RESPONSE OF GLACIERS TO CLIMATE CHANGE A CASE STUDY OF PARVATI BASIN, KULLU (HIMACHAL PRADESH) 1963-2006

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ANIL KUMAR

Centre for the Study of Regional Development

School of Social Sciences

JAWAHARLAL NEHRU UNIVERSITY

New Delhi 110067

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जवाहरलाल नेहरू विश्वविद्यालय
JAWAHARLAL NEHRU UNIVERSITY
Centre for the Study of Regional Development
School of Social Sciences
New Delhi-110067

DECLARATION

This is to certify that the dissertation entitled **"RESPONSE OF GLACIERS TO CLIMATE CHANGE: A CASE STUDY OF PARVATI BASIN, KULLU (HIMACHAL PRADESH) 1963-2006** is my bonafide work for the degree of **MASTER OF PHILOSOPHY** and may be placed before the examiners for evaluation.

Date: 27-07-09

ANIL KUMAR

FORWARDED BY

We recommend that the dissertation be placed before the examiners for evaluation.

Dr. Milap Chand Sharma
Supervisor

Prof.R.K.Sharma
Chairperson

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Dedicated to

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INTRODUCTION

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Introduction

A glacier is " mass of ice (includes rock debris, water and air) on land, which shows evidence of present and past internal deformation due to the force of its own weight" and moves slowly down a valley from above snowline towards the sea level under the force of gravity (Edward M.,1986). There is constant exchange of mass and heat between the glacier and both the atmosphere above and the bed, or water body, below. The variation in glacier mass influences the areal extent and thickness of the ice, while the thermal regime is thought to influence many geologically significant glacial processes. The continual transfer of mass and heat, which ultimately responds to variations in climate, controls the balance between erosion and deposition and the nature of sedimentary processes (Reading H.G, 1986).

One of the greatest challenges facing human kind in the next century will be predicting and coping with the consequences of rapid climate change (Gore, 2006). The evidence of rapid change has been mounting over the last few decades and the broader public is now becoming genuinely concerned about the prospects of a very different world (Watson et al., 1997, Dyurgerov and Meier, 2000; Houghton et al., 2001; IPCC, 2007 a, b). Many of these concerns pivot about the on going rapid changes in the cryosphere (Corell et al., 2004;). The most pronounced global effect is the rise of sea level from melting of glaciers. For the good reasons, glaciers have emerged as the poster-children of climate change (Gore, 2006). Accompanying the growing concern about climate change is awareness that the hydrological system of the globe could be radically altered. This, in turn, has consequences for the availability of water as a resource, and the types and frequencies of natural hazards associated with its delivery to transport across the surface of Earth. Climate change will inevitably alter how we manage our water resources (a sizable fraction of which lies in glacier ice) and will significantly alter the hazards posed by mountainous regions. The study of glaciers therefore lies at the core of several societal and intellectual challenges of our time (Coudrain et al., 2005).

Since most of the Himalayan glaciers are said to be in a phase of retreat, it indicates a negative "Mass Balance" persisting ever since 1880s (Mayewski & Jeschke, 1979; Mayewski et al, 1980, Hasnain & Kulkarni, 2001). In the backdrop of the "Global Warming" issues, it is necessary to evaluate the response of the largest fresh water reservoir that is stored as ice in the higher latitudes and altitudes.

The study of glacier fluctuations is relevant in understanding the climate, and climate change, over temporal scales from years to centuries and at spatial scales from regions to the global domain. It is internationally recognized that the mountain and sub- polar glaciers are substantial contributors to water cycle. The IPCC-1995 and IPCC-2000 has shown that glaciers contributed up to 20% to sea level rise over the previous century.

The Himalayas have the largest concentration of glaciers outside the polar caps. With glacier coverage of 33,000 km^2, the region is aptly called the "Water Tower of Asia" as it provides around 8.6 x 106 m^3 of water annually (Dyurgerov and Maier, 1997). These Himalayan glaciers feed seven of Asia's great rivers: the Ganga, Indus, Brahmaputra, Salween, Mekong, Yangtze and Huang Ho. It ensures a year round water supply to millions of people. Climate change has impacted the glacial ecosystem tremendously. Sixty-seven percent of glaciers are retreating at a startling rate in the Himalayas and the major causal factor has been identified as climate change (Ageta and Kadota, 1992; Yamada et al., 1996; Fushinmi, 2000). Glacial melt would affect freshwater flows and dramatically effect biodiversity, peoples livelihood, with a possible long-term implication on regional & global food security.

Glacier mass-balance data have gained an increased attention in detecting global climate change and explaining rising sea level (Meier, 1984; Oerlemans and Fortuin, 1992; Kuhn, 1993; Dyurgerov and Meier, 1997a; Gregory and Oerlemans, 1998). Glacier mass balance change is important to regional water supplies and power generation (Bezinge, 1979; Fountain and Tangborn, 1985; Bakalov et al., 1990).

1.2 Literature Review

Climatic change and its impacts on the fluctuation of glaciers is a natural phenomenon that have been occurring in the Earth's five billion-year-old history. In the past few decades, global climate change has had a significant impact on the high mountain environment: snow, glaciers and permafrost are especially sensitive to changes in atmospheric conditions because of their proximity to melting conditions. In fact, changes in ice occurrences and corresponding impacts on physical high-mountain systems could be among the most directly visible signals of global warming. This is also one of the primary reasons why glacier measurements have been used for climate system monitoring for many years (Haeberli 1990; Wood 1990).

1.2a Historical Overview

There have been at least 17 major glacial advances (glaciations) in the last 1.6 million years alone (Goudie, 1983). The most recent, the Last Glacial, reached its peak some 20,000 to 18,000 years ago and came to an end about 10,000 years ago .Glaciations are followed by 'interglacial' periods, during which the glacier ice retreats as a result of global warming. The interglacial typically continues for about 10,000 years before the cooling or the next glaciation begins. This cyclical activity, which reoccurs at intervals of approximately 100,000 years is generally accepted to be caused by gradual changes in the Earth's rotation, tilt and orbit around the sun, which affects the amount of solar radiation the earth receives (Milankovitch 1941& Bradley 1985).

Glacial cycles are punctuated by relatively short periods of localized cooling and warming, during which glaciers advance and retreat. The most recent cooling episode of the present interglacial commonly referred to as the 'Little Ice Age' (LIA), which affected parts of North America (Curry, 1969), Asia (Chu Ko-Chan, 1973) and Europe from about 1300 AD through to the latter half of the 19th century. During the LIA (1550-1850 AD) glaciers were much longer than today (Yamada et al., 1998). It may have been the result of volcanic eruptions and the presence of volcanic ash in the atmosphere that caused cooling by reducing the amount of solar radiation reaching the Earth's surface (Lamb, 1970). Changes to ocean currents have also been suggested to be the cause, along with tectonic activity, concentration of carbon dioxide in the atmosphere and sunspot activity (Goudie, 1983).

1.2b The Current Scenario

The 20th century has been a watershed, in terms of glacial fluctuations on a global scale. This has been a period of dramatic glacier retreat in almost all alpine regions of the globe, with accelerated glacier and ice-fields melt in the last two decades. The first phase of this glacier retreat was associated with emergence from the Little Ice Age that ended in the 19th century. It corresponded with a warming of 0.3°C in the first half of the 20th century in the northern hemisphere (24° to 40°N) (WWF Report, 2005). In the last 25 years, a second 0.3°C warming pulse has caused northern hemisphere temperatures to rise to unprecedented levels compared to the last 1,000 years. The 1990s was the warmest decade of the millennium and 1998 the hottest year of the millennium (Anthwal A., 2006). In all, there was a temperature rise of close to 1°C across the continents. Research shows that the glacier cover of mountain regions worldwide has decreased significantly in recent years as a result of warming trends. A recent comparison of historical glacier data with images from the ASTER (Advance Space borne

Thermal Emission and Reflection Radiometer) instrument on NASA's TERRA satellite by the United States' Geological Survey revealed a significant shrinkage of mountain glaciers in the Andes, the Himalayas, the Alps and the Pyrenees over the past decade (Wessels et al., 2001). These observations are consistent with published results from many other glacier studies around the world that also recorded rapid glacier retreat in recent years. A study by (Dyurgerov & Meier, 1997) who considered the mass balance changes of over 200 mountain glaciers globally, concluded that the reduction in global glacier area amounted to between 6,000 and 8,000 km^2 over a 30 year period between 1961 and 1990.

According to Haeberli and Hoelzle (2001) of the World Glacier Monitoring Service (WGMS), the measurements taken over the last century "clearly reveal a general shrinkage of mountain glaciers on a global scale". They observed that the trend was most pronounced during the first half of the 20th century, and that glaciers had started to grow again after about 1950. However, they claim that mountain glacier retreat has been accelerating again since the 1980s at a "rate beyond the range of pre-industrial variability". Based upon a number of scientific investigations (Kuhn 1993, Oerlemans 1994) and the IPCC (1996b), there are forecasts that up to a quarter of the global mountain glacier mass could disappear by 2050 and up to half could be lost by 2100.

Closer to the present focus of our areas of study, Himalayan glaciers have also been found to be in a state of general retreat since 1850 (Mayewski & Jeschke 1979).

At present, there is about 26 million km^3 of ice on our planet, which cover almost 10% of the world's land area. Moreover, during northern hemispherical winter, snow covers almost 66% of land. In the context of the Himalayas, the youngest mountain belt of the earth that runs in an arcuate shape for about 2500 kilometres between Indus gorge in the west and the Brahmaputra gorge in the east, there are over 9000 glaciers of varied shapes, sizes and aspects. During cold phases the Himalayan ranges are thought to have supported glaciers almost 3 times the present size that reached now inhabited areas (Dyurgerov M., 2002). The interglacial melting resulted in further broadening of these basins and aggrading huge Quaternary sediment deposits that exists even today. Because of large scale glacial erosion these valleys (straths) show erosional surfaces related to those advances. The Pleistocene series of the Quaternary period is well known for its frequent climatic changes (WWF Report, 2005). Widespread ice-sheets and glaciers existed during the glacial stages and ice started melting during the interglacials giving rise to sea level rise up to 100m and transgressing the coastal areas considerably (Pal, 1987). The study of Himalayan glaciers began with Madden (1847), (Bandyopadhyay, 1998), but more serious observation were recorded by Blanfordin

(1873, 1877, 1891) and Theobold in 1874; followed by Bose (1891); Oldham (1904); Geological Society of India (GSI,1907;Cotter & Brown, 1907; Pascoe and Walker,1907). The detailed work of Mayewski and Jeschke (1979) are among the initial records of the Himalayan glaciology. The results of the above discussed studies refer that Himalayan glaciers are in a general trend of retreat since the last little Ice Age. Available data indicates that during the Pleistocene the earth had experienced four or five glaciation periods separated by interglacial periods. During the interglacial period the climate was warmer and deglaciation occurred on a large scale. This suggests that glaciers are constantly changing with time and it can profoundly affect the run-off of Himalayan rivers. Glacial changes can be further accelerated due to greenhouse effect, caused by man-made changes in the earth's environment (Kulkarni A., Rathore B.P., Alex S., 2004)

In 2001, the Intergovernmental Panel of Climate Change (IPCC) of the UN had suggested an increase in global temperature by 0.2 to 0.6°C from the year 1900. This has caused wide-scale retreat of glaciers in the Himalaya, Alps, Andes and Rocky mountains (Lozan, J.L., 2001). Future changes in glacial extent are important, because it can influence river run-off pattern. Many parts of the Himalaya, north of Pir Panjal range, receive little precipitation during monsoon. Melting of glaciers provides water for streams and rivers in the region from July to October. Future changes in glacial length due to climatic variations can be estimated using ablation rate at terminus and change in mass balance (Nye, J.F., 1960 & Paterson, W.S.B., 1998). The mass balance of a glacier is usually referred to as the total loss or gain in glacier mass at the end of a hydrological year. It is estimated by measuring the total accumulation of seasonal snow and ablation of snow and ice. This can be measured by various ways. In direct measurement, net balance is measured at representative points on the glacier. In the photogrammetric method (Paterson, W.S.B., 1998 & Braithwaite, R.J., 1984) contour maps are prepared at an interval of a few years. Two maps can be compared to determine the change in glacier volume. In the hydrological method, net balance can be determined for the whole basin by measuring precipitation, run-off and evapotranspiration. These methods need extensive field investigations, and due to the rugged terrain of the Himalayas, this method provides the mass balance of only a few glaciers. In fact the Himalaya due its wide extent, stupendous heights and intricate topographic forms occupies a unique position in geomorphology. Continued tectonics, high relief, glacial, high magnitude-low frequency processes, glacio-fluvial and fluvial action are all altitudinally organized and definitively zoned (Hewitt, 1989).

Attempts at the reconstruction of temperature and climate patterns on a global scale have established an overall increase in surface air temperature by about 0.5°C–1.1°C in the last century (Jones, P.D. et. al., 1986) . The rise is felt to be real in the last two decades and ten warmest years after 1860 have all been experienced since 1980. While it is difficult to attribute this warming to the effects of solar variability and volcanism alone, the rapidity of the climate change, coinciding with the industrial revolution, has compelled many anthropogenic (man-made) changes have been the major contributors. Studies based on temperature data recorded for various stations located in the plains of India, have indicated a slight warming trend of about 0.4°C in the long-period data up to the late 1980s (Hingane, L.S., Rupa Kumar et. al., 1985). For the country as a whole, a small warming trend of the order of 0.2°C–0.4°C was estimated, and the pattern over India conforms to the global trend (Srivastava, H.N. et. al., 1992). Studies in Nepal Himalaya and hills of Uttarakhand have pointed towards a small positive trend in temperature. Contrary to the global observations, pre-monsoon cooling (March–May) has also been reported in some portions of western Himalaya (Yadav, R.R. et. al., 2004).

High mountain areas such as the Alps, Rockies, Himalayas, etc. are considered as the 'hotspots' of biodiversity with climatic regimes that are similar to those of widely separated latitudinal belts and their ecosystems, as the most vulnerable regions of the world. Consequent to the general rise in air temperature, river systems have shown impacts of shifts in climate regimes, which resulted in the disruption of the existing socio-economic structures of population inhabiting their basins. The Himalayas, which act as a barrier on the earth, where polar, tropical and Mediterranean influences interact, play an important role in maintaining and controlling the monsoon system over the Asian continent (Borgaonkar, H.P. & Pant, G.B., 2001). Small glaciers (all glaciers other than the two major ice sheets, Greenland and Antarctica), have a total area of at least 680103 km^2 (Meier and Bahr, 1996). Although they make up only 4% of the total land ice area, they may have contributed to as much as 30% of sea-level change in the 20th century due to rapid ice volume reduction connected with global warming (Meier, 1984). It is important that changes in glacier mass balance be estimated accurately to compare with other components of the water balance of the Earth, such as changes in the amount of water stored in the ground, and changes in mass of the Greenland and Antarctica ice sheets (Warrick and Oerlemans, 1990; Meier, 1993; Paterson, 1993; Warrick et al., 1996).

The critical link between glaciers and climate is the glacier mass balance (Meier, 1965). The idea and the goal to measure mass balances of mountain and sub polar glaciers in different regions for a global assessment was formulated more than 100 years ago by Forel (1894), the first President of the Commission on Glaciers.

It is widely recognized that human activities will affect water resources and hydrological processes. The most obvious effect is climate change, which has resulted in the increase of global temperature and modified precipitation patterns. One of the most significant consequences of climate change may be the alternation of the regional hydrological cycles and subsequent changes in water resources and stream flow regimes (Chen-Ya-Ying, et. al., 2001). The effects of changes in temperature and precipitation on hydrology have been investigated by many hydrologists. Salinger et al. (1995, 1996) concluded that air temperatures in Australia have risen by 0.5–0.9°C since the beginning of the last century. Muttiah and Wurbs (2002) found that both the average temperature and precipitation of the United States increased during the 20th century mostly due to the increase in intense rainstorms. The variability of runoff and water resources is particularly higher for drier climates, e.g., a higher percentage change in runoff resulting from a small change in precipitation and temperature in arid or semi-arid regions (Gan, 2000).

Over the past three million years, the Earth's surface has experienced repeated large periods of glaciation, separated by short warm interglacial periods. During the peak of glaciation approximately 46 million km^2 area was covered by glaciers, three times more than the present ice cover over the earth (Embelton & King, 1975). A number of ideas were proposed to explain repeated cycle of glaciations on the earth. One of the explanations is related to natural variation in the earth's orbit around the sun. These orbital cycles (100,000, 41,000 and 22,000 years) can cause 10% variation of incoming solar radiation in various parts of the globe (Ruddiman, W.F., 2005). These regular changes in the amount of sunlight reaching the surface of the earth might have produced repeated cycles of glaciation. This can also produce asynchronous behaviour in the development of glacial extent in the northern and southern hemisphere. This aspect was extensively studied in tropical Andes; maximum extent of last glaciation was estimated at around 34,000 yrs (BP) which retreated by 21,000 yrs BP (Smith, J.A. et.al., 2005) This cycle of glaciation is different from that reported in the northern hemisphere, where the peak of the last glaciation was estimated approximately about 17,000 to 21,000 years ago (Denton, G.H. & Hughes, T.J., 1981).

Natural variations in the earth's orbit are well synchronized with atmospheric variations in methane and carbon dioxide, leading to repeated cycle of glaciations. However, this natural cycle might have altered due to the greenhouse effect caused by man-made changes in the earth's environment (Ruddiman, W.F., 2005). Some of the hypotheses suggest this alteration might have started long before the beginning of the Industrial Revolution. Invention of agriculture about 10,000 years ago might have led to large-scale deforestation and rice cultivation. However, this pace of change might have accelerated from the beginning of the Industrial Revolution. This has led to an increase in global temperature by 0.6 to 0.2°C from 1900 (Lozan, J.L., 2001). In addition, recent development in climate modelling suggests that the existing greenhouse gases and aerosols in the atmosphere have led to the absorption of 0.85 to 0.15 W/m^2 more energy by the earth than that emitted to space. This means additional global warming of about 0.6°C has occurred without further change in atmospheric composition (Hansen, J.L. et. al., 2005). Mass balance is one of the important parameters which can be influenced by global warming. Mass balance is usually referred to as a total loss or gain in glacier mass at the end of the hydrological year. Geographical parameters which can influence mass balance are area–altitudinal distribution and aspect, since higher altitude has lower atmospheric temperature. In addition, aspect and slope significantly influences the amount of solar radiation received.

Given the projected changes in climate, based on different IPCC scenarios for 2050 and 2080, simulations with a tropical glacier–climate model indicate that glaciers will continue to retreat (Mathias, V. et. al., 2007). Many smaller, low-lying glaciers are already completely out of equilibrium with current climate and will disappear within a few decades. But even in catchments where glaciers do not completely disappear, the seasonal stream flow do change, due to the reduction of the glacial buffer during the dry season, will significantly affect the water availability downstream. In the short-term, as glaciers retreat and lose mass, they add to a temporary increase in runoff to which downstream users will quickly adapt, thereby raising serious sustainability concerns. Climate change may cause the glaciers of the Himalayans to recede at a much higher rate than anyone could have anticipated, warn both Indian and foreign environment experts. Environmentalists suggestad that continuous carbon emissions in the atmosphere cause increased temperatures, which, in turn, force glaciers to recede at very high speeds. The report also says that some 70 % of all glaciers in the mountain range are starting to retreat, and that, if the trend continues, most of them could be gone by 2035 (Tudor, V., 2008). Worldwide, glaciers hold most of Earth's fresh water reserves, which makes them indispensable to human existence. Considering the fact that Himalayan glaciers are the largest spreads of ice after the polar caps, it's easy to see how a reduction in their levels could adversely affect countless millions of people, living near rivers fueled from the glaciers (Meier & Bahr, 1996).

During the dry season, glaciers supply the vast majority of water to these water flows, and any reduction in these levels could jeopardize crops along their courses. This could cause significant food security problems throughout the region, with potential catastrophic implications for the stability of the area. The Fourth Assessment Report by the IPCC (2007a, b, c), previous assessment reports, and related documents present evidence of global climate change, with particular attention to issues facing water resources managers. These changes may have adverse or positive impacts on one or more sectors. Any or all of these changes could occur gradually or abruptly. Climate change and its potential impacts on water resources have become an increasingly common topic at scientific conferences and meetings among water managers.

1.2c Is Climate Changing?

Any discussion on climate change entails not just whether climate change is actually happening but also an assessment of the impact of climate change itself as aptly summarized by the IPCC working group I and II reports. Lately, it has been noticed based on observational evidence from all continents and most oceans that many natural systems are being affected by a rise in temperatures and their resultant regional climate changes. While historically, over 2000 years, the climate is known to have been subject to change on multiple time scales, the relatively steep increase over the last 100 years is what is of growing concern. Most reports admit that different temperature histories are subject to somewhat different set of uncertainties which are known to generally decrease as time nears the present (IPCC, 2007a, b). However, the IPCC reports state with certainty that a consistent picture of temperature changes is matter of serious concern especially that of the last 400 years. In fact, a specific emphasis is placed on climate and water. Evidence has largely been collected on the vulnerability of freshwater resources which are perceived to have been the most impacted by climate change considering the wide ranging consequences they could possibly have (Bates et. al., 2008). Therefore current water management practices need to become robust to cope with impeding calamities that might be products of climate change.

To understand how this climate change occurs is as crucial as assessing its impact. The changes in the earth's climate are largely understood to have been emergent properties of a global energy budget, increasing surface and atmospheric energy exchanges (Karner, 2002 & Cohn, 2005). As is widely known, the changes in the concentrations of the greenhouse gases, aerosols, and volcanic activity are primary drivers, indispensable in causing these changes to take place. Specifically, carbon dioxide, methane and nitrous oxide, derived from both natural and anthropogenic sources need to be taken into account. The GHG analysis, in fact has resulted in more awareness and rendered more visibility to the climate change studies. Its potential to affect sectors in which water resources play a role remains inevitable and this is typically reflected in changing temperature and precipitation regimes, increasing sea levels and its associated consequences (IPCC, 2007a).

Primarily, these temperature increases are to be having impacts on the mix of precipitation resulting in less snow and more rain, as elucidated in the IPCC report 2007. This directly tend to effect the origin and timing of runoff, the linkages of spring snowmelt and winter rainfall with there being less runoff in the former and more in the latter. As (Stewarts et. al., 2005) point out such shifts are already visible in northern New England, Great Lakes region and Western United States. Such a rise in temperature also holds the potential to accentuate evapotranspiration from vegetation and land surfaces, thereby decreasing the amount of water that then reaches the streams, lakes etc. Also, of particular human significance is the fact that the changing water temperatures and ocean circulation tends to change the intensity and frequency of coastal storms, thus directly impacting a substantial coastal population, something that (Knutson et. al.) speak of at length.

Of course, precipitation levels are not universal and tend to differ across countries. Seasonal patterns and extremities also cannot be negated. Locational specificity being crucial, a fear has gripped humanity about possible droughts and floods becoming more frequent and severe under future climatic conditions (Hodgkins & Dudley, 2006). As the IPCC 2007 report mentions, sea level varies over time, principally in response to global climate change. Rising at an average rate of about 1.07 – 0.5 mm/year during the twentieth century, such an increase has been particularly alarming over the last few decades (Bindoff et. al., 2007). As has been earlier mentioned, such changing sea levels could be potentially dangerous to coastal and estuarine regions with erosion of sandy beaches and saline intrusions becoming common occurrences. Such changes could be gradual or sudden, the pace or temporality being largely determined by future actions.

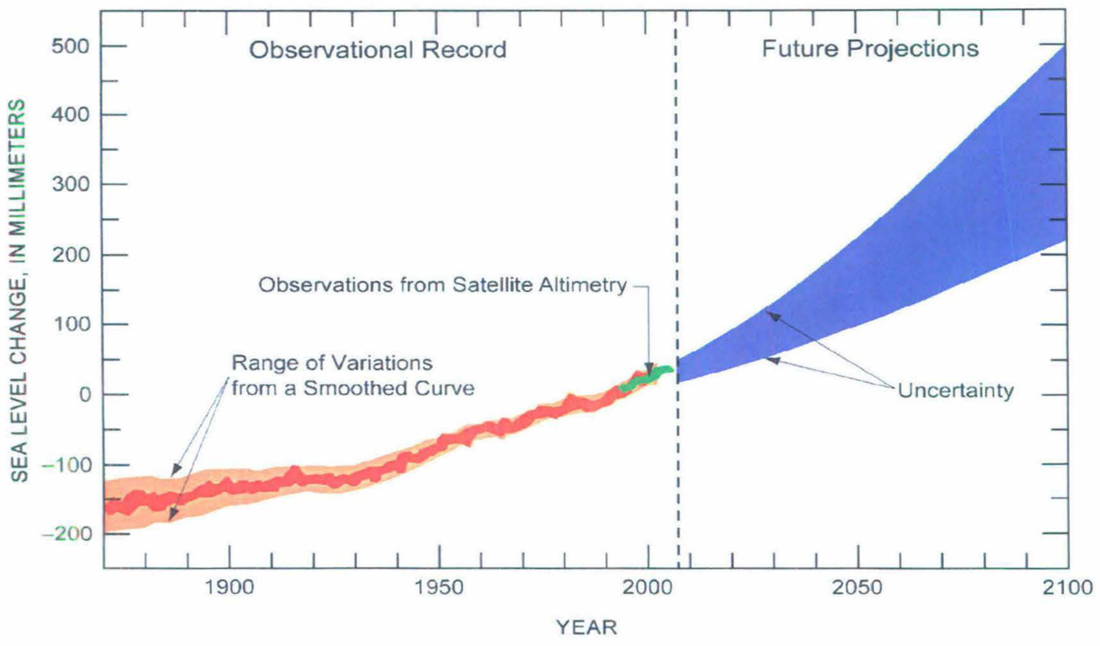


Figure 1.1-Global mean sea level (GMSL) observed since 1870 and projected for the future (deviation from the 1980–1999 mean). [Intergovernmental Panel on Climate Change (2007a]

An increasing number of glaciological studies are now focusing on monitoring temporal glacier changes using remote sensing in the mountain regions as Alaska, Patagonia, the Andes, the Alps, the Himalaya and Central Asia. Mass balance records show an acceleration of glacial loss in the last decades in many of these locations. Such studies show the potential of remote sensing data for providing useful information for glaciological applications such as: glacier area, length, surface elevation, surface flow fields, accumulation/ablation rates, albedo, equilibrium line altitude (ELA), accumulation area ratio (AAR) and the mass balance gradient in inaccessible terrains. In particular, the last three parameters are of importance for mass balance monitoring, as they react to annual fluctuations in climatic parameters such as precipitation, temperature and Humidity. While recent trends of glacier retreat may be attributed to 20th century climate fluctuations, the response of glaciers to such climate fluctuations is complex, and may also depend on non-climatic factors such as ice dynamics, glacier hypsometry (the distribution of glacier area versus elevation) and topography.

In order to obtain the mass balance of a large number of glaciers, accumulation area ratio (AAR) method can be used. AAR is a ratio between accumulation area and total glacier area. Accumulation area is the area of a glacier above the equilibrium line. In temperate glaciers, the extent of superimposed-ice zone is insignificant and therefore, the equilibrium-line coincides with the snow-line. Snowline at the end of the ablation season and thus the AAR can be estimated using remote sensing method.

1. 3 Hypotheses

Fluctuations in the snow line are largely dependent on climatic parameters, i.e. Temperature & Precipitation.

1) Glacier ice is the most sensitive parameter of climate change.
2) Global warming will cause depletion of glaciers, causing immense hardship for fresh water availability in the future.
3) Positive mass balance will result in a decreased discharge where as a sharp negative mass balance will cause floods such as GLOFs.

1. 4 Objectives

1) To assess glacial fluctuation in the Parvati basin over a period of time (1963-2006).
    a) Changes in the frontal positions.
    b) Fluctuations in the ELA (Equilibrium Line Altitude)
2) To analyze discharge pattern of Parvati river over a period of time (1968-2005).
3) To analyze trends in climatic variables like temperature and precipitation in the basin and their relationship with the discharge pattern and glacial behavior.

1. 5 Database

1) Survey of India topographical sheets of 1963 on 1:50000 No. 52H/4, H/8, H/12, H/16 and 53E/1, E/5, E/9, E/13
2) Landsat Satellite data of Multi-spectral Scanner (MSS) images of 1972, Thematic Mapper (TM) 1989and Enhanced Thematic Mapper (ETM^+) for the year 2000.
3) IRS-LISS-III image (2006)
4) Shuttle Radar Terrain Mapper (SRTM) for Stereoscopic data on 90 Meter resolution. of 2000.
5) River Discharge from BBMB (Bhakra Beas Management Board), for forty years (1968-2008).
6) Temperature and Precipitation data of the basin (Bhuntar) from IMD (Indian Meteorological Department from 1965 to 2005.

1. 6 Methodology

1) Measurement of Present and Former snow lines and terminus positions have been carried out through GIS environment.
    a. Geo-referencing of topographical sheet and satellite imageries.
    b. Vectorization of the geo-referenced images.
2) Equilibrium Line Altitude (ELA) has been determined using Meierdings (1982) Toe to Headwall Altitude Ratio (THAR) 0.5 (highest + lowest x 0.5) and Sissons (1974) Area Weighted Mean (AWM) (X = Aihi /Ai, where Ai is area in m^2, hi is mid-point altitude in contour interval).
3) For the determination of the nature of climatic variation in Parvati basin, the meteorological data i.e. temperature and precipitation, has been analyzed seasonally. In addition this seasonal trend of climatic parameters is compared with discharge pattern. The relationship between different variables annually and seasonally has been checked on parametric and non-parametric tests.
4) , Inferences have been drawn for the climate after analyzing the ELA fluctuations, climatic variations and discharge trend.

1. 7 Chapterization Scheme

Chapter 1 deals with introduction on the research theme, along with literature review covering previous studies on the relative topics of climate change and glaciers. This chapter also covers the hypotheses, objectives of the study, data base and methodology, which are to be followed to work on the objectives.

Chapter 2 deals with the environmental setting of the study area, including topographical and drainage characteristics, geological and land map settings, climate, soil, vegetation and in the last a little bit of morphometric analyses of the Parvati river is discussed which cover stream ordering, bifurcation ratio, circulatory ratio, elongation ratio, hypsometric curve, longitudinal and cross profile.

Chapter 3 deals with glacier dynamics by measuring glacial advance and retreat over different time period along with change in equilibrium line altitude, length of glacier and change in glacial area.

Chapter 4 deals with the nature of variation in the climatic parameters like temperature and precipitation over a period of 40 years and later the discharge pattern of Parvati river is analyzed and relationship has been established among them. In the last the relationship is checked by correlation matrix and parametric and non-parametric tests.

Chapter 5 summarizes and concludes the present work.

CHAPTER TWO

GEO-ENVIRONMENTAL SETTINGS

CHAPTER TWO

GEO-ENVIRONMENTAL SETTINGS

2.1 Study area

The Parvati river originates in the Kullu tehsil of Kullu district in Himachal Pradesh. It rises from the Mantalai glacier at an altitude of about 5200 meters above mean sea level. Mantalai glacier is located on the western slopes of the great Himalayan ranges. The basin lies between 31°50 to 32°5 north latitudes and 77°5 to 77°50 east longitude. The river Parvati is one of the major tributaries of the Beas. Which confluences at Bhuntar at an elevation of 1096 meters above mean sea level. It drains an area of 1938 Km^2. The entire basin area falls with in the SoI topographical sheets (on 1:50000 Scale), number 52 h/4, h/8, h/12, h/16 and 53 E/1, E/5, E/9, E/13.

2.2 Physiography

The Parvati river basin is a hilly and mountainous tract with altitude ranging from 1096 to 6250 meters above mean sea level (Figure No.2.1). The basin presents an intricate mosaic of mountain ranges, hills and valleys. The white snow clad peaks are the most prominent land mark. The Pir panjal, Dhauladhar and the great Himalayan ranges stand as a guard over Kullu. The mountain slopes in the basin are covered with forests and meadow. The valleys are interspersed with numerous streams joining the Parvati river from left and right-banks. The basin is marked by a gradual increase in elevation towards the Dhauladhar, Pir Panjal and Great Himalayan ranges. The series of parallel ranges are divided by longitudinal valleys, except the Kullu valley which is transverse to the main alignment.

The various streams and rivers have carved out valleys. The main being those of Malana Nal, Tos Nal, Kasol Nal, and various other small streams. Some of the important ranges of the basin are Chandrakhari Dhar, Sharakandi Dhar, Rorung Dhar, Phgachi Dhar, Rajthathi Dhar and Ori Dhar.

There are evidences of extensive glaciation during the ice ages and the Present glaciers are merely shrunken remnants. Enormous heaps of terminal moraines are now covered with grass

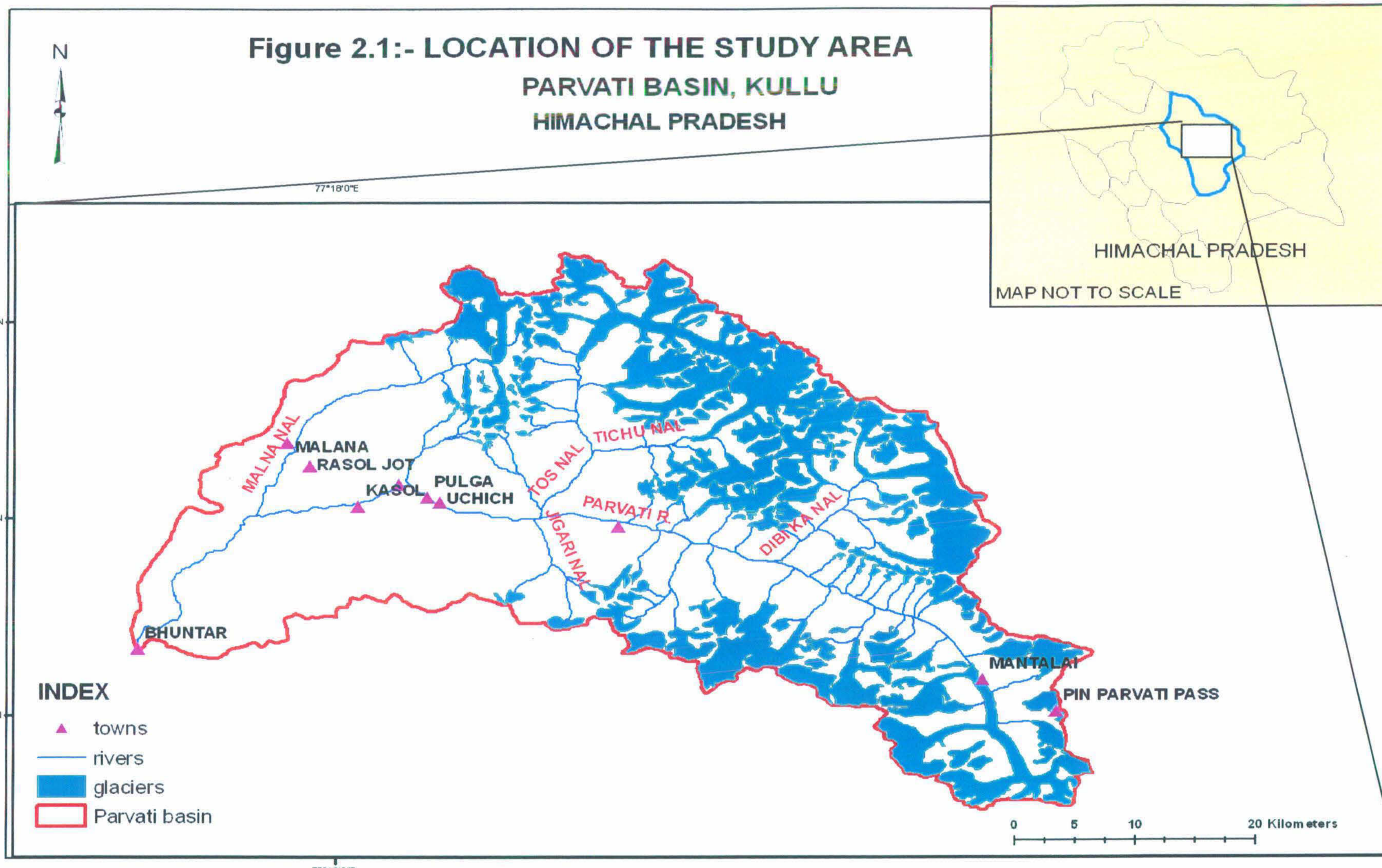


Figure 2.1:- LOCATION OF THE STUDY AREA

and trees. Ice transported blocks with smoothened and striated surfaces, hanging and U-shaped valleys are notable features in the basin. For example, large accumulation of fluvial glacial materials is seen on the either banks at the higher level down streams of Pulga gorge. This accumulation of the glacial materials near the Pulga village provides the evidence for old glacial valleys on the right bank of the present-Parvati river. On the basis of this accumulated material it can be concluded that the original Parvati glacial valley may lie concealed under the glacial moraines on the right bank.

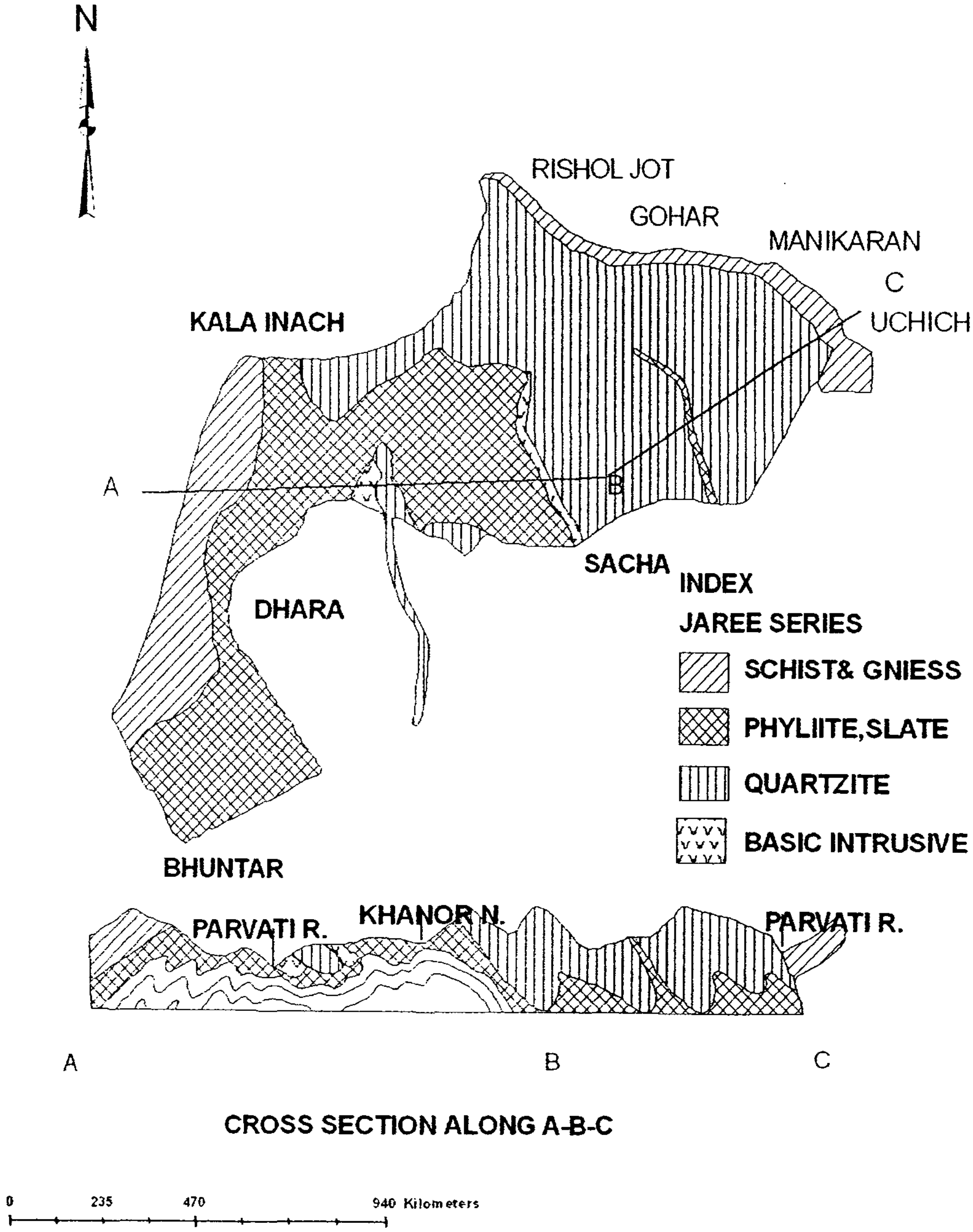
2.3 Geology

The rock types found in the basin are phyllite, slate, quartzite, limestone, schists, and granites; classified on the basis of their formation. These rocks are named either on their rock types or after local names where these were first studied. For example between Jari-Kasol-Manikaran section the Parvati valley has been carved out through a thick massive quartzite with subordinate phyllites and slates dipping at 30^c to 50^c in North East direction and named as the Jari series. Apart from this we also find gneiss Kullu formation, Baniar formation, and tourmaline granites gneiss are presumably the oldest rocks made over 1500 million years old and comprised various types of gneissic and schistose rock with in layers of quartzite, granite and pegamatites. The Larzi formation contain thick layer of grey dolomite and pink limestone besides slates, phyllifezed quartzite. The Tourmaline occurs as intrusive, the probable source of high radioactivity in the area, where rocks and many hot springs are seen e.g. Manikaran (Sehgal, M.N., 1973).

Some minerals found in the area are of considerable economic importance, such as, Beryl, building stones, Kyanite, Copper and limestone. Silver mine has also been located in Uchich, which is located in the Parvati basin.

Part of the relief in the basin is of tectonic origin and it can be seen from the folded structures, which appears as ridge or arch, as in the anticlines valleys and trough like on the syncline. Because of the lineaments (faults), stream at numerous places in the basin flows straight and joins the main stream at right angle.

Figure 2.2:- GEOLOGICAL MAP OF A PART OF PARVATI VALLEY KULLU DISTRICT, (H.P.)



Source-Geological Survey of India 1973

2.4 Soil

The soils of the basin vary according to aspect, altitude and climate. On the whole, the soils in the basin are young and thin and general occur in the valley on gently slopped hills. The soils of the basin can be classified on the basis of climate and altitude (Gupta, M.L., 1985).

MID- HILL SOIL ZONE (1000 meters – 1500 meters)

Between this altitudinal zone, soil are loam to clay- loam in texture with grayish – brown colour and are well drained. These soils are neutral to slightly acidic in nature.

HIGH-HILL SOIL ZONE (1500 meters -2100 meters)

The soils in high hill i.e. between 1500 m. to 2100 m. are found on steep slopes, having good drainage. Soil texture ranges from silty – loam to clay – loam, with dark brown colour. In favourable aspects, soils are quite deep. The organic matter is quite high and its reaction is acidic to neutral.

MOUNTAINOUS SOIL ZONE (2100 meters – 3000 meters)

The soil found in this altitudinal zone is shallower as compared to that of high hill soil zone. Soil texture is silty loam to loam, with dark brown to light brown colour. These soils are not used for agricultural purposes. Above 3000 meters altitude the basin is mostly covered with snow skelitols, and without vegetation. Soil above this altitude exists only in patches which are of no use.

2.5 Geomorphic Features of the Parvati Basin

Geomorphology is the science which is concerned with the study of landform on the surface of the earth and the relationship between these landforms and the geological structure beneath. As it is seen from the geomorphic map that the north eastern and south-eastern part of the basin has high altitude and is mostly covered with the valley glaciers. This part of the basin has a dominance of landforms carved out by the action of glaciers; such as moraines, scree, rockfall and rocky waste.

Moraines are unsorted debris brought down by the action of glaciers. This material is derived from the rock floor upon which the glacier moves. The moraines develop at or near the edge of the active glaciers and are designated as terminal moraine. In valley glacier system as in the Parvati basin, the moraines are dragged with in the ice or along between the ice and the valley wall as lateral moraines. Lateral moraines are widespread in the basin and are mostly confined in the north eastern and south eastern part of the basin where two glaciers join medial moraines are formed. Scree deposit is also found in the basin and is mostly confined on both the banks of river Parvati towards source upstream of Khirganga, River terraces and flood plains are confined only in the lower reaches of the basin along with the banks of river Parvati and its other tributaries (Rai, G., 1990). The landforms in the Parvati river basin are also subjected to tectonic activity, which has resulted number of land forms having tectonic origin.. Numerous springs in the basin are found, located mostly in the lower reaches near Kasol and Manikaran. Khirganga hot springs are located at an altitude of 3500 meters.

2.6 Climate

There is much diversification in the climatic conditions due to variation in elevation (1096 meters to 6250 meters) and aspect in the Parvati basin. The two main climatic characteristics of the region are the seasonal rhythm of weather and vertical zoning.

Control of climate: The hydrological characteristics of an area are determined largely by (1) the climate of the region and (2) the geological structure of the area. In general climatic factors are most important because these determine, to a considerable extent, the magnitude and distribution of precipitation, the occurrence of snow and ice, the effect of wind, temperature, humidity and evaporation of a particular area.

2.6a Altitudinal Variation and Orientation

Variations in elevation cause wide differences in climate with in a basin. Temperature in the free atmosphere decreases with elevation at an average rate of less than 6.5°C per km., similar variation of surface temperature with altitude is also observed in mountainous regions, such as the Parvati Basin. Apart from altitudinal variations, orientation also affects the climate. Air is cooled as it rises up the windward slope of mountain and is warmed as it descends on the leeward slope. Temperature contrasts between the two slopes are further accentuated because of the more favourable radiation conditions on the leeward side, where cloudiness is less than on the windward side. Diurnal wind system is also common in mountainous regions. During the day, surface temperature along a mountain slope are higher than those at corresponding level in the free air. Consequently, a convectional current is generated.

In the Parvati river basin, orographic influences on climatic is significant. The lowest elevation in the basin is 1096 meters above mean sea level at Bhuntar and the highest elevation in the basin is 6250 meters above mean sea level. This altitudinal difference results in wide range of climatic variations.

2.6b Temperature

Temperature plays a very important role in determining the hydrology of Parvati basin. Generally the basin experiences low normal monthly maximum and minimum temperature. The highest monthly maximum temperature is experienced in the month of June after which the temperature continue to fall and the lowest monthly minimum temperature is experienced in the month of January. Parvati river basin does not have any meteorological station. So the temperature at Bhuntar (1096) has been taken for the study. Average monthly maximum temperature is 32.75°C in the month of June and normal monthly minimum temperature is as low as 1.68°C in the month of January at Bhuntar. Due to wide range of altitudinal variation the temperature keeps on decreasing with altitude, which results in very low temperature in the Parvati basin. Mean annual maximum temperature at Bhuntar is 25.25°C and mean annual minimum temperature recorded is 10.19°C

2.6c Precipitation

Rainfall is the most fundamental hydrologic element determining the runoff from a catchment. Rainfall characteristics vary both in time and space. Generally the rainfall increases from the plains to the hills according to relief and aspect. The precipitation in spatial variability as compare to flat terrains, such as Indo-Gangetic plain. Besides the altitude, great changes in rainfall are brought about by local factors such as conditions on ridge tops, situations in the main or side valley, and its closed or open characters rings local variation in precipitation. The average monthly rainfall is lowest in the month of December to January but precipitation in the form of snow is highest during these months. During April to June the western disturbances continue to affect the region but with lower intensities. These months are characterized by thunderstorm activities in which the mechanisms of orographic lifting play a very important role.

It has also been observed that the solid precipitation continuous at altitude higher than 3000 meters (a.s.l.) even up to the end of June. During July and September, the southern slopes become windward side as the monsoon currents arrive from south easterly direction which results in heavy rainfall from south west monsoon. Lowest monthly rainfall at Bhuntar is recorded in the months of October and November. The highest monthly rainfall is recorded in the months of July, August and September.

2.6d Humidity

Air easily absorbs moisture in the form of water vapors. The amount absorbed depends on the temperature of the air and water. The greater the temperature of the air, the more water vapor it contains. Humidity can be expressed either in absolute terms or relative terms. Absolute humidity is the actual amount of water vapor present in certain quantity of air. On the other hand relative humidity is the percentage ratio of the mount of moisture in a given space to the amount which that volume could contain if it were saturated.

In the Parvati basin humidity is influenced by number of factors. The most-important factor affecting humidity are (1) Orographic configuration and (2) Vegetation. Generally, the relative humidity varies with temperature & decreases with elevation. Vegetation also influences humidity. Air over vegetation usually has higher moisture content (due to evapotranspiration) than over base soil. Relative humidity is generally higher in Himachal region than in the adjoining plains during the pre-monsoon (May-June) and monsoon period (July-September). After September relative humidity sharply declines. Relative humidity at Bhuntar is lowest during the months of March to May (40 to 45 percent). It is highest in the Monsoon season (July to September) and it varies between 60 to 70 percent. In the other months relative humidity varies between 45 to 60 percent (I.M.D., Pune).

2.7 Natural Vegetation

Owing to wide range of altitudinal and climatic conditions, Parvati basin has diversified flora and fauna. Forests are not uniformly distributed throughout the basin, but mostly confined to highest hills and interior valleys, in the lower and more accessible areas the forests have been cleared to make room for cultivation and settlement. The natural vegetation in the basin has a climatic altitudinal zonation as classified as under (Singh, R.L., 1984).

Vegetation Zone	Altitude in Meters
Tropical and sub-tropical	< 1525
Temperate	1525-3650
Alpine	3650-4650

On the basis of composition, the vegetation in the basin can be classified into (a) coniferous forests and (b) broad leaved forests. The distribution of different species follows fairly regular altitudinal stratification except when the micro-climatic changes due to the aspect, exposure and local changes in rock and soils. Generally, speaking the sequence of important timber species growing in the basin are Oak, Chir, Deodar, Kail, Spruce and Silver spruce. Broad leaved forests are found in the basin at lower elevations along the Parvati river valley.

2.8 Drainage

The River Parvati is one of the largest tributaries of the Beas which rises from the Pin Parvati glacier situated in the western slopes of the Great Himalayan range. The catchment of Parvati river is fed by melting glaciers and rainfall, it is protected by fairly extensive cores of natural vegetation. It has a total catchment area of 1938 Km^2. The river is joined by number of left and right bank tributaries. Detailed account of some of the important tributaries is given below in the Table-2.1

Table 2.1: Major Tributaries of Parvati River

S. NO.	Name of Tributary	Bank	Distance from source Kms	Length kms	Area km^2
1	**Dibi Ka Nal**	Right	16	10	155
2	**Toss Nal**	Right	31	15	404
3	**Jigrai**	Left	31.5	7	39
4	**Brahamganga**	Right	39	6	45
5	**Kasol Nal**	Left	43	10	58
6	**Malana Nal**	right	49	21	127

Dibi ka Nal

Dibi ka Nal is one of the most important tributary of the Parvati river. It originates from Dibi-ka-Nal glacier at an elevation of about 4600 meters (a.s.l.). It is a right bank tributary of the Parvati and joins it at a distance of 16 kms from the source. The total length of the stream is 10 kms and the catchment area of the tributary is approximately 155 km^2.

Toss Nal

It is also one of the largest tributary of Parvati river. It is formed by junction of two stream, each of which originate from two independent large glaciers. The Tichu glacier feeds the Tichu Nal and the Saraumga glacier feeds the upstream of Toss Nal. Both these stream joins two kilometers below the snout of these glacier. The total length of Toss Nal is 10 km and it joins Parvati at a distance of 31 km from the source. The total catchment area of Toss Nal is 404 km^2. It originates at an elevation of about 4300 meters (a.s.l.) and joins the Parvati river at 2213 meters above mean sea level. Other tributaries which joins Toss Nal are Jirah ka Nal nad Maskas Gaus.

Jigrai Nal

It is a left bank tributary of river Parvati. The total length of the stream is 7 kms and it covers catchment areas of 39 km^2. It joins Parvati river near Barshayani village 31.5 kms down streams from the source.

Brahamganga Nal

It is a right bank tributary of the river Parvati. It originates at an elevation of 4400 meters above mean sea level and joins Parvati near Manikaran on an elevation of 1697 meters above mean sea level. The total length of the Nal is 6 kms and the total catchment area is about 45 km^2. It joins the river Parvati at a distance of 3.9 kms from the source.

Malana Nal

It is a largest right bank tributary of the river Parvati. It originates from Dudhan glacier at an elevation of 4800 meters above mean sea level. It joins river Parvati at an elevation of 1379 meters above mean sea level near Jari, which is situated at a distance of 49 kms downstream from the source of Parvati. The total length of Malana Nal is 21 kms and has a catchment area of

127km^2. Lahori Nal is one of the tributary of Malana Nal and it joins at an elevation of 1525 meters above mean sea level.

Kasol Nal

It is one of the important tributary of the river Parvati. It is joined by numbers of intermittent streams. Dolog Nal rises from Tiri thach at an elevation of 3600 meters above mean sea level. Further downward it is joined by another stream called Garanju Nal. Garanju Nal and Dolag Nal joins Garhan Gad nal at an elevation of 2200 meters (a.s.l.), which is joined further downstream by Matigargh Nal at an elevation of 1900 meters above mean sea level. All these streams converge and forms Kasol Nal and it joins Parvati near Kasol. Kasol Nal is left bank tributary and it joins the river Parvati 43 kms downstream from the source of Parvati. The length of Kasol Nal is 10 km and has a catchment area of 58 km^2.

2.9 Topographic Characteristics of Parvati River Basin

The entire area of a river basin whose surface runoff drains into the river is considered as hydrologic unit and is called a drainage basin or catchment area of the river. Topographical characteristics of a basin play a significant role in determining the magnitude of like flood, total discharge and the basin lag, stream hydrology, as defined by the discharge hydrographs and by the time element, such as flood frequency and lag is significantly related to many components of the basin and network morphometery. Network extent is of considerable hydrological and geomorphological significance. Since it is an index which measures both the nature of dissection with in the basin and extent of the hydrologically significant network.

The drainage basin has been accepted as an ideal areal unit for the interpretation and analysis of hydrological processes. Keeping these facts in view, morphometric analysis of the basin has been attempted.

2.9a Basin Morphometry

The drainage basin accepted as an ideal unit for the interpretation and analysis of the topographic characteristics. Measurement of the shape or geometry, of any natural form, or relief feature is termed as morphometry. Three basic form elements of Parvati basin have been analyzed and they are linear, aerial and relief aspect.

First and simplest are the linear properties of the stream channel system. Linear properties are limited to number of stream, lengths, and arrangement of sets of line segment. The analysis of linear properties is made on the basis of a projection of the stream channel system to a horizontal plain.

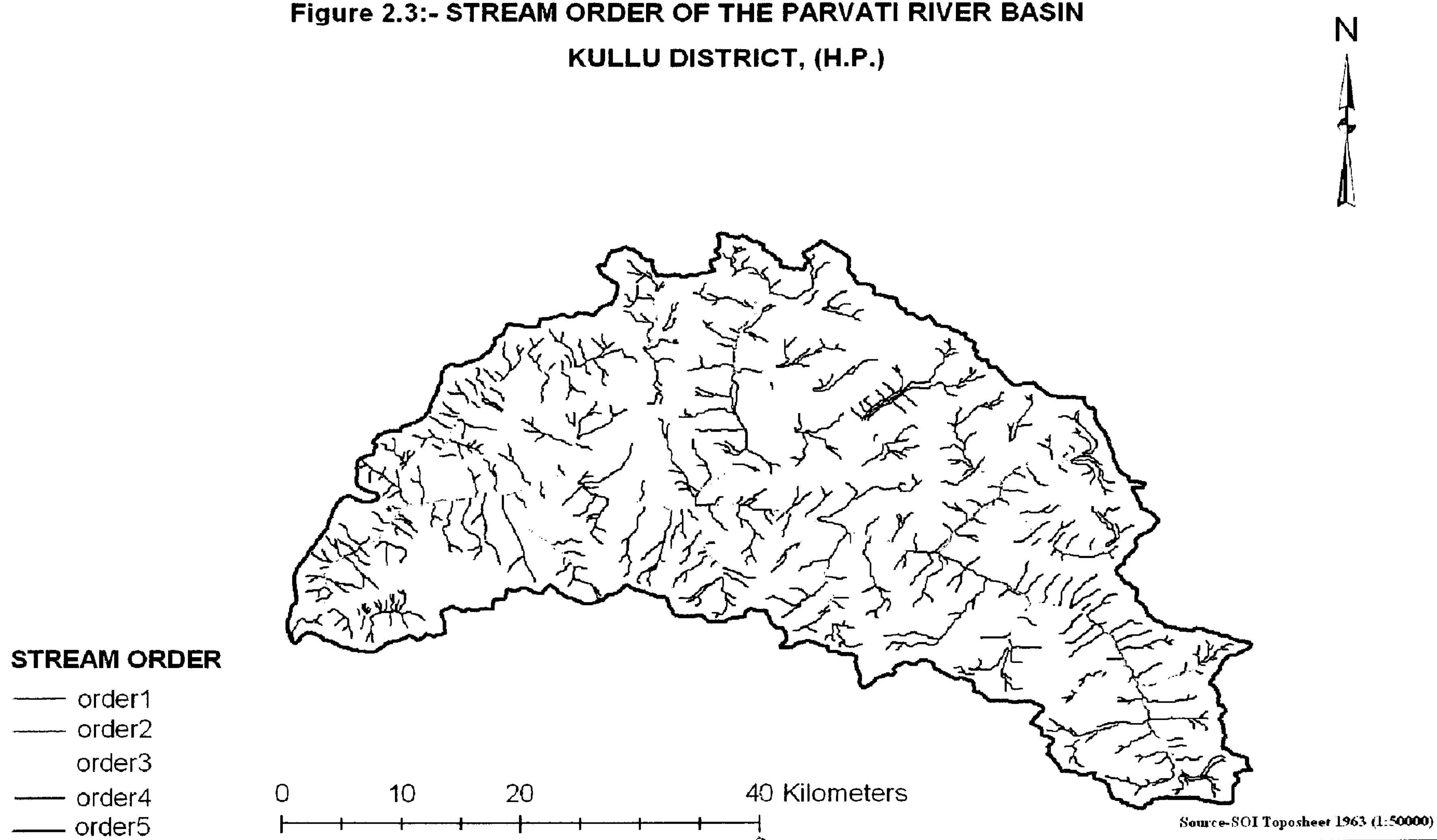
2.9b Stream Orders

The initial step in drainage basin analyses is designation of stream orders. Streams are ordered after Strahler's adoption of the Horton's scheme of classification (Horton, R.E., 1945). Each fingertip channel is designated as a segment of the first order. At the junction of any two first order segments, a channel of the second order is produced and extends down to the point where it joins another second order channel, where upon a segment of third order results and so forth. As it is seen from the table below that Parvati river has 1891 first order streams, 431 second order, 70 third order, 17 fourth order and 4 fifth order stream. Total number of streams in the basin is 2414. Stream ordering of the main tributaries of Parvati river is given in the Table 2.2 & Figure 2.3.

Table 2.2: NUMBER OF STREAMS OF INDIVIDUAL ORDER

S. NO.	BASIN NAME	NUMBER OF STREAMS OF INDIVIDUAL ORDER					TOTAL NO OF STREAMS
		Nu 1	**Nu 2**	**Nu 3**	**Nu 4**	**Nu 5**	
1.	**Parvati**	1891	431	70	17	4	2414
2.	**Toss Nal**	274	69	7	3	1	354
3.	**Malana Nal**	291	67	13	2	1	374
4.	**Jigari Nal**	53	8	2	1	-	64
5.	**Brahamganga Nal**	98	15	4	2	1	120
6.	**Kasol Nal**	191	38	8	2	1	240

Figure 2.3:- STREAM ORDER OF THE PARVATI RIVER BASIN
KULLU DISTRICT, (H.P.)



2.9c Bifurcation Ratio

The bifurcation ratio is expressed as the ratio of the no. of streams, of an order to the next higher order and it speaks of a hierarchical system of a drainage basin. This ratio is of fundamental importance in drainage basin analysis as it is the foremost parameter to link with hydrological regime of a watershed under uniform lithological and climatic conditions. According to Horton, the bifurcation ratio as designated by Rb varies from a minimum of 2 in "flat or rolling drainage basins" to 3 or 4 in "mountainous or highly dissected drainage basins". Vats (1958) observed that the minimum possible value of 2.0 is rarely approached under natural conditions because the bifurcation ratio is a dimension less property and because drainage systems in homogenous materials trend to display geometrical similarity. High bifurcation ratio is expected in region of steeply, differing rocks strata where narrow strike valleys are confined between hog back ridges. Bifurcation ratio of the basin has been calculated using following formulas:

Bifurcation Ratio (Rb) = No./ No+1.........1, where No. is the number of streams in each order.

Table 2.3: BIFURCATION RATIO OF PARVATI RIVER & ITS TRIBUTARIES

S. NO.	BASIN	RATIO OF NO. OF STREAMS OF AN ORDER TO THE NEXT HIGHER ORDER					Rb
		Nu1/Nu2	**Nu2/Nu3**	**Nu3/Nu4**	**Nu4/Nu5**	**Nu5/Nu6**	
1.	**Parvati**	4.38	6.15	4.11	4.25	4	4.56
2.	**Toss Nal**	3.97	9.85	2.33	3	-	4.74
3.	**Malana Nal**	4.34	5.15	6.5	2	-	4.49
4.	**Jigari Nal**	6.62	4	2	-	-	4.20
5.	**Brahamganga Nal**	6.53	3.75	2	2	-	3.57
6.	**Kasol Nal**	5.02	4.75	4	2	-	3.94

As it is seen from the above table that the average value of bifurcation ratio of the Parvati river and its tributaries confirms the characteristics of natural stream system having dissected drainage basins.

The network analysis of Parvati river basin and its subcatchment reveals the fact that the branching of stream in some basin is controlled by geological structure, lithological characteristics, slope and rainfall intensity.

2.9d Stream Density

The stream density of a drainage basin expressed as the number of streams per square Kms and it is expressed as

Stream density d = Ns/A...........2

Where Ns = Number of streams

A = Area of the basin

The total number of streams in the basin is 2414 and the area of the basin is 1938.096 kms. Hence the calculated stream density of the basin is 1.24 numbers of streams per km^2.

2.9e Drainage Density

Drainage density is defined as the total length of all the streams channels per unit area and it serves as an index of the areal channel development of the basin. Drainage density is directly related to the amount and intensity of precipitation and inversely related to the amount of vegetative covers (Chosley,1957). Mathematically drainage density can be expressed as

Dd = Ls/A..........3

Ls = 2033 Kms.

Where Ls = total length of all the stream in the basin

A = Area of the basin

Drainage density of the basin is of considerable importance because it is directly controlled by the interaction between geology and climate. As the two factors differs from region to region and also with in the basin, wide variation in drainage density is expected. In general resistant surface materials or those with high infiltration capacity have widely spaced streams and consequently low drainage densities. As resistance or surface permeatility decreases runoff is usually removed in greater no. of closely spaced channels as a result drainage density is much higher. Thus drainage density not only reflects the geology of the area but it may also serve as a useful parameter in climatic geomorphology.

The drainage density of the Parvati basin is 1.04 per km^2. The drainage density of Parvati indicates a well developed drainage network and torrential runoff causing intense flood during high flow period.

2.9f Shape of the Basin

The shape is also considered as an outline form of drainage basin, projected upon the horizontal datum plane of a map. It is a dimensionless property and controlled by stream discharge characteristics and underlying lithology. In the present study two shape parameters, i.e. elongation and circulatory has been taken to assess the shape of the Parvati river basin.

Elongation Ratio

It is defined as the ratio of a diameter of a circle of the same area as the basin to the maximum basin length and designated as Re, mathematically it can be expressed as and is given by Schumn (1956).

Basin elongation (Re) = $2/\sqrt{\pi} * \sqrt{A/L^2}$ 4

Where L = Basin length horizontal to river channel, and is calculated as 71 Kms.

Elongation ratio of Parvati basin is 0.88.

Circulatory Ratio

Circulatory ratio can be defined as "the ratio of, the basin area divided by area of a circle with the same basin perimeters" and it is given by Miller (1953).

Miller's circulatory Index (R) = $4\ A/P^2$............5

Where A = Area of the basin

P = Perimeter of the basin (221 Km)

The calculated circulatory index of Parvati river basin is .50.

Basin elongation and circulatory ratio varies from 0 to 1, value of unity shows that basin is perfectly circular to elongated. As in the case Parvati river the elongation ratio is .88 which is nearer to unity and so the basin is elongated but not perfectly. The circulatory ratio of the basin is .50, hence it can be conclusive that the shape of the basin is more toward elongation but not completely circular.

2.10 Mean and Median Elevation of Parvati Basin

The mean elevation is determined as weighted average elevations between two adjacent contours. The mean elevation of a drainage basin is computed by following formulae.

$Z_b \quad = \quad Ea_1 \ Z_1/Ea_1$.............6

Where Z_b = Mean elevation of drainage basin.

a_1, a_2 = areas between the successive contours of the basin.

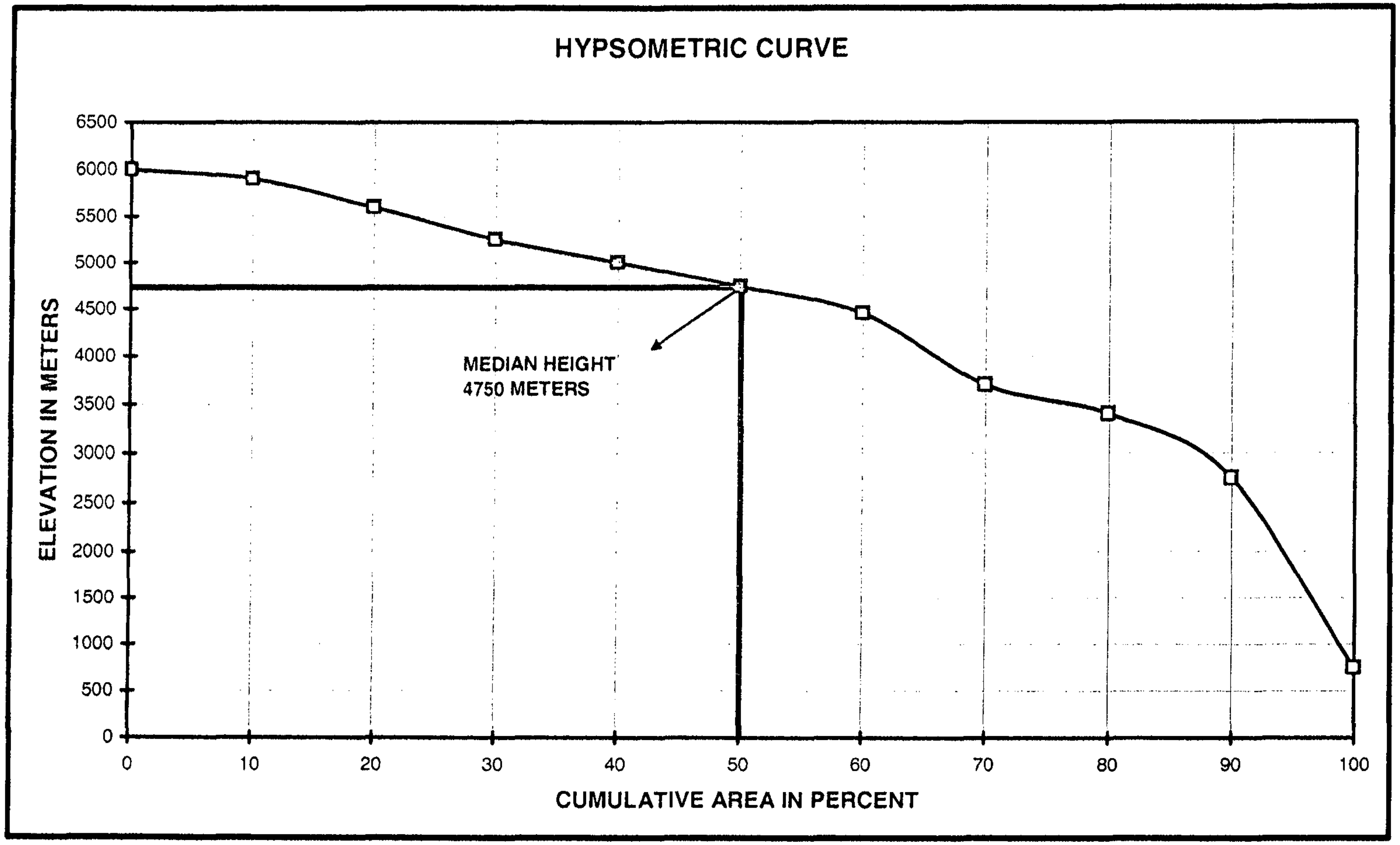
Z_1, Z_2 = mean elevation between the two successive contours of the basin.

Ea_1 = total area of the basin.

Table 2.4: COMPUTATION OF MEAN ELEVATION OF THE BASIN

CONTOUR ELEVATION IN METERS 1	MEAN ELEVATION BETWEEN CONTOURS (METERS) Z_i 2	AREA BETWEEN CONTOURS (Sq. Km.) a_i 3	PRODUCT (2)*(3) Z_i*a_i 4
1200-1600	1400	38.178	53449.2
1600-2000	1800	68.65	123570
2000-2400	2200	112.07	246554
2400-2800	2600	111.72	290472
2800-3200	3000	130.75	392250
3200-3600	3400	148.75	505750
3600-4000	3800	175.45	666710
4000-4400	4200	212.72	893424
4400-4800	4600	302.85	1393110
4800-5200	5000	368.91	1844550
5200-5600	5400	230.12	1242648
5600-6000	5800	37.92	219936
		$\sum a_i$ = 1938.09643	**7872423**

Figure 2.4:- HYPSOMETRIC CURVE OF THE PARVATI BASIN



Mean elevation of the basin = 7872423/ 1938.09 = 4061.93 meters

2.10a Median Elevation of Parvati Basin

The median elevation of the basin is calculated with the help of hypsometric curve. It relates elevation with area. This analysis is used to measure percentage of area above or below given altitude and vice-versa. Cumulative area is plotted on abscissa and altitude on ordinate to represent area elevation relationship. It helps in identifying major relief features of the earth and erosional surfaces.

Table 2.5: CUMULATIVE PERCENT OF AREA UNDER DIFFERENT C.I

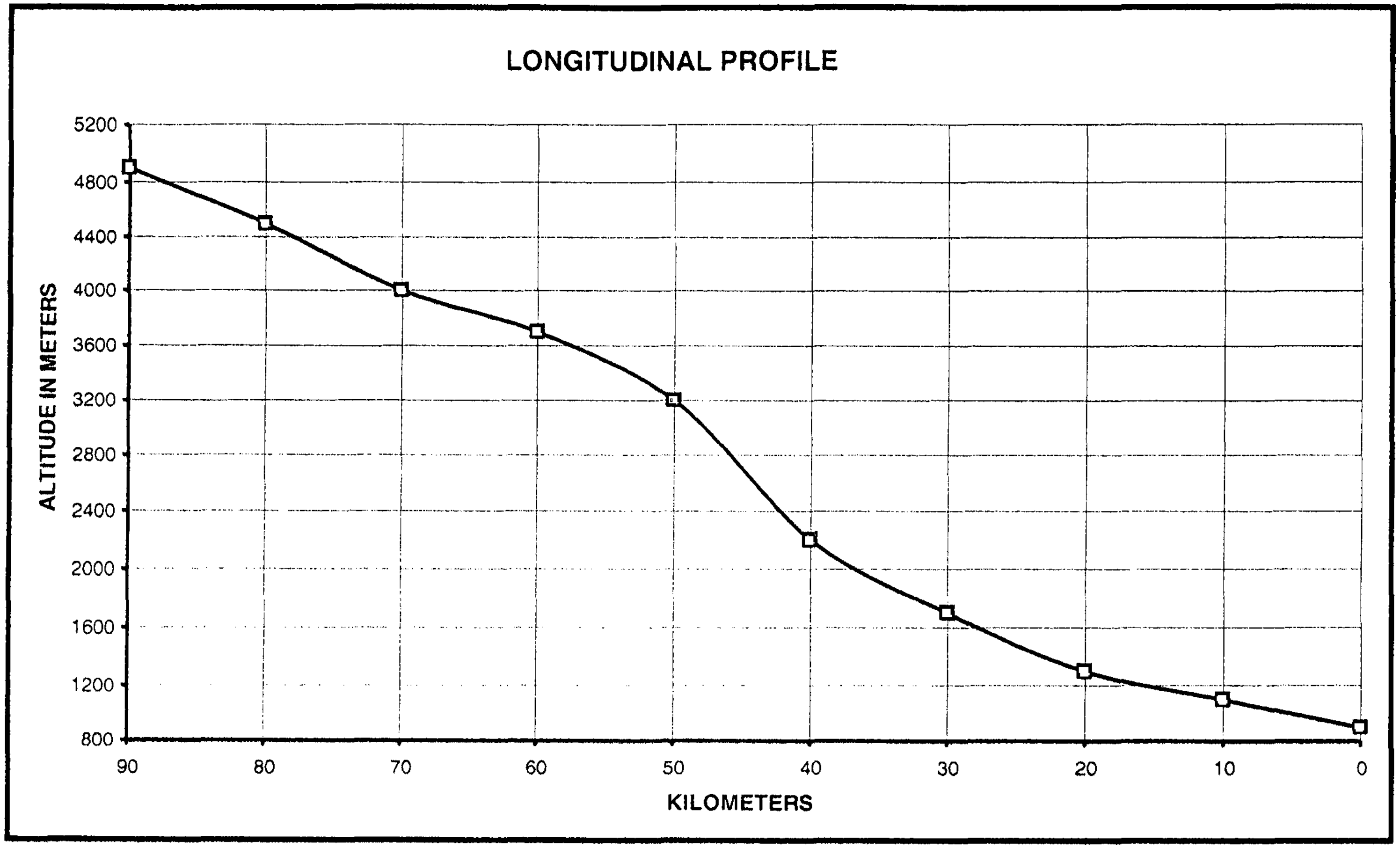
HEIGHT IN METERS	AREA IN Sq. Km.	PERCENT OF AREA	CUMULATIVE % OF AREA
1200-1600	38.178	1.97	100
1600-2000	68.65	3.54	98.03
2000-2400	112.07	5.78	94.49
2400-2800	111.72	5.76	88.71
2800-3200	130.75	6.75	82.94
3200-3600	148.75	7.68	76.19
3600-4000	175.45	9.05	68.52
4000-4400	212.72	10.98	59.47
4400-4800	302.85	15.63	48.49
4800-5200	368.91	19.03	32.87
5200-5600	230.12	11.87	13.83
5600-6000	37.92	1.96	1.96

Total area of basin = **1938.096 Km^2**.

The hypsometric curve of Parvati river basin exhibits a convexity in the upper reaches. This shows that the basin is highly dissected. The dissection is accounted both by tectonic disturbance as well as intensive fluvial action.

The median height of the Parvati basin is obtained by plotting the contour elevation (lower limit) against the corresponding cumulative percent of total area. The median elevation for

Figure 2.5:- LONGITUDINAL PROFILE OF THE PARVATI BASIN



50 percent of total area is read from the hypsometric curve (Figure 2.4) as 4750 meters. The mean elevation of the basin is 4061.93 meters a.s.l.

2.11 Long Profile of Parvati River

Longitudinal profile of a river relates the river length to altitude. The main aim to present such graph is to show the slope or gradient of the main channel. Careful study of the long profiles of rivers reveals a variety of features. The general form of the profile is concave upwards, but the degree of concavity varies considerably with the underlying geology, lithology and climate.

The Parvati river originates at an altitude of 4800 a.s.l. and stretches for a length of 96 km. Analysis of the longitudinal profile (Figure 2.5) reveals that the regular concave section is separated by convex section. These irregularities may be due to the presence of more resistant rocks across the stream, due to initial change in slope resulting from tectonic movements. The slope of the river is convex in shape between 4000 to 2800 meters above mean sea level and from 2800 to 1200 meters above mean sea level the river profile is concave in shape and same is true between 4800 to 4000 mean sea level height. The smooth longitudinal profile of a river represents a local balance between erosion and deposition, but in the case of Parvati river as it is seen from the longitudinal profile that the profile has irregularities such as break in the slopes and it can be attributed to gradual upliftment of the Himalayan region, the local tectonic forces and retreat of glaciers.

2.12 Cross Profile of Parvati River

It is impossible to divorce the study of the cross-profile from the study of the long profile. Different river shows three types of differences in the cross section. It can be seen in the shape of channel, the shape of the floor of the valley, and the shape of the valley as a whole channel shape vary considerably in a cross section. Valley profile varies from narrow steep-sided trenches to gentle open forms. Apart from this symmetry of the cross section also vary considerably depending upon the resistance offered by the valley slopes.

Figure 2.6 - CROSS PROFILE OF PARVATI UPSTREAM KHIRGANGA

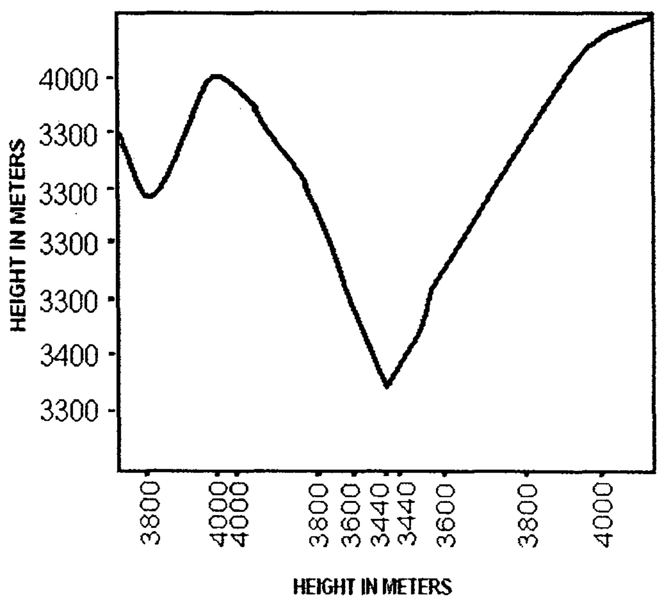
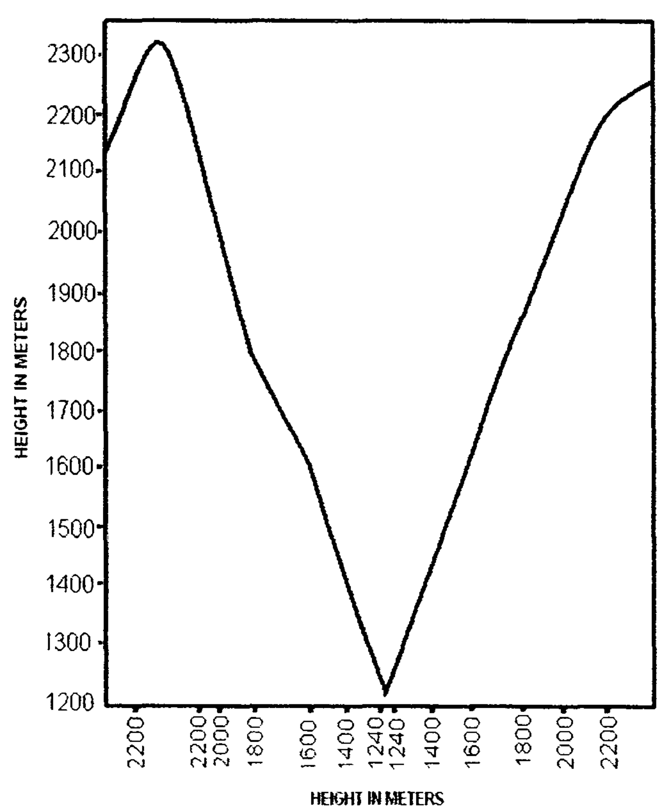


Figure 2.7 - CROSS PROFILE OF PARVATI RIVER BHUNTAR



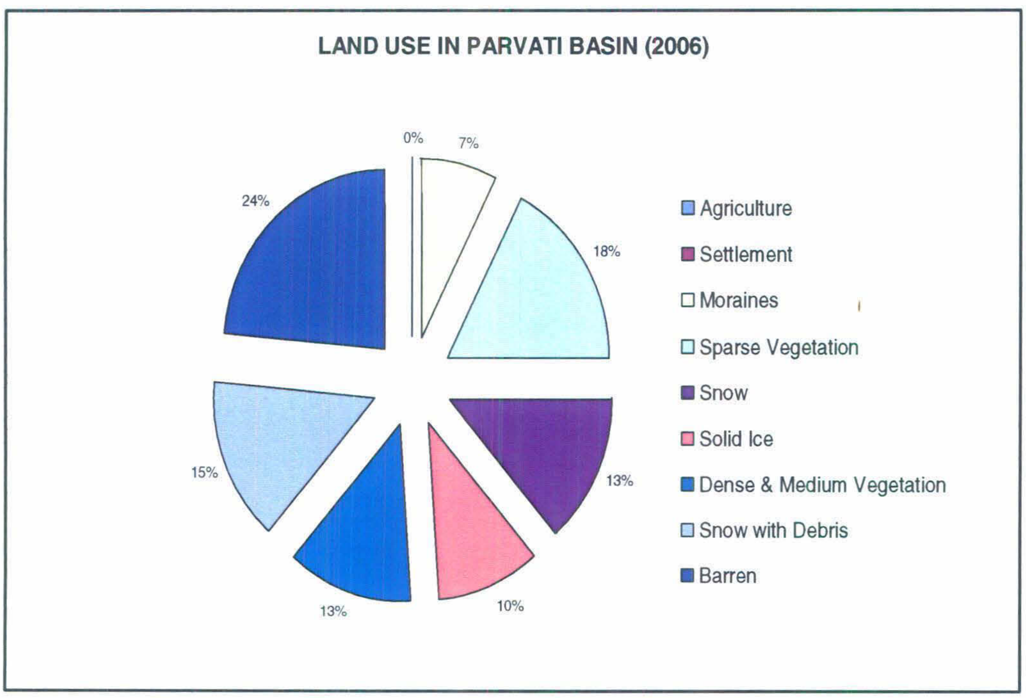
The cross profile of Parvati river is drawn at two section.

(1) Cross profile of Parvati river upstream Khirganga at an elevation of 3400 a.s.l. (Figure 2.6)

(2) Cross profile of Parvati river near Bhuntar (Figure 2.7)

It is seen from the cross profile (Figure 2.6) drawn upstream of Khirganga that the valley is v shaped, slopes are very steep and valley floor is very narrow. It can happen only if stream is actively down cutting or rocks very resistant to erosion, or the stream engaged in eroding laterally at the base of slop. In the case of Parvati river the steepness of slope is due to gradual upliftment of Himalaya which leads to active down cutting by stream in order to attain equilibrium. This profile also indicates that glacier ice did not descend to these altitudes.

2.13 LAND-USE/COVER PATTERN IN THE PARVATI BASIN (2006):



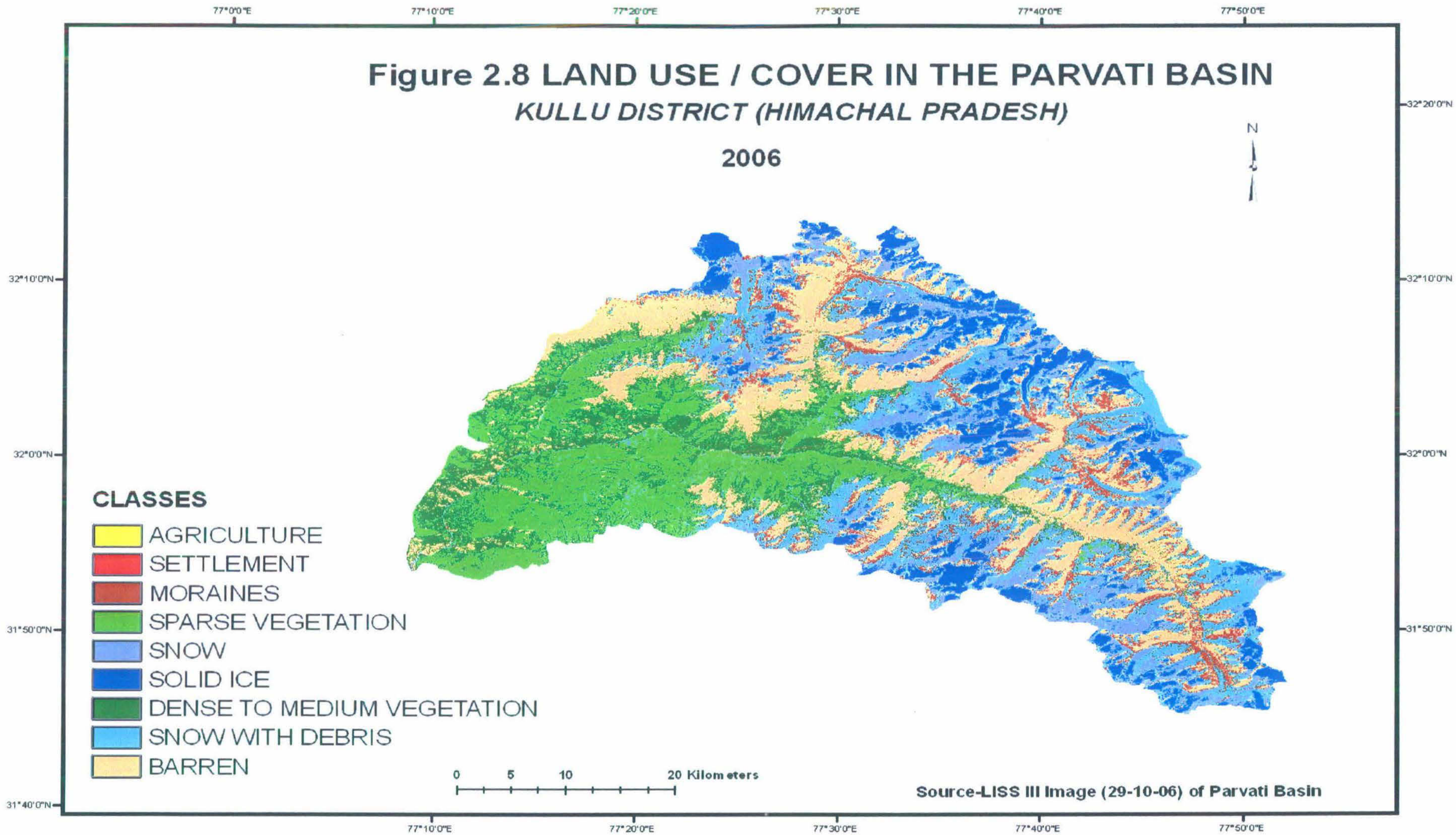


Figure 2.8 LAND USE / COVER IN THE PARVATI BASIN

KULLU DISTRICT (HIMACHAL PRADESH)

2006

Table below shows the Land-Use pattern in the Parvati basin, larger part of the basin is Barren, i.e.457 km^2 but on clubbing the categories indicating Snow, Solid ice and Snow with debris, covers a total area of 748 km^2. On the Vegetation part the basin is covered mainly by Sparse type with a total coverage of 340 km^2, where as Dense and Medium Vegetation covers 291 km^2. Moraines also show a considerable presence in the basin, covering 145km^2. Settlements and Agriculture have a negligible cover, less than 2 km^2.

Table 2.6: Land Use Cover in Parvati Basin 2006

S. No.	Class Name	% Area Under Each Class (Sq.Km.)
1.	Agriculture	0.144899312
2.	Settlement	1.015254782
3.	Moraines	145.0989084
4.	Sparse Vegetation	340.5114641
5.	Snow	261.4377024
6.	Solid Ice	196.7867001
7.	Dense & Medium Vegetation	244.2397854
8.	Snow with Debris	291.6967091
9.	Barren	457.1650063
	TOTAL AREA OF BASIN	**1938.09643**

2.14 Geothermal resource

The Parvati valley has number of hot springs located at Kasol, Manikaran and Khirganga. They are part of hot springs wide spread in the Himalaya which are closely associated with the faults and thrusts of the mobile belt. Geothermal potential of the Parvati basin in Himalayan Orogenic belts has been studied by Bhatnagar et. al. 1967-73. All these studies have been summarized below.

Kasol, Manikaran, Khirganga Hot Spring Areas

All these hot springs are located in the valley of river Parvati. Kasol is about 32 km away from Bhuntar. Manikaran hot springs are located on the upstream side at a distance of about 4 km from Kasol. Khirganga hot springs is about 15 km further upstream of Manikaran, opposite Nakthan village. All these hot springs are located in the Himalayan mobile belt. The majority of the hot springs in this belt tend to align themselves either along or parallel to the major fault zones or along their associated faults.

Surface manifestation and geological setting

The hot springs of Manikaran, Kasol and Khirganga are located on the right bank of the river Parvati. At Manikaran, the Parvati river valley is about 60 meters wide and the surface thermal manifestations are confined to several groups of hot springs emerging at various locations spreading up to a distance of about 1.3 km along the Parvati river from the old bridge to Brahamganga. The major groups of springs are situated near Harihar temple. The most important spring in this group is the one which issues like a geyser close to the bank of Parvati from which at an interval of every two minute stream escape for 15 to 30 seconds.

The maximum height up to which the water rises is about 50 cm. There are numerous other hot springs in Manikaran along the Parvati River and on the terraces. Hot water emerges only at one location in Kasol and the general temperature is much lower than at Manikaran and the same is true for Khirganga.Between Uchich and Manikaran, the contact between schist and under lying quartzite runs in N-W direction and then swings to west downstream of Manikaran. The contact between these two groups is a major thrust contact and probably forms a part of the Central Himalayan thrust, which is an extensive feature related to Cenozoic folding in the Himalayan mobile belt. This deep thrust and its associated fault seems to be the place of emergence of the hot springs. The resource of thermal fluids is provided by the large brecciated material in the shear zones (Bhatnagar et.al. 1967-73).

2.15 Summary

The Parvati basin lies between 31°50 to 32°5 north latitudes and 77°5 to 77°50 east longitude. The river Parvati is one of the major tributaries of the Beas. Which confluences at Bhuntar at an elevation of 1096 meters above mean sea level. It drains an area of 1938 Km^2. The Parvati river basin is a hilly and mountainous tract with altitude ranging from 1096 to 6250 meters above mean sea level. The basin presents an intricate mosaic of mountain ranges, hills and valleys.

There are evidences of extensive glaciation during the ice ages and the Present glaciers are merely shrunken remnants. Enormous heaps of terminal moraines are now covered with grass and trees. Ice transported blocks with smoothened and striated surfaces, hanging and U-shaped valleys are notable features in the basin. The rock types found in the basin are phyllite, slate, quartzite, limestone, schists, and granites; some minerals found in the area are of considerable economic importance, such as, Beryl, building stones, Kyanite, Copper and limestone. Owing to wide range of altitudinal and climatic conditions, Parvati basin has diversified flora and fauna. Forests are not uniformly distributed throughout the basin, but mostly confined to highest hills and interior valleys, in the lower and more accessible areas the forests have been cleared to make room for cultivation and settlement.

Parvati river has 1891 first order streams, 431 second order, 70 third order, 17 fourth order and 4 fifth order stream. Total number of streams in the basin is 2414 with stream density of 1.24 numbers of streams per km^2. The drainage density of the Parvati basin is 1.04 per km^2 Parvati river's elongation ratio is .88, conclude that the shape of the basin is not completely circular, but more toward elongation. Analysis of the longitudinal profile reveals that the regular concave section is separated by convex section. These irregularities may be due to the presence of more resistant rocks across the stream, due to initial change in slope resulting from tectonic movements. The slope of the river is convex in shape between 4000 to 2800 meters above mean sea level and from 2800 to 1200 meters above mean sea level the river profile is concave in shape and same is true between 4800 to 4000 mean sea level height. Cross profile drawn upstream of Khirganga conclude that the valley is V shaped, slopes are very steep and valley floor is very narrow. It can happen only if stream is actively down cutting or rocks very resistant to erosion, or the stream engaged in eroding laterally at the base of slop.

In case of Parvati river the steepness of slope is due to gradual upliftment of Himalaya which leads to active down cutting by stream in order to attain equilibrium. This profile also indicates that glacier ice did not descend to these altitudes. The larger part of the basin is Barren, i.e.457 km^2. Snow, Solid ice and Snow with debris, covers a total area of 748 km^2. On the Vegetation part the basin is covered mainly by Sparse type with a total coverage of 340 km^2, where as Dense and Medium Vegetation covers 291 km^2. Moraines also show a considerable presence in the basin, covering 145km^2. Settlements and Agriculture have a negligible cover, less than 2 km^2. The Parvati valley has number of hot springs located at Kasol, Manikaran and Khirganga. They are part of hot springs wide spread in the Himalaya which are closely associated with the faults and thrusts of the mobile belt.

CHAPTER THREE

GLACIER AND SNOW LINE FLUCTUATIONS

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3.1 Introduction

Applied geomorphology seeks data that could be used for meaningful environmental management. This is particularly true for glaciological and periglacial environments where regimes are significantly controlled by variation in thermal and moisture fluxes at the air-earth interface. Both the Quaternary and Holocene geomorphology literature reveals that a wide array of climatological methods could be used to interpret glacial landscapes and chronologies to understand climate change and its reasons, there fore interpretations of glacier-climate interrelationships often rely on micrometeorological data recorded at single, so called "representative stations" (Melvin,G.M. et. al., 1992). This is especially true where: (1) there is need to identify components of the energy and moisture fluxes affecting accumulation and ablation processes; (2) linkages are sought between these components and broader atmospheric conditions; and (3) the micrometeorological station is seen as representative of the full glacier environment.

Global climate has long been regarded as the critical factor in earth-surface environmental changes affecting floral, faunal distributions, and regional hydrological budgets including rivers, lakes and glaciers. A wide range of oceanic and continental indicators has been used as a means of reconstructing earth-surface conditions, especially over the past 2 Ma, as a basis for climatic models designed to provide insight into changes in the general circulations of the atmosphere (e.g. CLIMAP Project, 1976; COHMAP, 1988).

The timing and extent of last Pleistocene and Holocene alpine glacier fluctuations in the Himalaya and Tibet are poorly defined due to the logistical and political inaccessibility of the region, and the general lack of modern studies of the glacial successions. Nevertheless, renewed interest in the region and the aid of newly developing numerical dating techniques have provided new insights into the nature of latest Pleistocene and Holocene glacier oscillations (Owen, L., 2005). These studies provide abundant evidence for significant glacial advances throughout the Last Glacial cycle. In the high Himalayan and Tibetan regions glaciers reached their maximum extent early in the Last Glacial cycle. However, true Last Glacial Maximum advances were significantly less extensive. Notable glacier advances occurred during the Late glacial and the early Holocene, with minor advances in some regions during the mid-Holocene (Benn. D. I. & Owen, L. A., 2005). There is abundant evidence for multiple glacial advances throughout the latter part of the Holocene, although these are generally very poorly defined, these advances were less extensive than the early Holocene glacier advances. The poor chronological control on latest Pleistocene and Holocene glacial successions makes it difficult to construct correlations across the region, and with other glaciated regions in the world, which in turn makes it hard to assess the relative importance of the different climatic mechanisms that force glaciation in this region. The Late glacial and Holocene glacial record, however, is particularly well preserved in several regions, notably in Muztag Ata and Kongur, and the Khumbu Himal.

Himalayan glaciers have been in a state of general retreat since 1850 (Mayewski & Jeschke 1979) and recent publications confirm that, for many, the rate of retreat is accelerating. Jangpang and Vohra (1962), Kurien and Munshi (1972), Srikanta and Pandi (1972), Vohra (1981), and many others have made significant studies on the glacier snout fluctuation of the Himalayan glaciers. But a dramatic increase in the rate seems to have occurred in last three decades. In 1998, researchers LA Owen and MC Sharma showed, by studying the longitudinal profiles of the river, that between 1971 and 1996, the Gangotri Glacier had retreated by about 850 m. This would yield a post-1971 retreat rate of 34 m a year. For the post-1971 period, the 61-year (1935- 1996) data of GSI too shows that the retreat rate is about 28 m/year, indicating a clear increase in the rate after 1971. The 1996-1999 data of Naithani and associates too matches this general trend of an increased rate.

3.2 Equilibrium Lines and Glacial Cover

The glacial and periglacial environment are sensitive indicator of climate change as these promptly react to global warming. In fact, several instability events which have been recently reported from the Alps can reasonably be considered as the first effects of the accelerated climate change, which is affecting not only the precipitation regime, but also the cryosphere structure (Marta, C. & Giovanni, M., 2007) . The traditional "glaciologic" method for determining glacier mass balance consists of placing a network of stakes and pits on the glacier surface and measuring the change in surface level (accumulation and ablation) while taking into account snow/firn density, either between two fixed dates (annual mass balance) or at the end of the ablation and accumulation seasons (seasonal mass balance) (Kaser, G. et. al., 2002). The equilibrium line altitude (ELA) is the average altitude at which accumulation balances ablation over one year. On an annual basis, the ELA reacts to a combination of climatic variables, particularly precipitation and air temperature. The long-term average, or steady-state ELA, is the altitude for which the glacier as a whole has a mass balance of zero, and is said to be in equilibrium with climate. Whether the annual ELA is above or below the steady-state ELA is a key indicator to assess the state of health of a glacier: annual ELAs that are higher than the steady-state ELAs indicate a negative mass balance for that particular year.

In remote, rugged areas such as the Himalayas, the glaciologic method is difficult to apply due to complicated logistics and political or cultural conflicts. A new remote-sensing approach used to estimate glacier mass balance involves determining the total mass balance of a glacier from measured or inferred volumetrics and/or ELA altitudes.

The ice-covered area on the Tibetan Plateau, together with that on the mountains of the Himalaya, Karakoram, Hindukush and Pamir, totals 95000 km^2 of ice cover, making up 4 % of the area of High Asia. Changes in temperature and precipitation patterns in mountains can be tested by comparing the present distribution of glaciers with the distribution of glaciers that existed in the past. The characteristic of glaciers that is most useful for purposes of comparison is the altitude of the equilibrium line (ELA). However, the precise altitude on present glaciers may be obscure for variety of reasons, and altitudes of former glaciers can only be inferred from the geologic evidences. The effects of increases and decreases in precipitation values vary across the Himalayas and the Plateau as indicated by studies of summer temperature and annual precipitation relationships at equilibrium line locations on existing glaciers (Derbyshire, E. et. al., 1991). It is reflected in the studies that, if annual precipitation decreases at the equilibrium line from 2500 to 1000 mm, the corresponding summer temperature will fall from 4 to 2°C, equivalent to a relative shift in the equilibrium line of 340m. However, in the case of an annual precipitation decline from 1000 to 300 mm, the corresponding fall would be of the order of 4°C, equivalent to an equilibrium line lowering of 680 m (Derbyshire, E. & Jingtai, W., 1991). Thus, while a large decrease in precipitation may have only moderate effects on equilibrium line altitudes in the regions of high precipitation such as those in the eastern Plateau, the southern slope of the Himalaya, and the Pamir, much drier central, north-eastern and north-western parts of the Plateau will have a marked effect on equilibrium line altitudes.

Surface heating of the Tibetan Plateau raises near surface air temperatures above those of the free air at comparable altitudes. For example, at 30° N mean air temperature in Xizang reduced to sea level is 8.7°C higher than the actual sea level temperature (Yafeng, S. et. al., 1991). The higher temperatures in this 'heat island' are found in the western part of the Plateau where the present day snowlines are the highest in the northern hemisphere. The westerlies are split into northern and southern streams on either side of the Plateau making the periphery moister than the centre. Two vertical precipitation maxima exist on the southern slopes of the Himalaya, one between 1000 and 2000 m above sea level and the second at about 6000 m where precipitation values are three times greater than at 5300 m, (Lanzhou Institute of Glaciology, 1975). Even at 6000 m the precipitation on the north side is only one third of the total on the south side, the modern equilibrium line consequently being 500 m higher on the northern slopes. Total mean precipitation on the North slope of the Himalaya is only 10 % of that on the southern slope in terms of monsoonl rainfall. Equilibrium lines are at their lowest in southeast Xizang (4500 m) where monsoonal flows from the Bay of Bengal are influential.

Table 3.1- Glacier Retreat in the Himalaya

Glacier	Period	Retreat of Snout (meter)	Average Retreat of Glacier Snout (meter/year)
Tirloknath Glacier (Himachal Pradesh)	1969-1995	400	15.4
Pindari Glacier (Uttaranchal)	1845-1966	2840	23.47
Milan Glacier (Uttaranchal)	1909-1984	990	13.2
Ponting Glacier (Uttaranchal)	1906-1957	262	5.1
Chota Shigri Glacier (Himachal Pradesh)	1986-1995	60	6.7
Bara Shigri Glacier (Himachal Pradesh)	1977-1995	650	36.1
Gangotri Glacier (Uttaranchal)	1977-1990	364	28
Gangotri Glacier (Uttaranchal)	1985-2001	368	23
Zemu Glacier (Sikkim)	1977-1984	194	27.7

Source: IPCC, 2001

3.3 Glaciers in the Parvati Basin

A large part of the Parvati basin in its upper reaches is covered by either glacier or snow. The glaciers are separated by steep sloping ranges which run in various directions. The permanent snow line is at an altitude of 5000 meters above mean sea level. The total glaciated terrain above this height is about 903.88 km^2 (Kulkarni et. al., 2005). The glaciers are varying in size, ranging from less than a km square to more than 80 km^2. The largest of the glaciers are found on the Northern slopes of the river Parvati. The important glaciers among them are Saraumga, Tichu, Dibi ka Nal, Parvati and Dudhon glaciers. Apart from these there are large number of glaciers, interconnected with small glaciers on the left and right bank of the Parvati river. The

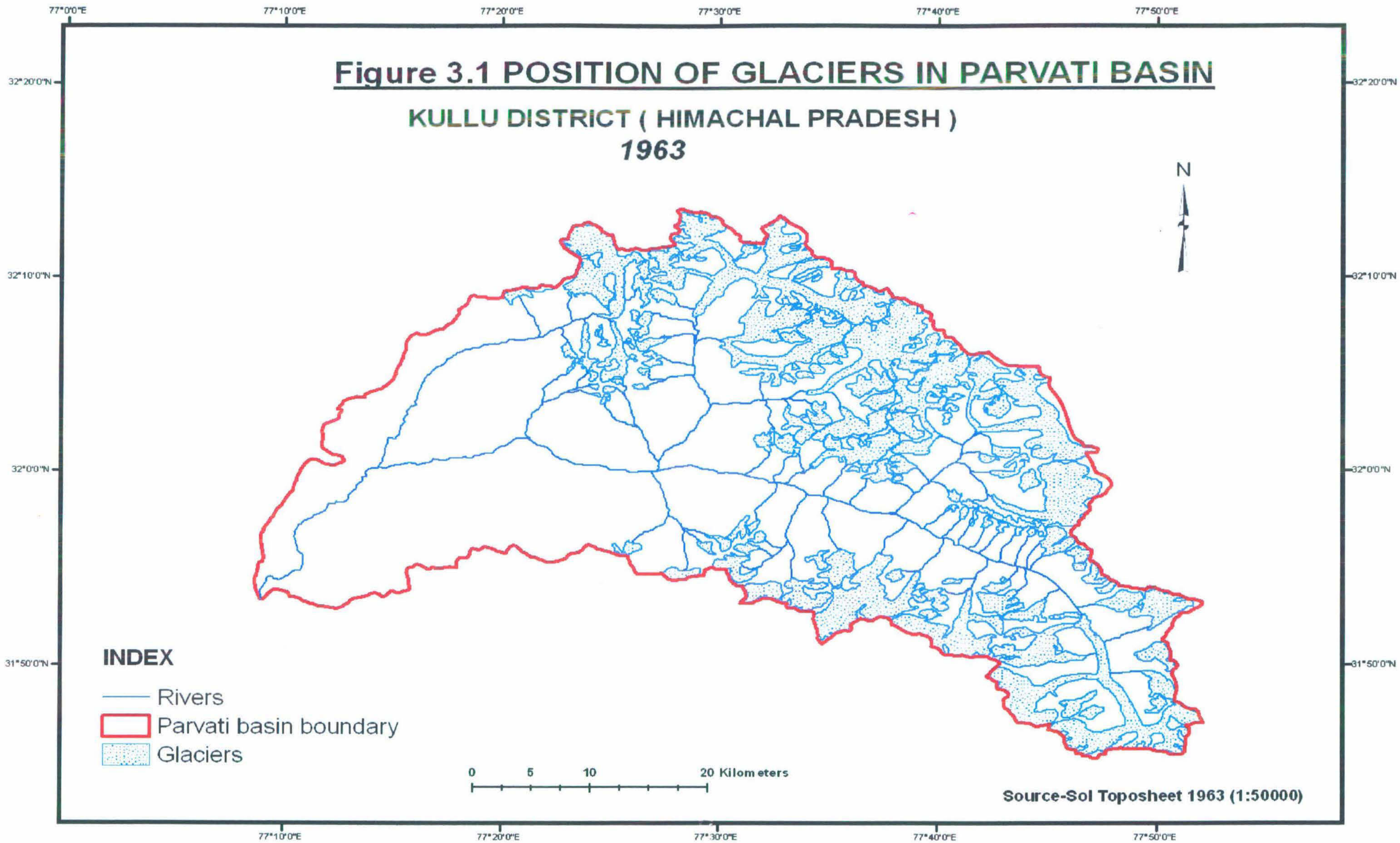


Figure 3.1 POSITION OF GLACIERS IN PARVATI BASIN

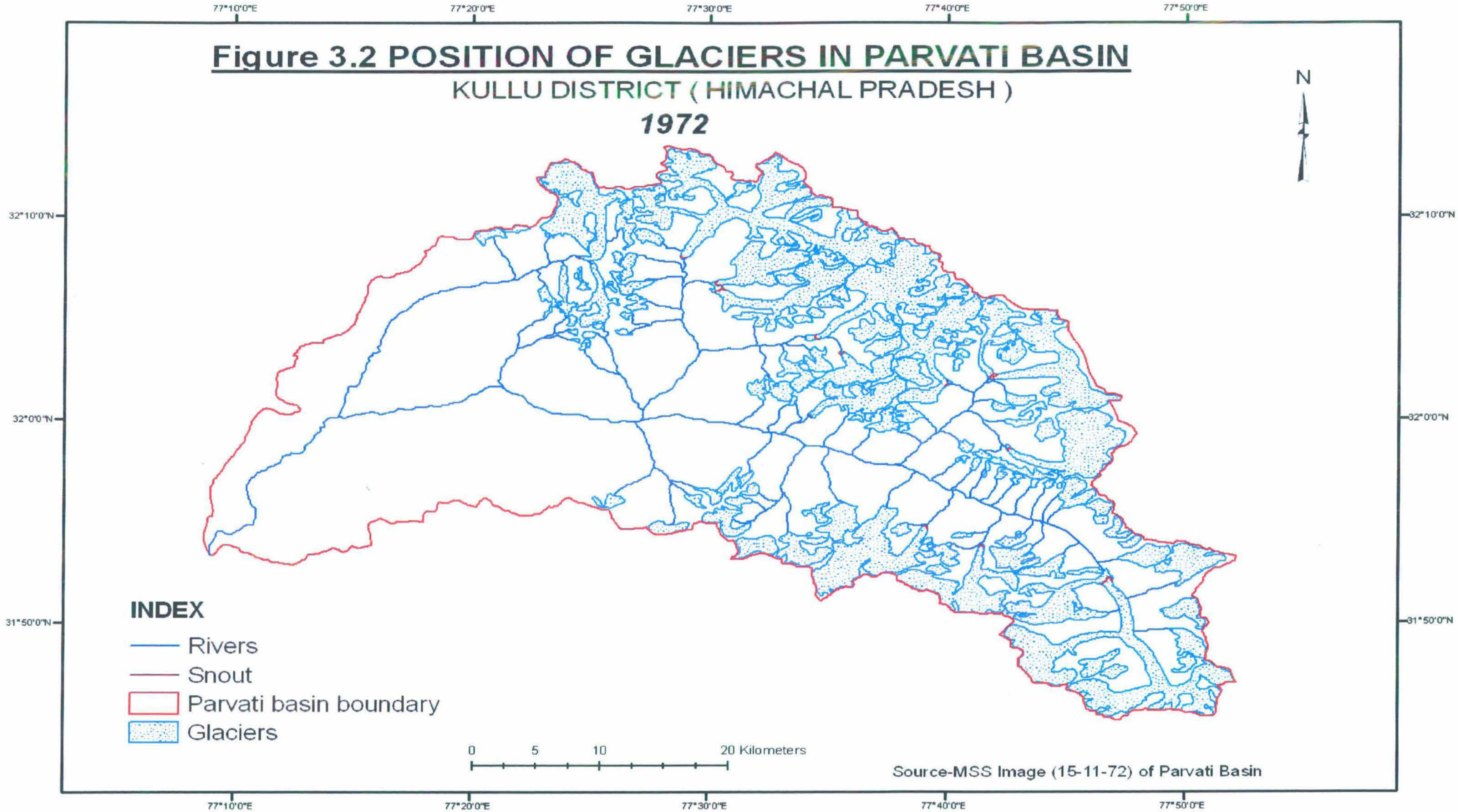


Figure 3.2 POSITION OF GLACIERS IN PARVATI BASIN
KULLU DISTRICT (HIMACHAL PRADESH)
1972

long profile of the Parvati river shows a bulge (bend) which could be interpreted to the fact as glaciers extension in the past down to 3500 meters a.s.l.

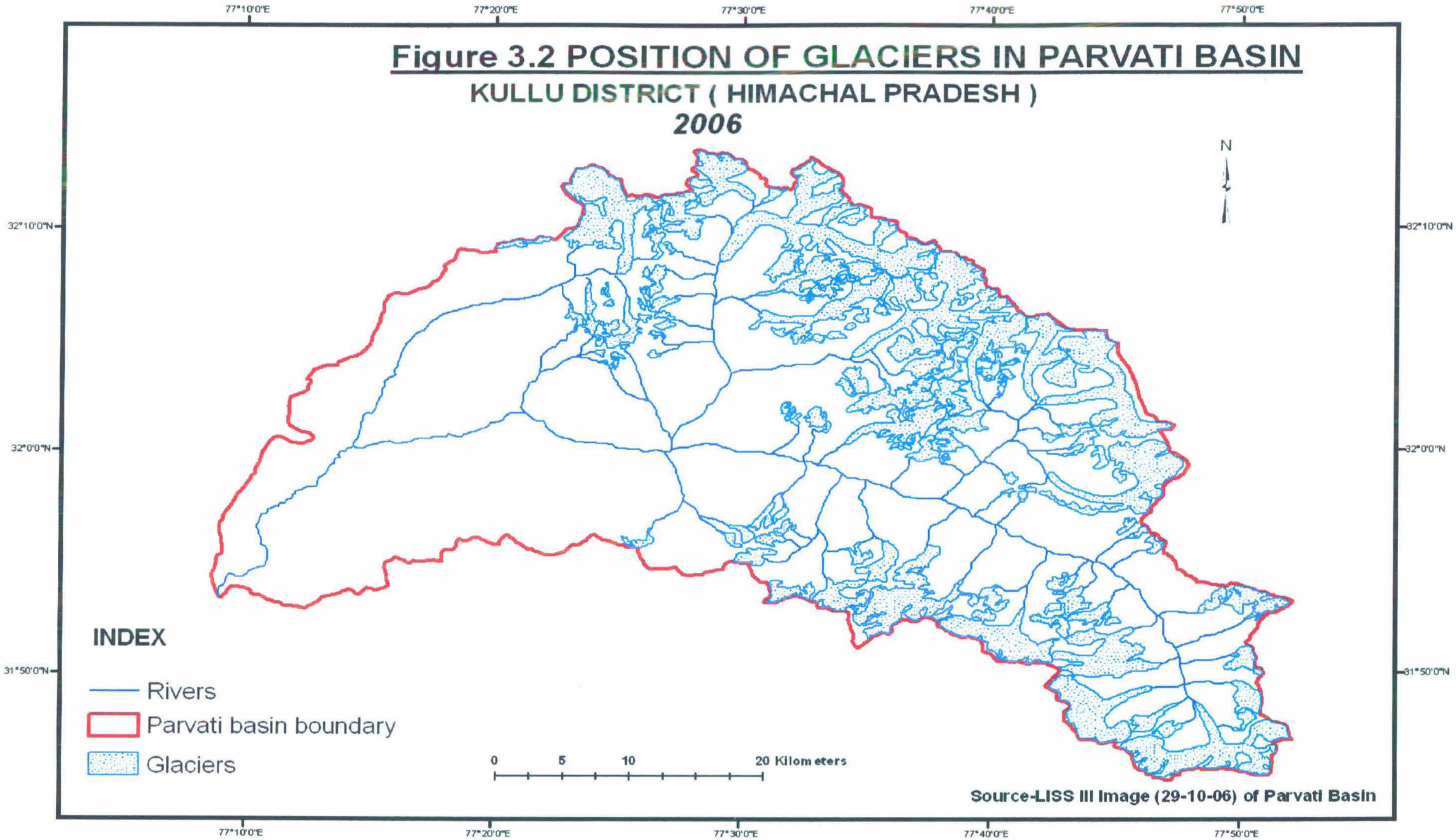
3.3a Change in Areal Extent of the Glaciers

It is clearly observable from Table 3.2 & 3.3 that most of the glaciers in the Parvati Basin are retreating continuously. During 1963-2006, very large shrinkage has been taken place in the basin. (Figure 3.1 & 3.2). Total glaciated area in the basin decreased from 463.8 km^2 in 1963 to 340.6 km^2 in 2006 (Table 3.2 & 3.3); thus the basin experienced a loss of 123.1 km^2 during the period. In percentage terms, the total area decreased during the period come to about 26.6%. However, there may be an error based on the SoI toposheet terminus position which gives such a large difference in terms of glacier retreat.

Table 3.2 - CHANGE IN THE AREAL EXTENT OF LARGE GLACIERS IN PARVATI BASIN (1963-2006)

Name/No.	Toposheet glaciers area (1963)	Imagery glaciers area (2006)	Change (▲)	% Decrease in Area
Man Talai (99)	46.8	31.0	15.8	33.8
Sara umga (74)	54.7	34.0	20.7	37.8
Tichu I (57)	34.8	30.2	4.6	13.3
Dibika I (3)	33.1	26.5	6.6	20.0
Tos (8)	31.8	22.1	9.7	30.4
Fatiruni (93)	24.5	17.9	6.5	26.7
Girvokoti (66)	23.2	18.0	5.2	22.5
Dibika II (34)	23.0	20.1	2.9	12.6
Daunspar (7)	22.8	21.1	1.7	7.4
Bakar bihar (92)	17.8	15.8	2.0	11.1
Total for big glaciers	**312.3**	**236.6**	**75.7**	**24.2**

Source : Calculation based on SOI Toposheet (1963) & LISS III(29-10-2006) image of Parvati basin


77°10'0"E
77°20'0"E
77°30'0"E
77°40'0"E
77°50'0"E
Figure 3.2 POSITION OF GLACIERS IN PARVATI BASIN
KULLU DISTRICT (HIMACHAL PRADESH)
2006
N
32°10'0"N
32°0'0"N
31°50'0"N
INDEX
Rivers
Parvati basin boundary
Glaciers
0 5 10 20 Kilometers
Source-LISS III Image (29-10-06) of Parvati Basin

With reference to the changes in the areal extent of the large glaciers in the basin (Table 3.2), the largest glacier (Saraumga) shows a decrease of 20.70 km^2, which is the highest amount of decrease exhibit by a glacier. Saraumga glacier also shows the largest decrease in percentage terms (37.8 %), Mantalai the second largest glacier in the basin shows a decrease of 15.8 km^2 (33.8 %), e.g. the source of Parvati river. Other large glaciers in the basin also followed the same decreasing trend like Tichul (13.3%), Dibika1 (20.0%), Tos (30.4%), Fatiruni (26.7%), Girvo koti (22.5%), Dibika2 (12.6%), Daunspar (7.4%) and Bakarbihar (11.1%). Average decrease in the areal extent of large glaciers in the basin is 75.7 km^2, which is 24.2% of the total.

On comparing large glaciers with the smaller ones in terms of change in the areal extent Table. 3.3 clearly shows that small glaciers have lost much area than the larger ones in terms of percentage during the given period. There are many glaciers or ice patches which were totally absent from the basin by 2006. For more detailed analysis of these glaciers, these have been categorised on the basis of percentage decrease during the period Table no. (3.4). The glaciers which lies in the category of (**0-10 %**) decrease are No. 59, 79, 30, 31, 81, 75, 7, 47, 89, 91, 42, 72, 33, 64, which lie in the category of **(10-20 %)** decrease are No.63, 6, 65, 4, 92, 56, 77, 88, 90, 41, 34, 57, 67, 80, 53, 5, 60, 87, 52, 97, 55, 39, 32, that fall in the category of **(20-30%)** decrease are No.3, 76, 9, 24, 1, 96, 21, 46, 66, 82, 40, 94, 18, 23, 29, 86. The Table 3.3 clearly shows that all the large glaciers of the basin fall in the categories that show the decrease less than 35 % but categories like **(30-40%)** decrease which includes glaciers No. 98, 71, 8, 20, 54, 61, 35, 44, 70, 58, 69, 22, 51, 36, 94, 50, 99, 74, like **(40-50%)** decrease which includes glaciers No.62 ,83 ,49, 45, 19, 48, and the category **(50-60%)** decrease includes No. 43, 37, 28, 27 and the last (>**60 %**) decrease includes No. 95, 85, 38, 73, 84, 78, 2, 26, 17, 16, 25, 14, 13, 15, 11, 12, 10. are dominated by the small glaciers. An important feature of the basin is that almost all the glaciers (studied) shows a negative change in the areal extent during the period.

Table 3.3 CHANGE IN THE AREAL EXTENT OF SMALL GLACIERS IN PARVATI BASIN (1963-2006)				
Name/No.	**Glaciers area (1963)**	**Glaciers area (2006)**	**Change (▲)**	**% Decrease in Area**
Tichu2	10.9	10.0	0.9	8.2
Parbati	10.6	8.4	2.2	20.6
94	7.7	5.0	2.7	35.4
60	6.0	5.1	1.0	16.0
58	5.4	3.7	1.7	31.9
96	5.1	4.0	1.1	21.2
54	4.6	3.2	1.4	30.7
84	4.0	0.7	3.4	83.4
95	4.0	1.6	2.4	60.8
62	3.8	2.1	1.7	43.6
61	3.7	2.6	1.1	31.0
86	3.6	2.6	1.0	29.0
4	3.5	3.2	0.4	10.9
79	3.5	3.4	0.1	2.5
90	3.1	2.7	0.4	12.1
72	3.0	2.7	0.3	9.6
70	2.5	1.7	0.8	31.7
88	2.5	2.2	0.3	11.8
78	2.4	0.0	2.4	100.0
97	2.3	1.9	0.4	17.3
81	2.2	2.1	0.1	4.6
85	2.2	0.9	1.3	61.0
56	2.2	2.0	0.2	11.3
80	2.1	1.8	0.3	14.7
82	2.1	1.6	0.5	23.7
75	2.1	2.0	0.1	4.8
2	2.0	0.0	2.0	100.0
83	1.8	1.0	0.8	43.8
73	1.7	0.3	1.4	81.1
76	1.6	1.3	0.3	20.0
64	1.5	1.4	0.2	9.9
1	1.5	1.2	0.3	21.2
26	1.5	0.0	1.5	100.0
71	1.4	1.0	0.4	30.1
28	1.4	0.6	0.7	53.6
55	1.4	1.1	0.3	19.4
89	1.3	1.2	0.1	8.4
37	1.3	0.6	0.7	51.9
59	1.3	1.2	0.0	1.4
87	1.3	1.1	0.2	16.5
77	1.2	1.1	0.1	11.8
63	1.1	1.0	0.1	10.0
98	1.1	0.8	0.3	30.0
65	1.1	1.0	0.1	10.7
36	1.0	0.7	0.4	35.4
17	1.0	0.0	1.0	100.0
Source : Calculation based on SOI Toposheet (1963) & LISS III (29-10-2006) image of Parvati basin				

Table 3.4 - Percentage Decrease in Glaciated Area in Parvati River Basin (From 1963-06)													
0-10		10-20		20-30		30-40		40-50		50-60		>60	
Glacier	% Decrease	Glacier	% Decrease	Glacier	% Decrease	Glacier	% Decrease	Glacier	% Decrease	Glacier	% Decrease	Glacier	% Decrease
59	1.4	63	10.0	3	20.0	98	30.0	62	43.6	43	50.8	95	60.8
79	2.5	6	10.4	76	20.0	71	30.1	83	43.8	37	51.9	85	61.0
30	2.7	65	10.7	9	20.6	8	30.4	49	46.7	28	53.6	38	62.7
31	2.8	4	10.9	24	21.0	20	30.5	45	46.9	27	54.0	73	81.1
81	4.6	92	11.1	1	21.2	54	30.7	19	48.5			84	83.4
75	4.8	56	11.3	96	21.2	61	31.0	48	48.8			78	100.0
7	7.4	77	11.8	21	22.2	35	31.3					2	100.0
47	8.3	88	11.8	46	22.4	44	31.6					26	100.0
89	8.4	90	12.1	66	22.5	70	31.7					17	100.0
91	9.0	41	12.5	82	23.7	58	31.9					16	100.0
42	9.5	34	12.6	40	24.8	69	32.5					25	100.0
72	9.6	57	13.3	93	26.7	22	33.7					14	100.0
33	9.8	67	14.7	18	27.4	51	34.5					0	100.0
64	9.9	80	14.7	23	28.1	36	35.4					13	100.0
		53	15.2	29	28.2	94	35.4					15	100.0
		5	15.5	86	29.0	50	37.9					11	100.0
		60	16.0			99	33.8					12	100.0
		87	16.5			74	37.8					10	100.0
		52	17.0										
		97	17.3										
		55	19.4										
		39	19.5										
		32	19.7										

Source : Calculation based on SOI Toposheet (1963) & LISS III (29-10-2006) image of Parvati basin

3.3b Glacier Fluctuation in the Parvati Basin

One of the queries that a glaciologist is perpetually engaging with, respect to glacier behaviour is, "whether the glaciers are advancing or retreating?" The answer would be straight forward, either it is advancing or retreating but this answer is not the true explanation of the glacier health. The health of the glacier encompasses much more than these fluctuations, as some of glaciers may not retreat but thin. Therefore, advancing and retreating is not always the right option to denote the glacier behaviour. In Parvati basin, glaciers are retreating at an alarming rate which is the result of a number of factors like temperature, precipitation, topography, altitude and anthropogenic activities; calculation is based on SoI Toposheet map and IRS-LISS-2006 image.

Table 3.4-Glacier Fluctuations in the Parvati Valley

Glacier Name	Total Advance and Retreat between the Periods (Meters)				Rate of Retreat and Advance (m/yr.)			
	1963-72	1972-89	1989-2000	2000-2006	1963-72	1972-89	1989-2000	2000-2006
Man Talai	1062	4917	681	441	118	289	62	74
Sara umga	94	320	270	242	10	19	25	40
Dibika I	291	389	377	233	32	23	34	39
Tichu I	347	376	190	231	39	22	17	39
Fatiruni	325	119	176	144	36	7	16	24
Girvo koti	161	287	250	132	18	17	23	27
Tos	215	390	308	222	24	23	28	37
Dibika II	150	433	472	256	17	25	43	43
Parbati	105*	111*	83	143	12	7	8	23
Tichu II	95*	167*	187	142	11	10	17	24
Bakar Bihar	128	358	396	234	14	21	36	39
Daunspar	146	113	327	223	16	7	29	37
Parvati Basin	243	642	310	220	27	38	28	37

*Source: Calculation based on SoI Toposheet (1963), MSS image (1972), TM image (1989), ETM+(2000) & LISS III (2006) image of Parvati basin, Note:- * advance*

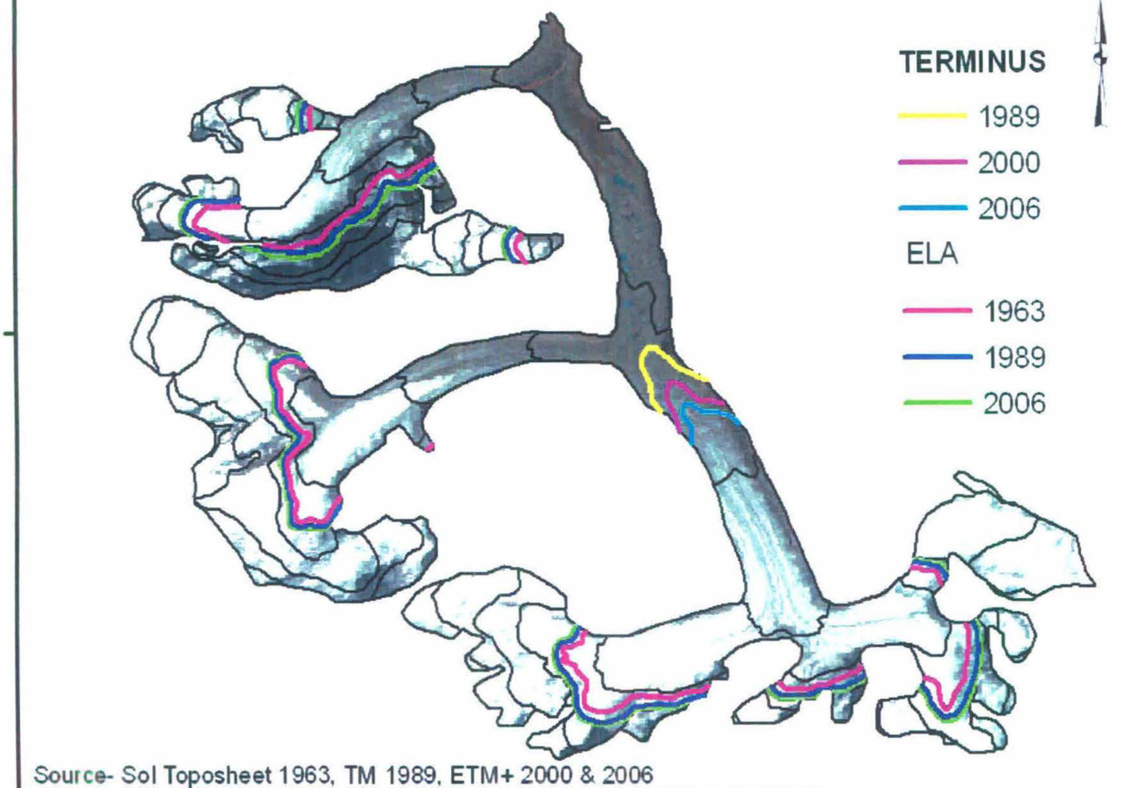


Figure 3.3a TERMINI & ELA FLUCTUATIONS OF MANTALAI GLACIER (1963-2006)

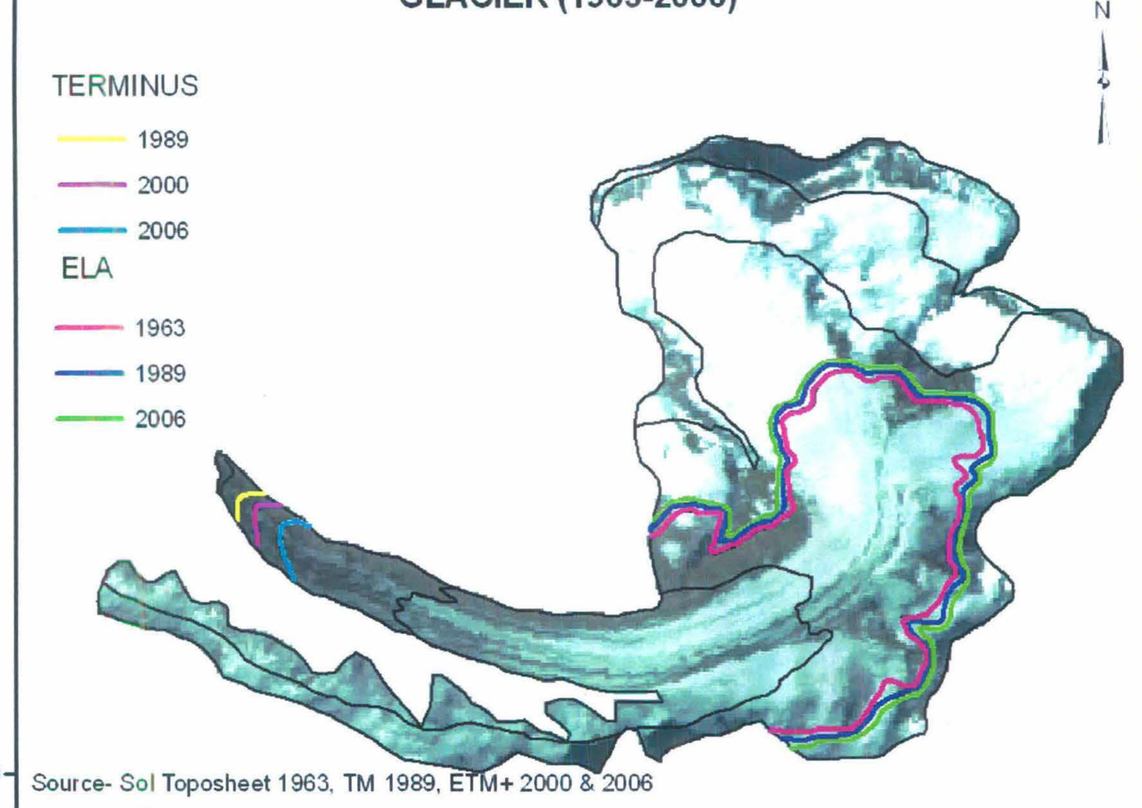


Figure 3.3b TERMINI & ELA FLUCTUATIONS OF FATIRUNI GLACIER (1963-2006)

Plate 3.1: Accumulation area of the Pin Parvati Glacier (5300 m). Bergshrund in the background is covered by fresh snow.

Plate 3.2: Proglacial lake at Mantalai (4070 m). Arrow indicates the recent terminal position of Parvati Glacier.

Termini Fluctuations of Fatiruni Glacier

The Fatiruni glacier shows a retreat of 325 meters in 9 years from (1963-1972) with, an average rate of 36 meter per year, such a large retreat may be due to error in SoI toposheets. In the next 17 years (1972-1989) the retreat was 119 metres, with an average rate of 7 meters per year. The retreat from 1989-2000 was 176 meters, with a rate of 16 meter per year, the period from 2000-2006 show a retreat of 144 meters, with a rate of 24 meter per year which is the highest rate of retreat in this basin after 1972.. (Table 3.5, 3.6, 3.7, 3.8). The areal extent of glacier decreased from 24.5 km^2 in 1963 to 17.9 km^2 in 2006. The Fatiruni glacier shows a decrease of length from 9.86 km to 9.38 km (Figure 3.3 & 3.4b).

Table 3.6 - Glacial Parameters in Parvati Basin, 1963

Name of Glacier	Length in Km	Area in Km2	Head-wall (M)	Terminus (M)	AWM (M)	AAR (.44)	THAR (M)	Mean ELA (M)
Man Talai	15.36	46.8	5400	4040	4870	4738	4720	**4776**
Sara umga	16.6	54.7	5850	3620	4929	4775	4735	**4813**
Dibika I	9.06	33.1	5600	4520	5173	5012	5060	**5082**
Tichu I	11.33	34.8	5400	4120	5013	4940	4760	**4904**
Fatiruni	9.86	24.5	5500	4600	5204	5075	5050	**5110**
Girvo koti	11.02	23.2	5600	3840	4993	4885	4720	**4866**
Tos	10.58	31.8	5600	4080	5029	4920	4840	**4930**
Dibika II	9.63	23	5660	4520	5261	5140	5090	**5164**
Parbati	7.22	10.6	5500	4320	5143	5074	4910	**5042**
Tichu II	4.51	10.9	5200	4480	5090	4945	4840	**4958**
Bakar Bihar	6.31	17.8	5300	4080	5008	4947	4690	**4882**
Daunspar	7.9	22.8	5100	4160	4991	4985	4630	**4869**
Parvati Basin	**9.9**	**27.8**	**5476**	**4198**	**5059**	**4953**	**4837**	**4950**

Source : Calculation based on SoI Toposheet (1963)

Termini Fluctuations of Mantalai Glacier

According to Kulkarni et al., (2001) Mantalai glacier have retreated by 5991 meter in 28 years (1962-1990) with retreat rate of 214 meter per year. From 1990-98 there was a further retreat of 459 meter in 8 years with a rate of 57 meter per year, and for 2000-2001 there was a retreat of 97 meter .The current study refers that the glacier had shrinked 1062 meter in 9 years (1963-1972) with retreat rate of 118 meter per year. From 1972-1989 there is a retreat of 4917 meter with a rate of 289 meters per year. The retreat from 1989-2000 was 681 meters, with a rate of 62 meter per year, and from 2000-06 the retreat was of 441 meter with a rate of 74 meter per year (Table 3.5) In 1963, glacial areal extent was 46.8 km^2 and was fed by two

Figure No. 3.4 a

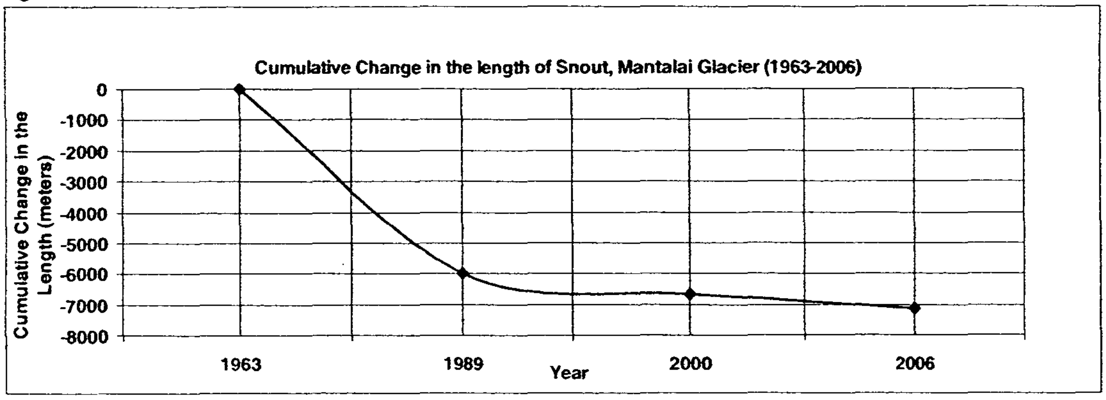


Figure No. 3.4 b

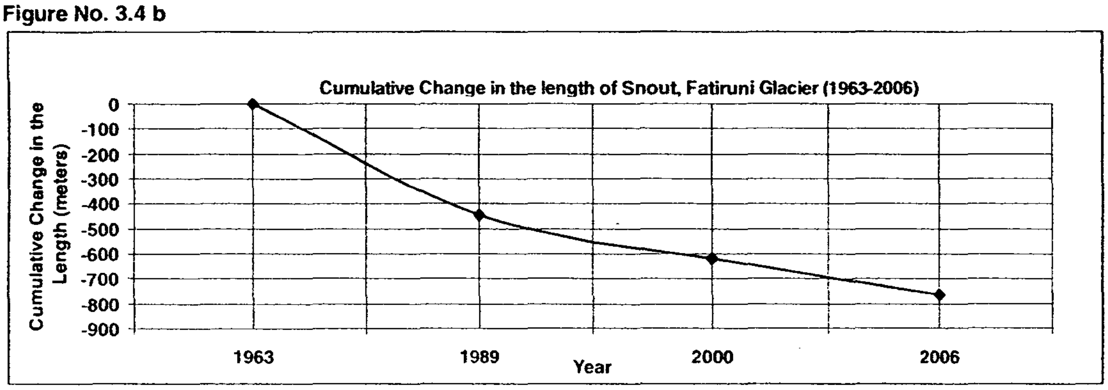


Figure No. 3.4 c

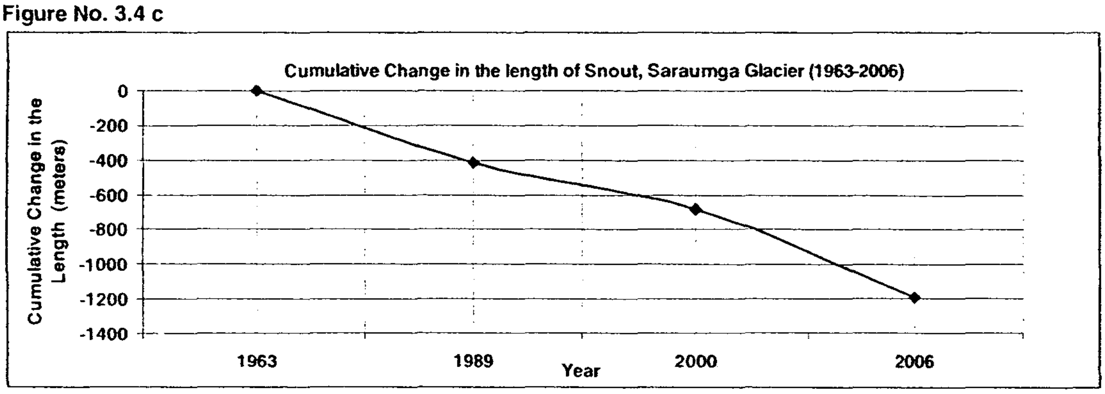
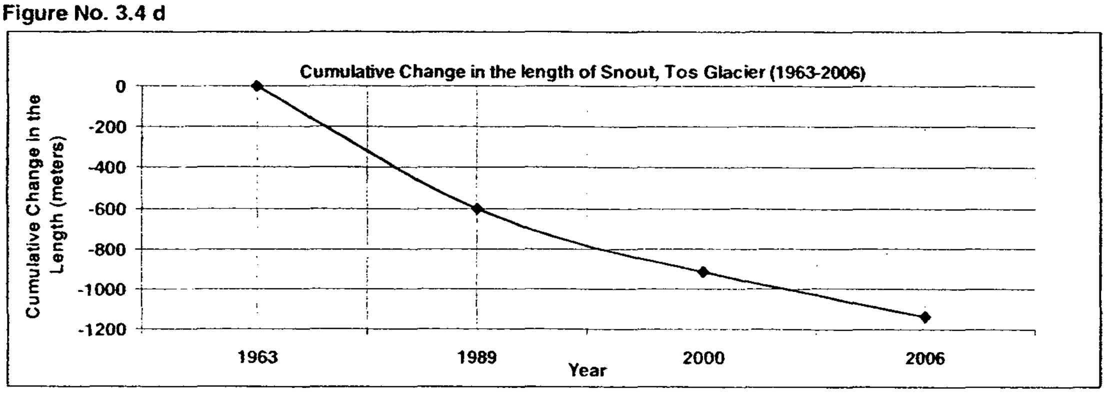


Figure No. 3.4 d



major tributary glaciers. The main and tributary glaciers are facing northwest and northeast, respectively. In the period between 1963 and 1989, the glacier has experienced large retreat. Therefore, the main and tributary glaciers got completely detached from each other, forming two independent glaciers. The amount of retreat is high in the period between 1963 and 1989, possibly because of gentle topography of the deglaciated region and the glacial areal extent was 31.0 km^2 in 2006 (Table 3.5, 3.6, 3.7, 3.8). Plate 3.1 show the accumulation area of Pin-Parvati glacier with bergshurnd in the background, which is covered by fresh snow. The length of this glacier decreased from 15.36 km in 1963 to 9.38 km in 2006 (Figure 3.3 & 3.4a). In Plate 3.2 the arrow indicates the recent terminal position of Parvati glacier and in front of the terminus there is proglacial Lake of Mantalai.

Table 3.7-Glacial Parameters in Parvati Basin, 1989

Name of Glacier	Length in Km	Aspect	Head wall (M)	Terminus (M)	AWM (M)	AAR (.44)	THAR (M)	Mean ELA (M)
Man Talai	9.38	NW	5400	4080	4917	4774	4740	**4810**
Sara umga	16.27	SW	5850	3680	4973	4798	4765	**4845**
Dibika I	8.3	NW	5600	4600	5191	5030	5100	**5107**
Tichu I	10.6	NW	5310	4240	5061	4947	4778	**4929**
Fatiruni	9.41	W	5500	4680	5224	5077	5090	**5130**
Girvo koti	10.5	W	5600	3920	5029	4889	4760	**4893**
Tos	9.9	NW	5600	4080	5038	4965	4840	**4948**
Dibika II	9.05	NE	5660	4560	5301	5148	5110	**5186**
Parbati	7.44	NW	5500	4360	5112	5081	4930	**5041**
Tichu II	4.77	SW	5200	4480	5057	4962	4840	**4953**
Bakar Bihar	5.8	SN	5300	4200	5021	4958	4750	**4910**
Daunspar	7.6	SE	5100	4200	5024	4990	4650	**4888**
Parvati Basin	**9.1**		**5470**	**4257**	**5079**	**4968**	**4863**	**4970**

Source : Calculation based on ETM image (09-10-1989) of Parvati basin

Plate 3.3 show the truncated spurs below the Pin Parvati pass, which indicate the extent of glacier thickness in the past. The glaciers of the Parvati basin do not seem to have descend below Tunda Bhoj (3285 m). Down from here the river profile is V shaped with sharp gradient shown in Plate 3.4.

Termini Fluctuations of Saraumga Glacier

Saraumga, the largest glacier of the basin shows a retreating pattern but the rate of retreat was comparatively lower than Mantalai glacier. The Saraumga glacier shows a retreat of 94 meters

Figure 3.5a TERMINI & ELA FLUCTUATIONS OF SARAUMGA GLACIER (1963-2006)

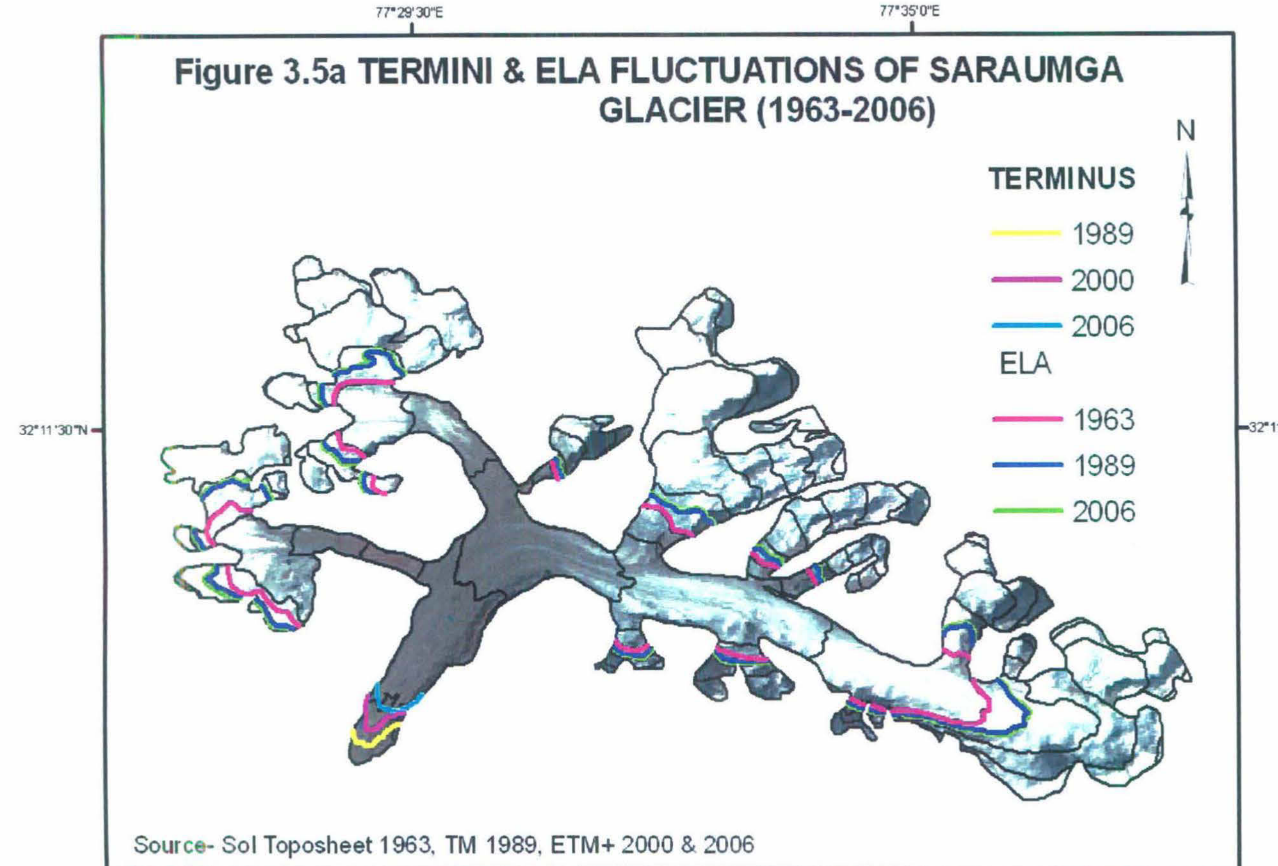


Figure 3.5b TERMINI & ELA FLUCTUATIONS OF TOS GLACIER (1963-2006)

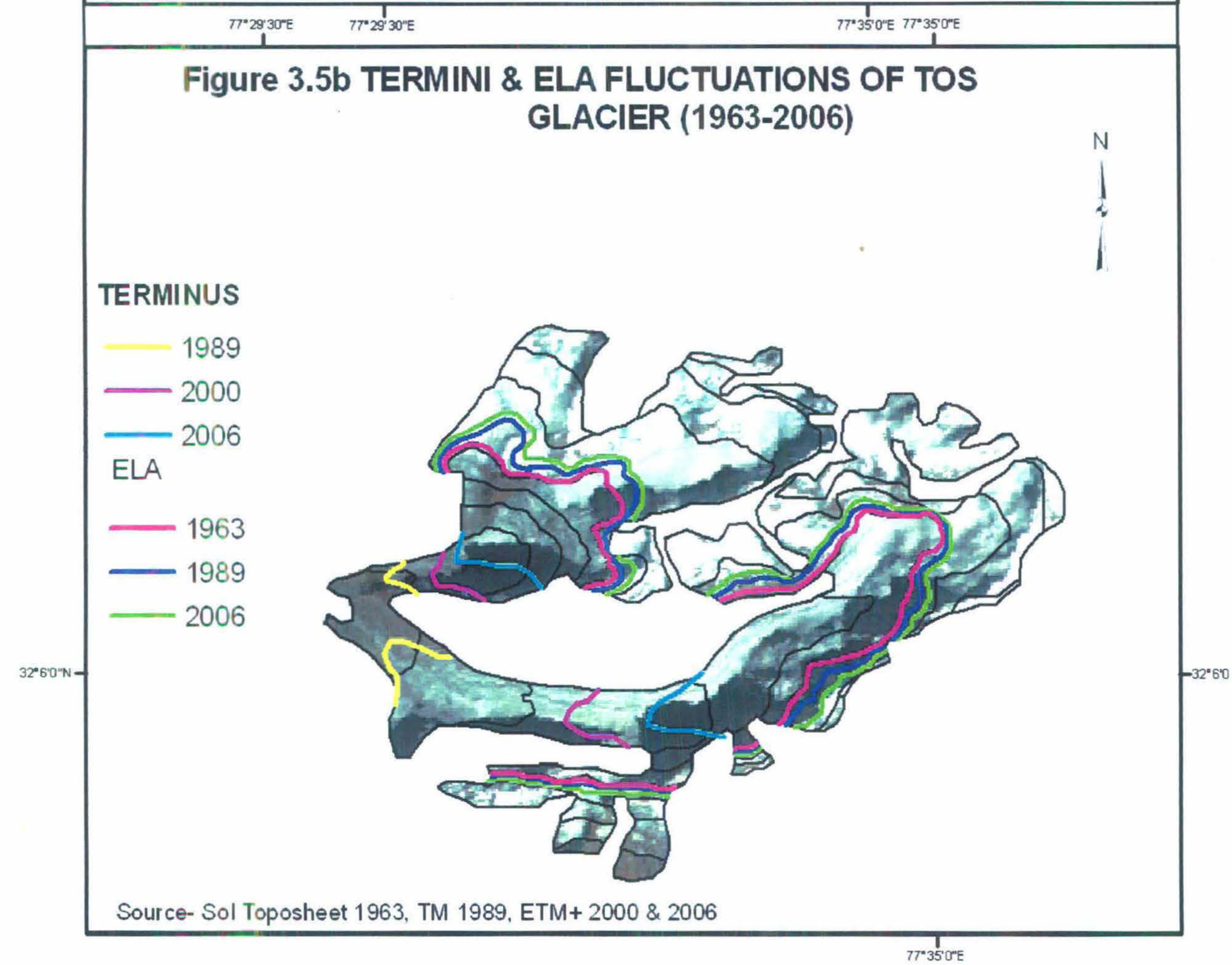


Plate 3.3. Truncated spurs below the Pin Parvati pass indicate extent of glacier thickness in the past.

Plate 3.4. The glaciers of Parvati basin do not seem to have descended below Tunda Bhoj (3285 m). River profile downstream is V-shaped and gradient sharp.

in 9 years from (1963-1972) with annual rate of 10 meter per year. From 1972-1989 there is a retreat of 320 meters with a rate of 19 meter per year. In the succeeding 11 years (1989-2000), the retreat was 270 metres with a rate of 25 meters per year, (Table 3.5, 3.6, 3.7, 3.8).The highest rate of retreat was shown by the glacier for period of 2000-06, i.e. 40 meter per year. The areal extent of the glacier decreased from 54.7 km^2 in 1963 to 34 km^2 in 2006. The rate of retreat of Saraumga glacier is lower than Mantalai glacier because Mantalai glacier lies entirely in the low altitude zone. The length of the glacier decrease from 16.6 km in 1963 to 16.17 km in 2006. (Figure 3.4c & 3.5).

Table 3.8-Glacial Parameters in Parvati Basin, 2006

Name of Glacier	Length in Km	Area in Km2	Headwall (M)	Terminus (M)	AWM (M)	AAR (.44)	THAR (M)	Mean ELA (M)
Man Talai	8.26	31.0	5140	4320	4921	4802	4730	**4818**
Sara umga	16.17	34.0	5510	4000	4963	4820	4756	**4846**
Dibika I	7.7	26.5	5520	4640	5207	5050	5080	**5112**
Tichu I	10.1	30.2	5300	4280	5059	4954	4790	**4934**
Fatiruni	9.38	17.9	5600	4600	5224	5085	5100	**5136**
Girvo koti	10.45	18.0	5440	4040	5054	4895	4740	**4896**
Tos	9.8	22.1	5400	4280	5058	4980	4840	**4959**
Dibika II	8.9	20.1	5580	4640	5296	5156	5112	**5188**
Parbati	7.21	8.4	5440	4400	5143	5087	4920	**5050**
Tichu II	4.44	10.0	5160	4520	5060	4980	4840	**4960**
Bakar Bihar	5.6	15.8	5120	4320	5047	4987	4720	**4918**
Daunspar	7.4	21.1	5000	4280	5050	4994	4640	**4895**
Parvati Basin	8.8	21.2	5360	4360	**5090**	**4983**	**4856**	**4976**

Source : Calculation based on LISS III (29-10-2006) image of Parvati basin

Termini Fluctuations of Tos Glacier

In line with the trend of Mantalai and Saraumga glacier, this glacier also follows the same retreating trend but the rate is lower than the Mantalai glacier. The Tos glacier shows a retreat of 215 meters in 9 years from (1963-1972), with annual rate of 24 meter per year. From 1972-1989 there is a retreat of 390 meters with a rate of 23 meter per year. In the succeeding 11 years (1989-2000), the retreat was 308 metres, with annual rate of 28 meters per year, (Table 3.5, 3.6, 3.7, 3.8).The highest rate of retreat was shown by the glacier in the period of 2000-06, is 37 meter per year. The areal extent of the glacier decreased from 31.8 km^2 in 1963 to

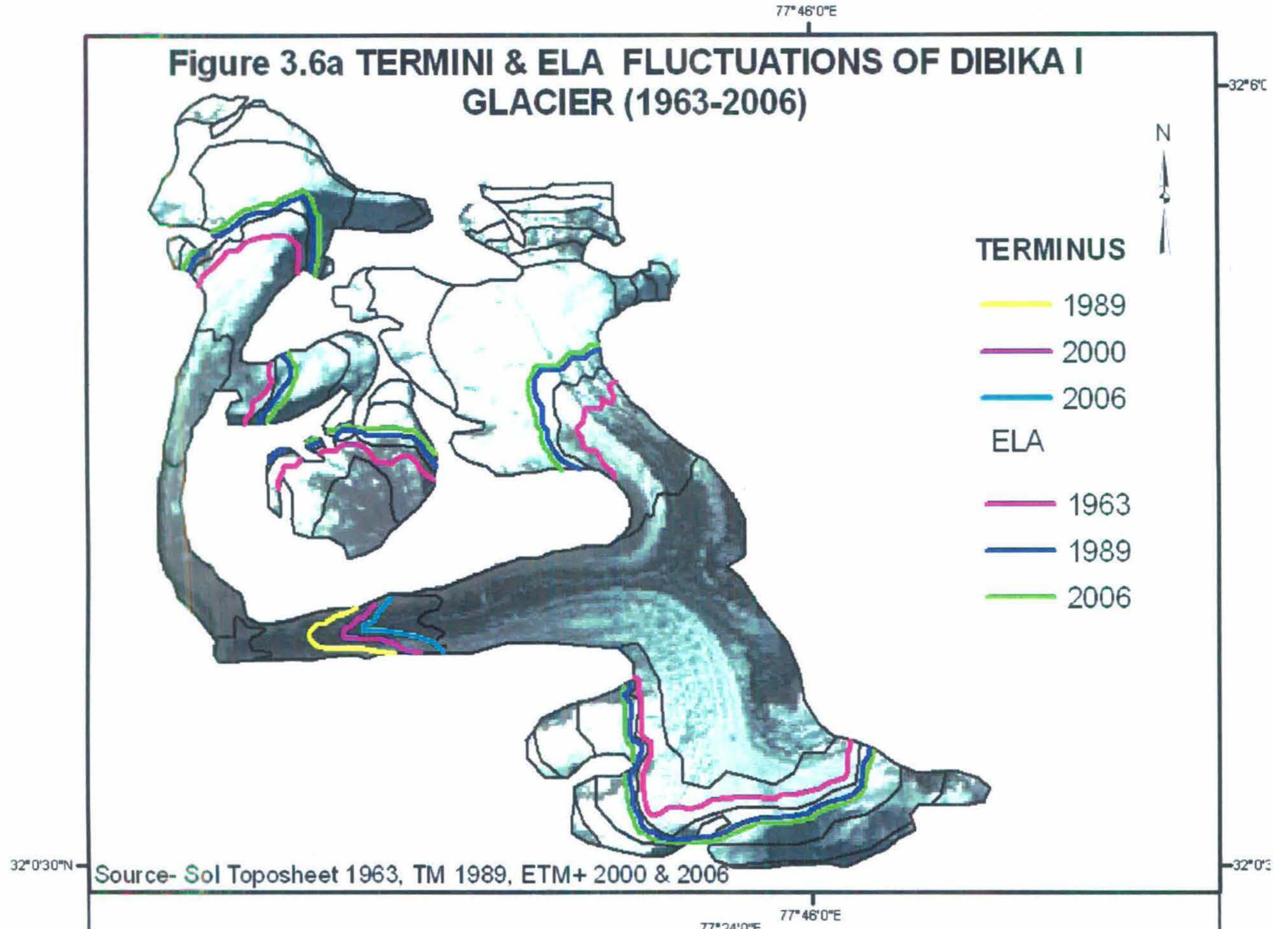


Figure 3.6a TERMINI & ELA FLUCTUATIONS OF DIBIKA I GLACIER (1963-2006)

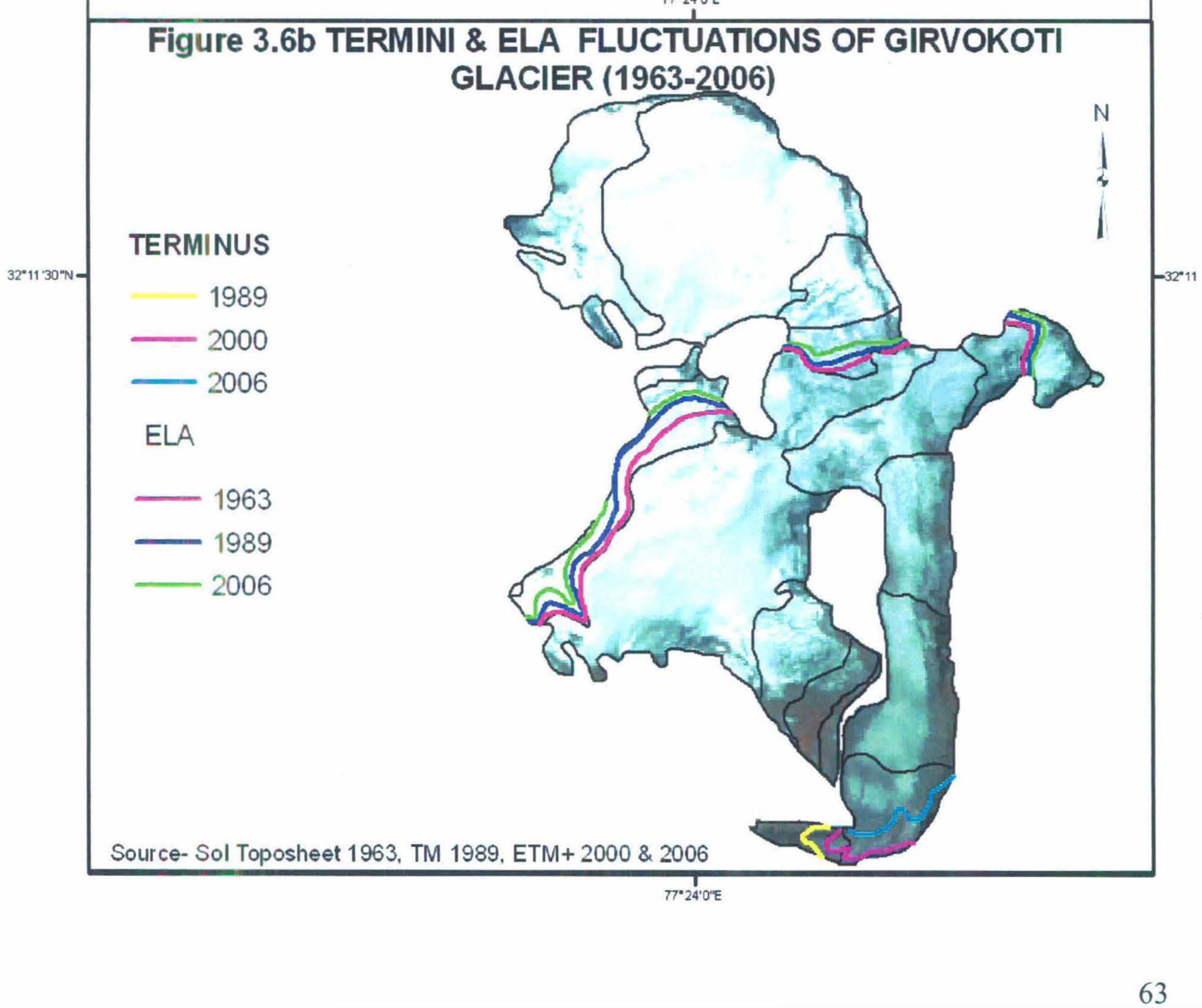


Figure 3.6b TERMINI & ELA FLUCTUATIONS OF GIRVOKOTI GLACIER (1963-2006)

Figure No. 3.7 a

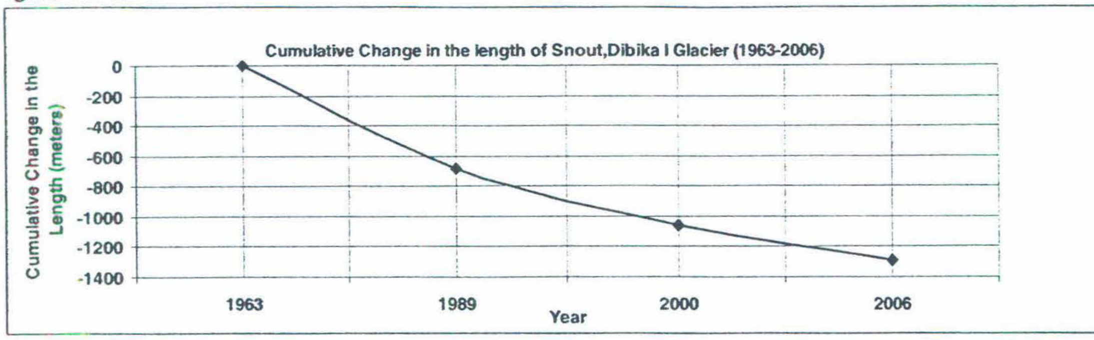


Figure No. 3.7 b

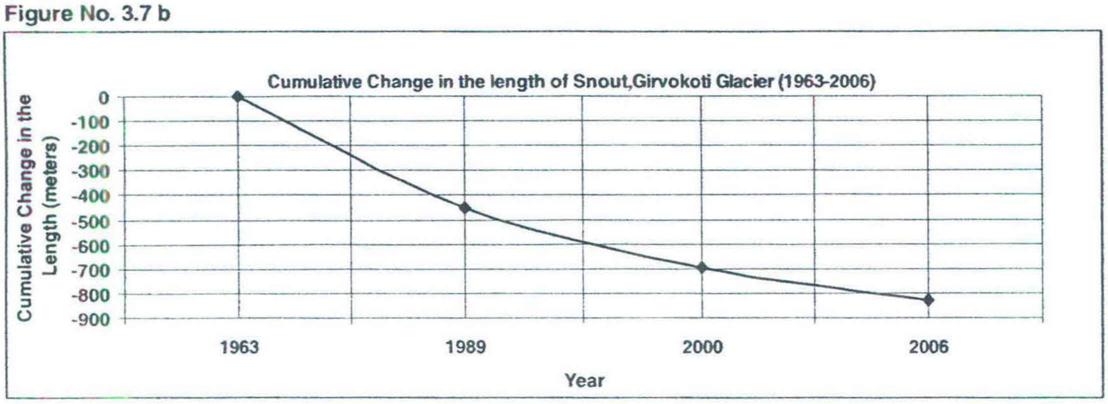


Figure No. 3.7 c

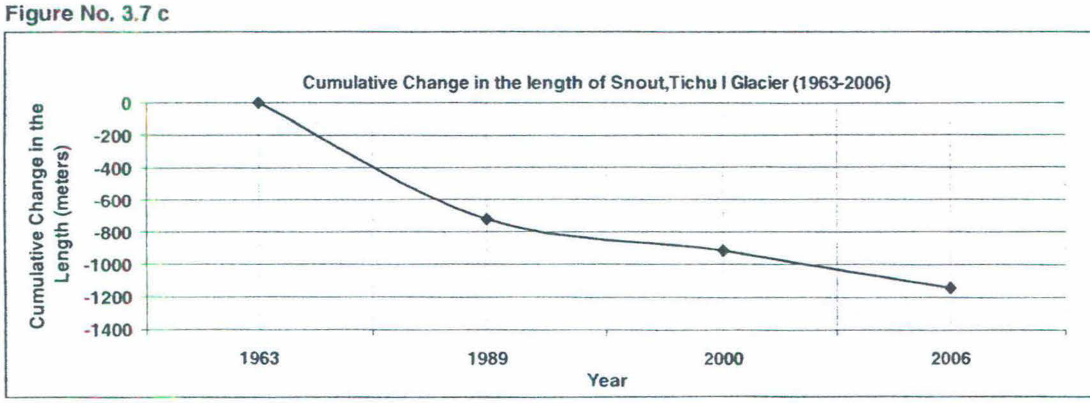
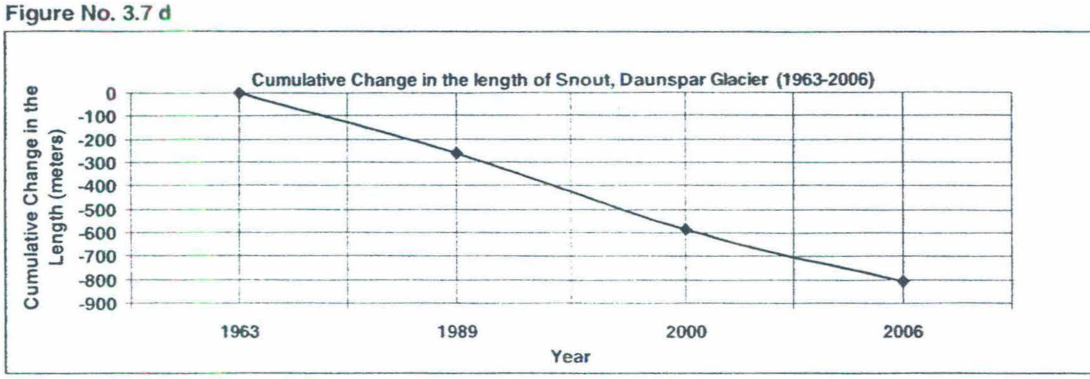


Figure No. 3.7 d



22.1 km^2 in 2006. The length of the glacier reduced from 10.58 km in 1963 to 9.8 km in 2006. (Figure 3.4d & 3.5).

Termini Fluctuations of Dibika I Glacier

Dibika I glacier follows the same trend like of Mantalai glacier that is, shows the largest decrease during the period of 1963-1989. The Dibika I glacier shows a retreat of 291 meters in 9 years from (1963-1972), with a rate of 32 meter per year, from 1972-1989 there is a retreat of 389 meters with a rate of 23 meter per year. In the succeeding 11 years (1989-2000), the retreat was 377 metres with a rate of 34 meters per year, (Table 3.5, 3.6, 3.7, 3.8).The highest rate of retreat was shown by the glacier in the period of 2000-06, that was 39 meter per year. The areal extent of the glacier decreased from 33.1 km^2 in 1963 to 26.5 km^2 in 2006. The length of the glacier reduced from 9.06 km in 1963 to 7.7 km in 2006. (Figure 3.6 & 3.7a).

Termini Fluctuations of Girvokoti Glacier

The Girvokoti glacier shows a retreat of 161 meters in 9 years from (1963-1972), with a rate of 18 meter per year, from 1972-89 there is a retreat of 287 meters with a rate of 17 meter per year, in the succeeding 11 years (1989-2000), the retreat was 250 metres with a rate of 23 meters per year, (Table 3.5, 3.6, 3.7, 3.8).The highest rate of retreat was shown by the glacier in the period of 2000-06, that was 27 meter per year. The areal extent of the glacier decreased from 23.2 km^2 in 1963 to 18 km^2 in 2006. The length of the glacier reduced from 11.02 km in 1963 to 10.45 km in 2006. (Figure 3.6 & 3.7b).

Termini Fluctuations of Tichu I Glacier

Tichu I glacier also follows the same trend like other glaciers except Mantalai, this glacier shows the greatest retreat rate per year in the period from 1963-72. The highest rate of increase in this period is attributed to factors like temperature, which shows an increasing trend over the years. Tichu I glacier shows a retreat of 347 meters in 9 years from (1963-1972), with a rate of 39 meter per year, this may be due to the error in SoI toposheets. From 1972-89 there is a retreat of 376 meters with a rate of 22 meter per year, In the succeeding 11 years (1989-2000), the retreat was 190 metres with a decreased rate of 17 meters per year, (Table 3.5, 3.6, 3.7, 3.8). The highest rate of retreat was shown by the glacier in the period of 2000-06, i.e. 39 meters per year, with a total retreat of 231 meters in the period. The areal

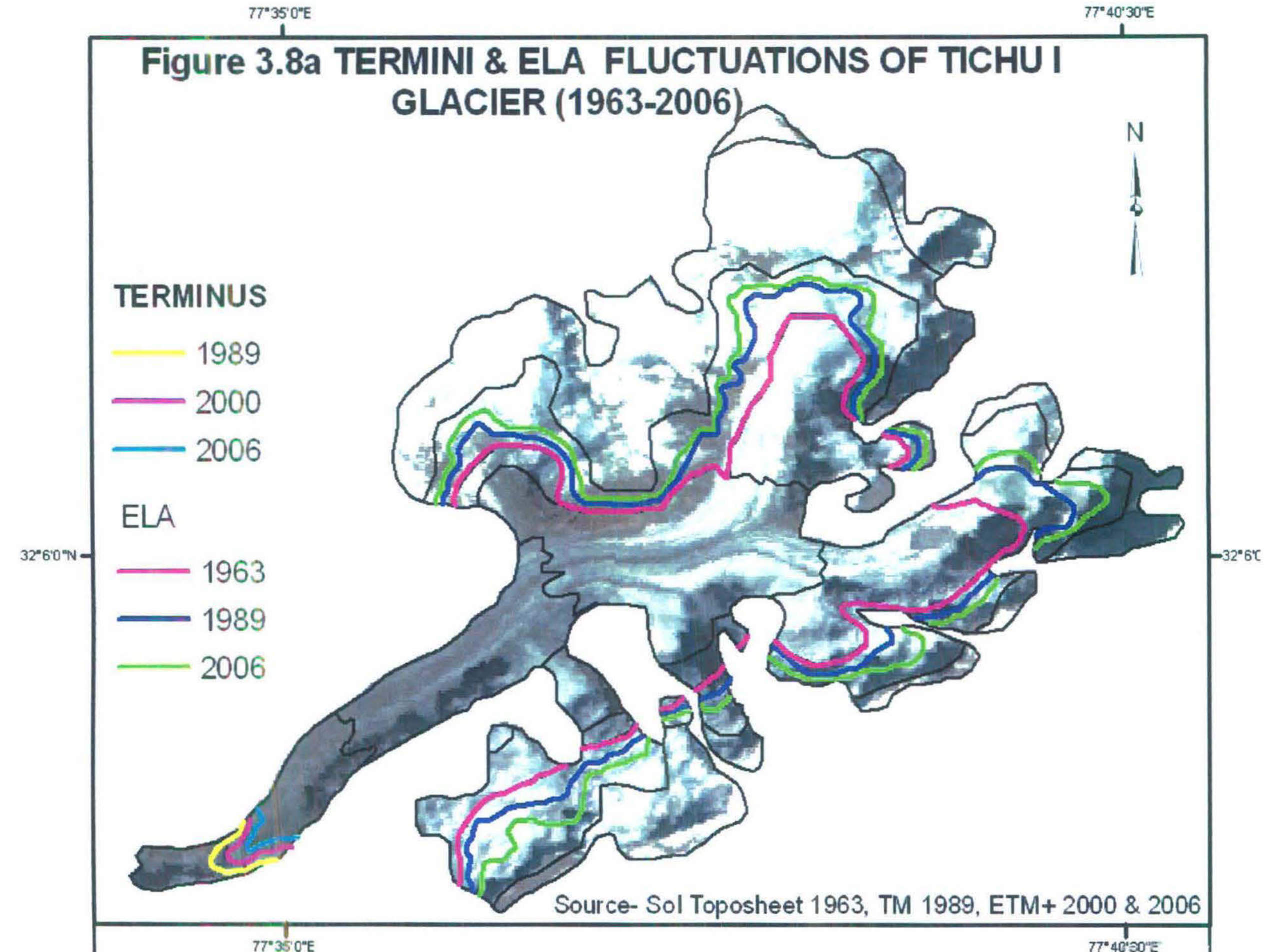


Figure 3.8a TERMINI & ELA FLUCTUATIONS OF TICHU I GLACIER (1963-2006)

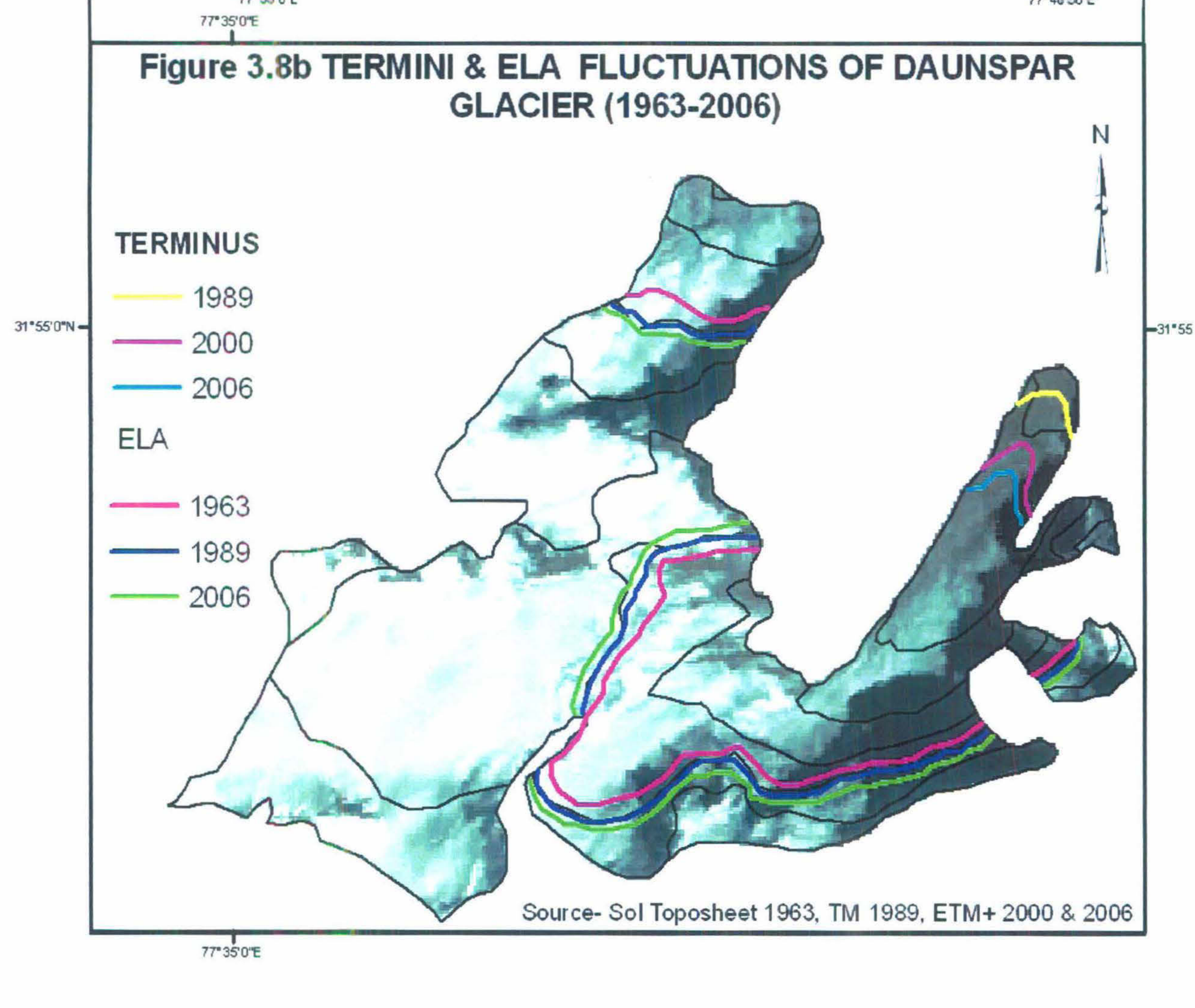
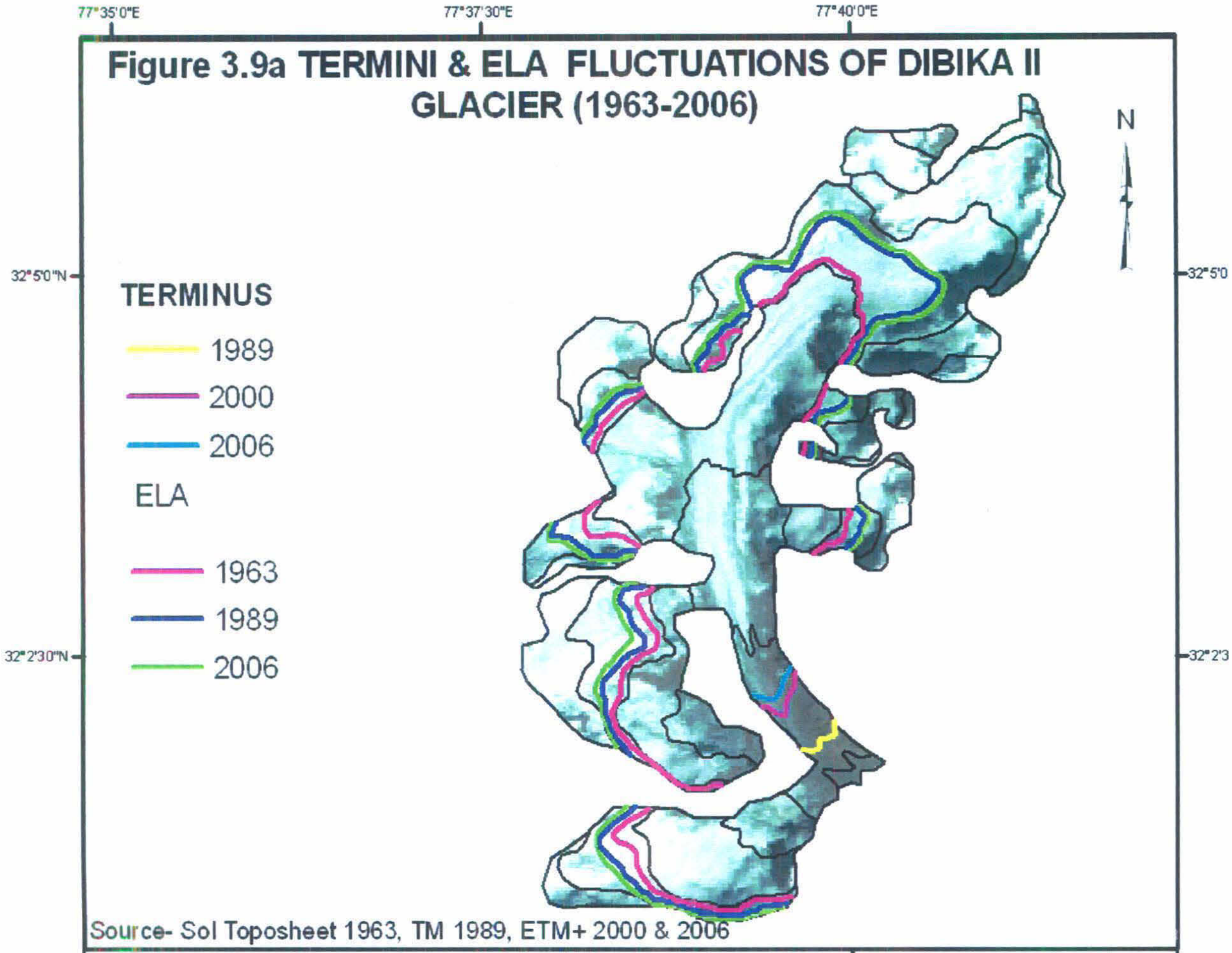


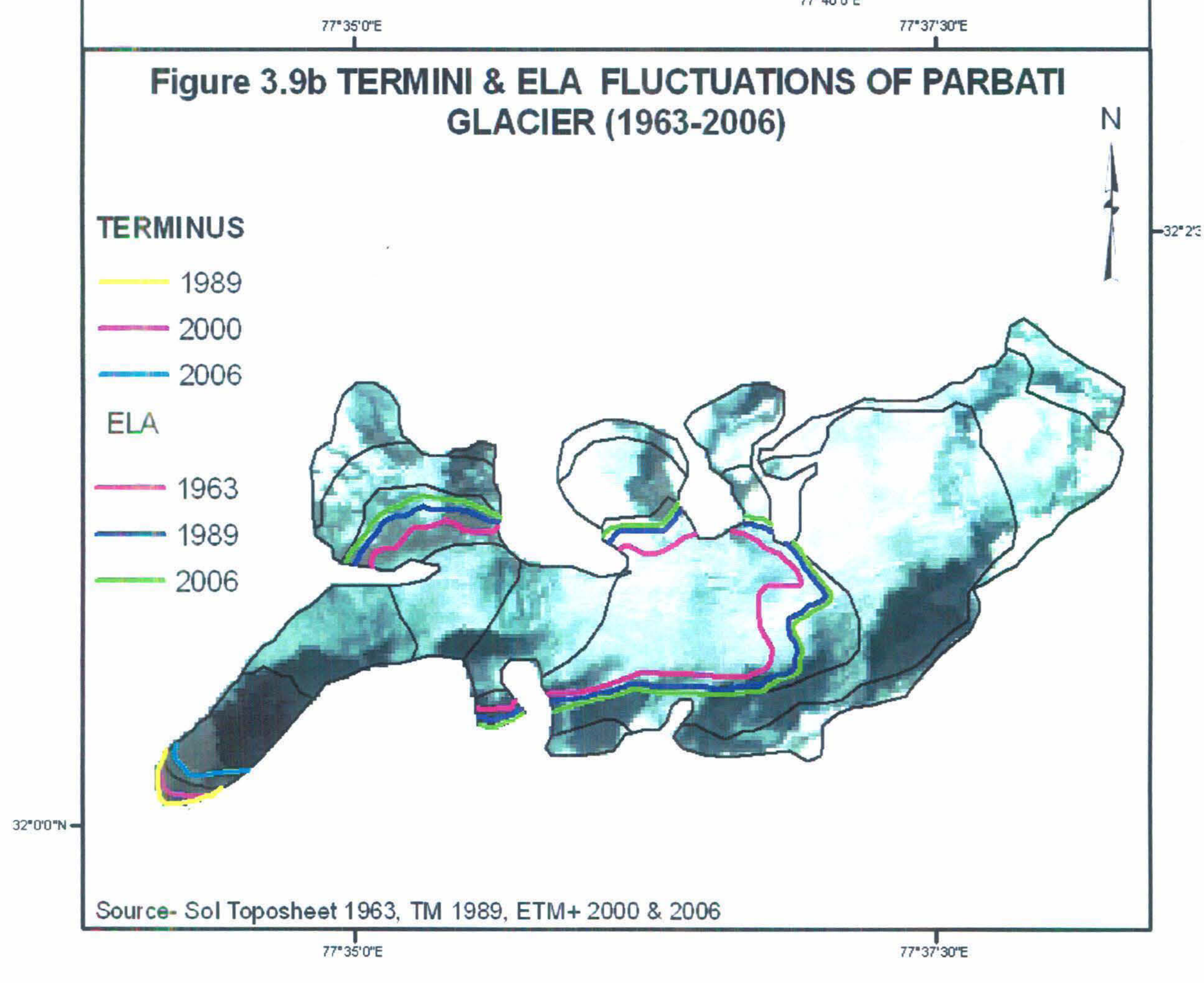
Figure 3.8b TERMINI & ELA FLUCTUATIONS OF DAUNSPAR GLACIER (1963-2006)

Plate 3.5: Lateral moraine, truncated spurs, outwash terraces and talus cones near Udi Thach at 3800 m.

Plate 3.6: Variability in discharge is reflected by these channel-bars above Udi Thach (at Yaunra).



77°35'0"E
77°37'30"E
77°40'0"E
Figure 3.9a TERMINI & ELA FLUCTUATIONS OF DIBIKA II GLACIER (1963-2006)
N
32°5'0"N
32°2'30"N
TERMINUS
1989
2000
2006
ELA
1963
1989
2006
Source- SoI Toposheet 1963, TM 1989, ETM+ 2000 & 2006



77°35'0"E
77°37'30"E
Figure 3.9b TERMINI & ELA FLUCTUATIONS OF PARBATI GLACIER (1963-2006)
N
32°0'0"N
TERMINUS
1989
2000
2006
ELA
1963
1989
2006
Source- SoI Toposheet 1963, TM 1989, ETM+ 2000 & 2006

extent of the glacier decreased from 34.8 km^2 in 1963 to 30.2 km^2 in 2006. The length of the glacier reduced from 11.33 km in 1963 to 10.1 km in 2006. (Figure 3.7c & 3.8).

Termini Fluctuations of Daunspar Glacier

Daunspar glacier shows a different trend, the period from 1989-2000 shows the largest amount of retreat in absolute terms that was 327 meters with a retreating rate of 29 meters per year, the period from 1963-1972, shows the retreat of 146 meters with the retreating rate of 16 meters per year. From 1972-89 there is a retreat of 113 meters with a rate of 7 meter per year, the period from 2000-06 follows almost the same trend and shows the annual rate of retreat, i.e. 37 meters per year, the highest rate of retreat shown by this glacier with a total retreat of 223 meters. (Table 3.5, 3.6, 3.7, 3.8). The areal extent of the glacier decreased from 22.8 km^2 in 1963 to 21.1 km^2 in 2006. The length of the glacier reduced from 7.9 km in 1963 to 7.4 km in 2006. (Figure 3.7d & 3.8).

Termini Fluctuations of Dibika II Glacier

Dibika II glacier also follows the opposite trend of Mantalai, the period from 1963-72 shows the lowest retreat with 150 meters at the retreating rate of 17 meters per year. From 1972-89 there is a retreat of 433 meters with a rate of 7 meter per year. Period from 1989-2000 shows the total retreat of 472 meters at the retreating rate of 43 meters per year. The period from 2000-06 shows a total retreat of 256 meters at the annual retreating rate of 43 meters. (Table 3.5, 3.6, 3.7, 3.8). The areal extent of the glacier decreased from 23 km^2 in 1963 to 20.1 km^2 in 2006. The length of the glacier reduced from 9.63 km in 1963 to 8.9 km in 2006. (Figure 3.9 & 3.10a).

Termini Fluctuations of Parbati Glacier

Parbati glacier shows a very different trend, in comparison with other glaciers of the basin, shows advance in the period of 1963-72 i.e. was 105 meters and of 111 meters during the period 1972-89 with a advancing rate of 7 meters per year, but the other periods follows the same retreating trend. In the period from 1989-2000, it shows a total retreat of 83 meters at the retreating rate of 8 meters per year. The last phase of the study period that is from 2000-06 also shows the retreating trend with a total retreat of 143 meters at the retreating rate of 23 meters per year. (Table 3.5, 3.6, 3.7, 3.8). The areal extent of the glacier decreased from 10.6 km^2 in 1963 to 8.4 km^2 in 2006. The length of the glacier reduced from 7.22 km in 1963 to 7.21 km in 2006. (Figure 3.9 & 3.10b).

Figure No. 3.10 a

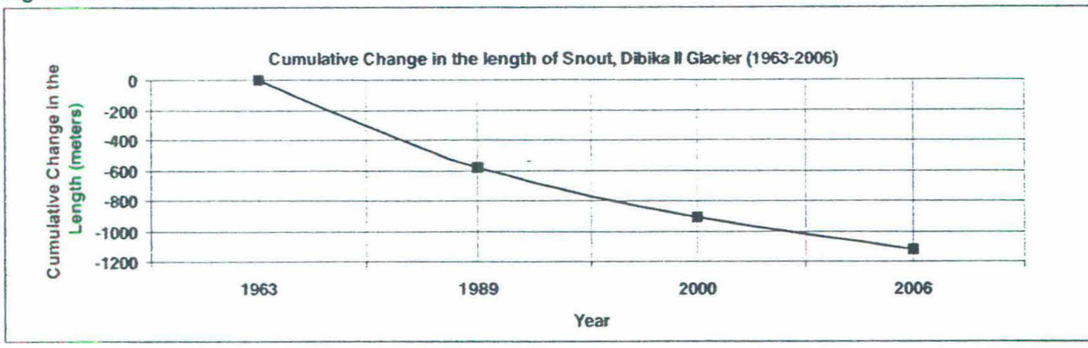
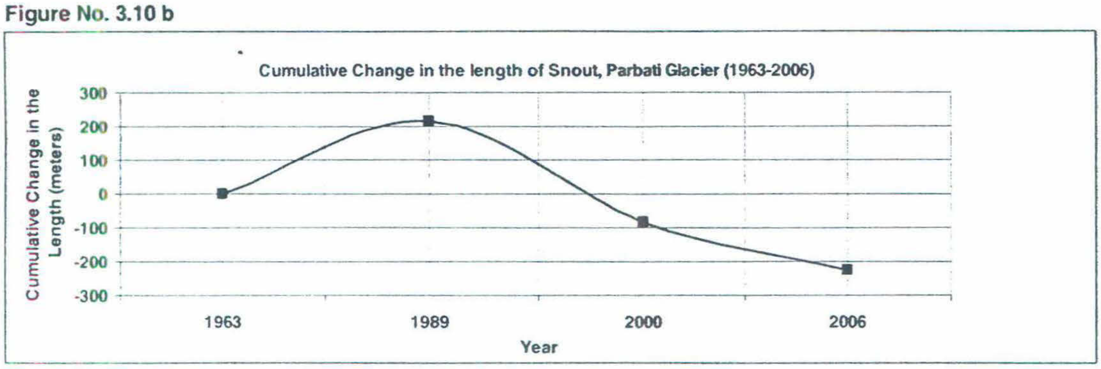


Figure No. 3.10 b



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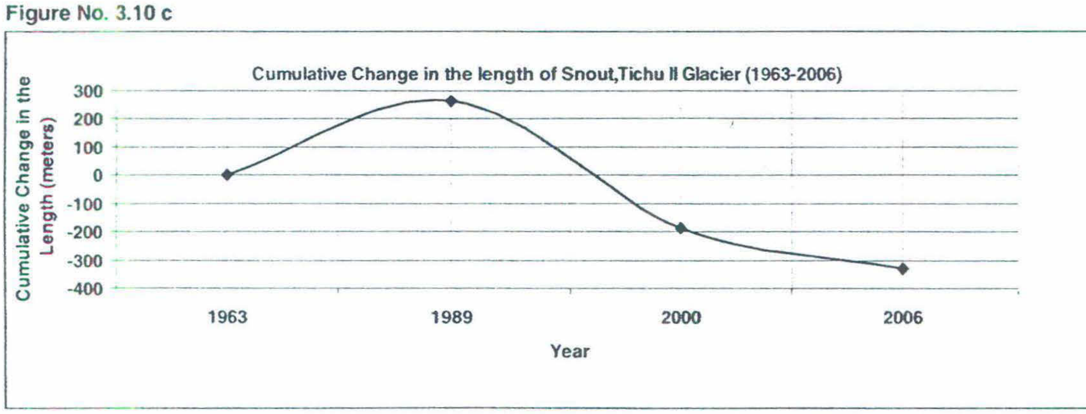
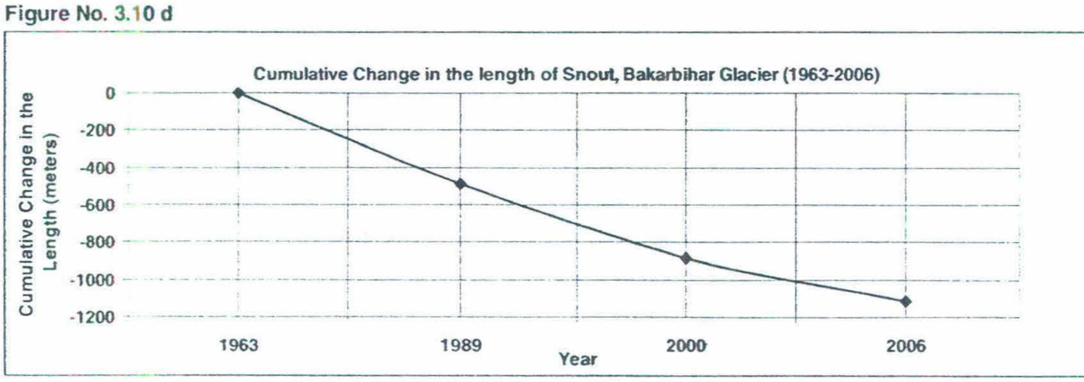


Figure No. 3.10 d



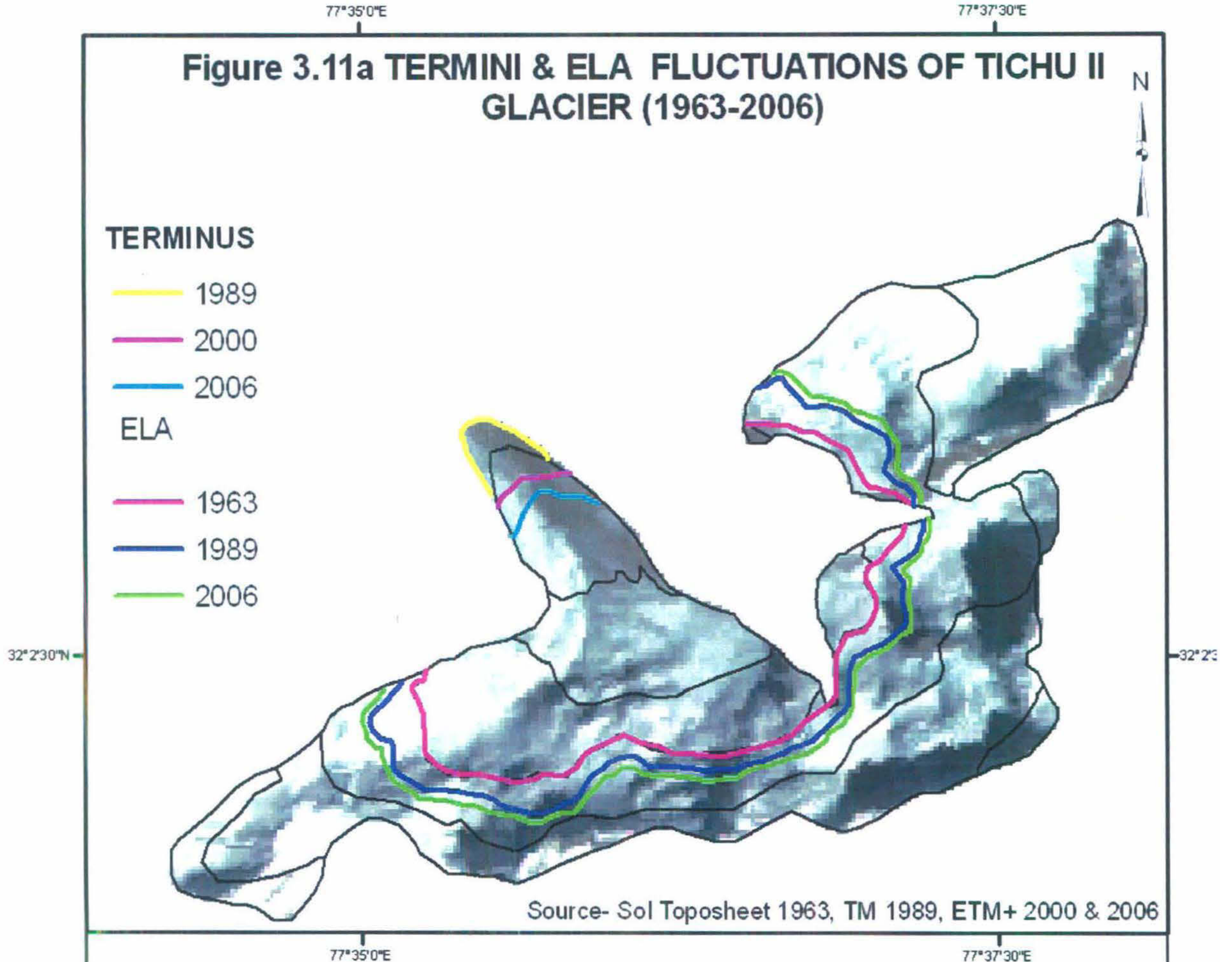


Figure 3.11a TERMINI & ELA FLUCTUATIONS OF TICHU II GLACIER (1963-2006)

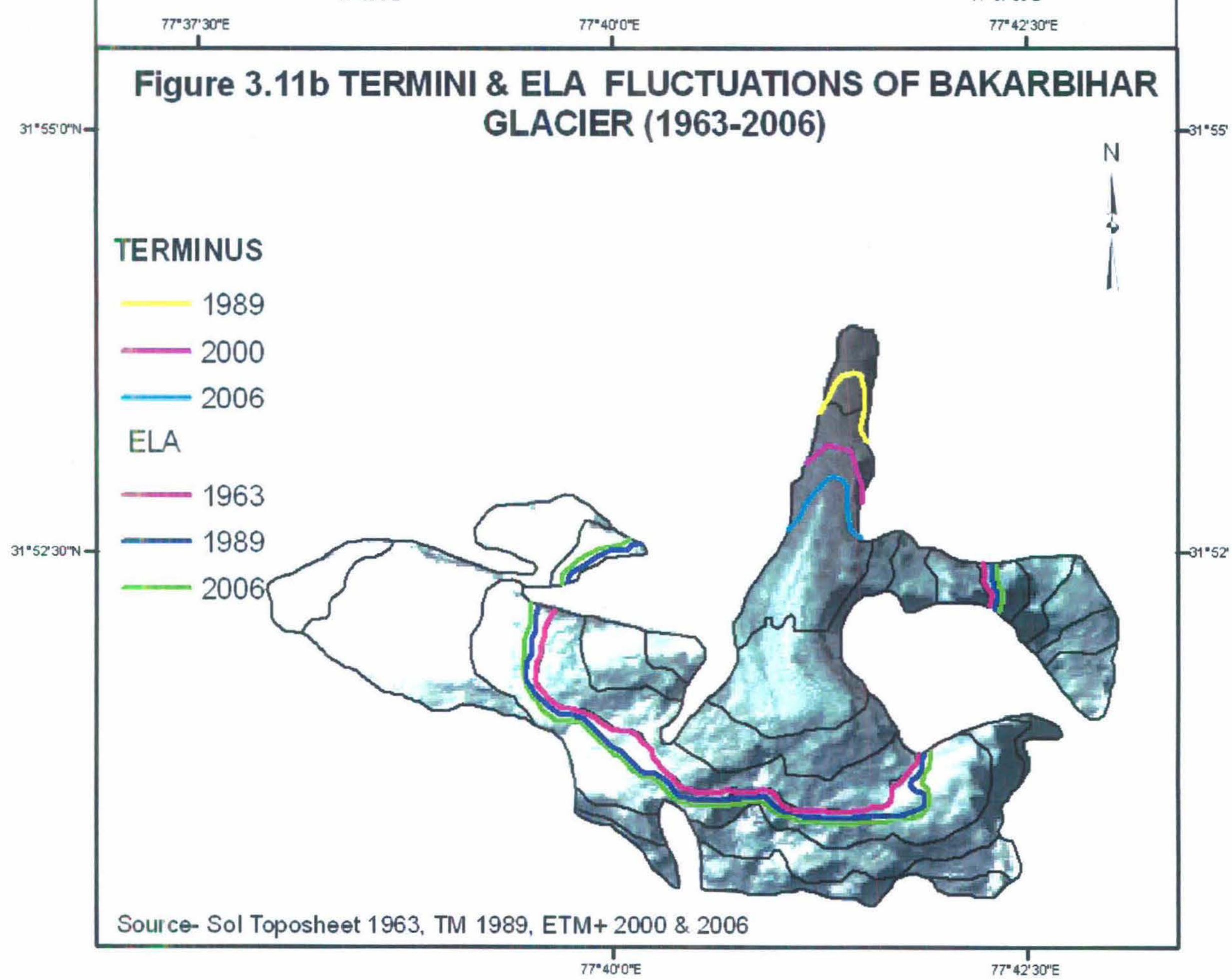


Figure 3.11b TERMINI & ELA FLUCTUATIONS OF BAKARBIHAR GLACIER (1963-2006)

Plate 3.7: Looking up valley from Yaunra (3850 m) towards Mantalai. Lateral moraine of Mantalai glacier in the background and moraines (lateral of Parvati glacier) in the foreground.

Plate 3.8: Down valley view from Mantalai (4070 m) of the lateral moraine of Mantalai glacier. Mantalai (lake) formed due to blockade of the Parvati valley at right angle.

Termini Fluctuations of Tichu II Glacier

Tichu II is the glacier which can be placed in the category of Parbati glacier as it also follows the same trend. The period from 1963-72 show an advancing trend with a total advance of 95 meters at the advancing rate of 11 meters per year. In the period from 1972-89 it show an advance of 107 meters at the rate of 10 meters per year. The succeeding periods follows the same decreasing trend like the other glaciers of the basin. The period from 1989-2000, shows a retreat of 187 meters at the annual retreating rate of 17 meters. The period from 2000-06 shows a total retreat of 142 meters at the retreating rate of 24 meters per year which is the highest rate of retreating exhibited by this glacier. (Table 3.5, 3.6, 3.7, 3.8). The areal extent of the glacier decreased from 10.9 km^2 in 1963 to 10.0 km^2 in 2006. The length of the glacier reduced from 4.51 km in 1963 to 4.4 km in 2006. (Figure 3.10c & 3.11).

Termini Fluctuations of Bakarbihar Glacier

Bakarbihar glacier shows a different trend, the period from 1989-2000 shows the largest amount of retreat in absolute terms that was 396 meters with a retreating rate of 36 meters per year, the period from 1963-1972 shows the retreat of the glacier, which is about 128 meters with the retreating rate of 14 meters per year, in the succeeding years i.e. from 1972-89 it show a retreat of 358 meters, with a retreating rate of 21 meters per year.The last period from 2000-06 it follows almost the same trend like of most of the glaciers and shows the rate of retreat that is 39 meters per year , with a total retreat of 234 meters. (Table 3.5, 3.6, 3.7, 3.8). The areal extent of the glacier decreased from 17.8 km^2 in 1963 to 15.8 km^2 in 2006. The length of the glacier reduced from 6.31 km in 1963 to 5.6 km in 2006. (Figure 3.10d & 3.11).

3.4 Assessment Method of Equilibrium Line Altitude

Palaeoclimatic reconstructions based on the limits of former glaciers commonly make use of estimates of the associated equilibrium-line altitudes (ELAs), where accumulation of snow is exactly balanced by ablation. The equality of accumulation and ablation at the ELA means that the local climate can be parameterized in terms of accumulation-season precipitation and ablation-season temperatures, using statistical and analytic methods (Kuhn, 1989; Ohmura et al, 1992; Selzer, 1994).

A variety of methods has been devised to estimate the steady-state ELAs of former glaciers as a means to reconstructing palaeoclimates in glaciated regions. One of the methods used by me in the study is most widely used techniques that is-

(1) Accumulation-area ratio (AAR) method which is based on the assumption that the accumulation area of the glacier (i.e. the area above the ELA) occupies some fixed proportion of the total glacier area (e.g. Meier and Post, 1962; Porter, 1975; Torsnes et al., 1993). For modern mid- and high-latitude glaciers, steady-state AARs generally lie in the range 0.5-0.8 (Porter, 1975). Glaciers with debris-covered snouts will have rather lower AARs (0.1-0.4), due to the effect of debris on lowering ablation and increasing the relative size of the ablation area (Muller, 1980; Kulkarni, 1992; Clark et al., 1994). The AAR method implicitly assumes that the ratio between the altitudinal ablation and accumulation gradients on the glacier (bnb / bnc) has some fixed value.

An important shortcoming of the AAR method is that it takes little account of variations in glacier shape, particularly the distribution of glacier area over its altitudinal range, or hypsometry. Accumulation area ratios on modern glaciers are influenced by glacier hypsometry so that, for example, a glacier with a wide accumulation area and a narrow snout will have a different AAR than one with a narrow accumulation basin and a broad snout, even if the ELAs are the same (Furbish and Andrews, 1984). Therefore, former glacier ELAs based on a uniform assumed AAR value may be subject to significant errors if there is a wide range of glacier types and shapes in the area under consideration. The other methods used are:

(2) THAR (Terminus-to-head altitude ratio) - Terminus-to-head altitude ratio methods assume that the glacier ELA can be approximated by some constant ratio between the altitude of the terminus and the head of the glacier. As for AAR methods, this depends crucially on the choice of the correct ratio, which may differ for modern and ancient glaciers in the same region. But this method is very crude.

(3) AWM (Area Weighted Mean) - this method is more elaborate and involves calculations of the variation in altitudinal distribution of the former ice masses. It rests on two assumptions:

a) That the reconstructed glaciers were at their maximum extent and therefore in equilibrium, so that the firn line at the end of ablation season marks the line where total accumulation and ablation were exactly balanced.

b) That a linear relationship exists between the ablation gradient (the rate of decrease in the ablation rate with altitude) and accumulation gradient (the rate of decrease of accumulation with decrease in altitude).

The equilibrium firn line can then be calculated from the following equation:

$$X = \frac{\sum_{i=0}^{n} A_i h_i}{\sum_{i=0}^{n} A_i}$$

Where x = the altitude of the firn line in meters.

Ai = the area of the glacier surface at contour interval i in km2.

hi = the altitude of the mid-point of contour interval i; and n + 1= the number of contour intervals.

After calculating the ELAs of different glaciers by these methods, the average ELA is calculated for each glacier by averaging the ELAs.

Table 3.9:-ELA Fluctuations in the Parvati Basin (1963-2006)

Glacier Name	Mean ELA (M) 1963	Mean ELA (M) 1989	Mean ELA (M) 2006	(▲) ELA 1963-2006	(▲) ELA 1989-2006
Man talai	4776	4810	4818	42	8
Sara umga	4813	4845	4846	33	1
Dibika I	5082	5107	5112	31	5
Tichu I	4904	4929	4934	30	5
Fatiruni	5110	5130	5136	27	6
Girvo koti	4866	4893	4896	30	4
Tos	4930	4948	4959	30	12
Dibika II	5164	5186	5188	24	2
Parbati	5042	5041	5050	8	9
Tichu II	4958	4953	4960	2	7
Bakarbihar	4882	4910	4918	36	8
Daunspar	4869	4888	4895	26	7
Average ELA	4950	4970	4976	26	6

Source : Calculation based on SoI Toposheet (1963).TM image (1989) & LISS III (2006) image of Parvati basin

3.5 Summary

ELA in the Parvati basin has risen by 6 meter from average sea level (a.s.l.) since the last studied period of 1963. In 1963 the ELA of the basin was 4950 meters which rises to 4976 meters in 2006 (with in a span of 43 years). In the Parvati basin the largest fluctuations in the ELA are shown by Tos Glacier, ELA of the glacier has risen 12 meters from a.s.l. The next largest change in the ELA is shown by Parbati glacier 9 meters from a.s.l. The ELA change of rest of the studied glaciers lies between 5 meters to 8 meters from a.s.l., with an overall basin average of 6 meters from a.s.l. (Table 3.8). Such a fluctuation in the ELA is not possible but due to the error in the SoI toposheets it is, to overcome this difference there is a need of ground truthing to identify the exact reasons for the above but the role of factors like aspect, orientation, duration of sun shine, nature of valley of glacier and climatic variables like temperature and precipitation cannot be denied. In the period 1963-72, the basin show an average retreat of 27 meters per year, which raises to 38 meters per year in the succeeding period i.e. from 1972-89. The rate was decreased to 28 meters in the period from 1989-2000, which further raises to 37 meters per year in 2000-06. The largest rate of retreat among glaciers was shown by Mantalai in every period, which is exceptionally higher and may be due to the error in SoI Toposheets.

There is considerable variation in the reconstructed change in ELA (▲ELA) between glaciers within specific regions and between regions. This is not only related to climate gradients, but also results from differences in glacier aspect: southeast- and south-facing glaciers show larger ▲ELAs in Parvati basin (Himalayas) than north- or west-facing glaciers. One of the parameters which can influence snow line is orientation and topography of glacial valley. The Mantalai glacial valley is gentle and wide causing more solar radiation to be received on the glacial surface, resulting the highest rate of retreat i.e.74 meters per year. In addition, gentle slopes cause less accumulation of avalanche snow. If snow pack is shallow, it can expose glacial ice for longer duration. Low albedo of ice compared to snow can cause further absorption of solar radiation and lead to more negative mass balance. Another factor which can influence AAR is glacial area below snow line at the end of the ablation season.

Contemporary equilibrium-line altitudes (ELAs) for glaciers in the high mountains of the Himalaya have considerable variation because the region is influenced by two major climatic systems (the mid-latitude westerlies and the south Asian summer monsoon) and glaciers are subject to strong topographic controls. Reconstructions of past ELAs based on the former extent of glaciers are numerous, but were estimated using a variety of methods some of which are not appropriate for high-altitude glaciers which are strongly influenced by topography and have extensive supraglacial debris cover.

A factor that is often not considered when calculating ΔELA is that modern and former ELAs are commonly determined for different points in space. Where ELA surfaces are sloping, as is usually the case, this introduces a source of error in ΔELA over and above that associated with the modern and former ELA estimates. The simplest assumption is that all

ΔELA can be attributed to changes in temperature, which can be estimated by using an assumed average environmental lapse rate in the atmosphere. However, if there were associated changes in precipitation, the estimated temperature change would be different. The meaning of ΔELA is clearest where independent temperature or precipitation proxies are available, although this is commonly not the case. However, the difficulty of separating out the temperature and precipitation signals need not negate the usefulness of ΔELA in providing Palaeoclimatic information.

CHAPTER FOUR

ASSESSMENT OF RIVER DISCHARGE AND METEOROLOGICAL ELEMENTS

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4.1 Introduction:

The Himalayas and the adjacent Tibetan–Qinghai plateau are the source of the major Asian rivers amongst which are the Indus, Ganges, Brahmaputra, Irrawaddy, Salween, Mekong, Yellow and Yangtze rivers. Discharge from these rivers sustains the lives of hundreds of millions of people living downstream and preservation of these water resources is crucial (Immerzeel, 2008a). The precipitation in the upstream parts of the basins falls partly in the form of snow, causing a natural delay of river discharge. Snow cover dynamics on the Tibetan–Qinghai plateau therefore influence the water availability downstream in the major river basins of Asia, specifically in spring at the onset of the (irrigation) growing season (Barnett et al., 2005; Immerzeel, 2008b).

The recently published fourth assessment report of the International Panel on Climate Change (IPCC 4AR) (IPCC, 2007a) concludes that warming of the global climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. The IPCC (2007a) report also concludes that the warming is expected to be greatest over land and at most high northern latitudes, where snow cover is projected to contract, and that it is very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. The spatial variation in observed and projected climate change is large and mountain ranges and their downstream areas are particularly vulnerable for several reasons. Firstly, the rate of warming in the lower troposphere decreases with altitude, i.e. temperatures will decrease more in high mountains than at low altitudes (Bradley et al., 2006). Secondly, mountain areas exhibit a large spatial variation in climate zones due to large differences in altitude over small horizontal distances (Beniston et al. 1997). Finally, mountains play an important role in the water supply of downstream areas. More than one sixth of the global population depends on water supplied by mountains; and changes in hydrology and water availability are expected to be large in mountain basins (Barnett et al., 2005; Viviroli et al., 2007). Especially the diminishing role of snow and ice as a natural store for water supply will have a tremendous impact.

In addition, snow cover extent in the Himalayas and on the Tibetan– Qinghai plateau could influence the strength of the monsoon. Upper tropospheric air temperatures above the plateau are among the warmest on the planet because of the heating of the elevated land with altitudes of over 3500 m (Takayuki,S., 1994). The troposheric temperature gradient between the plateau and the Indian Ocean is shown to be associated with the Indian monsoon rainfall (Fu & Fletcher, 1985). Snow in the Himalayas and on the plateau affects the land surface thermodynamics and could reduce this thermal gradient. An extensive snow pack results in a number of conspiring thermodynamic effects that reduce the temperature gradient (Barnett et al., 1989; Shaman & Tziperman, 2005); (i) an increased snow pack yields a higher albedo leaving less solar radiation for the sensible heat flux, (ii) of the energy which is left a substantial part is required for sublimation and (iii) the melting of the snow leaves a wetted surface and a large part of the energy is consumed by the latent heat flux. More than a century ago, Blanford (1884) already suggested that winter snow cover in the Himalayas could be a predictor of subsequent summer rainfall in India. Shaman et al. (2005) report an inverse relationship between the spring snow depth on the Tibetan plateau and monsoon precipitation in Bangladesh. Kripalani et al. (2004) also found a significant negative relation between spring snow cover in the western Himalayas and the Indian monsoon and conclude that the well-documented negative relationship between winter snow and summer rainfall has recently changed into a positive relationship in the western Himalayas.

In recent years, there has been increased attention to the variable and changing nature of climate, and concern about associated shifts in water resource regimes. Simulating modelling of the association between climate change and water resources have focused particularly on the relationships between stream flow, precipitation and temperature. Stream flow provides a gross measure of the surface water regime in its most accessible form, and precipitation and temperature provide gross measures of the climate state. Stream flow is one of the surface signatures of precipitation. Temperature affects the type of precipitation, available energy and evapotranspiration, the surface and soil characteristics, and ultimately the runoff.

Scientific investigation on global climate change and its consequences began improve in the 1980s (Muzik, 2002). It is understood that the climate system on the Earth has changed on both regional and global scales over the last century, it is also expected that such changes will continue in the near future (IPCC, 2001). Increase in the atmospheric concentrations of anthropogenic greenhouse gases is considered to be responsible for such climate changes. Increasing global mean surface temperature will lead to change in precipitation and atmospheric moisture because of changes in atmospheric circulation and a more active hydrological cycle (Singh et al.,2006). Human activities, primarily the burning of fossil fuels and changes in land cover/use, are believed to have resulted in the increasing of atmospheric concentration of greenhouse gases. This alters energy balances and tends to warm the atmosphere, which will result in climate change. Some investigations indicate that mean annual global surface temperature has increased by about 0.3–0.6°C since the late 19th Century and it is anticipated to further increase by 1–3.5°C over the next 100 years (IPCC, 1996). These changes in global climate would severely affect the mid and high latitudes of the Northern Hemisphere where temperatures have been noticeably getting warmer since the 1970s (IPCC, 2001). Such changes in climate will also have significant impact on local and regional hydrological regimes, which will in turn affect ecological, social and economical systems (Dibike and Coulibaly, 2005).

Global warming, resulting from increased concentrations of atmospheric greenhouse gases, is usually estimated with Global Circulation Models (GCMs), and there have been remarkable advances in the development of these models over the past 20 years (Huntingford et al., 2006). However, raw output from GCMs is inadequate for assessing impacts of climate change on hydrological responses at regional scales. This is because the spatial resolution of GCM grids is too coarse to resolve many important sub-grid scale hydrological processes, and of the GCM output is often unreliable at individual grid. GCMs were not developed for investigating climate change impact on hydrological cycle and do not provide a direct estimation of hydrological responses to climate change. Therefore, in climate change impact studies, hydrological models are required to simulate sub-grid scale phenomenon. However, such hydrological models require input data at similar sub-grid scale, which has to be provided by converting the GCM outputs into at least a reliable regional hydrological time series at the selected watershed scale. The methods used to convert GCM outputs into local meteorological variables required for reliable hydrological modelling are usually referred to as 'downscaling' techniques (Dibike and Coulibaly, 2005). A variety of techniques are developed for downscaling during the past decades. The most conventional method is to perturb historical time series of high resolution meteorological variables by the difference or ratio of the means of GCM output between the altered and controlled climate runs. Another alternative methodology, statistical downscaling, involves bridging the two discordant scales by establishing empirical relationships between features reliably simulated by the GCM at grid-box scales and surface predictands at sub-grid scales. Climate change will affect the hydrological cycle in a region through changes in the duration, amount, and form of precipitation, evaporation and transpiration rates, and soil moisture (Merritt et al., 2006). During the past years, a great deal of work on climate change has been done from different viewpoints. For example, quite a lot of investigators studied the impact of climate change on water resources and hydrological cycle (e.g., Roberts, 1998; Chiew and McMahon, 2002; Hurk et al., 2002; Drogue et al., 2004; Skaugen et al., 2004; Booij, 2005; Govender and Everson, 2005; Islam et al., 2005; Kim et al., 2005; Zierl and Bugmann, 2005; Andersson et al., 2006; Hagg et al., 2007; Thodsen, 2007). Also some works investigated the impact of climate change on groundwater and soil moisture in unsaturated zone (e.g., Ritcey and Wu, 1999; Eckhardta and Ulbrich, 2003), return flow, evaporation, snowcover and snowmelt (e.g., Chattopadhyay and Hulme, 1997; Seidel et al., 1998; Singh and Bengtsson, 2005; Gosain et al., 2005), hydrological extremes (e.g., Cunderlik and Simonovic, 2005) as well as ecological system and water quality (e.g., Krysanova et al., 2005; Tripathi et al., 2005; Griensven and Bauwens, 2005; Wilby et al., 2006).

For the present study, an attempt has, therefore, been made to determine the global warming trend in the Parvati basin by analysing temperature data of about fourty years from 1968 to 2005 in a seasonal frame and correlating this trend with the precipitation data. These two factors are the most important in the climate change study and further correlate these two factors with the discharge pattern individually to reach at a conclusion. One drawback of the study is the absence of hydrological modelling to reach the conclusion; this is due to the unavailability of Meteorological data for other stations.

4.2 Seasonal Analysis of Discharge, Precipitation and Temperature

In comparison to a modest increase (0.5°C–1.1°C) in the global air temperature, the NWH (North Western Himalaya) region has warmed at a much higher rate (1.6°C/100 years) in the last century. Increase in air temperature is significantly higher during the winter season (1.7°C/100 years) than the monsoon season (0.9°C/100 years) (Jones, P.D. et. al., 1986). The winters in the last two decades have been unusually warm, with a total rise of about 4.4°C in average temperature (Bhutiyani, M.R. et. Al., 2007). Precipitation in the NWH has, in the monsoon as well as winter seasons, more or less remained the same. The variations in both temperature and precipitation are translated into changes in the hydrological regimes of the Parvati river basin of the NWH by way of variability in snow-melt run-off, glacier melting and monsoon run-off, and increase or decrease in average annual and annual peak discharge.

4.2.1 -Trend analysis of winter, spring, summer, autumn and annual discharge

There are three components of discharge in a glacierized basin; snow-melt run-off, glacier melt and run-off due to monsoon rainfall. Because of sparse database an accurate assessment of the contribution by each component of the discharge is impracticable. However, based on the yearly hydrographs (computed from average of daily discharge values from 1968 to 2005 of Parvati river the following periods can be identified to estimate the contributions by various components:

(a) Winter discharge (November–January) sub-glacial melting & groundwater storage
(b) Spring discharge (February-April) base flow & seasonal snow-melt
(c) Summer discharge (May-July) base flow, monsoon rainfall & glacier melt
(d) Autumn discharge (August-October) base flow, monsoon rainfall & glacier melt

Although seasonal snow cover is an important parameter in the hydrological regime of a basin, its contribution is confined to the spring season when snow-melt and base flow constitute two components of the discharge. Once the summer sets in, it is the exposed glacier ice in the ablation zone which is the main contributor to the melt along with monsoon rainfall. The contribution by snow cover above the equilibrium line to the discharge is insignificant in this period.

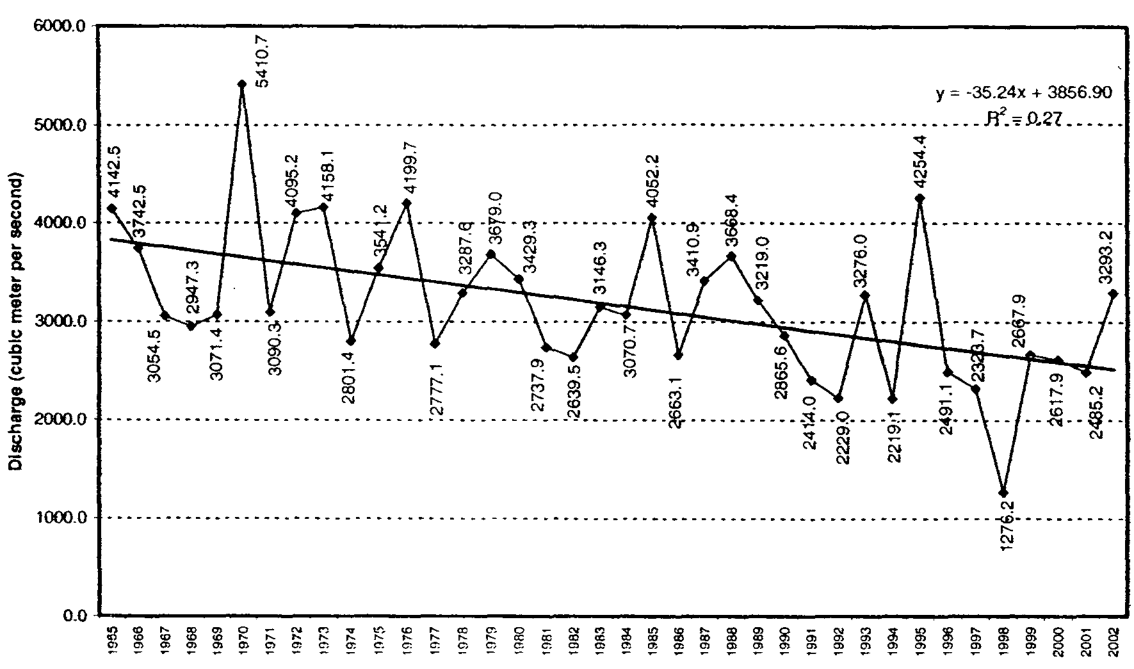

Figure No. 4.1a Trend of Discharge during Spring Season (1968-2005)

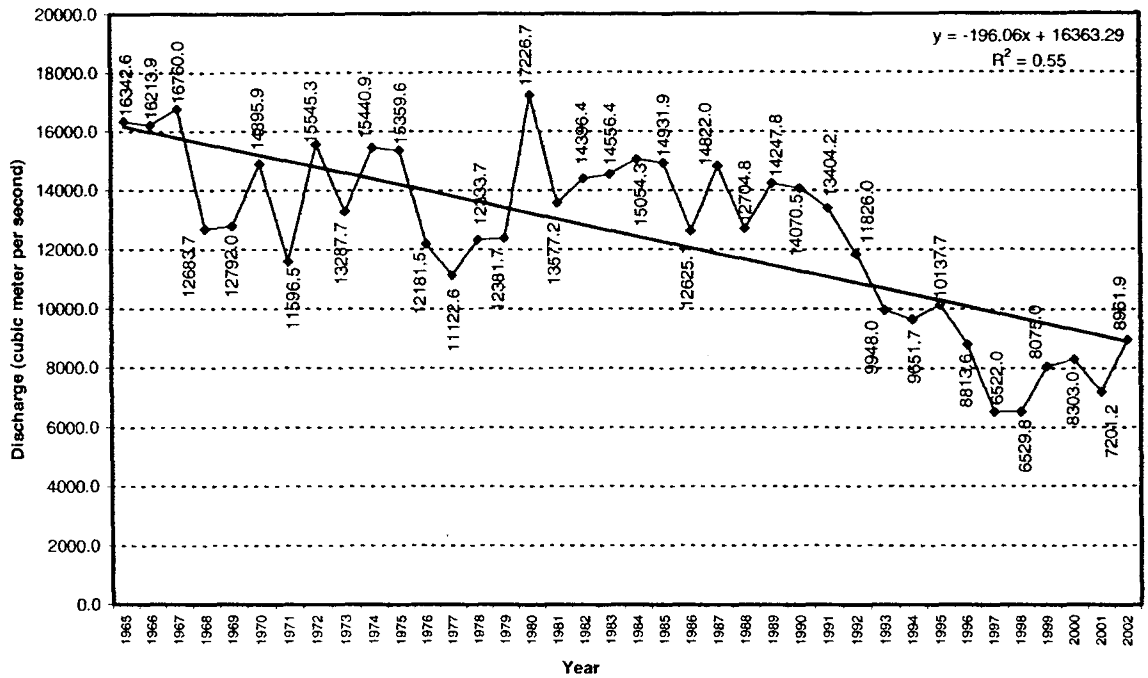

Figure No. 4.1c Trend of Discharge during Autumn Season (1968-2005)

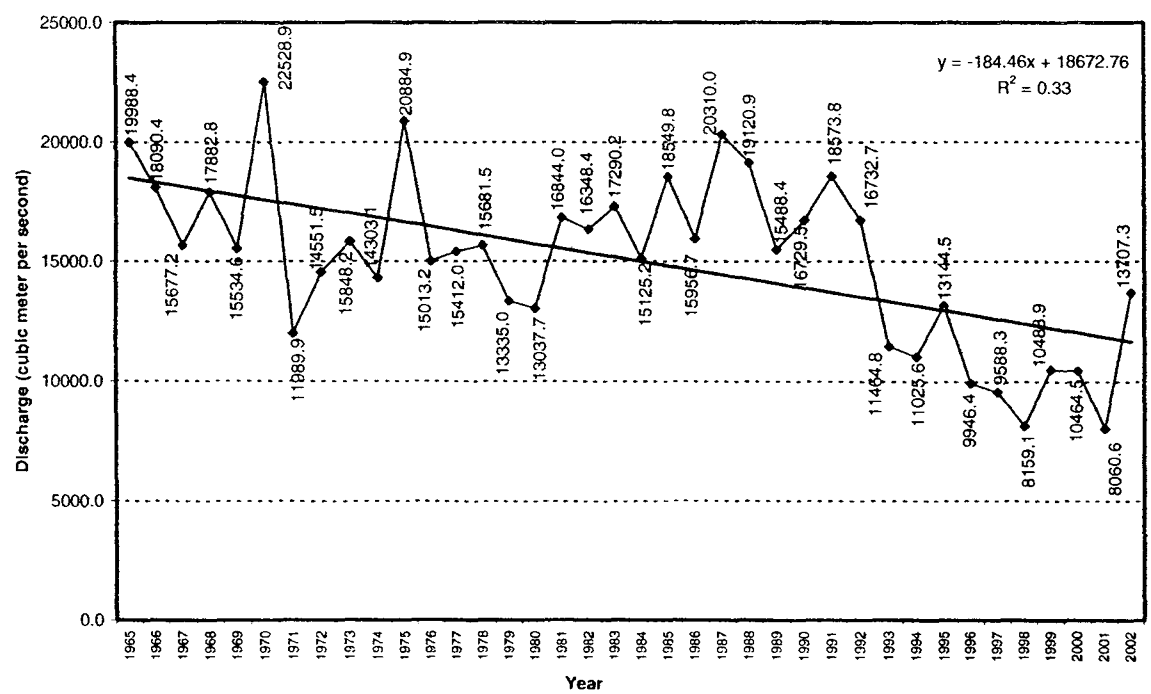

Figure No. 4.1b Trend of Discharge during Summer Season (1968-2005)

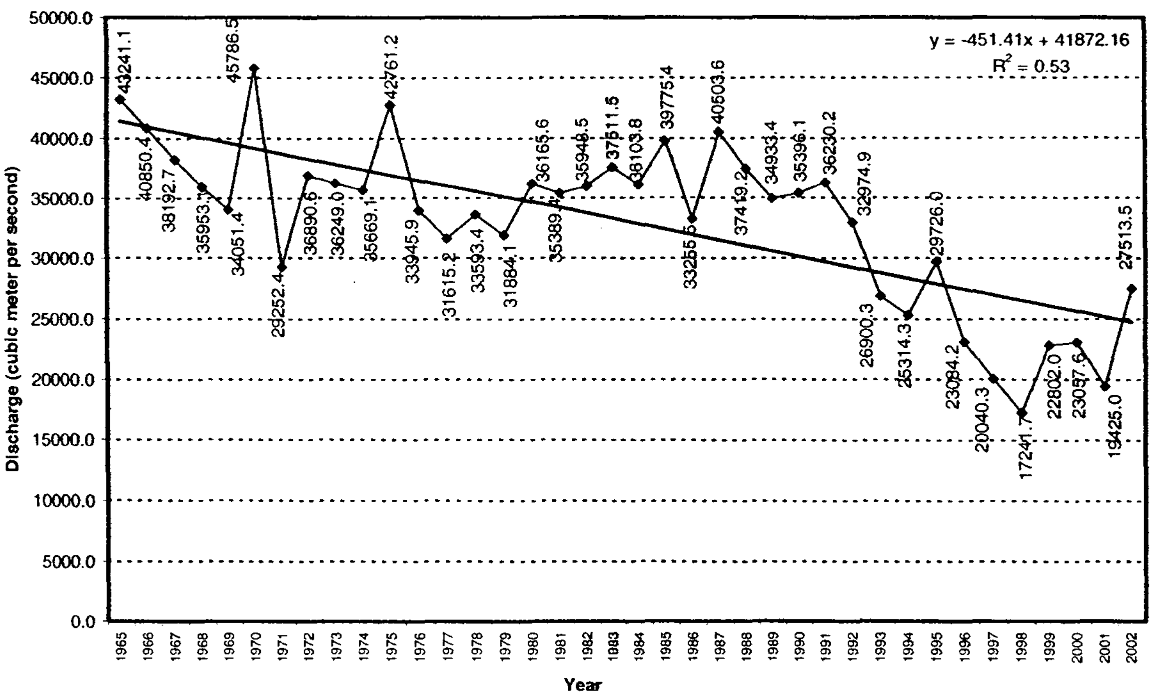

Figure No. 4.1e Trend of Annual Discharge (1968-2005)

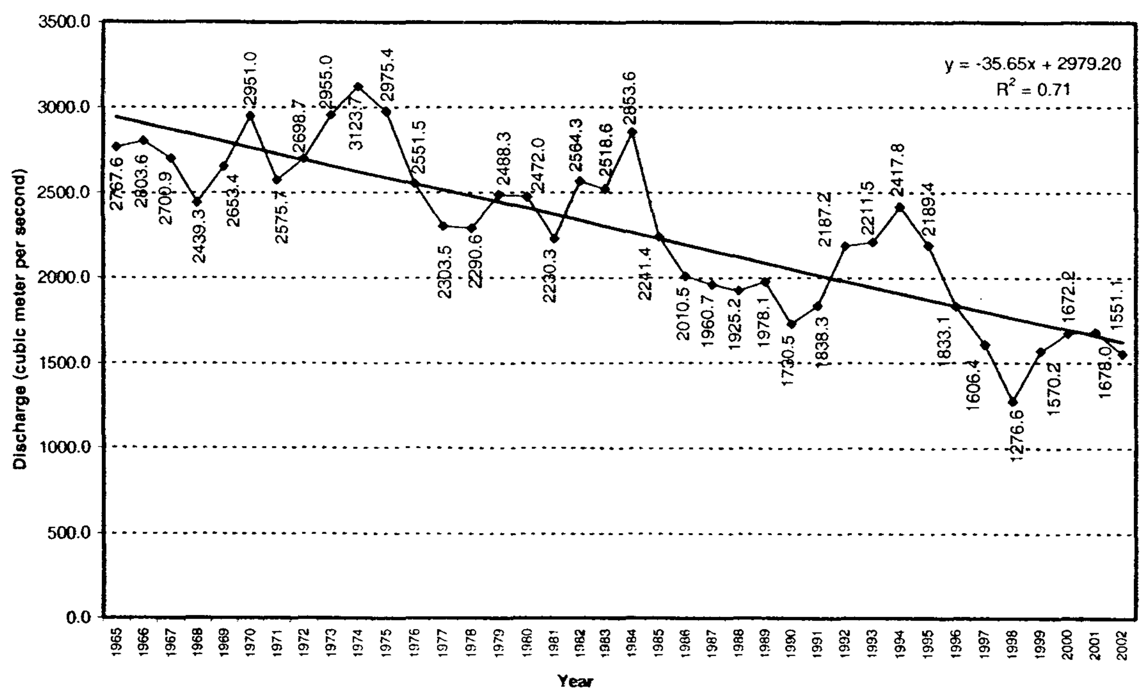

Figure No. 4.1dTrend of Discharge during Winter Season (1968-2005)

These data indicate that in last four decades there has been significant decrease in the discharge of the Parvati river in all four seasons. Annual trend of the discharge also shows a remarkable decline. The maximum amount of discharge is found during summer season (Figure No.4.1b & Annexure No.4.1), which lies between (15000-20000 m^3/ second), is mainly contributed by the glacier melt, base flow and pre monsoonal rainfall. The minimum amount of discharge is during winter season, which lies between (2000-3000 m^3/ second), is largely base flow from sub-glacial melting and groundwater storage. Autumn, Summer and Winter season discharge trend shows a remarkable decline over the years, while decline in the Spring season is comparatively lower than other three seasons (Figure No.4.1 a, b, c, d, e & Annexure No.4.1, 4.2, 4.3).

4.2.2 - Trend analysis of winter, spring, summer, autumn and annual Temperature

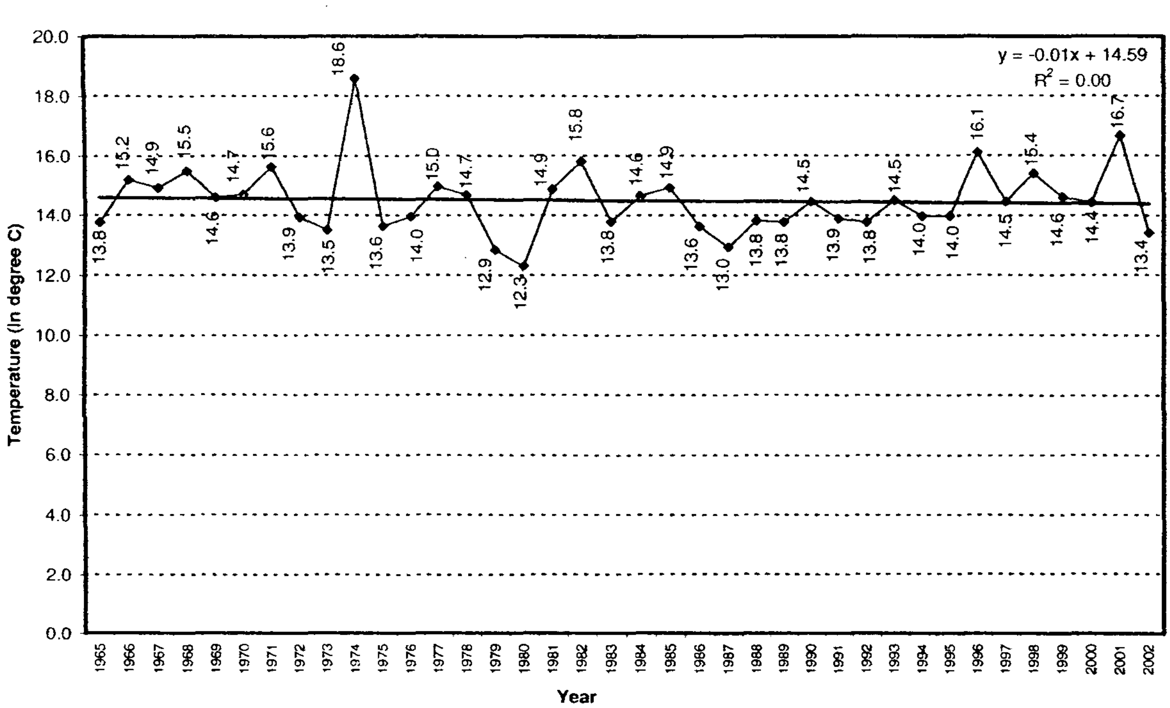

Figure No. 4.2a Trend of Mean Temperature during Spring season (1968-2005)

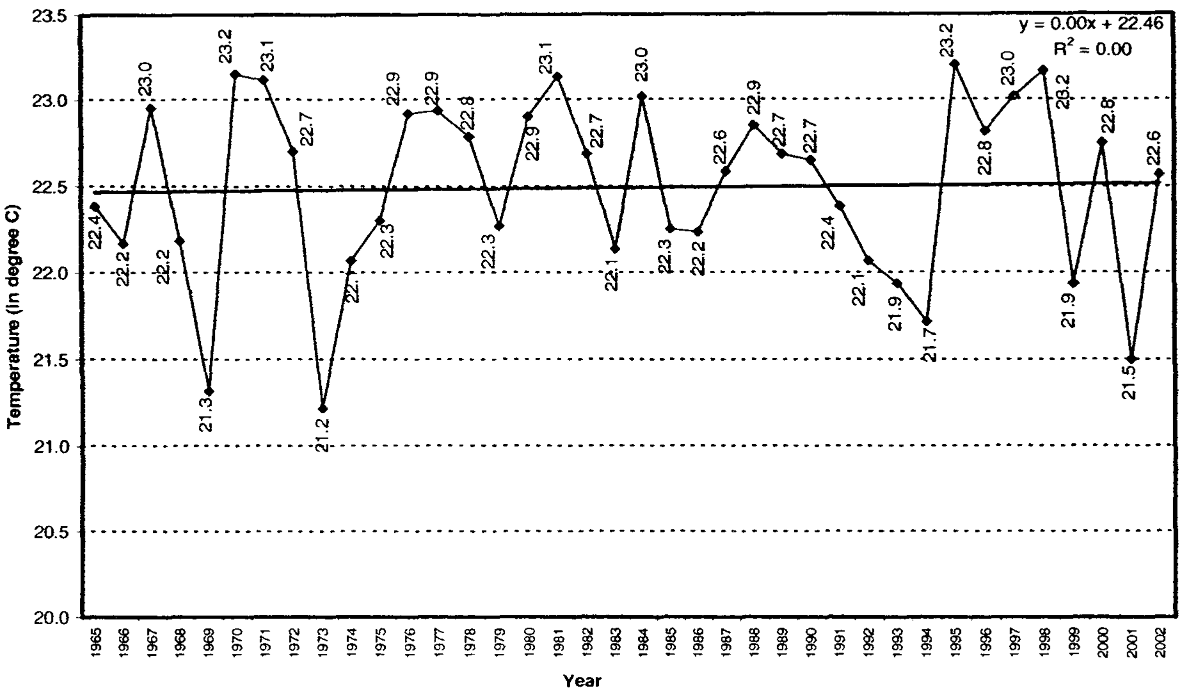

Figure No. 4.2cTrend of Mean Temperature during Autumn season (1968-2005)

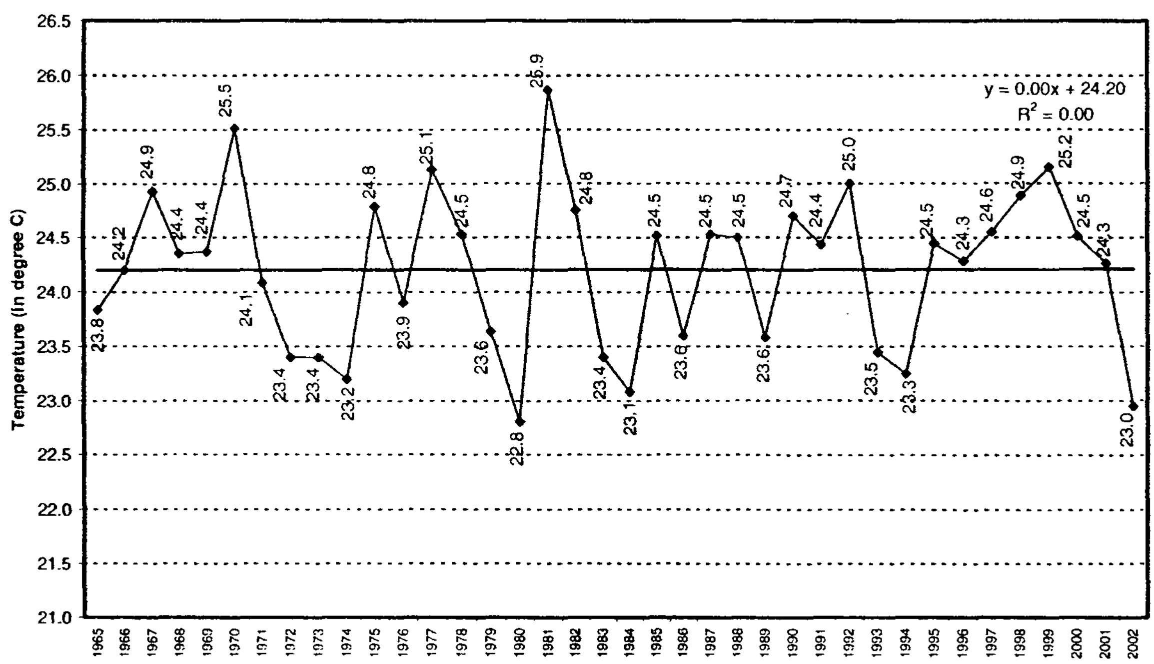

Figure No. 4.2b Trend of Mean Temperature during Summer season (1968-2005)

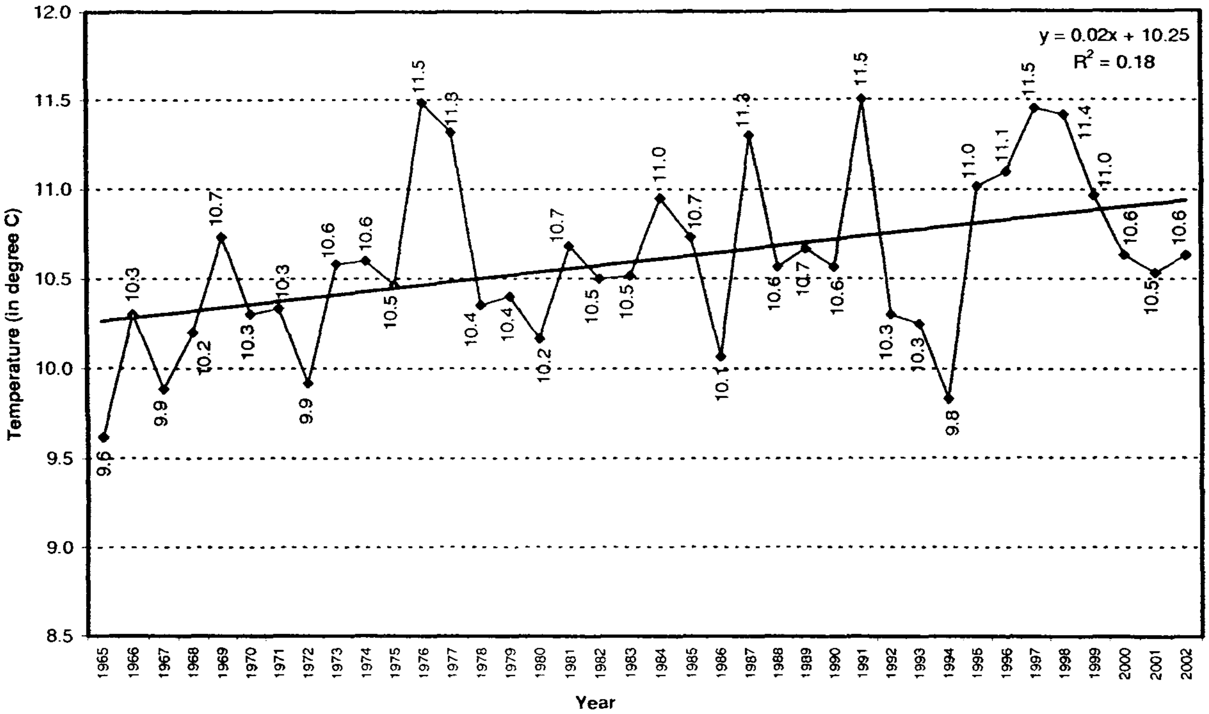

Figure No. 4.2d Trend of Mean Temperature during Winter season (1968-2005)

After analysing the factors like temperature, which is the core variable in the climate change studies, an increasing trend is observed in the Parvati basin. The winter season, among all the seasons shows slightly greater increase in the temperature over the years which ranges from

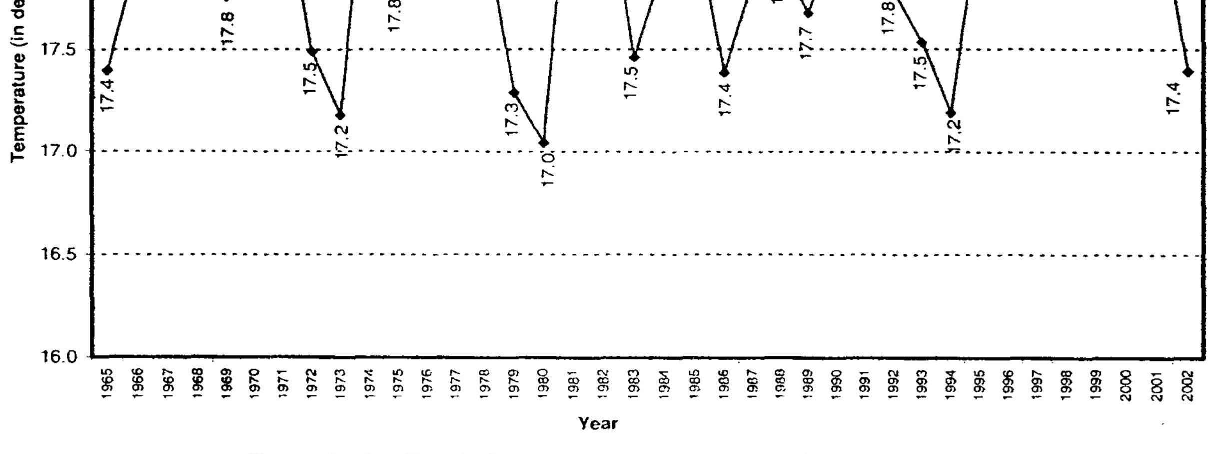

Figure No. 4.2eTrend of Annual Mean Temperature (1968-2005)

(10.3°C-10.8°C) (Figure No.4.2d & Annexure No.4.2). The summer (24°C-24.3° C) and The autumn (22.3°C-22.6°C) season show a very small increase in the temperature (Figure No.4.2 b, c & Annexure No.4.2) , while spring season shows a negligible amount of increase over the years (Figure No.4.2 a). The annual trend of the mean temperature of the basin also shows a slightly increasing trend over years, ranging from 17.7°C-18.1°C.

4.2.3 -Trend analysis of winter, spring, summer, autumn and annual Precipitation

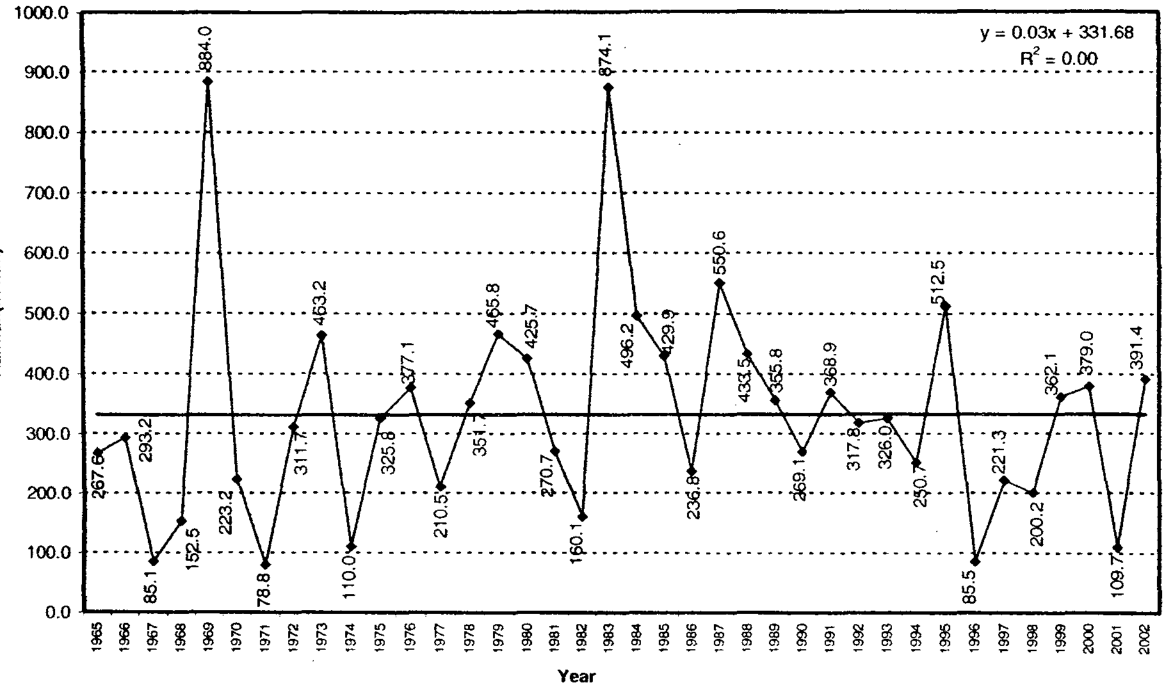

Figure No. 4.3a Trend of Rainfall during Spring season (1968-2005)

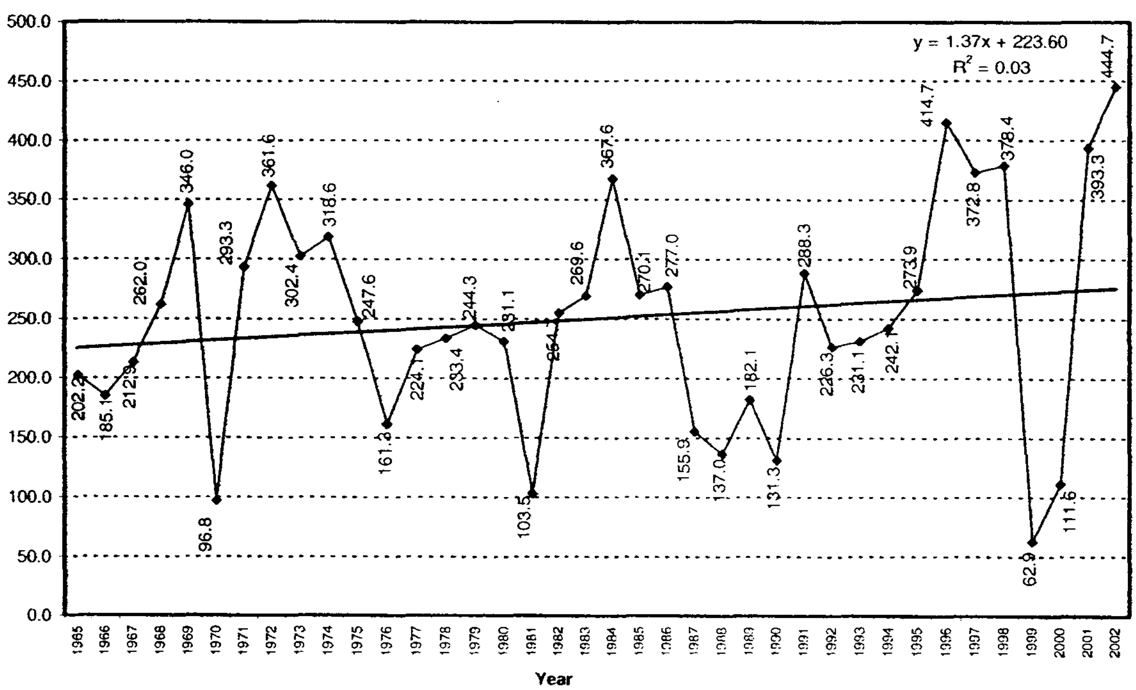

Figure No. 4.3b Trend of Rainfall during Summer season (1968-2005)

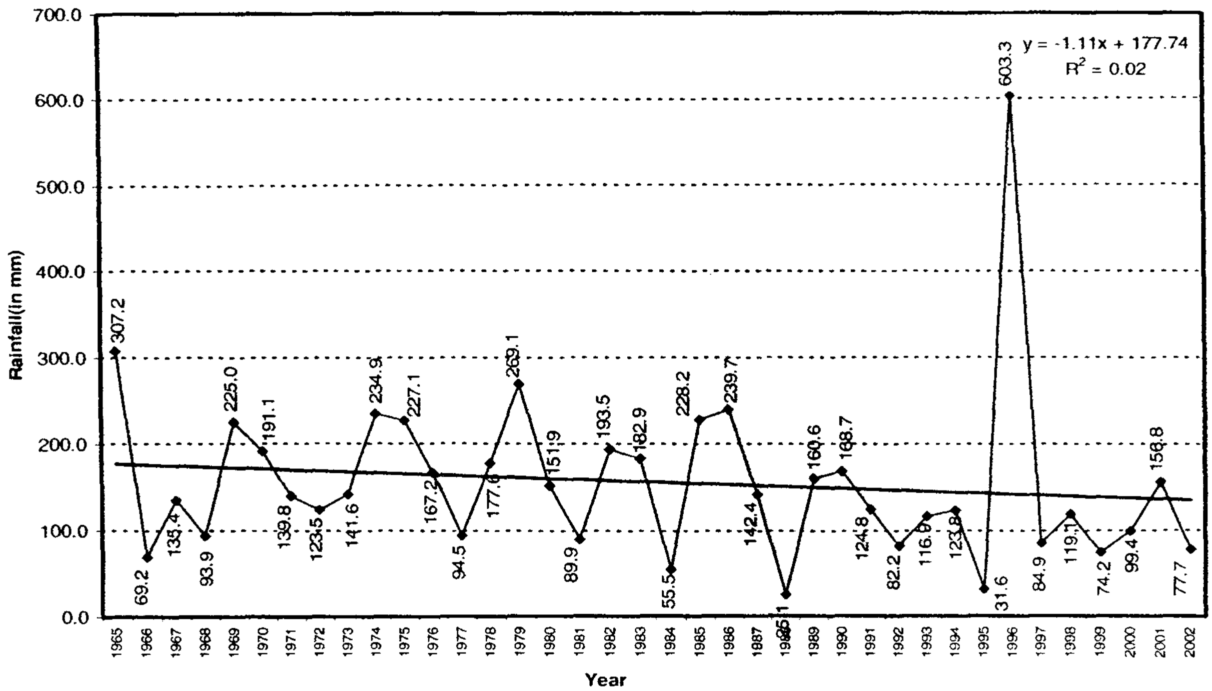

Figure No. 4.3d Trend of Rainfall during Winter season (1968-2005)

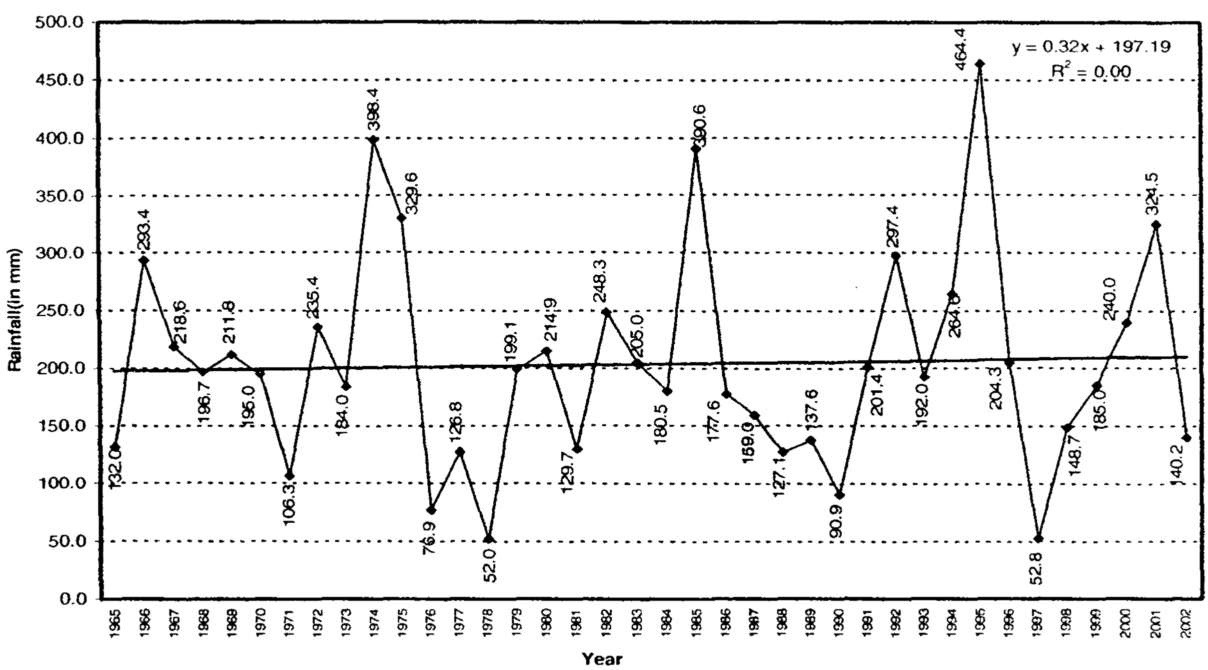

Figure No. 4.3c Trend of Rainfall during Autumn season (1968-2005)

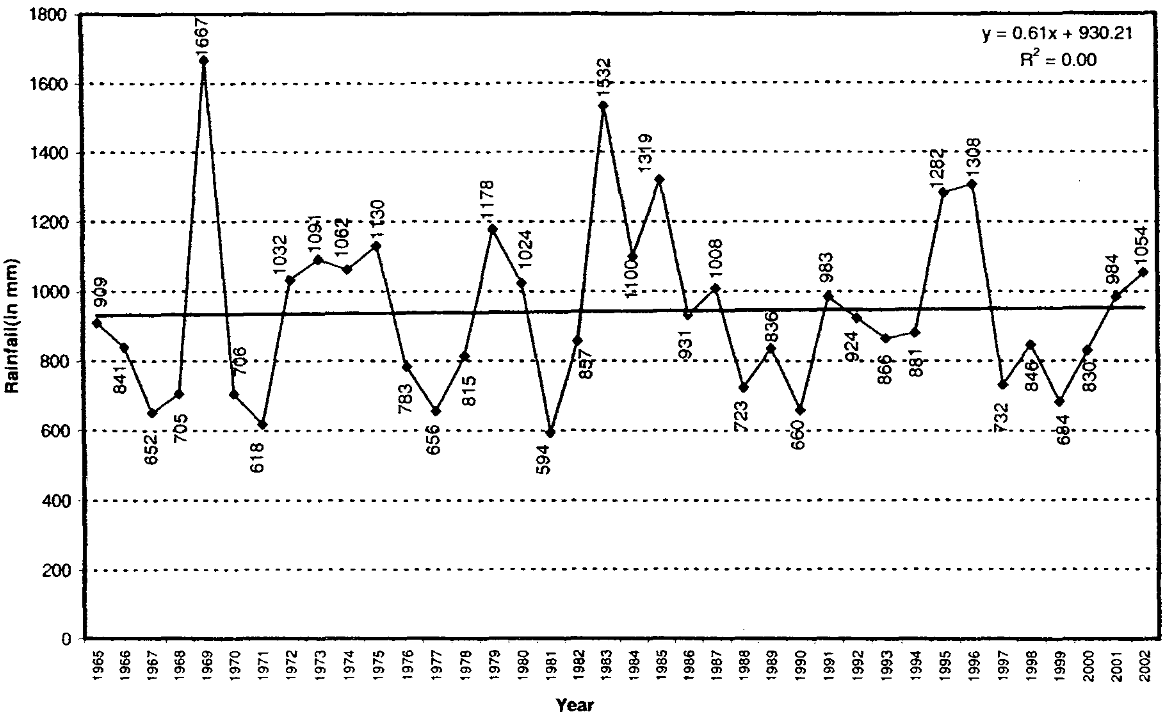

Figure No. 4.3e Trend of Annual Rainfall (1968-2005)

Another variable which is very important in climate change study is the Precipitation. Seasonal trend analysis of the precipitation pattern reflects negligible or a slight change in the precipitation over the years in the basin. Trend line of the spring, autumn and winter season precipitation shows a negligible change over the years, while summer season shows a slight increase in the precipitation over the years (Figure No.4.3 a, b, c. d & Annexure No.4.3). Annual pattern of precipitation in the basin also shows a slight increase.

4.3 -Relationship between Discharge, Temperature and Precipitation in the Parvati Basin

Relationship between Discharge, Temperature and Precipitation for different seasons has been shown below through correlation matrices. Annually, there is a significant negative correlation between temperature and precipitation showing that as temperature increases there is a decrease in the precipitation. Temperature and discharge also show a negative relationship but there is a insignificant positive relationship between precipitation and discharge which signifies that if there is increase in the precipitation, the discharge also increases and vice versa.

	Annual Temperature	Annual Precipitation	Annual Discharge
Annual Temperature	1	-0.34 #	-0.23
Annual Precipitation	-0.34 #	1	0.08
Annual Discharge	-0.23	0.08	1
# Correlation is significant at the 0.05 level (2-tailed).			

Table 4.1-Relationship between Annual Discharge, Temperature and Precipitation

Spring season

Spring season also shows significant negative correlation between temperature and precipitation as it is shown by annual trend. The relationship between precipitation and discharge show insignificant positive relationship.

	Spring Temperature	Spring Precipitation	Spring Discharge
Spring Temperature	1	-0.53 # #	-0.31
Spring Precipitation	-0.53 # #	1	0.26
Spring Discharge	-0.31	0.26	1
# # Correlation is significant at the 0.01 level (2-tailed).			

Table 4.2-Relationship between Discharge, Temperature and Precipitation in Spring Season

Summer season

Summer season follows the same trend as above except that the relationship between precipitation and discharge show a significant negative correlation as evaporation exceeds precipitation in this season.

	Summer Temperature	Summer Precipitation	Summer Discharge
Summer Temperature	1	-0.46 # #	0.21
Summer Precipitation	-0.46 # #	1	-0.40 #
Summer Discharge	0.21	-0.40 #	1
# # Correlation is significant at the 0.01 level (2-tailed).			
# Correlation is significant at the 0.05 level (2-tailed).			

Table 4.3-Relationship between Discharge, Temperature and Precipitation in Summer Season

Autumn season

Autumn season also shows a similar relationship between variables as it is shown by the others in annual trend except the relationship between temperature and discharge showing a positive relationship but neither of the relationship was found significant.

	Autumn Temperature	Autumn Precipitation	Autumn Discharge
Autumn Temperature	1	-0.31	0.04
Autumn Precipitation	-0.31	1	0.13
Autumn Discharge	0.04	0.13	1

Table 4.4-Relationship between Discharge, Temperature and Precipitation in Autumn Season

Winter season

Winter season shows a similar trend as the annual trend, regarding the relationship between temperature and discharge, which shows a strong negative correlation and the relationship between precipitation and discharge also follow annual trend.

	Winter Temperature	Winter Precipitation	Winter Discharge
Winter Temperature	1.00	-0.08	-0.45 # #
Winter Precipitation	-0.08	1.00	0.12
Winter Discharge	-0.45 # #	0.12	1.00
# # Correlation is significant at the 0.01 level (2-tailed).			

Table 4.5-Relationship between Discharge, Temperature and Precipitation in Winter Season

4.4 Trend analysis of standardized indices of Discharge of Parvati river:

For more detailed analysis of hydrological and climatic responses of Parvati river, Standardized indices of Discharge, Temperature and Precipitation variables has been carried out. Standardized discharge indices (SDI) were computed by subtracting the mean and dividing by the standard deviation of the discharge data series. In a similar manner, the Standardized indices of Temperature and Precipitation variables have been computed (Figure No.4.4 a, b, c. d & Annexure No.4.4).

The SDI data series were subjected to trend analysis by two established statistical techniques: standard parametric technique, such as linear regression analysis and non-parametric test such as Kendall–tau- b test (Table No.4.6).

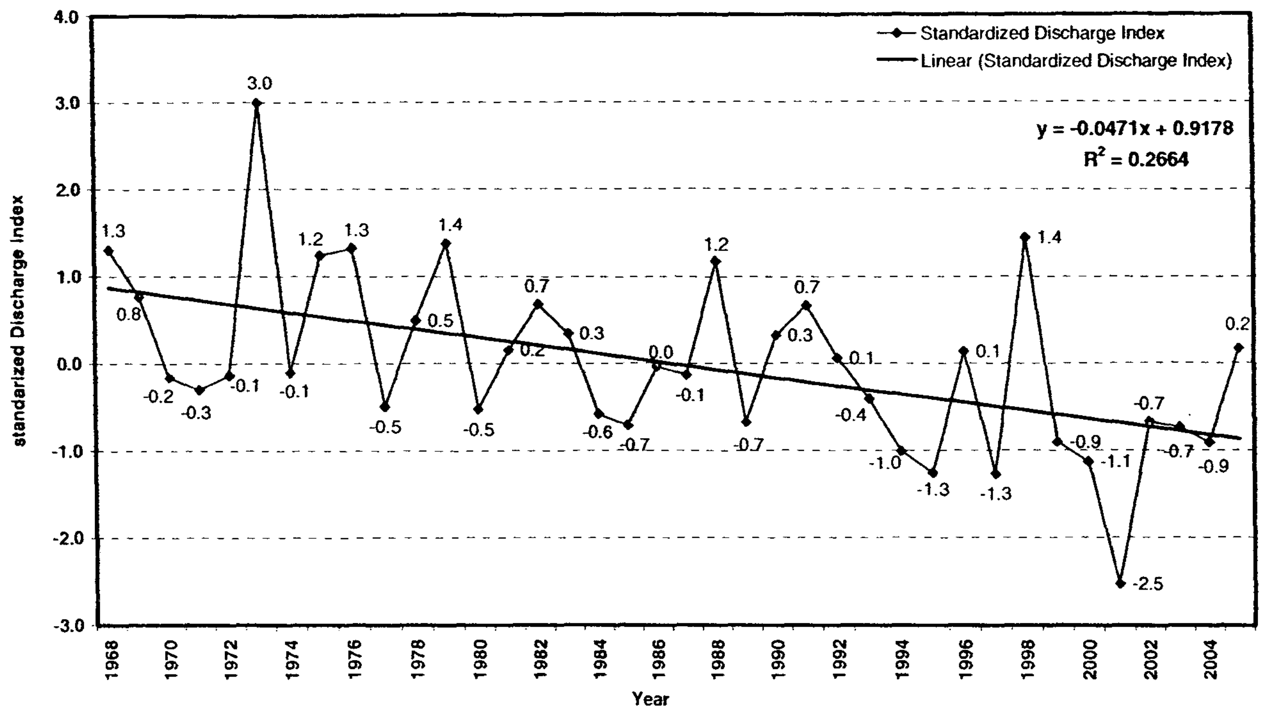

Figure No.4.4a Temporal Variation and Linear Trend in Discharge during Spring Season 1968-2005

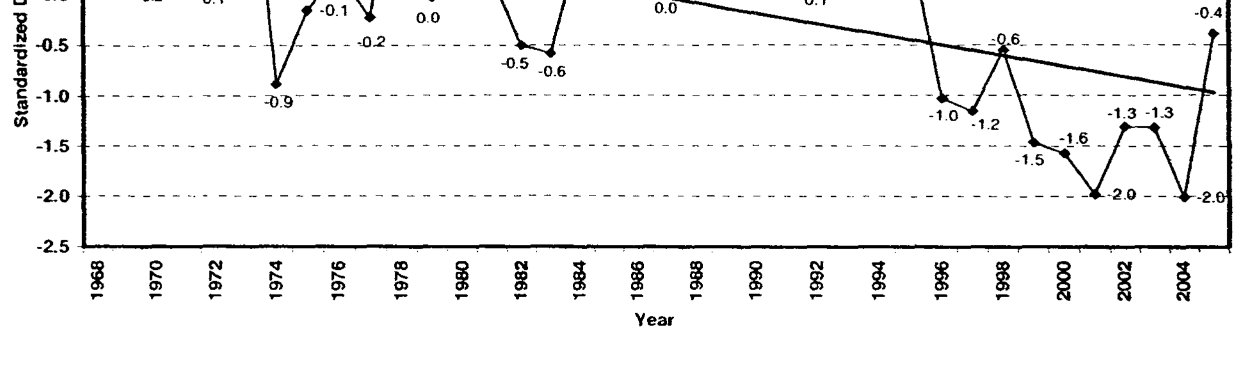

Figure No.4.4b Temporal Variation and Linear Trend in Discharge during Summer Season 1968-2005

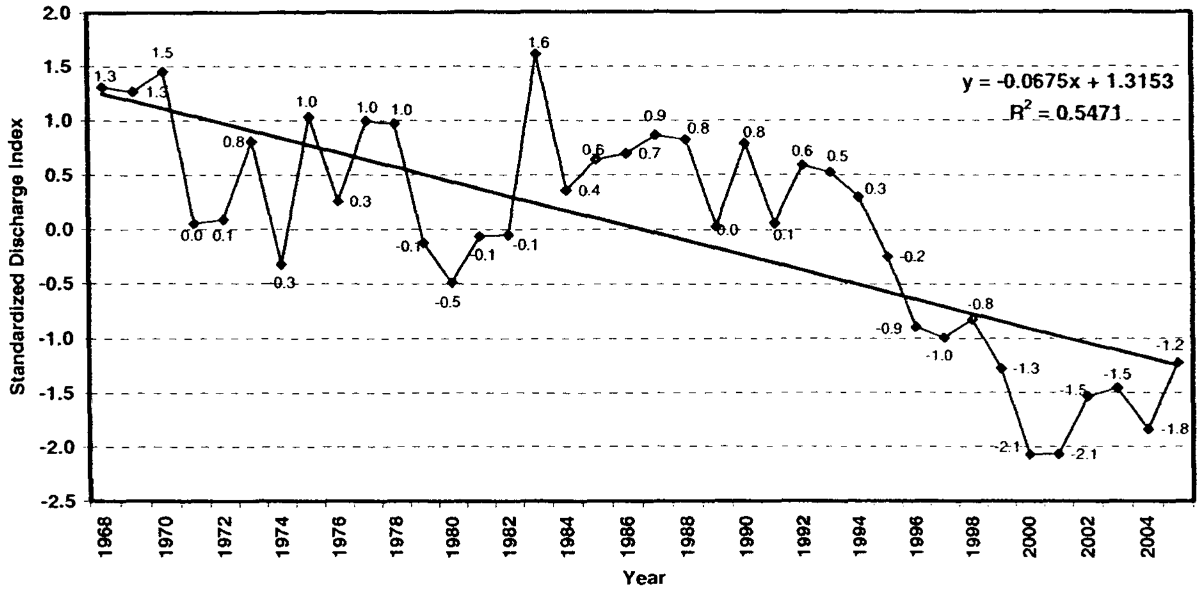

Figure No.4.4c Temporal Variation and Linear Trend in Discharge during Autumn Season 1968-2005

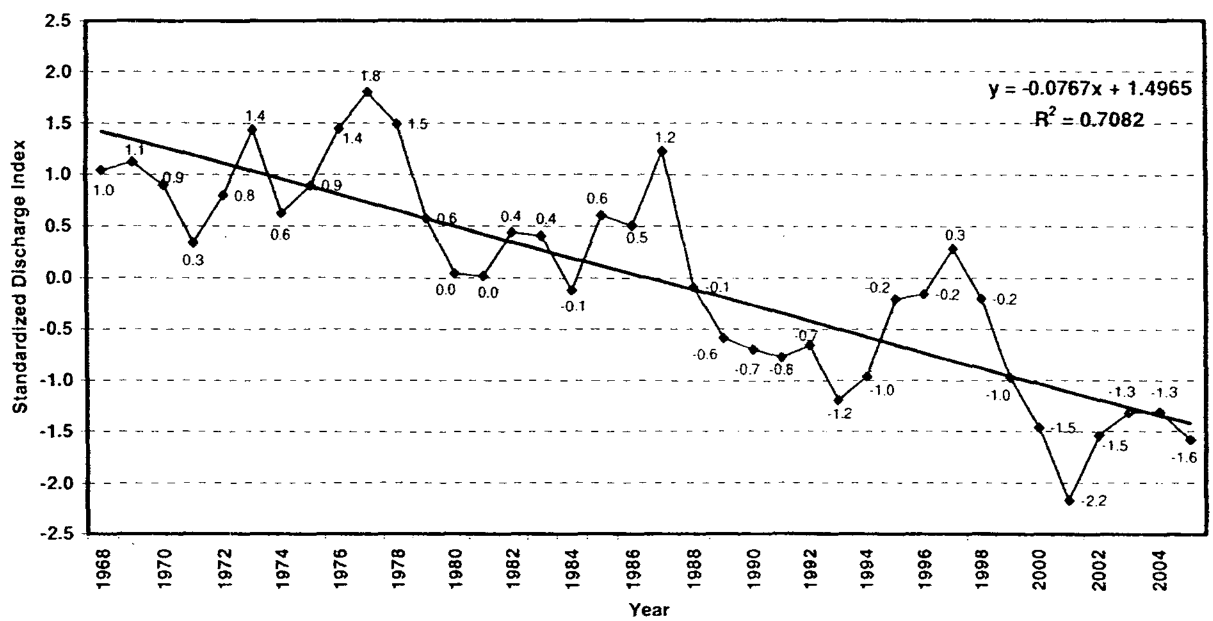

Figure No.4.4d Temporal Variation and Linear Trend in Discharge during Winter Season 1968-2005

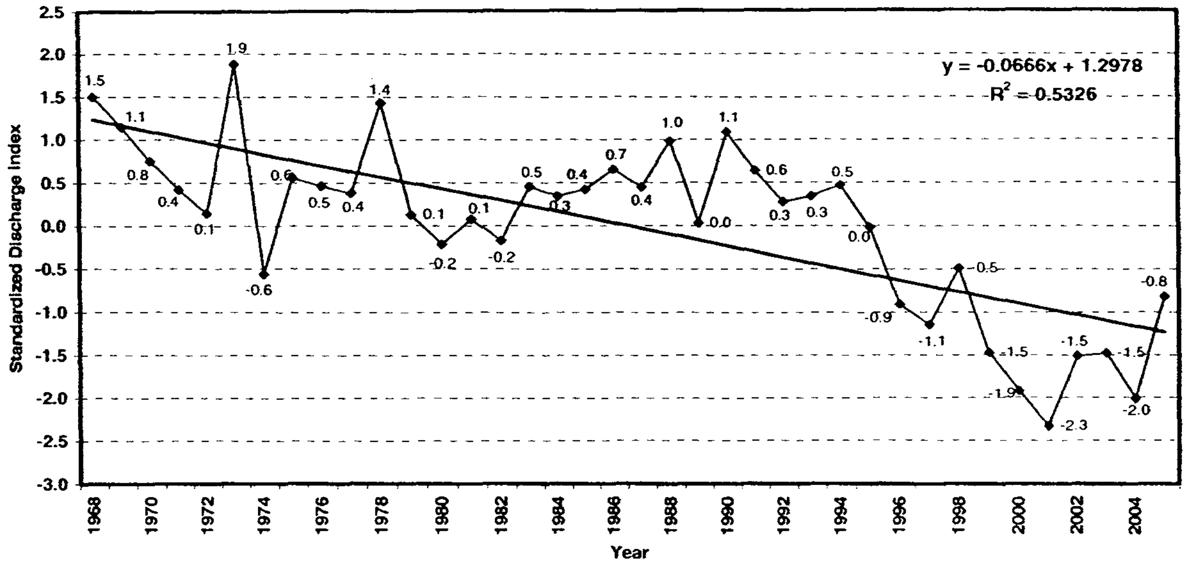

Figure No.4.4e Temporal Variation and Linear Trend in Annual Discharge 1968-2005

Table No. 4.6: Results of trend analyses of SDI, SPI and STI in the Parvati Basin

Data availability	Index	Season	Trend analysis	
			Kendall's tau-b non-parametric test	Linear regression coefficient b
1968-2005	Standardized Discharge Index	Spring	(–0.366)**	(-.047)*
		Summer	(–0.351)**	(-.053)*
		Autumn	(–0.516)**	(-.067)*
		Winter	(–0.664)**	(-.077)*
		Annual	(–0.502)**	(-.067)*
1968-2005	Standardized Precipitation Index	Spring	(+ 0.056)	(+.001)
		Summer	(+ 0.089)	(+.010)
		Autumn	(– 0.027)	(+.001)
		Winter	(– 0.073)	(+.001)
		Annual	(+ 0.059)	(+.004)
1968-2005	Standardized Temperature Index	Spring	(–0.007)	(-0.005)
		Summer	(+ 0.087)	(+.009)
		Autumn	(+ 0.090)	(+.019)
		Winter	(+ 0.335)**	(+.039)*
		Annual	(+ 0.163)	(+.019)

**Significant at 95% confidence level. (+), Increasing; (–), Decreasing.*

Figure No. 4.4 (a, b, c, d, e) and Table 4.6 show the results of trend analyses of discharge in the spring, summer, autumn, winter seasons along with annual discharge in the Parvati river in a relatively shorter time-span of about 40 years (1968–2005). These data indicate that in the last four decades, discharge in the Parvati river has shown a statistically significant decrease in all the seasons, with winter discharge declining remarkably. Baring these, other studies on "Changing stream flow patterns in the rivers of North-western Himalaya" show statistically insignificant variation in discharge in other basins during all the three seasons, indicating episodic fluctuations (Bhutiyani, M.R. et. al., 2007). These may have been caused by the variations in the precipitation and temperature. Similar results have been obtained in different parts of the world (including the Himalayas) in the study of long-term trends in the mean stream flow of the rivers as possible indicators of climate change.

4.5 Group wise analyses of SDI, SPI, STI of Parvati river:

To further investigate the episodic variation in detail, Parvati discharge data is analysed with Temperature and Precipitation data on seasonal basis. Four distinct periods of variation has been identified, namely

1) Group A (up to 1975)
2) Group B (1975-1985)
3) Group C (1985-1995)
4) Group D (1995-2005)

Spring season

Group wise analyses of the discharge data in spring season reflects that discharge in Group A and Group B is above the normal whereas, group C shows some fluctuations in the pattern. Early years in Group C show discharge above the normal, and in the later years discharge is below the normal. Group D discharge pattern is almost below the normal. Further. group wise analyses of temperature and precipitation data show almost negligible deviation from the normal (Figure No.4.5 a, b, c & Annexure No.4.4).

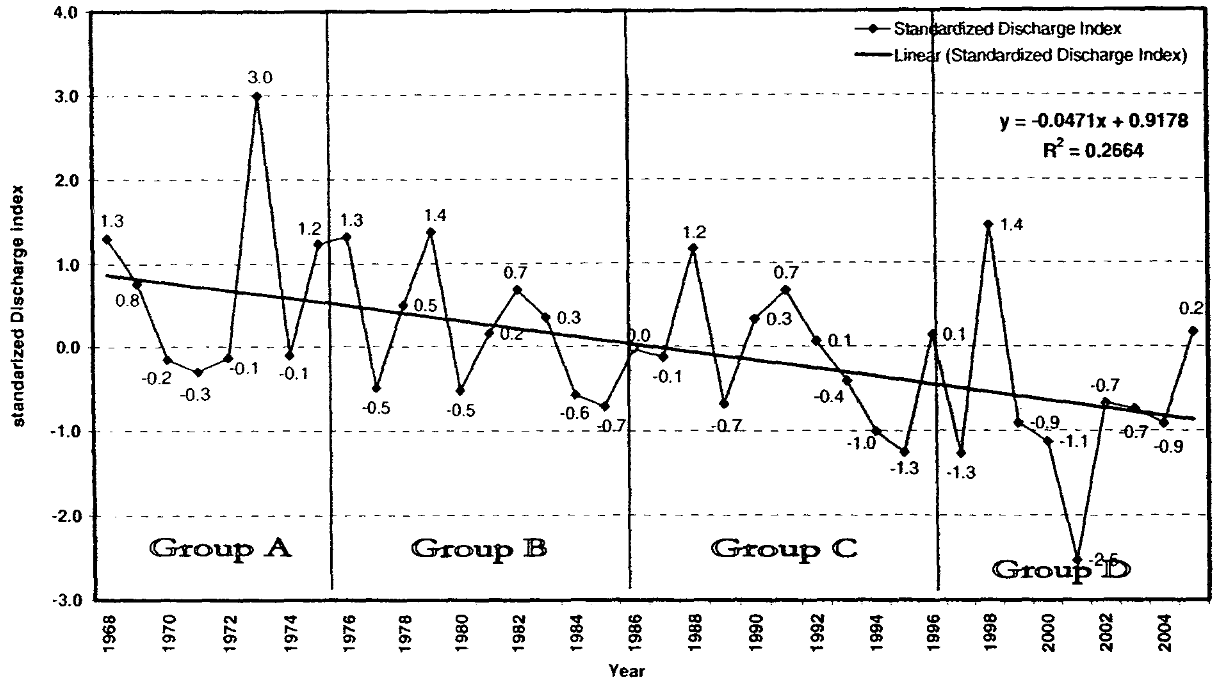

Figure No.4.5a Temporal Variation and Linear Trend in Discharge during Spring Season 1968-2005

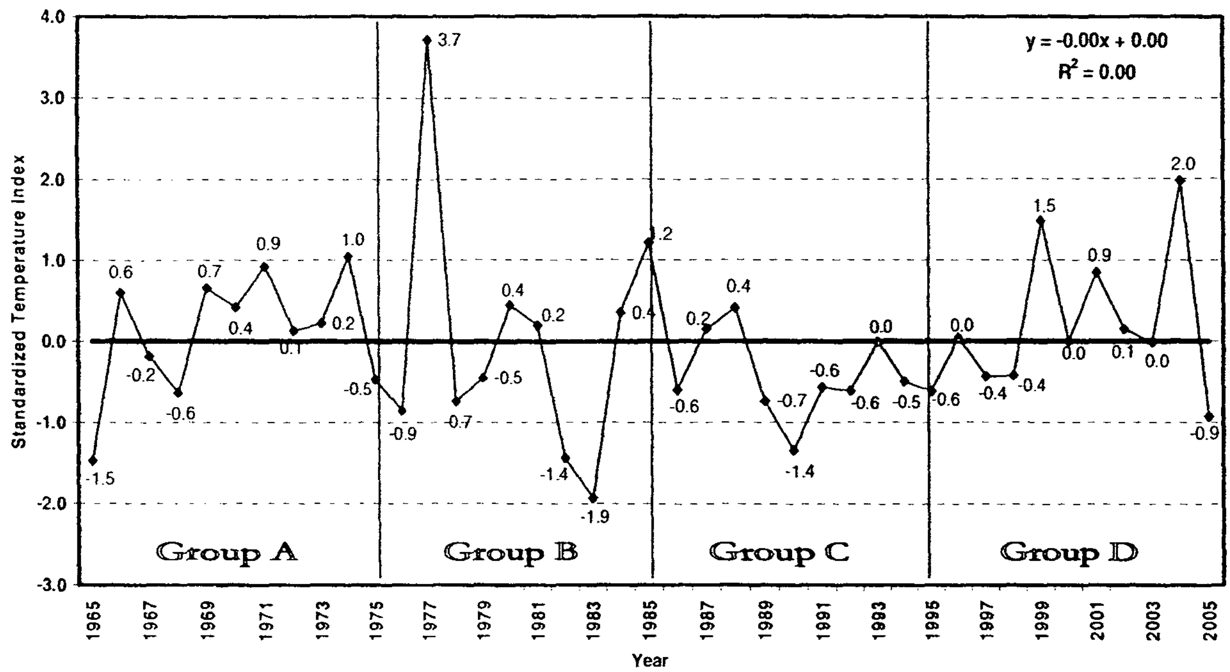

Figure No.4.5b Temporal Variation and Linear Trend in Temperature during Spring Season 1968-2005

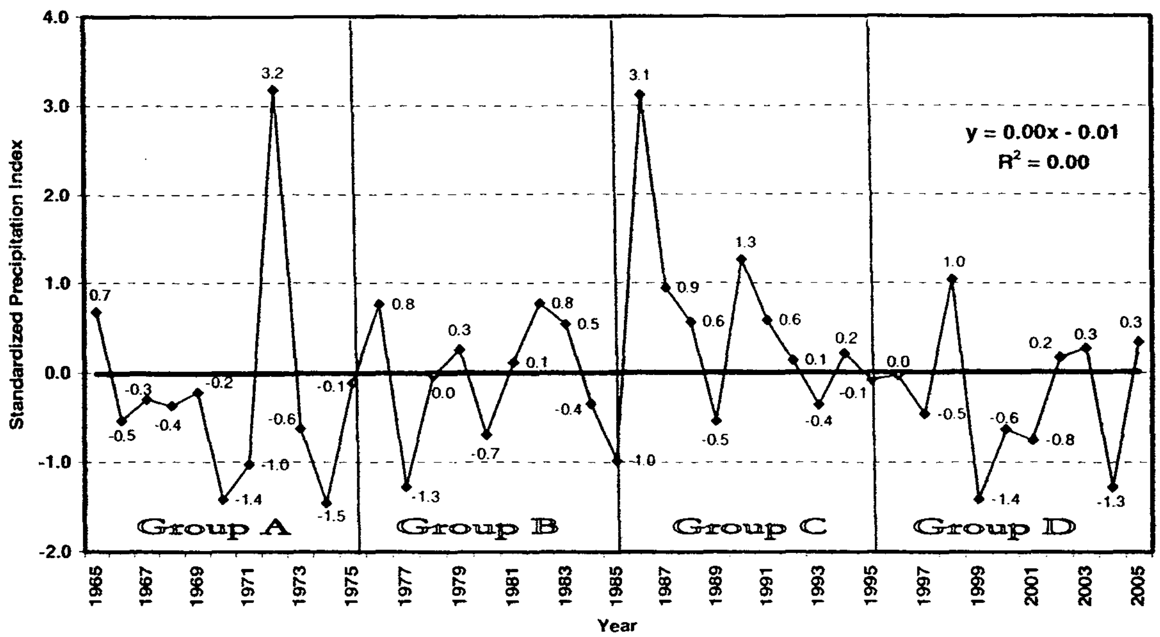

Figure No.4.5c Temporal Variation and Linear Trend in Precipitation during Spring Season 1968-2005

Figure No. 4.5 (a,b,c): Temporal variation of spring SDI of the Parvati river at Bhuntar and its relationship with spring SPI and STI of the NWH during the period (1968-2005)

Summer season

Group wise analyses of the discharge data in summer season reflects that discharge in Group A, Group B and Group C is above the normal but Group D shows a complete reversal in the pattern as discharge is below the normal. Further group wise analyses of the temperature data shows that from Group A to Group D it is continuously increasing but the increase is not so prominent and all the groups are almost above normal. Precipitation data also shows the same trend like temperature. The important point is that in Group D discharge is decreases as temperature increases, this relationship is not easy to explain as a no. of factors plays a role but one of the reason is, decrease in the glacial area if the basin (Figure No.4.6 a, b, c & Annexure No.4.4).

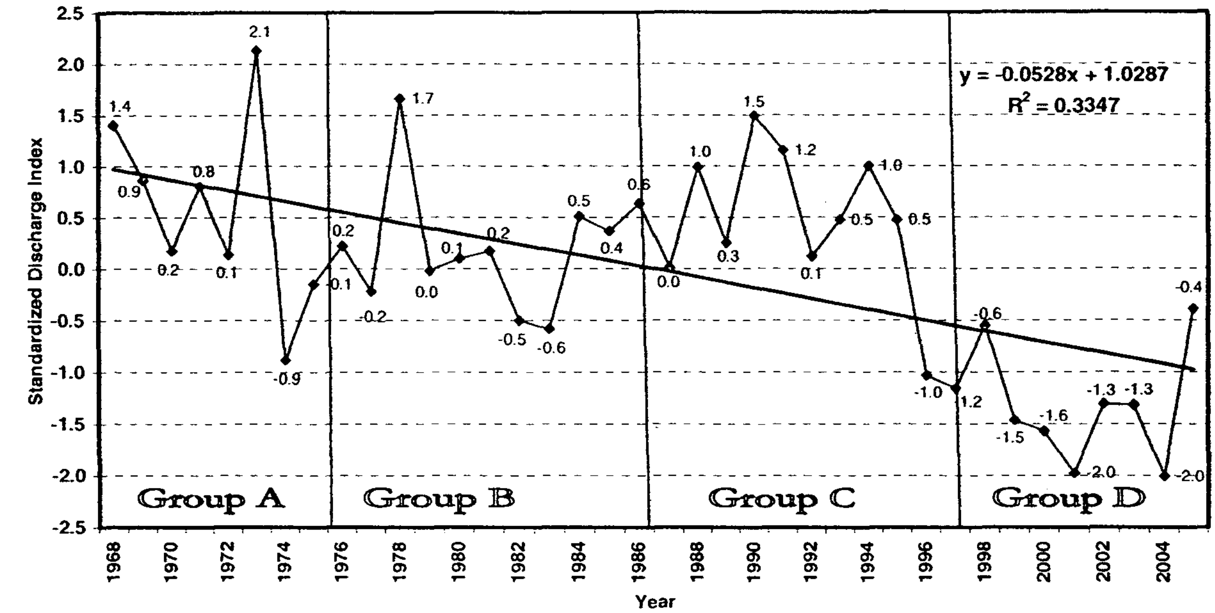

Figure No.4.6a Temporal Variation and Linear Trend in Discharge during Summer Season 1968-2005

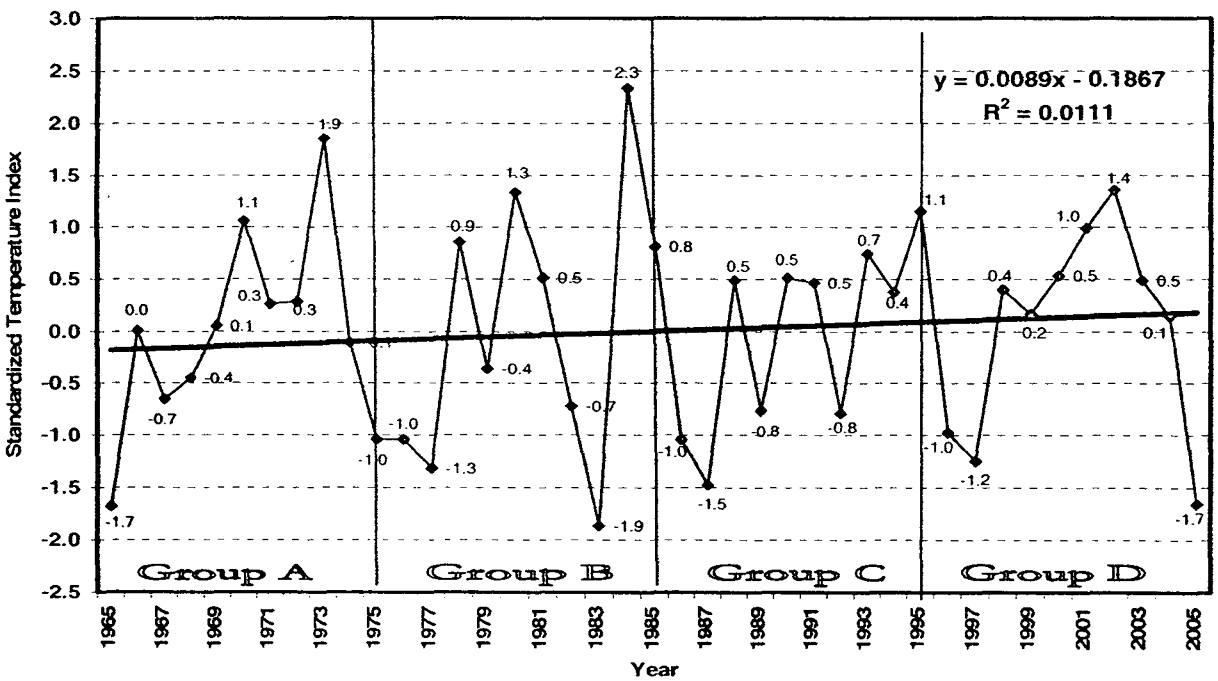

Figure No.4.6b Temporal Variation and Linear Trend in Temperature during Summer Season 1968-2005

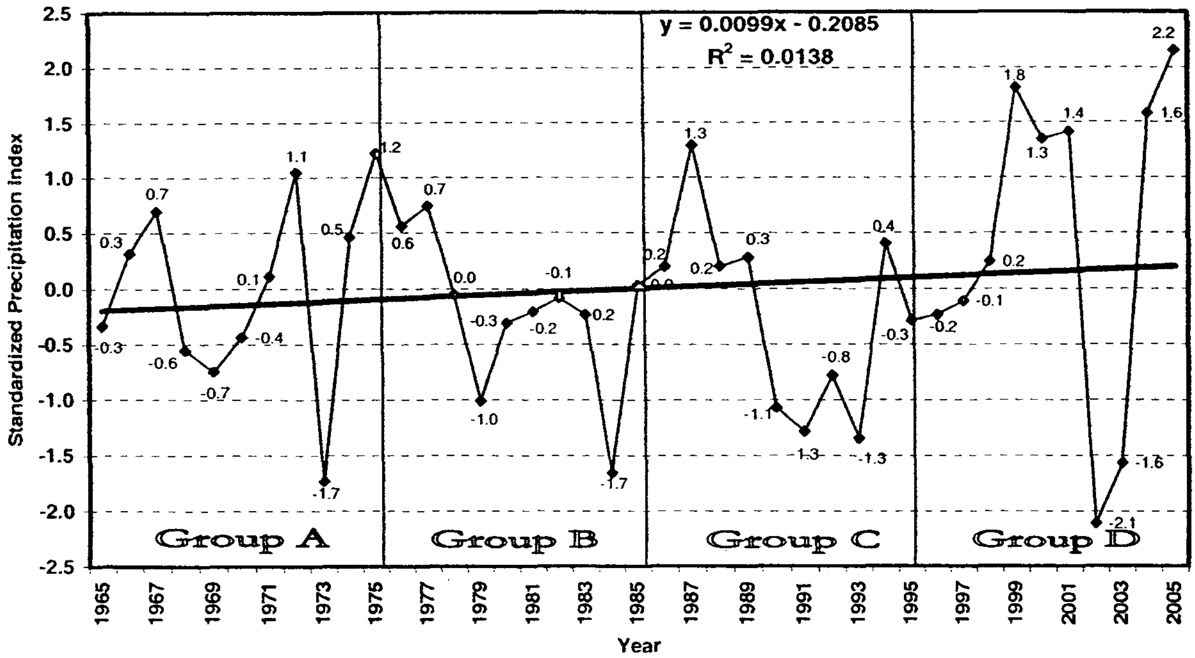

Figure No.4.6c Temporal Variation and Linear Trend in Precipitation during Summer Season 1968-2005

Figure No. 4.6 (a,b,c): Temporal variation of summer SDI of the Parvati river at Bhuntar and its relationship with summer SPI and STI of the NWH during the period (1968-2005)

Autumn Season

This season shows the same discharge pattern as it is shown for summer season. From Group A to Group D the discharge is rapidly decreasing. The first three groups namely A, B and C are above the normal and the last group D is completely below normal. The period from 1968 up to 1995 (the first three groups) is marked by decreasing discharge, more or less average monsoon precipitation and below average but increasing air temperature. This indicates that the glaciers act as natural regulators of discharge in the Parvati river basin, contributing more during the warm years (below average monsoon) due to excessive melting and less during comparatively colder (above average monsoon) years due to reduced melting. The period between 1995 and 2005, during which the Parvati river appears to have recorded decreasing discharge values, is also characterized by significant rise in air temperature and almost average precipitation. Ironically, the average precipitation, coupled with increasing temperature should have caused further increase in the component of glacier-melt and enhanced discharge. On the contrary, discharge during this period has decreased. Although mass balance and length data of the glaciers in the NWH are not available for a long period, a limited number of studies in the last four decades have demonstrated negative mass balance, significant ice-loss and faster recession of the glaciers during this period (Figure No.4.7 a, b, c & Annexure No.4.4).

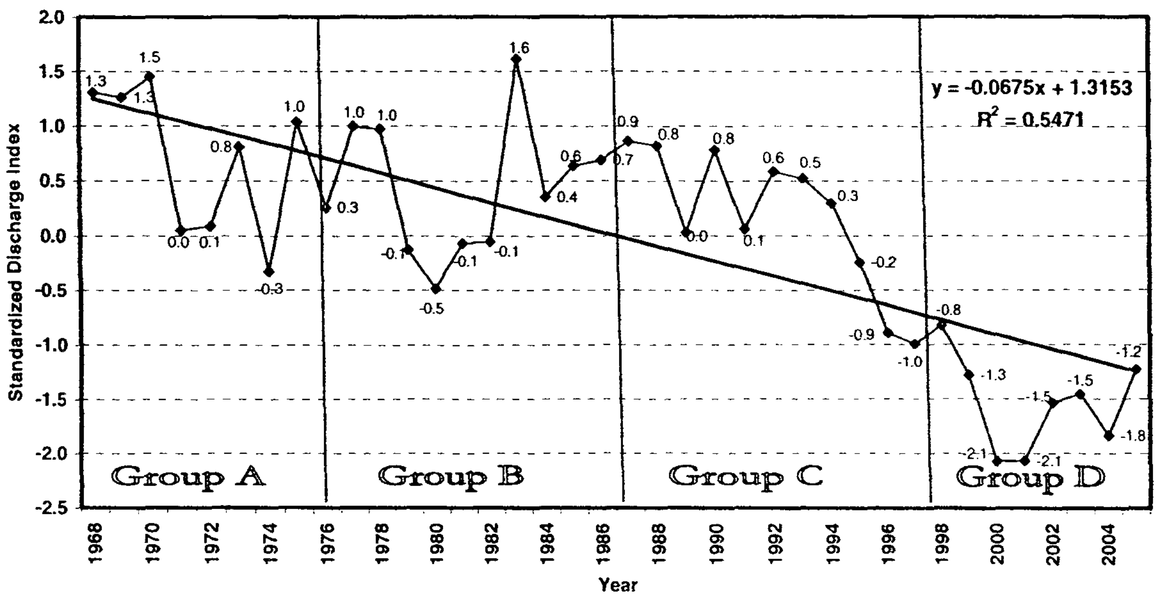

Figure No.4.7a Temporal Variation and Linear Trend in Discharge during Autumn Season 1968-2005

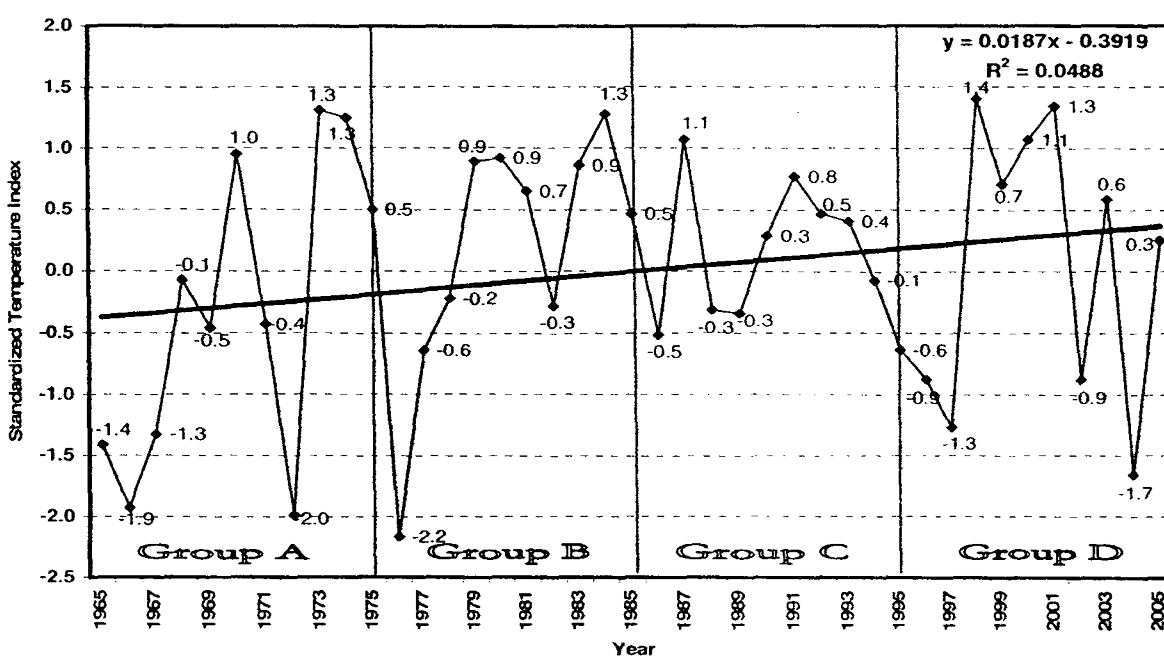

Figure No. 4.7b Temporal Variation and Linear Trend in Temperature during Autumn Season 1968-2005

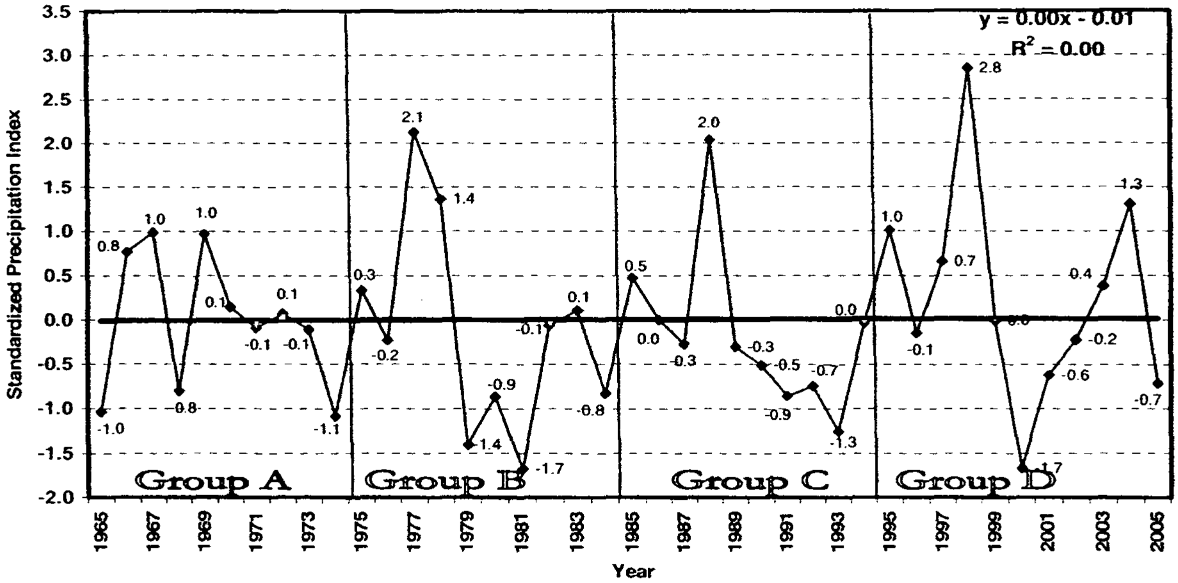

Figure No.4.7c Temporal Variation and Linear Trend in Precipitation during Autumn Season 1968-2005

Figure No. 4.7 (a,b,c): Temporal variation of autumn SDI of the Parvati river at Bhuntar and its relationship with autumn SPI and STI of the NWH during the period (1968-2005)

Winter season

Discharge pattern follows the decreasing trend from Group A (above normal) to Group D (below normal) in this season. Temperature pattern shows an increasing trend from Group A (below normal) to Group D (above normal). Below normal winter discharge in the Parvati river (primarily caused by sub-glacial melting and groundwater storage with less radiational melting on the surface) from 1995 to 2005 appears to be largely related to diminishing contribution from glaciers in the basin which are thinning considerably, as contribution by groundwater storage has more or less remained constant. The precipitation follows more or less the normal trend (Figure No.4.8 a, b, c & Annexure No.4.4).

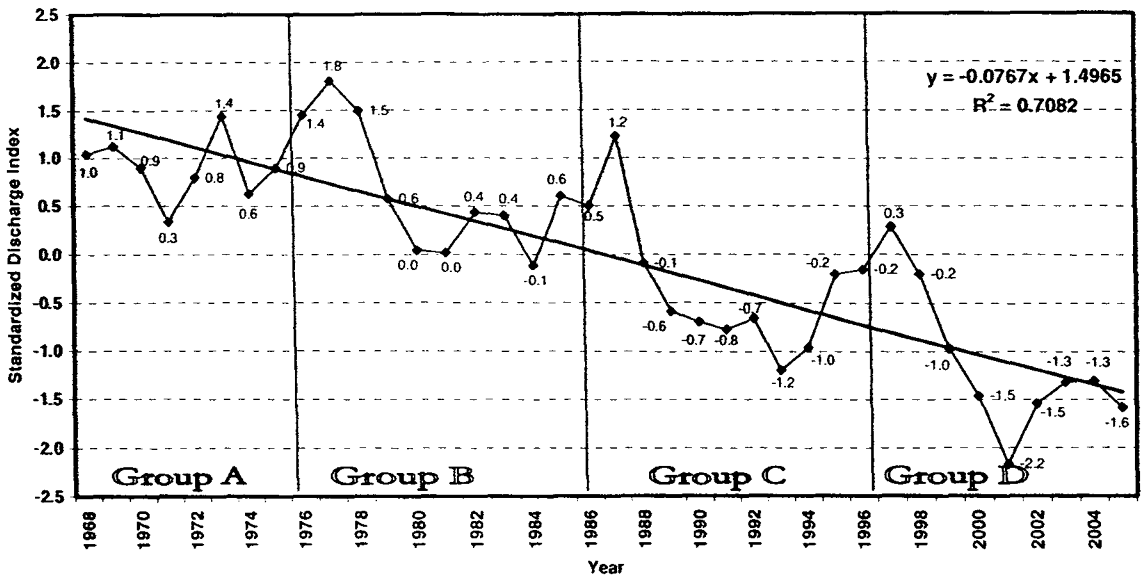

Figure No.4.8a Temporal Variation and Linear Trend in Discharge during Winter Season 1968-2005

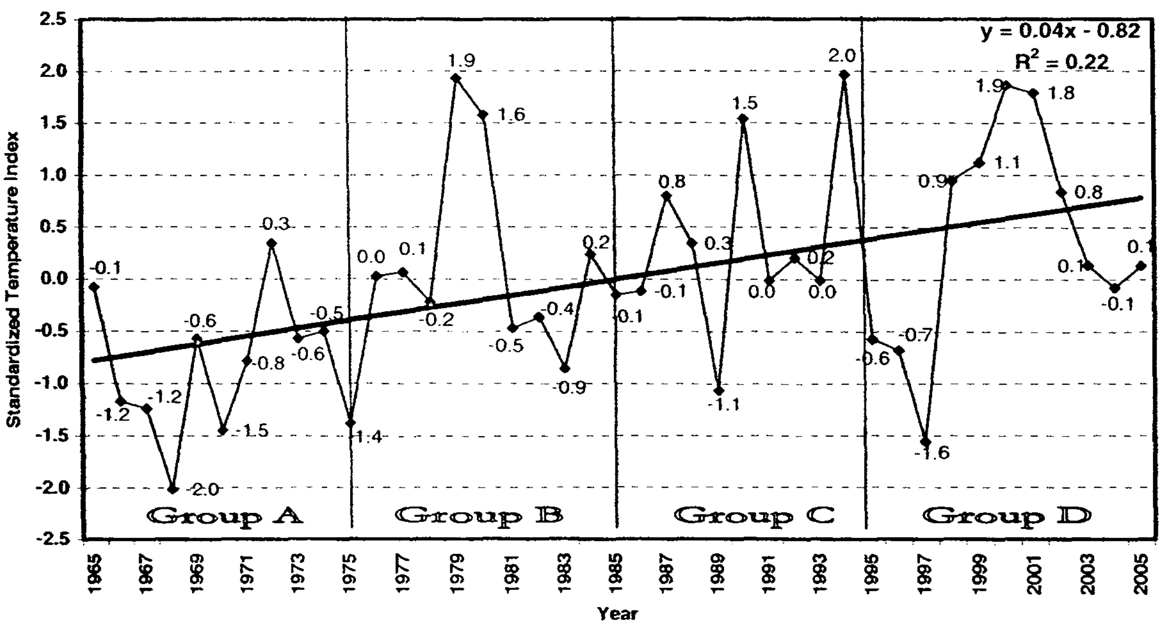

Figure No.4.8b Temporal Variation and Linear Trend in Temperature during Winter Season 1968-2005

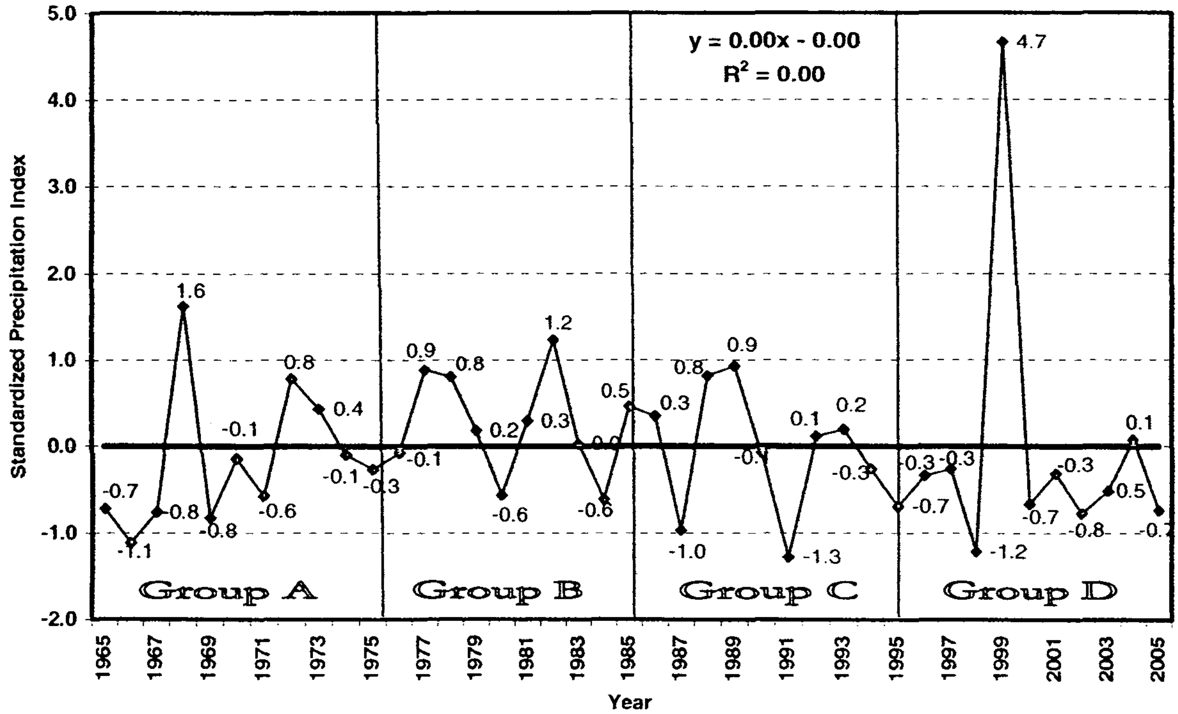

Figure No.4.8c Temporal Variation and Linear Trend in Precipitation during Winter Season 1968-2005

Figure No. 4.8 (a,b,c): Temporal variation of winter SDI of the Parvati river at Bhuntar and its relationship with winter SPI and STI of the NWH during the period (1968-2005)

Annual

Annual pattern also shows a similar trend in discharge and temperature pattern over the period. Discharge is decreasing significantly in all the seasons, and temperature is increasing slightly in all seasons, with winter season showing a statistically significant change in the temperature (Figure No.4.9 a, b, c & Annexure No.4.4).

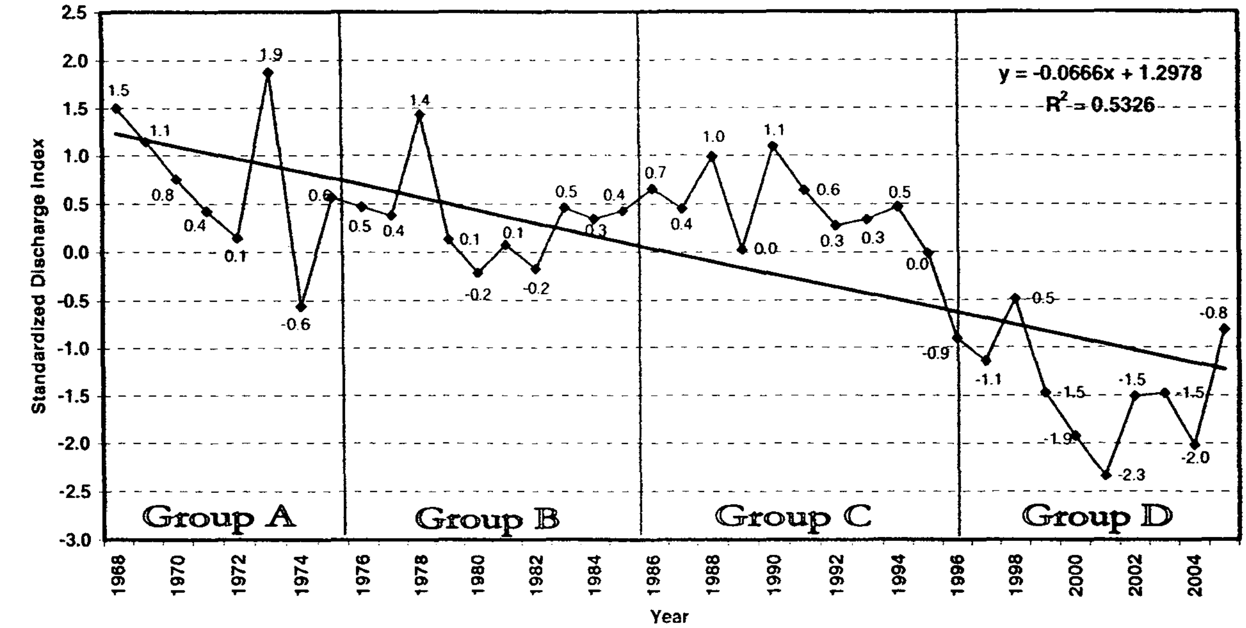

Figure No.4.9a Temporal Variation and Linear Trend in Annual Discharge 1968-2005

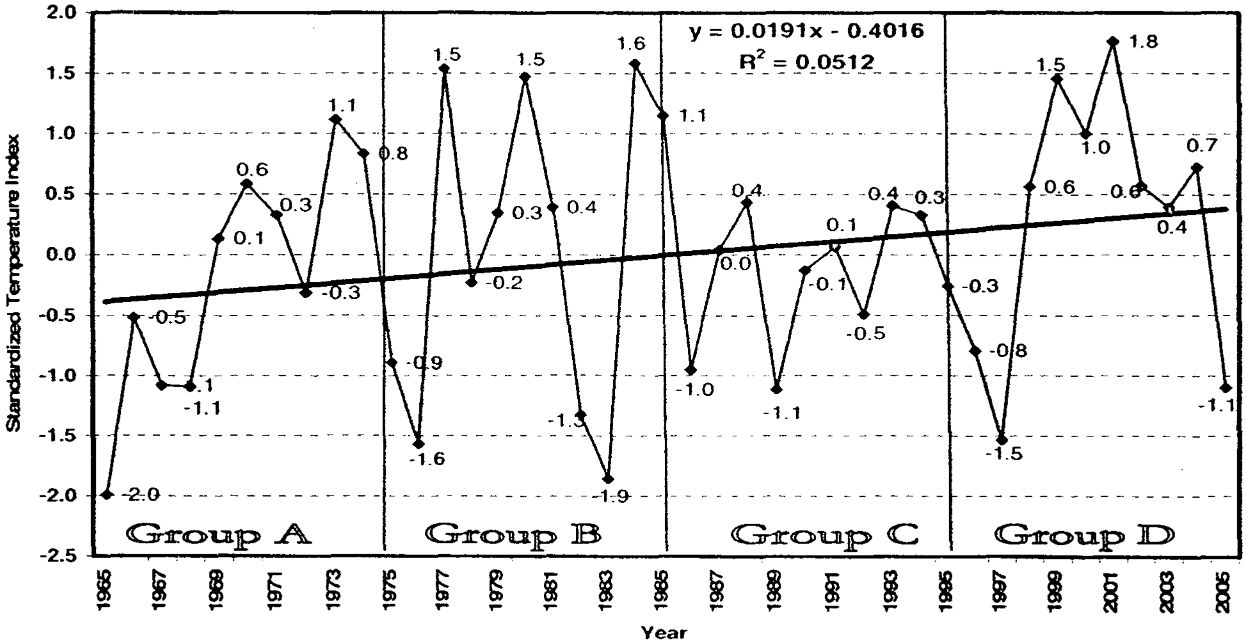

Figure No.4.9b Temporal Variation and Linear Trend in Annual Temperature 1968-2005

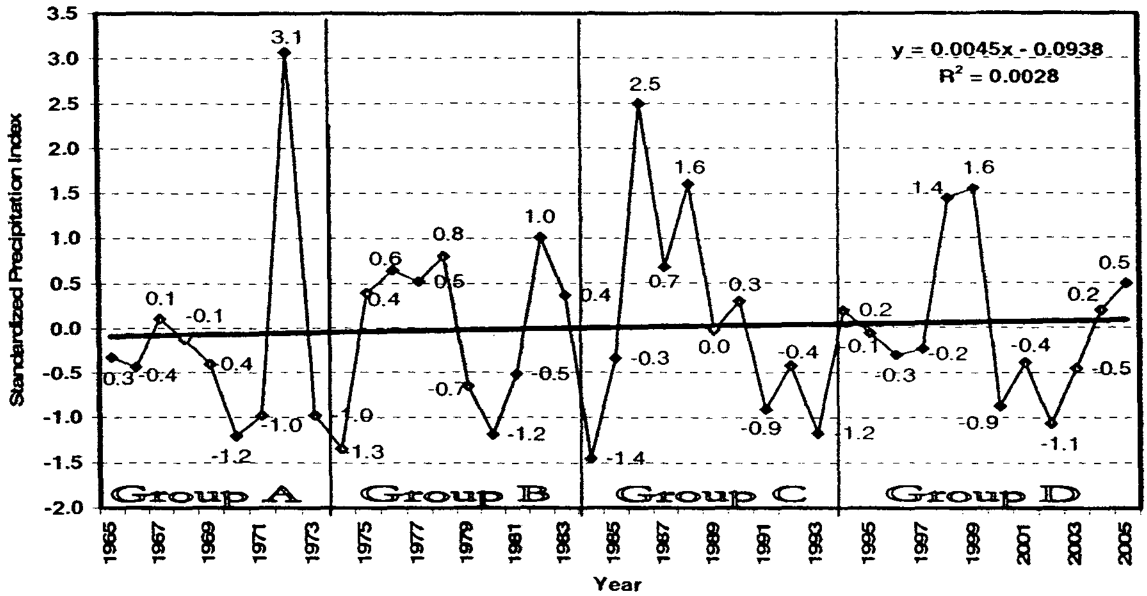

Figure No.4.9c Temporal Variation and Linear Trend in Annual Precipitation 1968-2005

Figure No. 4.9 (a,b,c): Temporal variation of annual SDI of the Parvati river at Bhuntar and its relationship with annual SPI and STI of the NWH during the period (1968-2005)

4.10 SUMMARY

This study indicates a significantly decreasing pattern in average annual and monsoon discharge in the Parvati River. The statistics of the trend analysis of discharge, temperature and precipitation in all seasons on parametric and non-parametric scales is shown above in Table No.4.6. It is clearly evident from the table that, declining trend in discharge of the Parvti river is shown a in all the seasons and is significant at 95% of confidence level. Precipitation figures show an increasing trend in spring and summer seasons but is not significant. Precipitation Figures suggests that there is no significant change in the precipitation regime in the basin. Temperature figures in the basin clearly demonstrate a slight increase in temperature in all the seasons, but only the winter season temperature figures are showing a significant positive change.

From the above data and literature reviewed, it is concluded that there is a slight increase in the temperature over the last fourty years in the basin. This also demonstrates the loss of glacial area and precipitation follows almost the similar trend in the period, despite of that discharge is continuously decreasing. This declining trend in the discharge is largely attributed to the waning of the glaciers and ice patches to a large extent resulted loss in glacial area of the basin.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

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The Himalayas occupie a unique position in geomorphology with its wide extent, stupendous heights and intricate topographic forms, having the largest concentration of glaciers outside the polar caps with a coverage of about 33000 km^2. Unlike the low-altitude glaciers in the Alps, the Himalayas offers a dynamic environment for the substance and continuity of glacial environment and associated processes only because the immense altitudinal variation is sustained through the tectonic uplift. The Himalayan glaciers are waiting for a more organised investigation, which till the time are investigated over a scattered area in a subroutine manner, mainly due to the inaccessible terrain.

Climate of the Himalaya is primarily determined by two seasonal atmospheric conditions: the summer monsoon and the winter westerlies. Monsoonal precipitation accounts for the large amount of annual precipitation in the Himalaya. The amount of precipitation decreases toward the west because it is supplied mainly from south east. It is also influenced by the orographic condition: the pockets of very high precipitation are located at the southern slope of middle mountains (lesser Himalaya), where cumulus clouds develop by an orographically induced up-valley wind. Most of the winter precipitation originates from cyclone disturbances associated with trough embedded in the Subtropical Jet Stream flowing along the southern periphery of the Tibetan Plateau. Disturbances from around the Mediterranean Sea are usually dissipated over the Western Himalaya, therefore, the amount of precipitation in winter decreases towards the east. The trend analysis of the precipitation behaviour in the Parvati valley suggest that there is no significant change in the amount of precipitation in any of the seasons during a span of about fourty years however, there is a clear warming trend in all seasons, with the strongest trend in winter and the weakest in spring. The discharge of the Parvati river is continuously decreasing, the probable reason for such trend is the excessive waning of small glaciers and decrease in the areal extent of glaciers as literature suggests, but this need a more comprehensive and detailed research.

The snowline increases towards the north in the Himalaya, probably reflecting the latitudinal gradient in the amount of precipitation. The highest snowline is just north of the Great Himalaya, attaining at an altitude of 6000 to 6200 m. The longitudinal change of the snowline is not very clear in the central part of Himalaya, but at the eastern and western ends, it is lower than 5000 m. Termini of glaciers descend as low as 3000 m at the western and eastern ends of the Himalaya, while they are located at an altitude of more or less, 5000 m in the central part of the Himalaya, the probable causes of this is the latitudinal effect and differences in the amount and type of precipitation. The average ELA of the Parvati basin was 4976 meters in 2006. The amount of glacial retreat depends upon overall mass balance and rate of melting at the terminus. Debris cover can influence rate of melting at the terminus. Excessive debris retards melting and protects a glacier from retreat. One of the parameters which can influence snow line is orientation and topography of glacial valley. The Parvati glacial valley is gentle and wide causing more solar radiation to be received on the glacial surface. In addition, gentle slopes cause less accumulation of avalanche snow. If snow pack is shallow, it can expose glacial ice for longer duration. Low albedo of ice compared to snow can cause further absorption of solar radiation and lead to more negative mass balance. Therefore, it appears that wide valley, gentle slope and low altitude are the major cause for rapid retreat of the Mantalai glacier. Other glaciers of the basin also show the retreating trend like Saraumga, Tichu, Girvokoti, Dibika, Ratiruni, Tos, Bakarbihar.

There is conclusive evidence of the increase of temperature in the Parvati basin. The debate on the climate change, which suggests that Himalayan glaciers are melting at a very fast rate (IPCC, 2001, 2006, 2007) is recently contradicted by a study done by the researchers at Newcastle University in 2008, which reported that the glaciers are growing rather than shrinking and they blamed global warming for the growth of the glaciers.

Conclusions

1) Total glaciated area in the basin decreased from 463.8 km^2 in 1963 to 340.6 km^2 in 2006. However, such a large reduction in the glacial area may be due to an error in the SoI toposheets, which were created for topographical details and not for the glacier positioning .

2) The average rate of retreat in the Parvati Basin was 27 meters per year in the period from 1963-72, the largest retreat shown by Mantalai glacier i.e.118 m/year. In the succeeding years 1972-89, the average rate of retreat was increased to 38 m/year, in 1989-2000, the average rate of retreat was decreased to 28 m/year, which further raises to 37 m/year in 2000-2006.

3) The mean ELA of the basin was 4950 meter in 1963, which rose to 4970 meter in 1989, with a fluctuation of 20 meters. Such a large difference in ELA value may be due to an error in the SoI toposheets. The period from 1989-2006 show a fluctuation of 6 meters. For more accurate analysis there is a need of ground truthing.

4) The trend analysis of discharge of Parvati shows that in last four decades there has been significant decrease in the discharge of the Parvati river in all four seasons. The maximum amount of discharge occurs during summer season which lies between (15000-20000 m^3/ second), is mainly contributed by the glacier melt, base flow and pre monsoonal rainfall.

5) The annual trend of the mean temperature of the basin shows a slightly increasing trend over years, ranging from 17.7°C to 18.1°C. The winter season, among all the seasons shows greatest increase in the temperature years i.e. by .5°C, this rose from 10.3°C to 10.8°C.

6) Trend analysis of the precipitation pattern reflects negligible change in the precipitation over the years in the basin. Trend line of the spring, autumn and winter season precipitation shows a negligible change over the years, while summer season shows a slight increase in the precipitation over the years. Annual pattern of precipitation in the basin also shows a slight increase i.e. from 909 mm. to 1054 mm.

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APPENDICES

Annexure 3.1:-CHANGE IN THE AREAL EXTENT OF GLACIERS IN PARVATI BASIN (1963-2006)				
	Toposheet glaciers area	Imagery glaciers area	Change (▲)	% Decrease in Area
Total area (Km2)	**463.8**	**340.6**	**123.1**	**26.6**
Man Talai (99)	46.8	31.0	15.8	33.8
Sara umga (74)	54.7	34.0	20.7	37.8
Tichu1 (57)	34.8	30.2	4.6	13.3
Dibika1 (3)	33.1	26.5	6.6	20.0
Tosna-pf (8)	31.8	22.1	9.7	30.4
Ratiruni (93)	24.5	17.9	6.5	26.7
Girvi koti (66)	23.2	18.0	5.2	22.5
Dibika2 (34)	23.0	20.1	2.9	12.6
Daunspar khol (7)	22.8	21.1	1.7	7.4
Bakar bihar khol (92)	17.8	15.8	2.0	11.1
Total for big glaciers	**312.3**	**236.6**	**75.7**	**24.2**
Tichu2 (91)	10.9	10.0	0.9	8.2
Parbati (9)	10.6	8.4	2.2	20.6
94	7.7	5.0	2.7	35.4
60	6.0	5.1	1.0	16.0
58	5.4	3.7	1.7	31.9
96	5.1	4.0	1.1	21.2
54	4.6	3.2	1.4	30.7
84	4.0	0.7	3.4	83.4
95	4.0	1.6	2.4	60.8
62	3.8	2.1	1.7	43.6
61	3.7	2.6	1.1	31.0
86	3.6	2.6	1.0	29.0
4	3.5	3.2	0.4	10.9
79	3.5	3.4	0.1	2.5
90	3.1	2.7	0.4	12.1
72	3.0	2.7	0.3	9.6
70	2.5	1.7	0.8	31.7
88	2.5	2.2	0.3	11.8
78	2.[illegible]	0.0	2.4	100.0
97	2.[illegible]	1.9	0.4	17.3
81	2.2	2.1	0.1	4.6
85	2.2	0.9	1.3	61.0
56	2.2	2.0	0.2	11.3
80	2.1	1.8	0.3	14.7
82	2.1	1.6	0.5	23.7
75	2.1	2.0	0.1	4.8
2	2.0	0.0	2.0	100.0
83	1.8	1.0	0.8	43.8
73	1.7	0.3	1.4	81.1
76	1.6	1.3	0.3	20.0
64	1.5	1.4	0.2	9.9
1	1.5	1.2	0.3	21.2
26	1.5	0.0	1.5	100.0
71	1.4	1.0	0.4	30.1
28	1.4	0.6	0.7	53.6
55	1.4	1.1	0.3	19.4
89	1.3	1.2	0.1	8.4
37	1.3	0.6	0.7	51.9
59	1.3	1.2	0.0	1.4

87	1.3	1.1	0.2	16.5
77	1.2	1.1	0.1	11.8
63	1.1	1.0	0.1	10.0
98	1.1	0.8	0.3	30.0
65	1.1	1.0	0.1	10.7
36	1.0	0.7	0.4	35.4
17	1.0	0.0	1.0	100.0
16	0.8	0.0	0.8	100.0
5	0.8	0.7	0.1	15.5
67	0.8	0.7	0.1	14.7
25	0.8	0.0	0.8	100.0
38	0.8	0.3	0.5	62.7
35	0.7	0.5	0.2	31.3
18	0.7	0.5	0.2	27.4
39	0.7	0.5	0.1	19.5
29	0.6	0.4	0.2	28.2
19	0.6	0.3	0.3	48.5
6	0.6	0.5	0.1	10.4
40	0.5	0.4	0.1	24.8
31	0.5	0.5	0.0	2.8
20	0.5	0.3	0.2	30.5
14	0.5	0.0	0.5	100.0
0	0.5	0.0	0.5	100.0
44	0.5	0.3	0.1	31.6
48	0.4	0.2	0.2	48.8
30	0.4	0.4	0.0	2.7
49	0.4	0.2	0.2	46.7
13	0.4	0.0	0.4	100.0
45	0.4	0.2	0.2	46.9
32	0.4	0.3	0.1	19.7
41	0.4	0.3	0.0	12.5
51	0.3	0.2	0.1	34.5
15	0.3	0.0	0.3	100.0
11	0.3	0.0	0.3	100.0
69	0.3	0.2	0.1	32.5
22	0.3	0.2	0.1	33.7
42	0.3	0.3	0.0	9.5
23	0.3	0.2	0.1	28.1
43	0.3	0.2	0.2	50.8
12	0.3	0.0	0.3	100.0
50	0.3	0.2	0.1	37.9
21	0.3	0.2	0.1	22.2
24	0.3	0.2	0.1	21.0
33	0.3	0.2	0.0	9.8
47	0.3	0.2	0.0	8.3
52	0.2	0.2	0.0	17.0
27	0.2	0.1	0.1	54.0
46	0.1	0.1	0.0	22.4
10	0.1	0.0	0.1	100.0
53	0.1	0.1	0.0	15.2
Total for small glaciers	151.5	**104.0**	47.4	31.3

Annexure No.4.1: Seasonal Discharge of Parvati River (1968-2005)					
Year	Spring Discharge	Summer Discharge	Autumn Discharge	Winter Discharge	Annual Discharge
1968	4142.5	19988.4	16342.6	2767.6	43241.1
1969	3742.5	18090.4	16213.9	2803.6	40850.4
1970	3054.5	15677.2	16760.0	2700.9	38192.7
1971	2947.3	17882.8	12683.7	2439.3	35953.1
1972	3071.4	15534.6	12792.0	2653.4	34051.4
1973	5410.7	22528.9	14895.9	2951.0	45786.5
1974	3090.3	11989.9	11596.5	2575.7	29252.4
1975	4095.2	14551.5	15545.3	2698.7	36890.6
1976	4158.1	15848.2	13287.7	2955.0	36249.0
1977	2801.4	14303.1	15440.9	3123.7	35669.1
1978	3541.2	20884.9	15359.6	2975.4	42761.2
1979	4199.7	15013.2	12181.5	2551.5	33945.9
1980	2777.1	15412.0	11122.6	2303.5	31615.2
1981	3287.6	15681.5	12333.7	2290.6	33593.4
1982	3679.0	13335.0	12381.7	2488.3	31884.1
1983	3429.3	13037.7	17226.7	2472.0	36165.6
1984	2737.9	16844.0	13577.2	2230.3	35389.4
1985	2639.5	16348.4	14396.4	2564.3	35948.5
1986	3146.3	17290.2	14556.4	2518.6	37511.5
1987	3070.7	15125.2	15054.3	2853.6	36103.8
1988	4052.2	18549.8	14931.9	2241.4	39775.4
1989	2663.1	15956.7	12625.1	2010.5	33255.5
1990	3410.9	20310.0	14822.0	1960.7	40503.6
1991	3668.4	19120.9	12704.8	1925.2	37419.2
1992	3219.0	15488.4	14247.8	1978.1	34933.4
1993	2865.6	16729.5	14070.5	1730.5	35396.1
1994	2414.0	18573.8	13404.2	1838.3	36230.2
1995	2229.0	16732.7	11826.0	2187.2	32974.9
1996	3276.0	11464.8	9948.0	2211.5	26900.3
1997	2219.1	11025.6	9651.7	2417.8	25314.3
1998	4254.4	13144.5	10137.7	2189.4	29726.0
1999	2491.1	9946.4	8813.6	1833.1	23084.2
2000	2323.7	9588.3	6522.0	1606.4	20040.3
2001	1276.2	8159.1	6529.8	1276.6	17241.7
2002	2667.9	10488.9	8075.0	1570.2	22802.0
2003	2617.9	10464.5	8303.0	1672.2	23057.6
2004	2485.2	8060.6	7201.2	1678.0	19425.0
2005	3293.2	13707.3	8961.9	1551.1	27513.5
Source:-Bhakra Beas Management Board, Discharge in Cusec					

Annexure No.4.2: Seasonal Temperature of Parvati River (1968-2005)					
Year	**Spring Temp.**	**Summer Temp.**	**Autumn Temp.**	**Winter Temp.**	**Annnual Temp.**
1968	13.8	23.8	22.4	9.6	17.4
1969	15.2	24.2	22.2	10.3	18.0
1970	14.9	24.9	23.0	9.9	18.2
1971	15.5	24.4	22.2	10.2	18.1
1972	14.6	24.4	21.3	10.7	17.8
1973	14.7	25.5	23.2	10.3	18.4
1974	15.6	24.1	23.1	10.3	18.3
1975	13.9	23.4	22.7	9.9	17.5
1976	13.5	23.4	21.2	10.6	17.2
1977	18.6	23.2	22.1	10.6	18.6
1978	13.6	24.8	22.3	10.5	17.8
1979	14.0	23.9	22.9	11.5	18.1
1980	15.0	25.1	22.9	11.3	18.6
1981	14.7	24.5	22.8	10.4	18.1
1982	12.9	23.6	22.3	10.4	17.3
1983	12.3	22.8	22.9	10.2	17.0
1984	14.9	25.9	23.1	10.7	18.6
1985	15.8	24.8	22.7	10.5	18.4
1986	13.8	23.4	22.1	10.5	17.5
1987	14.6	23.1	23.0	11.0	17.9
1988	14.9	24.5	22.3	10.7	18.1
1989	13.6	23.6	22.2	10.1	17.4
1990	13.0	24.5	22.6	11.3	17.8
1991	13.8	24.5	22.9	10.6	17.9
1992	13.8	23.6	22.7	10.7	17.7
1993	14.5	24.7	22.7	10.6	18.1
1994	13.9	24.4	22.4	11.5	18.1
1995	13.8	25.0	22.1	10.3	17.8
1996	14.5	23.5	21.9	10.3	17.5
1997	14.0	23.3	21.7	9.8	17.2
1998	14.0	24.5	23.2	11.0	18.2
1999	16.1	24.3	22.8	11.1	18.6
2000	14.5	24.6	23.0	11.5	18.4
2001	15.4	24.9	23.2	11.4	18.7
2002	14.6	25.2	21.9	11.0	18.2
2003	14.4	24.5	22.8	10.6	18.1
2004	16.7	24.3	21.5	10.5	18.2
2005	13.4	23.0	22.6	10.6	17.4
Source:-Indian Meteorological Department, Pune, Temperature in degree C					

Annexure No.4.3: Seasonal Precipitation of Parvati River (1968-2005)					
Year	**Spring Precipitation**	**Summer Precipitation**	**Autumn Precipitation**	**Winter Precipitation**	**Annual Precipitation**
1968	267.6	202.2	132.0	307.2	909
1969	293.2	185.1	293.4	69.2	841
1970	85.1	212.9	218.6	135.4	652
1971	152.5	262.0	196.7	93.9	705
1972	884.0	346.0	211.8	225.0	1667
1973	223.2	96.8	195.0	191.1	706
1974	78.8	293.3	106.3	139.8	618
1975	311.7	361.6	235.4	123.5	1032
1976	463.2	302.4	184.0	141.6	1091
1977	110.0	318.6	398.4	234.9	1062
1978	325.8	247.6	329.6	227.1	1130
1979	377.1	161.3	76.9	167.2	783
1980	210.5	224.1	126.8	94.5	656
1981	351.7	233.4	52.0	177.6	815
1982	465.8	244.3	199.1	269.1	1178
1983	425.7	231.1	214.9	151.9	1024
1984	270.7	103.5	129.7	89.9	594
1985	160.1	254.7	248.3	193.5	857
1986	874.1	269.6	205.0	182.9	1532
1987	496.2	367.6	180.5	55.5	1100
1988	429.9	270.1	390.6	228.2	1319
1989	236.8	277.0	177.6	239.7	931
1990	550.6	155.9	159.0	142.4	1008
1991	433.5	137.0	127.1	25.1	723
1992	355.8	182.1	137.6	160.6	836
1993	269.1	131.3	90.9	168.7	660
1994	368.9	288.3	201.4	124.8	983
1995	317.8	226.3	297.4	82.2	924
1996	326.0	231.1	192.0	116.9	866
1997	250.7	242.1	264.6	123.8	881
1998	512.5	273.9	464.4	31.6	1282
1999	85.5	414.7	204.3	603.3	1308
2000	221.3	372.8	52.8	84.9	732
2001	200.2	378.4	148.7	119.1	846
2002	362.1	62.9	185.0	74.2	684
2003	379.0	111.6	240.0	99.4	830
2004	109.7	393.3	324.5	156.8	984
2005	391.4	444.7	140.2	77.7	1054
Source:-Indian Meteorological Department, Pune, Precipitation in mm.					

Annexure No. 4.4: Seasonal Standard Indices of Discharge,Temperature and Precipitetion of Parvati River (1968-2005)

Year	Spring SDI	Spring STI	Spring SPI	Summer SDI	Summer STI	Summer SPI	Autumn SDI	Autumn STI	Autumn SPI	Winter SDI	Winter STI	Winter SPI	Annual SDI	Annual STI	Annual SPI
1968	1.3	-0.6	-0.4	1.4	-0.4	-0.6	1.3	-0.1	-0.8	1.0	-2.0	1.6	1.5	-1.1	-0.1
1969	0.8	0.7	-0.2	0.9	0.1	-0.7	1.3	-0.5	1.0	1.1	-0.6	-0.8	1.1	0.1	-0.4
1970	-0.2	0.4	-1.4	0.2	1.1	-0.4	1.5	1.0	0.1	0.9	-1.5	-0.1	0.8	0.6	-1.2
1971	-0.3	0.9	-1.0	0.8	0.3	0.1	0.0	-0.4	-0.1	0.3	-0.8	-0.6	0.4	0.3	-1.0
1972	-0.1	0.1	3.2	0.1	0.3	1.1	0.1	-2.0	0.1	0.8	0.3	0.8	0.1	-0.3	3.1
1973	3.0	0.2	-0.6	2.1	1.9	-1.7	0.8	1.3	-0.1	1.4	-0.6	0.4	1.9	1.1	-1.0
1974	-0.1	1.0	-1.5	-0.9	-0.1	0.5	-0.3	1.3	-1.1	0.6	-0.5	-0.1	-0.6	0.8	-1.3
1975	1.2	-0.5	-0.1	-0.1	-1.0	1.2	1.0	0.5	0.3	0.9	-1.4	-0.3	0.6	-0.9	0.4
1976	1.3	-0.9	0.8	0.2	-1.0	0.6	0.3	-2.2	-0.2	1.4	0.0	-0.1	0.5	-1.6	0.6
1977	-0.5	3.7	-1.3	-0.2	-1.3	0.7	1.0	-0.6	2.1	1.8	0.1	0.9	0.4	1.5	0.5
1978	0.5	-0.7	0.0	1.7	0.9	0.0	1.0	-0.2	1.4	1.5	-0.2	0.8	1.4	-0.2	0.8
1979	1.4	-0.5	0.3	0.0	-0.4	-1.0	-0.1	0.9	-1.4	0.6	1.9	0.2	0.1	0.3	-0.7
1980	-0.5	0.4	-0.7	0.1	1.3	-0.3	-0.5	0.9	-0.9	0.0	1.6	-0.6	-0.2	1.5	-1.2
1981	0.2	0.2	0.1	0.2	0.5	-0.2	-0.1	0.7	-1.7	0.0	-0.5	0.3	0.1	0.4	-0.5
1982	0.7	-1.4	0.8	-0.5	-0.7	-0.1	-0.1	-0.3	-0.1	0.4	-0.4	1.2	-0.2	-1.3	1.0
1983	0.3	-1.9	0.5	-0.6	-1.9	-0.2	1.6	0.9	0.1	0.4	-0.9	0.0	0.5	-1.9	0.4
1984	-0.6	0.4	-0.4	0.5	2.3	-1.7	0.4	1.3	-0.8	-0.1	0.2	-0.6	0.3	1.6	-1.4
1985	-0.7	1.2	-1.0	0.4	0.8	0.0	0.6	0.5	0.5	0.6	-0.1	0.5	0.4	1.1	-0.3
1986	0.0	-0.6	3.1	0.6	-1.0	0.2	0.7	-0.5	0.0	0.5	-0.1	0.3	0.7	-1.0	2.5
1987	-0.1	0.2	0.9	0.0	-1.5	1.3	0.9	1.1	-0.3	1.2	0.8	-1.0	0.4	0.0	0.7
1988	1.2	0.4	0.6	1.0	0.5	0.2	0.8	-0.3	2.0	-0.1	0.3	0.8	1.0	0.4	1.6
1989	-0.7	-0.7	-0.5	0.3	-0.8	0.3	0.0	-0.3	-0.3	-0.6	-1.1	0.9	0.0	-1.1	0.0
1990	0.3	-1.4	1.3	1.5	0.5	-1.1	0.8	0.3	-0.5	-0.7	1.5	-0.1	1.1	-0.1	0.3
1991	0.7	-0.6	0.6	1.2	0.5	-1.3	0.1	0.8	-0.9	-0.8	0.0	-1.3	0.6	0.1	-0.9
1992	0.1	-0.6	0.1	0.1	-0.8	-0.8	0.6	0.5	-0.7	-0.7	0.2	0.1	0.3	-0.5	-0.4
1993	-0.4	0.0	-0.4	0.5	0.7	-1.3	0.5	0.4	-1.3	-1.2	0.0	0.2	0.3	0.4	-1.2
1994	-1.0	-0.5	0.2	1.0	0.4	0.4	0.3	-0.1	0.0	-1.0	2.0	-0.3	0.5	0.3	0.2

1995	-1.3	-0.6	-0.1	0.5	1.1	-0.3	-0.2	-0.6	1.0	-0.2	-0.6	-0.7	0.0	-0.3	-0.1
1996	0 1	0.0	0.0	-1.0	-1.0	-0.2	-0.9	-0.9	-0.1	-0.2	-0.7	-0.3	-0.9	-0.8	-0.3
1997	-1.3	-0.4	-0.5	-1.2	-1.2	-0.1	-1.0	-1.3	0.7	0.3	-1.6	-0.3	-1.1	-1.5	-0.2
1998	1.4	-0.4	1.0	-0.6	0.4	0.2	-0.8	1.4	2.8	-0.2	0.9	-1.2	-0.5	0.6	1.4
1999	-0.9	1.5	-1.4	-1.5	0.2	1.8	-1.3	0.7	0.0	-1.0	1.1	4.7	-1.5	1.5	1.6
2000	-1.1	0.0	-0.6	-1.6	0.5	1.3	-2.1	1.1	-1.7	-1.5	1.9	-0.7	-1.9	1.0	-0.9
2001	-2.5	0.9	-0.8	-2.0	1.0	1.4	-2.1	1.3	-0.6	-2.2	1.8	-0.3	-2.3	1.8	-0.4
2002	-0.7	0.1	0.2	-1.3	1.4	-2.1	-1.5	-0.9	-0.2	-1.5	0.8	-0.8	-1.5	0.6	-1.1
2003	-0.7	0.0	0.3	-1.3	0.5	-1.6	-1.5	0.6	0.4	-1.3	0.1	-0.5	-1.5	0.4	-0.5
2004	-0.9	2.0	-1.3	-2.0	0.1	1.6	-1.8	-1.7	1.3	-1.3	-0.1	0.1	-2.0	0.7	0.2
2005	0.2	-0.9	0.3	-0.4	-1.7	2.2	-1.2	0.3	-0.7	-1.6	0.1	-0.7	-0.8	-1.1	0.5

Source:- Calculated from Data of Indian Meteorological Department, Pune