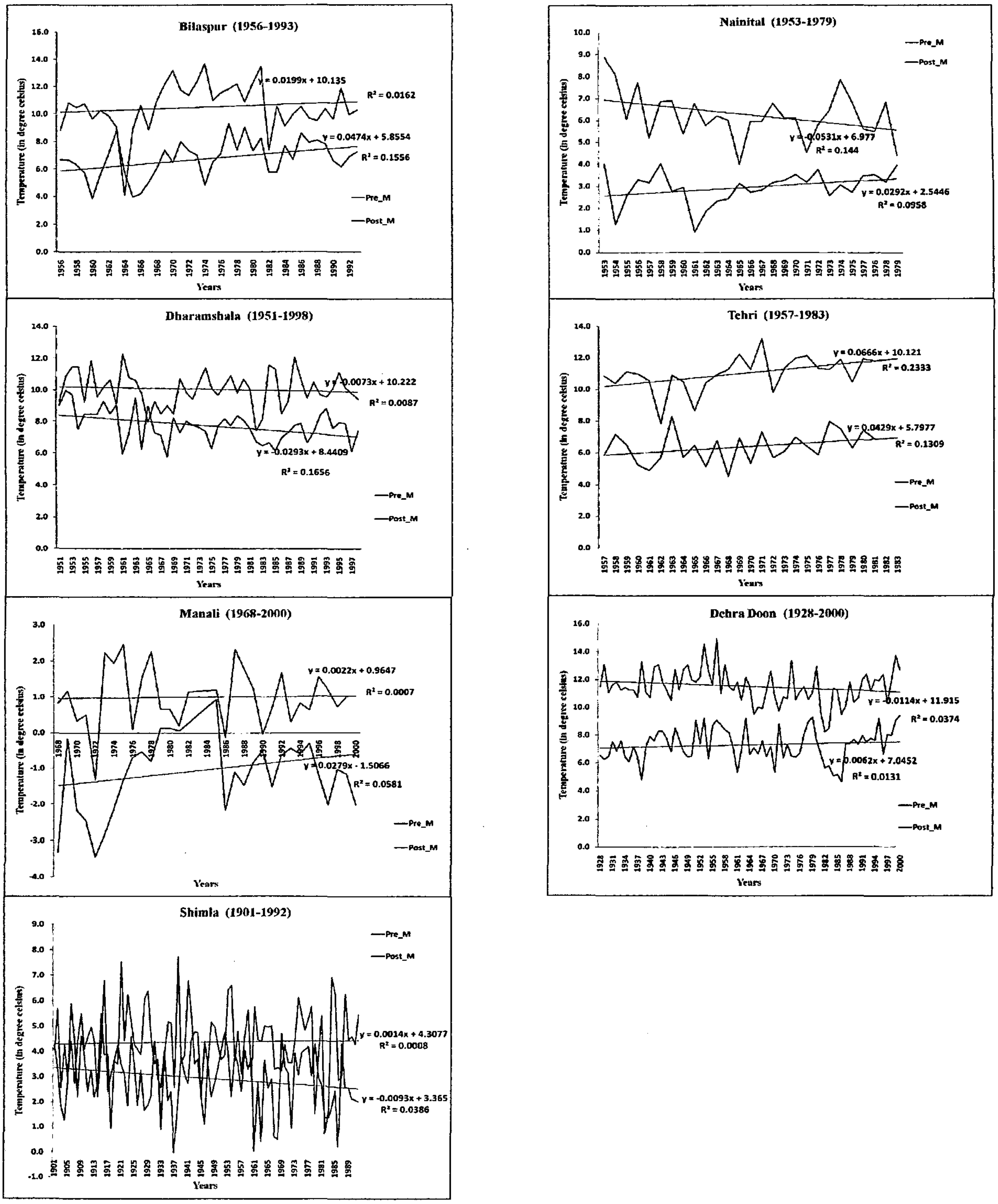
Western Himalaya



Central Himalaya

Figure 4.13: Trend in lowest monthly minimum temperature.

Source: National Data Centre, IMD, Pune



Western Himalaya

Central Himalaya

Figure 4.14: Trend in lowest monthly minimum temperatur

Source: National Data Centre, IMD, Pune

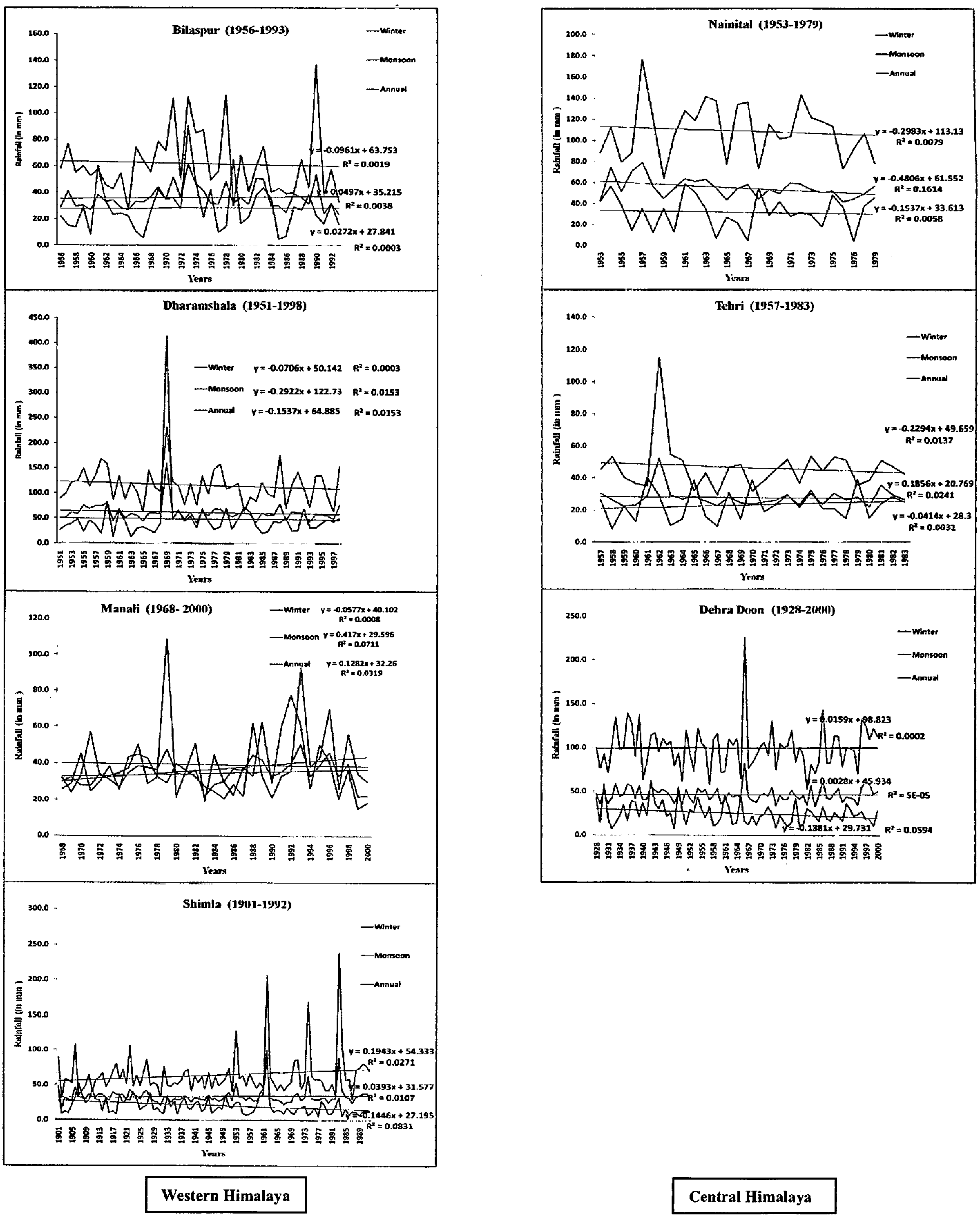
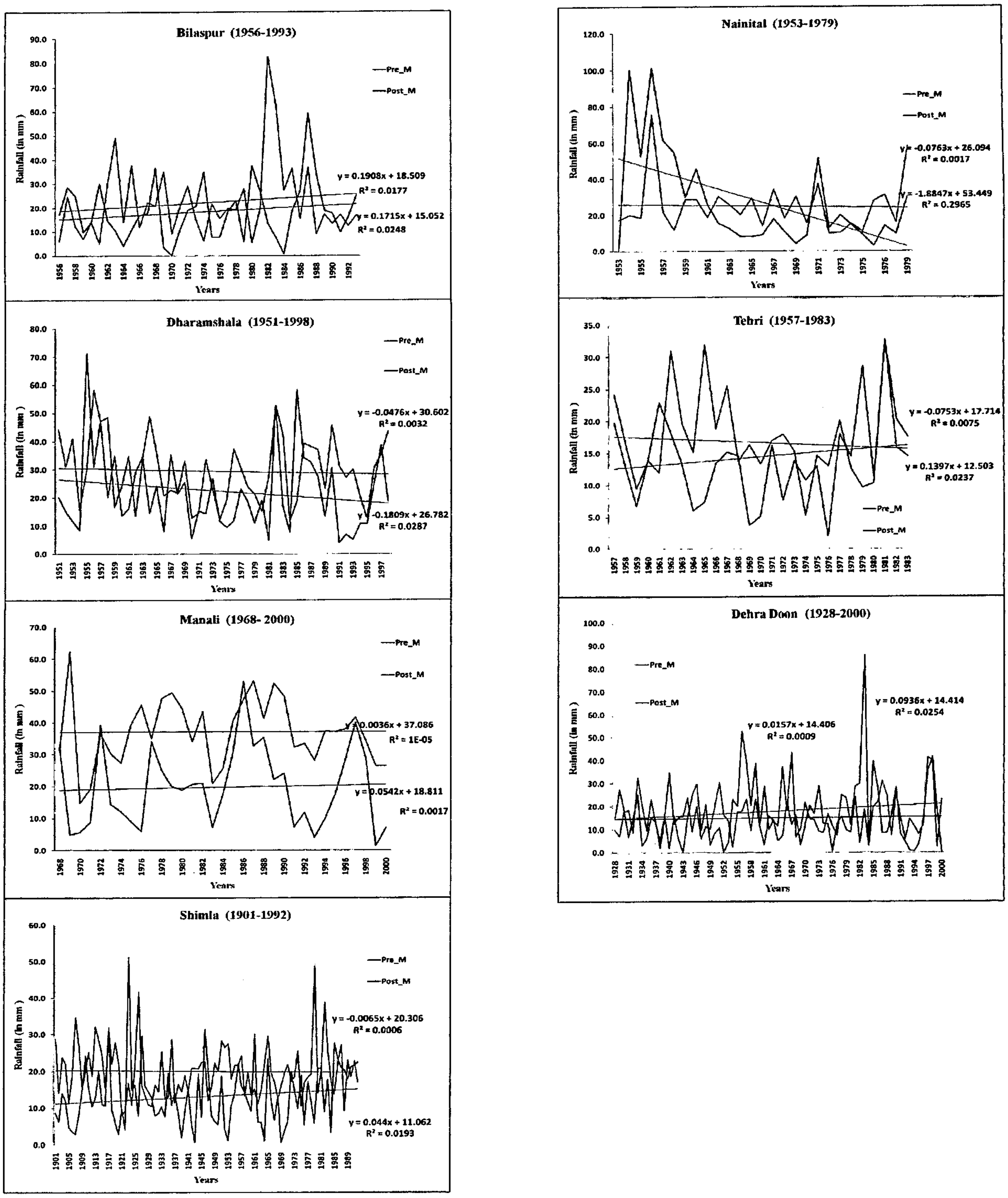


Figure 4.15: Trend in highest monthly rainfall.

Source: National Data Centre, IMD, Pune



Western Himalaya

Central Himalaya

Figure 4.16: Trend in highest monthly rainfall.

Source: National Data Centre, IMD, Pune

4.3 Results and Discussion

The simple linear regression analysis provided very interesting information about trends in the climatic variables. The major results of the analysis are listed below;-

i. It is expected that only two meteorological stations i.e. Shimla and Dehra Doon reflected statistically significant positive or negative trend in the selected climatic parameters recorded for a relatively longer time span.

ii. The stations with short time span data series show statistically insignificant positive or negative trend in climatic parameters.

iii. The temperature regime displayed a significant increasing trend in Himachal Pradesh and a significant decreasing trend in Uttarakhand.

iv. Maximum and mean monthly temperature reflected significant increasing trends in Himachal Pradesh. The monsoon and winter season temperature marked significant increasing trend in Himachal Pradesh while Uttarakhand recorded decreasing trend. Joshimath recorded decreasing trend in both the maximum and mean monthly temperature regimes while Tehri recorded significant increasing trend in maximum and mean monthly temperature.

v. Dehra Doon showed significant increasing trend in maximum and mean monthly temperature. The monsoon season reflected a deceasing trend at Dehra Doon.

vi. Minimum temperature showed decreasing trend in Uttarakhand while similar trends were also observed in Himachal Pradesh. The monsoon season recorded decreasing trends in Uttarakhand but in Himachal Pradesh, Manali was the only exception in this regime, which recorded increasing trend.

vii. The rainfall scenario is more evident in Uttarakhand than Himachal Pradesh. A decreasing trend in monsoon rainfall is common for all the stations in the region which consequently followed by the decreasing trend in annual rainfall in the Central-Western Himalaya.

viii. Uttarakhand reflected decreasing trend in rainfall received during monsoon, post-monsoon and winter season (except Tehri) marked a significant decreasing trend in monthly rainfall.

ix. Himachal Pradesh marked decreasing trend in monsoon, winter and annual season rainfall. The pre-monsoon rainfall, interestingly, showed significant increasing trend at all the meteorological stations of the region.

x. Rainy days denote wet period. The trend analysis results of monthly rainfall and rainy days are quite similar to each-other. Rainy days in monsoon and winter season experienced significant decreasing trend in Himachal Pradesh while Uttarakhand experienced decreasing trend in rainy days during post-monsoon season.

xi. The trend analysis of climatic extremes suggests that Western Himalaya recorded significant increasing trend in temperature regime. On the other hand, the Central Himalaya experienced increasing trend in temperature extremes but didn't marked a significant result like Western Himalaya.

xii. Shimla and Dharamshala recorded increasing trend in annual highest maximum temperature but Bilaspur and Manali recorded increasing trend in the lowest minimum temperature throughout the year.

xiii. Nainital marked a decreasing trend in highest maximum temperature while Tehri recorded an increasing trend in annual lowest minimum temperature.

4.4 Chapter summary and conclusion

The simple linear regression analysis provides significant or insignificant trend in climatic variables recorded in Central-Western Himalayan region. The temperature regime displayed increasing trends in Himachal Pradesh and a decreasing trend in Uttarakhand in maximum and minimum temperature. Maximum and mean monthly temperature depicted significantly increasing trends in the Himachal Pradesh with Shimla and Bilaspur recorded increase during all the seasons (significant at 95 % confidence level). The monsoon and winter temperature depicted an increasing trend as compared to other seasons for the same state. Uttarakhand recorded almost reverse of these trends. Decreasing trend in mean temperature was observed in the state. Joshimath recorded decreasing trends in both maximum and mean monthly temperature regimes. Tehri recorded an increasing trend in all the seasons except in monsoon season. Dehra Doon, more or less, showed increasing trends in the maximum and mean monthly temperature regimes. The monsoon season again marked a deceasing trend at Dehra Doon (significant at 95 % confidence level). The minimum temperature showed decreasing trend in Uttarakhand while similar trend was also observed in Himachal Pradesh. The monsoon season recorded decreasing trend at all the stations of Uttarakhand but in Himachal Pradesh, Manali (significant at 95 % confidence level) was the only exception in this regime, which recorded increasing trend.

The rainfall scenario is much evident in Uttarakhand than Himachal Pradesh. A decreasing trend in monsoon rainfall is common for all the stations (significant at 95 % confidence level) in the region which consequently marked a decreasing trend in annual rainfall in the Central-Western Himalaya. Uttarakhand experienced decreasing trend in rainfall during monsoon and post-monsoon season. The winter season reflected a significant decreasing trend in monthly rainfall in Uttarakhand (except at Tehri). Himachal Pradesh experienced decreasing trend in monsoon, winter and annual rainfall. The pre-monsoon rainfall, interestingly, showed increasing trend at all the meteorological stations of the region (significant at 95 % confidence level). Number of rainy days is directly correlated with the monsoon rainfall. The trend analysis results of monthly rainfall and rainy days are highly similar to each-other. The monthly rainy days experienced decreasing trend during monsoon and winter seasons in Himachal Pradesh while Uttarakhand reflected decreasing trend in rainy days during post-monsoon season.

The trend analysis of climatic extremes suggests that Western Himalaya recorded significant increasing trend in temperature regime. On the other hand, the Central Himalaya experienced increasing trend in temperature extremes but didn't marked a significant result like Western Himalaya. Shimla and Dharamshala recorded increasing trend in annual highest maximum temperature but Bilaspur and Manali recorded increasing trend in the lowest minimum temperature throughout the year. Uttarakhand also reflected the same trend. Nainital marked a decreasing trend in highest maximum temperature while Tehri recorded an increasing trend in annual lowest minimum temperature.

Chapter Five

Comparison of climatic variability in the Central-Western Himalaya and the Western Rajasthan: A case study

5.1 Introduction

Climate varies over the time and space. The geographical location, latitudinal and longitudinal extent, coastal or continental location, aspect and altitudinal extent etc. are the major factors which govern the nature of climate over the space. India is a country with great physiographical diversities. The great Himalayan altitudinal and longitudinal extent, flat Indo-Gangetic plain and solid and age-old southern Indian peninsula all represent the Indian physiographical diversity. The climate is a function of all these physical elements and got changed over the space as the physical properties of the space differed from one-another. These varying physical properties force the climate of a place to be change according to the available physical conditions. That's why the climate of the Himalayan region is greatly differs from the climate of the southern plateau region and north-western desert region. But one important fact is that nothing is static and permanent in the natural system and over the time each and every system got altered. So, time is the passive factor which induced changes in the systems of the Earth. Climate, as a dynamic phenomenon, recorded cyclic episodes of climatic changes after the industrial revolution. These changes occurred naturally or induced by human beings influence the entire globe. The major question which emerges from the above discussion is that whether the entire earth with physiographic diversities is influenced by cyclic variations in the climate. Some variations or changes in climate occur on global scale but many others of a short-term nature are regional. In the current era, the climate is varying because of the natural and anthropogenic factors.

This case study dealt with the question that whether the variations in the climate show similar trends for all the physiographic regions or reflect some temporal-spatial variations. Therefore two physiographically different regions of India were selected, i.e. the Central-Western Himalaya (Shimla and Dehra Doon meteorological stations) and Western Rajasthan (Bikaner and Jodhpur meteorological stations). The selection criteria were mainly based on the physiography and different climatic conditions prevailing in the respective region.

5.2 A brief introduction of the Western Rajasthan

The Western Rajasthan is a physiographic region with arid climate that prevails over a vast mass of sand. There are three principal landforms in the desert region — the predominantly sand covered Thar, the plains with hills including the central dune free country and the semi-arid area surrounding the Aravalli range. The Thar desert slopes imperceptibly towards the Indus Plain and surface unevenness is mainly evolved due to sand dunes. The dunes located in south are relatively high rising up to 152 m whereas in the north these features are relatively low and rise up to 16 m above the ground. The Aravalli forms the main dividing line between the Thar desert in west to the plain in east of Rajasthan. The soils of the Arid Zone are generally sandy to sandy-loam in texture. The consistency and depth vary according to the topographical features. The low-lying loams are heavier and may have a hard pan. Some of these soils contain a high percentage of soluble salts in the lower horizons.

Bikaner and Jodhpur, two meteorological stations of the western Rajasthan were selected for the study. The data availability and physical settings were considered for the selection of meteorological stations. Bikaner is situated in the middle of the Thar Desert with very little rainfall and extreme temperature regime. In summer, temperature exceeds 50 ^{0}C and during the winter it dips down to freezing point. The climate of Bikaner is characterized by seasonal variations in temperature. In the summer season it is very hot when the temperature varies from 28 ^{0}C to 41.2 ^{0}C. In the winter, it is fairly cold with temperature varies from 5 ^{0}C to 23 ^{0}C. The annual rainfall is in the range of 260 to 440 mms (District gazetteer, Bikaner 1998).

Jodhpur district covers 11.60 per cent of the total arid zone of the state. General slope of the terrain is towards west. Extreme heat in the summer and cold in the winter are the major characteristics of the desert area. The temperature varies from 49 ^{0}C in summer to 1 ^{0}C in the winter. The sandstorm (aandhi) is very common in summer season. The rainy days are limited to a maximum of 15 days in a year. The average rainfall is 302 mm. The soil of the region is mainly classified as sandy and loamy (District gazetteer, Jodhpur 1998). The basic information about the meteorological stations included in this study is given in Table 5.1. Figure 5.1 shows map of the study area.

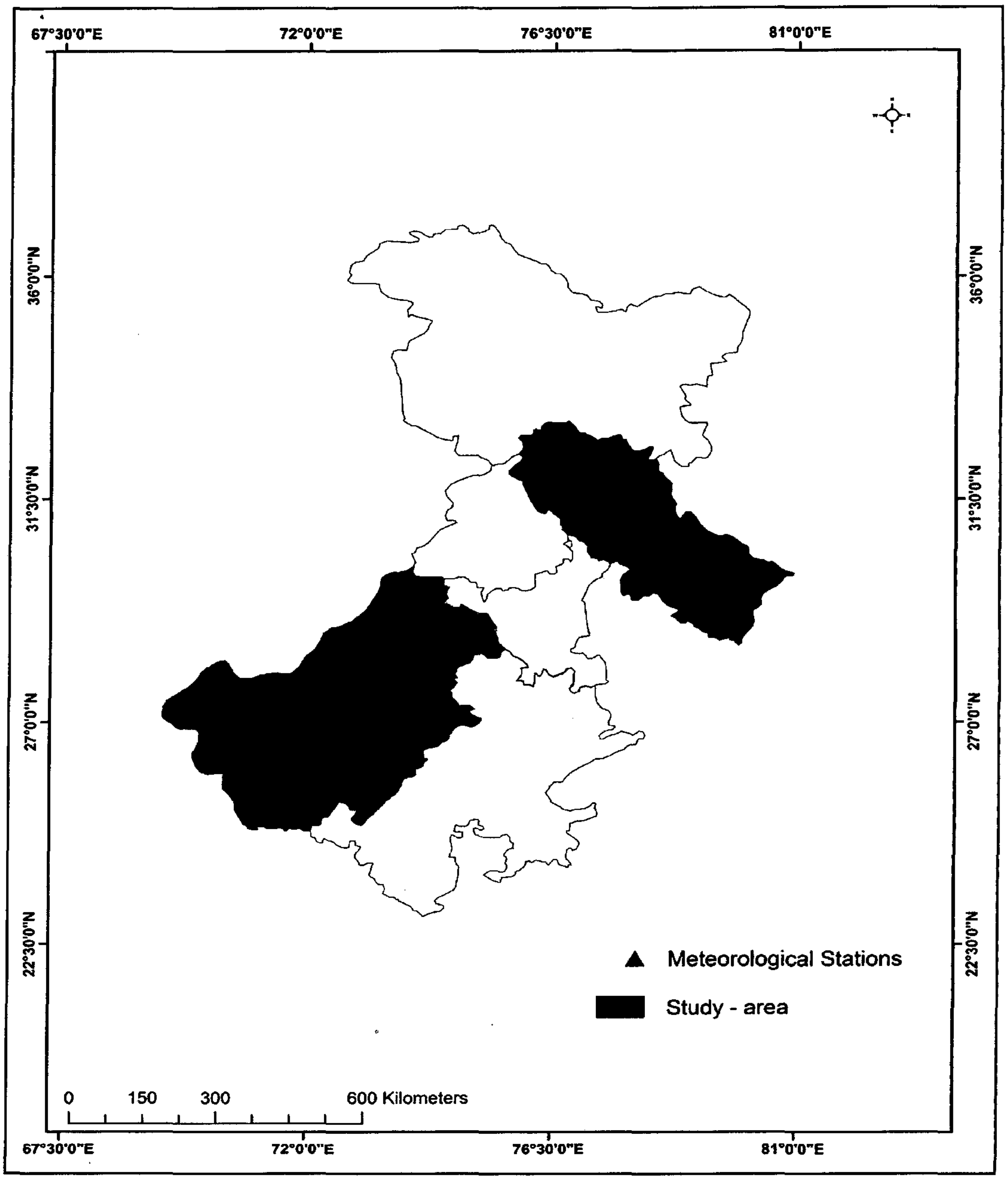


Figure 5.1 Location map of the Central-Western Himalaya and the Western Rajasthan.

Table 5.1 Meteorological stations used in the case study

Region	*Station*	*Data span*	*Variables*	*Seasons*	*Month*
Central-Western Himalaya	Dehra Doon	1928-2000	Maximum Temperature		
	Shimla	1901-1992	Minimum Temperature	Winter	Jan-Feb
				Monsoon	June-Sept
Western Rajasthan	Bikaner	1901-2000	Mean Temperature	Annual	
	Jodhpur	1901-2000	Total Monthly Rainfall		

Note: Variables and seasons are common to all the stations.

Two meteorological stations of the Central-Western Himalaya viz. Shimla and Dehra Doon and two meteorological stations of the Western Rajasthan viz. Bikaner and Jodhpur were selected for the study. Four variables mean maximum temperature, mean minimum temperature, mean monthly temperature and total monthly rainfall were used and only two prominent season winter and monsoon along with the annual records were included in this study. This case study incorporated the following sub-heads;-

i. Comparison of seasonal variation in climatic parameters using Simple Average method.
ii. Comparison of the spatial variation in climatic parameters using Coefficient of Variation method.
iii. Comparison of trend analysis using Simple Linear Regression method.

5.3 Comparison of seasonal variation using Simple Average method

5.3.1 Mean Monthly Maximum Temperature

Table 5.2 shows the seasonal variation recorded in the temperature regime of the Central-Western Himalayan and Western Rajasthan. The maximum temperature showed almost similar variation in both of the regions. BP-III for all the four stations recorded more or less identical variation. The winter season reflected the similar variation. In the BP-II, an increase in the maximum temperature for winter season was high compared to the BP-III for all the stations while monsoon season represented spatial variations. The Himalayan region experienced decrease in the maximum temperature in monsoon season during BP-III compared to BP-II while the Western Rajasthan marked a decrease during BP-II especially, Bikaner recorded -0.3 ^{0}C decrease in the maximum temperature compared to BP-I and a sharp increase during next period BP-III. This is the major spatial variations recorded between these two different physiographic regions. The annual maximum temperature also followed the same trend like the monsoon one. The Western Rajasthan (WR) recorded increasing trend in annual maximum temperature for the BP-III while the Central-Western Himalaya (CWH) followed a decreasing trend.

Table 5.2 Seasonal variation in temperature using simple average method

Variation in Mean Monthly Maximum Temperature *(in Degree Celsius)*

Region	Station	Height (in m)	Base-line Periods	BP-Code	Winter			Monsoon			Annual		
					CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Central-Western Himalaya	Shimla	2397	(1901-1930)	BP-I	16.1	8.2		3.4	20.2		3.7	15.6	
			(1931-1960)	BP-II	11.9	9.4	1.1	2.0	21.3	1.1	2.6	16.9	1.3
			(1961-1992)	BP-III	12.1	9.9	0.5	2.8	21.6	0.3	2.9	17.2	0.3
	Dehra Doon	640	(1931-1960)	BP-II	4.4	20.2		1.9	31.2		1.5	27.7	
			(1961-1990)	BP-III	4.9	20.8	0.6	2.2	31.2	0.0	1.6	27.9	0.2
Western Rajasthan	Bikaner	242	(1901-1933)	BP-I	7.1	23.7		2.7	38.4		2.0	33.3	
			(1934-1966)	BP-II	5.5	24.3	0.6	2.1	38.1	-0.3	1.6	33.5	0.2
			(1967-2000)	BP-III	4.3	24.7	0.4	2.2	38.5	0.4	1.6	33.9	0.4
	Jodhpur	231	(1901-1933)	BP-I	5.7	26.0		3.0	36.0		1.8	33.4	
			(1934-1966)	BP-II	4.8	26.4	0.4	2.1	36.0	0.0	1.3	33.6	0.2
			(1967-2000)	BP-III	3.5	26.7	0.3	2.6	36.5	0.5	1.6	33.9	0.3

Variation in Mean Monthly Minimum Temperature *(in Degree Celsius)*

Region	Station	Height (in m)	Base-line Periods	BP-Code	Winter			Monsoon			Annual		
					CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Central-Western Himalaya	Shimla	2397	(1901-1930)	BP-I	52.9	2.3		2.4	15.1		4.2	9.6	
			(1931-1960)	BP-II	38.9	2.5	0.1	2.4	15.2	0.1	4.0	9.9	0.2
			(1961-1992)	BP-III	44.2	2.1	-0.3	4.5	14.5	-0.7	4.9	9.4	-0.5
	Dehra Doon	640	(1931-1960)	BP-II	10.2	7.1		1.7	22.6		3.0	15.7	
			(1961-1990)	BP-III	15.4	6.3	-0.8	3.7	21.5	-1.2	4.1	14.7	-1.0
Western Rajasthan	Bikaner	242	(1901-1933)	BP-I	11.3	9.1		2.6	27.4		2.6	19.8	
			(1934-1966)	BP-II	18.9	6.9	-2.3	1.6	27.2	-0.2	3.3	18.4	-1.4
			(1967-2000)	BP-III	18.2	8.0	1.1	2.3	27.4	0.2	3.7	19.1	0.7
	Jodhpur	231	(1901-1933)	BP-I	9.3	11.1		2.2	26.0		2.4	19.8	
			(1934-1966)	BP-II	10.3	10.9	-0.2	1.7	26.2	0.2	2.1	19.9	0.1
			(1967-2000)	BP-III	12.1	10.1	-0.8	2.2	26.0	-0.2	2.3	19.5	-0.4

Source: National Data Centre, IMD, Pune

Table 5.3 Seasonal variation in temperature and rainfall using simple average method

Variation in Mean Monthly Temperature (in Degree Celsius)

Region	Station	Height (in m)	Base-line Periods	BP-Code	Winter			Monsoon			Annual		
					CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Central-Western Himalaya	Shimla	2397	(1901-1930)	BP-I	24.0	5.3		2.6	17.7		3.7	12.6	
			(1931-1960)	BP-II	17.3	5.9	0.6	1.9	18.2	0.5	3.1	13.4	0.8
			(1961-1992)	BP-III	17.1	6.0	0.1	2.9	18.0	-0.2	3.0	13.3	-0.1
	Dehra Doon	640	(1931-1960)	BP-II	5.2	13.7		1.5	26.9		1.7	21.7	
			(1961-1990)	BP-III	6.1	13.6	-0.1	2.2	26.3	-0.6	2.2	21.3	-0.4
Western Rajasthan	Bikaner	242	(1901-1933)	BP-I	7.4	16.4		2.4	32.9		1.8	26.5	
			(1934-1966)	BP-II	6.1	15.6	-0.8	1.7	32.7	-0.2	1.5	25.9	-0.6
			(1967-2000)	BP-III	6.8	16.3	0.7	2.1	33.0	0.3	2.2	26.5	0.6
	Jodhpur	231	(1901-1933)	BP-I	6.3	18.6		2.5	31.0		1.9	26.6	
			(1934-1966)	BP-II	5.5	18.7	0.1	1.8	31.1	0.1	1.4	26.8	0.2
			(1967-2000)	BP-III	5.1	18.4	-0.3	2.3	31.3	0.2	1.7	26.7	-0.1

Variation in Total Monthly Rainfall (in mm)

Region	Station	Height (in m)	Base-line Periods	BP-Code	Winter			Monsoon			Annual		
					CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation	CV (in per cent)	Simple Average	Variation
Central-Western Himalaya	Shimla	2397	(1901-1930)	BP-I	56.5	75.0		27.1	300.8		18.3	138.4	
			(1931-1960)	BP-II	45.6	55.4	-19.6	19.6	289.0	-11.8	13.3	126.9	-11.5
			(1961-1992)	BP-III	116.1	50.0	-5.5	46.0	292.8	3.8	34.6	129.8	2.8
	Dehra Doon	640	(1931-1960)	BP-II	51.8	60.8		19.6	503.5		14.9	195.9	
			(1961-1990)	BP-III	56.5	50.6	-10.1	23.4	480.8	-22.6	16.9	188.2	-7.7
Western Rajasthan	Bikaner	242	(1901-1933)	BP-I	146.3	6.0		54.4	62.6		43.9	25.5	
			(1934-1966)	BP-II	100.1	6.5	0.5	51.9	61.0	-1.6	41.3	24.2	-1.3
			(1967-2000)	BP-III	102.9	7.6	1.1	42.5	61.8	0.8	39.7	28.4	4.3
	Jodhpur	231	(1901-1933)	BP-I	144.4	3.8		63.5	81.4		55.0	30.5	
			(1934-1966)	BP-II	154.9	5.9	2.2	41.1	83.1	1.7	33.7	30.7	0.2
			(1967-2000)	BP-III	128.4	3.8	-2.1	49.1	91.9	8.8	39.7	37.3	6.6

Source: National Data Centre, IMD, Pune

Winter maximum temperature **Monsoon maximum temperature** **Annual maximum temperature**

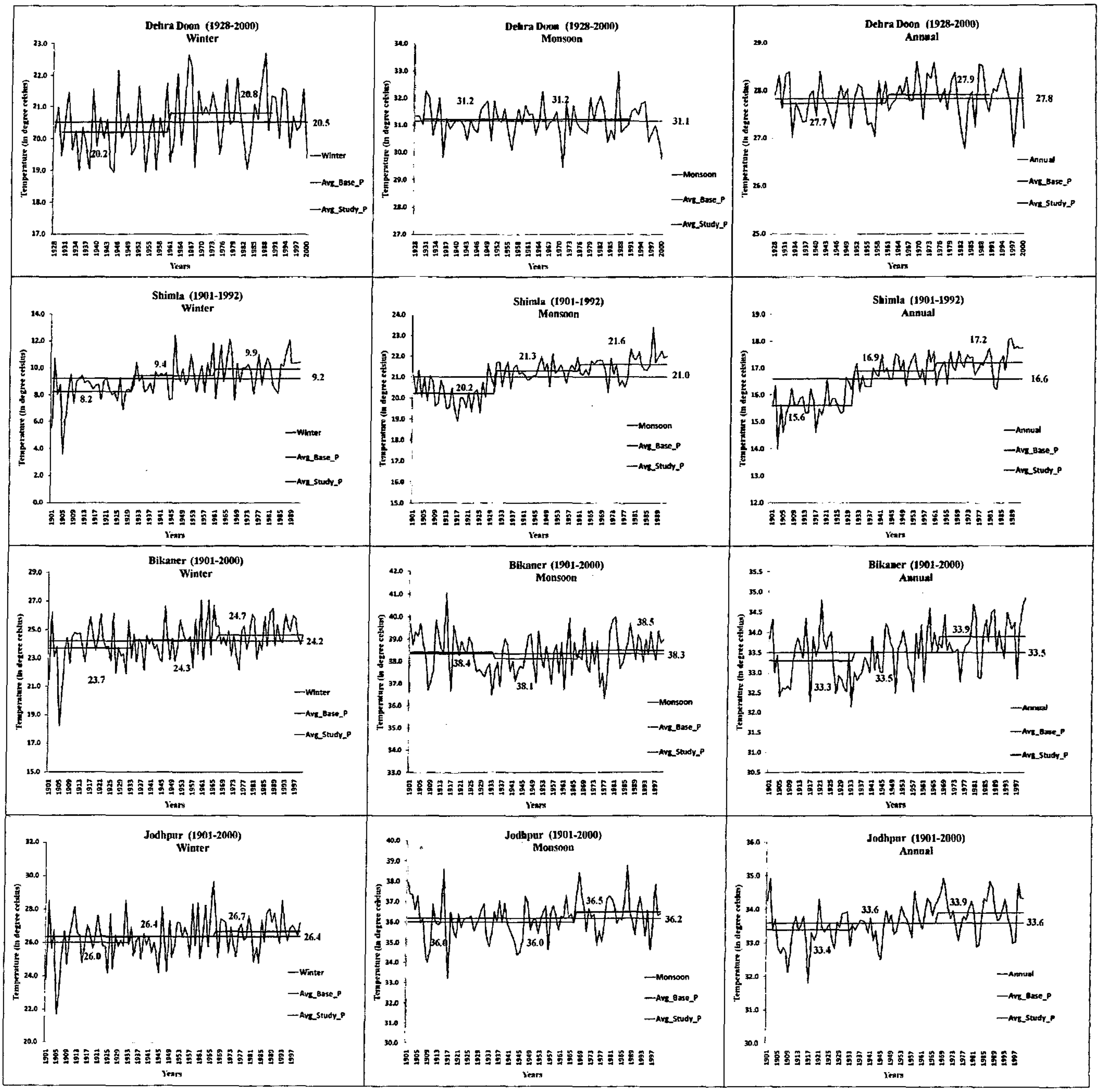


Figure 5.2: Seasonal variations in mean monthly maximum temperature.

Source: National Data Centre, IMD, Pune

Winter minimum temperature | **Monsoon minimum temperature** | **Annual minimum temperature**

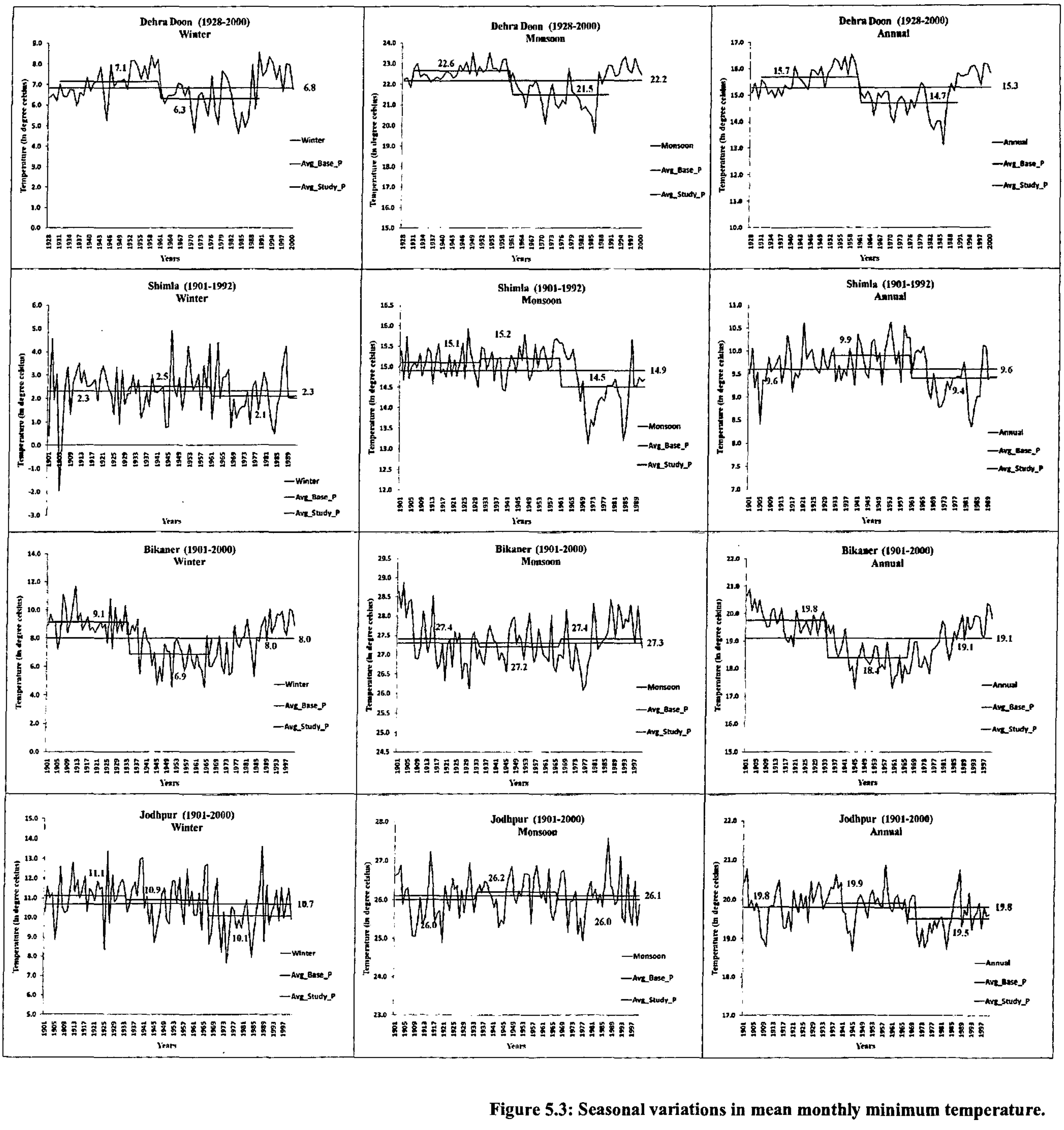


Figure 5.3: Seasonal variations in mean monthly minimum temperature.

Source: National Data Centre, IMD, Pune

5.3.2 Mean Monthly Minimum Temperature

Table 5.2 and Figure 5.3 show the seasonal variation patterns in mean monthly minimum temperature. Shimla, Dehra Doon and Jodhpur recorded increase in minimum temperature during 1930-60 while decrease in minimum temperature during 1960-90. Bikaner marked reverse variations to above results in minimum temperature. Bikaner recorded a high decrease in minimum temperature during all three seasons of BP-II and a sharp increase during BP-III. The winter season recorded relatively high increase (1.1 ^{0}C) during BP-III compared to monsoon season at Bikaner. The annual minimum temperature marked high increase of 0.7 ^{0}C at Bikaner. Overall, the winter and monsoon season recorded relatively high decrease in minimum temperature during BP-III. The coefficient of variation (CV) values denotes the consistency or inconsistency in climatic variables. A low value of CV shows consistency in time series data while a high value of CV denotes inconsistency in data. The winter season reflected high value of CV which indicates the inconsistency in minimum temperature record. Shimla recorded, exceptionally, high inconsistency in minimum temperature during winter season. The Western Rajasthan recorded relatively high consistency in minimum temperature in all seasons as compared to the Central-Western Himalaya.

5.3.3 Mean Monthly Average Temperature

Table 5.3 and Figure 5.4 show the seasonal-spatial variation recorded in the mean monthly temperature. The period BP-II recorded increase in the average temperature at Shimla, Dehra Doon and Jodhpur while Jodhpur marked relatively low increase compared to the former two stations. BP-III recorded decrease in the mean temperature at Dehra Doon, Shimla and Jodhpur during annual record. Bikaner again stands out from other three stations. The station recorded relatively high decrease in mean temperature during BP-II and an increase during BP-III. Within WR region, monsoon season showed some interesting results. Bikaner and Jodhpur recorded an increase in mean temperature during monsoon season for the period BP-III. A decrease in mean temperature reflected at Shimla and Dehra Doon during monsoon season for BP-III. Overall, the BP-II recorded increase in men temperature and BP-III recorded decrease at CWH stations and at Jodhpur of WR region. Bikaner recorded increase in mean temperature which is a point of concern for the further studies. High elevation station, Shimla again recorded high value of CV for mean monthly temperature which implies that the station marked with high inconsistency in mean temperature compared to the other low elevation stations. The winter season reflected relatively high inconsistency in mean temperature during all the BPs at Shimla.

5.3.4 Total Monthly Rainfall

Monthly Rainfall didn't show variation at all the stations. Table 5.3 and Figure 5.5 show variation in monthly rainfall records. Shimla recorded relatively high decrease in monthly rainfall in all seasons during BP-II while an increase marked during BP-III in all seasons except in winter. The winter rainfall reflected continuous decrease in monthly rainfall at the station. Dehra Doon recorded decrease during BP-III. Bikaner marked an increase in rainfall in winter season during BP-III. Jodhpur marked an increase in winter rainfall during BP-I and BP-II while recorded decrease during BP-III. However, monsoon and annual rainfall marked relatively high increase at all the stations. Overall, the monsoon season recorded relatively high increase in rainfall during BP-III except Dehra Doon. Annual rainfall reflected the same results as the monsoon rainfall that constitutes a large chunk of the annual rainfall. The arid Western Rajasthan region recorded exceptionally high inconsistency in monthly rainfall in all the seasons but winter season marked with relatively high inconsistency in rainfall compared to other seasons. Interestingly, Shimla recorded high CV value for winter rainfall during BP-III. Except this, the Central-Western Himalaya reflected relatively low CV value for monthly rainfall compared to Western Rajasthan. Therefore, the WR marked with high inconsistency in monthly rainfall records than CWR.

Winter mean monthly temperature | **Monsoon mean monthly temperature** | **Annual mean monthly temperature**

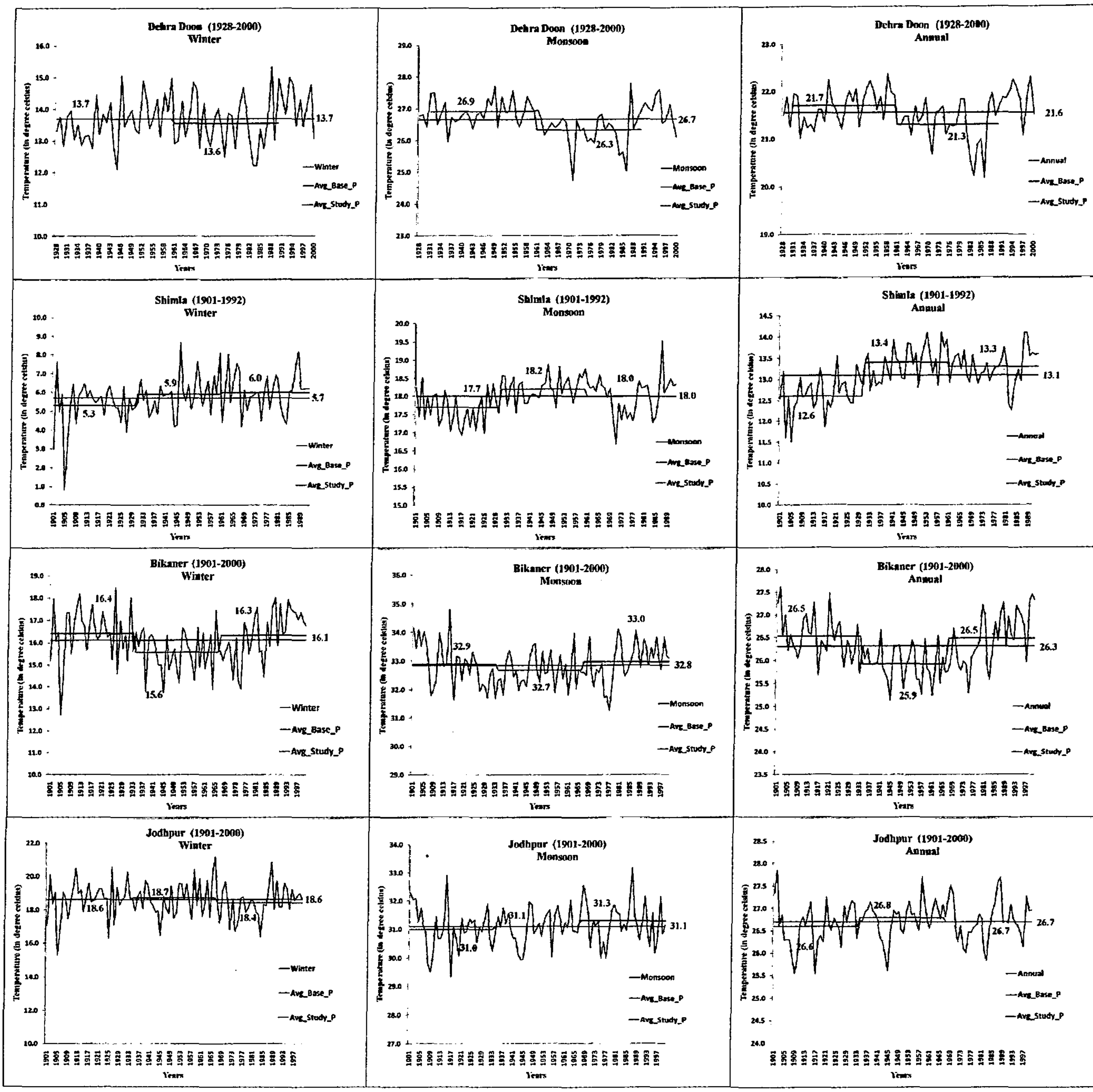


Figure 5.4: Seasonal variations in mean monthly temperature.

Source: National Data Centre, IMD, Pune

Winter monthly rainfall | **Monsoon monthly rainfall** | **Annual monthly rainfall**

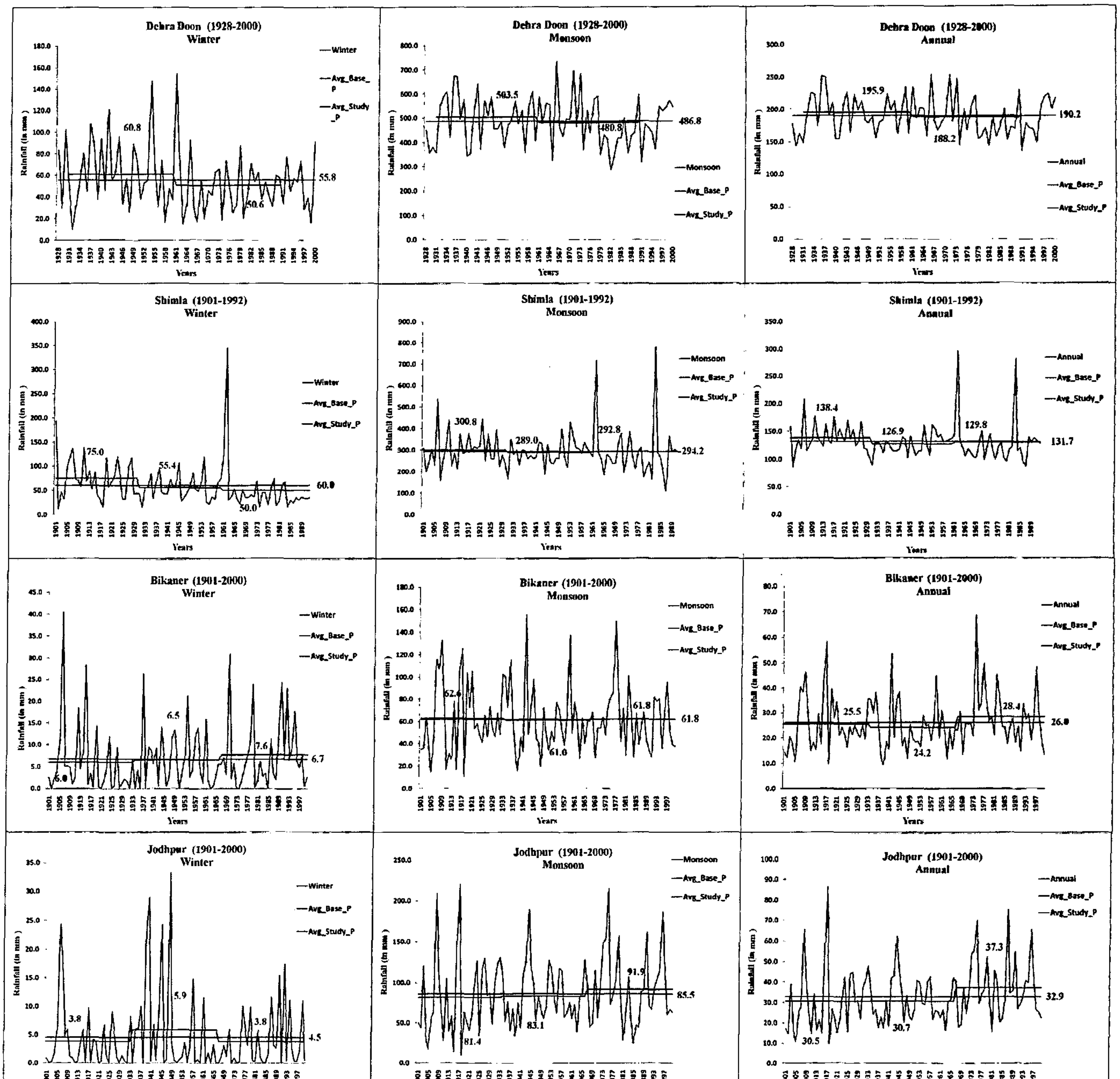


Figure 5.5: Seasonal variations in total monthly rainfall.

Source: National Data Centre, IMD, Pune

5.3.5 Results and Discussion

The temperature regime reflected relatively high seasonal-spatial variations compared to the rainfall regime. The maximum temperature experienced increase at all the stations during BP-III while this increase in temperature marked with diminishing rate of increase. Bikaner showed relatively high seasonal variation. Some major observations from the analysis are listed below;-

i. During BP-II, increase in the maximum temperature for winter season was relatively high compared to the increase during BP-III at all the stations. Himalayan region reflected decrease in maximum temperature in monsoon season during BP-III compared to BP-II.

ii. The Western Rajasthan reflected decrease during BP-II. Bikaner recorded decrease by -0.3 ^{0}C in maximum temperature compared to BP-I, and a sharp increase during BP-III. This is the major spatial variations recorded between these two different physiographic regions.

iii. The annual maximum temperature also followed the same trend like the monsoon season. The Western Rajasthan (WR) reflected an increase in annual maximum temperature during BP-III compared to the Central-Western Himalaya (CWH).

iv. Shimla, Dehra Doon and Jodhpur showed identical trends in minimum temperature but Bikaner marked reverse trend within the WR region. The minimum temperature recorded an increase at the three former meteorological stations during BP-I and BP-II and a decrease during BP-III.

v. Bikaner recorded relatively high decrease in minimum temperature in all three seasons during BP-II and a sharp increase during BP-III. The winter minimum temperature recorded an increase by 1.1 ^{0}C at Bikaner during BP-III compared to monsoon season. The annual minimum temperature also marked a relatively high increase at Bikaner.

vi. Overall, the winter season recorded relatively high decrease in minimum temperature during BP-III compared to monsoon and annual minimum temperature record at Shimla, Dehra Doon and Jodhpur.

vii. An increase in mean temperature recorded at Shimla, Dehra Doon and Jodhpur during BP-II.

viii. Bikaner recorded relatively high decrease in mean temperature during BP-II and an increase during BP-III. Bikaner and Jodhpur recorded an increase in mean temperature during monsoon season for the period BP-III. A decrease in mean temperature reflected at Shimla and Dehra Doon during monsoon season for BP-III.

ix. Overall, the BP-II recorded increase in men temperature and BP-III recorded decrease at CWH stations and at Jodhpur of WR region. Bikaner recorded increase in mean temperature.

x. Monthly Rainfall didn't show variation at all the stations. Shimla recorded relatively high decrease in monthly rainfall in all seasons during BP-II while an increase marked during BP-III in all seasons except in winter.

xi. The winter rainfall reflected continuous decrease in monthly rainfall at the station. Dehra Doon recorded decrease during BP-III.

xii. Bikaner marked an increase in rainfall in winter season during BP-III. Jodhpur marked an increase in winter rainfall during BP-I and BP-II while recorded decrease during BP-III. However, monsoon and annual rainfall marked relatively high increase at all the stations.

xiii. The monsoon season recorded relatively high increase in rainfall during BP-III except Dehra Doon. Annual rainfall reflected the same results as the monsoon rainfall that constitutes a large chunk of the annual rainfall. Rainfall data series didn't showed any common variation pattern for the stations.

The simple average method simply compared climatic conditions of two different physiographic regions and produced some very interesting results. An increase in maximum temperature, decrease in minimum temperature and monsoonal rainfall in the CWH region are some of the striking observations. Bikaner marked with outstanding records of both temperature and rainfall regime in the Western Rajasthan region.

5.4 Comparison of spatial variation using Coefficient of Variation (CV) method

The spatial diversity forces the climate of one place to be different from another one. This diversity produces the spatial variations in the climatic variables. The coefficient of variation (CV) is a suitable method to measure spatial variability. Data availability was mostly restricted in between 1930-1990 period at all four stations. Data availability at Dehra Doon is from 1928 to 2000, at Shimla from 1901 to 1992 and at Bikaner and Jodhpur from 1901 to 2000. That's why the most common contemporary period 1930-1990 was taken for the variation analysis. Table 5.4 represents the information about the meteorological stations included in this study.

Table 5.4 Meteorological stations used in spatial variation analysis

Region	Station	Height (in m)	Data Spane	Variable	Season	Month
Central-Western Himalaya	Dehra Doon	640	1930-90	Monthly Mean Temperature	Winter	Jan-Feb
					Pre-monsoon	March-May
	Shimla	2397	1930-90			
Western Rajasthan	Bikaner	242	1930-90	Monthly Rainfall	Monsoon	June-Sept
					Post-monsoon	Oct-Dec
	Jodhpur	231	1930-90		Annual	
		Note; seasons and variables are common to all the stations				

5.4.1 Mean Monthly Temperature

Shimla recorded relatively high variability in all seasons compared to other three stations. Table 5.5 and Figure 5.6 show the spatial variability in mean monthly temperature. The winter season recorded the highest CV at Shimla compared to the other stations. This shows the inconsistency in winter season mean temperature at the station. This trend was followed during all seasons. Shimla recorded highest variability in all seasons compared to other three stations. The winter season recorded highest variability at all the stations followed by the post-monsoon season. Monsoon season reflected lowest value of CV. The CWH region recorded more spatial variability than the WR region. The major factor behind this is the altitudinal variations between these two regions.

Table 5.5 Spatial variability in mean monthly temperature (1930-90) using Coefficient of Variation Method

(CV in Per Centages)

Region	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
Central-Western Himalaya	Dehra Doon	640	5.53	4.28	2.10	3.68	2.11
	Shimla	2397	19.98	8.39	2.81	9.62	4.09
Western Rajasthan	Bikaner	242	7.13	3.57	2.10	4.88	2.12
	Jodhpur	231	5.60	2.93	2.23	3.20	1.69

Source: National Data Centre, IMD, Pune

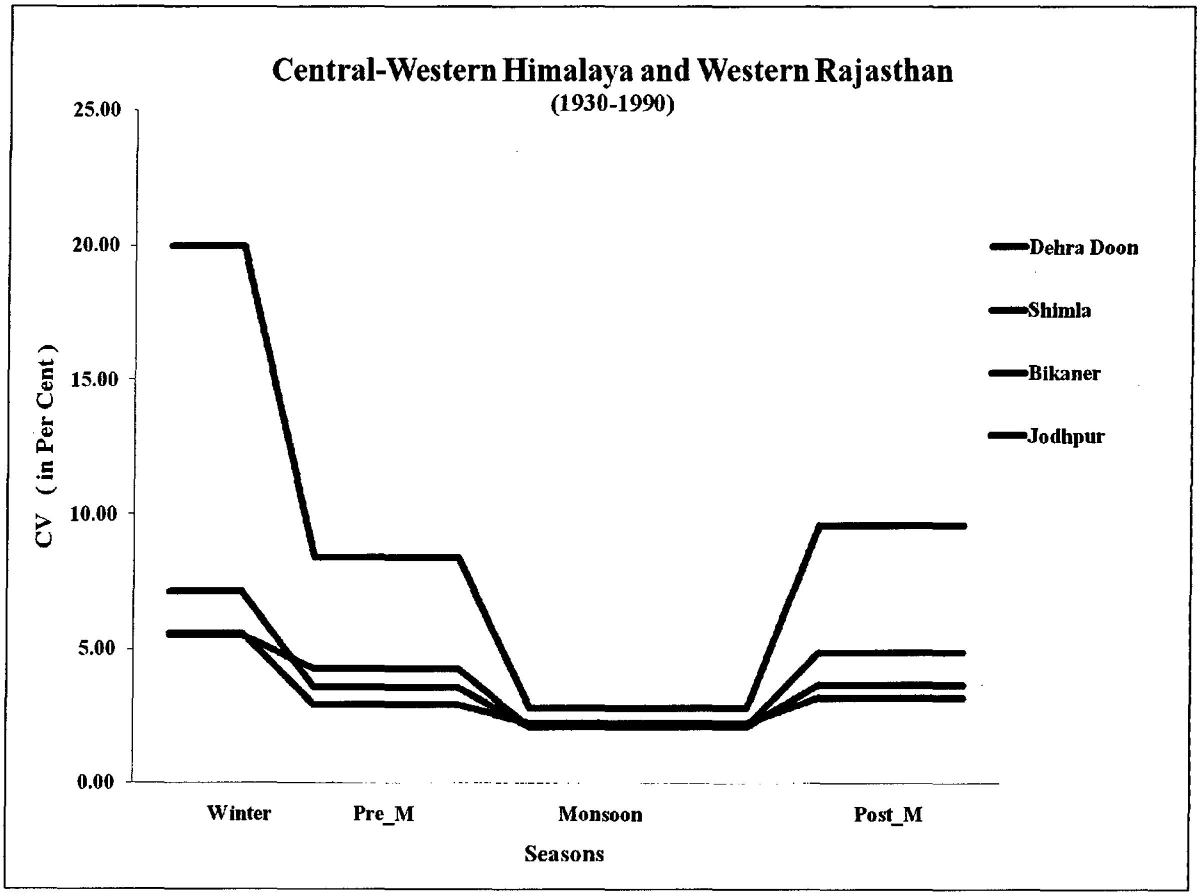


Figure 5.6: Spatial variability in mean monthly Temperature (1930-90).

Data-Base: National Data Centre, IMD, Pune

Table 5.6 Spatial variability in monthly rainfall (1930-90) using Coefficient of Variation Method

(CV in Per Centages)

Region	Station	Height (in m)	Winter	Pre_M	Monsoon	Post_M	Annual
Central-Western Himalaya	Dehra Doon	640	52.97	84.19	21.05	92.25	16.05
	Shimla	2397	75.33	46.28	32.89	71.02	24.11
Western Rajasthan	Bikaner	242	114.84	184.95	49.30	197.87	41.77
	Jodhpur	231	150.48	163.65	51.52	187.80	43.94

Source: National Data Centre, IMD, Pune

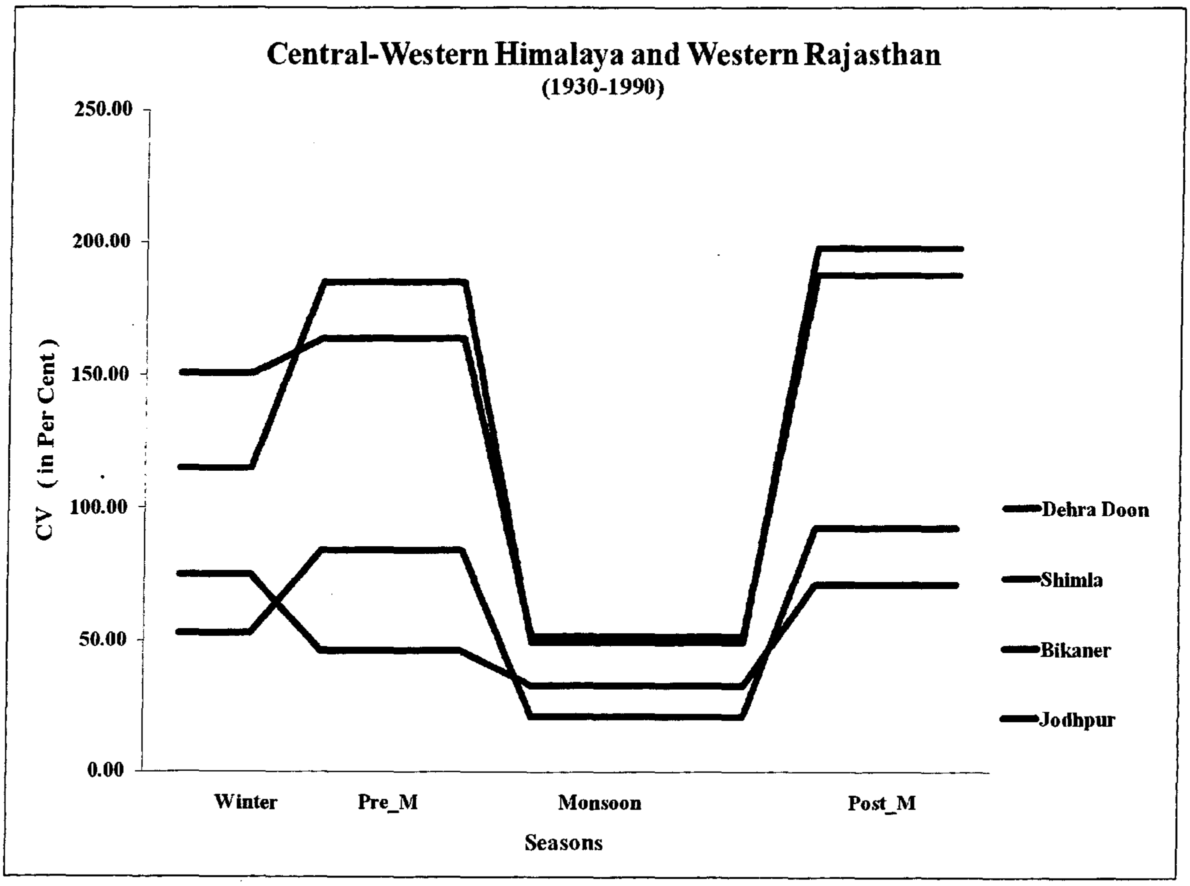


Figure 5.7: Spatial variability in monthly rainfall (1930-90).

Data-Base: National Data Centre, IMD, Pune

5.4.2 Total Monthly Rainfall

The Western Rajasthan region showed relatively high variability in monthly rainfall compared to the Central-Western Himalayan region. This denotes variation in performance of monsoon in these regions. The arid and deserted WR region reflected poor performance of monsoon that is uncertain, sporadic and un-evenly distributed in the region. On the other hand, the Himalayan region reflected relatively good performance of the monsoon. Secondly, the western disturbances of the post-monsoon and winter season also provide good amount of rainfall either in the form of rain or snow in the Himalayan region. The highest variability recorded in the post-monsoon period at all the stations except Shimla which recorded the highest variability in monthly rainfall during winter season. The monsoon season recorded lowest variability at all the stations because monsoon is very common and more or less simultaneously occurred at all the stations. Overall, the WR region recorded high variability in rainfall compared to the CWH region.

5.4.3 Results and Discussion

The CWH region recorded relatively high variability in mean monthly temperature compared to the WR region. The major factor behind this is the altitudinal variations. Shimla reflected relatively high variability in mean temperature because of its higher location. The normal laps rate is the main reason for such type of variability. The other three stations are located at the altitude between 230 and 640 m (amsl) while Shimla located at 2400 m (amsl). The winter season recorded relatively high variability at all the stations followed by the post-monsoon period. The monsoon season recorded lowest variability in mean temperature.

The WR region marked relatively high variability in monthly rainfall compared to the CWH region. The arid and deserted region receives less amount of rainfall whereas the Himalayan region records good amount of rainfall during monsoon and winter season. That's why variability in rainfall is relatively low in the CWH region. Relatively high variability in monthly rainfall recorded during post-monsoon season at all the stations except Shimla which recorded the highest variability during winter season. The variability in monsoon rainfall is relatively low at all meteorological stations. It can be concluded that rainfall in winter and post monsoon season is more inconsistent than monsoon season rainfall in both regions. However, these regions receive considerable amount of rainfall from western disturbances and retreating monsoon.

5.5 Comparison of trends in climatic variables using Simple Linear Regression method

In this analysis only winter, monsoon and annual data of rainfall and mean monthly maximum, minimum and mean temperature were included. Table 5.7 depicts the basic information about the meteorological stations included in this study.

Table 5.7 Meteorological stations used in trend analysis

Region	Station	Height (in m)	Data Spane	Variable	Season	Month
Central-Western Himalaya	Dehra Doon	640	1928-2000	Mean Monthly Maximum Temperature Mean Monthly Minimum Temperature	Winter	Jan-Feb
	Shimla	2397	1901-1992			
Western Rajasthan	Bikaner	242	1901-2000	Mean Monthly Temperature Monthly Rainfall	Monsoon	June-Sept
	Jodhpur	231	1901-2000		Annual	
		Note; seasons and variables are common to all the stations				

5.5.1 Mean Monthly Maximum Temperature

Maximum temperature marked an increasing trend at all the stations. However, Dehra Doon recorded a decreasing trend in maximum temperature during monsoon season while other stations recorded an increasing trend in maximum temperature (significant at 95 % confidence level for Shimla and Bikaner). The WR region recorded increase in maximum temperature at both the stations, Bikaner and Jodhpur for maximum temperature while the CWH region also repeated the same trend.

Table 5.8 Trend analysis in temperature and rainfall using simple linear regression method

Trend analysis of Maximum Temperature

Region	Station	Years	Height (in m)	Winter (b-values)	Monsoon (b-values)	Annual (b-values)		Station	Winter (trends)	Monsoon (trends)	Annual (trends)
Central-Western Himalaya	Shimla	1901-1992	2397	0.027	0.020	0.025		Shimla	(+)*	(+)*	(+)*
	Dehra Doon	1928-2000	640	0.011	-0.002	0.002		Dehra Doon	(+)*	(-)	(+)
Western Rajasthan	Bikaner	1901-2000	242	0.017	0.001	0.009		Bikaner	(+)*	(+)	(+)*
	Jodhpur	1901-2002	231	0.013	0.005	0.008		Jodhpur	(+)*	(+)	(+)

Trend analysis of Minimum Temperature

Region	Station	Years	Height (in m)	Winter (b-values)	Monsoon (b-values)	Annual (b-values)		Station	Winter (trends)	Monsoon (trends)	Annual (trends)
Central-Western Himalaya	Shimla	1901-1992	2397	-0.0010	-0.0097	-0.0037		Shimla	(-)	(-)	(-)
	Dehra Doon	1928-2000	640	0.001	-0.009	-0.004		Dehra Doon	(+)	(-)	(-)
Western Rajasthan	Bikaner	1901-2000	242	-0.013	0.0001	-0.009		Bikaner	(-)	(+)	(-)
	Jodhpur	1901-2002	231	-0.011	0.0005	-0.004		Jodhpur	(-)	(+)	(-)

Trend analysis of Mean Monthly Temperature

Region	Station	Years	Height (in m)	Winter (b-values)	Monsoon (b-values)	Annual (b-values)		Station	Winter (trends)	Monsoon (trends)	Annual (trends)
Central-Western Himalaya	Shimla	1901-1992	2397	0.013	0.005	0.011		Shimla	(+)*	(+)*	(+)*
	Dehra Doon	1928-2000	640	0.006	-0.006	-0.001		Dehra Doon	(+)	(-)	(-)
Western Rajasthan	Bikaner	1901-2000	242	0.002	0.001	-0.002		Bikaner	(+)*	(+)	(-)
	Jodhpur	1901-2002	231	0.001	0.003	0.002		Jodhpur	(+)	(+)	(+)

Trend analysis of Total Monthly Rainfall

Region	Station	Years	Height (in m)	Winter (b-values)	Monsoon (b-values)	Annual (b-values)		Station	Winter (trends)	Monsoon (trends)	Annual (trends)
Central-Western Himalaya	Shimla	1901-1992	2397	-0.486	-0.084	-0.118		Shimla	(-)*	(-)	(-)
	Dehra Doon	1928-2000	640	-0.271	-0.481	-0.136		Dehra Doon	(-)	(-)*	(-)
Western Rajasthan	Bikaner	1901-2000	242	0.015	-0.027	0.030		Bikaner	(+)	(-)	(+)*
	Jodhpur	1901-2002	231	-0.009	0.179	0.106		Jodhpur	(-)	(+)*	(+)*

Source: National Data Centre, IMD, Pune

(-) increasing trend
(+) decreasing trend
* significant at 95 % confidence level

5.5.2 Mean Monthly Minimum Temperature

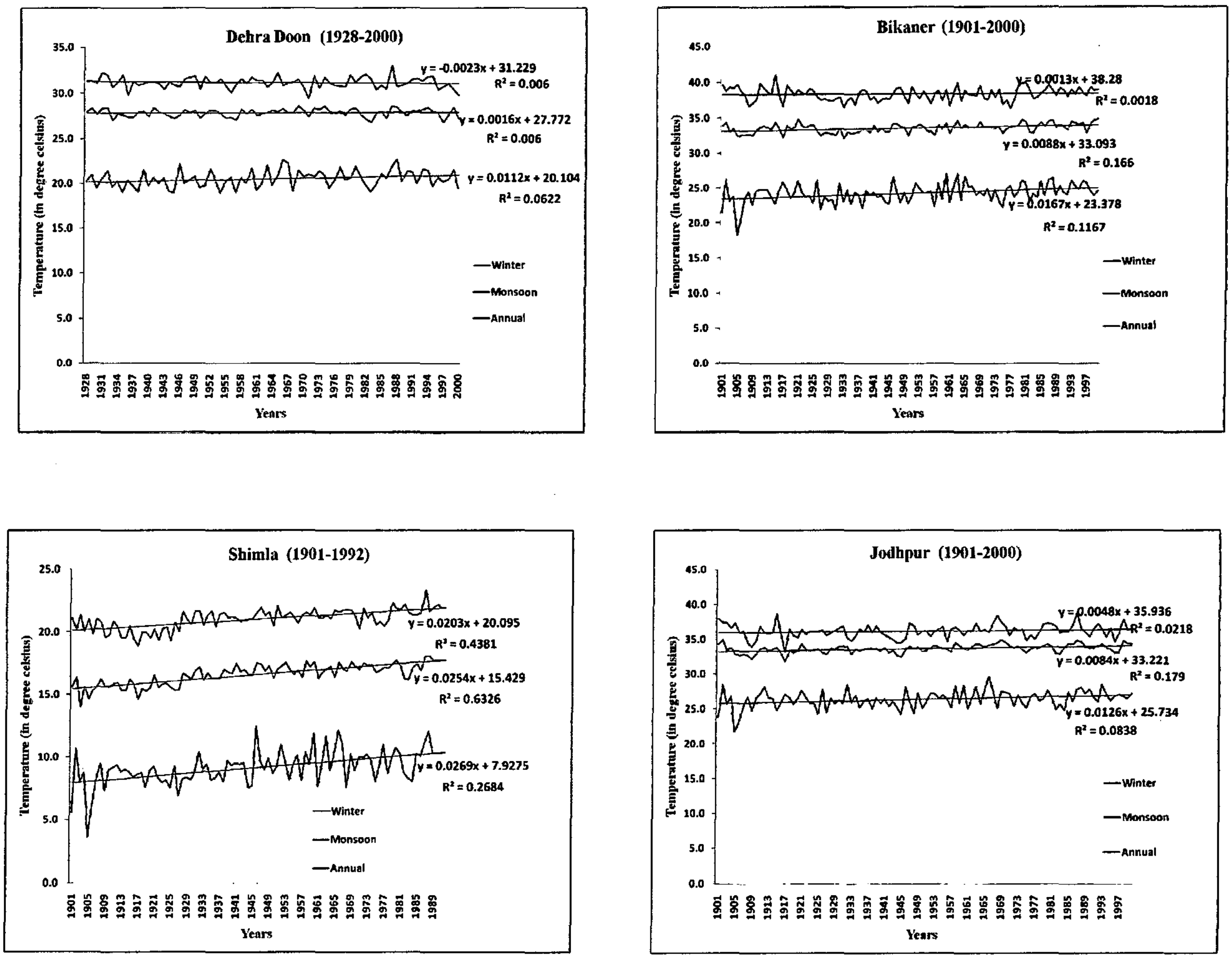
Table 5.8 shows trend in mean monthly minimum temperature. The minimum temperature marked a decreasing trend in the CWH region during all seasons except winter season at Dehra Doon. The WR region recorded decreasing trend in winter and annual minimum temperature but reflected increasing trend in monsoon season minimum temperature. thus, these two regions are not reflecting the similar trend in monsoon minimum temperature.

5.5.3 Mean Monthly Temperature

The mean monthly temperature recorded increasing trend for regions. The WR region marked a significant increasing trend in mean monthly temperature. Stationwise analysis reflected that a significant increasing trend recorded in mean temperature during winter and monsoon season at Jodhpur and Bikaner (significant at 95 % confidence level). A decreasing trend represented at Bikaner in annual mean temperature records. In CWH region Shimla recorded increasing trend in temperature regime (significant at 95 % confidence level). Dehra Doon marked increasing trend in winter mean temperature while recorded a decreasing trends monsoon and annual mean temperature. Therefore, it can be concluded that the winter mean temperature reflected increasing trends while the monsoon season marked a decreasing trend. However, the annual mean temperature reflected fluctuations for both regions.

5.5.4 Total Monthly Rainfall

Rainfall recorded significant variations at all meteorological stations. The CWH region marked decreasing trend in monthly rainfall during each season (significant at 95 % confidence level for winter rainfall at Shimla and monsoon rainfall at Dehra Doon). However, the region receives fair amount of rainfall compared to WR region but a decreasing trend especially in the monsoon season reflects deficit in rainfall. On the other hand, the WR region recorded increasing trend in monthly rainfall. Bikaner recorded an increasing trend in winter season and annual rainfall (significant at 95 % confidence level). However, monsoon rainfall showed a decreasing trend similar to the CWH region. Jodhpur reflected an increasing trend in monsoon and annual rainfall (significant at 95 % confidence level). Increasing trend in the monsoon rainfall was only recorded at Jodhpur. Overall, the WR region marked an increasing trend in annual rainfall while the CWH region experienced a decreasing trend. It is very promising result that the region with arid climate marked increasing trend in annual rainfall.

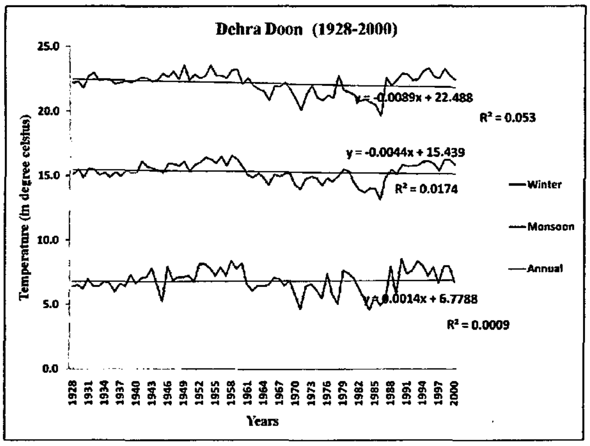


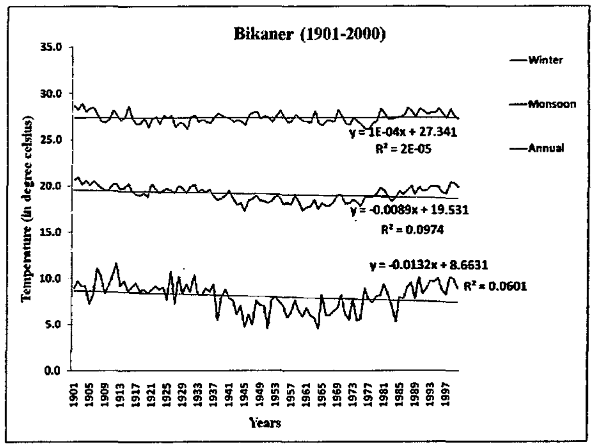
Central-Western Himalaya

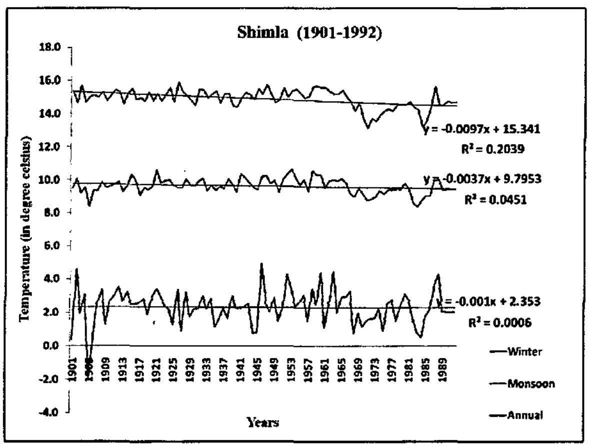
Western Rajasthan

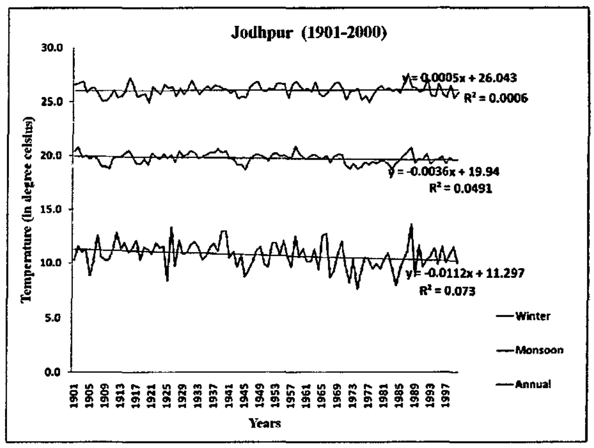
Figure 5.8: Trend analysis of mean monthly maximum temperature.

Source: National Data Centre, IMD, Pune







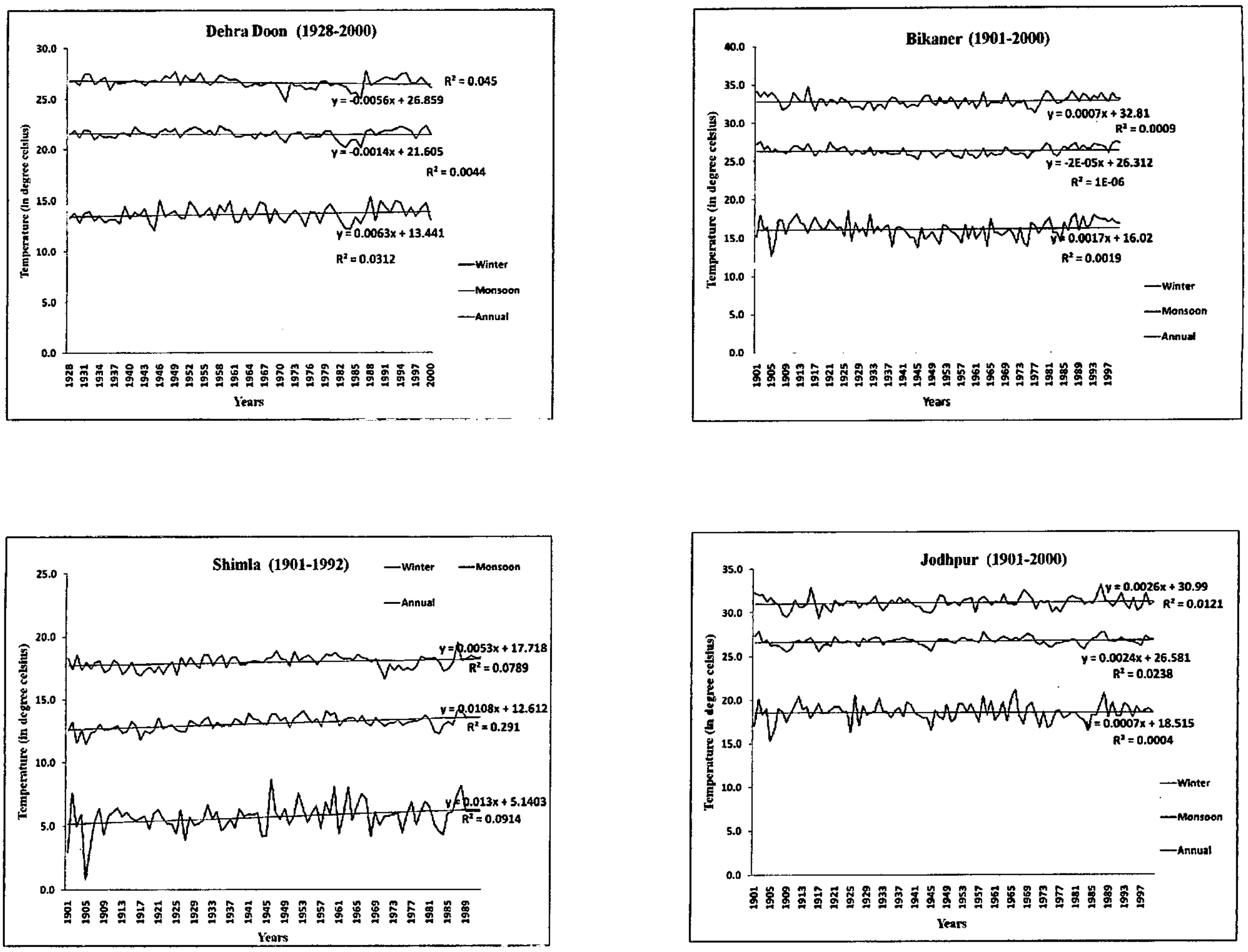


Central-Western Himalaya

Western Rajasthan

Figure 5.9: Trend analysis of mean monthly minimum temperature.

Source: National Data Centre, IMD, Pune

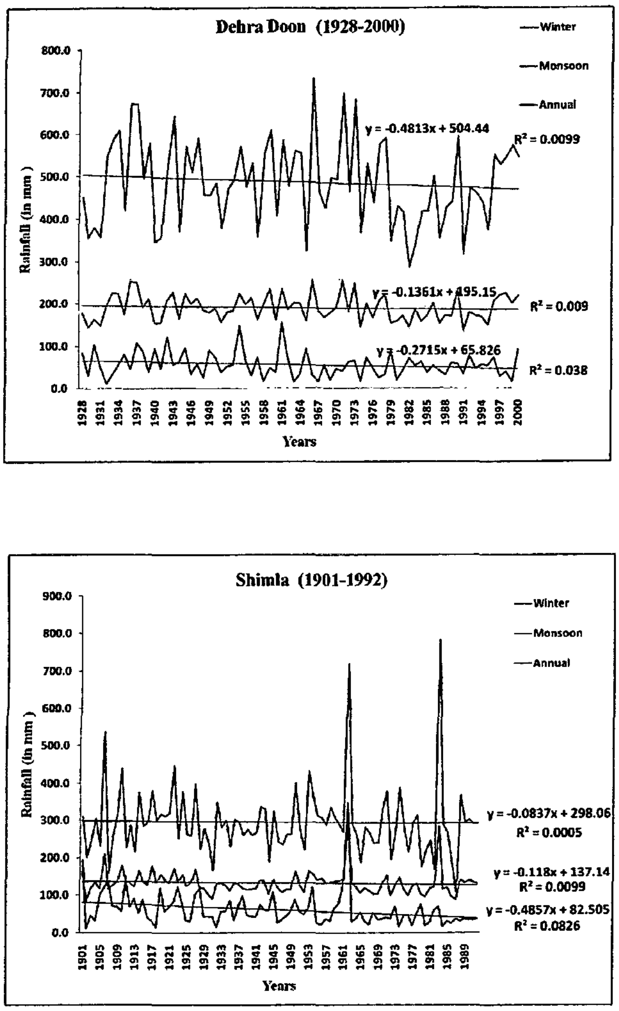


Central-Western Himalaya

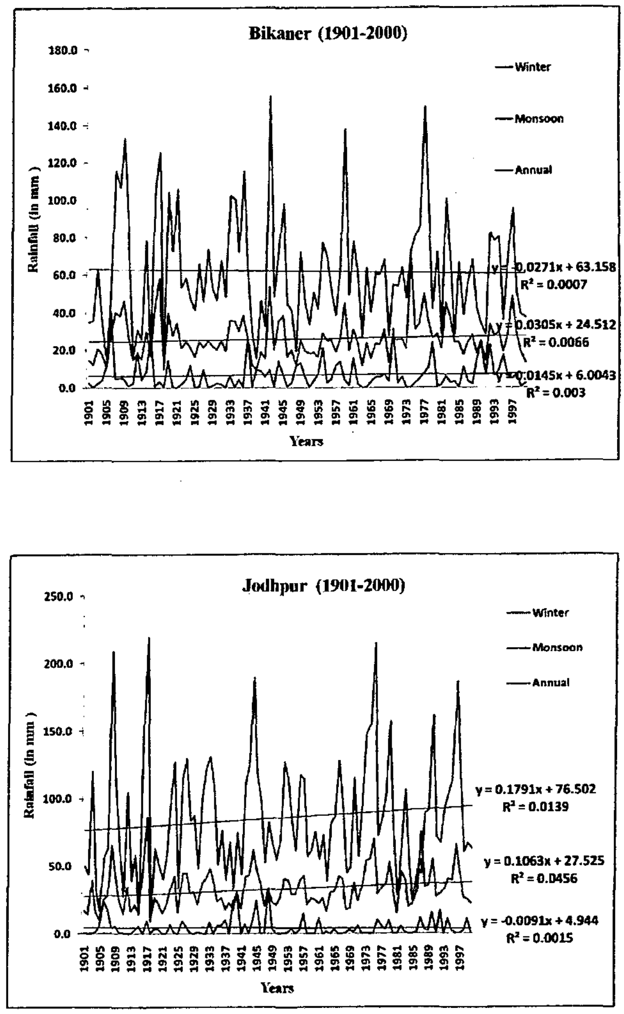
Western Rajasthan

Figure 5.10: Trend analysis of mean monthly temperature.

Source: National Data Centre, IMD, Pune



Central-Western Himalaya



Western Rajasthan

Figure 5.11: Trend analysis of total monthly rainfall.

Source: National Data Centre, IMD, Pune

5.5.5 Results and Discussion

Trend analysis represents momentum of the climatic variables. The important result is an increasing trend recorded in maximum temperature in both regions (significant at 95 % confidence level). The minimum temperature marked decreasing trend while mean temperature marked increasing trend. The winter and monsoon season reflected increasing trend in mean temperature. Annual temperature recorded increasing trend at Shimla and Jodhpur while

Dehra Doon and Bikaner recorded a decreasing trend. The monthly rainfall recorded increasing trend in the WR region while the CWH region recorded a decreasing trend in rainfall especially in monsoon rainfall. Some of the major observations are as follows;-

i. Maximum temperature experienced increasing trend at all the stations. Only Dehra Doon recorded a decreasing trend in maximum temperature during monsoon season.
ii. Minimum temperature reflected decreasing trend in the CWH region during all seasons except winter at Dehra Doon. The WR region recorded a decreasing trend in winter and annual minimum temperature but marked an increase in monsoon minimum temperature.
iii. The mean temperature marked an increasing trend in both regions. The WR region experienced significant increasing trend.
iv. In the CWH region, Shimla recorded an increasing trend in winter, monsoon and annual mean temperature. Dehra Doon recorded increasing trend in winter mean temperature and recorded a decreasing trend during monsoon and annual mean temperature.
v. Summarily the winter mean temperature experienced increasing trend and monsoon mean temperature reflected a decreasing trend. The annual mean temperature reflected fluctuations in both regions.
vi. Rainfall recorded significant variations at all meteorological stations. The CWH region marked decreasing trend in monthly rainfall during each season. However, the region receives fair amount of rainfall compared to WR region but a decreasing trend especially in the monsoon season reflects deficit in rainfall.
vii. On the other hand, the WR region recorded increasing trend in monthly rainfall. Bikaner recorded an increasing trend in winter season and annual rainfall. However, monsoon rainfall showed a decreasing trend similar to the CWH region.
viii. Jodhpur reflected an increasing trend in monsoon and annual rainfall. Increasing trend in the monsoon rainfall was only recorded at Jodhpur.
ix. Summarily, the WR region marked an increasing trend in annual rainfall while the CWH region experienced a decreasing trend. It is very promising result that the region with arid climate marked increasing trend in annual rainfall.

5.6 Chapter summary and conclusion

The case study was aimed to compare the climatic variation recorded by two different physiographic regions viz. the Central-Western Himalaya and the Western Rajasthan. This study provides some of very important and significant results about the climatic variations recorded in these regions. The simple average method was used to analyze the temporal-seasonal variation and the coefficient of variation method was used for the calculation of the spatial variation within and between the regions. The simple linear regression method was applied to analyze trend in climatic variables using best-fit line.

The simple average method successfully compared the climatic conditions of two different physiographic regions and produced some striking results. An increase in maximum temperature, a decreasing trend in minimum temperature and decreasing monsoon rainfall in the CWH region and the different records at Bikaner in every aspect of the climate were some of the interesting results. The maximum temperature experienced increasing trend at all the stations during 1960-90. The winter maximum temperature reflected significant increasing trend in the CWH region. The high elevation station Shimla recorded increasing trend in temperature during winter season. The minimum temperature recorded an increase at Shimla, Dehra Doon and Jodhpur during 1901-60 and a decrease during 1960-90. The winter season recorded relatively high decrease in minimum temperature during 1960-90 compared to monsoon and annual minimum temperature at Shimla, Dehra Doon and Jodhpur. The mean temperature marked increase during 1930-90 while decease during 1960-90 at the CWH stations and at Jodhpur. Bikaner reflected persistent increase in mean temperature during 1901-2000. The rainfall regime reflected decrease in CWH region while increase in WR region. Shimla recorded relatively high decrease in winter rainfall while Dehra Doon recorded decrease in monsoon rainfall during 1960-90.

The CWH region recorded relatively high variability in mean monthly temperature compared to the WR region. The major factor behind this is the altitudinal variations between these two regions. Shimla reflected relatively high inconsistency in mean temperature. Both, the CWH and the WR, regions marked relatively high inconsistency in mean temperature records during winter season while relatively high consistency during monsoon season. The Western Rajasthan marked relatively high variability in monthly rainfall compared to the

Central-Western Himalaya because of less amount of rainfall received by the former during monsoon and post-monsoon season. It is perceived that rainfall in winter and post monsoon season is more inconsistent than monsoon season rainfall in both regions.

Trend analysis using simple linear regression method provided some striking results. An increasing trend recorded in maximum temperature in both regions which was found significant at 95 % confidence level. The winter and monsoon season reflected statistically significant increasing trend in mean temperature in both regions. The monthly rainfall recorded increasing trend in Western Rajasthan while the Central-Western Himalaya recorded a statistically significant decreasing trend in rainfall especially in monsoon season. Both, Bikaner and Jodhpur marked an increasing trend in annual rainfall while a (statistically significant) increasing trend in monsoon rainfall reflected at Jodhpur only among all four meteorological stations.

Chapter Six

Summary and Conclusion

Climate is the long-term characteristics of the atmospheric conditions that not only affect the physical landscape but also the cultural and social landscape. In the nature, nothing is static and permanent. Each system and each unit of a system under go cyclic change over period of time. On the basis of temporal extent changes in climatic condition can be termed as climate change, climate shift and climatic variation. Climatic variation refers to the fluctuations recorded in the climatic parameters for a shorter time period, while the former two are used for the long-term (time period varies from epoch to era) climatic fluctuations and reversals. These variations in the climatic parameters suggest about the changing pattern of the climate and on that basis the future climate become predictable with much accuracy.

A large longitudinal extent, massive vertical dimension and continentality make the Himalayan region a much potential and attractive part of the world for the study of climate. This climatic study covered the Central-western Himalayan part of the massive Himalayan mountain system. The Central-Western Himalaya is the hot spot of the climate studies as the region has countless glaciers which are considered as thermometer of the Earth. That's why the current study has significant locational and situational importance. The instrumental records of rainfall and temperature were included in the study provided by the National Data Centre, Indian Meteorological Department, Pune. Study covered temporal variations analyzed with the moving average, naturalized accumulated departure from mean and simple average method, spatial variation analysis by coefficient of variation and trend analysis by simple linear regression method. A case study for the comparison of the climatic variations, experienced by the Central-Western Himalaya and the Western Rajasthan regions, was also incorporated.

The temporal-seasonal variation analysis using moving average method suggests cyclic fluctuation in rainfall and temperature regime in CWH region while the normalized accumulated departure from mean (NADM) and simple average method quantifies the variability in rainfall and temperature and also permits visual as well as statistical comparison of unlike data series. Cyclic fluctuation recorded in mean monthly maximum temperature in the region. The Central Himalayan meteorological stations recorded decrease in rainfall in almost every season while Western Himalaya reflected cyclic fluctuations. The seasonal variation analysis using simple average method provides that increasing trend in maximum temperature was more prominent at the high elevated site, Shimla while the decreasing trend in minimum temperature became more prominent at the low elevated site, Dehra Doon. A decreasing trend in rainfall recorded during winter and monsoon season in the CWH region. Spatial variation analysis using coefficient of variation method provides some interesting findings. It suggests that site with high elevation recorded relatively high variability in temperature as compared to low elevated stations. Relatively low variability in climatic parameters, such as rainfall and temperature is marked during monsoon season while relatively high variability in mean temperature is observed during winter season.

The trend analysis of rainfall and temperature regimes using simple linear regression method marked striking results. The temperature regime displayed statistically significant (at 95 % confidence level) increasing trends in Himachal Pradesh while a decreasing trend in Uttarakhand. The Western Himalaya recorded an increasing trend in maximum temperature. On the other hand, the Central Himalaya reflected decreasing trend in minimum as well as mean temperature. The monsoon and winter season temperature depicted a significant increasing trend in the Western Himalayan region. A decreasing trend in monsoon rainfall is common for all the stations (significant at 95 % confidence level) in the CWH region which consequently marked a decreasing trend in annual rainfall of the region. Uttarakhand experienced significant decreasing trend in rainfall during monsoon and post-monsoon season while Himachal Pradesh reflected decreasing trend in monsoon, winter and annual rainfall. The monthly rainy days marked a decreasing trend during monsoon and winter seasons in Himachal Pradesh.

The case study provides some significant results about the climatic variations recorded in two different physiographic regions viz. the Central-Western Himalaya and the Western Rajasthan. The maximum temperature experienced increasing trend in both the regions during 1960-90. The winter maximum temperature reflected significant increasing trend in the CWH region. The mean temperature marked increase during 1930-90 while decease during 1960-90 at the CWH stations and at Jodhpur station of the WR. Bikaner reflected persistent increase in mean temperature during 1901-2000. The rainfall regime reflected decrease in CWH region while increase in WR region in simple average analysis. Both, the CWH and the WR, regions marked relatively high inconsistency in mean temperature records during winter season while relatively high consistency during monsoon season. The Western Rajasthan marked relatively high variability in monthly rainfall compared to the Central-Western Himalaya because of less amount of rainfall received by the former during monsoon and post-monsoon season. It is perceived that rainfall in winter and post monsoon season is more inconsistent than monsoon season rainfall in both regions. Trend analysis suggests an increasing trend recorded in maximum temperature in both regions which was found significant at 95 % confidence level. The winter and monsoon season reflected statistically significant increasing trend in mean temperature in both regions. The monthly rainfall recorded increasing trend in Western Rajasthan while the Central-Western Himalaya recorded a statistically significant decreasing trend in rainfall especially in monsoon season. Both, Bikaner and Jodhpur marked an increasing trend in annual rainfall while an increasing (statistically significant) trend in monsoon rainfall recorded at Jodhpur only among all four meteorological stations.

In the concluding remarks; this study provided vital records of the climatic conditions of the Himalayan region and also experienced the data scarcity and un-availability of authentic and continuous data series for climatic elements. The maximum temperature recorded absolute increase and also reflected increasing trend in the Central-Western Himalayan region. The high elevation station Shimla marked relatively high increase in maximum temperature. Minimum temperature recorded decreasing trend in the Central Himalaya. A decrease in rainfall recorded in winter and monsoon season. Spatial variation analysis represented that monsoon season recorded lowest spatial variability in both, rainfall and temperature regime. The winter season reflected relatively high variability in temperature regime. The comparison of climatic variables between the CWH and the WR region provided very important results. The maximum temperature recorded a statistically significant increasing trend in both the regions and minimum temperature marked an increasing trend during monsoon season in the WR region. A decreasing trend in monsoon rainfall was a major concern point in the CWH region. On the other hand, the WR recorded statistically significant increasing trend in monsoon as well as annual rainfall. Therefore, it can be concluded that the Western Himalaya recorded increasing trend in temperature regime while the Central Himalaya marked statistically significant decreasing trend in rainfall. The Western Rajasthan recorded an increasing trend in temperature during winter season and importantly, marked a statistically significant increasing trend in rainfall.

Bibliography

Adel, M. M. (2002). "Man-made climatic changes in the Ganges basin", *International Journal of Climatology*, Vol.22, pp. 993–1016.

Aizen, V. B., Aizen, E. M., Melack, J. M. and Dozier, J. (1997). "Climatic and hydrologic changes in the Tien Shan, central Asia". *Journal of Climate*, Vol.10, pp. 1393–1404.

Anupama, K., Ramesh, R., Bonnefille, R. (2000). "Modern pollen rain from the Biligirirangan-Melagiri hills of southern Eastern Ghats, India." *Rev. Palaeobot. Palynol.* 108, pp. 175–196.

Archer, D. R. (2003). "Contrasting hydrological regimes in the Indus Basin", *Journal of Hydrology*, No. 274, pp. 198–210.

Archer, D. R. (2004). "Hydrological implications of spatial and altitudinal variation in temperature in the Upper Indus Basin', *Nord. Hydrol*, 35 (3), pp. 209–222.

Archer, D. R. and Fowler, H. J. (2004) "Spatial and temporal variations in precipitation in the Upper Indus Basin, global tele-connections and hydrological implications", *Hydrol. Earth Syst. Sci.*, Vol. 8, pp. 47–61.

Armstrong, R., Alford, D. and Racovitenau, A. (2009). "Glaciers as indicators of climate change", Sustainable Mountain development (ICIMOD), No. 56, pp. 3.

Baines, P.G. and Folland. C.K. (2007)." Evidence for rapid global climate shift across the late 1960s", *Journal of Climate,* Vol. 20, pp. 2721–2744.

Basitha, Ashoke and Arya, D.S. and Goel, N.K. (2009). "Analysis of the Historical Change in Rainfall in the Indian Himalaya", *International Journal of Climatology*, Vol. 29, Issue- 4, 30th march, 2009, pp. 555-572.

Beaufort, L., Bassinot, F., Vincent, E. (1999). "Primary production response to orbitally induced variations of the southern oscillation in the equatorial Indian Ocean." In Abrantes, F., Mix, A. (Eds.), *Reconstructing Ocean History: A Window into the Future.* Kluwer Academic/Plenum Publishers, pp. 245–271.

Beniston, M. (2003). "Climatic change in mountainous regions: a review of possible impact", Climatic Change, No. 59, pp. 5–31.

Beniston, M., Diaz, H. F., Bradley, R. S. (1997). "Climate Change at High Elevation Sites: an overview." *Climatic Change* 36: pp. 233–251, 1997.

Bhutiyani, M.R .and Kale, V.S.and Pawar, N.J (2009). "Climate Change and the Precipitation Variation in the Northwestern Himalaya", *International Journal of Climatology*, Vol. 29, Issue- 4, 30th march, 2009.

Bhutiyani, M.R. and Kale, V.S.and Pawar, N.J. (2007). "Long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century", *Climatic Change* (2007) 85, pp. 159–177.

Bonnefille, R., Anupama, K., Barboni, D., Pascal, J.P., Prasad, S., Sutra, J.P. (1999). "Modern pollen spectra from tropical South India and Sri Lanka: altitudinal distribution." J. *Biogeogr.* 26, pp. 1255–1280.

Bookhagen, Bodo and Thiede, Rasmus C., and Strecker, Manfred R. (2005). "Abnormal monsoon years and their control on erosion and sediment f lux in the high, arid northwest Himalaya". *Earth and Planetary Science* Letters, 231, pp. 131– 146.

Borgaonkar, H.P., Ram, Somaru, Sikder, A.B. (2008). "Assessment of tree-ring analysis of high-elevation Cedrus deodara D. Don from Western Himalaya (India) in relation to climate and glacier fluctuations." *Dendrochronologia* 27 (2009) pp. 59–69.

Burns, Stephen J and Fleitmann, Dominik and Matter, Albert and Kramers, Jan. Al Subbary3, and Abdulkarim, (2003). "Indian Ocean Climate and an Absolute Chronology over Dansgaard/Oeschger Events 9 to 13", *Science*, Vol. 301, 5 September, 2003.

Crowley, T. J. (2000). "Causes of climate change over the past 1000 years", Science, No.289, pp. 270– 277.

Dash, S.K. and Hunt, J.C.R. (2007). "Variability of climate change in India", Current Science, pp. 782-788.

Dash, S.K., Kulkarni, M.A., Mohanty, U.C. and Prasad, K. (2009). "Changes in the characteristics of rainfall events in India', Jouranl of Geophysical Research, pp. 1-12.

Daun, K., Yao,T. and Thompson, L.G. (2006). "Response of monsoon precipitation in the Himalayas to global warming", Journal of Geophysical Research, No. 111.

Diaz, H.F, Grosjean, M. and Graumlich, L. (2003). "Climate variability and change in high elevation regions: past, present and future", *Climatic Change, No.* 59, pp.1–4.

Diaz, H.F. and Bradley, R.S. (1997). "Temperature variations during the last century at high elevation sites", *Climatic Change, No.* 36, pp.253–279.

Duplessy, J.C. (1982). "Glacial to interglacial contrasts in the northern Indian Ocean." *Nature* 295, pp. 494– 498.

Easterling, D. R., and Coauthors (1997). "Maximum and minimum temperature trends for the globe", *Science*, No. 277, pp. 364–367.

Folland, C. K., and Coauthors. (2001a). "Observed climate variability and change. Climate Change 2001: The Scientific Basis", J.T. Houghton et al., Eds., *Cambridge University Press*, pp. 99–182.

Fowler, H.J. and Archer, D.R. (2005). "Conflicting Signals of Climatic Change in the Upper Indus Basin", *Journal of Climate*, Vol. 19, pp. 4276-4293.

Fowler, H.J. and Archer, D.R. (2005). "Hydro-climatological variability in Upper Indus Basin and implications for water resources." In: Wagner, T. *et al.*, (eds.) *Regional Hydrological Impacts of Climate Change – Impact Assessment and Decision Making.* Proceedings of Symposium S6 held during the Seventh IAHS Scientific Assembly at Foz do Iguacu, Brazil, IAHS Publication 295, pp. 131–138.

Gadgil, Alka and Dhorde, Amit. (2005). "Temperature trends in twentieth century at Pune, India", *Atmospheric Enviornment,* 39, pp. 6550-6556.

Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodan M.S. and Xavier, P.K. (2006). "Increasing trend of extreme rain events over India in a warming environment", Science, pp. 1442-1444.

Gupta, Anil K. and Thamban, M. (2007). "Holocene Indian Monsoon Variability", Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur - 721 302, *Glimpses of Geosciences Research in India.*

Hingane, L. S., Kumar, K. R. and Murty, B. V. R. (1985). "Long term trends of surface air temperature in India". Journal of Climatology, Vol. 5, pp. 521–528.

Hu, Z. Z., Yang, S. and Wu, R. G. (2003). "Long-term climate variations in China and global warming signal", J. Geophys. Res., Vol. 108, pp. 4614-20.

IMD. (2009). A report on high temperatures during January, 2009

Intergovernmental Panel on Climate Change (IPCC) (1996). Watson, R. T., Zinyowera, M. C., Moss, R. H., and Dokken, D. J. (eds.), Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Changes: Scientific Technical Analyses, *Cambridge University Press*, Cambridge, pp. 878.

Intergovernmental Panel on Climate Change (IPCC) (2001). Climate Change. The IPCC Third Assessment Report, Vol. I, the scientific basis, II-Impacts, Adaptation and Vulnerability, III-Mitigation, *Cambridge University Press*, Cambridge and New York.

Intergovernmental Panel on Climate Change (IPCC) (2001). McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., and White, K. S. (eds.), Climate Change 2001. Impacts, Adaptation, and Vulnerability, *Cambridge University Press*, Cambridge, pp. 1,032.

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability, Working Group II Contribution to the Intergovernmental Panel on Climate Change – Fourth Assessment Report Summary for Policymakers.

Juyal, N., Pant, R.K., Basavaiah, Bhushan, Jain, N. R., Saini, M. N.K., Yadav, M.G., Singhvi, A.K. (2009). "Reconstruction of Last Glacial to early Holocene monsoon variability from relict lake sediments of the Higher Central Himalaya, Uttrakhand, India." *Journal of Asian Earth Sciences* 34 (2009) pp. 437–449.

Kothwale, D.R., Rupa Kumar, K. (2005). "On the recent changes in surface temperature trends over India", Geophysical Research Letters, No. 32, pp. 1-4.

Kothyari, U. C., and Singh, V. P. (1996). "Rainfall and temperature trends in India", Hydrol. Processes, Vol. 10, pp. 357–372.

Kumar, K. R., and Hingane, L. S. (1988). "Long term variation of surface air temperature at major industrial cities of India", Climatic Change, Vol. 13, pp. 287–307.

Liu, X. and Chen, B. (2000). "Climatic warming in the Tibetan Plateau during recent decades", International Journal of Climatology, Vol. 20, Issue 14, pp. 1729–1742.

Lowe, J.J. and Walker, M.J.C. (1984.). "Reconstructing Quaternary Environments". In: *Longmans, London* (1984), pp. 389-396.

Mayewaski, A. Paul and Pregent, Gerad P. and Jeschek, Peter A. and Ahmad, Nasiruddin. (1980). "Himalayan and Trans-Himalayan Glacier Fluctuations and the South Asian Monsoon Record", *Arctic and Alpine Research*, Vol. 12, No. 2 (May, 1980), pp. 171-182.

Miehe, G. (1992). "Recent climatic changes in the Karakoram as indicated by vegetation features and geomorphological processes", Abstracts, Int. Symp. on the Karakoram and Kunlun Mountains, Kashi, China, UNESCO, 110.

Mujumdar, P.P. and Ghosh, S. (2007). "Assessment of Impact of Global Climate Change on Precipitation at Regional Scale", *Jalvigyan n Sameeksha*, Vol.22, 2007.

Newcastle University, UK. (2006). News release: "Why some Himalayan glaciers aren't melting due to climate change Mountain climate change trends could predict water resources", *Newcastle University, UK*, August 24, 2006.

Owen, L. A. and Pickering, K. T. (1997). "An introduction to global environmental issues", Edition: 2 - 1997 - 512 pages.

Pal, Indrani and Al-Tabbaa, Abir. (2007). "Long-term changes and variability of monthly extreme temperatures in India" *Theoretical and Applied Climatology*, Volume 100, Numbers 1-2, pp. 45-56.

Pant, G.B. and Borgaonkar, H.P. (1984). "Climate of the hill regions of Uttar Pradesh", *Himalayan Research and Development,* Vol. 3, pp. 13–20.

Pant, G.B., Borgaonkar, H.P. and Rupa, K. K. (1999). "Climate variability over the Western Himalaya since little ice age: dendroclimatic implications", In: Proceedings of national snow science workshop "Technology in support of snow and avalanche research", Manali (India), October 1999.

Pant, G.B., Rupa, K.K., Parthasarathy, B. and Borgaonkar, H.P. (1988). " Long-term variability of the Indian summer monsoon and related parameters", Adv Atmos Sci, Vol. 5, pp. 469–481.

Pant, R.K. and Jugal, N.B.N and Saini, N.H. and Yadava, M.G. and Appel, E. and Singhvi, A.K. (2005). "A 20 ka Climatic Record from Central Himalayan Loess Deposits", *Journal of Quaternary Science*, Vol.20, Issue – 5, July 5, 2005, pp – 485-492.

Parthasarathy, B. and Munot, A. A. and Kothawale, D. R. (1994). All-India Monthly and Seasonal Rainfall Series: 1871-1993", Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pune, India, *Theory. Appl. Climatology*. 49, pp. 217-224.

Phadtare, Netajirao R. (2000). "Sharp Decrease in Summer Monsoon Strength 4000–3500 cal yr B.P. in the Central Higher Himalaya of India Based on Pollen Evidence from Alpine Peat", *Quaternary Research* 53, pp. 122–129.

Prabhu, C.N. and Shankara, R. and Anupamab, K. and Taiebc, M. and Bonneville, R. and Vidalc, L. and Prasad, S. (2004). "A 200-ka pollen and oxygen-isotopic record from two sediment Cores from the eastern Arabian Sea", *Palaeogeography, Palaeoclimatology, Palaeoecology* 214 (2004) pp. 309– 321.

Prasad, Sushma and Enzel, Yehouda (2006). "Holocene paleoclimates of India." *Quaternary Research* 66 (2006) pp. 442–453

Rakhecha, P.R., Kulkarni, A.K., Mandal, B.N. and Dhar, O.N. (1983). "Winter and spring precipitation over the northwestern Himalaya", *Proceedings of the First National Symposium on Seasonal Snow Cover*, New Delhi, pp. 175–181.

Rashida, H. and Flowera, B.P. and. Pooreb, R.Z and Quinnc, T.M. (2007). "A 25 ka Indian Ocean Monsoon Variability Record from the Andaman Sea", *Quaternary Science Reviews* 26 (2007) pp. 2586–2597.

Sharma, K.P., Moore, B. and Vorosmarty, C.J. (2000). "Anthropogenic, climatic and hydrologic trends in the Kosi Basin, Himalaya", Climate Change, No. 47, pp. 141–165.

Sharma, M. C. and Owen, L. A. (1996). "Quaternary glacial history of NW Garhwal, Central himalayas", *Quaternary Science Reviews*, Vol. 15, Issue 4, 1996, pp. 335-365.

Shekhar, M.S., Chand, H., Kumar, S., Srinivasan, K. and Ganju, A. (2010). "Climate-change studies in the Western Himalaya", Annuals of Glaciology, pp. 105-112.

Shrestha, A. B., Wake, C., Mayewski, P. A. and Dibb, J. (1999). "Maximum temperature trends in the Himalaya and its vicinity: An analysis based on temperature records from Nepal for the period 1971–94", J. Climate, Vol.12, pp. 2775–2786.

Shrestha, M. L., and Shrestha, A. B. (2004). "Recent trends and potential climate change impacts on glacier retreat/glacier lakes in Nepal and potential adaptation measures", OECD Global Forum on Sustainable Development: Development and Climate Change, Paris, France, OECD, pp. 5–14.

Singh, N., and Sontakke, N. A. (2002). "On climatic fluctuations and environmental changes of the Indo-Gangetic plains, India", Climatic Change, Vol.52, pp. 287–313.

Thapliyal, V. and Kulshrestha, S.M. (1991). "Decadal changes and trends over India", Mausam Vol. 42, pp. 333–338.

Thompson, L.G., Yao, T., Mosley-Thompson, E., Davis, M.E., Henderson, K.A. and Lin, P.N. (2000). "A high-resolution millennial record of the South Asian monsoon from Himalayan ice cores", Science, No. 289, pp.16–19.

Vedwan, Neeraj and. Rhoades, Robert E, (2001). "Climate Change in the Western Himalayas of India: a study of local perception and response", *Climate Research*, Vol. 19: pp. 109–117, December 4.

Yadav, R. R., Park, W.K., Singh, J. and Dubey, B. (2004) "Do the western Himalayas defy global warming? ", Geophys. Res. Lett., Vol.31.

Yadav, Ram R. (2007). "Basin Specificity of Climate Change in Western Himalaya, India: Tree-Ring Evidences", *Current Science*, vol. 92, no. 10, 25 May, 2007.

Yadav, Ram R. and Singh, Jayendra. (2002). "Tree-Ring-Based Spring Temperature Patterns over the Past Four Centuries in Western Himalaya", *Quaternary Research* 57, pp. 299–305.