CHAPTER I
INTRODUCTION

1.1. Background of the study

The word monsoon is a derivative of the Arabic word *Mausim* or from the Malayan *Monsim* which means season. The term was first applied by the Arab navigators to winds over the Arabian Sea between Arab and India, which blow for 6 months from the northeast and for another 6 months from the southwest.

In meteorology, Monsoon signifies the directional shifting of winds from one season to the other. In summer, there is warm and moist wind blowing from the ocean towards the lands, while during winter time a cold and dry wind originating on land blows towards ocean. The term monsoon in singular form is sometimes applied to planetary winds which affect upper layers of the atmosphere over the whole globe. Sometimes it is used for regional winds blowing in the lower layers of the atmosphere over a well defined territory (Pedelaborde, 1963).

"The word monsoon is used only for wind systems where the seasonal reversal is pronounced and exceeds a minimum number of degrees." This term is applied to systems of wind which show at least 120 degrees of change of wind direction with a change of the season, and which are characterised by constancy higher than 40 percent and a mean resultant speed of more than $3ms^{-1}$. Such monsoons occupy a very large area situated mainly in the tropics (Nieuwolt, 1977).

Ramage (1971) defined the monsoon area as encompassing regions with January and July surface circulations in which:

1. The prevailing wind direction should shift by at least 120 degrees between January and July.
2. The average frequency of prevailing wind directions in January and July should be 40%.
3. The mean resultant wind in at least one of the months should exceed 3m/s.

4. There should be at least fewer than one cyclone-anticyclone alteration every two years in either months, over a five degree latitude- longitude grid.

Das (1968) described the monsoon as a system of wind shifts, caused by the differential heating of the land and sea, that is, by the different response of land and ocean to incoming radiation from the sun.

1.2. Statement of the problem

According to Khanal (1996) and Chalise (1997), every year more than 450 people are killed and properties amounting more than US$2.5 million are lost due to hazards related to weather in Nepal. The total annual environmental hazards in Nepal amounts to the death of 1150 people, 4000 animals, destruction of 18000 houses and properties amounting to more than 1476.7 million rupees (Khanal, 1996). In an average, the loss is equivalent to nearly 5% of the real GDP and 13% of the total development expenditure of the government. In India, average annual loss of life due to floods is about 1439 and the total property damage is equivalent to 7683 million Rupees (Sharma, 1999). On an average 4888 people are killed and 59 million get affected annually from various types of disasters. In China, landslides alone are estimated to cost US$15 billion in economic losses and 150 deaths annually (Li, 1996).

Triggering factors such as rainfall and earthquakes make the mountains highly vulnerable to landslides and other mass-wasting processes. The combination of weak geology and a monsoonal climate makes each physiographic zone of Nepal unique in its vulnerability to landslides. At present the most active parts of the Himalaya are the Siwalik and the Mahabharat ranges.

The seasonal change of weather associated with the monsoon circulation over Asia, especially over the Indian subcontinent, has intrigued meteorologist and climatologist over a century. The livelihoods of nearly billion people depend on the seasonal monsoon rains. The weather in Nepal during monsoon period is controlled by the Indian monsoon regime from June to September. The depressions that form along the Bay of Bengal are the main causative agents for the rain producing monsoon events in the country. Monsoon brings not only life to millions of people in Nepal but excessive rainfall or deficit rainfall brings about hazardous consequences in the country. Excessive rainfall can cause flood in the country with loss of life and properties. Also the deficit of monsoon rainfall can cause drought in many parts of the country with loss of crops. The excessive rise of temperature in the beginning of monsoon period affects the livelihood of people. Monsoon brings coolness on temperature, maintains circulation of water to operate and balance the hydrological cycle. But if the excessive temperature rises then it brings unusual hardships to the livelihood of people. The failure of crop cultivation can bring economic failure as Nepal is an agricultural country and 80% of the people depend on the monsoon rains for crop cultivation. This can bring famine in the country. So, the study of monsoon is important.

In this context, the present study has been done to fulfill the following objectives.

1.3. Objectives of study

The specific objective of the study is

- To analyze rainfall during the monsoon period.(1 June -30 September)
- To study about the long term rainfall pattern of Nepal.
- To study about the relationship between temperature and rainfall pattern.
- To analyze extreme maximum temperature and rainfall in June 2005.
- To study about the weather related disasters in monsoon 2005.

1.4. Justification of the study

Summer monsoon in Nepal plays a key role in the social and economic aspects of the Nepalese people. Monsoon brings water to the people in the country and the farmers depend on monsoon rain for the growth of their crops. Since most of the land is far from irrigation, only the natural rain could be helpful to them.

The bottom line for evaluating the worth of these contributions depend nearly on the ability of meteorologists in analyzing weather processes at work, and in making forecasts of the kind of weather activity these processes will produce. Thus, the art of forecasting is the cornerstone on which factual contribution to society rests.

The definite benefits of the study of summer monsoon in Nepal are:-

- This compiled study of summer monsoon in Nepal can be useful for researchers in analyzing the summer monsoon in Nepal.
- The broad aspects of the study can be helpful to the social and economic development of people's livelihood.
- Agriculture production can be increased if the nature of the monsoon is well understood in advance.
- Since every year during monsoon period floods, landslides occurs, these problems could be alleviated through weather forecasting and warning.

1.5. Literature Review

This chapter reviews the summarization of methods applied in the study of summer monsoon. The literature review of the method, research and previous work done on same aspect are very important for the further new research. Of the several literatures about Summer Monsoon, only some of them which are relevant to study have been reviewed.

Baros and Lang (2001) in a monthly weather review "*Monitoring the Monsoon in the Himalayas: Observations in Central Nepal, June 2001*" studied the monsoon by launching radiosondes around the clock from two sites, one in the Marsyangdi River basin on the eastern footslopes of the Annapurna range, and one farther to the southwest near the border with India. The flights supported rainfall and other hydrometeorological observations (including surface winds) from the Marsyangdi network that has been operated in this region since the spring of 1999.They also compared the MOHPREX data with the NCEP-NCAR reanalysis data which revealed that upper level winds are characterized relatively well by the reanalysis, taking into account the coarse model topography.

Devkota (2004) has studied the southwest summer monsoon. He has studied the climatic variation relying upon empirical investigation .He has analyzed the comprehensive rainfall (1956-2000) and temperature (1968-2000) data sets from Nepal from various statistical methods. The analytical results are summarized under four categories (1) observed climate and variability, (2) forecasting of summer monsoon rainfall, (3) Regional climate model diagnostics, and (4) impact of climate on agriculture and water resources.

Mandal et al., (1993) studied the advance of southwest monsoon in 1991 that was initiated with an onset vortex forming in the Bay of Bengal. The vortex formed as a low pressure area in the southwest Bay on June 5 and moved northwestward over the peninsula after crossing the Tamilnadu Coast. It lay over the northern parts of Maharashtra on June 8 and 9 and recurved eastwards over Madhya Pradesh till June 12, 1991 and later dissipated over the same area. Under the influence of this low pressure area the monsoon progressed rapidly northwards and covered most parts of the peninsular and eastern India 3 to 7 days before the normal dates.

The study done by DHM (2003), "*Proceedings of Seminar on Summer Monsoon and Prediction Techniques*" has focused on the various factors associated with the monsoon and the prediction techniques in the SAARC region. It has also focused on the numerical forecasting techniques and its impact in the region.

Barros et al., (2004) carried out a study "*Probing orographic controls in the Himalayas during the monsoon using satellite imagery*". They investigated the linkages between the space-time variability of observed clouds, rainfall, large-circulation patterns and topography in northern India and the Himalayas using remote sensing data. The results suggested that space time distribution of precipitation, the spatial variability of the diurnal cycle of convective activity, and the terrain (landform and altitudinal gradients) are intertwined at spatial scales ranging from the order of a few km(1-5km) up to the continental scale. Furthermore, this relationship is equally strong in the time domain with respect to the onset and intra-seasonal variability of the monsoon.

Webster et al., (1998) conducted a study "*Monsoons: Processes, predictability, and the prospects for prediction*" in which the Tropical Ocean-Global atmosphere (TOGA) program sought to determine the predictability of the coupled ocean-atmosphere system. The World Climate Research Programme's (WCRP) Global Ocean-Atmosphere-Land System (GOALS) program seeks to explore predictability of the global climate system through investigation of the major planetary heat sources and sinks, and interactions between them. The Asian-Australian monsoon system, which undergoes a periodic and high amplitude variation on intraseasonal, annual, biennial and interannual time scales is a major focus of GOALS.

Researchers at Ohio State's Byrd Polar Research Centre and the Chinese Lanzhou Institute of Glaciology and Geocryology studied the ice cores drilled through a glacier more than four miles up in the Himalayan mountains have yielded a highly detailed record of the last 1,000 years of earth's climate in the high Tibetan Plateau.

The South Asian monsoon is a major climate events that cycles annually across India, Pakistan, the Southern Himalayan region, the Far East and reaches as far west as Africa. In the summer, when the Eurasian continent is warmed by solar radiation, prevailing winds flow onshore heavily laden with moisture from the oceans, and bringing the heavy monsoon rains that drench the regions. In winter, high pressure over the high Tibetan Plateau reverses the cycle and the dry winds from over the continent flow offshore and continents in the region are dry. Changes in the monsoon cycle can bring catastrophic flooding or droughts.

Rajbahak and Shrestha (2005) in their paper *"A diagnostic study of onset and withdrawal of summer monsoon in Nepal, 2003"* tried to explain the cause of delay in the onset and withdrawal of monsoon 2003 with the help of synoptic charts and satellite imageries.

Brahic (2007) in the special report earth "*Climate change may boost monsoon and worsen droughts*" explained that several drought conditions will increasingly encroach into the southern parts of Australia and the west of Indonesia if climate change strengthens the Asian monsoon as expected. The droughts will become common in areas of the countries that are commonly rarely affected, and for prolonged seasons the researchers say. And the droughts could be worse during the summer months, a time when agriculture is most vulnerable to them, bringing food shortages and wildfires to the region.

Das (2003) in his paper "*Mountain Weather forecasting using MM5 model*" investigated the high resolution mesoscale model triple nested at 10km resolution for mountain weather forecast. Several cases of heavy rainfall events associated with western disturbances, thunderstorms and severe weather have been studied. Preliminary results indicated that the model has a good capability of making severe weather forecasts upto 72 hours. Advance warnings from accurate weather forecasts from such models can be used for planning agriculture, water resources, transportation, public safety, industry and recreation. The mesoscale model can also be used to address climate related issues such as regional variations in precipitation characteristics, glacial shifts, intensity of droughts and floods over the mountain regions.

CHAPTER II

THE SOUTHWEST MONSOON

As the Indian subcontinent heats intensively in April and May the zonal westerlies over northern India begin to move northward but this is resisted by mountains. As a result the jet stream which has been south of the highlands at about 30°N during winter and spring tends to alternately disappear and then reappear south of the mountains. Disappearances become more frequent as the season advances and each disappearance is associated with a northward surge of summer monsoon. Finally in late May or early June, the jet disappears completely over Northern India and takes up a position at about 40°N to the north of the Himalayas and Tibet. Simultaneously there occurs a shift of the low latitude trough and ridge positions, and the upper trough which previously was located at about 85°E quickly moves westward some 10 degree and takes up a position over western India at approximately 75°E. With the disappearance of the jet over northern India and westward shift of the upper trough, the equatorial westerlies, or summer monsoon surge, northward over India accompanied by unsettled weather.

2.1. Weather Systems during Monsoon

Southwest Indian summer monsoon generates some systems, which are semi permanent in nature. These systems are present during the monsoon seasons on most of the days and remain more or less in the same location in a quasi-permanent state. Another systems which are generally migratory and may not be present on every day are monsoon disturbances.

2.2. Semi permanent Systems

2.2.1. The Heat Low

The heat low starts developing over central India in April and establishes itself over Pakistan in July. The heat low develops mainly due to the intense surface heating over the northern hemisphere during the summer months. However the heat low does not exactly develop over the region of highest temperature, which is over Sahara. The normal lowest surface pressure in the heat low is 994 hPa, which is the lowest surface pressure at msl over the northern hemisphere during summer. The heat low is shallow and extends up to only 1.5 km amsl. Aloft it is overlain by a high pressure cell.

2.2.2. Monsoon trough

The monsoon trough is not a quasi-stationary system. It shows periodical movements to the north and south of its normal position. When it moves north and lies close to Himalayan foothills, there is a remarkable change in the rainfall pattern over India. The rains cease abruptly over the plains of northern India, but increase equally rapidly in intensity over the foothills of Himalayas. This is known as a 'break' in monsoon situation. During break monsoon days, areas under the Sikkim and eastern Nepal Himalayas and their neighborhood receive heavy rainfall, which is 50 to 300 percent or more of the daily rainfall over these areas, while the areas south as well as to the north receives less rainfall. A southward shift of the axis of the seasonal monsoon trough from its normal position results in a well-distributed rainfall over the central parts of the India and adjoining northern parts of the Indian peninsula.

During a break situation, a paradox often arises in which flooded rivers from the Himalayas inundate areas in the Ganga plains, which are under drought conditions. Break situations very rarely last for more than a week at a time and generally occur in July and August of the summer season. The monsoon trough is the most important feature in the lower troposphere over Indian Subcontinent during the summer monsoon season, the four month period from June to September.

2.2.3. Easterly Jet Stream

The belts of strong easterly winds blow along the southern periphery of an upper tropospheric anticyclone. This narrow belt of strong easterlies is observed between 200 and 100hPa. These easterly winds, which often record speeds exceeding 100 knots, are known to meteorologists as the Easterly Jet Stream of the tropics. The core of the Easterly Jet Stream is located at about 150hPa (13 km).

2.2.4. Tibetan Anticyclone

The Tibetan High is a dominant feature which is related to the monsoon's onset. Tibetan Highland plays a crucial role in initiating the monsoon circulation over the Indian Subcontinent emerging of a zone of high pressure over it. The reasons for the formation of the high are not very well understood at present.

The Tibetan Plateau is 600 km wide in west and 1000 km wide in the east. Its length is about 2000 km. The average height is about 4 km. It is an enormous block of high ground acting as a formidable barrier. Tibetan plateau affects the atmosphere in two ways, acting separately or in combination as a mechanical barrier or as a high level heat source.

2.2.5. Mascarene High

This is a high pressure cell at the surface level observed over Western Indian Ocean, east of Madagascar. The outflow from this high travels northwards, gathers moisture over Indian Ocean and Arabian Sea and arrives at west coast of India as the southwesterly monsoon current.

The intensity of Mascarene High pressure at 30°S/60°E was above normal in September by 2.5 hPa in June and normal in August. It was below normal by about 1.5hPa during July. Source (Climate Diagnostic Bulletins, NOAA, and June to September 2005).

2.3. Monsoon Disturbances

2.3.1. Monsoon Depressions

A good part of the rainfall during the monsoon is generated by the westward passage of depressions or low pressure systems in the Bay of Bengal. On an average, one to three such systems are observed in the monsoon months, especially in July and August. The usual lifetime of these systems is around a week. Their mean tracks reveal west-northwestwards.

A depression or a low is an atmospheric vortex with a central region of low pressure. In the northern hemisphere, the wind blows round the centre in a counter-clockwise direction. The intensity of the vortex is measured by the strength of winds. Thus, when the winds round the vortex are strong, the depression is classified as deep depression; with still stronger winds a deep depression becomes a cyclonic storm and so on. The classification of atmospheric vortices is given below in Table. 2.1.

Table. 2.1. Classification of Atmospheric Vortices

System	Range of wind speed (m/s)
Low	8.5
Depression	8.5-13.5
Deep Depression	14.0-16.5
Cyclonic Storms	17.0-23.5
Severe Cyclonic Storms	24.0-31.5
Hurricanes/Typhoons	Greater than 32.0

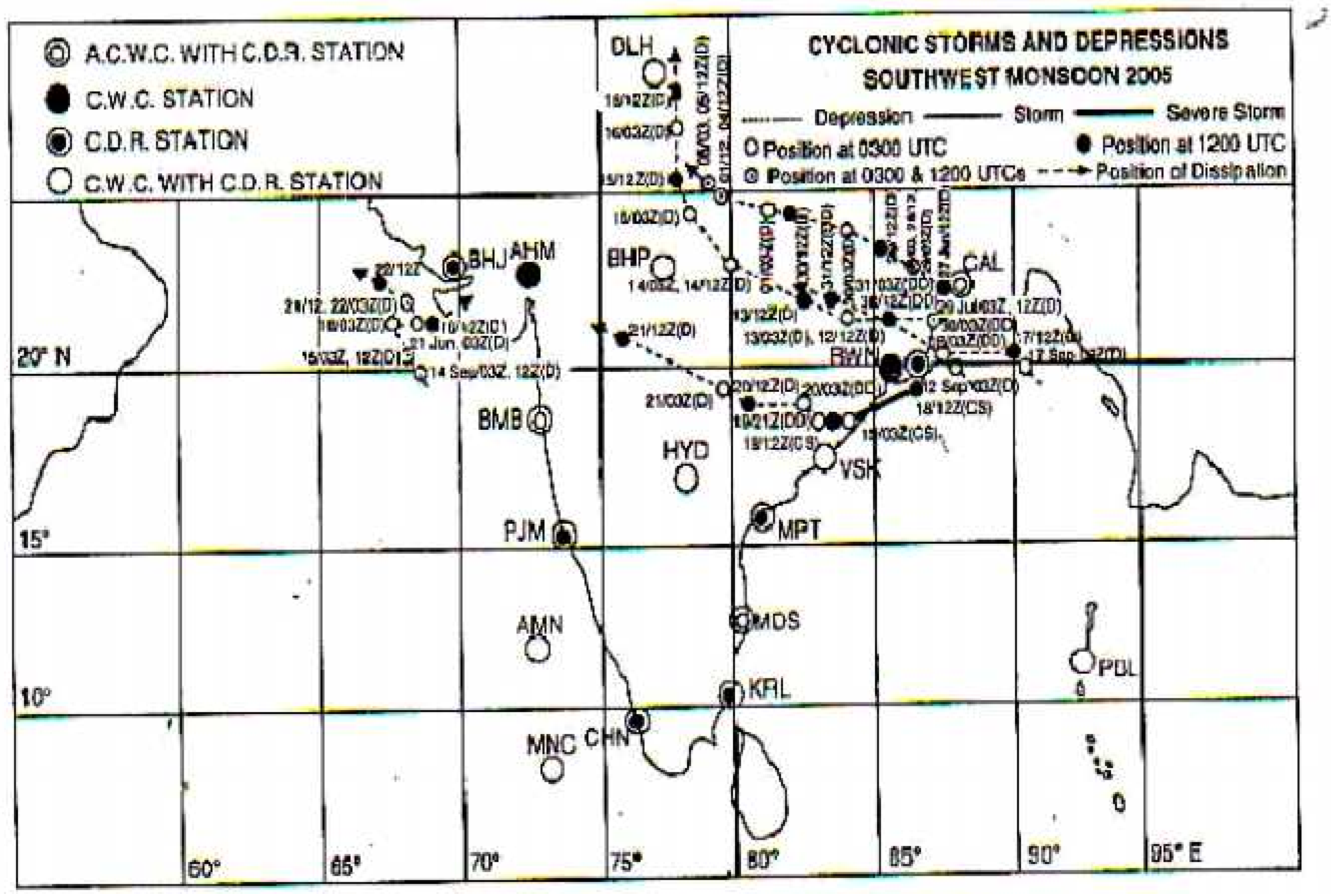
Source:Das,P.K.1968

Associated with these disturbances, both the Arabian Ocean and the Bay of Bengal branches of the summer monsoon currents strengthen considerably and cause heavy to very heavy rainfall over the region. However, it has been observed that in the summer monsoon, heavy rainfall generally occurs in the southwestern sector of these disturbances. During monsoon 2005, one cyclonic storm and 5 depressions were formed, two each over the Bay of Bengal and the Arabian Sea and one, a land depression.

2.3.2. Monsoon Lows

Low pressure areas are less intense than monsoon depressions but they form frequently during the monsoon months and their contribution to the rainfall is quite substantial. Passage of low pressure areas both of ocean or land origin or movement of upper circulations during summer monsoon months often cause heavy rains and consequent floods.

Altogether 6 low pressure areas/well marked low pressure areas were formed during the monsoon season in 2005. The tracks of the systems are shown in Fig. 2.1.



Source: Mausam, July 2006

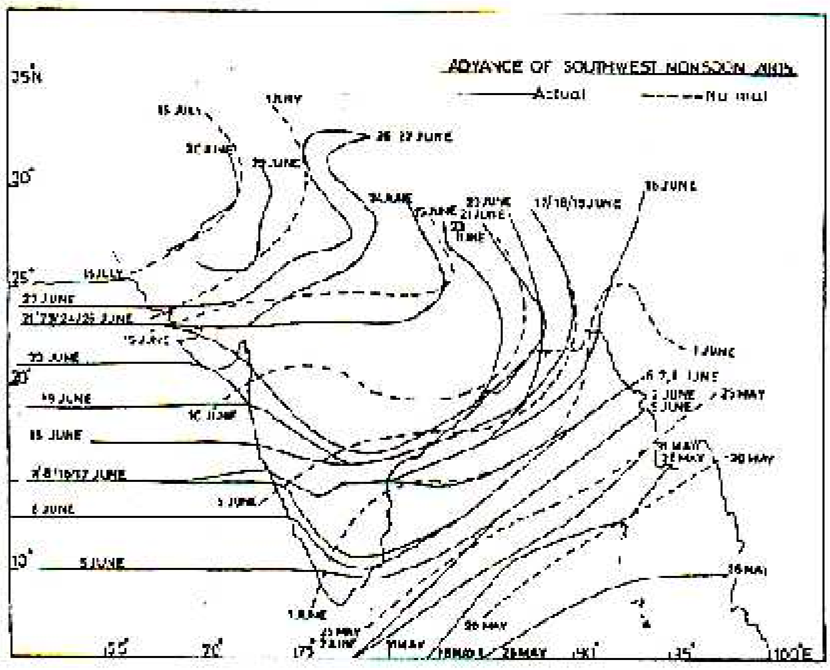
Fig.2.1 Tracks of Storms and Depressions during Southwest Monsoon 2005.

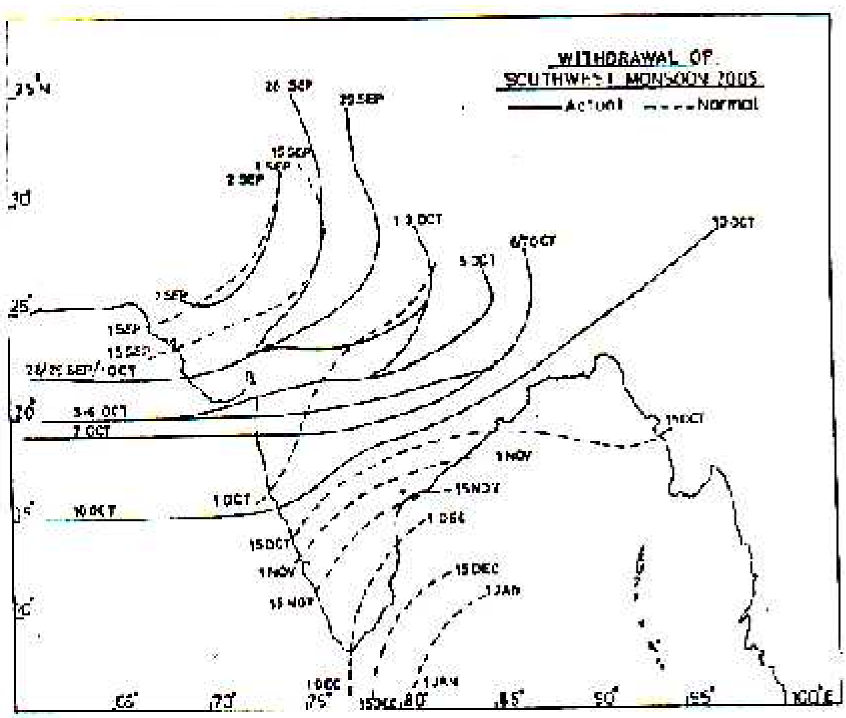
2.4. Onset and withdrawal of monsoon

The arrival and departure of the monsoon is defined from the onset and retreat. The monsoon is associated with precipitation hence sudden increase in rainfall over a large area. Cumulative rainfall chart is prepared for all the stations and the sudden change (rise) in curve is considered as the date of onset of monsoon and the sudden change (horizontal) is taken as retreat of the monsoon.

A prolonged absence of rainfall and a change of circulation patterns resulted in withdrawal of southwest monsoon from the extreme west Rajasthan on 2 September, near about the normal date (1 September). Monsoon 2005 retreated from the country on 29 September, delaying by nearly one week from its normal retreat days (23 September).

Monsoon does not start all over the places at one time rather the date of onset vary from year to year as well as from region to region. The normal dates of onset and withdrawal of monsoon and the dates of onset and withdrawal of monsoon 2005 are shown in the Fig. 2.2.





Source: Mausam, July 2006

Fig. 2.2. Advances and withdrawal of Monsoon 2005.

CHAPTER III
METHODOLOGY

3.1. Selected Stations

21 stations in Nepal are included in this study. The selection is so done that at least one station from one region is included in the study. Dadeldhura, Dipayal and Dhangadi from Far Western Region, Birendranagar, Nepalgunj, Jumla and Dang from Mid Western Region, Jomsom, Bhairawa, Pokhara from Western Region, Simara, Kathmandu, Jiri, Nagarkot, Janakpur, and Bharatpur from Central Region and Rajbiraj, Dhankuta, Dharan, Biratnagar, Taplejung and Okhaldhunga from Eastern Region are included in the study. The altitude of the station varies from 72m at Biratnagar station to 2300m at station Jumla. The locations and elevations of the stations plotted are given in Table. 3.1 and is shown in Fig. 3.1.

Table..3.1. Locations and Elevations of the Stations Plotted.

S.No	Station Name	Index No	Latitude(N)	Longitude(E)	Elevation(m)
1.	Dadeldhura	0104	29°18′	80°35′	1848
2.	Dipayal	0218	29°15′	80°57′	617
3.	Dhangadi	0209	28°41′	80°36′	170
4.	Birendranagar	0406	28°36′	81°37′	720
5.	Nepalgunj	0420	28°06′	81°40′	165
6.	Jumla	0303	29°17′	82°10′	2300
7.	Dang	0515	28°03′	82°30′	634
8.	Pokhara	0804	28°13′	84°00′	827
9.	Bhairawa	0705	27°31′	83°26′	109
10.	Simara	0909	27°10′	84°59′	154
11.	Kathmandu	1030	27°42′	85°22′	1336
12.	Okhaldhunga	1206	27°19′	86°30′	1720
13.	Taplejung	1405	27°21′	87°40′	1732
14.	Dhankuta	1307	26°59′	87°21′	1210
15.	Biratnagar	1319	26°29′	87°16′	72
16.	Janakpur	1111	26°43′	85°58′	90
17.	Nagarkot	1043	27°42′	85°31′	2163
18.	Jiri	1103	27°38′	86°14′	2003
19.	Jomsom	0601	28°47′	83°43′	2744
20.	Bharatpur	0914	27°40′	84°26′	223
21.	Dharan	1311	26°49′	87°17′	444

3.2. Data Collection

This dissertation paper is based on secondary source of data and information. The datas and information are collected from various agencies like DHM, Central Library of T.U., different official annual reports bulletins, journals, different books and dissertation (all of the data source has been mentioned in the reference of this dissertation paper) written by various authors. Further, more information were obtained from the websites of different countries related to meteorology. Necessary maps, charts, diagrams were presented for the illustration of discussions and findings. Finally a dissertation paper has been prepared to fulfill the objectives.

The data for rainfall (1972-2002) and temperature (1972-2002) for monsoon season are collected from Climatological Records of Nepal, Department of Hydrology and Meteorology. The data for rainfall (2003-2005) and absolute extreme temperature (2003-2005) for monsoon season are collected from Weather Summary of Nepal, Department of Hydrology and Meteorology. The data of daily rainfall for monsoon season from June to September are collected from the website www.mfd.gov.np of Department of Hydrology and Meteorology. The analyzed upper air as well as surface map is obtained from Meteorological Forecasting Division, Department of Hydrology and Meteorology. The events of weather hazards in the year 2005 are collected from the Kantipur daily, Himalayan times and the Rising Nepal.

For synoptic analysis different papers and meteorological sites were considered. The analyzed surface and upper air analysis were obtained from DHM. The synoptic charts are presented only to associate with significant weather changes in Nepal during the monsoon period. The dates selected represent heavy rainfall conditions of the country.

Similarly, the satellite image of TRMM and DMSP are also included in the study. It is not for any investigation but only to show the atmospheric condition at 27 July when Mumbai received exceptionally heavy rainfall.

For weather hazards important events in the year 2005 are selected to fulfill the objective properly. For weather hazards details for whole Nepal are considered. Most of the information was collected from Himalayan Times, The Rising Nepal and The Kantipur daily.

3.3. Methodology

The methodologies applied in the study are described below:

3.3.1. Estimation of the missing rainfall records

Sometimes, the measurement of rainfall at a particular point for a certain day or time is not possible, may be due to absence of observer or instrumental failure, under such conditions, the missing data is estimated with the help of data recorded at nearby stations using the following methods.

a. Arithmetic Mean Method
b. Normal Ratio Method
c. Graphical Method
d. National Weather Service Method
e. Long term mean rainfall for a new station, method.

Among all the methods, arithmetic mean method is simple and easy to calculate.

3.3.2. Analysis of rainfall data

The precipitation process is essentially random in nature. The rainfall obtained from a single rain gauge station is known as the point rainfall or station rainfall. The daily rainfalls recorded at a station may be totaled to yield the rainfalls for longer periods such as monthly rainfall, seasonal rainfall and annual rainfall. If the observed rainfall in any year is less than the normal annual rainfall then it is called a deficient year or a dry year and on the other way it is called a surplus year or a wet year.

It is not possible to tabulate all the rainfall measurement, data- wise; therefore it is felt desirable to take the mean value of rainfall for the entire year and to present the same in the following form.

a. Chronological Charts
b. Bar Diagram
c. Ordinate Graph

Among all these methods, the methods applied in the study are:

3.3.2.1. Chronological Charts: In this presentation the annual rainfall is plotted as the ordinate against the year in which it is recorded as the abscissa. The points plotted are joined by straight lines in between.

The rainfall data are plotted chronologically between time in x-axis and precipitation in y-axis. A rain event is associated with randomness. To overcome the random component, a simple moving average of order 3 or 5 is used. This helps to isolate the trend in the rainfall data. If there is any dry or wet cyclic trend associated with precipitation, then such a trend can be clearly visible from the plot. From the graph, the wet period mean, overall mean and dry period mean can be identified. Such a method is applicable to annual series.

The procedure to construct the moving average curve is as follows.

- The moving average curve is constructed with a moving period of m year where m is generally taken to be 3 or 5 years.
- Let x_1, x_2, …………….x_n be the sequence of given annual rainfall in the chronological order.
- Let y_i denote the ordinate of the moving average curve for the i^{th} year.

$$y_3 = \frac{x_1 + x_2 + x_3 + x_4 + x_5}{5}$$

$$y_4 = \frac{x_2 + x_3 + x_4 + x_5 + x_6}{5}$$

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.
.

$$y_{n-2} = \frac{x_{n-4} + x_{n-3} + x_{n-2} + x_{n-1} + x_n}{5}$$

Advantage of the moving average:

- Weight or coefficient sum to unity and they are symmetric about the middle point.
- We get the same trend fit whether we fit forward or backward.
- It is easy to update.

Disadvantage of the moving average:

- Data at the beginning and end of a series are lost.

3.3.2.2. Bar Diagram: In a bar diagram, the rainfall is represented as a rectangular bar whose height denotes the magnitude of the rainfall to some scale.

3.3.3. Temperature Rainfall Correlation

As it is well known fact that rainfall in monsoon season is affected by various factors like topography, altitude, atmospheric characteristics etc. and also the impact of temperature on rainfall is equally important. In January when the temperature is less there is less rainfall in Nepal and in June, July, August and September when the temperature is high there is high rainfall in Nepal.

Plotting the temperature against rainfall and drawing a best fit curve can develop this relationship. This gives a rough estimate of temperature as well as rainfall. The genuine method is drawing the best-fit “linear regression line” between temperature and rainfall. It gives accurate result, when correlation coefficient between them is found approximately unity.

3.4. Limitation of the Study

i. Selection of limited stations: Limited stations are selected for the data analysis for several reasons. Though this study tends to cover whole Nepal, its approach is limited. Only 21 stations are included in order to cover whole Nepal due to lack of time and resource constraints. Out of 21 stations only 11 stations are considered for temperature rainfall relationship. As a result it may have affected the result.

ii. Unavailability of data: The datas of rainfall and temperature are collected for about 30 years but it is not possible to obtain the rainfall and temperature data for 30 years because the stations were not fixed in those periods and for some fixed stations the datas are missing.. The data of rainfall and absolute extreme temperature for Bharatpur station are available only for 3 years and are kept for comparison of extreme temperature and rainfall of three year.

CHAPTER IV
STUDY AREA

4.1. Nepal

Nepal is situated in the central part of the Himalayan arc and is tectonically sandwitched between Tibet in the North and India in the south (Sharma, 1990). It is situated between the latitudes 26°22'Nto 30°27' N and 80°40'E to 88°12'E. The average east west length of the country is about 885 km and the average north south width is 193 km. In its small width of 150miles it can boast of such diverse conditions as the eternal snows of Mount Everest and the hot languid temperature of the plains of India (Brown, 1984). Owing to its unique geographical position, the Himalayan mountain range influences the weather and climate in various ways. It acts as a strong barrier for the circulation pattern, as a heat source in summer and heat sink in winter. Its varying snow cover and vegetation cover affects the monsoon rainfall, which keeps the ecosystem rich and healthy. The entire Himalayan range including the Hindu Kush belt with its numerous peaks, snow, glaciers and forests controlling the existing climate are the life line in the region. The surface boundary conditions of the Himalayas determine the performance of the monsoon rainfall which has immense impact on water resources and agriculture production.

4.1.1Topography

Nepal can be divided into eight distinct physiographic units: the Terai, the Siwalik (Churia) Range, the Dun Valleys, the Mahabharat Range, the Midlands, the Fore Himalaya, the Higher Himalaya, and the Inner and Trans Himalayan Valleys. Each of these units has distinct altitude, topographical, climatic, and vegetational characteristics (Upreti, 1998).

4.1.2 Seasons in Nepal.

Seasons in Nepal can be divided into four categories. They are

1. Pre-monsoon (March-May)
2. Monsoon (June-September)
3. Post-Monsoon (October-November)

4. Winter (December-February)

4.1.3. Climatology of Rainfall and Temperature in Nepal

Strong spatial and temporal variations exist in both seasonal as well as annual rainfall distribution in Nepal. Topography plays very important role in these variations. During winter, western part of Nepal gets more rainfall with low variability under the influences of western disturbances. In the remaining seasons, rainfall amount is higher in the eastern than western parts of the country. Both monsoon and annual rainfall are highest over the middle mountainous region and low over leeward side of the Annapurna Range. Rainfall amount during monsoon has a dominating contribution to the total annual rainfall. Within the monsoon season, strongest rainfall occurs in July. In general, rainfall variability is high over low rainfall and low over high rainfall areas.

The temperature distribution in spatial domain, particularly along north –south direction, is dominated by the topography. Annual range of temperature is higher over the western part of Nepal than eastern part. Effect of monsoon circulation is strongest in maximum temperature distribution. The lower altitude region shows stronger annual cycles of temperature than higher altitude region (Devkota, 2004).

4.2. Monsoon in Nepal

Nepal enjoys monsoon first and foremost in the southeastern part of Nepal. Early monsoon onset and heavy rainfall in Nepal is associated with westward passage of the depression over the Bay of Bengal. At the same time, shifting of seasonal monsoon trough towards the foothills of Himalaya is the favorable condition for rainfall in Nepal. However, shifting of monsoon trough towards the foothills of the Himalaya abruptly cease rainfall over the plains of the northern India.

The normal date of onset of monsoon for Nepal is June 10. Monsoon enters Nepal first in the eastern Nepal and advance from east to west. Within 2 days it reaches Kathmandu and within 4 to 7 days it covers whole Nepal. The date of onset and withdraw of monsoon in Kathmandu from 1981 to 2005 are given in Table. 4.2.

Table. 4.2. Dates of Onset and Withdrawal of Monsoon in Nepal.

Years	Onset	Withdraw
	June	Sept
1981	23	11
1982	27	20
1983	24	29
1984	11	20
1985	17	26
1986	12	5-Oct
1987	14	2
1988	11	9
1989	11	2-Oct
1990	12	30
1991	9	19
1992	21	18
1993	8	28
1994	10	27
1995	4	2
1996	31-May	15
1997	17	23
1998	15	3-Oct
1999	13	6-Oct
2000	5	25
2001	3	10
2002	15	30-Sep
2003	15	1-Oct
2004	9	20-Oct
2005	20	29

Source: Meteorological Forecasting Division, DHM

The physical feature of Nepal shows that there is a marked variation of rainfall from south to north and from east to west. As the monsoon enters into Nepal from southern plain area and ascends up the hills and mountains, heavy rainfall occurs in Nepal in the windward side of hills and mountains whereas leeward sides receive no rainfall or very less rainfall. Pokhara and its vicinity facing windward sides in Nepal are observed to be highest amount of rainfall area. The rainfall record shows that the normal monsoon rainfall in Pokhara is observed to 3074.8mm. Kathmandu, the capital of Nepal experiences normal monsoon rainfall amounting 1084.6mm.

Rainfall activities in Nepal show that most of the eastern parts and lower hilly regions of the country receive more than 80% of the total rainfall during the monsoon season. The northern mountain areas of central and western region show less than 60 percent of monsoon rainfall as these areas are frequently obstructed by western disturbances.

The mean rainfall over Nepal during the monsoon season amounts to be 1422.6mm with the standard deviation of 132.6mm and coefficient of variation of 9.3 percent. At the same time, the mean annual rainfall for whole Nepal amounts to be 1767.7mm. Hence it shows that 80 percent of the total annual rainfall in Nepal is contributed by monsoon (Shrestha, 2000). The unevenness of rainfall is the main characteristics of summer monsoon in Nepal as the average rainfall ranges from 250mm in Mustang to 5200mm in Lumle, Kaski. The rainfall generally increases from foothills of lower Himalayas in the south decreases to the greater Himalayas in the north. It increases with the altitude up to a certain height.

4.3. Weather Hazards associated with summer monsoon

The hills and mountains of Nepal, comprising three quarters of her national territory and being the home area to 56 percent of her total population, have been suffering increased environmental hazards notably deforestation, soil erosion, landslides, flash floods and desertification(Robbe,1954; Enke, 1971:20; Eckholm,1980:76-77; NPC,1985:200). These have caused decline in land productivity, aggravation of scarcity of fodder and fuel wood, contamination of surface water, diminished supply of both ground as well as surface water and destruction of valuable agricultural land. The ecological degradation process has followed a cyclic path, with increasing frequency and intensity of events in each successive cycle (Thapa and Weber, 1990).

Severe types of weather hazards which affect life of the people living in Nepal during summer monsoon are listed below.

4.3.1. Landslides

During the rainy season, yearly hundreds of landslides are occurring in Nepal. These landslides wipe out many villages, block road, and bury canals, sometimes entire mountain appears to be moving.

Landslide mostly occurs during the rainy season and hence heavy rainfall is the main factor for slide. The heavy rainfall is partly soaked by the top soil and the load of the soil increases and slump and slide occurs. The rain water generally lubricates the weak rock plane and slide occurs (Sharma, 1990).

4.3.2. Floods

A flood is a relatively high flow which overtops the natural or artificial banks in any reach of a river. Floods are produced when the capacity of the river channel is inadequate to carry off the high quantity of water (Reddi, 1998). During active monsoon period continuous rainfall for several days causes flood in several parts of the country. Specially, Terai region has to face the problem of flood during monsoon period because of low land. The dams built by India on one side are also the cause of floods as the rivers in Nepal has no outlet unless India opens the spillway. In Terai river erosion is seen in rainy season. The sediment load raises the level of the bed and hence water rises and flood occurs.

CHAPTER V
ANALYSIS

5.1. Rainfall in Monsoon 2005

Monsoon 2005 is considered for study because of its erratic pattern of rainfall in comparison with the years like 2003 and 2004. Due to climate change the general circulation pattern of atmosphere is being changed which also affects the monsoon in our region. Monsoon 2005 is the study of typical monsoon period affected by climate change, with erratic pattern of rainfall. It has been considered since last couple of years that the climate change phenomena is a major cause of the monsoonal wind in summer season.

5.1.1. Daily Monsoon rainfall (country average)

The plot of daily country average rainfall is presented in Fig.5.1.1. which is less than normal in the rainfall curve. The country's average has been computed from about 21 stations data.

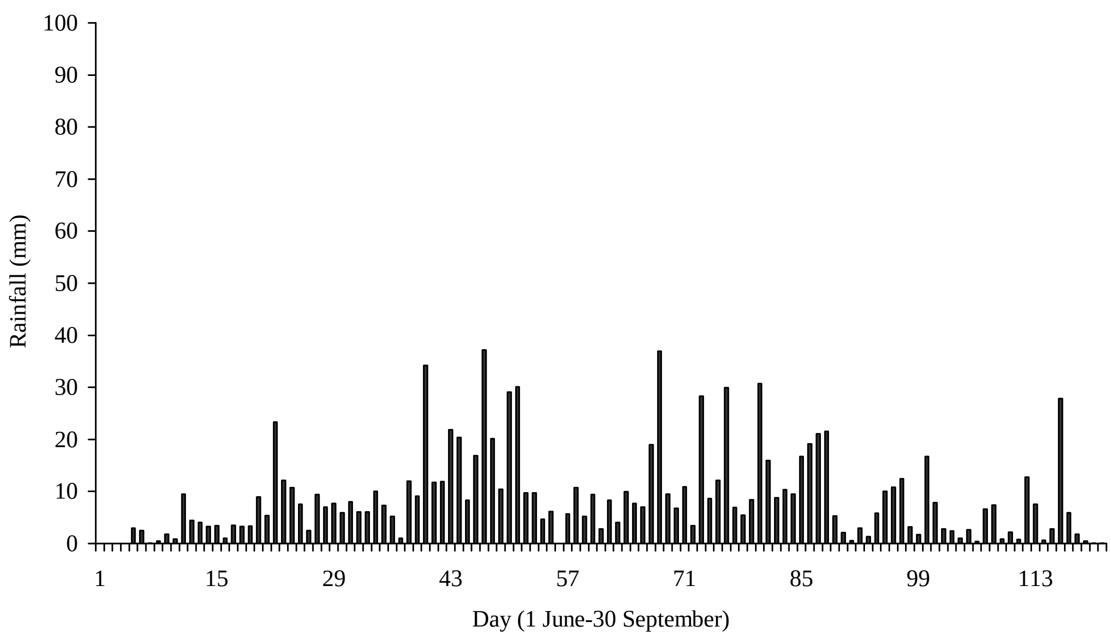


Fig: 5.1.1. Daily monsoon rainfall (country average)in Nepal during the monsoon season from June to September 2005

The daily monsoon rainfall of Nepal as shown in Fig 5.1.1. is computed as country's average from 21 stations data. The figure shows that there is high rainfall at 22 June which is also the date of onset of summer monsoon in Nepal. The figure also shows that there is high rainfall at 10, 18 and 22 July at Nepal .In August the rainfall seems to be more compared to July. In September 22 there is high rainfall.

5.1.2. Monthly Monsoon rainfall (country average)

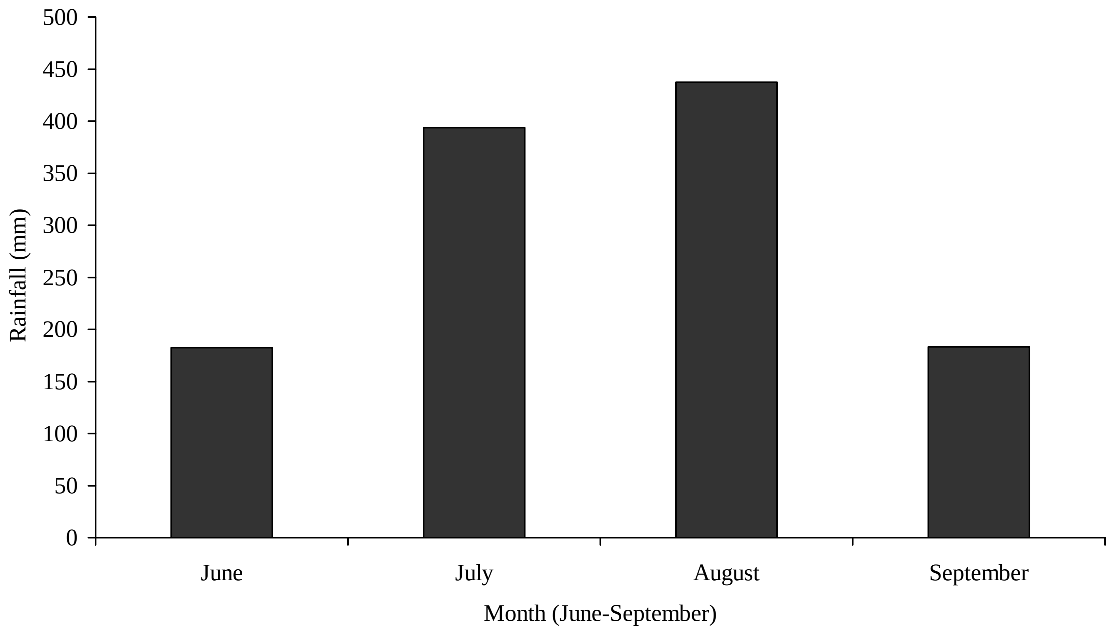


Fig.5.1.2. Monthly monsoon rainfall (country average) in Nepal during monsoon season from June to September 2005

The country's average of monthly monsoon rainfall is computed from 21 stations data. Fig.5.1.2. shows that there is high rainfall in July and August. June and September received more or less same amount of rainfall.

5.2. Monsoon Rainfall in Nepal

Nepal receives about 80% of total rainfall in monsoon season only. The moving average trend has been adopted to see whether there is any trend in the monsoonal rainfall for 21 stations in Nepal. It has also been adopted to see the monsoon rainfall in 2005.

Out of 3 stations in far western region as shown in Fig.5.2.1., the moving average curve and linear curve of 2 stations at Dadeldhura (Station No. 0104) and Dipayal (Station No. 0218) shows decreasing trend of rainfall while 1 station at Dhangadi (Station No. 0209)shows increasing trend of rainfall. The 3 year moving average curve shows that there is dry period in Dadeldhura and Dipayal in 2005 while in Dhangadi the monsoon rainfall is normal.

Out of 4 stations in mid western region as shown in Fig.5.2.2., the moving average curve and linear curve of 2 stations at Jumla (Station No. 0303) and Nepalgunj (Station No. 0409) shows decreasing trend of rainfall while 2 stations at Dang (Station No 0515) and Birendranagar (Station No. 0406) shows increasing trend of rainfall. The 3 year moving average curve shows that there is dry period in Nepalgunj and wet period in Birendranagar in 2005 while in Jumla and Dang the monsoon rainfall is normal.

Out of 3 stations in western region as shown in Fig.5.2.3., the moving average curve and linear curve of 2 stations at Jomsom (Station No.0601) and Bhairawa (Station No.0705) shows decreasing trend of rainfall while stations at Pokhara (Station No 0804) shows increasing trend of rainfall. The 3 year moving average curve shows that there is dry period in Bhairawa and Pokhara in 2005 while in Jomsom the monsoon rainfall is normal.

The moving average curve and linear curve of all the selected stations at Jiri (Station No. 1103), Kathmandu (Station No.1030), Nagarkot (Station No.1043), Simara (Station No. 0909) and Janakpur (Station No. 1111) in central region as shown in Fig.5.2.4., shows increasing trend of rainfall. Most of the stations showed increasing trend from 1996 onwards.

Out of 5 stations in eastern region as shown in Fig.5.2.5., the moving average curve and linear curve of 3 stations at Okhaldhunga (Station No.1206) and Taplejung (Station No.1405) and Biratnagar shows increasing trend of rainfall, station at Dhankuta (Station No.1307) shows decreasing trend of rainfall and station at Dharan showed more or less steady trend of rainfall. The 3 year moving average curve shows that there is dry period in Biratnagar and Taplejung and wet period in Okhaldhunga and Dhankuta in 2005 while in Dharan the monsoon rainfall is normal.

Hence from the above analysis, we may forecast that monsoonal rainfall may persist more or less a steady trend for station Dharan on coming years. Monsoonal rainfall may occur in rising trend for stations Dhangadi, Dang, Birendranagar, Pokhara, Jiri Kathmandu, Nagarkot, Simara, Janakpur, Okhaldhunga, Taplejung and Biratnagar and falling trend may persist in station Dadeldhura, Dipayal, Jumla, Nepalgunj, Jomsom, Bhairawa and Dhankuta for coming year. Similarly there was less rainfall in stations Dadeldhura, Dipayal, Nepalgunj, Bhairawa and Pokhara, more rainfall in stations Birendranagar, Jiri, Kathmandu, Nagarkot, Simara and Janakpur and normal rainfall was received in stations Dhangadi, Jumla, Dang and Jomsom in monsoon 2005.

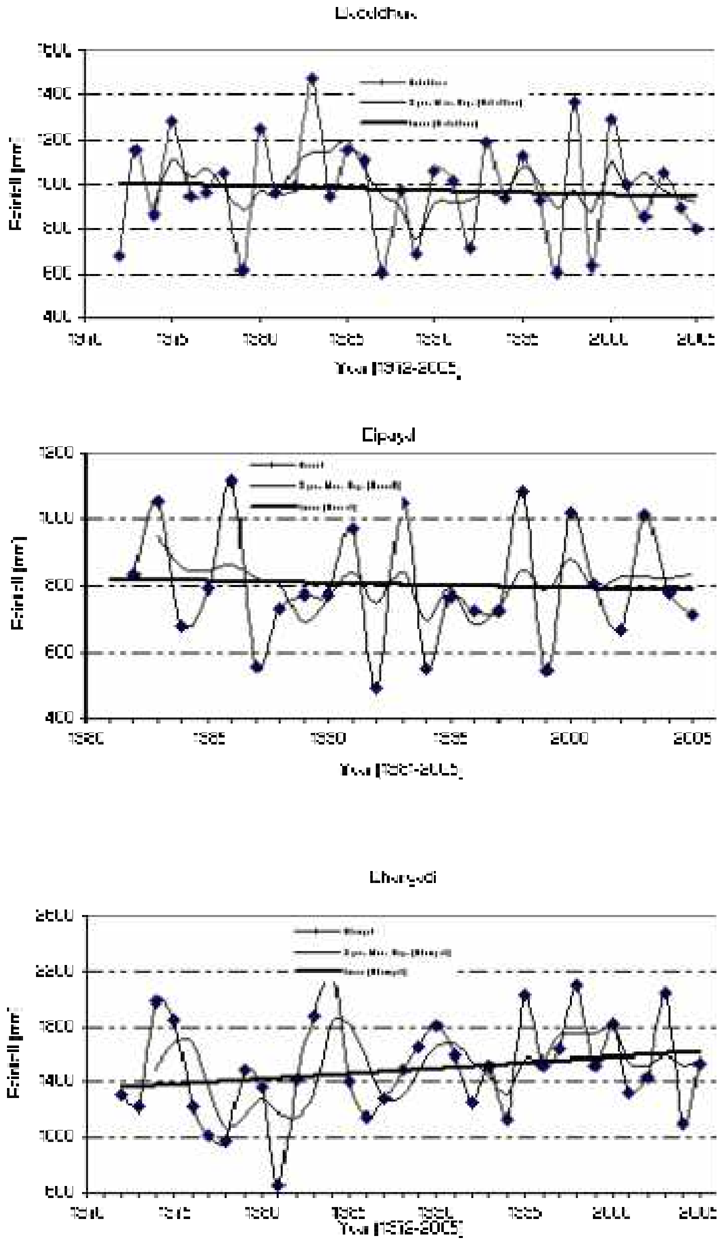


Fig.5.2.1. Monsoon Rainfall in Far Western Region

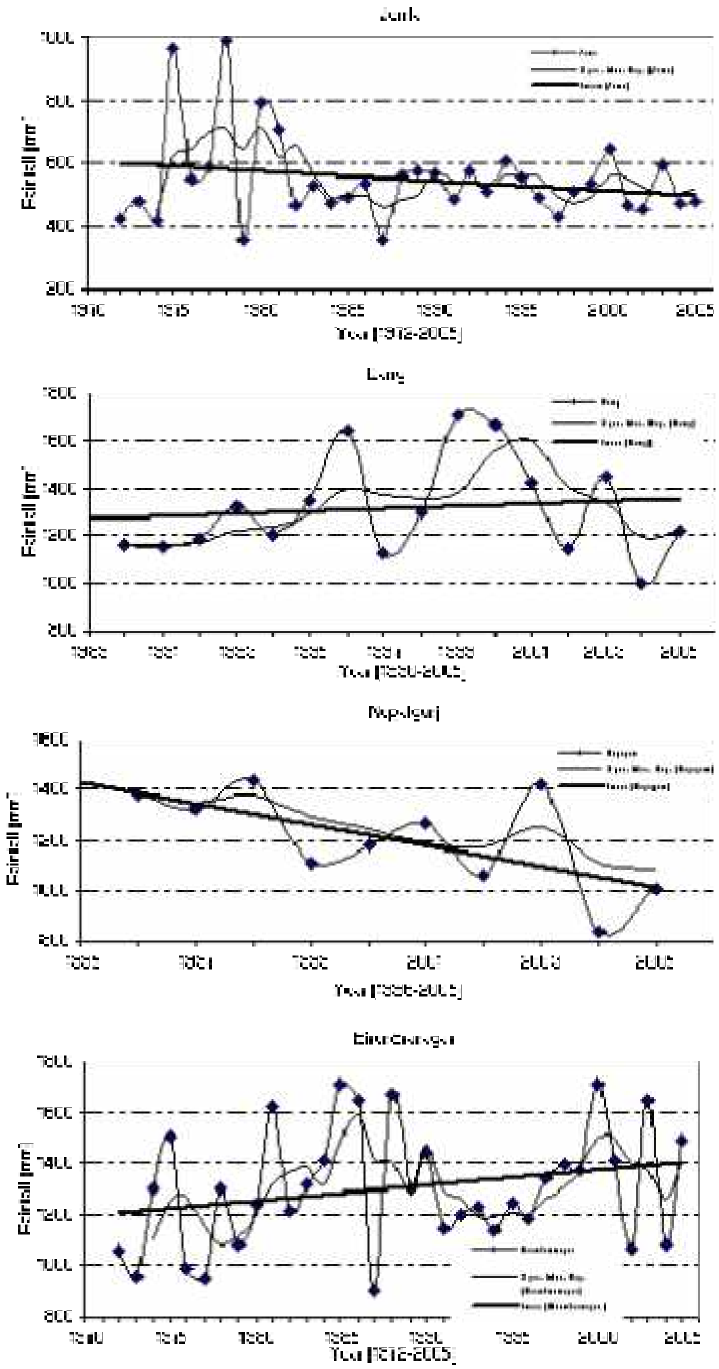
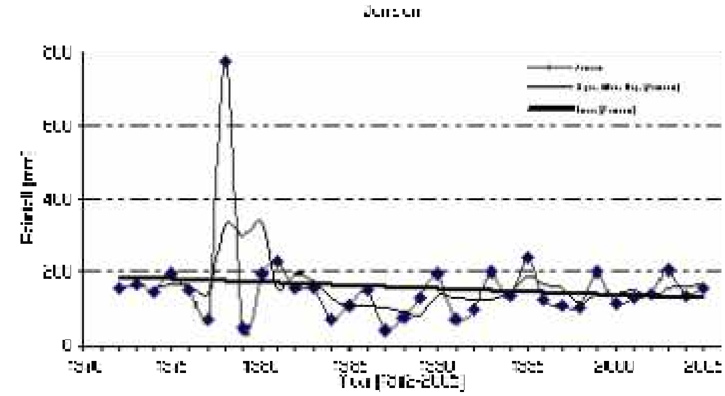
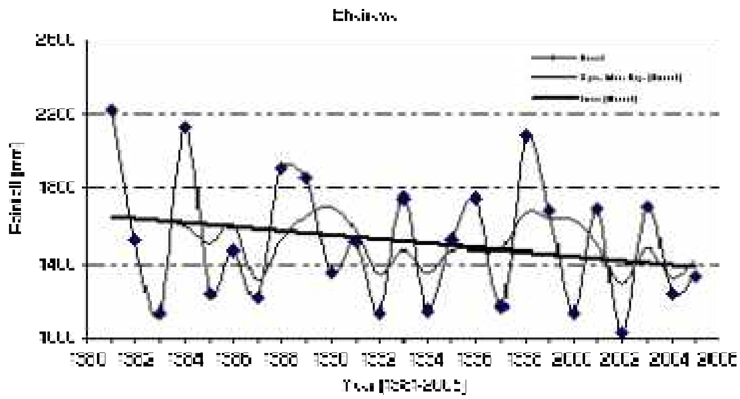


Fig. 5.2.2. Monsoon Rainfall in Mid Western Region





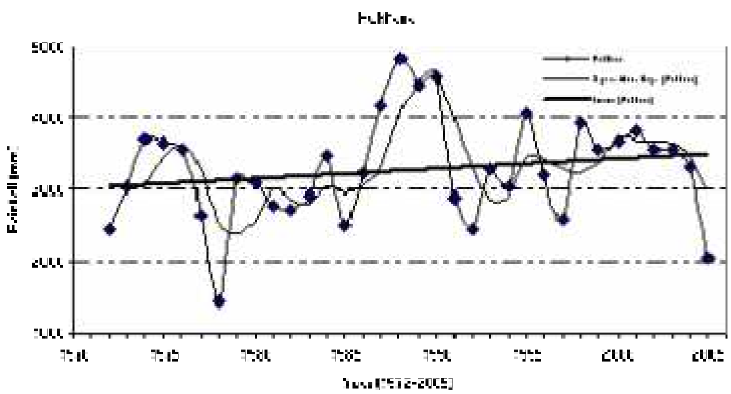
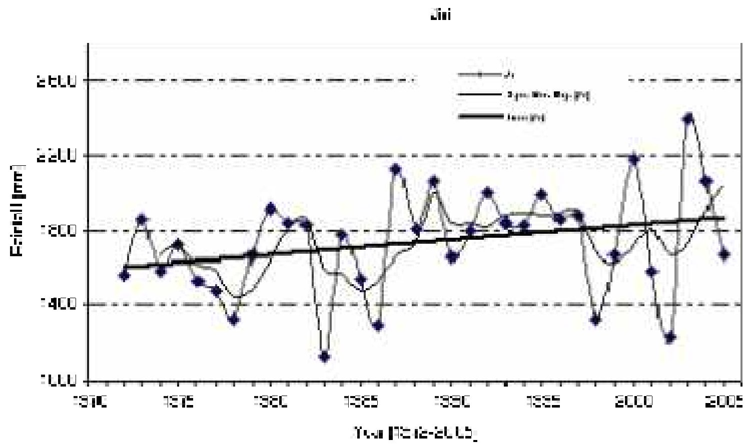
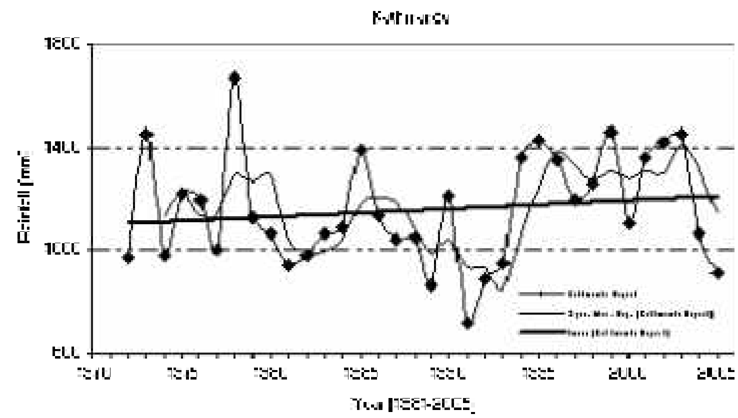
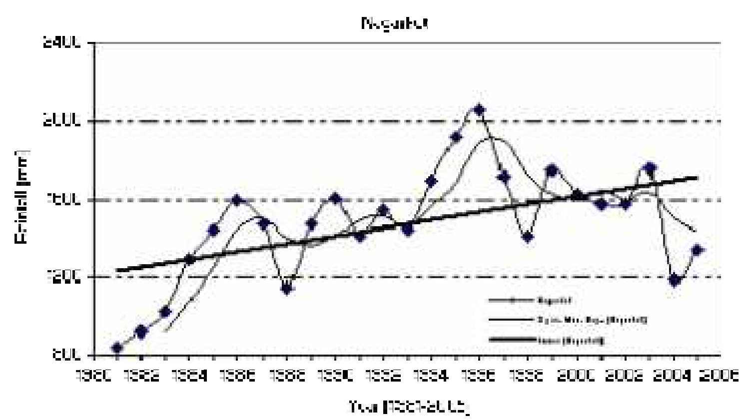


Fig. 5.2.3. Monsoon Rainfall in Western Region


Jiri
Rainfall [mm]
Year [1972-2005]


Kathmandu
Rainfall [mm]


Nagarkot
Rainfall [mm]

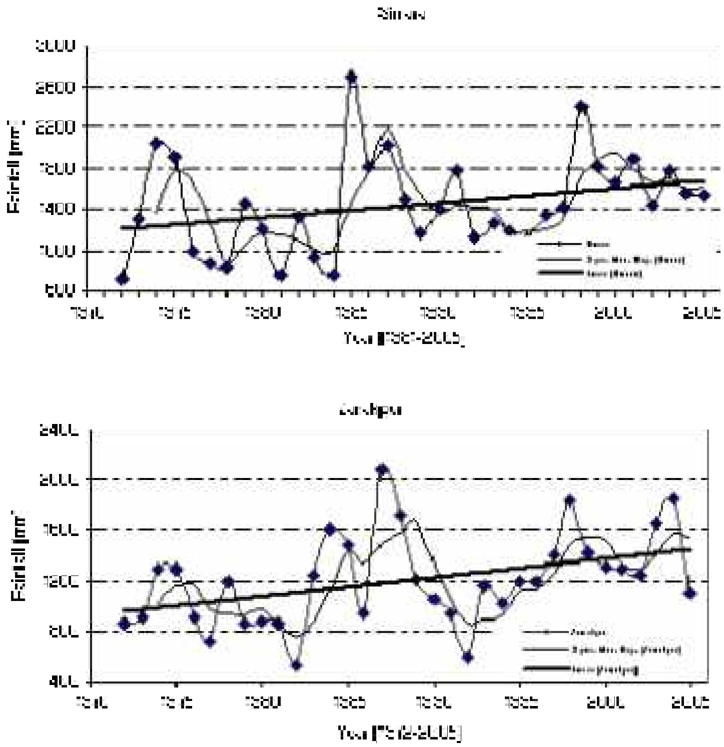
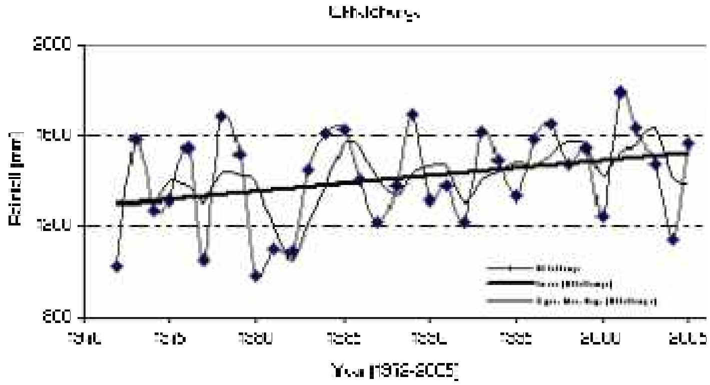
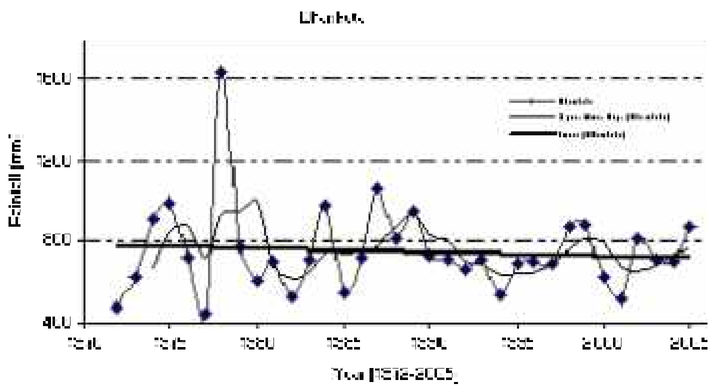
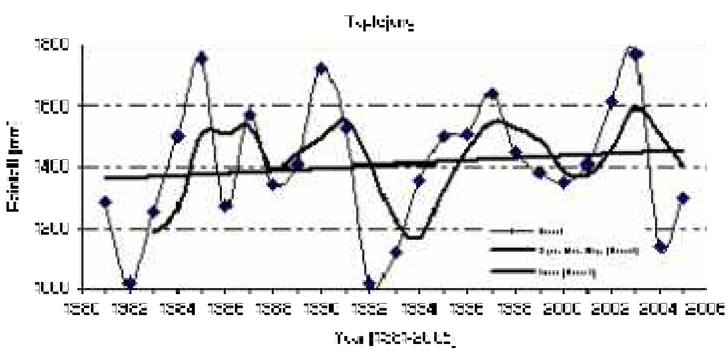


Fig.5.2.4. Monsoon Rainfall in Central Region


2000
1600
1200
800
Rainfall [mm]
Year [1912-2005]


Rainfall [mm]


Rainfall [mm]

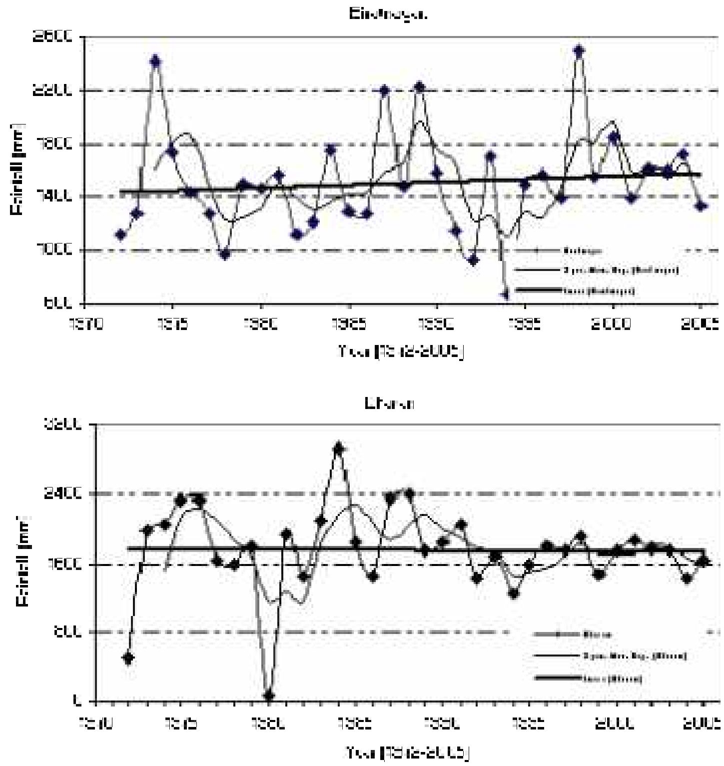


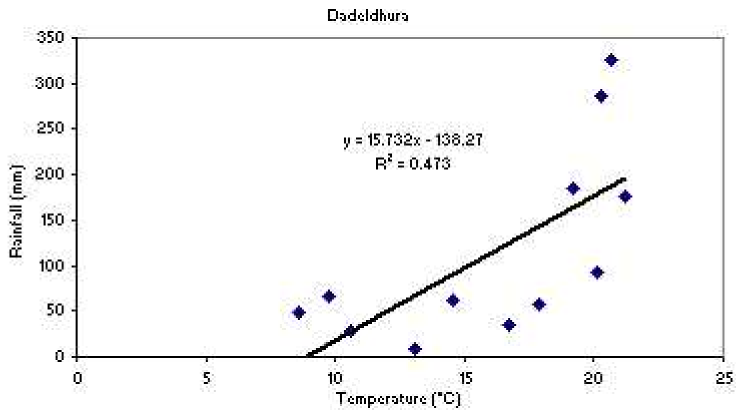
Fig. 5.2.5. Monsoon Rainfall in Eastern Region

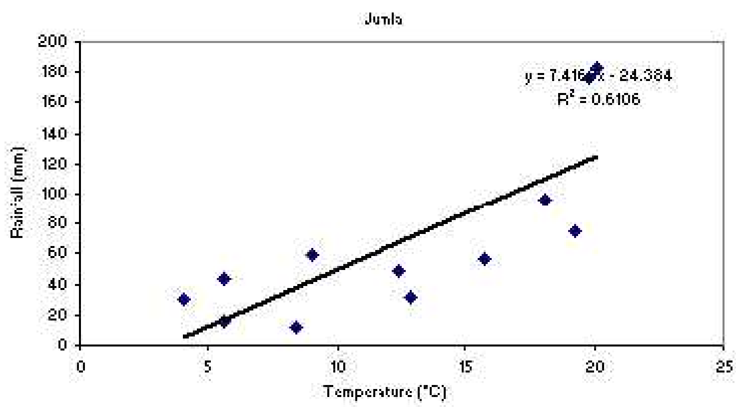
5.3. Relationship between Rainfall and Temperature in Nepal

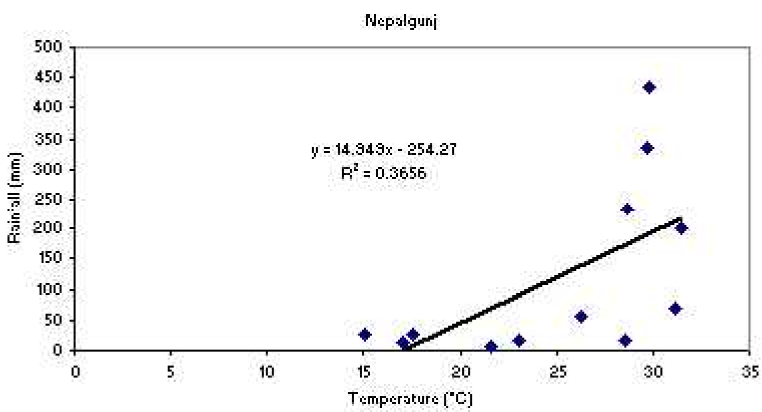
The temperatures of the selected stations are different to each other. The 30 yr's mean monthly rainfall and temperature shows that the monsoon season receives the maximum rainfall and maximum temperature while the winter season receives the minimum rainfall and minimum temperature.11 stations are considered in order to study the relation between rainfall and temperature in Nepal.

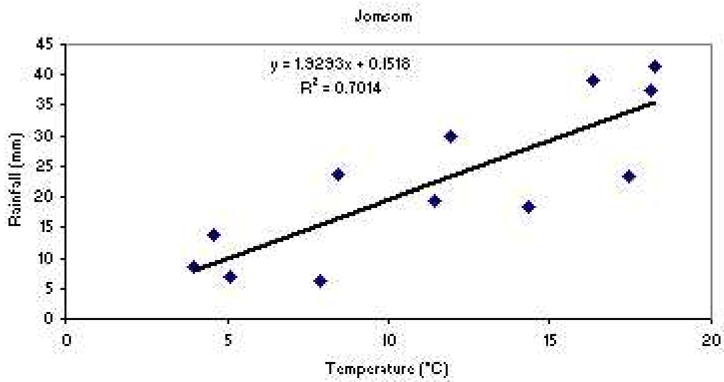
Out of 11 stations in Nepal, station Dadeldhura (Station No. 0104) showed coefficient of determination R^2 as 0.473 , Jumla (Station No.0303) showed coefficient of determination R^2 as 0.616, Nepalgunj (Station No.0409) showed coefficient of determination R^2 as 0.3656, Jomsom (Station No.0601) showed coefficient of determination R^2 as 0.7014, Kathmandu Airport (Station No.1030) showed coefficient of determination R^2 as 0.7244, Janakpur Airport (Station No.1111) showed coefficient of determination R^2 as 0.4773, Nagarkot (Station No.1043) showed coefficient of determination R^2 as 0.6596, Jiri (Station No.1103) showed coefficient of determination R^2 as 0.7213, Dhankuta (Station No.) showed coefficient of determination R^2 as 0.6567, Okhaldhunga (Station No.1206) showed coefficient of determination R^2 as 0.596 and Biratnagar (Station No.1319) showed coefficient of determination R^2 as 0.528.

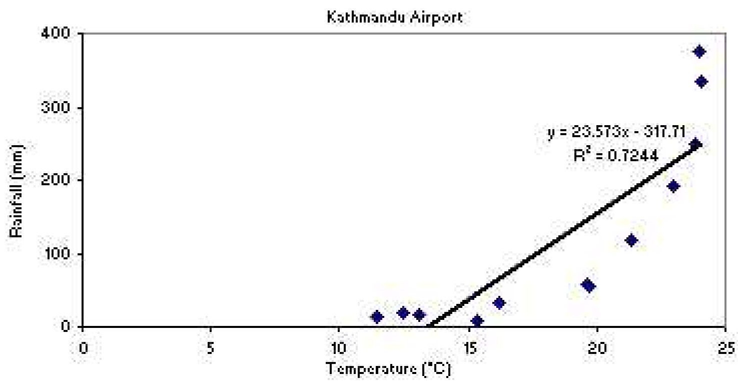
The stations at Dadeldhura, Nepalgunj and Janakpur Airport showed less determination of coefficient compared to stations at Jumla, Jomsom, Kathmandu Airport, Nagarkot, Jiri, Dhankuta, Okhaldhunga and Biratnagar. High correlation coefficient 0.851 is shown by station Kathmandu Airport while station at Nepalgunj showed correlation coefficient as 0.604.

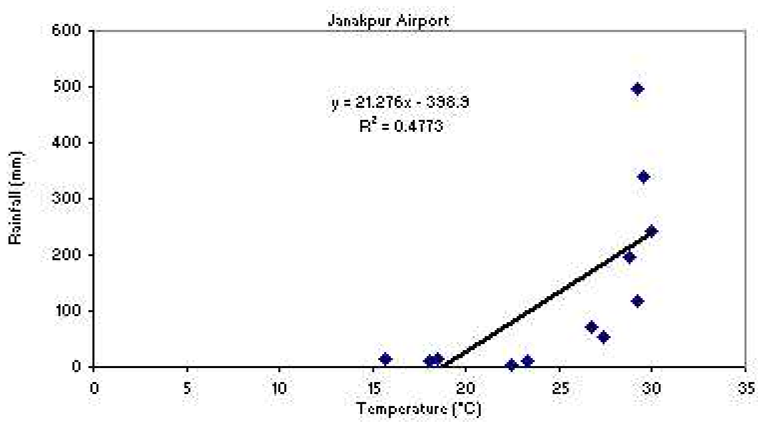

Dadeldhura
y = 15.732x - 138.27
R^2 = 0.473
Rainfall (mm)
Temperature (°C)

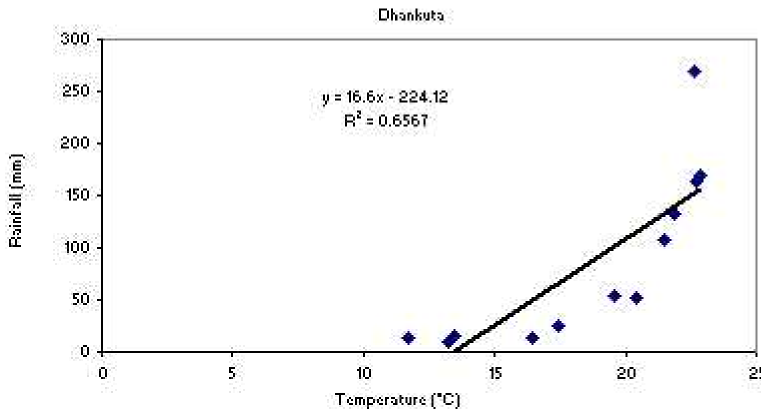

Jumla
y = 7.4166x - 24.384
R^2 = 0.6106
Rainfall (mm)
Temperature (°C)

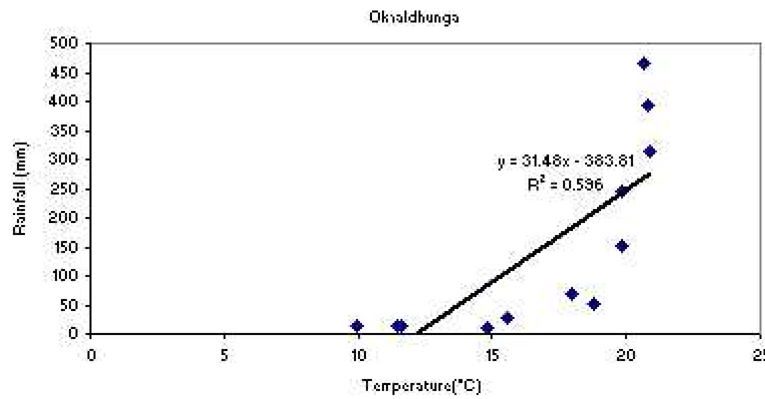

Nepalgunj
y = 14.949x - 254.27
R^2 = 0.3656
Rainfall (mm)
Temperature (°C)

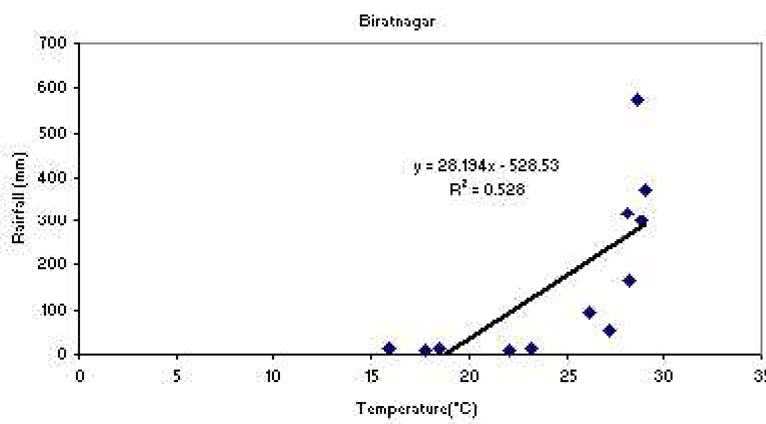

Jomsom
y = 1.9293x + 0.1518
R^2 = 0.7014
Rainfall (mm)
0 5 10 15 20 25 30 35 40 45
0 5 10 15 20
Temperature (°C)

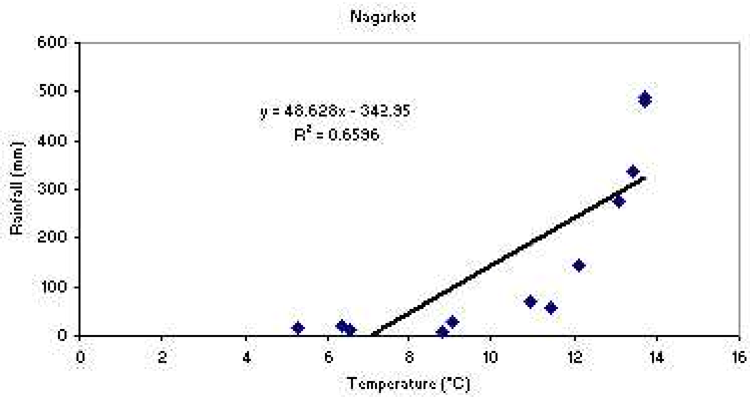

Kathmandu Airport
y = 23.573x - 317.71
R^2 = 0.7244
Rainfall (mm)
0 100 200 300 400
0 5 10 15 20 25
Temperature (°C)

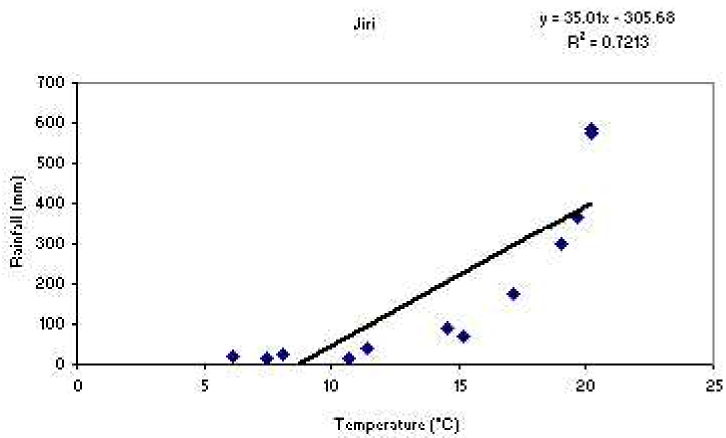

Janakpur Airport
y = 21.276x - 398.9
R^2 = 0.4773
Rainfall (mm)
0 100 200 300 400 500 600
0 5 10 15 20 25 30 35
Temperature (°C)


Dhankuta
y = 16.6x - 224.12
R² = 0.6567
Rainfall (mm)
Temperature (°C)


Okhaldhunga
y = 31.48x - 383.81
R² = 0.596
Rainfall (mm)
Temperature(°C)


Biratnagar
y = 28.194x - 528.53
R² = 0.528
Rainfall (mm)
Temperature(°C)





5.3.1. Temperature Rainfall Relation at 11 Stations in Nepal

5.4. Extreme Temperature and Rainfall in Monsoon Season (2003-2005)

The extreme temperature in June 2005 was extremely high and in stations like Dipayal, the temperature was the first in history. The extreme temperature and rainfall at different 21 stations are compared in Fig. 5.4.1. and Fig. 5.4.2. respectively. Similarly, the extreme temperature and rainfall of monsoon season in 2003, 2004 and 2005 are compared respectively. Extreme temperature is studied to know the relationship between the extreme temperature and monsoon rainfall.

The study shows that in June 2005 when extreme temperature was higher compared to extreme temperature in June 2003 and 2004, rainfall in June 2005 was less in most of the stations compared to rainfall in June 2003 and 2004. Rainfall at some places in the eastern region was found normal but in the Western region of the country the rainfall was less by about 50%.

In July 2005 extreme temperature was less than 2003 and more than 2004 in most of stations and the study shows that there was more rainfall in Far Western Region compared to 2003 and 2004 and less in eastern Region in most of the stations compared to rainfall in July 2003 and 2004.

In August 2005 when extreme temperature was more or less same in most of the stations compared to extreme temperature in August 2003 and 2004 rainfall was more in most of stations compared to rainfall in August 2003 and 2004.

In September 2005 when extreme temperature was more compared to extreme temperature in September 2003 and 2004 rainfall was less in most of the stations.

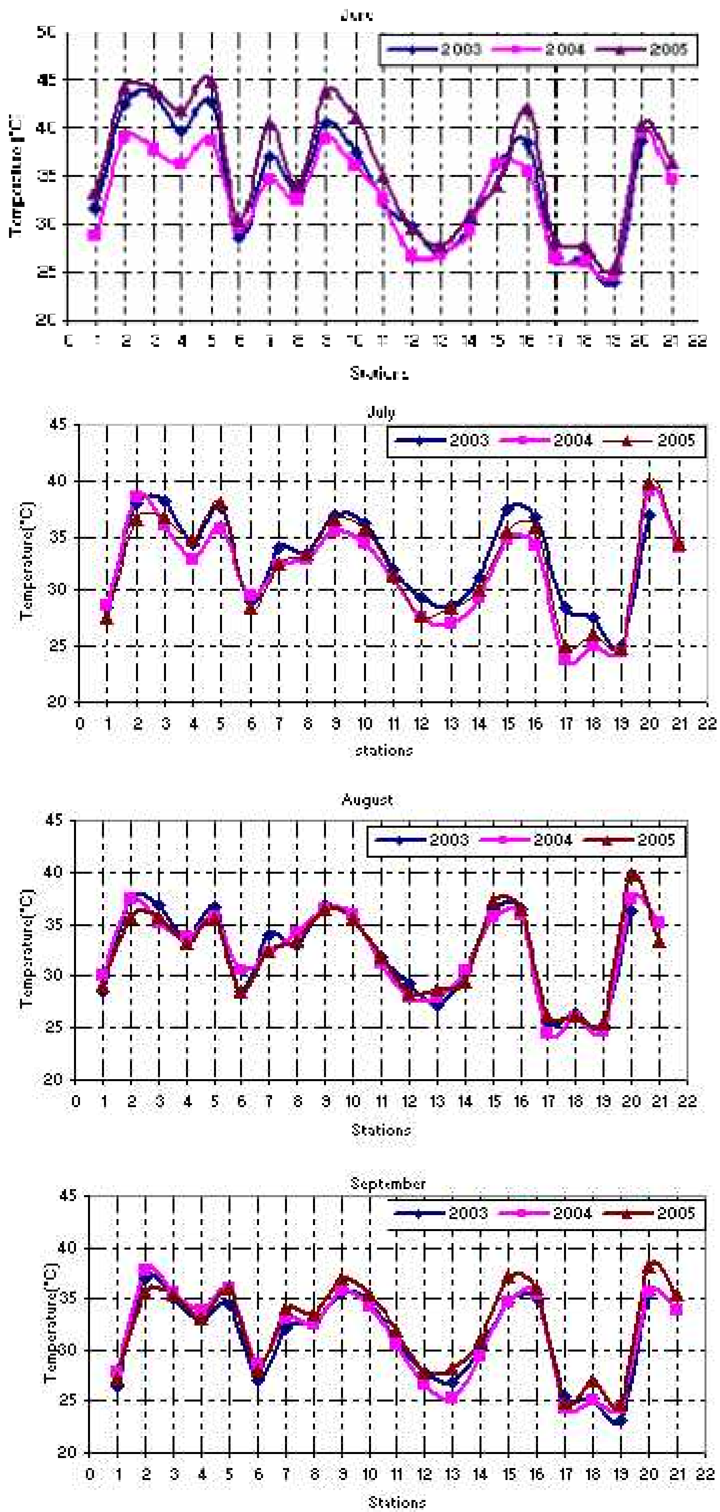


Fig.5.4.1.Extreme Temperature in the month of June, July, August and September as recorded by different stations from 2003-2005.

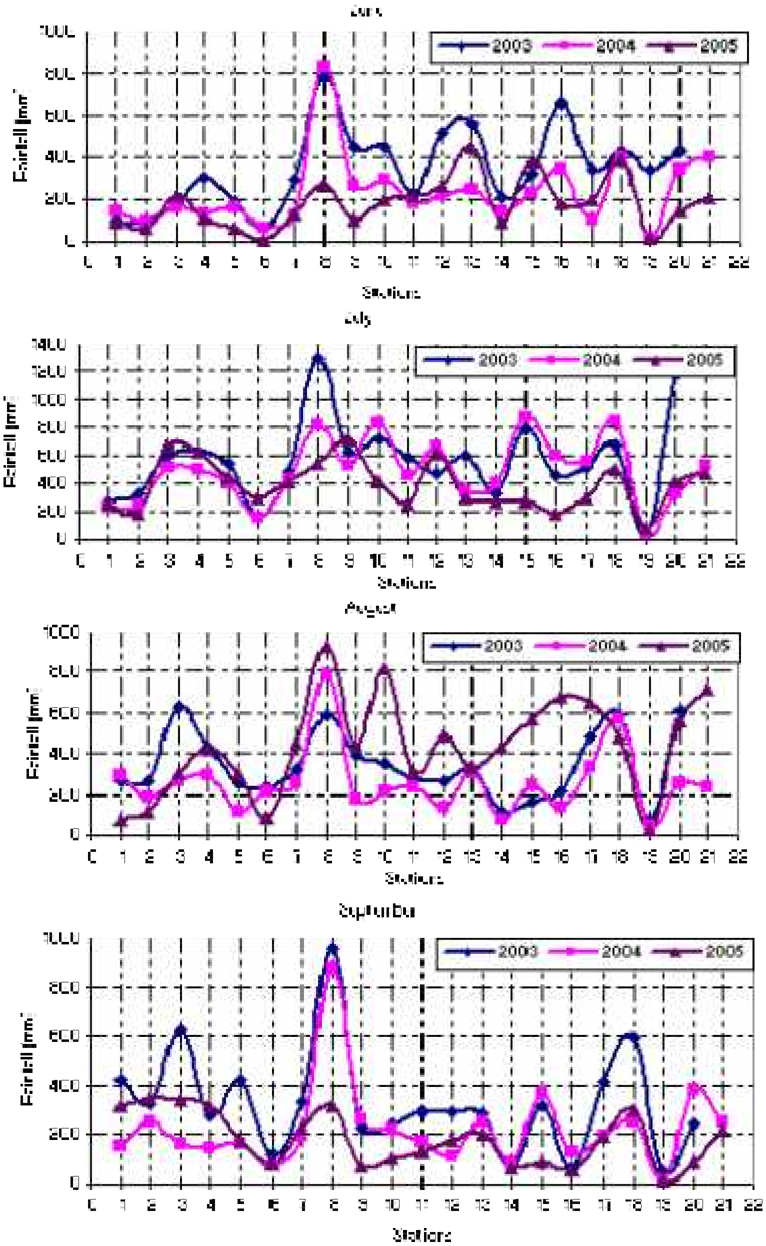
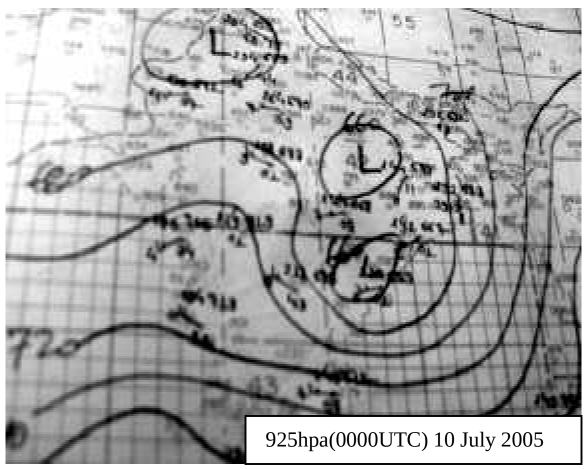


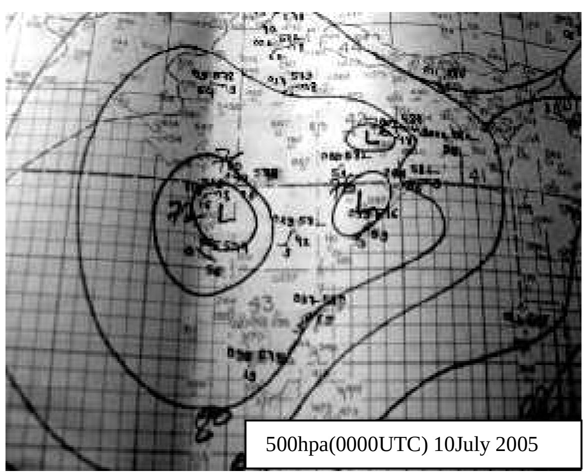
Fig: 5.4.2. Rainfall in the month of June, July, August and September as recorded by different stations from 2003-2005.

5.5. Weather Related Disasters

Landslides and floods are common in monsoon season. Due to its uneven topography, the country faces water induced disasters such as landslides and floods. These disasters cause the loss of life and millions of properties. Precipitation more than 50mm in a day (24 hours) has been considered mainly in this study.

Gaighat-Diktel road section was damaged due to heavy rain in 8 July. The incessant downpour of rainfall for few days triggered landslide and washed away portions of the road. The 24 hrs extreme rainfall recorded was 154.6mm in 8 July in Hetauda station. The upper air charts of 10 July at 925hpa and 500hpa in Fig 5.5.1. show the presence of low in the southern part of Indian sub continent.





Source: Meteorological Forecasting Division, DHM

Fig. 5. 5. 1. Upper air maps for 10 July at 0000UTC at 925hpa and 500 hPa.

There was landslide on the Prithvi Highway near the Nangdi River at Darechowk VDC-3 some 3 km from Muglin bazaar in 10 July. The 24 hrs extreme rainfall recorded was 95.4mm in 10 July in Pokhara station.

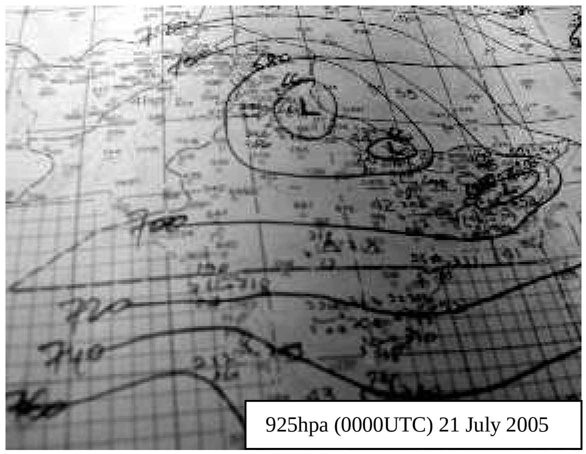
A cyclonic circulation concentrated into deep depressions over North Bay of Bengal from 5-8 July. Similarly, a westerly trough was also seen over the Western Himalayan Region during the first week, which interacted with the monsoon system and enhanced the rainfall activity.

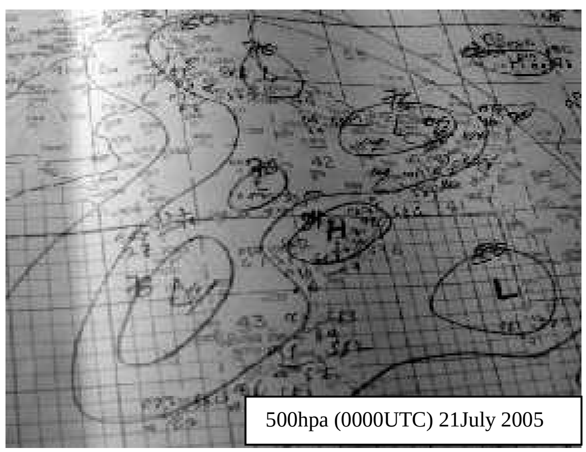
Hundreds of locals were displaced followed by inundation of villages on both sides of the Rapti River in 19 July. Incessant rainfall for two days and blockade of smooth flow of water through the Laxmanpur dam had drowned seven villages of Holiya, Gangapur, Fattehpur VDC's in Banke district. Eighteen houses were collapsed in Holiya VDC alone. The 24 hrs extreme rainfall recorded was 77mm in 19 July in Nepalgunj station. Gobargada village in Rajbiraj was inundated with flood. Similarly due to continuous rainfall, flood in Khando River displaced people in Saptari district. The 24 hrs extreme rainfall recorded was 51mm in 19 July in Rajbiraj station in Birgunj.

Table 5.5.1. Frequency of Rain at Some Stations in Eastern and Western Regions in July

Stations	Precipitation in mm			
	No of Rainy Days			
	≥1.0mm	≥10.0mm	≥25.0mm	≥50mm
Nepalgunj	16	11	7	4
Bhairawa	18	12	8	5
Pokhara	24	14	8	2
Hetauda	20	16	12	6

The western disturbance, as an upper air system, moved across western Himalayan region on the third and last week of August which might be the cause of intense rainfall activity in Nepal during this period. The presence of low is shown in Fig.5.5.2. in the upper air map at 925hPa and 500hPa till 21 July which shows that the rainfall activity continued for many days.

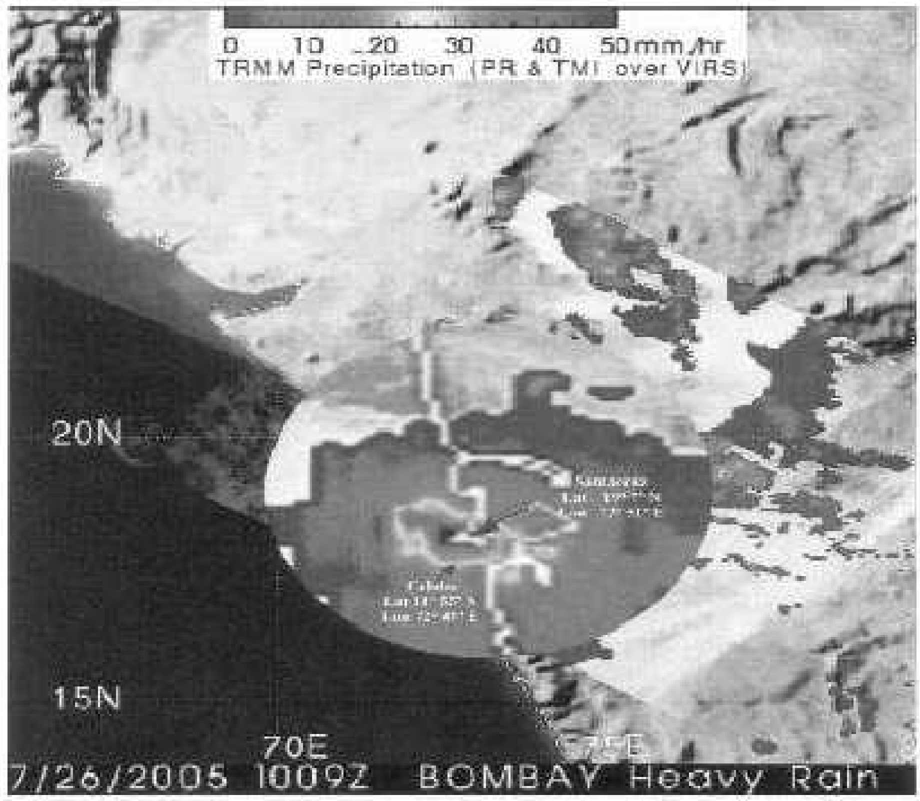

925hpa (0000UTC) 21 July 2005


500hpa (0000UTC) 21July 2005

Source: Meteorological Forecasting Division, DHM

Fig.5.5.2. Upper air maps for 21 July at 0000UTC at 925hpa and 500 hPa.

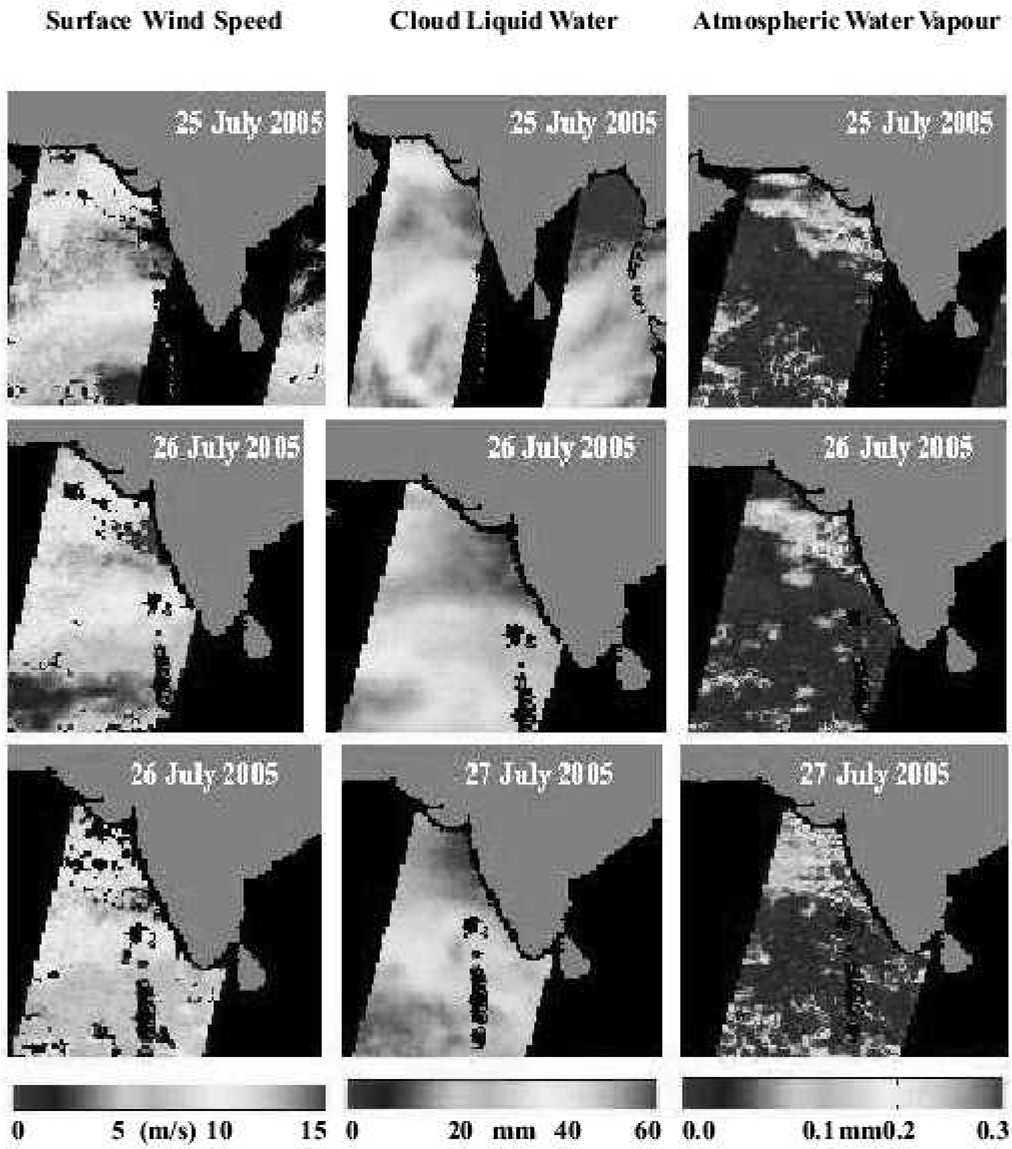
India’s worst ever recorded day of rainfall triggered landslides and building collapses in the western states of Maharastra which killed at least 786 people and brought the financial capital Mumbai to a near standstill. Mumbai was deluged with 944mm of rainfall on 27 July, which is the highest recorded rainfall in the metropolitan in 95 years.



Source: IITM, Annual Bulletin 2006

Fig. 5.5.3. TRMM measured precipitation rates for excessive to very heavy rainfall event over Santacruz on 26 July 2005.

On 26 July integrated water vapour (60 mm), cloud liquid water content 0.3 mm), deep convection (85 W/m^2) and precipitation rates (50 mm/hr) were of maximum value in the region of vortex, when TRMM satellite was passing over Santacruz as shown in Fig. 5.5.3. The satellite derived parameters observed on 25th and 27th July showed less magnitude as compared to 26th July as shown in Fig 5.5.4.



Source: IITM, Annual Bulletin 2006

Fig.5.5.4. DMSP F13 SSMI Monitored Variations in Geophysical Parameters during 25 to 27 July 2005

Five members of a family were killed in a landslide caused by heavy rain in Lachyang, Nuwakot. The 24 hrs extreme rainfall recorded was 89.2mm in 29 July in Nuwakot.

The control room at the Koshi Barrage recorded the water as flowing 9496.15 cubic meter per second on 8 August afternoon crossing the danger mark. Four people including a child were killed due to the floods and landslides after incessant downpour of rainfall.

Incessant rainfall had inundated six wards 2, 4,6,17, 19 and 22 of Biratnagar. Water level increased to about 0.762m. Incessant downpour for days affected the people of Gaighat. The flood also affected huts.

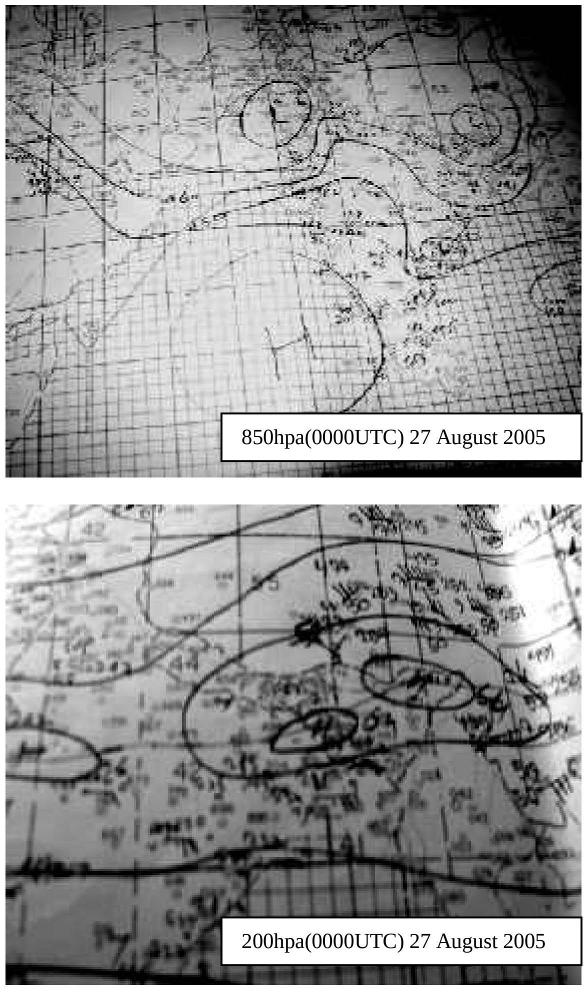
Due to continuous rainfall roads were damaged in many places in Dolalghat. Landslide from 15 August rainfall damaged the property equal to 2 lakhs. At least four persons were killed and dozens of villages were affected with the torrential downpour triggering floods and landslides continuously for three days in eastern Terai. Butwal Mahendra Highway remains disrupted to vehicular movement. The 24 hrs extreme rainfall recorded was 117.8 mm in Dhankuta in 15 August.

Continuous rainfall for two days adversely affected lives of people in Morang, Saptari, Jhapa and Sunsari districts, with Urlabari (Morang) being worst hit. Over 200 houses had submerged and about 200 families have been displaced in Sunsari after the Koshi River flooded, and over 12 houses in Saptari have submerged after Khado and Mahuli Rivers overflowed their banks. Almost 2 lakh cusec of water was recorded in Koshi River. The 24 hrs extreme rainfall recorded was 105mm in Biratnagar in 25 August.

Six houses collapsed at Hile of Dhankuta due to incessant downpour of rainfall. Kathmandu- Trishuli section of Pasang Lhamu Highway was blocked after landslide at Balkot village. The landslide damaged at least 30m of highway. The 24 hrs extreme rainfall recorded was 128.6mm in Dhankuta in 26 August. Similarly, the 24 hrs extreme rainfall recorded was 330.6mm and 73mm in Dharan and Chatara in 26 August.

At least 150 persons in Rauthat were displaced because of flood in Bagmati River and Ward No 1 and 3 were flooded with the water level reaching over 1.21m in 27 August. Flood caused by continuous rainfall for two days swept away 8 houses and hundreds of bighas of cultivable land in Makawanpur. The 24 hrs extreme rainfall recorded was 186.8mm in 27 August.

The analyzed surface and upper air maps of 27 August is shown in Fig. 5.5.5. The presence of low towards the northern part of subcontinent shows that the rainfall activity was intense towards the foothill of Himalayas. The frequency of rain in eastern region in the month of August is given in Table 5.5.1.



850hpa(0000UTC) 27 August 2005

200hpa(0000UTC) 27 August 2005

Source: Meteorological Forecasting Division, DHM

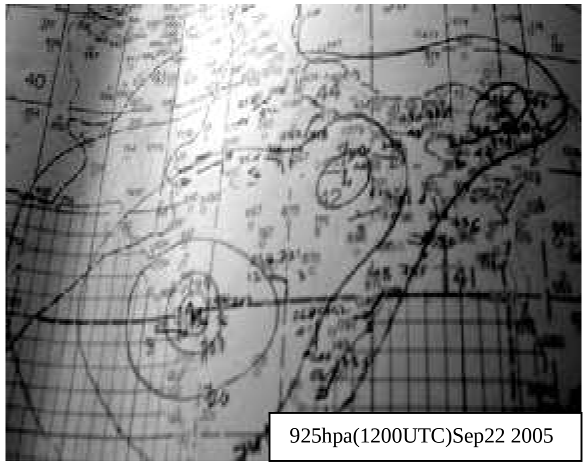
Fig:5.5.5. Upper Air Maps for 27 August at 0000UTC at 850hpa and 200 hPa.

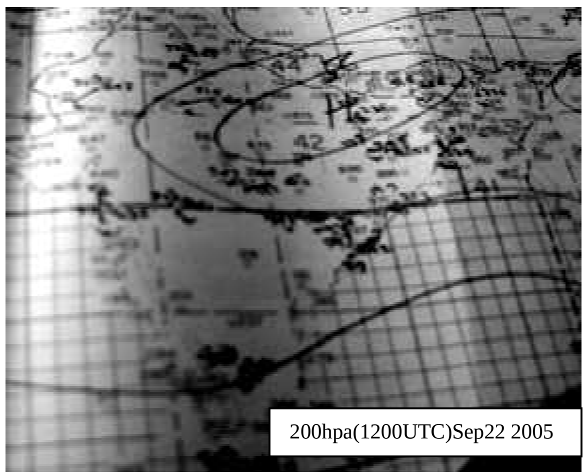
Table 5.5.2. Frequency of Rain at Some Stations in Eastern Region in August.

Stations	Precipitation in mm No of Rainy Days			
	≥1.0mm	≥10.0mm	≥25.0mm	≥50mm
Dhankuta	14	12	4	2
Dharan	19	9	7	5
Chatara	23	13	8	6
Biratnagar	18	12	8	5
Taplejung	20	10	6	1
Illam	16	12	10	6
Kankai	26	15	6	5
Okhaldhunga	17	10	5	3

At least 700 houses at Chandani VDC in Kanchanpur district were inundated by the flooded river on 9 September. Eight houses collapsed and at least 1,500 residents were affected after the embankment in the Mahakali River crumbled and the village got submerged.

Under the influence of the cyclonic storm formed in the northeast Bay from 17-21 September which initially moved west southwest and then west northwest there was heavy rainfall which caused flood around the country. The presence of low towards the southern part of Indian subcontinent on 22 September is shown in Fig. 5.5.6. which moved further northwards and rainfall activity became more intense in Far Western Region.





Source: Meteorological Forecasting Division, DHM

Fig:5.5.6. Upper Air Maps for 22 September at 1200UTC at 925hpa and 200hPa.

Life in the far western region was paralysed due to incessant downpour of rainfall. The 24 hrs extreme rainfall recorded was 144.7mm in 25 September in Dipayal. Similarly the 24hrs extreme rainfall recorded was 160mm and 81mm in Dadeldhura and Darchula respectively. Landslides blocked the Bhimdutta Highway (link between Terai and Hill), KI Singh Highway (from Dadeldhura to Silgadhi) and on certain other sections of the roads. A number of houses collapsed, landslides buried fields and agricultural land and hundreds of water mills were swept away by floods and landslides in far western hilly districts. Floods caused damage worth Rs 8 lakhs in Baitadi. In Darchula, three houses were swept away and three other were collapsed. Due to incessant rain members of 200 households were displaced in Dadeldhura. Over 60 houses located in Sirsh and Jogbudha

VDC's were damaged including offices of two micro-hydro project in Sirsh and dozens of cattle were marooned due to flooding in the Rangun River.

Rainfall activity in last week of September in far western region was active. The frequency of rain at some stations is given in Table 5.5.2.

Table. 5.5.2. Frequency of Rain at Some Stations in Far Western Region in September

Stations	Precipitation in mm			
	No of Rainy Days			
	≥1.0mm	≥10.0mm	≥25.0mm	≥50mm
Dadeldhura	12	6	3	1
Sundarpur	9	8	7	4
Darchula	23	13	5	2
Biratnagar	18	12	8	5
Dhangadi	10	7	6	2
Dipayal	10	6	4	4

CHAPTER VI
SUMMARY, CONCLUSION AND RECOMMENDATION

6.1. Summary

Monsoon 2005 is considered for study because of its erratic pattern of rainfall in comparison with the years like 2003 and 2004. Due to climate change the general circulation pattern of atmosphere is being changed which also affects the monsoon in our region. Monsoon 2005 is the study of typical monsoon period affected by climate change, with erratic pattern of rainfall. It has been considered since last couple of years that the climate change phenomena is a major cause of the monsoonal wind in summer season.

In 2005 first onset of monsoon in eastern Nepal was on 20 June and covered the entire country within 2 days on 22 June which was slightly behind schedule (10 June). The arrival of monsoon in eastern Nepal was delayed by 10 days. In all, one cyclonic storm and four depressions over the Arabian Sea and Bay of Bengal and one land depression formed during the season. Monsoon 2005 retreated from the country on 29 September, delaying by nearly one week from its normal retreat days (23 September).

The daily monsoon rainfall of Nepal shows that there is high rainfall on 22 June which is also the date of onset of summer monsoon in Nepal. It also shows that there is high rainfall on 10, 18 and 22 July in Nepal .In August the rainfall seems to be more compared to July. The country's average of monthly monsoon rainfall shows that there is high rainfall in July and August. June and September received more or less same amount of rainfall.

Three year moving average curve shows that monsoonal rainfall may persist more or less a steady trend for station Dharan on coming years. Monsoonal rainfall may occur in rising trend for stations Dhangadi, Dang, Birendranagar, Pokhara, Jiri Kathmandu, Nagarkot, Simara, Janakpur, Okhaldhunga, Taplejung and Biratnagar and falling trend may persist in station Dadeldhura, Dipayal, Jumla, Nepalgunj, Jomsom, Bhairawa and Dhankuta for coming year. Similarly there was less rainfall in stations Dadeldhura, Dipayal, Nepalgunj, Bhairawa and Pokhara, more rainfall in stations Birendranagar, Jiri, Kathmandu, Nagarkot, Simara and Janakpur and normal rainfall was received in stations Dhangadi, Jumla, Dang and Jomsom in monsoon 2005.

The study of temperature and rainfall at different stations shows that the monsoon season receives the maximum rainfall and maximum temperature while the winter season receives the minimum rainfall and minimum temperature. The stations at Dadeldhura, Nepalgunj and Janakpur Airport showed less determination of coefficient compared to stations at Jumla, Jomsom, Kathmandu Airport, Nagarkot, Jiri, Dhankuta, Okhaldhunga and Biratnagar. High correlation coefficient 0.851 was shown by station at Kathmandu Airport.

The study of extreme temperature and rainfall in monsoon season in 2003, 2004 and 2005 shows that in June and September 2005 when extreme temperature was high, rainfall was less in most of the stations. In August 2005 when extreme temperature was more or less same in most of the stations compared to 2003 and 2004, rainfall was more in most of stations.

Precipitations more than 50mm in a day are considered mainly for the study of weather related disasters. Landslide in Hetauda and on Prithvi Highway was caused by heavy rainfall. The 24 hrs extreme rainfall recorded was 154.6mm in 8 July in Hetauda station and 95.4mm in July 10 in Pokhara station. A cyclonic circulation concentrated into deep depressions over North Bay of Bengal from 5-8 July. Flood in Rapti River inundated seven villages in Banke district. The 24 hrs extreme rainfall recorded was 77mm in 19 July in Nepalgunj station. Village in Rajbiraj was inundated with flood. The 24 hrs extreme rainfall recorded was 51mm in July 19 in the Rajbiraj station. The western disturbance, as an upper air system, moved across western Himalayan region on the third and last week of August which may be the cause of intense rainfall activity in Nepal. India’s worst ever recorded day of rainfall triggered landslides and building collapses in the western states of Maharastra which killed at least 786 people and brought the financial capital Mumbai to a near standstill. Mumbai was deluged with 944mm of rainfall on 27 July, which is the highest recorded rainfall in the metropolitan in 95 years.

Similarly, in 29 July landslide occurred in Nuwakot. The 24 hrs extreme rainfall recorded was 89.2mm in 29 July in Nuwakot.

Landslide in Dolalghat was caused by heavy rainfall. Floods and landslides occurred in eastern Terai due to continuous rainfall for three days. Butwal Mahendra Highway was affected by landslide. Flood in Morang, Saptari, Jhapa and Sunsari districts was caused by heavy rainfall. The 24 hrs extreme rainfall recorded was 105mm in Biratnagar in 25 August. Landslide in Kathmandu- Trishuli section of Pasang Lhamu Highway was caused by heavy rainfall. The 24 hrs extreme rainfall recorded was 128.6mm in Dhankuta in 26August. Similarly, the 24 hrs extreme rainfall recorded was 330.6mm and 73mm in Dharan and Chatara in 26 August. Intense rainfall caused flood in Bagmati River and Makawanpur district. The 24 hrs extreme rainfall recorded was 186.8 in 27 August in Hetauda. The presence of low towards the northern part of subcontinent in the upper air chart on 27 August shows that the rainfall activity was intense towards the foothill of Himalayas.

Heavy rainfall caused flood in Kanchanpur district in 9 September. Rainfall activity became more intense in far western region under the influence of the cyclonic storm formed in the northeast Bay of Bengal from 17-21 September which initially moved west southwest and then west northwest. Life in the far western region was paralysed due to incessant downpour of rainfall. Several landslides occurred in the Bhimdutta Highway, KI Singh Highway and other sections of road. The 24 hrs extreme rainfall recorded was 144.7mm in 25 September in Dipayal. Similarly the 24 hrs extreme rainfall recorded was 160mm and 81mm in Dadeldhura and Darchula respectively. Floods in Baitadi, Darchula and Dadeldhura affected lives of people and millions of property. A number of houses had collapsed, landslides had buried fields and agricultural land and hundreds of water mills had been swept away by floods and landslides in the far western hilly districts.

6.2. Conclusion

Monsoon 2005 is considered for study because of its erratic pattern of rainfall in comparison with other years like 2003 and 2004. Due to climate change the general circulation pattern of atmosphere is being changed which also affects the monsoon in this region. Monsoon 2005 is the study of typical monsoon period affected by climate change, with erratic pattern of rainfall. It has been considered since last couple of years that the climate change phenomenon is a major cause of the monsoonal wind in summer.

- The study of extreme temperature and rainfall in monsoon season in 2003, 2004 and 2005 shows that in June and September 2005 when extreme temperature was higher compared to extreme temperature in 2003 and 2004, rainfall was less in most of the stations while in July and August the rainfall was more or less same.

- The study of temperature and rainfall at different stations shows that the monsoon season receives the maximum rainfall and maximum temperature while the winter season receives the minimum rainfall and minimum temperature

- Three year moving average curve shows that monsoonal rainfall may persist more or less a steady trend for station Dharan on coming years. Monsoonal rainfall may occur in rising trend for stations Dhangadi, Dang, Birendranagar, Pokhara, Jiri Kathmandu, Nagarkot, Simara, Janakpur, Okhaldhunga, Taplejung and Biratnagar and falling trend may persist in station Dadeldhura, Dipayal, Jumla, Nepalgunj, Jomsom, Bhairawa and Dhankuta for coming year. Similarly there was less rainfall in stations Dadeldhura, Dipayal, Nepalgunj, Bhairawa and Pokhara, more rainfall in stations Birendranagar, Jiri, Kathmandu, Nagarkot, Simara and Janakpur and normal rainfall was received in stations Dhangadi, Jumla, Dang and Jomsom in monsoon 2005.

- Intense rainfalls even of short duration caused quick landslides and floods whereas prolonged rainfall caused slow landslides and floods. Daily precipitation of 50-100mm for one to two days is enough to cause small landslides in hilly areas and small-scale flood in Terai region. Similarly, precipitation exceeding 100mm for one to two days is enough to cause large landslides in hilly areas and large-scale floods in Terai region.

6.3. Recommendation

- More meteorological stations are required to extract more useful results.

- Upper air observatories are required in order to investigate the behavior of the atmosphere and this knowledge must be used for short and long term weather prediction.

- There was a behind schedule onset of monsoon in year 2005 and till the end of July farmers were not able to plant paddy. Adequate amount of rainfall is required to cultivate our lands. If the exact dates of onset of monsoon can be studied. It can be helpful to farmers.

- Forecasting tools needs to be efficient in order to save losses of our lives and property Most of the disasters like landslides, floods occur in Nepal during monsoon period. Though we cannot completely alleviate these problems we can minimize the losses of our property and lives of people by efficiently forecasting monsoon. Forecasting of monsoon through advanced technologies are also required to cope with the problems of agriculture and water resources.

BIBLIOGRAPHY

Barros, A.P. and Lang, T.J. (2001).**Monitoring the Monsoon in the Himalayas: Observations in the Central Nepal**. Monthly Weather Review 131, 7, 1408-1427.

Barros, A.P., Kim, G., Williams, E., Nesbitt, S.W. (2004). **Probing orographic controls in the Himalayas during the monsoon using satellite imagery.** Natural Hazards and Earth System Sciences, 4,29-51.

Brahic, C. (2007). **Climate change may boost monsoon and worsen drought**. Nature 445,229p

Brown, P. (1984) **Picturesque Nepal**. Today & Tomorrow's Printers &Publishers, 205p

Chalise, S.R., Khanal, N.R.(2001).**Rainfall and related Natural Disasters in Nepal**. Landslide Hazard Mitigation in the Hindu Kush Himalayas, ICIMOD

Coyle, F.W. (1980). **Introduction to meteorology**. 3d ed.

Das, P.K. (1968). **The Monsoons**. National Book Trust, India.

Das, S. (2003). **Mountain Weather Forecasting using MM5 Model**. In: Shrestha, M.L. and S.P.Prajapati (ed.),Proceedings of the training seminar on Summer Monsoon and prediction techniques ,Department of Hydrology and meteorology,Kathmandu,108-113.

Devkota, L.P. (2004). **Climate variability over Nepal: Observations, Forecasting, Model Evaluation and impacts on Agriculture and Water Resources.** (P.hd. Thesis) Central Department of Hydrology and Meteorology, Tribhuvan University, Nepal.

Government of Nepal, Department of Hydrology and Meteorology.(2004).**Weather Summary of Nepal Year-2003.** Department of Hydrology and Meteorology, Climate Division, Kathmandu.

Government of Nepal, Department of Hydrology and Meteorology.(2005).**Weather Summary of Nepal Year-2004.** Department of Hydrology and Meteorology, Climate Division, Kathmandu.

Government of Nepal, Department of Hydrology and Meteorology.(2006).**Weather Summary of Nepal Year-2005.** Department of Hydrology and Meteorology, Climate Division, Kathmandu.

Government of Nepal, Department of Hydrology and Meteorology (1984). **Climatological Records of Nepal (2002-2003)**.Department of Hydrology and Meteorology, Kathmandu.

Garg,S.K. (2002). **Hydrology and Water Resources Engineering**. Khanna Publishers, Twelth Edition, 1053p.

HMG, Department of Hydrology and Meteorology (1977). **Climatological Records of Nepal, Vol I(1971-1975)**.Department of Hydrology and Meteorology, Kathmandu, 366p.

HMG, Department of Hydrology and Meteorology (1982). **Climatological Records of Nepal, Vol I(1976-1980)**.Department of Hydrology and Meteorology, Kathmandu, 406p.

HMG, Department of Hydrology and Meteorology (1984). **Climatological Records of Nepal, Vol I(1981-1982)**.Department of Hydrology and Meteorology, Kathmandu, 174p.

HMG, Department of Hydrology and Meteorology (1986). **Climatological Records of Nepal, Vol I(1983-1984)**.Department of Hydrology and Meteorology, Kathmandu, 187p.

HMG, Department of Hydrology and Meteorology (1988). **Climatological Records of Nepal (1985-1986)**.Department of Hydrology and Meteorology, Kathmandu, 232p.

HMG, Department of Hydrology and Meteorology (1995). **Climatological Records of Nepal (1987-1990)**.Department of Hydrology and Meteorology, Kathmandu, 519p.

HMG, Department of Hydrology and Meteorology (1997). **Climatological Records of Nepal (1991-1994)**.Department of Hydrology and Meteorology, Kathmandu, 378p

HMG, Department of Hydrology and Meteorology (1999). **Climatological Records of Nepal (1995-1996)**.Department of Hydrology and Meteorology, Kathmandu, 266p.

HMG, Department of Hydrology and Meteorology (2001). **Climatological Records of Nepal (1997-1998)**.Department of Hydrology and Meteorology, Kathmandu, 193p

HMG, Department of Hydrology and Meteorology (2002). **Climatological Records of Nepal (1999-2000)**.Department of Hydrology and Meteorology, Kathmandu, 194p

HMG, Department of Hydrology and Meteorology (2004). **Climatological Records of Nepal (2001)**.Department of Hydrology and Meteorology, Kathmandu.

Keshavmurthy, R.N., Joshi, P.C.(1993). **Advances in Tropical Meteorology**. Monsoon variability, Satellite Applications and Modelling.

Lal, D.S. (2001). **Climatology**. Sharda Pustak Bhawan. 414p.

Mahajan, P.N., Sinha, S.K., Khaladkar, R.M., Nair, S., Narkhedkar,S.G., Madhukar, M., Prabhu, A. (2006). **Satellite Meteorology and Applications of Satellite Data in Weather Forecasting.** Indian Institute of Tropical Meteorology, India. Annual Report (2005-2006).

Mandal, G. S., Pant, M.C., Kathuria, S.N.(1993). **Onset vortex of Southwest monsoon 1991 some special features.** Das, S. (2003).In: Keshavamurty, R.N. and Joshi, P.C.(ed.),Advances in Tropical Meteorology.

Mausam, (July 2006) 57, 3. **Weather in India.**. Compiled by: N. Jayanthi., R.R Lele., S.S. Devi. Meteorological Office, Pune-411 005, India.527-566.

Nieuwolt, S. (1977). **Tropical Climatology**. Wiley.

Pedelaborde, P.(1963). **The Monsoon**. Methuen.

Pradhananga, D. (1996). **Study of synoptic pattern associated with floods with reference to the northern Sun Koshi and Bhote Koshi catchment.** (M.Sc.Thesis) Central Department of Hydrology and Meteorology, Tribhuvan University, Nepal, 93p.

Raj,Y.E.A.(2003).**Weather Systems Associated With Indian Summer Monsoon**. In Shrestha, M.L. and. Prajapati, S.P (ed.),Proceedings of the training seminar on Summer Monsoon and prediction technique.

Rajbahak, M., Shrestha, R.P. (2005). **A diagnostic study of onset and withdrawal of summer monsoon in Nepal.**

Ramage, C. S. (1954). **Monsoon Meteorology**, Academic Press.

Reddi, J.R. (1998). **A Text book of Hydrology**, Laxmi Publications,

Shakya, M. R. (2003**)**. **Summer Monsoon and Rainfall in Nepal**. In Shrestha. M.L. and Prajapati, S.P.(ed.),Proceedings of the training seminar on Summer Monsoon and prediction technique.

Sharma, C. K. (1990). **Geology of Nepal Himalaya and Adjacent Countries**.PP 398-400

Thapa, G. B., Weber, K. E. (1990). **Managing Mountain Water sheds**. The Upper Pokhara Valley; Division of Human Settlements Development; Asian Institute of Technology, Bangkok, Thailand326p.

Trewartha, G. T. (1966). **The Earth's Problem Climate**. The University of Wisconsin Press Methuen& Co. Ltd. London.334p.

UNEP (2002): **Early Warning, Forecasting and Operational Flood Risk Monitoring in Asia (Bangladesh, China and India**), A Technical Report of Project(GT/ 1010-00-04): Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP), P.O. Box 30552, Nairobi, Kenya.

Upreti, B.N. (2001). **The Physiographic and Geology of Nepal and their Bearing on the landslide Problem**. Landslide Hazard Mitigation in the Hindu Kush Himalayas, ICIMOD.

Annex I: Country Average in Nepal from June to September

June		July		August		September	
Date	Average (Rainfall in mm)	Date	Average (Rainfall in mm)	Date	Average (Rainfall in mm)	Date	Average (Rainfall in mm)
1	0.0	1	8.0	1	8.3	1	1.3
2	0.0	2	6.1	2	4.1	2	5.8
3	0.0	3	6.1	3	9.9	3	10.0
4	0.0	4	10.0	4	7.7	4	10.8
5	3.0	5	7.3	5	7.0	5	12.4
6	2.5	6	5.2	6	19.0	6	3.2
7	0.0	7	1.0	7	36.9	7	1.7
8	0.5	8	11.9	8	9.5	8	16.7
9	1.8	9	9.1	9	6.8	9	7.8
10	0.9	10	34.2	10	10.9	10	2.8
11	9.5	11	11.7	11	3.5	11	2.4
12	4.5	12	11.9	12	28.3	12	1.0
13	4.1	13	21.9	13	8.7	13	2.7
14	3.3	14	20.4	14	12.1	14	0.4
15	3.4	15	8.3	15	29.9	15	6.6
16	1.0	16	16.9	16	6.9	16	7.4
17	3.5	17	37.2	17	5.4	17	0.9
18	3.2	18	20.1	18	8.4	18	2.2
19	3.3	19	10.4	19	30.7	19	0.8
20	9.0	20	29.1	20	16.0	20	12.8
21	5.3	21	30.1	21	8.8	21	7.5
22	23.4	22	9.7	22	10.3	22	0.6
23	12.1	23	9.7	23	9.5	23	2.8
24	10.7	24	4.7	24	16.7	24	27.8
25	7.6	25	6.1	25	19.1	25	5.9
26	2.5	26	0.0	26	21.1	26	1.8
27	9.4	27	5.7	27	21.5	27	0.5
28	7.0	28	10.7	28	5.3	28	0.1
29	7.7	29	5.2	29	2.1	29	0.1
30	5.9	30	9.4	30	0.5	30	0.0
		31	2.8	31	2.9		

Annex II: Extreme Maximum Temperature in Monsoon Season

Table 1: Extreme Maximum Temperature in the Month of June

Stations	Places	Extreme Maximum Temperature in ^{o}C		
		2003	2004	2005
1	Dadeldhura	31.6	28.7	33.2
2	Dipayal	42.5	39	44.2
3	Dhangadi	43.6	37.7	44
4	Birendranagar	39.5	36.2	41.8
5	Nepalgunj	42.8	38.6	44.7
6	Jumla	28.5	29.5	30.5
7	Dang	37	34.5	40.5
8	Pokhara	33.5	32.6	34
9	Bhairawa	40.5	38.7	43.7
10	Simara	37.4	36	41
11	Kathmandu	32.3	32.4	35
12	Okhaldhunga	29.7	26.6	29.6
13	Taplejung	26.8	26.9	27.8
14	Dhankuta	30.2	29.3	31
15	Biratnagar	36.2	36.3	34
16	Janakpur	38.4	35.4	42
17	Nagarkot	26.5	26.4	28.2
18	Jiri	26.5	26	27.7
19	Jomsom	24	24.5	25.5
20	Bharatpur	38.5	39.4	40.2
21	Dharan		34.5	36.5

Table 2: Extreme Maximum Temperature in the Month of July

Stations	Places	Extreme Maximum Temperature in °C		
		2003	2004	2005
1	Dadeldhura	28.4	28.6	27.5
2	Dipayal	38	38.6	36.5
3	Dhangadi	38.2	36	36.7
4	Birendranagar	34.3	33	34.8
5	Nepalgunj	37.6	35.6	38
6	Jumla	29	29.5	28.5
7	Dang	34	32.5	32.6
8	Pokhara	33.5	33	33.4
9	Bhairawa	36.9	35.4	36.5
10	Simara	36.2	34.4	35.7
11	Kathmandu	32	31.2	31.5
12	Okhaldhunga	29.4	27.6	27.7
13	Taplejung	28.7	27	28.5
14	Dhankuta	31.3	29.4	30.1
15	Biratnagar	37.5	34.7	35.4
16	Janakpur	36.8	34.2	35.8
17	Nagarkot	28.5	23.8	25
18	Jiri	27.5	25	26.2
19	Jomsom	25.1	24.5	24.8
20	Bharatpur	36.9	39	39.8
21	Dharan		34	34.4

Table 3: Extreme Maximum Temperature in the Month of August

Stations	Places	Extreme Maximum Temperature in ^oC		
		2003	2004	2005
1	Dadeldhura	28.4	30	29
2	Dipayal	37.5	37.5	35.8
3	Dhangadi	37	35.2	35.7
4	Birendranagar	33.6	33.8	33.3
5	Nepalgunj	36.8	35.7	35.6
6	Jumla	28.5	30.6	28.4
7	Dang	34	32.4	32.5
8	Pokhara	33.1	34.2	33.5
9	Bhairawa	37	36.6	36.5
10	Simara	35.6	36	35.6
11	Kathmandu	31.9	31.1	32
12	Okhaldhunga	29.2	27.8	28.3
13	Taplejung	27.1	27.8	28.7
14	Dhankuta	30.3	30.6	29.5
15	Biratnagar	36.6	35.7	37.3
16	Janakpur	36.6	36	36.5
17	Nagarkot	25.5	24.5	26.1
18	Jiri	26.4	25.9	26.1
19	Jomsom	25.2	24.6	25.4
20	Bharatpur	36.4	37.5	39.8
21	Dharan		35.2	33.5

Table 4: Extreme Maximum Temperature in the Month of September

Stations	Places	Extreme Maximum Temperature in ^{o}C		
		2003	2004	2005
1	Dadeldhura	26.4	27.8	27.2
2	Dipayal	37	37.8	35.6
3	Dhangadi	35	35.6	35.5
4	Birendranagar	32.8	33.8	33.1
5	Nepalgunj	34.5	36	36
6	Jumla	27.1	28.6	28
7	Dang	32.2	33	34
8	Pokhara	32.6	32.5	33.4
9	Bhairawa	35.7	35.9	37
10	Simara	34.7	34.2	35.5
11	Kathmandu	30.7	30.5	32
12	Okhaldhunga	27.8	26.6	27.8
13	Taplejung	26.9	25.3	28.3
14	Dhankuta	30.2	29.3	31
15	Biratnagar	34.6	34.7	37.2
16	Janakpur	35	35.5	36
17	Nagarkot	25.4	24.2	24.8
18	Jiri	25.2	25	27
19	Jomsom	23.1	24.3	24.6
20	Bharatpur	35.5	35.6	38.2
21	Dharan		33.9	35.5

Annex III: Rainfall in Monsoon Season.

Table.1. Rainfall in the month of June

Stations	Places	Rainfall in mm		
		2003	2004	2005
1	Dadeldhura	90.8	141.6	90.5
2	Dipayal	98.6	95.6	65.7
3	Dhangadi	185.7	160.6	222.8
4	Birendranagar	308.8	136.2	114
5	Nepalgunj	191.4	164.7	70.9
6	Jumla	62.6	64.9	12.7
7	Dang	298.6	124.7	129.4
8	Pokhara	785.5	832.5	263
9	Bhairawa	450.9	262.7	106.9
10	Simara	450.5	300	202.6
11	Kathmandu	227.3	183	222.9
12	Okhaldhunga	515.7	220.6	263
13	Taplejung	558.2	251.9	447.9
14	Dhankuta	206.3	141	97.7
15	Biratnagar	324.1	224	381.1
16	Janakpur	660.6	347.6	180
17	Nagarkot	344.1	105.2	196
18	Jiri	430.3	404.1	393.2
19	Jomsom	344.4	21	17.9
20	Bharatpur	425.2	339.8	144.2
21	Dharan		395.8	208.1

Table. 2. Rainfall in the month of July

Stations	Places	Rainfall in mm		
		2003	2004	2005
1	Dadeldhura	269.2	230.3	260
2	Dipayal	329.1	244.4	179.7
3	Dhangadi	594.8	514.8	664.4
4	Birendranagar	623.1	503.4	631.8
5	Nepalgunj	545.3	402.6	448.1
6	Jumla	170.1	163.7	302.2
7	Dang	492.7	422.7	416.7
8	Pokhara	1291.8	816.9	548.8
9	Bhairawa	627.7	534	713.4
10	Simara	720.8	823	414.7
11	Kathmandu	591.5	459.5	253.5
12	Okhaldhunga	477.1	663.2	613.8
13	Taplejung	595.5	335.8	306.6
14	Dhankuta	323	397.7	277.6
15	Biratnagar	787.2	876.1	276.9
16	Janakpur	453.8	606.7	183.6
17	Nagarkot	519.8	563.5	302.2
18	Jiri	676.4	845.8	494.9
19	Jomsom	34.2	49.4	92.6
20	Bharatpur	1172.1	333.5	409.3
21	Dharan		535	476.8

Table. 3. Rainfall in the month of August

Stations	Places	Rainfall in mm		
		2003	2004	2005
1	Dadeldhura	265.4	291.5	74.2
2	Dipayal	260.3	185.9	119.4
3	Dhangadi	628.8	260.7	303.5
4	Birendranagar	434.6	298.2	421.4
5	Nepalgunj	257.8	114.2	303
6	Jumla	236.3	215.7	87.2
7	Dang	325.3	256.2	448.5
8	Pokhara	586	788.87	924.5
9	Bhairawa	393.7	181.1	438.3
10	Simara	354.6	216.7	812.8
11	Kathmandu	275.7	232.5	309.3
12	Okhaldhunga	266.7	138.9	493.2
13	Taplejung	328	302.9	331.6
14	Dhankuta	119.8	80.2	434.2
15	Biratnagar	168.1	249.2	572.7
16	Janakpur	214.4	133.4	677.9
17	Nagarkot	477.1	331.1	643
18	Jiri	589.9	564.8	480.2
19	Jomsom	80.3	51.8	33.2
20	Bharatpur	612.6	250.5	560.3
21	Dharan		235.2	717.5

Table.4. Rainfall in the month of September

Stations	Places	Rainfall in mm		
		2003	2004	2005
1	Dadeldhura	425.7	152	316.8
2	Dipayal	326.2	250.6	347.3
3	Dhangadi	622.8	165	342.7
4	Birendranagar	277.9	143.5	316.8
5	Nepalgunj	425.8	161.4	181.6
6	Jumla	121.4	72.3	82
7	Dang	330.7	197.8	228.8
8	Pokhara	953	867.2	313.5
9	Bhairawa	226.8	261.1	74
10	Simara	244.9	216	107.8
11	Kathmandu	294.2	168.1	126.5
12	Okhaldhunga	295.3	116.2	176.1
13	Taplejung	282.6	248.7	206.8
14	Dhankuta	61.1	89.6	65.8
15	Biratnagar	317.7	365.5	88.4
16	Janakpur	68.6	129.9	57.6
17	Nagarkot	416.6	192.3	194.5
18	Jiri	596.8	254.4	298.8
19	Jomsom	46.1	18.8	16.2
20	Bharatpur	246.2	385	88.5
21	Dharan		250.2	221.1

Annex IV: Mean Temperature and Rainfall at 11 Stations in Nepal

S.No.	Stations	Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Dadeldhura	Mean T	8.6	9.7	14.5	17.9	20.1	21.2	20.6	20.2	19.2	16.7	13.1	10.6
		Mean R	47.6	66.8	61.1	57.7	92.2	175.0	326.5	285.4	185.6	35.1	7.8	28.6
2	Jumla	Mean T	30.7	43.0	59.4	48.5	57.0	74.9	182.6	176.6	96.4	31.0	11.5	15.5
		Mean R	13.1	12.4	16.2	19.6	21.3	23.8	24.0	24.1	23.0	19.7	15.3	11.5
3	Nepalgunj	Mean T	15.1	17.6	23.1	28.6	31.1	31.5	29.8	29.7	28.6	26.3	21.6	17.0
		Mean R	26.4	25.9	16.4	16.7	68.0	201.9	435.3	334.2	232.3	55.8	5.3	14.3
4	Jomsom	Mean T	4.0	5.6	9.0	12.4	15.7	19.3	20.1	19.8	18.1	12.9	8.4	5.6
		Mean R	8.6	13.7	23.6	19.4	18.2	23.4	41.4	37.4	39.3	29.7	6.3	6.8
5	Kathmandu	Mean T	4.0	4.6	8.4	11.4	14.4	17.4	18.2	18.1	16.3	11.9	7.8	5.1
		Mean R	16.6	18.8	32.5	56.6	118.4	249.0	374.5	333.8	191.2	55.6	8.5	13.7
6	Janakpur	Mean T	15.7	18.5	23.3	27.4	29.2	30.0	29.2	29.5	28.8	26.7	22.4	18.0
		Mean R	13.7	13.4	10.9	54.6	119.5	242.2	495.9	338.4	197.3	71.4	2.3	9.9
7	Dhankuta	Mean T	11.7	13.5	17.4	20.4	21.5	22.7	22.7	22.8	21.8	19.5	16.5	13.3
		Mean R	13.5	14.8	25.2	51.8	107.4	162.7	270.1	169.7	132.2	53.3	13.9	10.6
8	Okhaldhunga	Mean T	9.9	11.7	15.6	18.8	19.9	20.9	20.7	20.8	19.9	18.0	14.8	11.5
		Mean R	13.2	14.0	27.8	52.3	150.4	313.1	465.3	391.5	245.1	68.9	11.8	12.7
9	Biratnagar	Mean T	15.9	18.4	23.2	27.2	28.2	28.9	28.7	29.0	28.2	26.1	22.1	17.8
		Mean R	12.8	12.8	15.6	54.5	166.6	299.1	573.8	370.7	320.3	93.7	8.8	7.5
10	Nagarkot	Mean T	5.3	6.4	9.1	11.5	12.1	13.4	13.7	13.7	13.1	10.9	8.8	6.5
		Mean R	17.6	20.4	29.7	55.5	144.3	336.1	488.2	480.7	275.1	71.2	9.6	11.7
11	Jiri	Mean T	6.2	8.1	11.4	14.5	17.2	19.7	20.2	20.2	19.0	15.2	10.7	7.4
		Mean R	18.4	24.0	41.9	89.0	175.5	367.3	586.5	574.6	298.8	70.6	13.8	15.2