A Study on Spatial and Temporal Distribution of Rainfall in Province Number 3, Nepal

IN PARTIAL FULFILLMENT FOR THE REQUIREMENT OF MASTER'S DEGREE OF SCIENCE IN HYDROLOGY AND METEOROLOGY

By

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DECLARATION

Thesis entitled **"A Study on Spatial and Temporal Distribution of Rainfall in Province Number 3, Nepal"** is being submitted to the Central Department of Hydrology and Meteorology, Institute of Science and Technology (IOST), Tribhuvan University, Nepal for the achievement of the Degree of Master of Science (M.sc). This is a research work carried out by me under the supervision of Assistant Professor Dr. Madan Sigdel, Central Department of Hydrology and Meteorology, Tribhuvan University. This research has not been submitted earlier in this or any other university or institute, here or elsewhere, for the achievement of any degree.

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RECOMMENDATION LETTER

This is to certify that Mr. Hridaya Raj Kuinkel has prepared the dissertation entitled **"A Study on Spatial and Temporal distribution of rainfall in Province Number 3, Nepal''** to fulfill the partial requirements for Master's degree in Hydrology and Meteorology. The study done by him has been carried out under my supervision and guidance.

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ACCEPTANCE

The present dissertation entitled " **A Study on Spatial and Temporal distribution of rainfall in Province Number 3, Nepal "** submitted by Mr. Hridaya Raj Kuinkel has been accepted as the partial fulfillment for master's degree in Hydrology and Meteorology.

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ABSTRACT

Daily observed precipitation data of 23 stations for the period of 1980-2015 is used in the study of spatial and temporal distribution of rainfall in Province 3 of Nepal. The study is basically focused on the study of space time variation and principal component analysis of rainfall. About 80.6% of annual rainfall is covered by monsoon rainfall so both spatial and temporal distribution of annual rainfall is proportionate with monsoon rainfall (JJAS). Highest rainfall pocket area is observed in northeastern part of Province in the periphery of Gumthang, Sindhupalchok with rainfall of 3828 mm while lowest rainfall is observed in Tamachit, Rasuwa with 720 mm. Temporally rainfall is high in 1999 with rain 2399.4 mm and low in 1992 with rain 1508 mm. July is highest rain month and November is lowest. Seasonally, increasing trend of rainfall is seen in Pre monsoon while decreasing trend is seen in Monsoon, Post monsoon and winter. On decadal rainfall analysis it is obtained highest rainfall in third decade (2000-2009) and lowest in last decade (2010-2015). Analysis of rainfall shows average annual rainfall in lowland is 1883.8 mm and highland is 1959.6 mm. The correlation coefficient between rainfall in highland and lowland is 0.79.

In most of the La Nina year there is increased rainfall and El Nino year the rainfall is decreased. So, we can conclude that there is some influence of large scale atmospheric phenomena like ENSO.

First component (PCA1) of Principal component analysis which covers largest information of space time variation of rainfall shows that pre monsoon precipitation pattern is highly concentrated in central part of the Province while monsoon is concentrated in southern part of the Province. Similarly, Post monsoon precipitation pattern is concentrated in central part of the Province while winter precipitation pattern is concentrated over both the central as well as southwestern part of the Province.

Key Words: Spatial, Temporal, Rainfall, ENSO, Inverse Distance Weighting, Principal Component Analysis

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LIST OF ABBREVIATIONS

ENSO	El Nino Southern Oscillation
SASM	South Asian Summer Monsoon
EASM	East Asian Summer Monsoon
a.s.l	above sea level
m	Meter
mm	Millimeter
DHM	Department of Hydrology and Meteorology
Sq. km.	Square Kilometer
WPSH	Western Pacific Subtropical High
IDW	Inverse Distance Weighting
CBS	Central Bureau of Statistics
SOI	Southern Oscillation Index
SST	Sea Surface Temperature

CHAPTER 1
INTRODUCTION

1.1 Introduction:

In Meteorology, precipitation is any product of the condensation of atmospheric water vapor that falls under gravity. The main forms of precipitation include drizzle, rain, sleet, snow, graupel and hail. Precipitation occurs when a portion of the atmosphere becomes saturated with water vapor, so that the water condenses and "precipitates". Thus, fog and mist are not precipitation but suspensions, because the water vapor does not condense sufficiently to precipitate. Two processes, possibly acting together, can lead to air becoming saturated: cooling the air or adding water vapor to the air. Rain forms as smaller droplets coalesce via collision with other rain drops or ice crystals within a cloud. Short, intense periods of rain in scattered locations are called showers (Glossary of Meteorology, 2009). Rainfall is the major component of the water cycle which vary both in space and time. The globally averaged annual precipitation over land is 715mm (28.1in), but over the whole Earth it is 990mm(39in).

Culturally, people in Nepal note six seasons or Ritu, each about two months long. These are the spring season (Basanta), summer (Grishma), monsoon season (Barsha), autumn (Sarada), winter (Hemanta) and prevernal season (Sisira). Monsoon is traditionally defined as a seasonal reversing wind accompanied by corresponding changes in precipitation. According to Indian Meteorological Department the large scale variations monsoonal rainfall is largely governed by relief, mountain barrier, distance from the sea and weather systems like monsoon trough as well as depressions originating from Bay of Bengal and Arabian sea. Usually, the term monsoon is used to refer the rainy phase of a season. The monsoon of South Asia is among several geographically distributed global monsoons. It affects the Indian subcontinent, where it is one of the oldest and most anticipated weather phenomena which is also socially, environmentally and economically important for the people living in this region.

Nepal, lying in the southern periphery of the Tibetan Plateau receives about 80% of the total annual rainfall during summer monsoon (June–September). Rainfall analysis shows that summer monsoon is more active in the southern part of Nepal but in the high Himalayas and Trans-Himalayan region other weather systems like western disturbances (Shrestha, 2000). Spatial variation of rainfall in the Province 3 is quite different from the other states of Nepal. Nepal Mountains are topographically very unique so the spatial feature of the rainfall in the country is highly influenced by the topography and altitude difference which results in significant local change.

Shrestha, Wake, Dibb, & Mayewski (2000) concludes that rainfall in Nepal is also influenced by large scale atmospheric phenomenon like EL NINO. According to Department of Hydrology and Meteorology (DHM) the year 2015 was one of the third strongest El Nino year on record.

The global climate change has direct impact in rainfall of many countries. Changes in precipitation pattern directly affect cryosphere, water resources management, agriculture pattern, hydrology and natural ecosystems. Loo et al., (2015) concludes that there is a relationship between global increase in temperature and precipitation change beyond the 1970's and there is a westward shift of East Asian Summer monsoon (EASM). Nepal has been ranked 4th vulnerable country in terms of climate change, 11th in earthquake vulnerability while stands on 30th position in the world in terms of flood hazard (UNDP/BCPR, 2004). In terms of numbers of people affected by all types of natural disasters in the period of 1971 to 2007, flood is the main disaster affecting 68.3% of the total affected people (Statistical Pocket Book, 2004).

In Province 3, the cities within and around Kathmandu valley, Bharatpur, Hetauda etc. there is rapid urbanization leading to the change of land use and land cover, and the rising concentration of atmospheric pollutants or aerosols such as sulphate and black carbon aerosols can directly affect the rain pattern and climate. The change in daily, monthly and seasonal rainfall during summer monsoon season over Province 3 would affect flooding pattern in eastern and central Nepal and Northern part of India.

This study is particularly carried out in the Province 3 due to the higher number of rain gauges, its long term data and its unique terrain.

1.2 Objectives of the study:

The major objective is concerned on study of temporal and spatial distribution of rainfall in Province 3 of Nepal. The secondary objectives of this study are:

- To study the decadal, annual and seasonal variability of rainfall from 1980-2015.
- To study the rainfall distribution in Province 3 using Principal Component Analysis (PCA).

1.3 Data and Methodology:

1.3.1 Data used:

The present study incorporates precipitation data of Province 3, Nepal. The monthly data of 23 stations for the period 1980-2015 obtained from Department of Hydrology and Meteorology of Nepal were utilized for analysis. Most of the stations with regular data for the 36-year period are utilized to study change in precipitation. Furthermore, the sea surface temperature data comprising ENSO from CPC NOAA (https://www.cpc.ncep.noaa.gov/) is also used. The station characteristics is shown in Table 1.

Station	Station Number	Latitude	Longitude	Elevation (m)
Rampur	902	27.65	84.35	189
Jhawani	903	27.59	84.52	177
Chisapani Gadhi	904	27.56	85.14	1729
Hetauda NFI	906	27.42	85.03	452
Markhu	915	27.62	85.15	1535
Manahari	920	27.53	84.81	272
Gumthang	1006	27.86	85.86	1846
Kakani	1007	27.81	85.26	2034
Thankot	1015	27.69	85.22	1457
Baunepati	1018	27.79	85.57	774
Dolalghat	1023	27.64	85.7	659
Bahrabise	1027	27.79	85.9	884
Kathmandu Airport	1030	27.7	85.36	1337
Dhunibesi	1038	27.72	85.16	991
Khopasi	1049	27.57	85.53	1442
Tamachit	1054	28.18	85.3	1770
Pansyakhola	1057	28.03	85.11	1982

Changunarayan	1059	27.72	85.43	1502
Chapagaun	1060	27.6	85.33	1478
Charikot	1102	27.67	86.05	1940
Bahun Tilpung	1108	27.18	86.17	1417
Nepalthok	1115	27.42	85.85	690
Hariharpur Gadhi	1117	27.33	85.5	250

Table 1: List of stations

1.3.2 Methodology

In this study, Inverse Distance Weighting(IDW) method is used for filling the missing data. Arc GIS 10.1 is used for the spatial analysis and presentation. Principal component analysis(PCA) is performed using XLSTAT 2016.

A. Distance power method / Inverse distance weighting (IDW)

The rainfall at a station is estimated as a weighted average of the observed rainfall at the neighboring stations. The weights are equal to the reciprocal of the distance or some power of the reciprocal of the distance of the estimator stations from the estimated stations. Let *Di* be the distance of the estimator station from the estimated station. If the weights are an inverse square of distance, the estimated rainfall at station A is:

$$PA = \left(\sum_{i=1}^{n} Pi/Di^2\right) \div \left(\sum_{i=1}^{n} 1/Di^2\right) \quad \text{(Shepard, 1968)}$$

Where:

PA = estimated rainfall at the test station at time

Pi = observed rainfall at the neighbor station i at time

Di^2 = square of distance between the test and the neighboring station i

n = number of neighboring stations taken into account.

Note: that the weights go on reducing with distance and approach zero at large distances. A major shortcoming of this method is that the orographic features and spatial distribution of the variables are not considered. The extra information, if stations are close to each other, is not properly used.

The procedure for estimating the rainfall data by this technique is illustrated through an example.

If A, B, C, D are the location of stations discussed in the example of the normal ratio method, the distance of each estimator station (B, C, and D) from station (A) whose data is to be estimated is computed with the help of the coordinates using the formula:

$Di^2 = [(x - xi)^2 + (y - yi)^2]$

where x and y are the coordinates of the station whose data is estimated and xi and yi are the coordinates of stations whose data are used in estimation.

B. Principal component analysis (PCA)

Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables (entities each of which takes on various numerical values) into a set of values of linearly uncorrelated variables called principal components. If there are n observations with p variables, then the number of distinct principal components is min (n-1, p). This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components. The resulting vectors (each being a linear combination of the variables and containing n observations) are an uncorrelated orthogonal basis set. PCA is sensitive to the relative scaling of the original variables (Pearson, 1901).

PCA seeks a linear combination of variables such that the maximum variance is extracted from the variables. It then removes this variance and seeks a second linear combination which explains the maximum proportion of the remaining variance, and so on. This is called the principal axis method and results in orthogonal (uncorrelated) factors. PCA analyzes total (common and unique) variance. Factor model in which the factors are based on summarizing the total variance. With PCA, unities are used in the diagonal of the correlation matrix computationally implying that all the variance is common or shared. Algorithm lacking underlying model.

The basic equation of PCA is, in matrix notation, given by: $Y = W'X$

Where,

W is a matrix of coefficients that is determined by PCA

X is adjusted data matrix, which consists of n observations (rows) on p variables (columns)

The major objectives of principal component analysis are:

- PCA reduces attribute space from a larger number of variables to a smaller number of factors and as such is a "non-dependent" procedure (that is, it does not assume a dependent variable is specified).
- PCA is a dimensionality reduction or data compression method. The goal is dimension reduction and there is no guarantee that the dimensions are interpretable (a fact often not appreciated by (amateur) statisticians).
- To select a subset of variables from a larger set, based on which original variables have the highest correlations with the principal component (Wold, Esbensen, & Geladi, 1987).

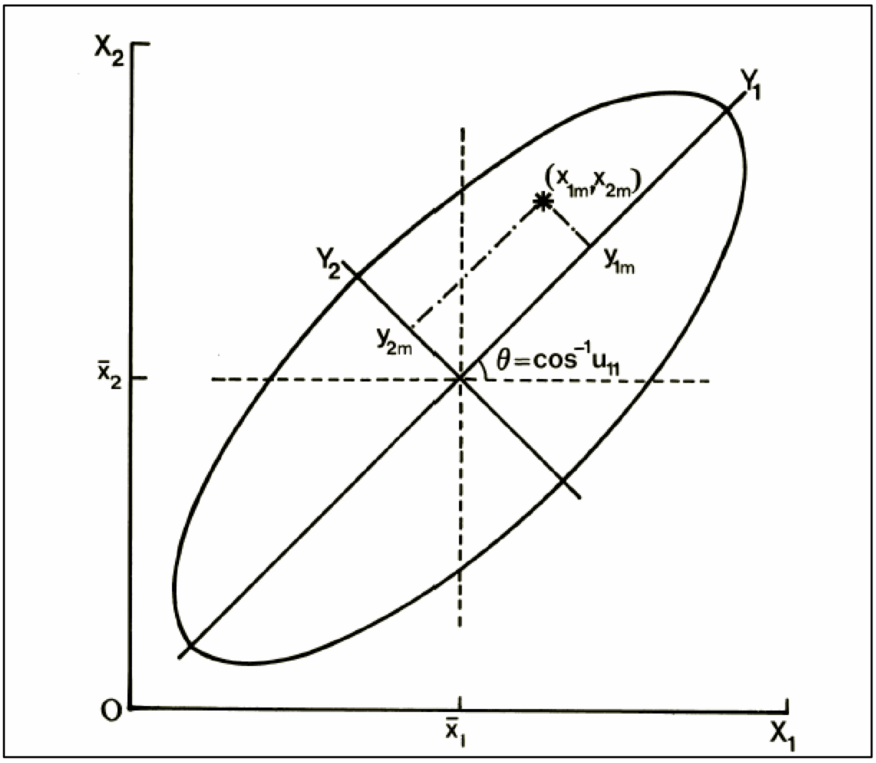

Figure1: Geometry of Principal Components

Figure 1 describes the idealized representation of scattered diagram for two variables, showing the mean for each variables x

Eigenvalue: Eigenvalues measure the amount of variation in the total sample accounted for by each factor. A factor's eigenvalue may be computed as the sum of its squared factor loadings for all the variables. Note that the eigenvalues associated with the unrotated and rotated solution will differ, though their total will be the same. Column sum of squared loadings for a factor, i.e., the latent root. It conceptually represents that amount of variance accounted for by a factor. Also called characteristic roots. The eigenvalue for a given factor measures the variance in all the variables which is accounted for by that factor. The ratio of eigenvalues is the ratio of explanatory importance of the factors with respect to the variables. If a factor has a low eigenvalue, then it is contributing little to the explanation of variances in the variables and may be ignored as redundant with more important factors.

Factor: Linear combination (variate) of the original variables. Factors also represent the underlying dimensions (constructs) that summarize or account for the original set of observed variables.

Factor loadings: Correlation between the original variables and the factors, and the key to understanding the underlying nature of a particular factor. Squared factor loadings indicate what percentage of the variance in an original variable is explained by a factor. The factor loadings, also called component loadings in PCA, are the correlation coefficients between the variables (rows) and factors (columns). Analogous to Pearson's r, the squared factor loading is the percent of variance in that variable explained by the factor. To get the percent of variance in all the variables accounted for by each factor, add the sum of the squared factor loadings for that factor (column) and divide by the number of variables. (Note the number of variables equals the sum of their variances as the variance of a standardized variable is 1.) This is the same as dividing the factor's eigenvalue by the number of variables.

Factor score: Composite measure created for each observation on each factor extracted in the factor analysis. The factor weights are used in conjunction with the original variable values to calculate each observation's score. The factor scores are standardized to reflect a z-score. Factor scores place each variable in a plane of multivariate variability. Also called component scores in PCA, these scores are the scores of each case (row) on each factor (column). To compute the factor-score for a given case for a given factor, one takes the case's standardized score on each variable, multiplies by the corresponding factor loading of the variable for the given factor, and sums these products.

CHAPTER 2

STUDY AREA

Province 3 is located between Province 1 in east, Province 2 in south, Gandaki Province in west and China in north (Figure 1). Politically the Province comprise of 13 districts (Figure 2). Most of the province is covered with hills, where Himalayas is located in north, Kathmandu valley in center and Chure range with small portion of Terai in south. Elevation of surrounding range from about 150m to above 8000m. Bagmati, Gandaki and Koshi river basin and its portion are located in this region.

Gaurishankar, Langtang, Jugal, Ganesh, etc. are the major mountains present in this Province. Deciduous forest, coniferous forest and alpine forest are available here due to the variation in altitude.

The east to west and north to south axes of Province are about 200 km and 137km. Kathmandu valley lies between 27°32 to 27°49 E and 85°11 to 85° 32 N. The Kathmandu valley, which has the capital city Kathmandu along with four other municipal towns, Lalitpur, Bhaktpur, Kirtpur and Madhyapur-Thime, along with Hetauda, Bharatpur, Banepa, Dhulikhel, etc. are the main urban area of Province 3.

Nepal has a great deal of variations in climate. Although Nepal lies near the northern limit of the Tropics, a very wide range of climates from Subtropical in the southern Terai to Tundra in the northern high Himalayas exists here. The remarkable differences in climatic conditions are primarily related to the enormous range of elevation within a short north-south distance. The presence of the east-west extending Himalayan massifs to the north and the monsoonal alteration of wet and dry seasons also greatly contribute to local variations in climate.

The main seasons in Province 3 and whole Nepal are Spring, Summer, Autumn and Winter. Spring, in this season the sky is not as blue as autumn and begins from February through April. Summer, it is the hottest season in Nepal generally begins in May and last through August. Autumn, it is known as the festival season begins with the end of monsoon and ends with the beginning of winter in November (September to November). Winter last from November till February and it is the cold months.

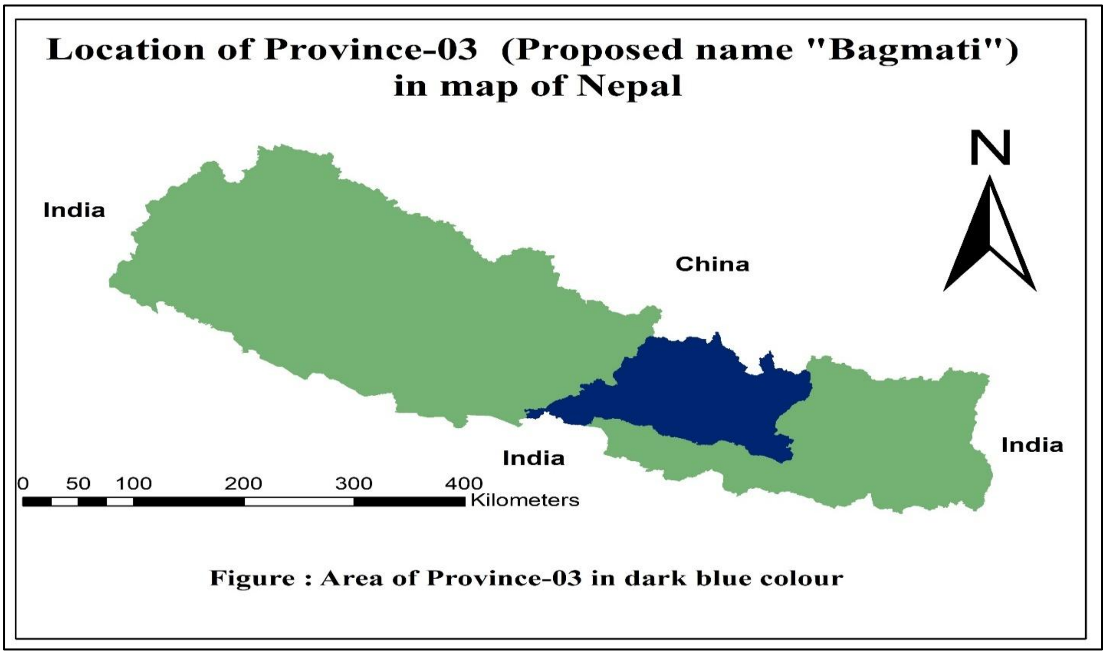

Figure1: Location of Province 3 in the map of Nepal

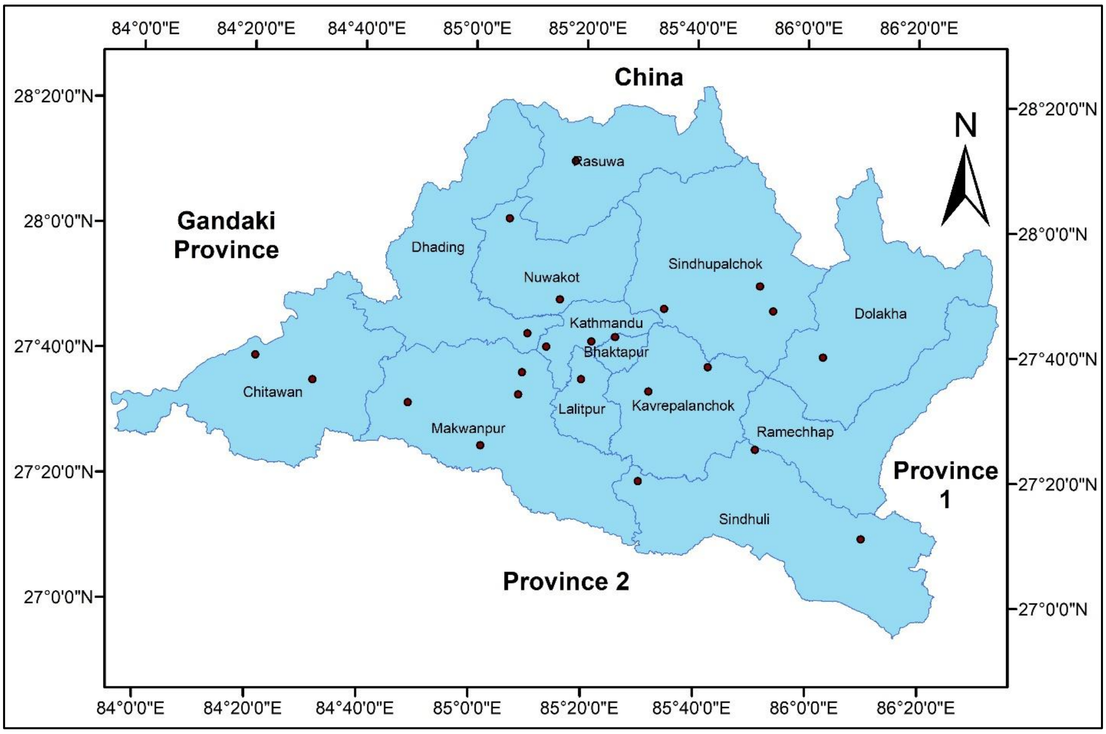

Figure 2: Political division of Province and location of the rainfall stations used (dot).

2.1 Topography:

Nepal is small landlocked country that covers an area of 147,181 km2 in the center of Hindu Kush Himalayas between India and china (Figure 1). Nepal stretches from 26º

22’ to 30º 27’ North latitude and from 80º 04’ to 88 º 12’ East longitudes. The country looks roughly rectangular in shape with the length from east to west of about 885 km and width ranging from 130 to 260 km. It contains 8 of the 10 highest mountain peaks in the world, including Mount Everest (at 8848 m), although some of its low lying areas are only about 80 m meters above sea level.

The country is divided into three broad ecological regions, i) The higher Himalayas in the north, ii) Hills and Valleys in the middle, and iii) Terai, an extension of Indo-Gangetic plain, in the south.

As in Figure 3, Nepal is divided into five geographic regions according to physiographic as well as topographic region: Terai plan, Siwalik hills, Middle Mountains, High Mountains (consisting of the Main Himalayas and the Inner Himalayan Valleys), and the high Himalayas. (*Statistical Pocket Book*, 2004)

Province 3 has a very diverse environment resulting from its impressive topography. Topographically, Province 3 is extended from southern Terai plain to northern high Himalayas. Climate and vegetation is highly influenced by topography as we can see sub-tropical climate along plain land in southern part, temperate climate along hills in middle part and alpine climate along high altitudes in northern part of Province. Forest is the dominant form of land cover in the Province.

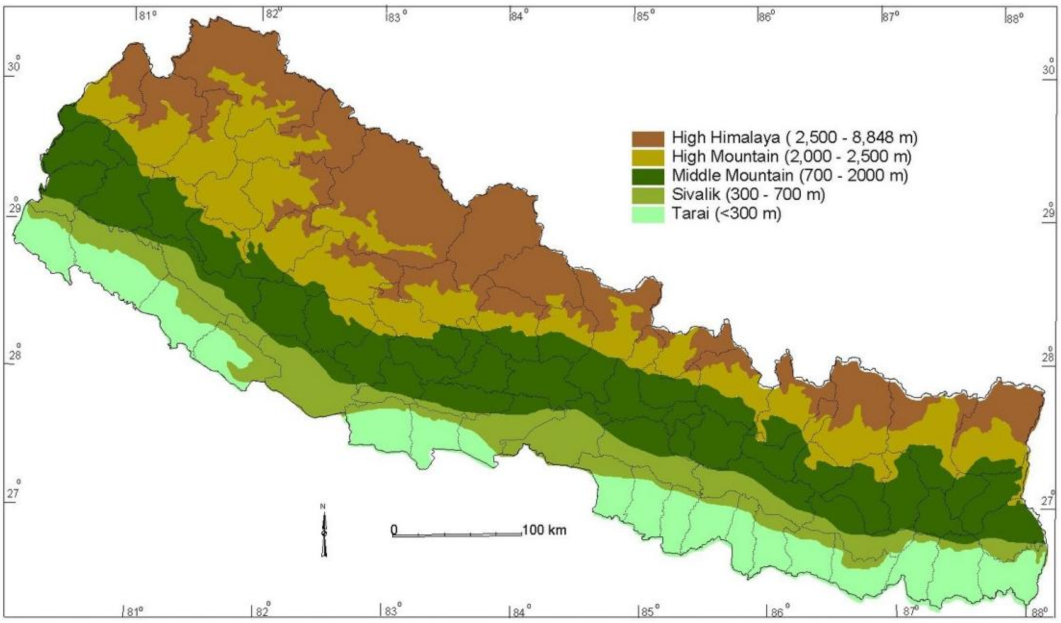

Figure 3: Physiographic division of Nepal (Department of survey Nepal,1983)

2.2 Climate of Nepal:

A. Tundra - climatic type: - Tundra type of climate is found in the higher Himalayas region of Nepal. Almost above snowline (5000 m), a permanent cover of snow and ice, Precipitation mostly falls in the form of snow occurs only.

B. Alpine - climatic type: - In the lower part of the Himalayas region, alpine type of climate is found. Above 4000m, cool summer and frosty winter, snow and ice, precipitation in the form of snow occurs only.

C. Cool temperate - climatic type: - This type of climate is found in the region of High Mountain region of Nepal. Cool summer and cool winter, winter

Precipitation in the form of snow at high altitude occurs only.

D. Warm temperate - climatic type: - This type of climate is found in the region of Mahabharata range of middle mountain region of Nepal. Warm summer and cool winter, occasionally snowfall in higher region of hills and precipitation in the form shower may occur.

E. Tropical/Subtropical - climatic type: - The sub-tropical type of climate is found in the lower region of Chure range or Terai of Nepal. The tropical type of climate is found in the Chure range or Siwalik of Nepal. Hottest and humid summer, mild and dry winter occurs. (Adopted from (Regmi, 1998))

2.2.1 Climatology:

The climatic condition of Province 3 and central Nepal depends on the prevailing wind regime from central Asia and the northern hemisphere's cold pole. Summer monsoon (June, July, August, and September) and western disturbance (Dec-May) are considered the main rain weather producing system. In the summer and early autumn, the prevailing wind regime in Province 3 is southwest monsoon. During March to May the Province experiences pre-monsoon thundershower activities and there is a strong wind in this season. The temperature in most part of Province 3 drops near freezing in winter and in summer it may rise to nearly 35°C. The mean annual air temperature in Kathmandu is 18°C. The coldest month is January and the warmest month is July and august. Fog is common in the morning during the months of October to February.

2.2.2 General seasons in Nepal:

According to season, Season of Nepal is divided into four parts; these

are as follows (Nayava, 1982):

A. Pre-monsoon season: (March - May)

B. Monsoon season: (June – September)

C. Post monsoon season: (October - November)

D. Winter season: (December -February)

A. Pre-monsoon season: It starts from March to May. In this period, much of the days of the month remain under the domination of the dry westerly wind. This wind system produces dusty and windy weather in the most of the country. Convective activity produces high to moderate rain shower especially in the hilly region. As a matter of the fact, the distribution of pre-monsoonal rainfall in the country are associated with the thermal convection associated with orographic effects which results thunderstorm associated with precipitation over the narrow bands with in the region.

B. Monsoon season: The season starts from June to September in Nepal is known as rainy season. Monsoon arrives from eastern Nepal on June 10th, and it arrives at Kathmandu on June 12th, within 2 to 3 days, it covers the whole country. The normal date of the retreat of the monsoon is September 23. When the monsoon circulation pattern is established, temperature begins to fall; air becomes most compared to other season. Relative humidity of this season becomes high. In Nepal, 60% to 80% of the annual rainfall falls during this season. Rainfall varies sharply from one place to another due to impact of the topography. When the moist south easterly wind approaches, the air stream is forced to rise resulting rainfall on the slope facing southwards. The month of July is the rainiest month of the rainy season.

C. Post monsoon season: The season is the changing period from season to another and harvesting season of monsoon crop field preparation is done for winter season crops. Sometimes, the country receives precipitation by cyclonic storm that develops in the Bay of Bengal and Arabian Sea. Regmi (1998) indicates the domination of westerly wind flow with falling in temperature gradually as an indication of pre-winter activity, negligible amount of rainfall occurs in this period.

D. Winter Season or Cold weather season: It runs from December to February.

Northwesterly wind pre-dominates the country in this season. Except in the region of great Himalayan and a high mountain, the winter is normal with great sunny days (Nayava, 1982). In winter, major weather effective elements are the western disturbances and so western Nepal receives higher amount of rainfall than eastern Nepal. This region is relatively dry & cool weather, lowest temperature and rainfall amount is very less but greater than post monsoon.

CHAPTER 3
LITERATURE REVIEW

3.1 Precipitation:

The term precipitation denotes all forms of water that reach the earth from the atmosphere. Precipitation may reach the surface of the earth in the form of drizzle, rain, snow, hail, sleets etc. The magnitude of precipitation varies with time and space.

For precipitation to form:

I) The atmosphere must have moisture,
II) There must be sufficient condensation nuclei present
III) Weather condition must be good for condensation of water vapor to take place, and
IV) The product of condensation must reach the earth.

The net precipitation at a place and its form depends upon wind, temperature, humidity and pressure within the regions enclosing the cloud and the ground surface at the given place.

3.2 Types of precipitation:

For the formation of clouds and subsequent precipitation, it is necessary that the moist air masses cool to form condensation. This is normally accomplished by the adiabatic cooling of moist air through a process of lifting to higher altitudes. Some of the terms and process connected to the weather system associated with precipitation in Nepal are given below.

Convective precipitation:

This is the type of precipitation due to the upward movement of air that is warmer than its surrounding. Generally, this kind of precipitation occurs in tropics. In the hot day the ground surface becomes heated, as does also the air to expand and rise by the contact with it. This causes the air to expand and rise by convection. As it rises it cools dynamically at the dry adiabatic rate of about 1°C /100m which in turns results in condensation and precipitation.

Orographic precipitation:

The precipitation caused by lifting of moist air from mountain barrier is called orographic precipitation. When moisture bearing winds usually blowing from oceans to land surfaces are forced far above the ground surface by the influence of the mountain ranges, the adiabatic cooling take place resulting condensation and precipitation on the windward ridge of the mountains.

Cyclonic (Tropical) precipitation:

A cyclone is a large low pressure region with the circular wind motion. Cyclone precipitation results due to the low atmospheric pressure over the water surface which moves to the land wards from lifting of air masses converging into a low pressure area or cyclone.

3.3 Factor affecting Monsoon Circulation

The Monsoon Trough

During Monsoon an elongated zone of low pressure develops along the Indo-Gangetic plains of north India. The axis of low pressure is roughly oriented from 30°N, 75°E to 23°N, 88°E (Ramaswamy, 1962). The northwestern end of the trough merges with a heat low over Indo-Pakistan and the southeastern end of the trough often lies over the northern Bay of Bengal, which is the birthplace of monsoon (Ramage, 1971). The position of the monsoon trough at different level. At surface (1000 hPa), it runs from Ganganagar to Calcutta, roughly parallel to the southern periphery of the Himalayan mountains. At 4 kilometers (600 hPa) it runs from Bombay to Sambalpur. In the vertical it extends up to about 6 kilometers (500 hPa). The latitudinal position of the surface monsoon trough varies from day to day. During the break monsoon, the monsoon trough shifts to the foot of Himalayas and the axis of the trough very roughly extends from 32°N, 75°E to 26°N, 90°E (Ramaswamy, 1962). During this condition, Nepal receives heavy rainfall while most parts of India receives below normal rainfall.

Monsoon Depression

The climatological average number of monsoon depressions which form in each of the four monsoon months, June to Sept. varies between 1 and 3. In addition, weaker systems called monsoon lows also form during the season. There is a wide scatter in the time interval between successive formations of MDs; it may be as small as 3 days and may even exceed a month. 90% of MDs last 2-5 days; the remaining 10% has life of a week or more. The most frequent spatial distance between two co-existing MDs is 1100-2000 km. Individual depressions during July and August follow a track which is close to the mean track, which runs in a west to North West direction. The scatter of the tracks in June and Sept. is larger and many of them recurve in a northerly or northeasterly direction.

Heat Low

The land low over south Asia during the pre-monsoon season (during March to May) is a part of the global scale low pressure belt extending from the Sahara to central Asia across Arabia, Iran, Afghanistan, Pakistan, northwest India, and even up to Myanmar. The subsidence of air which has been warmed by release of latent heat in monsoon rain systems to the east and then transported westwards by the upper tropospheric easterlies maintains the heat low (Ramage, 1966). During the summer months, the center of the seasonal low, popularly known as the 'heat low', is located over the region, where maximum temperatures of 45°C or more are experienced. The resulting steep horizontal pressure gradients generate strong surface winds which, together with loose sand, produce dust and sand storms. The boundary layer, consisting of approximately the lowest 1.5 km over the region, experiences a strong temperature inversion (Ramage, 1971).

Mascarene High

The summer monsoon currents over East Asia originate either from the north Pacific HIGH or from Mascarene HIGH (MH) over the subtropical Indian Ocean and Australian HIGH. MH is the high-pressure area at sea level south of the equator in the Indian Ocean near Mascarene island, with its center located near 30°S, 50°E.The mean monthly value of the central pressure in the region of MH during June, July, August and September is about 1025 (Ananthakrishnan, 1968).

Tibetan High

The Tibetan plateau, located more than 4500 m above sea level with a length of about 2000 km and width of about 600 km in the west and about 1000 km in the east, is considered to be one of the key factors in the development of monsoon circulation in the region. The atmospheric pressure on the surface of the plateau varies between 700 and 500 hPa. The Tibetan plateau exerts its influence as a mechanical barrier in the atmospheric flow as well as a high-level heat source. An anticyclone appears in the upper troposphere over Tibet during the Indian summer monsoon season, primarily due to latent and sensible heating over the plateau.

The Tibetan anticyclone is thus a warm high located over the Tibetan plateau in the middle or upper troposphere during the monsoon season and having the highest amplitude near 200 hPa.

El Niño Southern Oscillation (ENSO)

El Niño Southern Oscillation (ENSO) is an irregularly periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting the climate of much of the tropics and subtropics. The warming phase of the sea temperature is known as El Niño and the cooling phase as La Niña. The Southern Oscillation is the accompanying atmospheric component, coupled with the sea temperature change: El Niño is accompanied by high air surface pressure in the tropical western Pacific and La Niña with low air surface pressure (Halpern & Woiceshyn, 2001). The two periods last several months each and their effects vary in intensity. As shown by Kripalani & Kulkarni (1997), the interdecadal variation of the Pacific SST is not simply a result of the changes in the frequency of El Niño and La Nina events. Monsoon rainfall over Nepal shows large Interannual variability which has a good relationship with the Southern Oscillation Index (M. L. Shrestha, 2000).

Low Level Jet Stream

The Low Level Jet is also known as ‘‘Find later Jet’’ or "Somali Jet". It has been calculated that this current crossing the equator over the western Indian ocean accounts for about half of the total cross equatorial transport of air in the lower troposphere in July. Low Level Jet Stream over India with its large shear vortices field in the boundary layer has a prominent control on monsoon rainfall. To the north of the jet axis rainfall is found to be large, with the rain fall maximum a few degrees' latitude to the north of the jet axis: To the south of the jet axis, rainfall is suppressed. It is found that 70% of the water vapor that crosses the west coast of India comes from the southern hemisphere and 30% is due to evaporation from Arabian Sea. Somali Jet is normally strongest in July and August when core maximum speeds up to 100 knot have been observed. A study by Halpern & Woiceshyn (2001) has shown that, the inter annual variations of the Somali Jet in the Arabian Sea during 1988–99 were linked to El Nino and La Nina episodes. The average date of Somali Jet onset was two days later in El Nino events in comparison with La Nina conditions. The monthly mean strength of the Somali Jet was 0.4 m s-1 weaker during El Nino episodes than during La Nina intervals.

3.4 Precipitation climatology of Nepal:

The distribution of precipitation has high spatial variation in Nepal. Nepal experiences the seasonal summer monsoon rainfall from June to September. Most of the days during June to September are cloudy and rainy. About 80 % of the annual precipitation in the country falls between June and September under the influence of the summer monsoon circulation system. The amount of precipitation varies considerably from place to place because of the non-uniform rugged terrain. However, the amount of summer monsoon rains generally declines from southeast to northwest.

The winter months December to February are relatively dry with clear skies. However, few spells of rain do occur during these months. In winter, major weather effective elements are the western disturbances so rain decreases in amount from northwest to both southward and eastward direction. The direction of predominating wind is Northwesterly during this season.

During March to May the country experiences pre-monsoon thundershower activities. The pre-monsoon rainfall activities are more frequent in the hilly regions than in the southern plains.

The period of October and November is considered as a post monsoon season and a transition from summer to winter. During October the country receives a few spells of post-monsoon thundershowers, similar in character to the pre-monsoon ones.

The annual mean precipitation is around 1800 mm in Nepal. But owing to the great variations in the topography, it ranges from more than 5000 mm along the southern slopes of the Annapurna range in the central Nepal to less than 250 mm in the north central portion near the Tibetan plateau.

3.5 Previous studies on precipitation in Nepal:

There are many reports about the study on precipitation in Nepal. With regard to rainfall Nepal is highly dominated by summer monsoon and its circulation arising from Bay of Bengal. It is estimated that the summer monsoon accounts for 80 % of the annual rainfall in Nepal. The mean rainfall for Nepal during monsoon season amounts to be 1422.8mm with standard deviation of 132.6 mm and coefficient of variation 9.3 % (M. L. Shrestha, 2000). According to Pokhrel (2003), summer precipitation is high over middle mountains i.e. Mahabharata range; and decreased slightly over Terai and decreased rapidly over Himalayan range. In a study, Barros et al., (2000) and Lang & Barros (2002) have noted significant spatial variability in precipitation in central Nepal (factor of 4 differences over; 10 km distance), but it did not show any specific dependence on elevation, particularly at the seasonal scale.

Studies by Barros et al., (2000), Shrestha (2000), and Lang & Barros (2002) have shown that large rainfall amounts, on the order of 300 – 400 cm / yr., can fall along the southfacing slopes of the Himalayas. According to Shrestha & Sthapit (2016) there was a significantly increasing upward trend of the annual mean of weighted areal rainfall, with a rate of 2.2 mm per year in Bagmati river basin. According to Shrestha, Singh, & Nakamura (2012) two significant rainfall peaks appear over the southern slope of the Himalayas during summer monsoon season one at 500–700 m above MSL another at 2,000–2,200 m above MSL. Maximum annual precipitation increased with altitude for elevations below 2000 m but decreased for elevations of 2000–3500 m (Ichiyanagi, Yamanaka, Muraji, & Vaidya, 2007). Sigdel & Ma (2017) concluded that the north facing slope of central Nepal experience less rainfall as compared to south facing slopes. Summer monsoon precipitation over Nepal is highly correlated with the southern oscillation index (SOI) at an Interannual time scale (Sigdel & Ikeda, 2012).

The post-monsoon, pre-monsoon and winter rainfalls are decreasing significantly in most of the zones but monsoon rainfall is increasing throughout the Gandaki river basin (Panthi et al., 2015).

Both the dates of onset and withdrawal of summer monsoon are found to be delayed in recent years (Gautam & Regmi, 2013). The causes for summer droughts is El Nino, while the winter droughts could be related with positive DMI in Nepal (Sigdel & Ikeda, 2010).

Studies also have shown that the climatology of Himalayan rainfall variability differs markedly from the rest of the Indian subcontinent. Analysis of precipitation trend in Nepal and did not show any significant trend in annual and seasonal precipitation (Shrestha et al., 2000). GCM estimate shows the total precipitation in June, July and august will increase with 9.1% by 2030A.D (OECD Environmental Indicators, 2003). Similarly, other Model based projection have also shown the rising trend in annual precipitation over Nepal.

Karki, Schickhoff, Scholten, & Böhner (2017) suggests that the pre-monsoonal precipitation is significantly increasing over the lowlands and central Himalaya, while monsoonal precipitation is increasing in western mountain and central Himalayas increasing the risk of disasters. Liang, Dawadi, Pederson, & Eckstein (2014) has performed PCA of rainfall and temperature to find the growth of birch at the upper timberline in the Himalayas. Temporal and spatial analysis of drought risk assessment is performed in central Nepal (Dahal et al., 2016). Due to high cloud core over northern India, moisture accumulates and tends to flow toward Nepal producing high summer monsoon rainfall (Sigdel & Ikeda, 2012).

IPCC (2007) has also shown that the frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increase of atmospheric water vapor. Though there are various studies on the precipitation pattern over Nepal. There are limited studies on the precipitation pattern and the change in distribution pattern of rain over Provincial political division of Nepal. In the present paper, the authors have attempted to study various characteristics of rainfall over Province 3 and its change during recent decades.

CHAPTER 4

RESULT AND DISCUSCUSSION

4.1. Spatial Rainfall analysis

Spatial rainfall analysis is one of the best way to determine the distribution of rain in gauged and ungauged region. The major benefit of spatial analysis is that we can even estimate the rainfall of those place without stations. This helps in determining the hydrological system and cryospheric system of a place or region.

Interpolated GIS images for annual as well as for the four seasons Pre monsoon, Monsoon, Post monsoon and Winter season are shown in figure 4, 5, 6, 7 and 8 respectively.

Although there is unique spatial distribution of rainfall in different seasonal and annual image, the spatial distribution during annual and monsoon seems more or less the same. This may be due to high (about 80%) contribution of monsoon rainfall in annual rain amount.

Annual average rainfall of Province is 1926.69 mm, Gumthang has the highest annual rainfall of 3828mm. The second highest rainfall is observed in Pansyakhola 3057 mm. Kakani and Bahrabise follow Pansyakhola with the average annual rainfall of more than 2800 mm. Stations like Hariharpur Gadhi and Hetauda also have high rainfall. Annual high rainfall pockets are also noted in the higher elevation of northern part of the Province. Two distinct high rainfall pocket area is seen in this Province, one in northeastern part (Sindhupalchok) and other in northwestern part (Nuwakot).

The rainfall is observed lowest in north western part along Tamachit with annual rainfall about 720 mm. Low rainfall is also observed in the middle and southeastern part of Province at the periphery of Nepalthok, Dolalghat and Khopasi with average annual rainfall is less than 1200 mm. It is known that station in leeward slope and location near gorge of high hills obtain less rain. Location on and near Kathmandu valley also have considerably low annual rainfall.

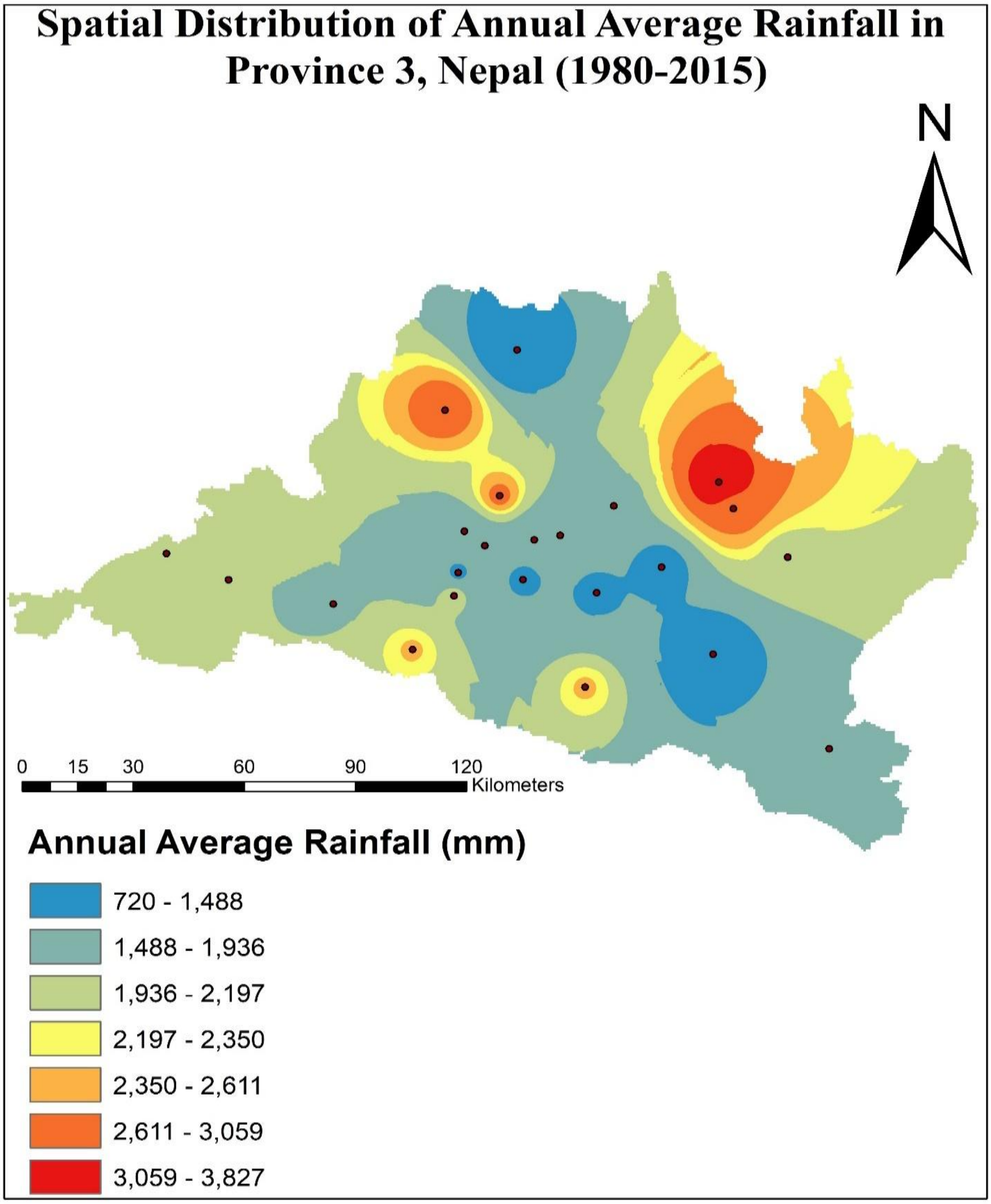

Figure 4: Spatial distribution of annual rainfall in Province 3, Nepal (1980-2015).

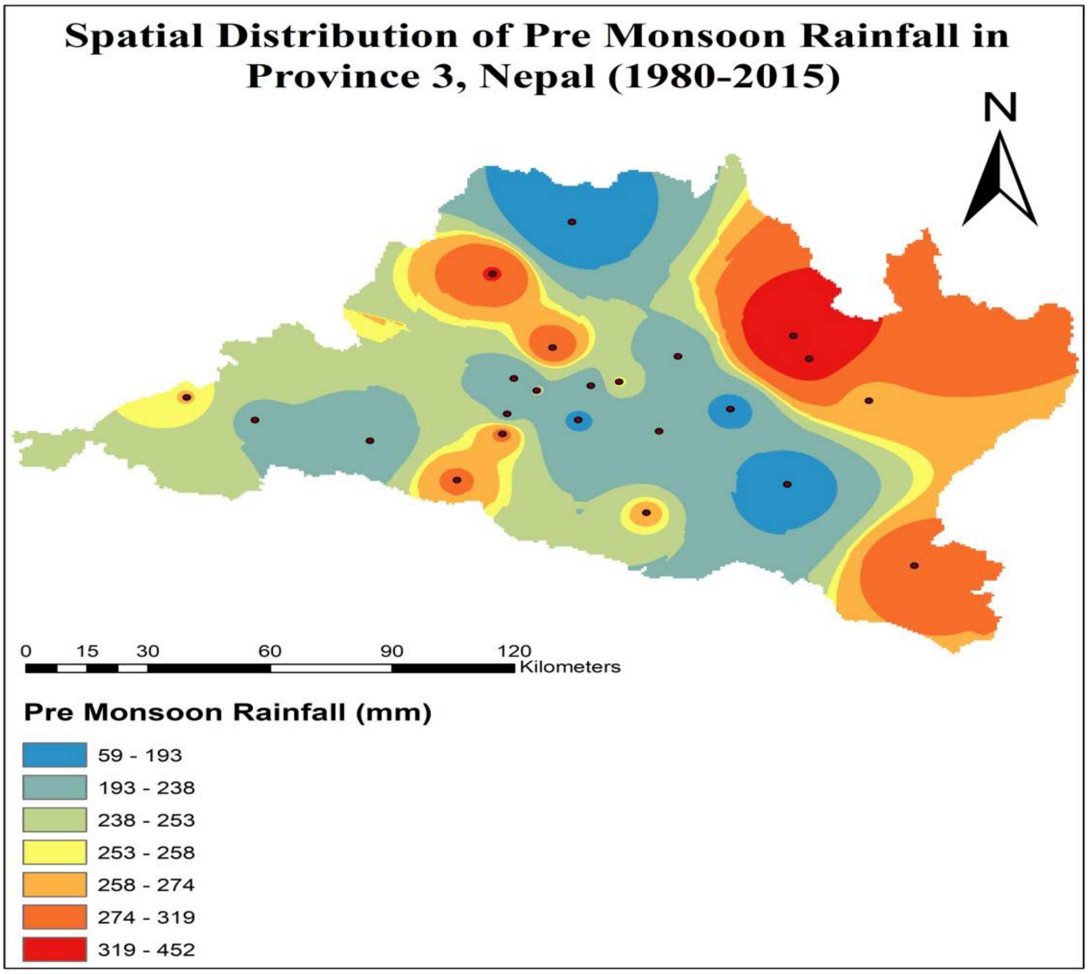

Figure 5: Spatial distribution of Pre monsoon rainfall in Province 3, Nepal (1980-2015).

Mean value of Pre monsoon rainfall is 244.94 mm. Gumthang has the highest average rain of 452.9 mm. Pre Monsoon rainfall is high in northeastern and northwestern part of the province. Pre monsoon rainfall is high in stations like Gumthang, Bahrabise, Pansyakhola, etc. in north and Bahun Tilpung, Hetauda and Chisapani Gadhi in south.

Low pre monsoon rainfall is seen along the northern and middle part of Province along with Kathmandu valley. Stations like Tamachit, Nepalthok, Chapagaun, Dolalghat, etc. has lowest rain which is below 193 mm.

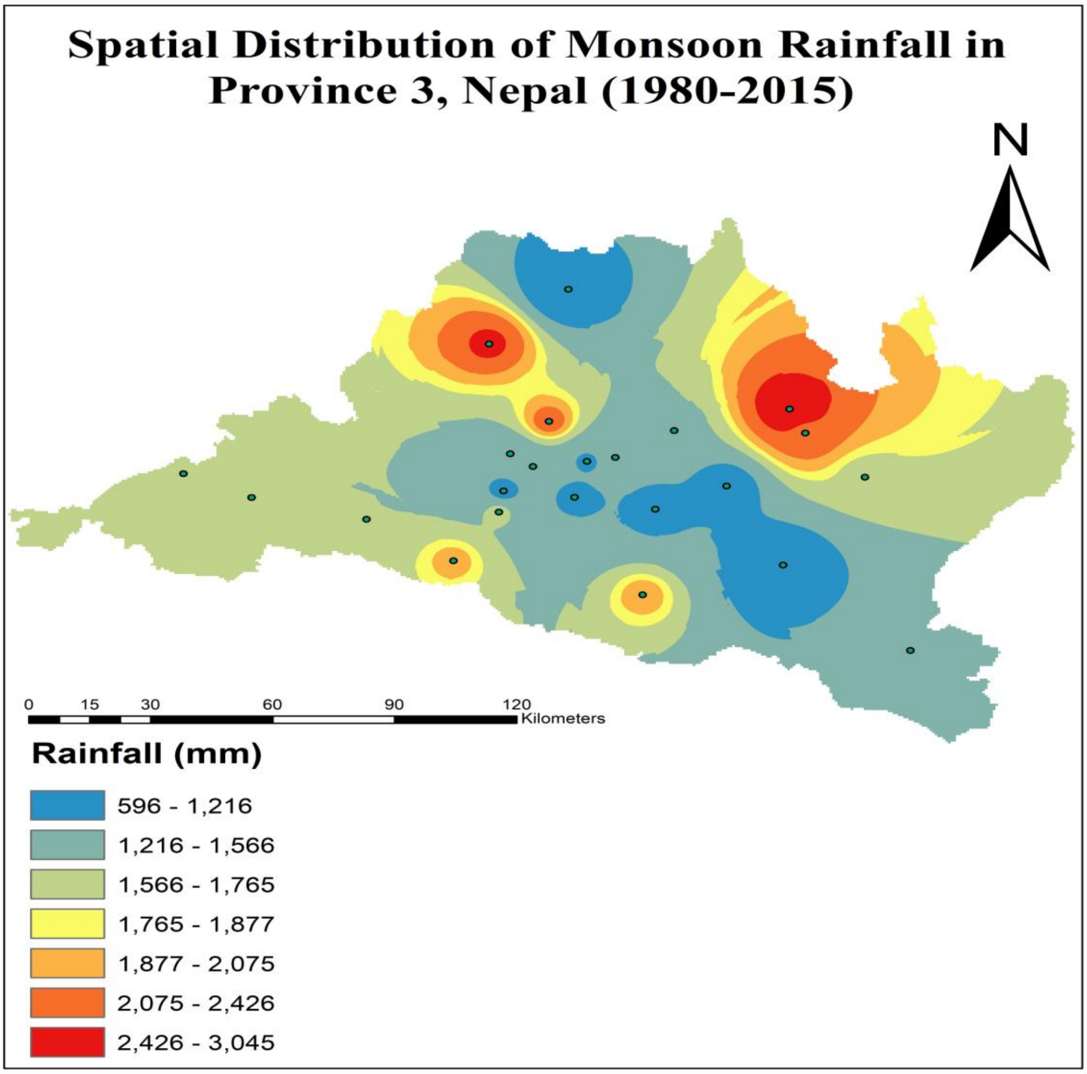

Figure 6: Spatial distribution of Monsoon rainfall in Province 3, Nepal (1980-2015).

Mean monsoon rainfall of the Province is 1552.9 mm. Similar pattern is seen in Monsoon and annual rainfall along whole province. Stations along northeastern and northwestern part of Province has high rainfall. Highest average monsoon rainfall is 3045 mm in Gumthang. High rainfall during this season is also found along stations like Pansyakhola, Kakani, Bahrabise, etc.

Monsoon rainfall is found low in northern and east-central portion of Province. Seven stations have monsoon rainfall below 1216mm. The lowest monsoon rainfall was found 596.26 mm in Tamachit, Rasuwa. Likewise, in annual rainfall, monsoon rain is also low in stations along gorge and leeward slope.

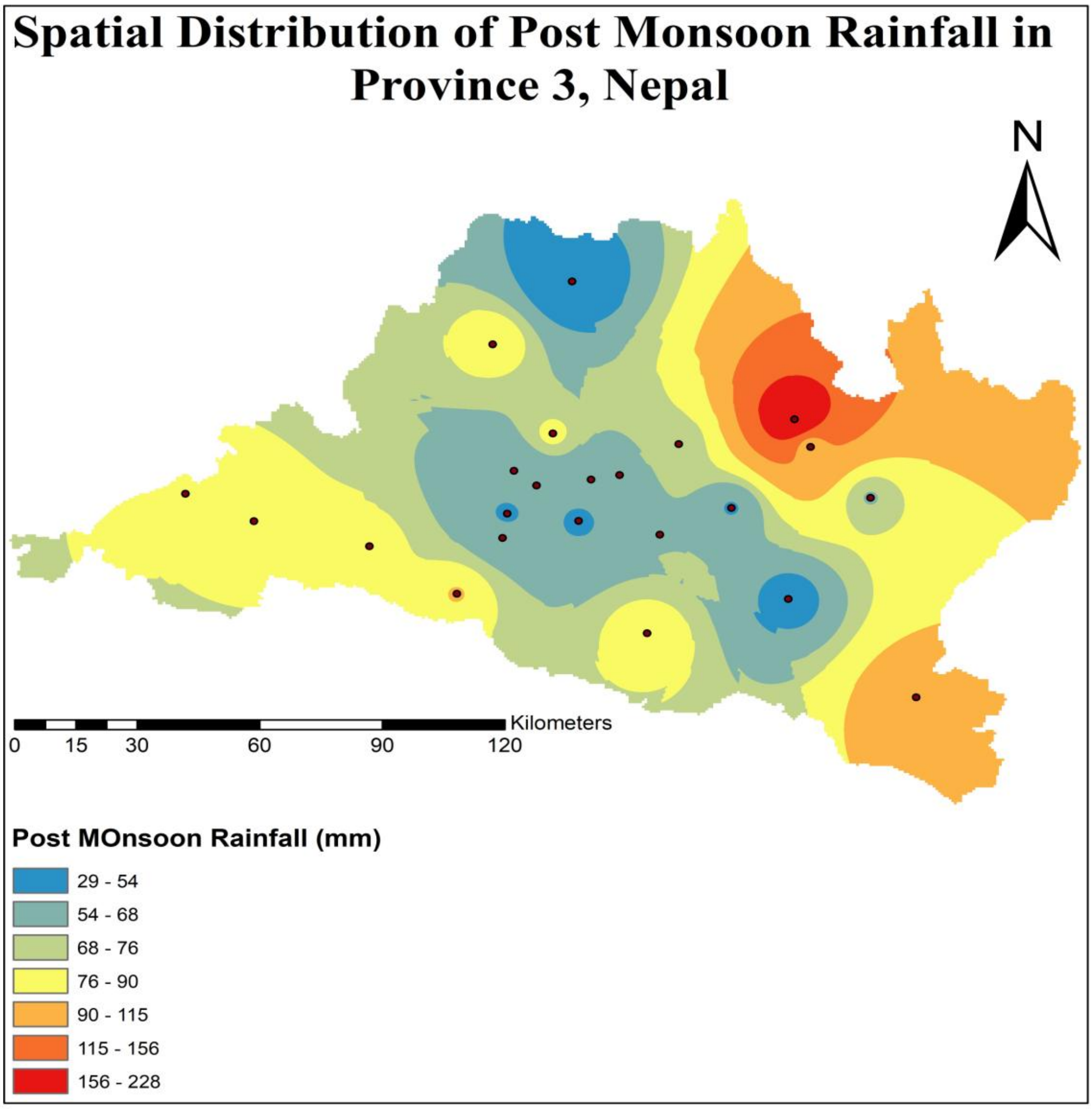

Figure 7: Spatial distribution of Post Monsoon rainfall in Province 3, Nepal (1980-2015).

Mean value of Post monsoon rain is 76.8mm. Post monsoon is seen greater in southeastern and northeastern part of the Province in station like Gumthang, Bahrabise and Bahun Tilpung. Post monsoon rainfall is highest in Gumthang with average rainfall exceeding 228 mm.

Low Post monsoon rainfall is obtained along northern and central part of Province. About six stations in this Province have rainfall below 54 mm. The lowest Post monsoon rainfall was obtained 29.85 mm in Tamachit.

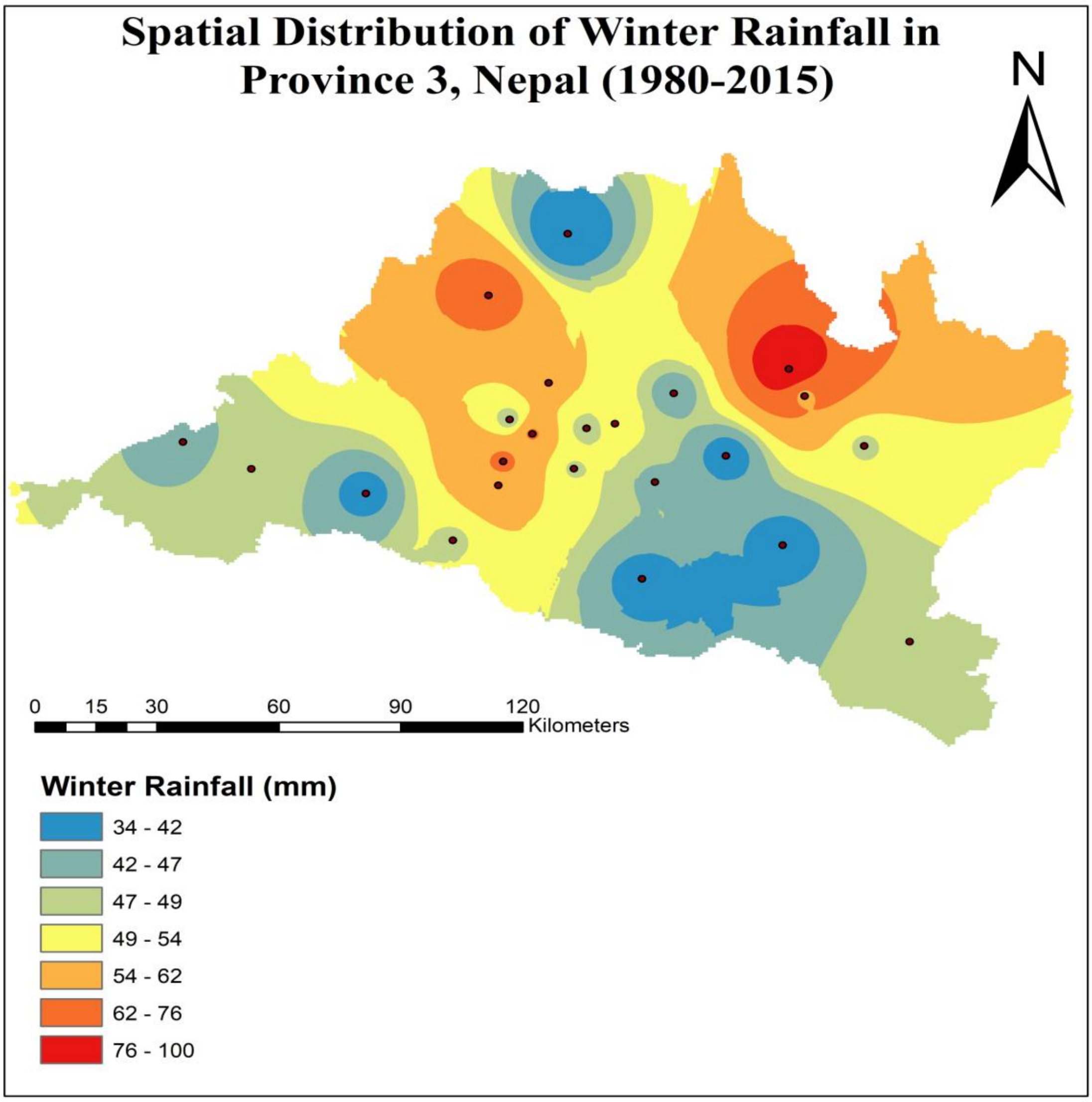

Figure 8: Spatial distribution of Winter rainfall in Province 3, Nepal (1980-2015).

The winter season mean value of rainfall for the Province 3 is 51.94mm. In winter, there is high rainfall in northwestern and northeastern part of Province. Highest winter rainfall is obtained 100 mm in Gumthang. Stations like Gumthang, Pansyakhola and Markhu have considerably high winter rainfall.

There is less winter rainfall along southeastern, southwestern and northern part of Province. About 5 stations have average winter rainfall less than 42 mm. The lowest rainfall is obtained 34 mm in Tamachit.

4.2 Temporal Rainfall Analysis:

Temporal rainfall analysis gives us the information about the amount and state of rain in different time period. Temporal rainfall analysis is very useful in determining the climate change. Temporal rainfall analysis is also helpful in future projection of rain. In present study, for obtaining temporal results, average and non-average data of 36 years' period is taken.

Result shows that the annual average rainfall in Province 3 of Nepal is 1926.69mm which is accompanied by pre monsoon 244.94mm, monsoon 1552.95mm, post monsoon 76.84mm and winter 51.94mm. From this result the percentage contribution of seasonal rainfall is pre monsoon 12.71%, monsoon 80.6%, post monsoon 3.98% and winter 2.69%. Trend analysis shows annual rainfall decreasing at -4.58 mm/yr., Monsoon at -4.17 mm/yr., Post monsoon at -0.26 mm/yr. and Winter at -0.32 mm/yr. In Pre monsoon there is slightly increasing trend of rainfall at the rate of 0.17mm/yr.

The highest rainfall is observed in the year 1999 with rain amount 2399.44mm and lowest rain is observed in year 1992 with rain amount 1508.0mm.

In case of individual stations Gumthang records highest annual rainfall 5526.7mm in 2000 and Tamachit records lowest annual rainfall 184.9mm in 2008. Even though Gumthang is high rainfall region it has highest decreasing trend with -20.7mm/yr. The station at Kathmandu airport has the highest increasing trend of 6.14mm/yr. among 23 station considered in this research.

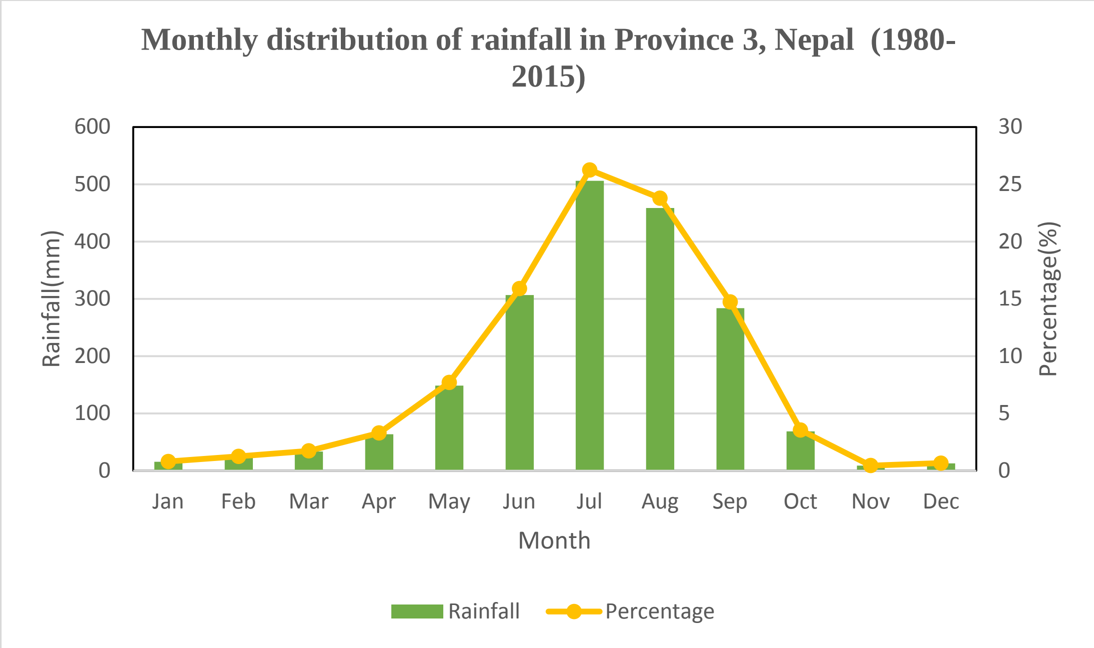

Figure 9: Monthly distribution of rainfall in Province 3, Nepal.

While analyzing average monthly distribution of rainfall (Figure 9) in Province it is found that the highest average rainfall occurs in the month of July with 505.68mm rain covering 26.24% of annual rain followed by August 458.21mm at 23.78% and June 306.25mm at 15.89%. The lowest average rainfall occurs in November with 8.67mm rain covering only 0.45% of annual rain followed by December 12.59mm at 0.65% and January 15.37mm at 0.79%.

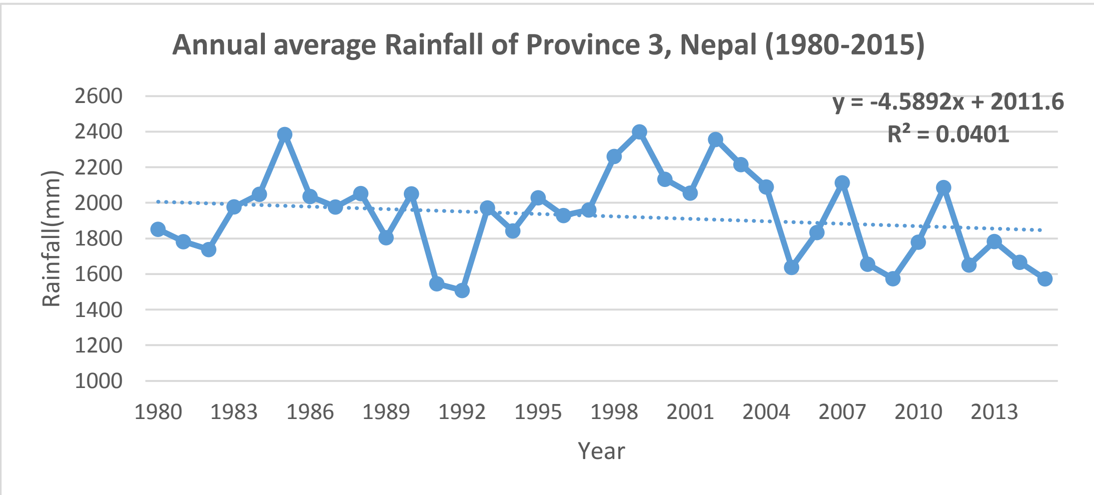

Figure 10: Annual average Rainfall of Province 3, Nepal (1980-2015).

Annual average rainfall of Province is 1926.69 mm. (Figure 10) Analysis of individual year shows that the highest amount of rainfall was on 2399.4 mm on 1999 which is followed by 2384.7mm in 1985 and 2356.6 mm in 2002. Lowest amount of rainfall was obtained in the year 1992 with rain amount of 1508 mm which is followed by 1546 mm in 1991 and 1573 mm in 2015. While investigating trend it is found that annual average rainfall is decreasing at the rate of -4.58 mm/year.

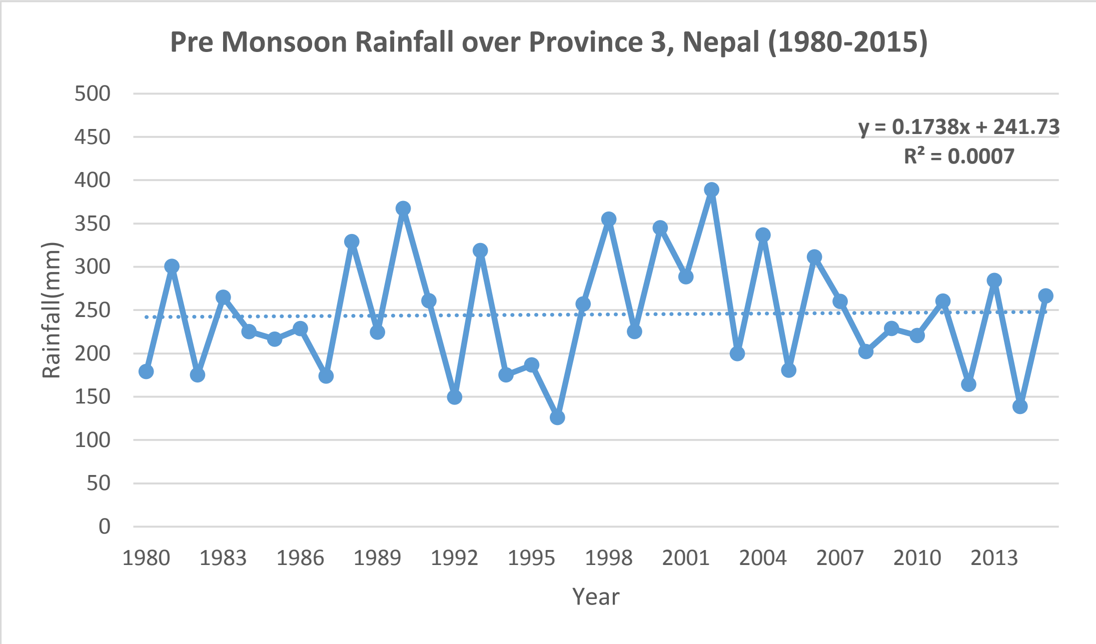

Figure 11: Pre monsoon rainfall over Province 3, Nepal (1980-2015).

The distribution of rainfall is diverse with maximum pre monsoon rain of 389mm in 2002 followed by 367.4 mm in 1990. Minimum rainfall was obtained 126mm in 1996 and 138.78 mm in 2014. The trend analysis shows that Pre Monsoon rain in this Province is increasing at the rate of 0.17 mm/year (Figure 11). Laskar (2009) also defines increasing trend of rainfall during the pre-monsoon season could be attributed to increase in thunderstorm activity over the South Asia region.

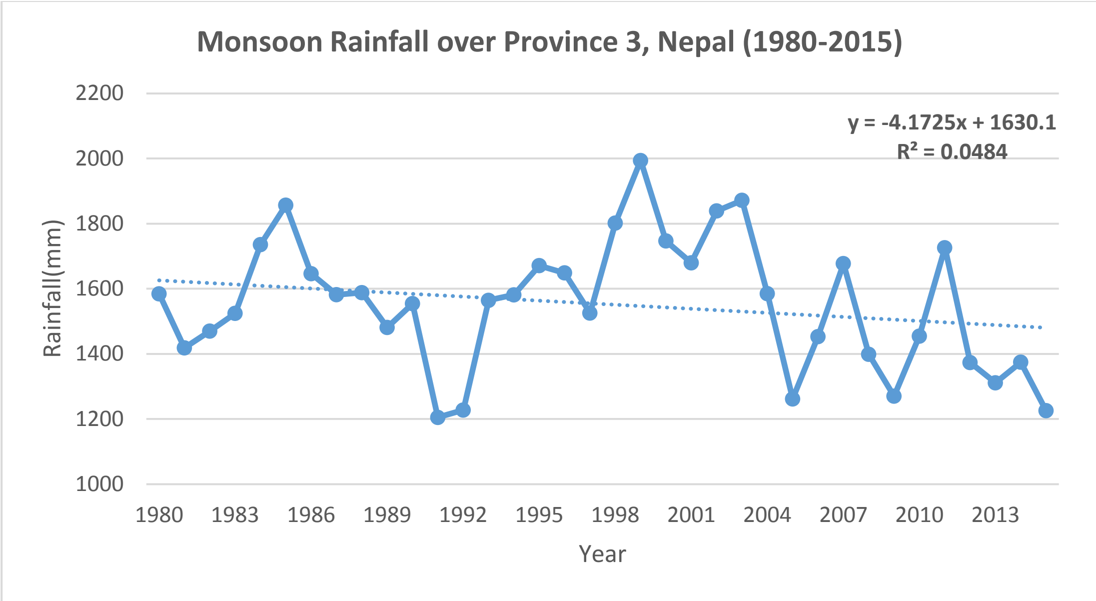

Figure 12: Monsoon rainfall over Province 3, Nepal (1980-2015).

Figure 12 shows maximum monsoon rain of 1993.8 mm was obtained in the year 1999 which is followed by 1871.68 mm in 2003. Minimum monsoon rainfall of 1204.7mm was obtained in 1991 which is followed by 1225.5 mm in year 2015. The trend analysis shows that Monsoon rain in this Province is decreasing at the rate of - 4.17 mm/year. According to Roxy et al., (2015) the high decreasing trend of Monsoon can be associated with drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient.

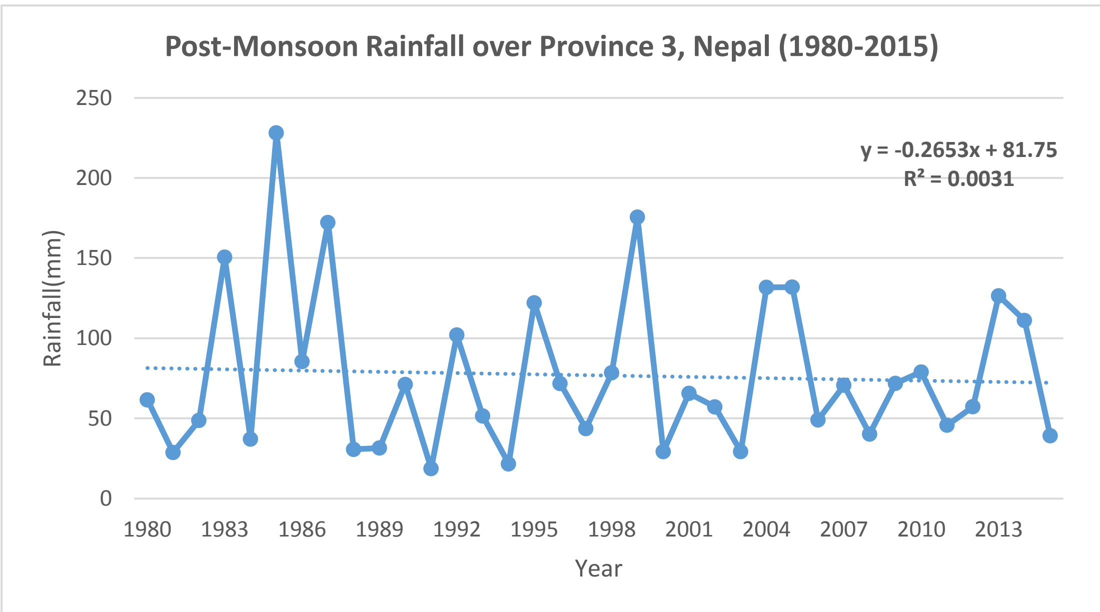

Figure 13: Post monsoon rainfall over Province 3, Nepal (1980-2015).

Figure 13 depicts maximum Post monsoon rain of 228.16 mm was obtained in the year 1999 which is followed by 175.5 mm in 1999. Minimum Post monsoon rainfall of 18.65mm was obtained in 1991 which is followed by 21.5 mm in year 1994. The trend analysis shows that Post Monsoon rain in this Province is decreasing at the rate of -0.26 mm/year. Similar result is obtained by Chen, Huang, Lo, & LinHo (2018) who suggests Anthropogenic Aerosols and Irrigation are the reason behind the reduction of Post monsoon rainfall in South Asia.

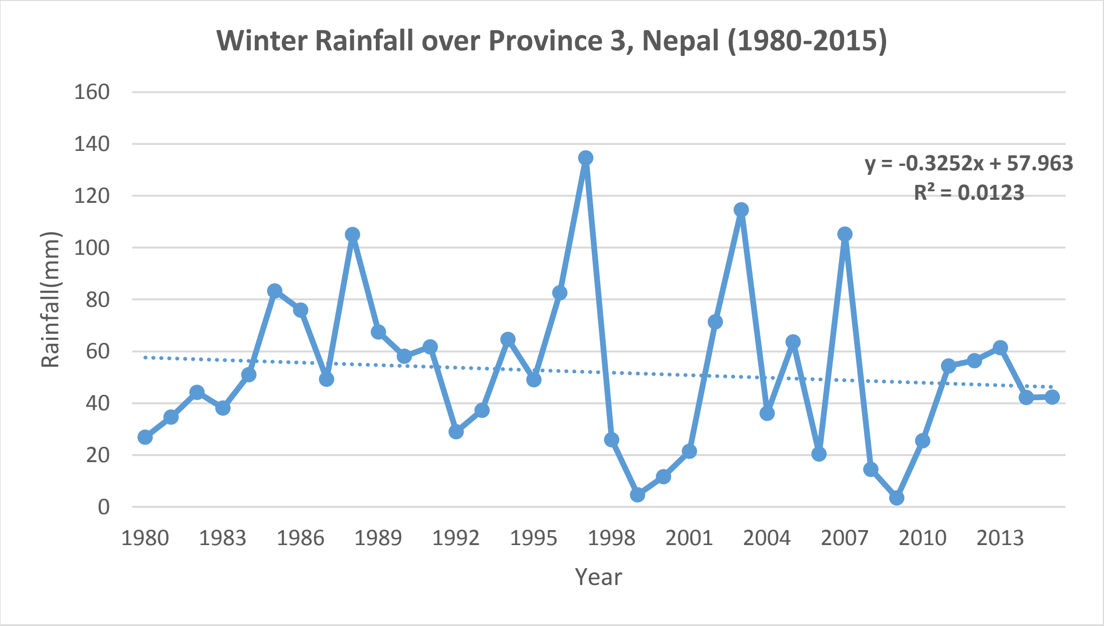

Figure 14: Winter rainfall over Province 3, Nepal (1980-2015).

Maximum Winter Monsoon rainfall of 134.66 mm was obtained in the year 1997 which is followed by 114.6 mm in 2003. Minimum Post monsoon rainfall of 3.53 mm was obtained in 2009 which is followed by 4.7 mm in year 1999. The trend analysis shows that Winter Monsoon rain in this Province is decreasing at the rate of -0.32 mm/year (Figure 14). Similar decreasing trend of rainfall is found in western Nepal (Wang, Yoon, Gillies, & Cho, 2013).

4.3 Decadal Rainfall Analysis:

Decadal rainfall analysis is one of the way to determine the rainfall characteristics in different period of time. In present days' change in rainfall is linked with climate change, so time period analysis of rainfall helps in determining the changing characteristics of climate and its association with weather phenomena. Furthermore, in this study it is found that annual average rainfall is in increasing trend in 80's and 90's decade whereas high decreasing trend is seen in last two decades (Table 2).

Decade	**Pre Monsoon**	**Monsoon**	**Post Monsoon**	**Winter**	**Annual**
First (1980's)	231.8	1588.63	87.46	57.64	1965.54
Second (1990's)	242.23	1577.27	75.64	54.81	1949.96
Third (2000's)	274.26	1578.27	67.67	46.3	1966.50
Last (2010's)	222.51	1410.78	76.44	47.09	1756.82

Table 2: Decadal distribution of seasonal and annual rainfall.

The first decade (1980-1989) the annual average rainfall was 1965.53 mm and has the increasing trend of 19.23mm/yr. In the first decade the average Pre monsoon rainfall was obtained 231.8 mm, Monsoon 1588.6 mm, Post Monsoon 87.4 mm and Winter Monsoon 57.6 mm.

In second decade (1990-1999) the average annual rainfall was 1949.96mm and has increasing trend of 63.41mm/yr. In second decade the average Pre Monsoon rainfall was 242.2 mm, Monsoon was 1577.2 mm, Post Monsoon was 75.6 mm and Winter Monsoon was 54.8 mm.

In third decade (2000-2009) the average annual rainfall was 1966.5mm and has decreasing trend of -64.47mm/yr. In this decade the average Pre Monsoon rainfall was 274.2 mm, Monsoon was 1578.2 mm, Post Monsoon was 67.6 mm and Winter Monsoon was 46.3 mm.

Last decade (2010-2015) the average annual rainfall was 1756.83mm and has decreasing trend of -61.66mm/yr. In this decade the annual average rainfall during Pre Monsoon was 222.5 mm, Monsoon was 1410.7 mm, Post Monsoon was 76.4 mm and Winter Monsoon was 47 mm.

4.4 Study of Rainfall between stations in Highland (above 1000m) and Lowland (below 1000m)

In Province 3 there is high variation in topography and rainfall characteristics within small spatial area. Study of rainfall within different altitude level gives us idea about the orographic features of a place and also helps in determining rainfall pocket area.

This type of study is also important in forecasting and estimating the impact of disasters like flood and landslide since the topography of Nepal is complex. In this study we obtained that the annual average rainfall on stations in highland is higher than the stations in lowland.

The difference of rainfall in accordance to elevation for the stations below 1000m and above 1000m shows that annually 75.8mm rainfall variation is seen. The 10 stations below 1000m vary from 177m to 991m in elevation and 13 stations above 1000m elevation vary from 1337m to 2034m.

In stations above 1000m elevation, average annual rainfall is 1959.6 mm, Pre monsoon rainfall is 256.4mm, Monsoon rainfall is 1567.2mm, Post monsoon 78.5mm and Winter 57.3mm.

In stations below 1000m elevation, average annual rainfall is 1883.8 mm, Pre monsoon rainfall is 230mm, Monsoon rainfall is 1534.3mm, Post monsoon is 76.6mm and winter is 44.8mm.

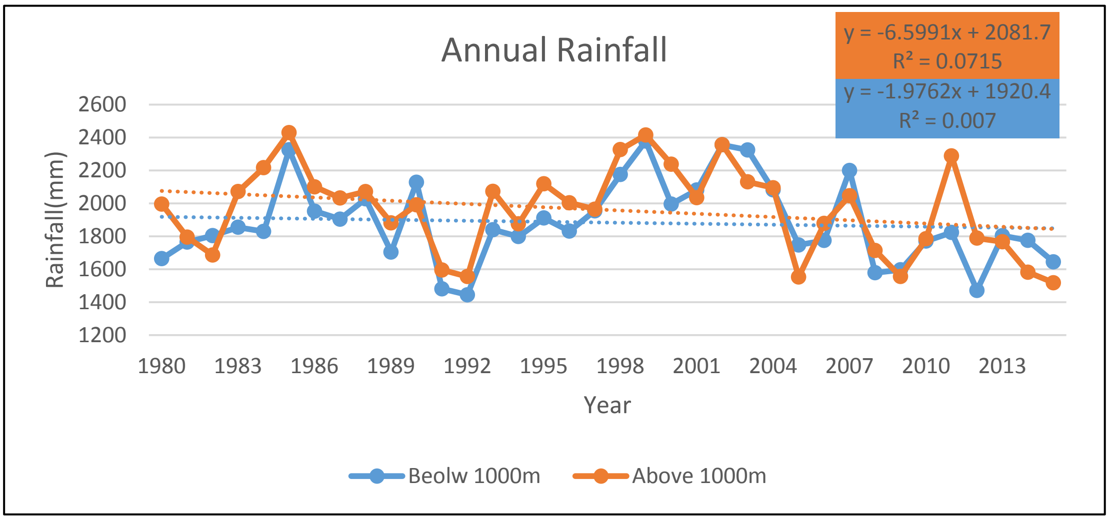

Figure 15: Annual rainfall of station below 1000m and above 1000m (1980-2015).

According to Figure 15, the annual average rainfall for the stations above 1000m is 1959.6 mm. Annual rainfall is highest in the year 1985 with rain amount 2429.9 mm which is followed by 2415.4 mm in year 1999. Lowest annual rainfall is seen in year 2015 with rain 1518.3 mm and which is followed by 2005 with rain 1553.3 mm.

The annual average rainfall for the stations below 1000m is 1883.8 mm. Annual rainfall is highest in the year 1999 with rain amount 2378.6 mm which is followed by 2356.2 mm in year 2002. Lowest annual rainfall is seen in year 1992 with rain 1444.9 mm and which is followed by 2012 with rain 1471.7 mm.

The correlation coefficient between annual rainfall of highland and lowland station is 0.78.

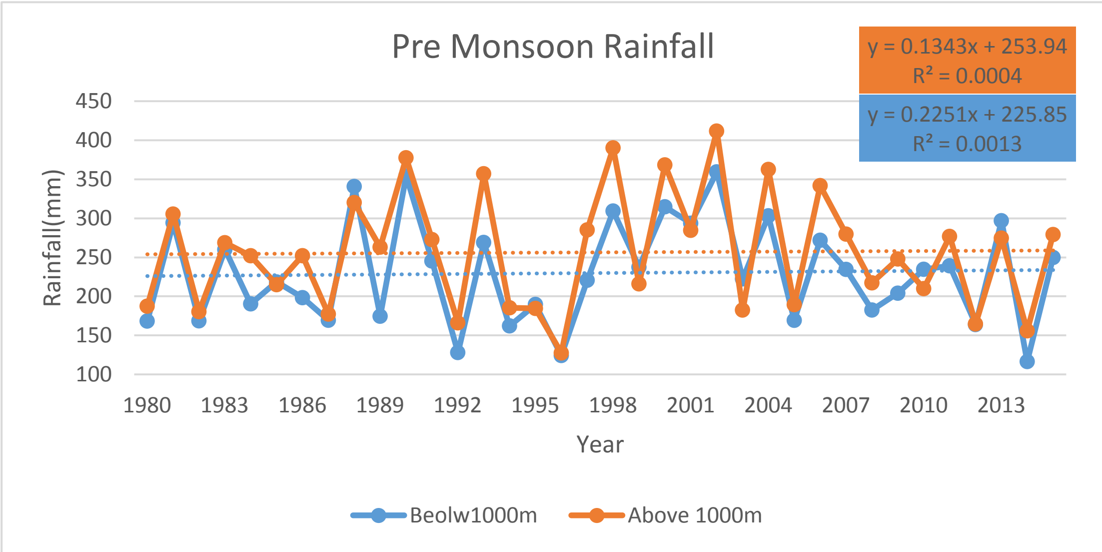

Figure 16: Pre Monsoon rainfall of station below 1000m and above 1000m (1980-2015).

As shown in Figure 20, the average Pre Monsoon rainfall for the stations above 1000m is 256.4 mm. Pre Monsoon rainfall is highest in the year 2002 with rain amount 411.7 mm which is followed by 390.2 mm in year 1998. Lowest Pre Monsoon rainfall is seen in year 1996 with rain 127.5 mm and which is followed by 2014 with rain 155.8 mm.

The average Pre Monsoon rainfall for the stations below 1000m is 230 mm. Pre Monsoon rainfall is highest in the year 2002 with rain amount 359.5 mm which is followed by 354.2 mm in year 1990. Lowest Pre Monsoon rainfall is seen in year 2014 with rain 116.5 mm and which is followed by 1996 with rain 124.2 mm.

The correlation coefficient between Pre Monsoon rainfall of highland and lowland station is 0.89.

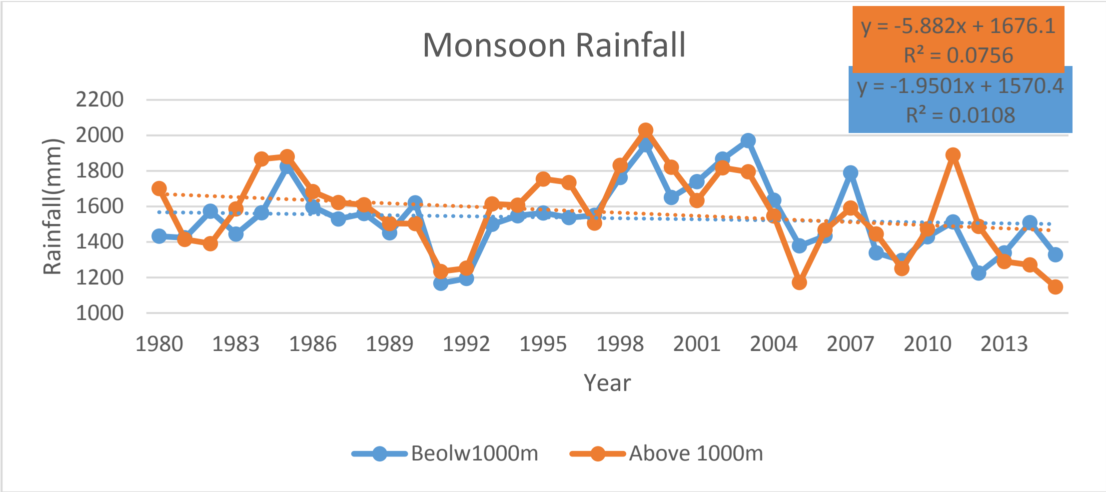

Figure 17: Monsoon rainfall of station below 1000m and above 1000m (1980-2015).

Figure 21 shows that the average Monsoon rainfall for the stations above 1000m is 1567.2 mm. Monsoon rainfall is highest in the year 1996 with rain amount 2029.3 mm which is followed by 1889.8 mm in year 2011. Lowest Monsoon rainfall is seen in year 2015 with rain 1146.5 mm and which is followed by 2005 with rain 1171.6 mm.

The average Monsoon rainfall for the stations below 1000m is 1534.3 mm. Monsoon rainfall is highest in the year 2003 with rain amount 1970.7mm which is followed by 1947.6mm in year 1999. Lowest Monsoon rainfall is seen in year 1991 with rain 1167.2 mm and which is followed by 1992 with rain 1194.5 mm.

The correlation coefficient between Monsoon rainfall of highland and lowland station is 0.75.

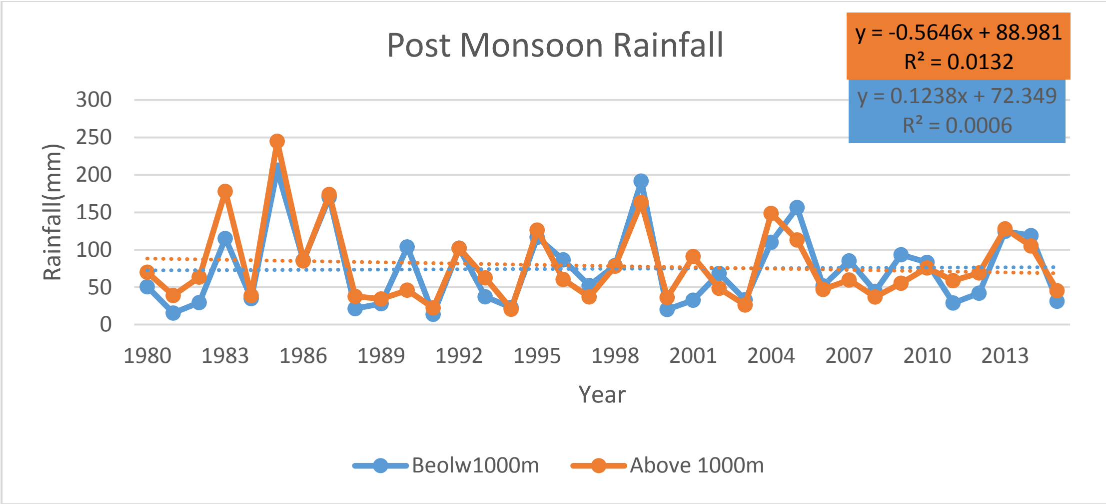

Figure 18: Post Monsoon rainfall of station below 1000m and above 1000m (1980-2015).

The average Post Monsoon rainfall for the stations above 1000m is 78.5 mm. Post Monsoon rainfall is highest in the year 1985 with rain amount 244.8 mm which is followed by 177.9 mm in year 1983. Lowest Post Monsoon rainfall is seen in year 1994 with rain 20.5 mm and which is followed by 1991 with rain 22.3 mm.

The average Post Monsoon rainfall for the stations below 1000m is 74.6 mm. Post Monsoon rainfall is highest in the year 1985 with rain amount 206.4 mm which is followed by 191.7 mm in year 1999. Lowest Post Monsoon rainfall is seen in year 1991 with rain 13.8 mm and which is followed by 1981 with rain 15.4 mm (Figure 22).

The correlation coefficient between Post Monsoon rainfall of highland and lowland station 0.87.

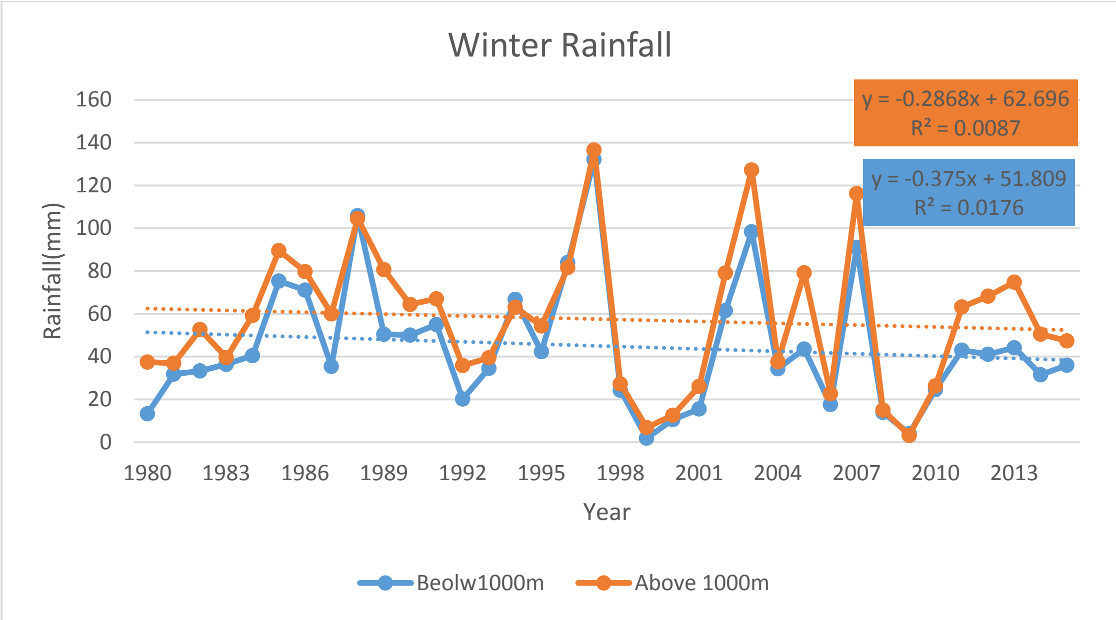

Figure 19: Winter rainfall of station below 1000m and above 1000m (1980-2015).

The average Winter Monsoon rainfall for the stations above 1000m is 57.3 mm. Winter rainfall is highest in the year 1997 with rain amount 136.5 mm which is followed by 127.2 mm in year 2003. Lowest Winter rainfall is seen in year 2009 with rain 3.1 mm and which is followed by 1999 with rain 6.9 mm.

The average Winter Monsoon rainfall for the stations below 1000m is 44.8 mm. Winter rainfall is highest in the year 1997 with rain amount 132.2 mm which is followed by 105.8 mm in year 1988. Lowest Winter rainfall is seen in year 1999 with rain 1.8 mm and which is followed by 2009 with rain 4 mm. (Figure 23)

The correlation coefficient between winter rainfall of highland and lowland station is 0.94.

4.5 Rainfall and its Relation with ENSO

Many studies are done to find the relation between large scale phenomena and rainfall in South Asia including Nepal. From those study we can conclude that there is relation between large scale phenomena and rainfall. Similar study is carried out to find the relation between rainfall in Province 3 of Nepal and large scale phenomena like El Nino and La Nina.

The terms El Niño and La Niña refer to periodic changes in Pacific Ocean sea surface temperatures(SST) that have impacts on weather all over the globe. El Nino- Southern Oscillation is one of the key factor which govern the monsoon rainfall in South Asia. The warming phase of the sea temperature is known as El Niño and the cooling phase as La Niña. In El Nino period there is usually below average rainfall in South Asian countries including Nepal while in La Nina the case is just opposite. The study of ENSO and rainfall helps in finding the high and less rainfall period. This helps in forecasting the problems and disasters like drought, flood and landslides. The study of ENSO helps in estimating the impact of rainfall in agriculture and climatic affairs.

The correlation coefficient shows how strong the linear relationship between two variables are. If the correlation is positive, that means both the variables are moving in same direction. Negative correlation implies, when one variable increases the other variable decreases. [If correlation is +/- 0.8 and above, high degree of correlation or the association between the dependent variables are strong. correlation between +/- 0.5 to+/-0.8, sufficient degree of correlation and less than +/-0.5, weak correlation.]

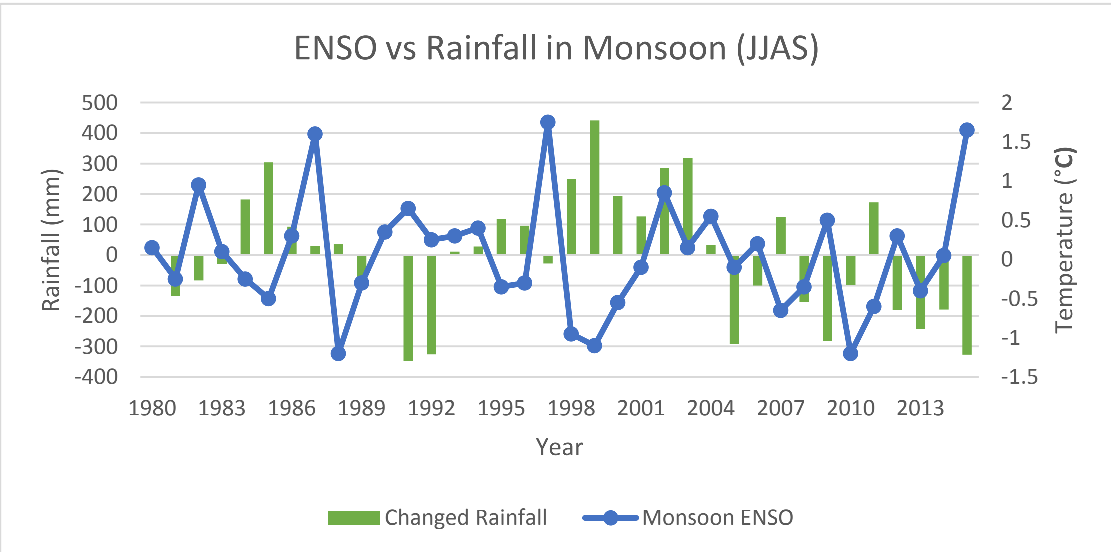

Figure 20: Relation between ENSO and Monsoon rainfall in Province 3, Nepal

In present study it is found that during summer monsoon (JJAS) period there were 17 La Nina episodes and 19 El Nino episodes (Figure 15). As compared to the threshold level of impact of ENSO +/- 0.5°C there were 8 El Nino(heating) and 8 La Nina(cooling) episodes greater than threshold. There is highest sea surface temperature of 1.75°C in 1997 and 1.65°C in 2015. Lowest sea surface temperature of

-1.2°C in 1988 and 2010 and -1.1°C in 1999. Highest rainfall is observed 440.8 mm in 1999 and 318.7 mm in 2003. Lowest rainfall is obtained in -348.2 mm in 1991 and -327.4 mm in 2015. Among 36 years' period inverse relation between SST and rainfall is seen in 27 individual year periods during monsoon. In strong El Nino year 2015, 2009, 1991, etc. have highest rainfall decline. In strong La Nina year 1985, 1998, 1999, 2011, etc. have highest rainfall incline.

The negative correlation is found between the rainfall and SST during monsoon with the correlation coefficient -0.35 which is above 90% significance level. This shows that as rainfall increases SST decreases and as rainfall decreases SST increases. So, we can conclude there is some correlation between rainfall and ENSO during monsoon season.

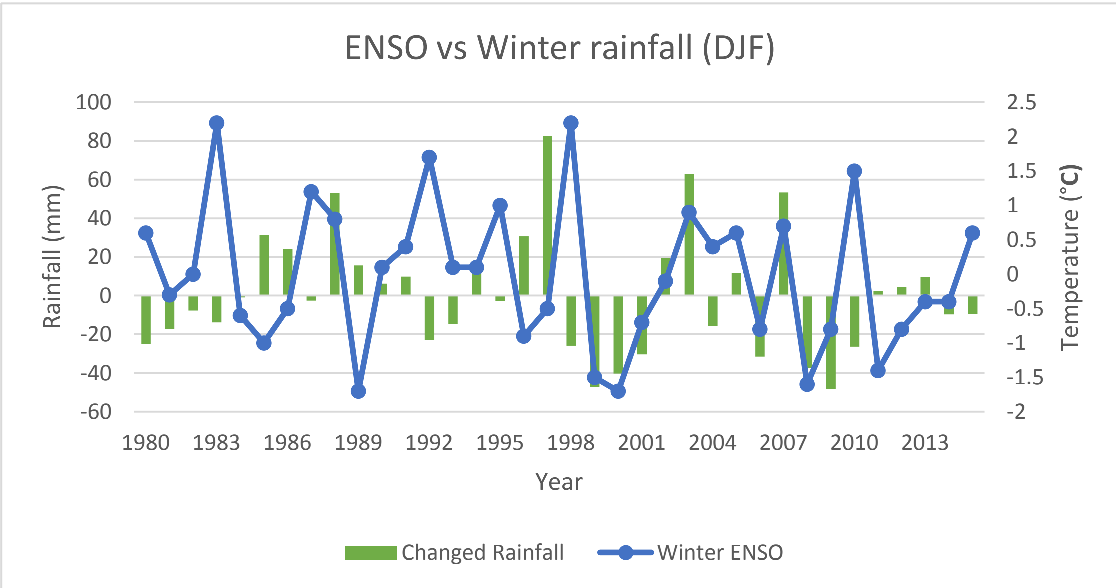

Figure 21: Relation between ENSO and Winter rainfall in Province 3, Nepal

In case of winter rainfall (DJF) period there were 12 El Nino and 12 La Nina episodes greater than threshold value of +/- 0.5°C. There is highest sea surface temperature of 2.2°C in two years 1983 and 1998. Lowest sea surface temperature of -1.7°C in two years 1989 and 2000. Highest rainfall is observed in 82.7 mm in 1997 and 62.7 mm in 2003. Lowest rainfall is obtained -48.4 mm in 2009 and -47.2 mm in 1999 (Figure16).

During winter rainfall positive correlation is found between rainfall and ENSO with the correlation value 0.08. This shows that there is not any significant relation between winter rainfall and ENSO.

4.6 Principal Component Analysis (PCA)

Principal Component Analysis is a very useful method to analyze numerical data structured in a multiple observations and variables table. It allows to quickly visualize and analyze correlations between the variables and visualize and analyze the observations on a low dimensional map. PCA also helps in determination of correlated and non-correlated factors.

Pearson (n) matrix is used in the Principal Component Analysis algorithm. According to Zikmund, Babin, Carr, & Griffin (2013) the acceptable variance explained in factor analysis for a construct to be valid is sixty per cent. In this study first five factors of eigenvalue are taken in consideration and explained them as PCA 1 to PCA 5. Where the first PCA1 covers large information regarding correlation between multiple variables and following PCA covers information in decreasing order. The percentage contribution of individual factor is determined as variance percentage.

Factor loadings of different individual stations is interpolated in GIS image which determines the correlation and non-correlation between multiple rainfall stations. In following GIS images, the red color determines the concentration of rainfall in higher amount and blue color determines less concentration of rainfall amount. Additionally, stations inside the same color are highly correlated with each other.

Factor scores of different years is plotted in line graph which helps in determining the temporal concentration of rainfall in different year period.

4.6.1 PCA during Pre Monsoon

March to May are the pre-monsoon months and hence, any rainfall in this period can be attributed as pre monsoon showers. The classic features of these showers are the form of precipitation which is mainly convective (i.e. thunderstorms).

About 74.31% of variance is explained by first five Principal component on Pre monsoon which is explained by PCA 1 with 51.3%, PCA 2 with 8.4%, PCA 3 with 5.4%, PCA 4 with 4.7% and PCA 5 with 4.3% (Figure 22).

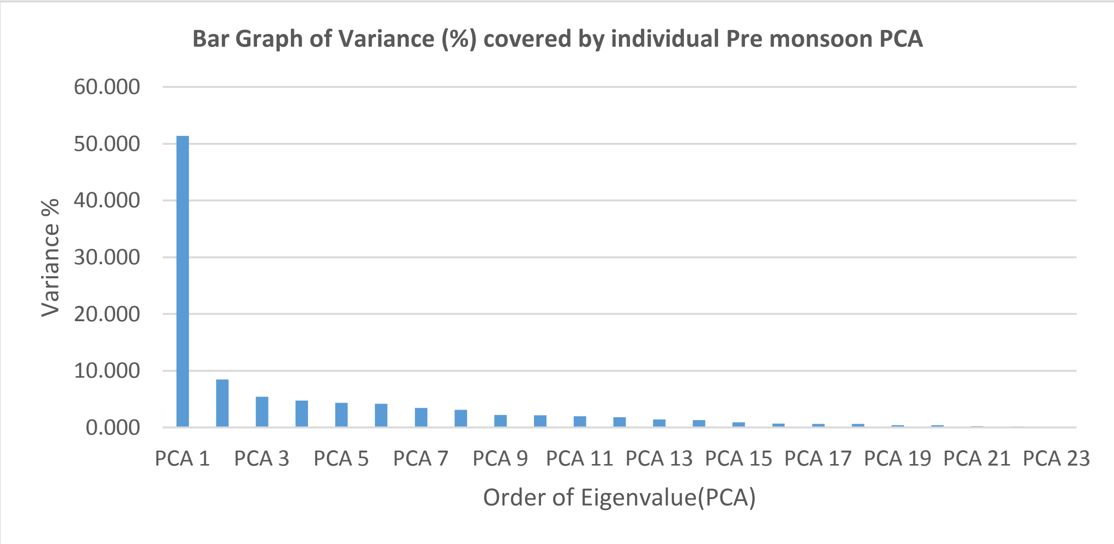

Figure 22: Bar graph of variance % covered by different eigenvalue during Pre monsoon season.

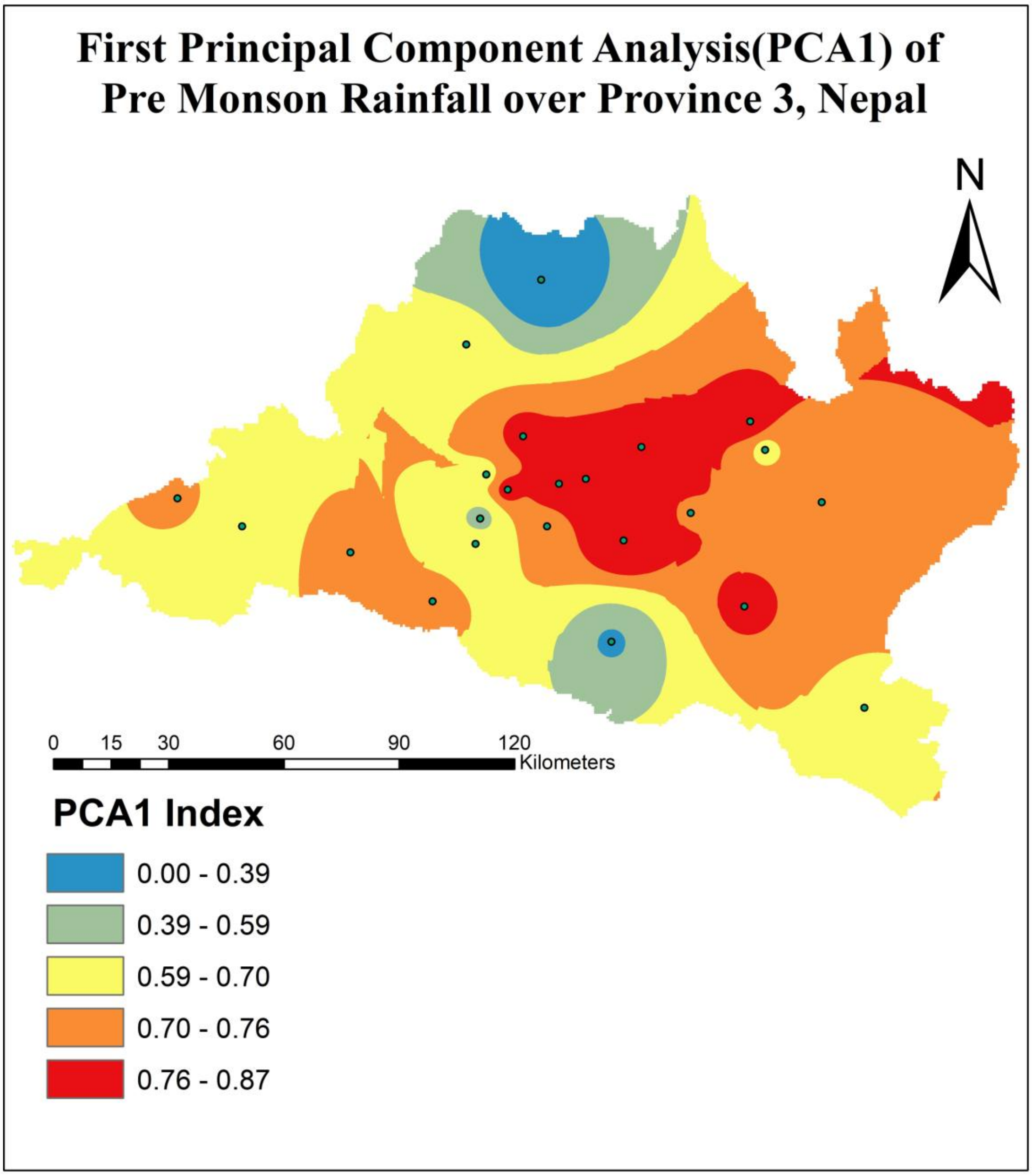

Figure 23: Spatial distribution of loadings covered by PCA1 during Pre Monsoon.

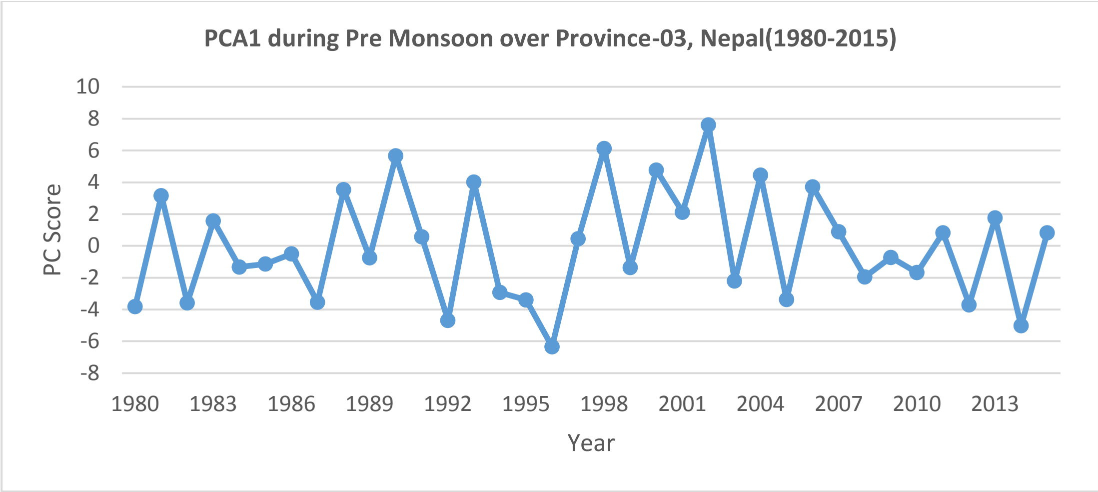

Figure 24: Temporal scores of rainfall covered by Pre monsoon PCA1 (1980-2015).

About 51.3 percent of variance is explained by the first component (PCA1). The spatial loadings are all positive having higher values in northeastern and central part of Province (Figure 23). The spatial loadings are high in stations along central and eastern part of Province in stations like Gumthang, Baunepati, Khopasi, Changunarayan, Kathmandu Airport, Thankot and Kakani. Spatial loadings are low in stations on northern and southern part in stations like Markhu, Tamachit and Hariharpur Gadhi.

The fluctuating time series of the scores of rain gives the information about dry and wet conditions as shown in Figure 24. The temporal scores of rainfall is high in 1990, 1998 and 2002 and less in 1992, 1996 and 2014. High rainfall occurs with positive/higher spatial loadings and positive time series.

High spatial loadings may define the area of intense convective activity which is due to differential heating and huge diurnal variation of temperature.

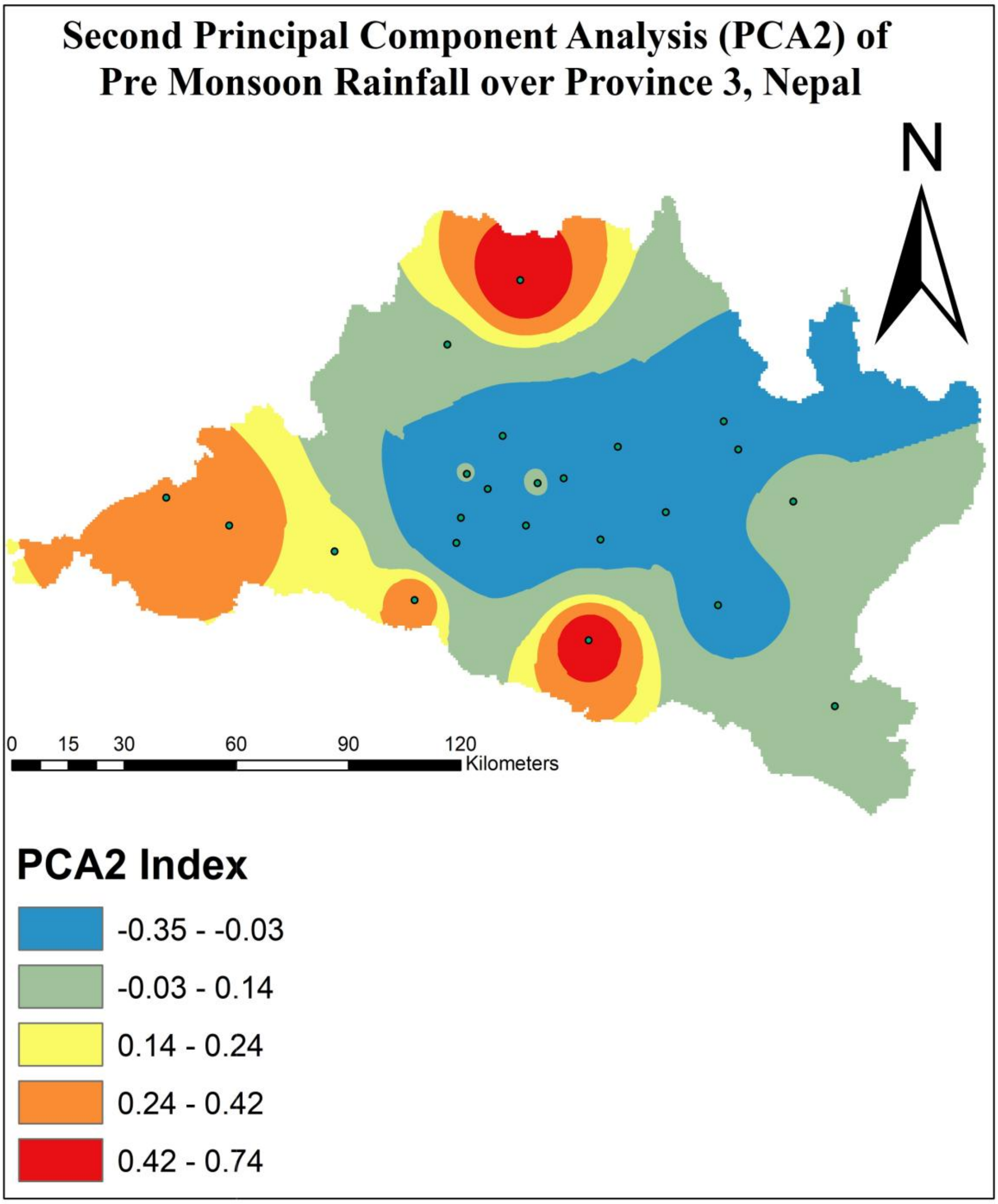

Figure 25: Spatial distribution of loadings covered by PCA2 during Pre Monsoon.

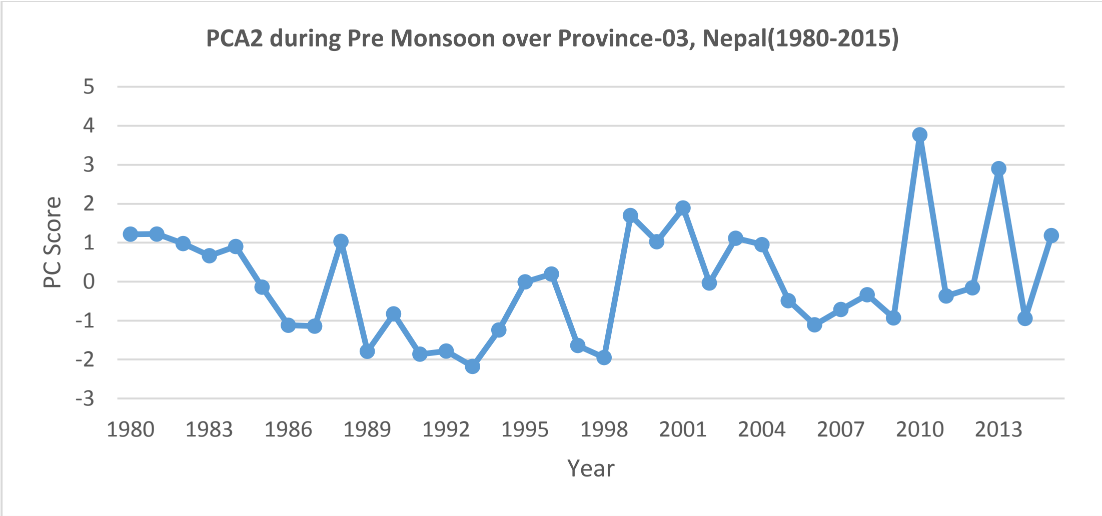

Figure 26: Temporal scores of rainfall covered by Pre monsoon PCA2 (1980-2015).

About 8.4 percent of variance is explained by the second component (PCA2). The spatial loadings are almost positive having higher values in northwestern and southern part of Province (Figure 25). The spatial loadings are high in stations like Tamachit, Hariharpur Gadhi, etc. and low in stations in like Nepalthok, Kakani, Khopasi, Gumthang, etc.

The temporal scores of rainfall is high in 2010 and 2013 and less in 1989, 1993, 1998 and 1991(Figure 26).

High spatial loadings may define the impact of certain local phenomena that enables the increased rainfall.

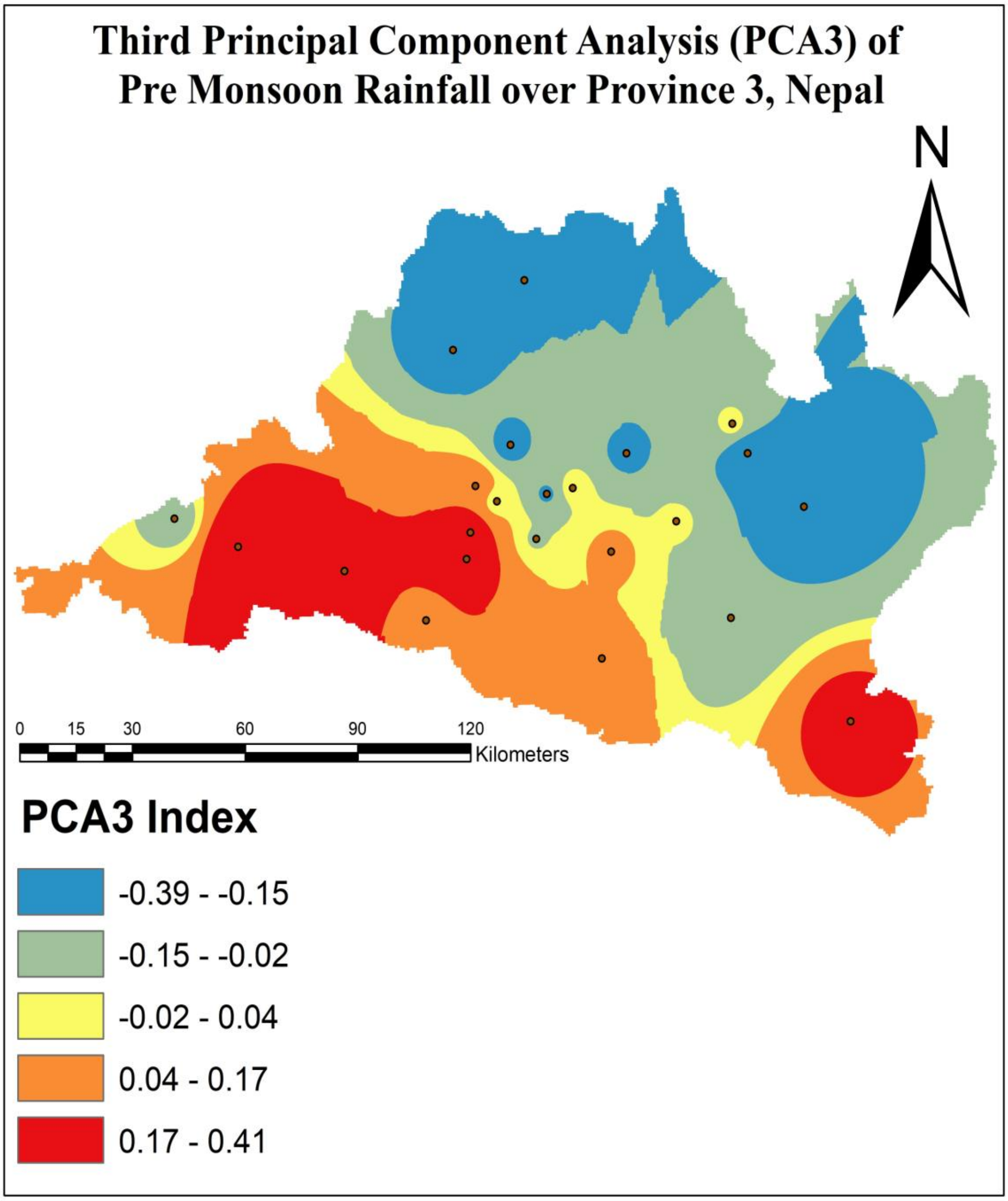

Figure 27: Spatial distribution of loadings covered by PCA3 during Pre Monsoon.

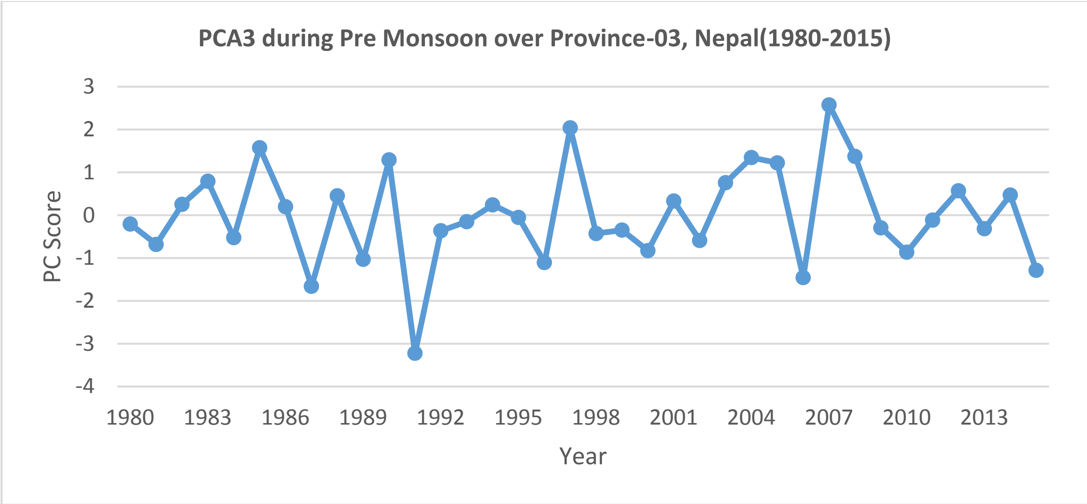

Figure 28: Temporal scores of rainfall covered by Pre monsoon PCA3 (1980-2015).

About 5.4 percent of variance is explained by the third component (PCA3). The spatial loadings are almost positive having higher values in southern part and negative value in northern part of Province (Figure 27). Almost clear difference between southern and northern part of Province is seen. The spatial loadings are high in stations like Bahun Tilpung, Manahari, Chisapani Gadhi, Markhu, etc. and low in stations like Charikot, Bahrabise, Tamachit, Pansyakhola, etc.

The temporal scores of rainfall is high in 2007 and 1997 and low in 1991 and 1987 (Figure 28).

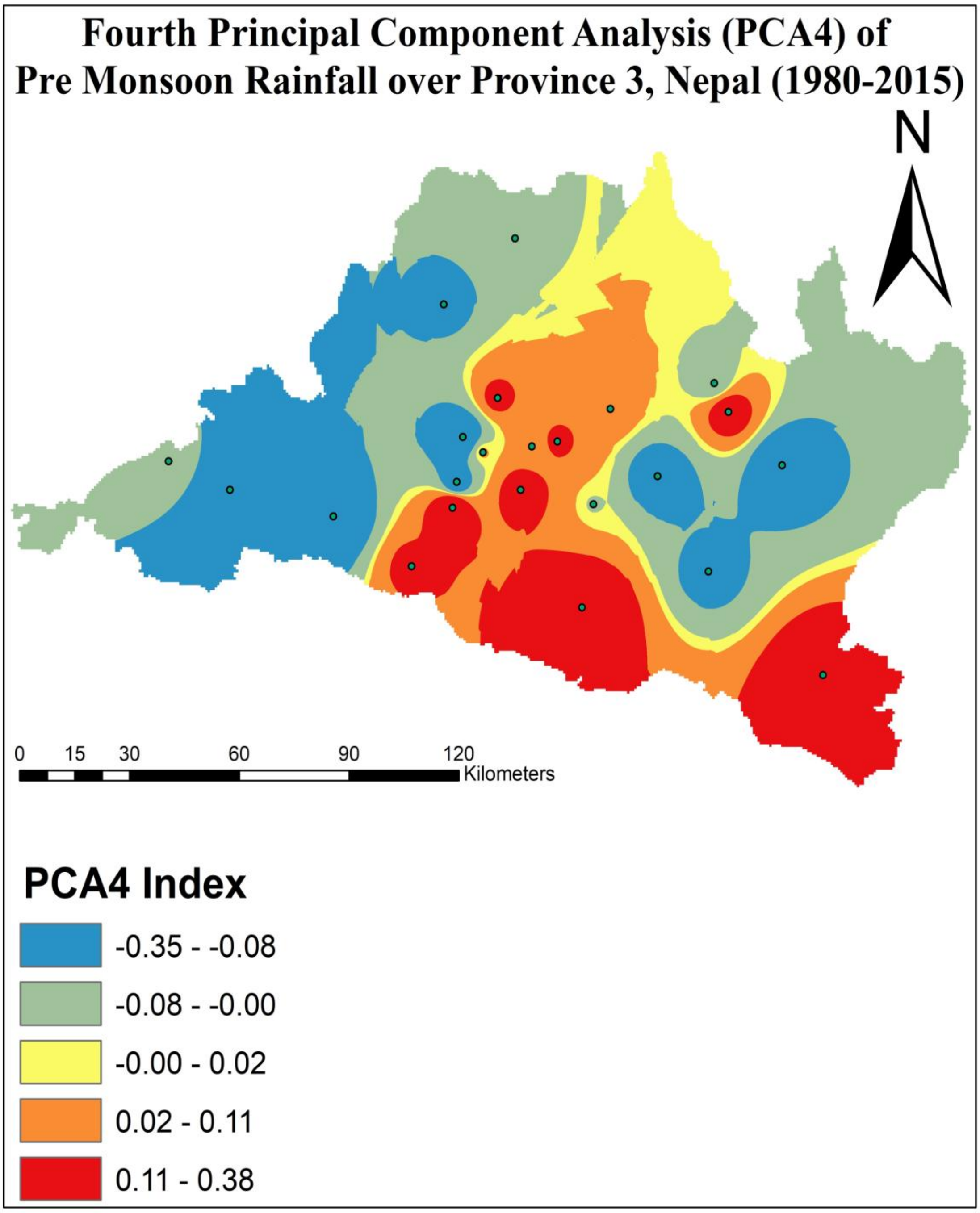

Figure 29: Spatial distribution of loadings covered by PCA4 during Pre Monsoon.

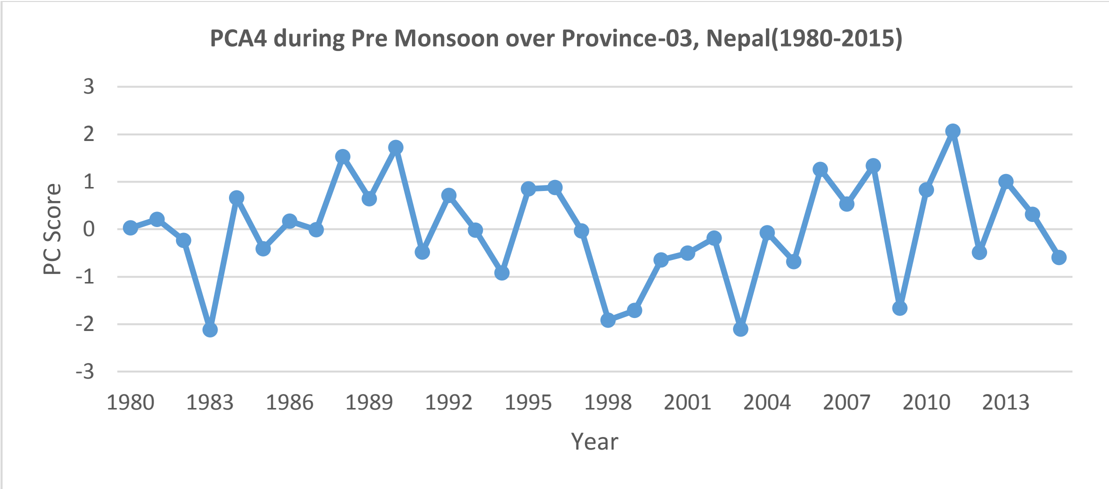

Figure 30: Temporal scores of rainfall covered by Pre monsoon PCA4 (1980-2015).

About 4.7 percent of variance is explained by the fourth component (PCA4). The spatial loadings are positive having higher values in southeastern and central part and negative and less value in rest of the place (Figure 29). The spatial distribution is not identically concentrated in particular location.

The temporal scores of rainfall is high in 2011,1990 and 1998 and low in 1983 and 2003 (Figure 30).

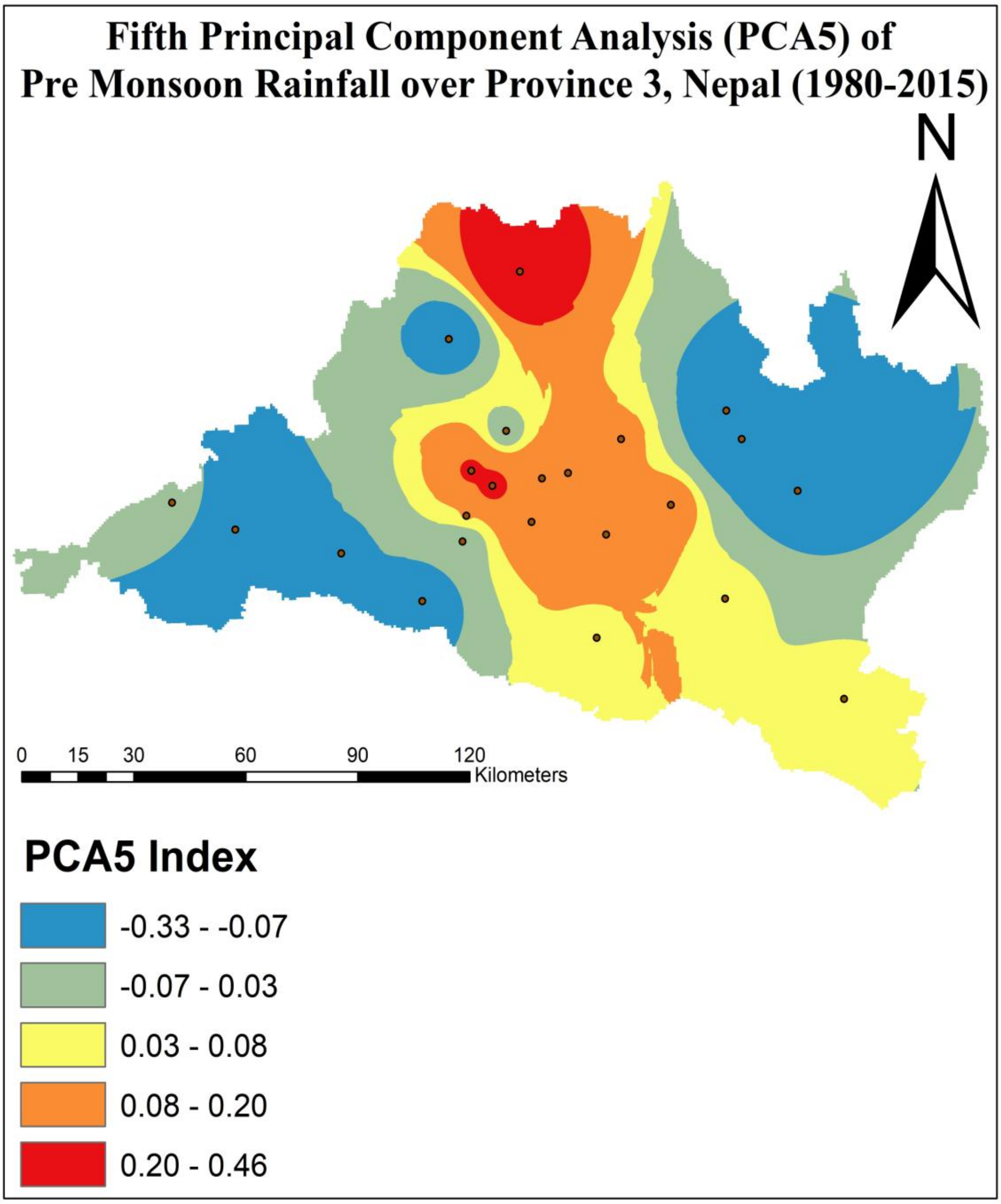

Figure 31: Spatial distribution of loadings covered by PCA5 during Pre Monsoon.

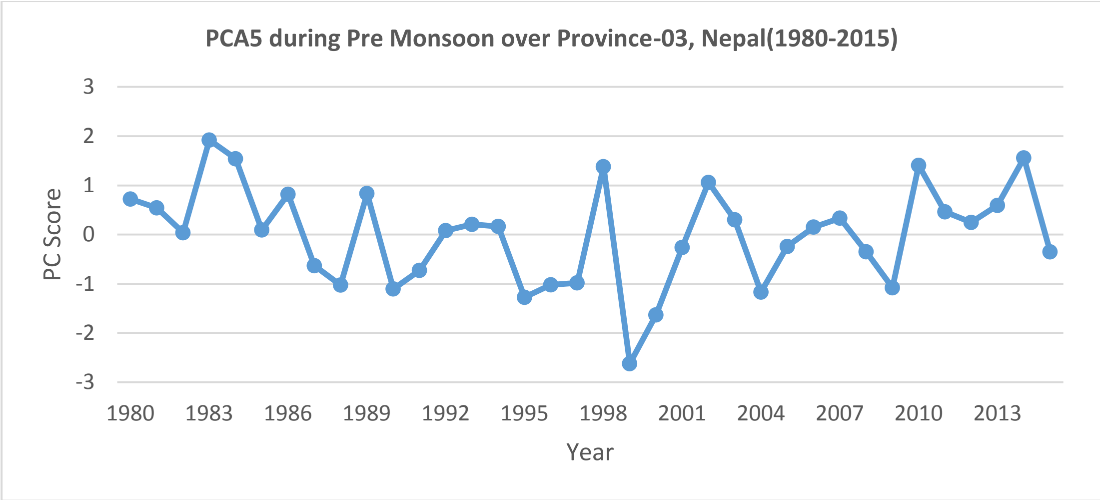

Figure 32: Temporal scores of rainfall covered by Pre monsoon PCA5 (1980-2015).

In Pre monsoon season the variance covered by PCA 5 is 4.3%. The spatial loadings are high in stations along central and northwestern part of Province. Spatial loadings are low in stations in northeastern, western and south western part of Province (Figure 31).

Temporal scores of rainfall is high in 1983,1984 and 2014 and low in 1999 and 2000 (Figure 32).

4.6.2 PCA during Monsoon

Monsoons are large-scale sea breezes which occur when the temperature on land is significantly warmer or cooler than the temperature of the ocean. These temperature imbalances happen because oceans and land absorb heat in different ways. This shifting of wind from sea to land cause heavy rains in the summer between June and September.

About 71.1% of variance is explained by first five Principal component on Monsoon which is explained by PCA 1 with 39.61%, PCA 2 with 11.5%, PCA 3 with 8.7%, PCA 4 with 5.7% and PCA 5 with 5.3% (Figure 33).

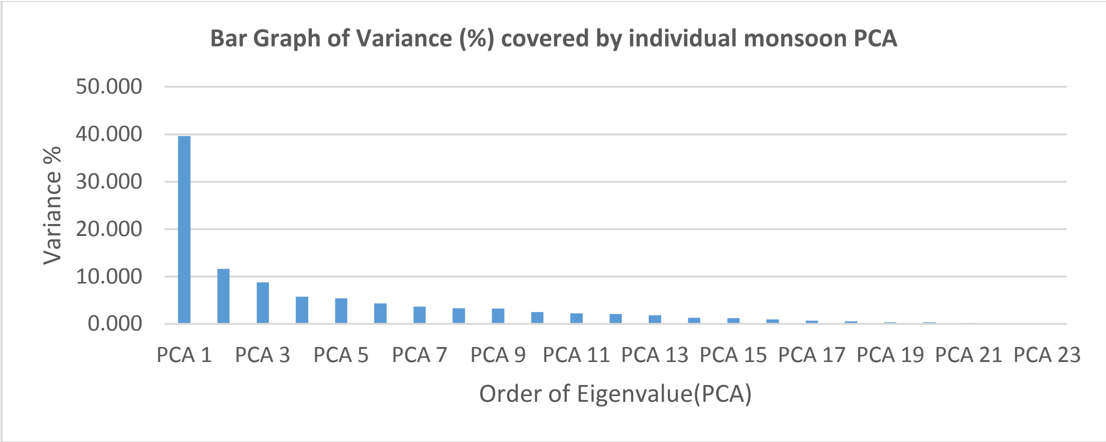

Figure 33: Bar graph of variance % covered by different eigenvalue during Monsoon season.

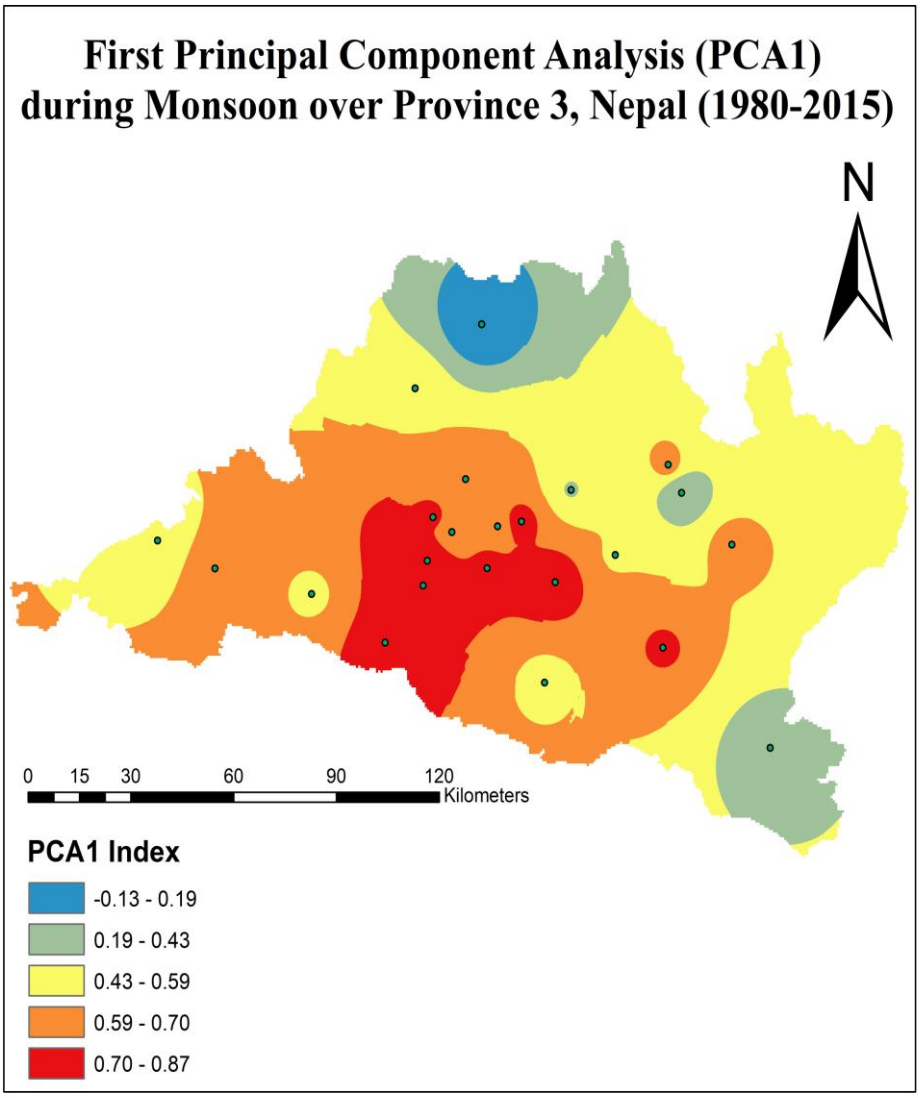

Figure 34: Spatial distribution of loadings covered by PCA1 during Monsoon.

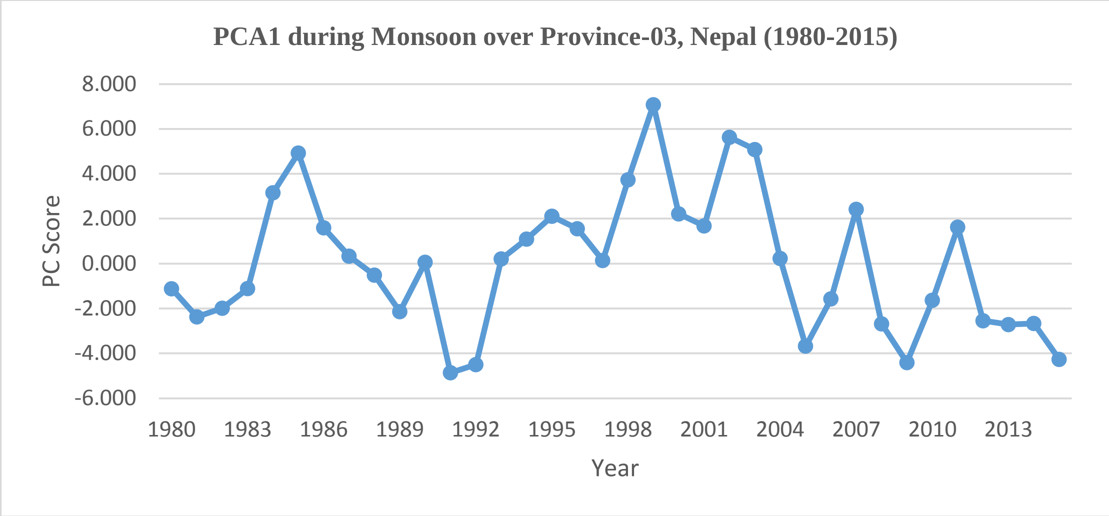

Figure 35: Temporal scores of rainfall covered by Monsoon PCA1 (1980-2015).

About 39.61 percent of variance is explained by the first component (PCA1). The spatial loadings are almost positive having higher values in southern and central part of Province (Figure 34). Negative loadings are seen in northwestern part of Province. The spatial loadings are high in stations like Markhu, Changunarayan, Hetauda, Nepalthok etc. and low in stations like Tamachit, Bahun Tilpung, Bahrabise, Baunepati, etc.

The fluctuating time series of the scores of rain gives the information about dry and wet conditions as shown in Figure 35. The temporal scores of rainfall is high in 1999, 2002and 2003 and less in 1991, 1992 and 2009. High rainfall occurs with positive/higher spatial loadings and positive time series during monsoon.

High spatial loadings of PCA1 are concentrated in central and southern part which might be due to northward shifting of moisture laden south easterly wind.

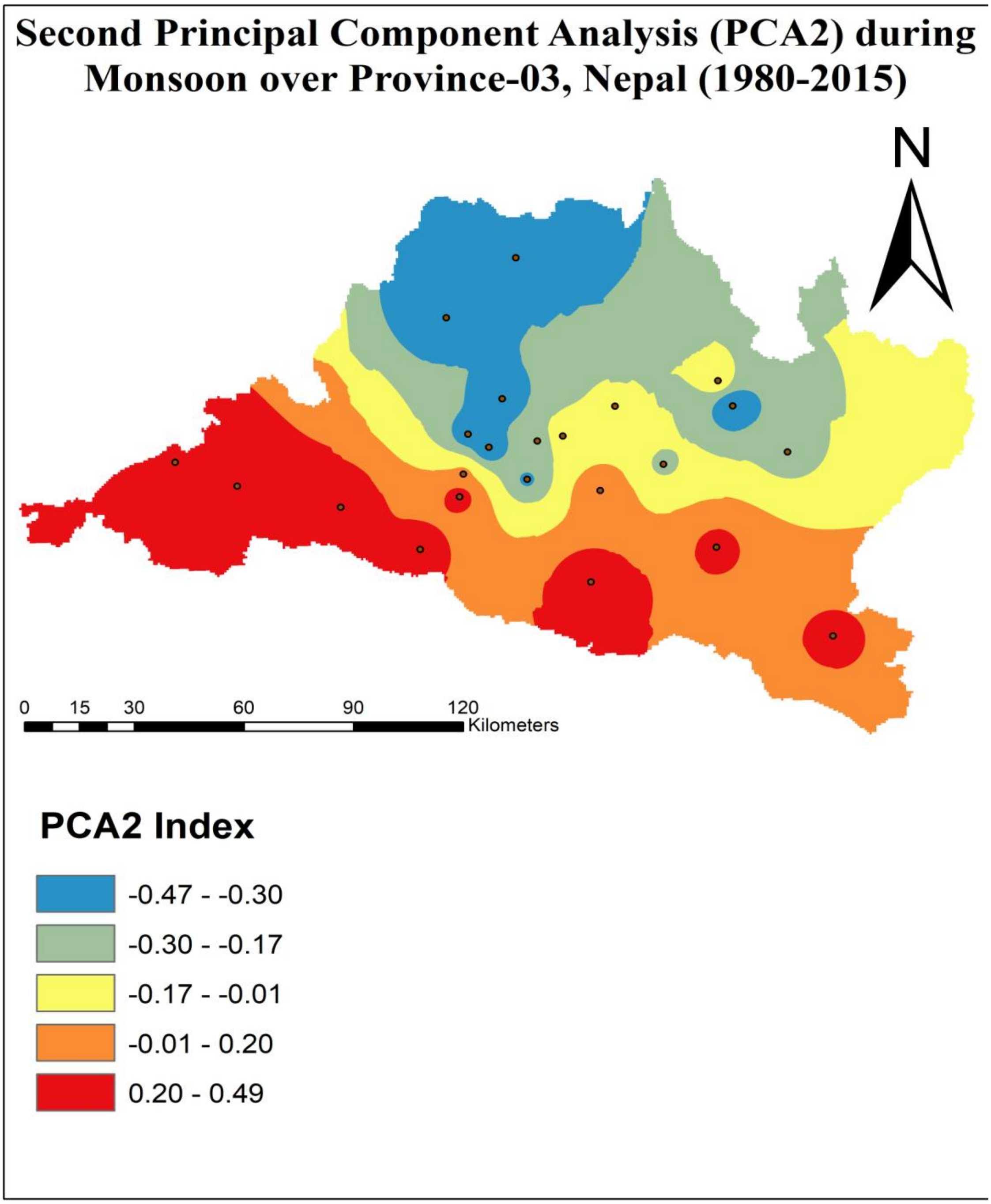

Figure 36: Spatial distribution of loadings covered by PCA2 during Monsoon.

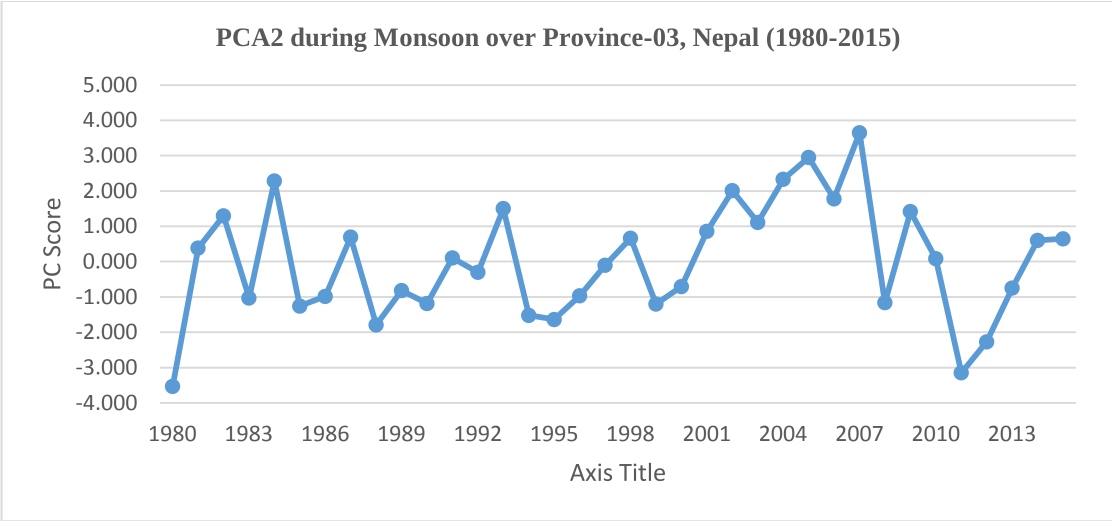

Figure 37: Temporal scores of rainfall covered by Monsoon PCA2 (1980-2015).

About 11.5 percent of variance is explained by the second component (PCA2). The spatial loadings are almost positive having higher values in southern part and negative value in northern part of Province (Figure 36). Great contrast is seen between south and north.

The temporal scores of rainfall is high in 2002 and 2007 and low in 1980 and 2011 (Figure 37).

PCA2 is high throughout the southern part of Province. One of the cause may be due to concentration of monsoon trough in Indo-Gangetic plain and foothills of the Himalayas.

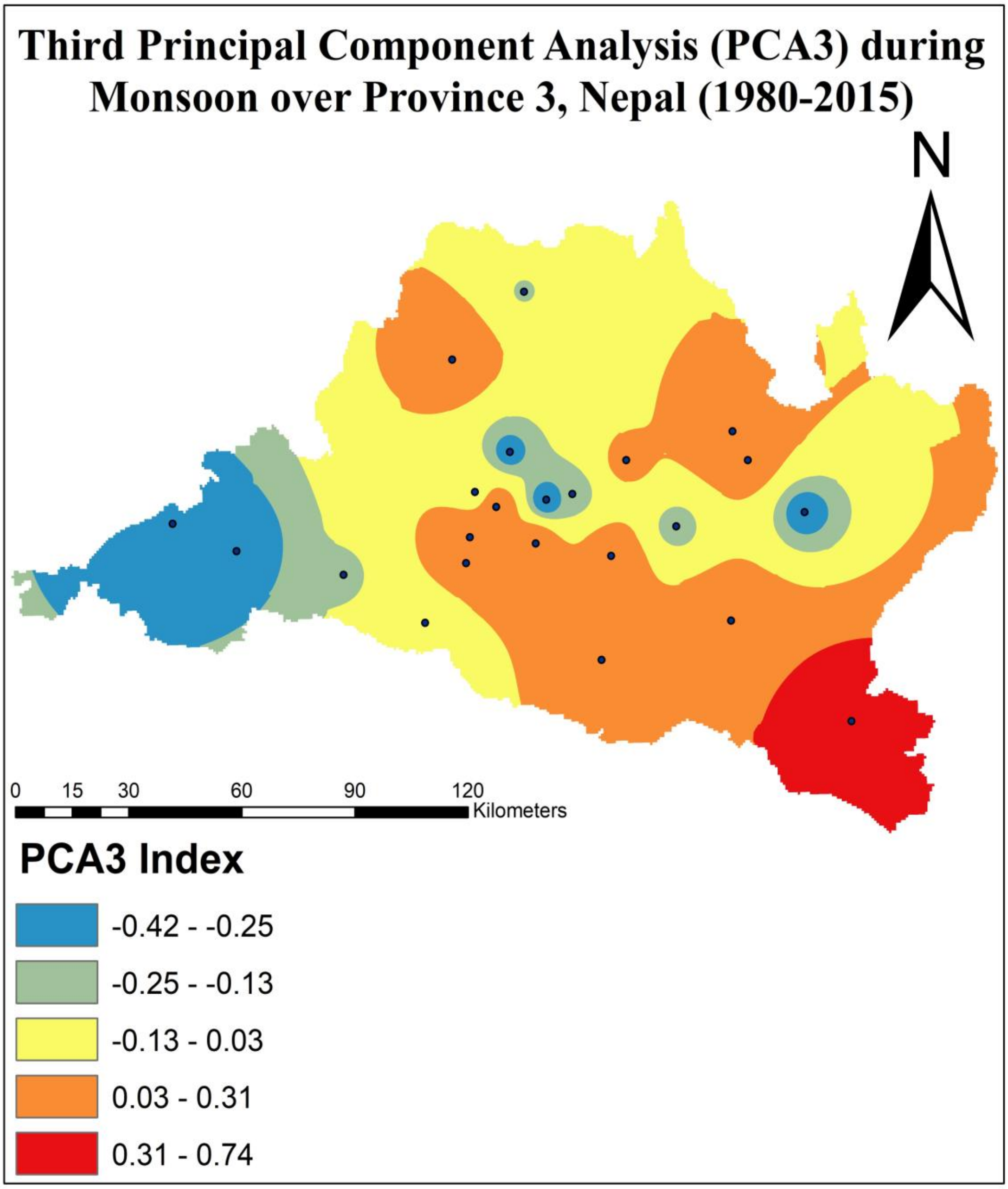

Figure 38: Spatial distribution of loadings covered by PCA3 during Monsoon.

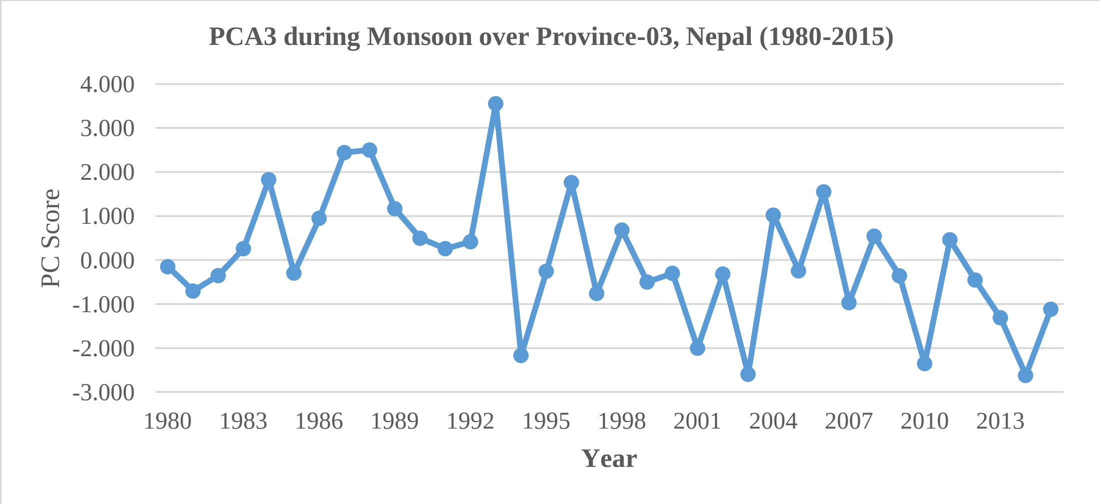

Figure 39: Temporal scores of rainfall covered by Monsoon PCA3 (1980-2015).

About 8.7 percent of variance is explained by the third component (PCA3). The spatial loadings are almost positive having higher values in southeastern part and negative value in central and northwestern part of Province (Figure 38). The spatial loadings are highest in station of Bahun Tilpung. Low spatial loadings are seen stations like Rampur, Charikot, Kathmandu Airport, Jhawani etc.

The temporal scores of rainfall is high in 1987, 1988 and 1993 and low in 1994, 2003, 2010 and 2014 (Figure 39).

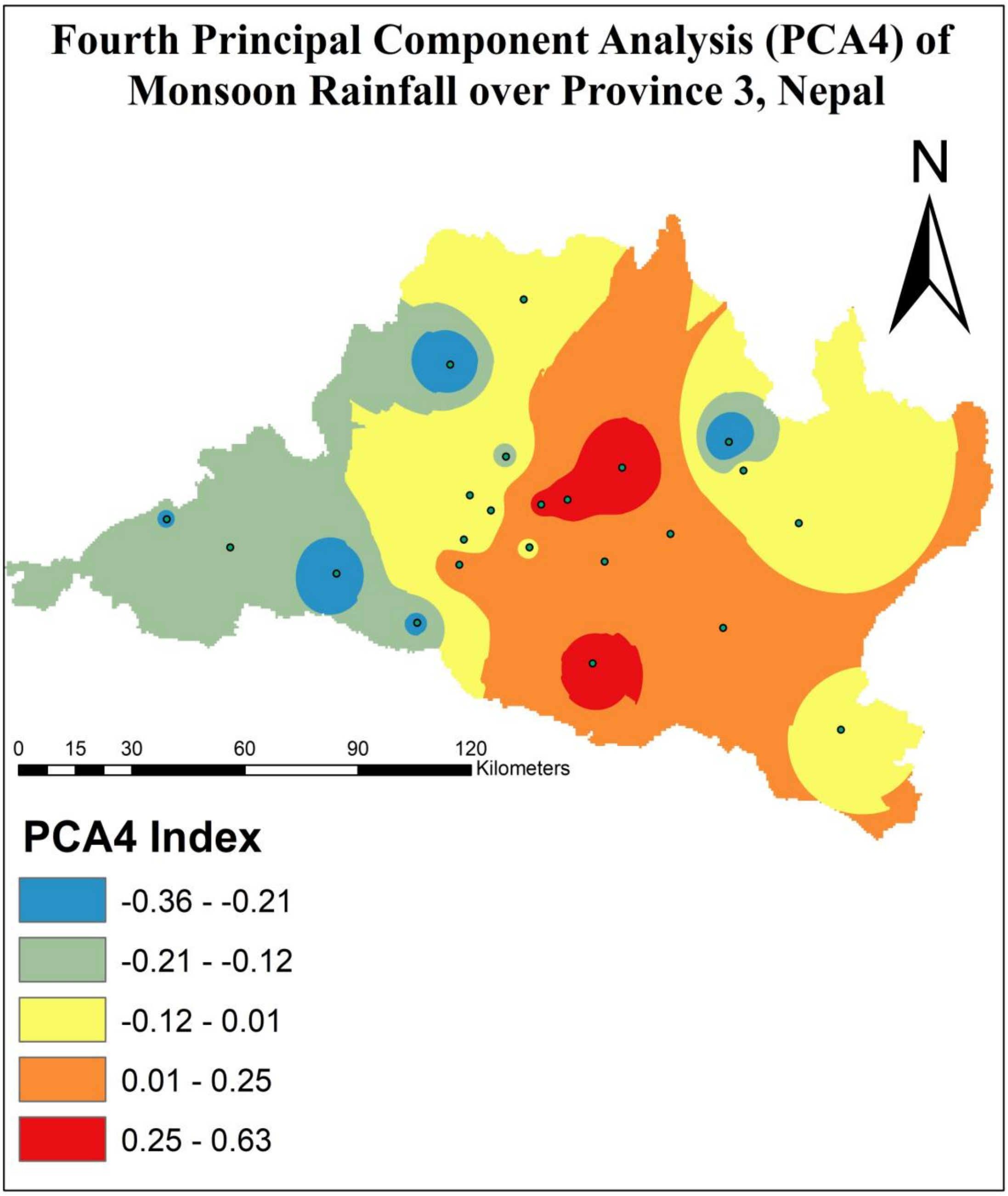

Figure 40: Spatial distribution of loadings covered by PCA4 during Monsoon.

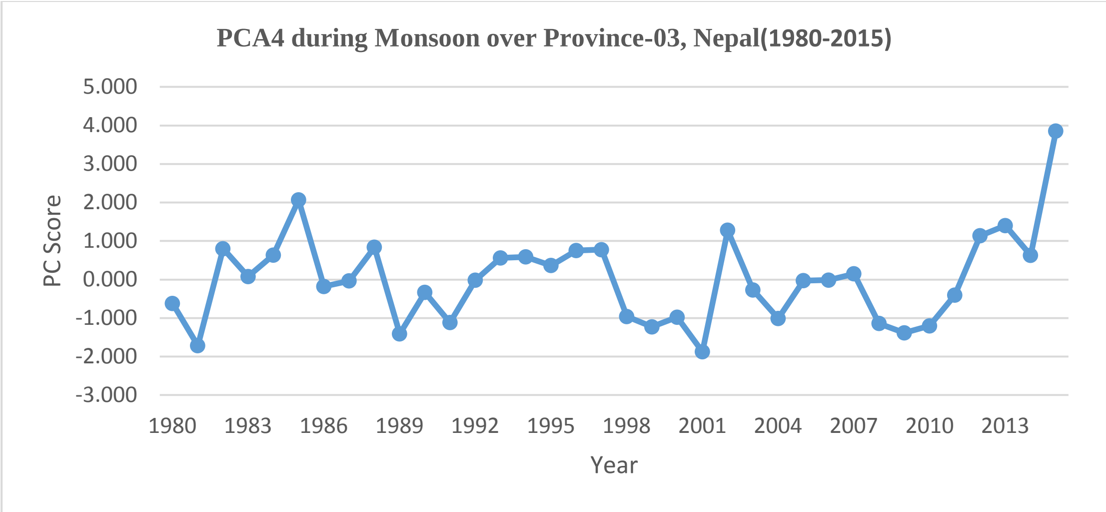

Figure 41: Temporal scores of rainfall covered by Monsoon PCA4 (1980-2015).

About 5.7 percent of variance is explained by the fourth component (PCA4). The spatial loadings are positive having higher values in southeastern and central part and negative and less value mainly in western part (Figure 40). The spatial loadings are high in stations like Kathmandu Airport, Baunepati, Hariharpur Gadhi, etc. and low in western and south western part of Province in stations like Pansyakhola, Manahari, Hetauda, etc.

The temporal scores of rainfall is high in 1985 and 2015 and low in 1981 and 2001 (Figure 41).

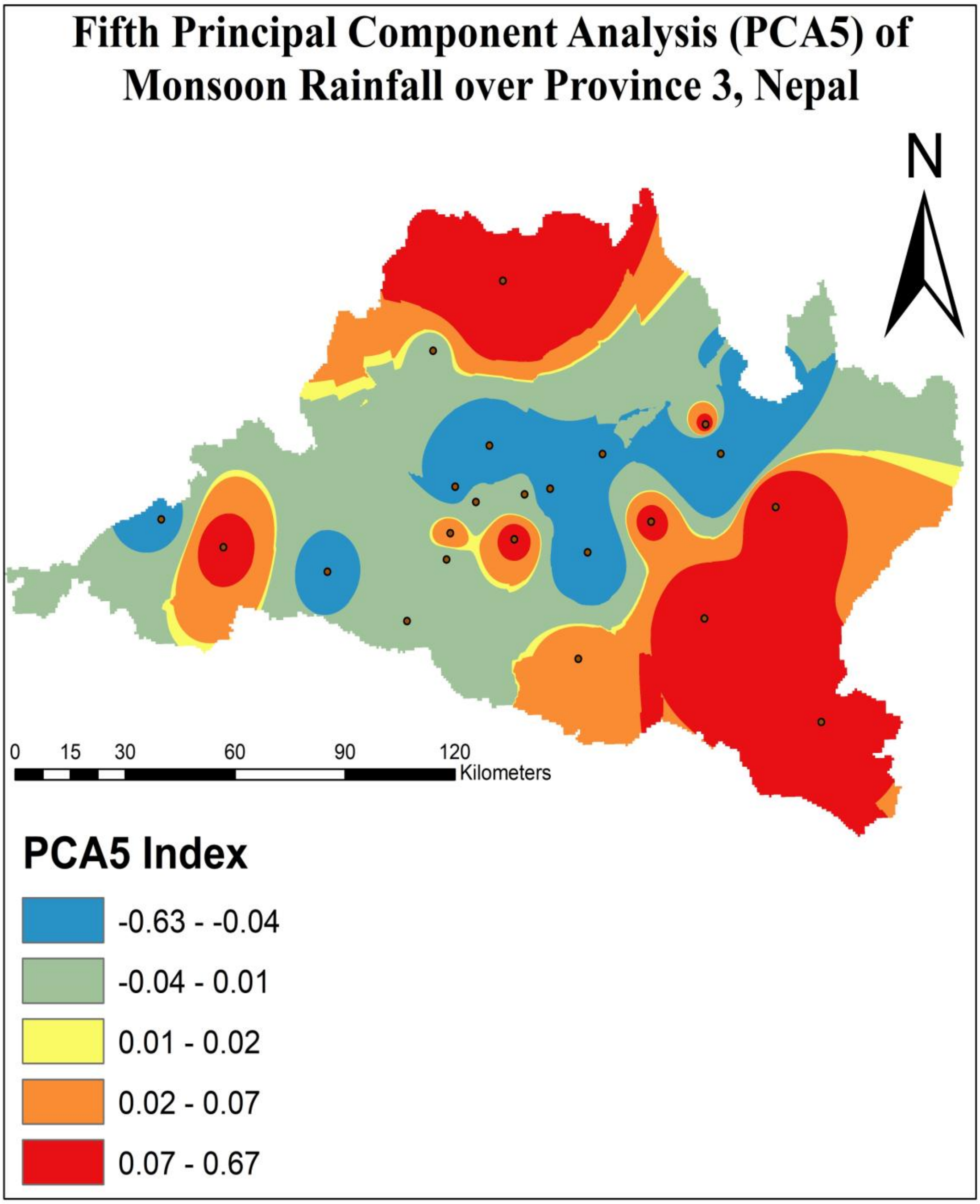

Figure 42: Spatial distribution of loadings covered by PCA5 during Monsoon.

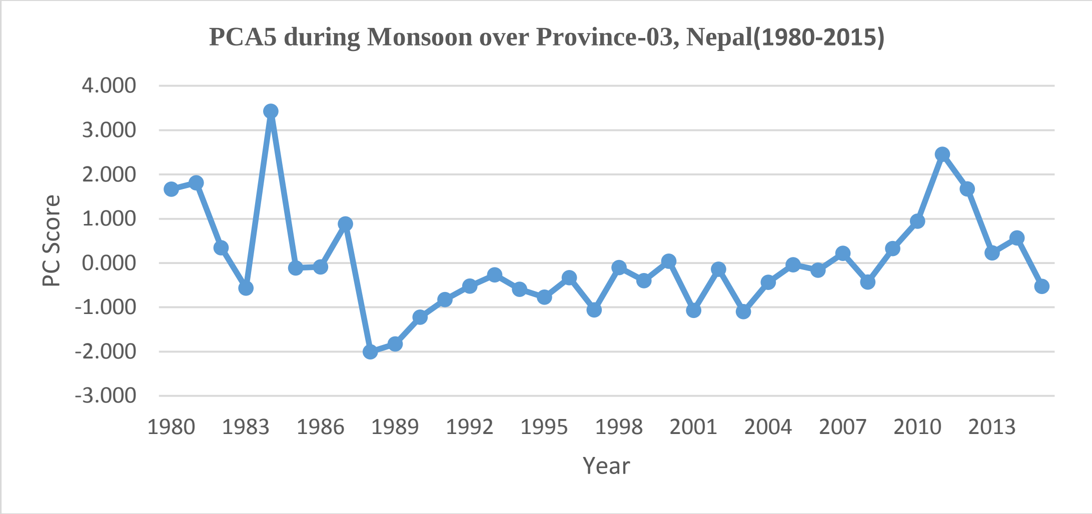

Figure 43: Temporal scores of rainfall covered by Monsoon PCA5 (1980-2015).

In monsoon season the variance covered by PCA5 is 5.3%. High spatial loadings are mainly concentrated in southeastern and northwestern part. Low spatial loadings are concentrated mainly in northeastern, central and southwestern part of Province (Figure 42).

The temporal scores of rainfall is high in 1984 and 2011 and low in 1988 and 1989 (Figure 43). The distribution is not spatially identical.

4.6.3 PCA during Post Monsoon

During the post-monsoon months of October to November, a different monsoon cycle, the northeast (or "retreating") monsoon, brings dry, cool, and dense air masses to large parts of South Asia.

About 81.30% of variance is explained by first five Principal component on Pre monsoon which is explained by PCA 1 with 59.2%, PCA 2 with 7.2%, PCA 3 with 5.9%, PCA 4 with 5% and PCA 5 with 3.9% (Figure 44).

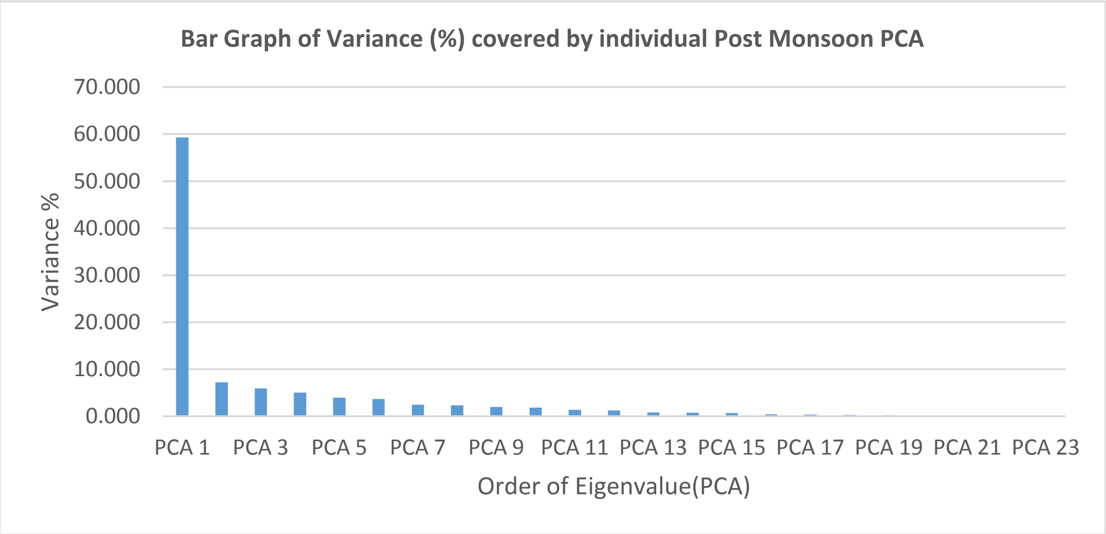

Figure 44: Bar graph of variance % covered by different eigenvalue during Post monsoon.

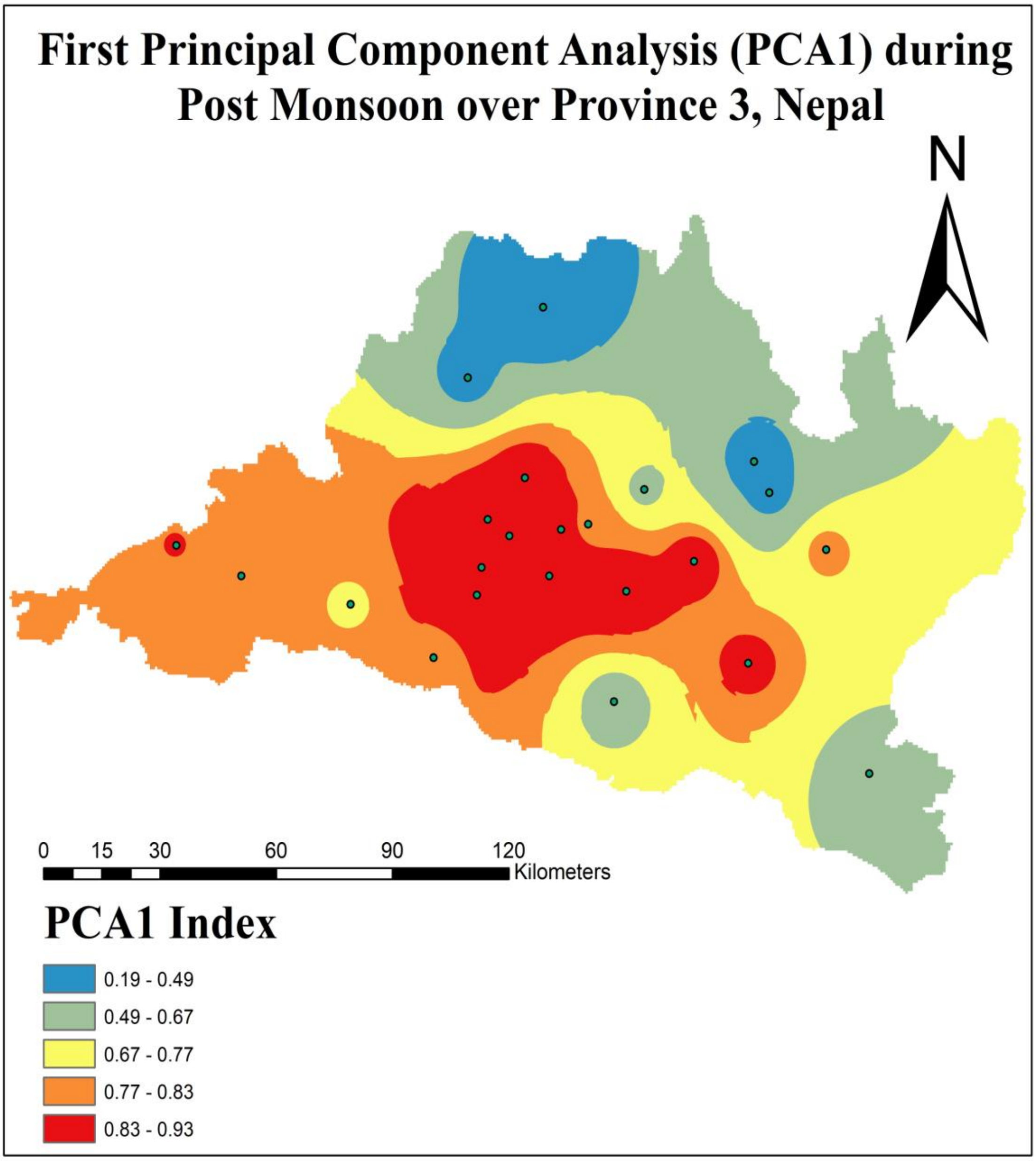

Figure 45: Spatial distribution of loadings covered by PCA1 during Post Monsoon.

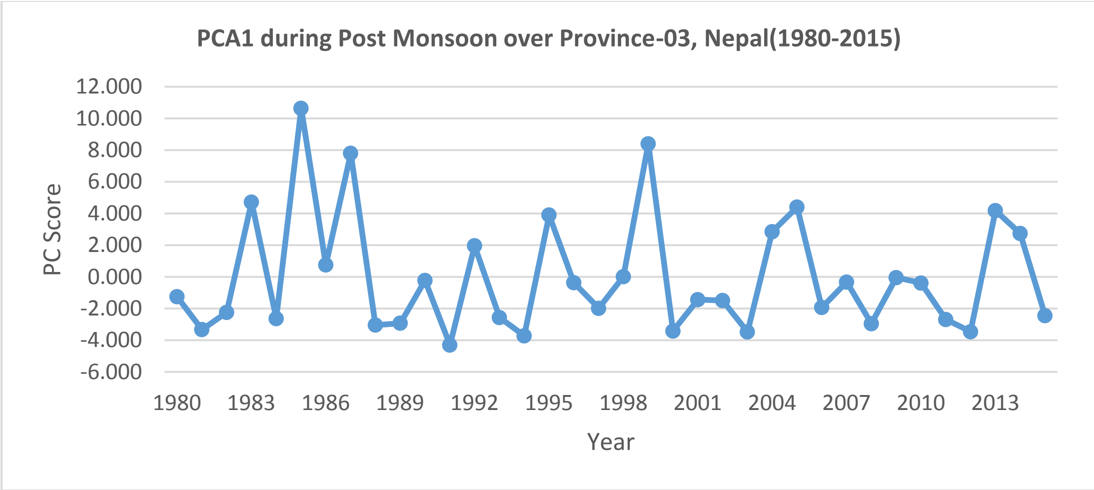

Figure 46: Temporal scores of rainfall covered by Post Monsoon PCA1 (1980-2015).

About 59.2 percent of variance is explained by the first component (PCA1). The spatial loadings are all positive having higher values in southwestern and central part of Province (Figure 45). The spatial loadings are high in stations like Kathmandu airport, Chapagaun, Chisapani Gadhi, Dolalghat, Khopasi etc. and low in stations like Tamachit, Pansyakhola, Gumthang, Bahun Tilpung and Bahrabise.

The fluctuating time series of the scores of rain gives the information about dry and wet conditions as shown in Figure 46. The temporal scores of rainfall is high in 1985, 1987 and 1999 and less in 1991, 1994, 2000, 2003 and 2012. High rainfall occurs with positive/higher spatial loadings and positive time series during Post monsoon.

High spatial loadings may be related to the differences in the prevailing local circulation between the summer monsoon and post-monsoon seasons.

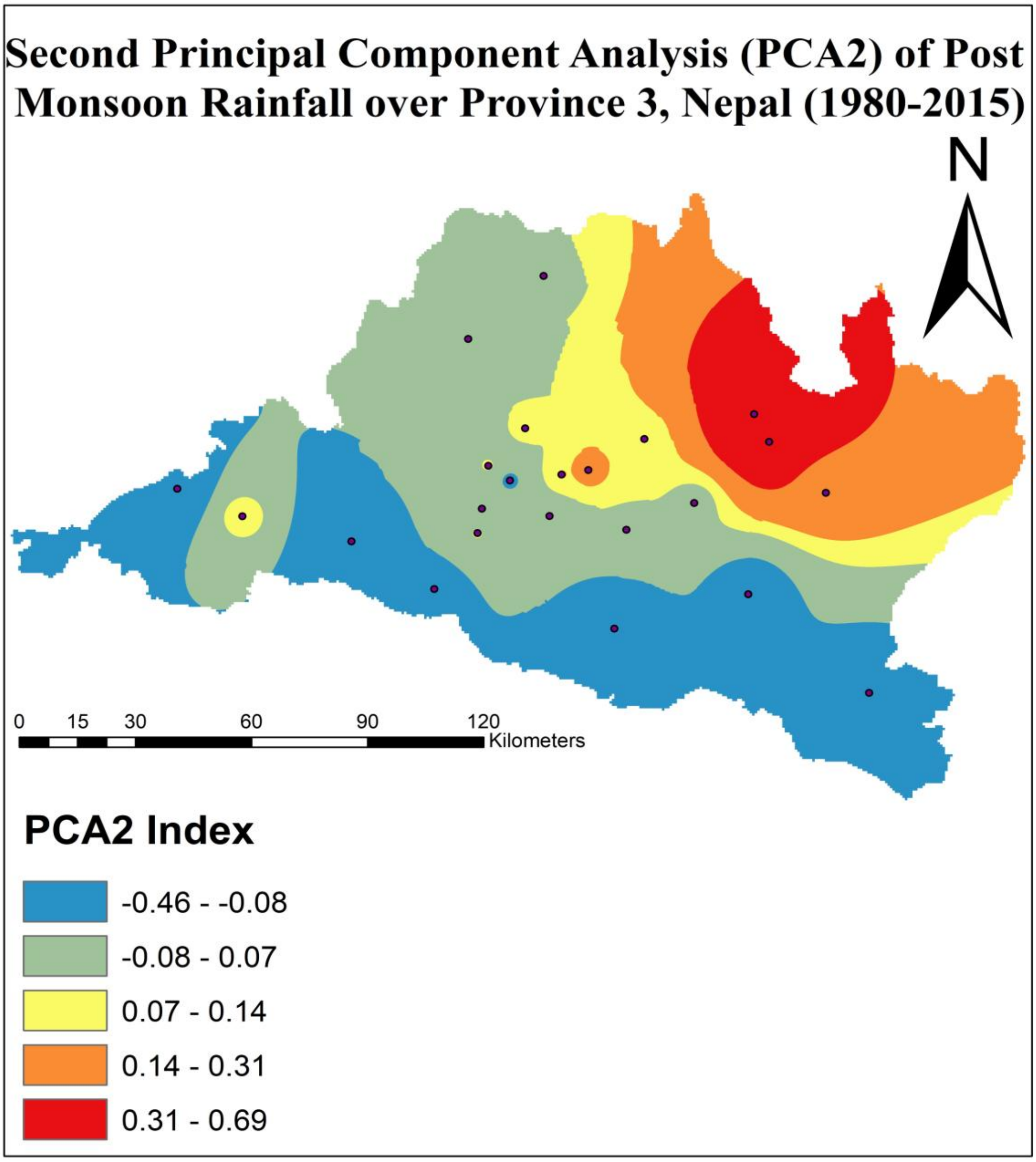

Figure 47: Spatial distribution of loadings covered by PCA2 during Post Monsoon.

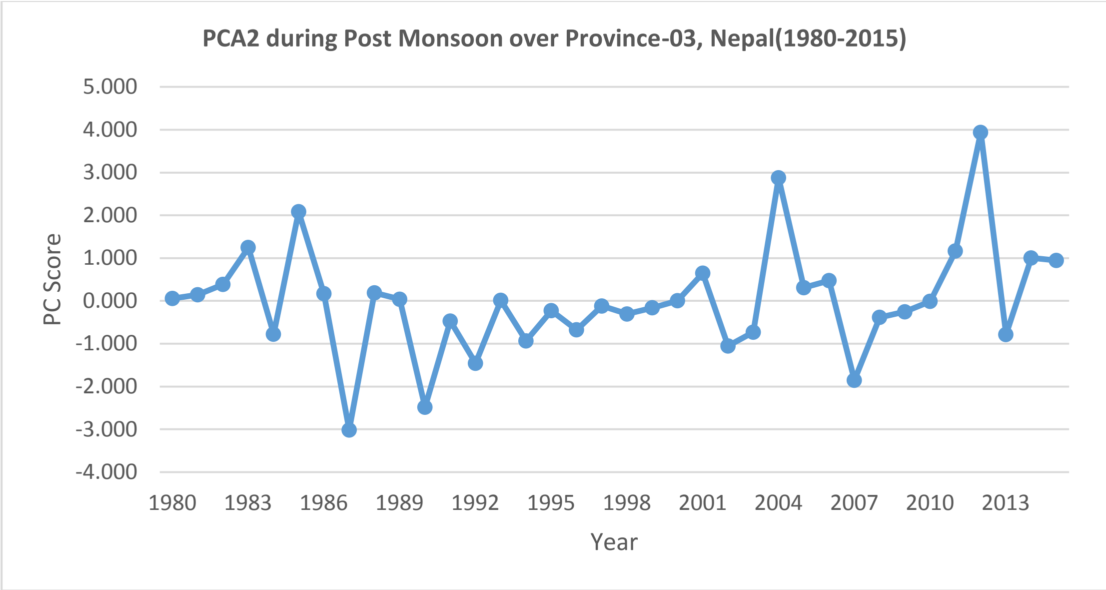

Figure 48: Temporal scores of rainfall covered by Post Monsoon PCA2 (1980-2015).

About 7.2 percent of variance is explained by the second component (PCA2). The spatial loadings are almost positive having higher values in northeastern part of Province (Figure 47). Negative and low spatial loadings is observed in southern part. The spatial loadings are high in stations like Gumthang and Bahrabise.

The temporal scores of rainfall is high in 2004 and 2012 and less in 1987 and 1990 (Figure 48).

PCA2 is almost concentrated in only two neighboring stations in northeastern part, this may be the reason of concentration of rainfall in pocket area along Gumthang.

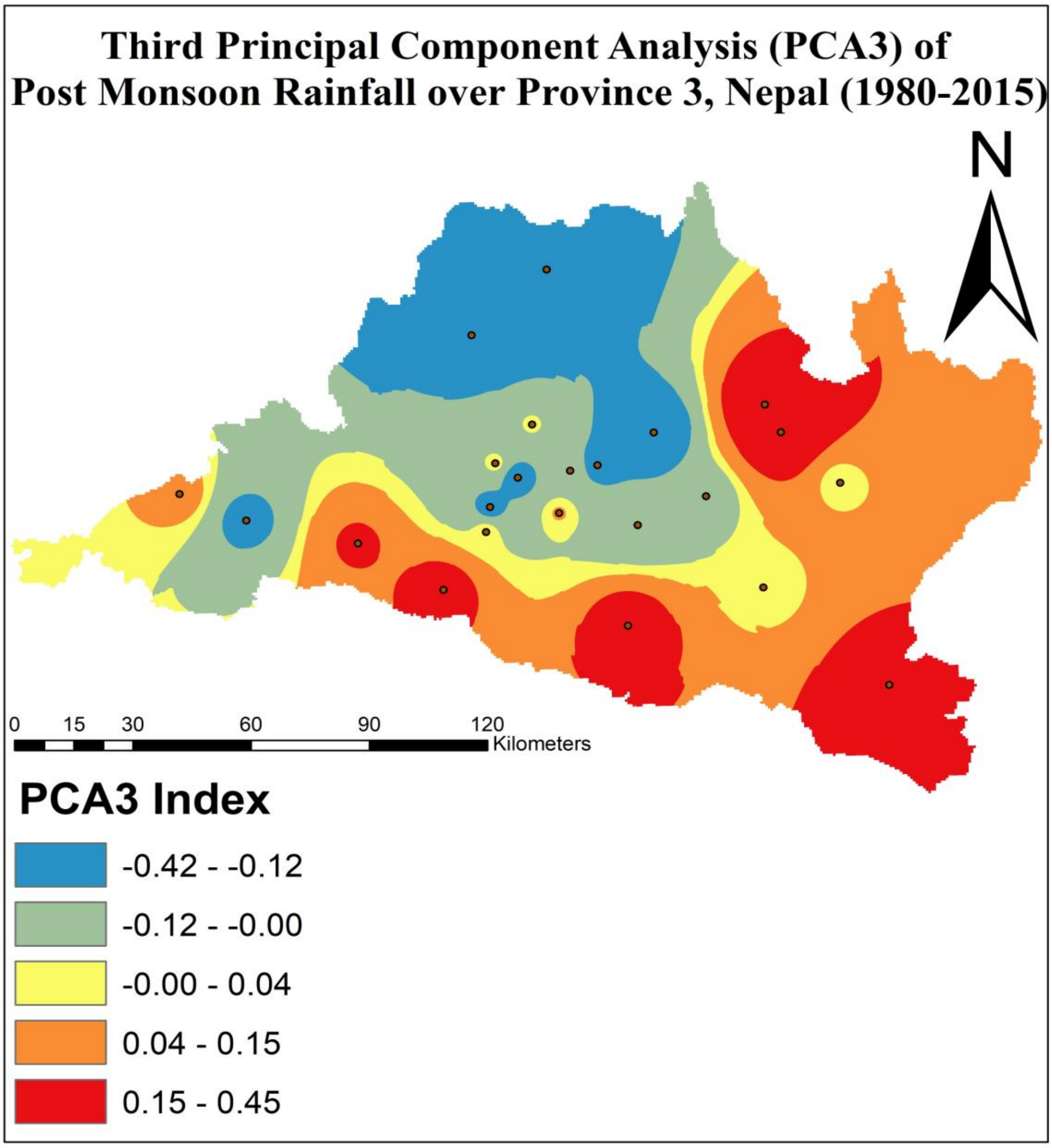

Figure 49: Spatial distribution of loadings covered by PCA3 during Post Monsoon.

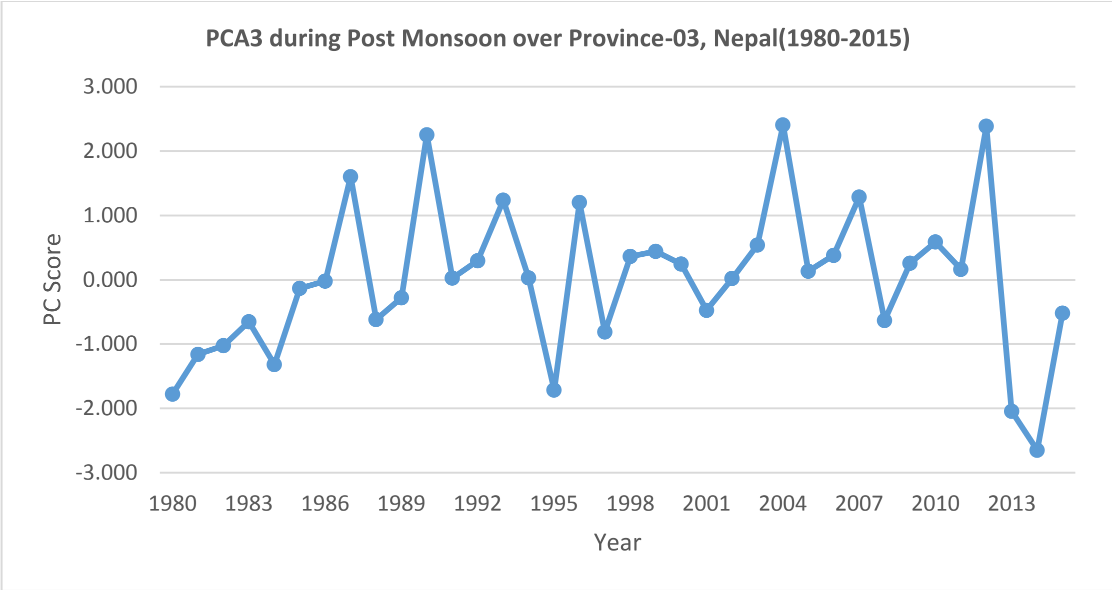

Figure 50: Temporal scores of rainfall covered by Post Monsoon PCA3 (1980-2015).

About 5.9 percent of variance is explained by the third component (PCA3). The spatial loadings are almost positive having higher values in south and eastern part and negative value is concentrated mainly in northwestern part of Province (Figure 49).

The temporal scores of rainfall is high in 1990, 2004 and 2012 and low in 1980, 1995, 2013 and 2014 (Figure 50).

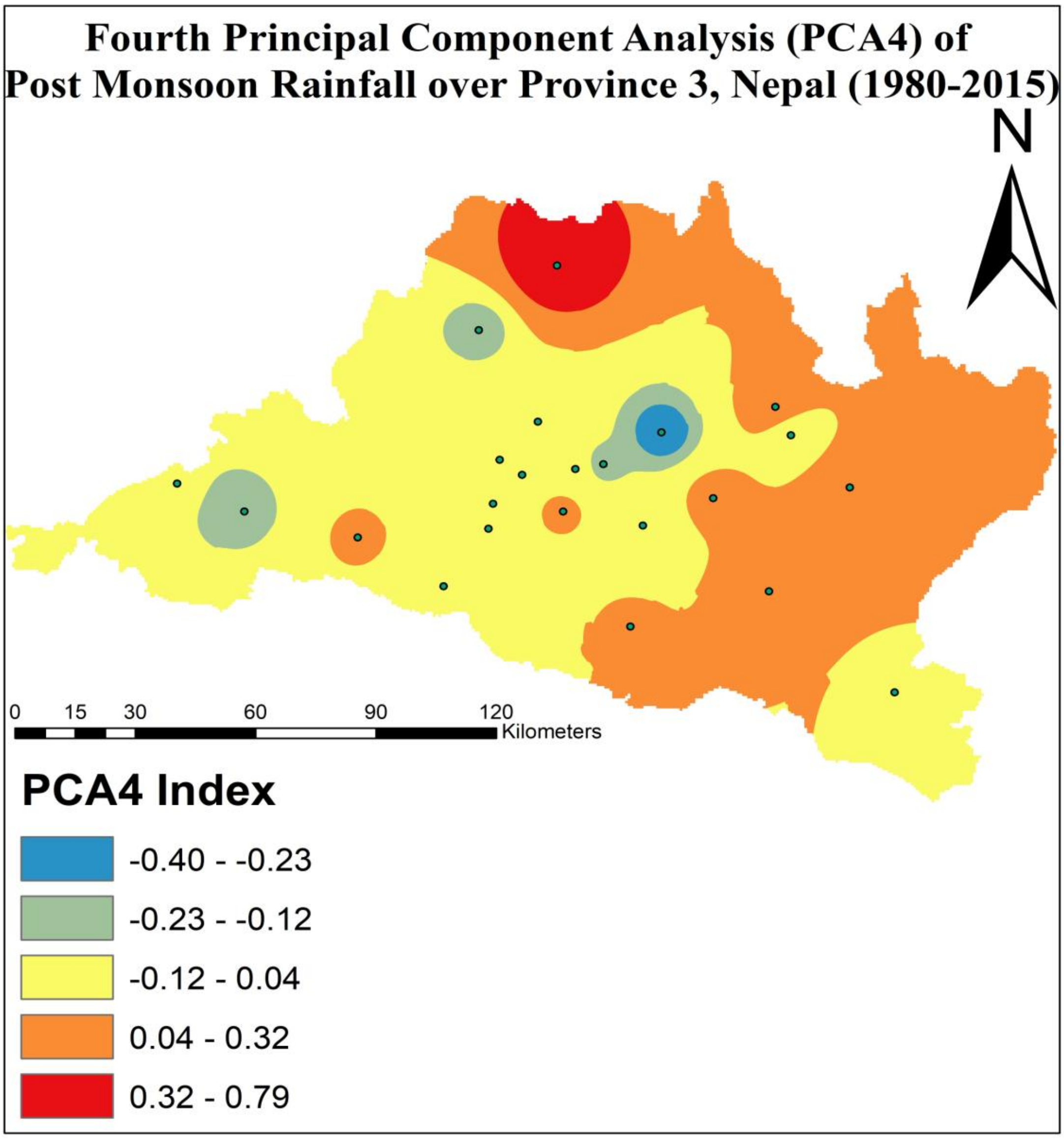

Figure 51: Spatial distribution of loadings covered by PCA4 during Post Monsoon.

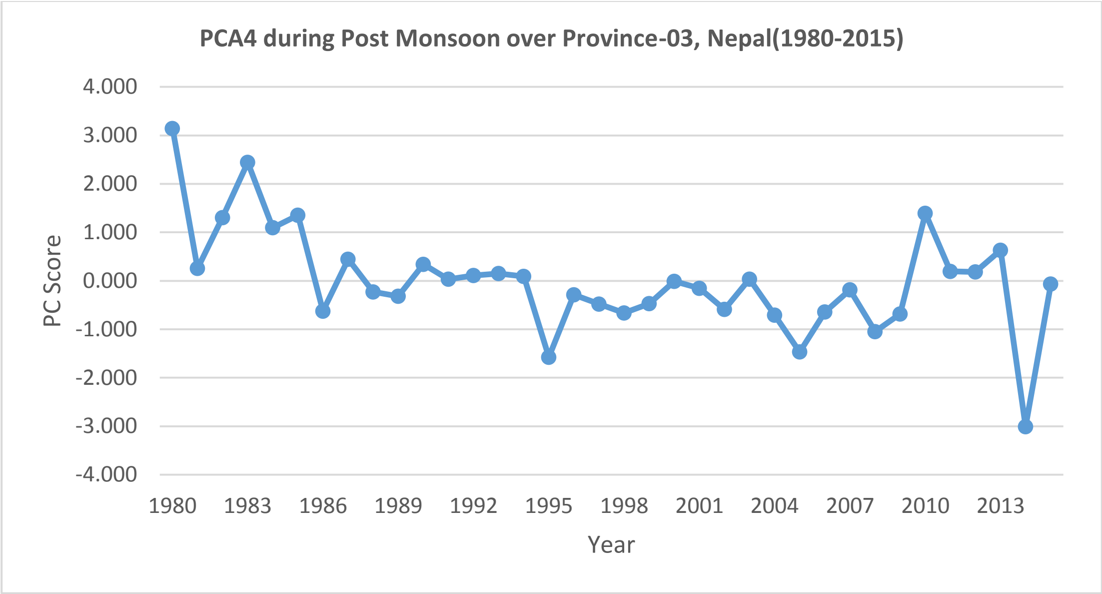

Figure 52: Temporal scores of rainfall covered by Post Monsoon PCA4 (1980-2015).

About 5 percent of variance is explained by the fourth component (PCA4). The spatial loadings are positive having higher values in north and eastern part and negative value in rest of the region (Figure 51). The spatial loadings are highest in Tamachit and lowest in Baunepati.

The temporal scores of rainfall is high in 1980 and 1984 and less in 2014 and 1995 (Figure 52).

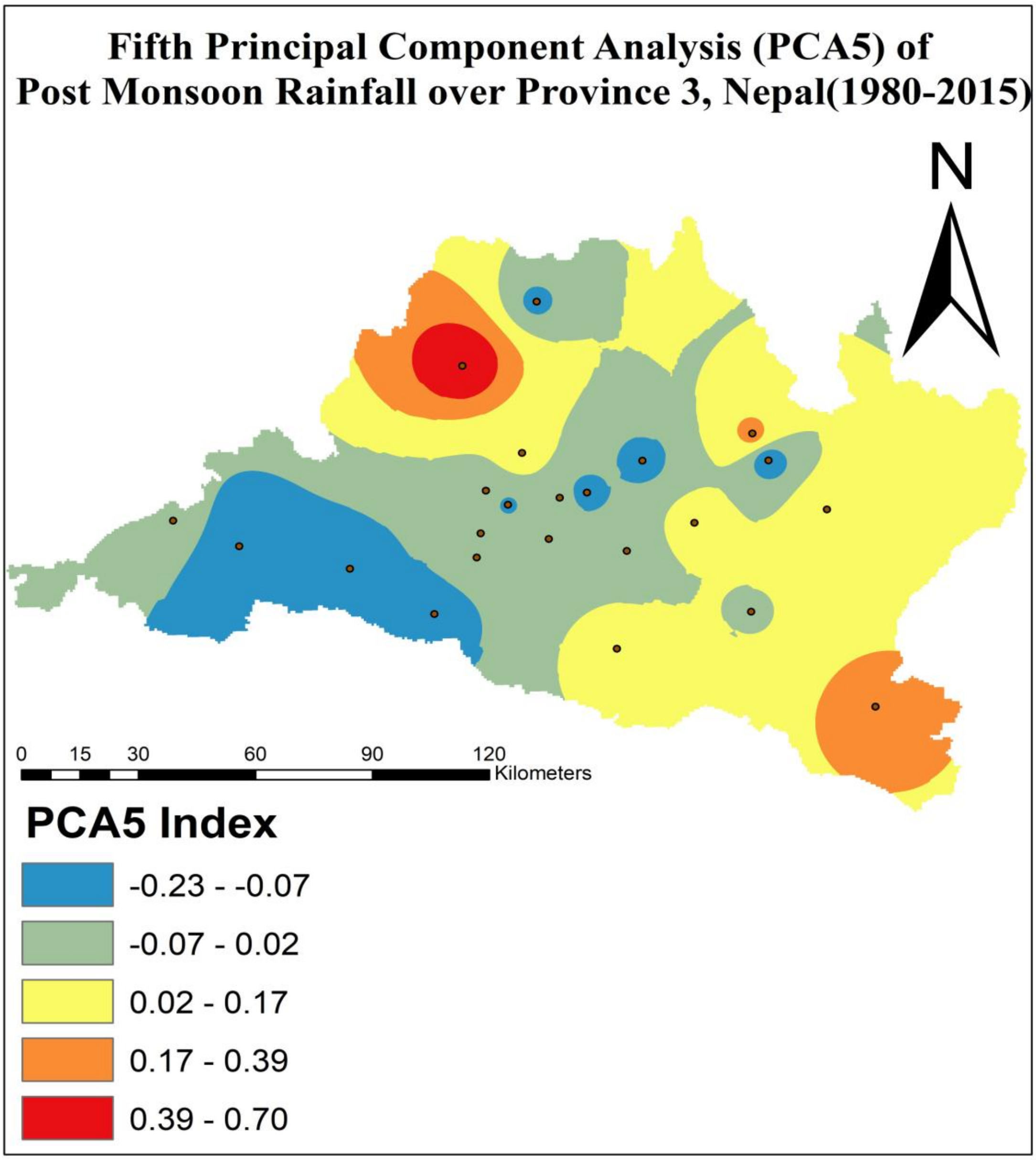

Figure 53: Spatial distribution of loadings covered by PCA5 during Post Monsoon.

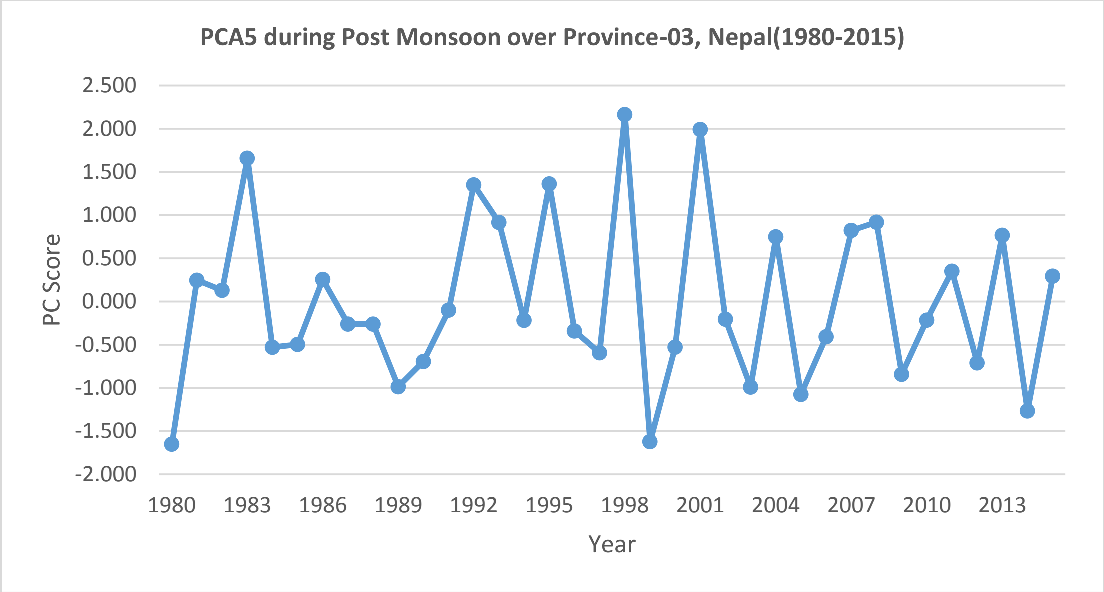

Figure 54: Temporal scores of rainfall covered by Post Monsoon PCA5 (1980-2015).

In Post monsoon season the variance covered by PCA5 is 3.9%. The spatial loadings are high in southeastern and northwestern part and low spatial loadings are observed in central and southwestern part of Province (Figure 53).

For PCA5 the temporal scores of rainfall is high in 1983,1998 and 2001 and low in 1980 and 1999 (Figure 54).

4.6.4 PCA during Winter

Winter is the season that last for three months from December to February. It is the season of least rainfall. Rainfall occurs mainly due to western disturbance and north easterly moist air. During winter high amount of precipitation is obtained in the form of snow in higher altitudes.

About 86.96% of variance is explained by first five Principal component on Winter which is explained by PCA 1 with 70.4%, PCA 2 with 5.4%, PCA 3 with 4.6%, PCA 4 with 3.7% and PCA 5 with 2.7% (Figure 55).

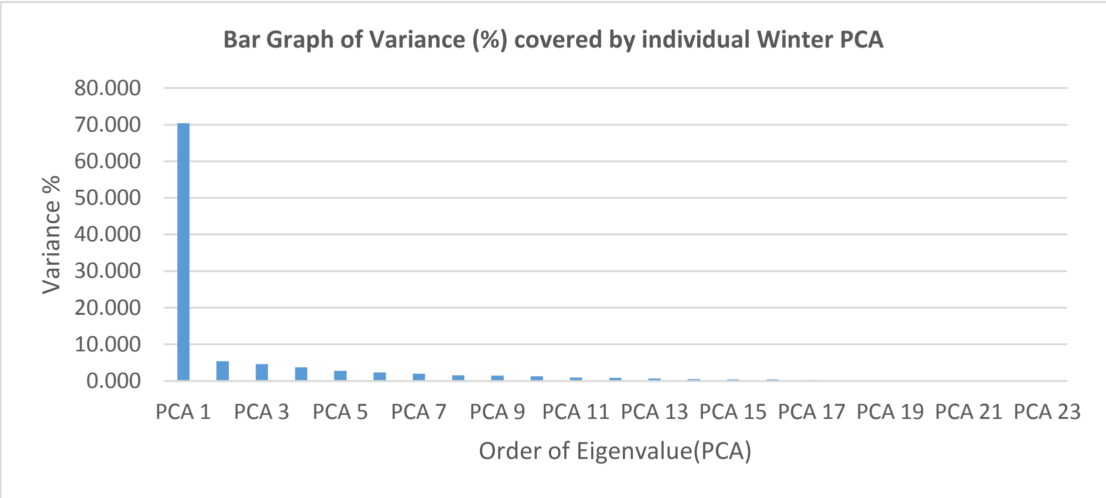

Figure 55: Bar graph of variance % covered by different eigenvalue during Winter season.

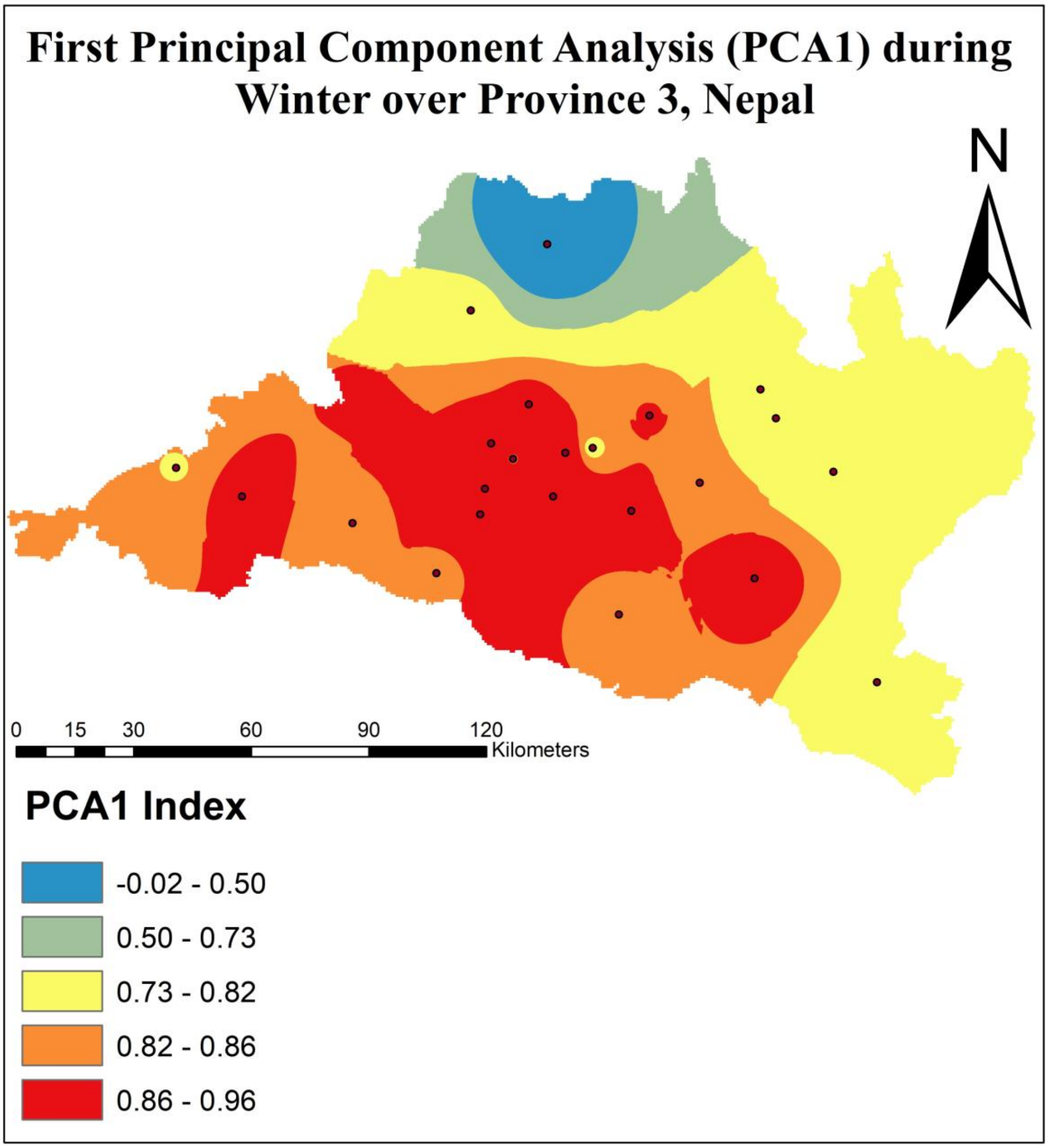

Figure 56: Spatial distribution of loadings covered by PCA1 during Winter Monsoon.

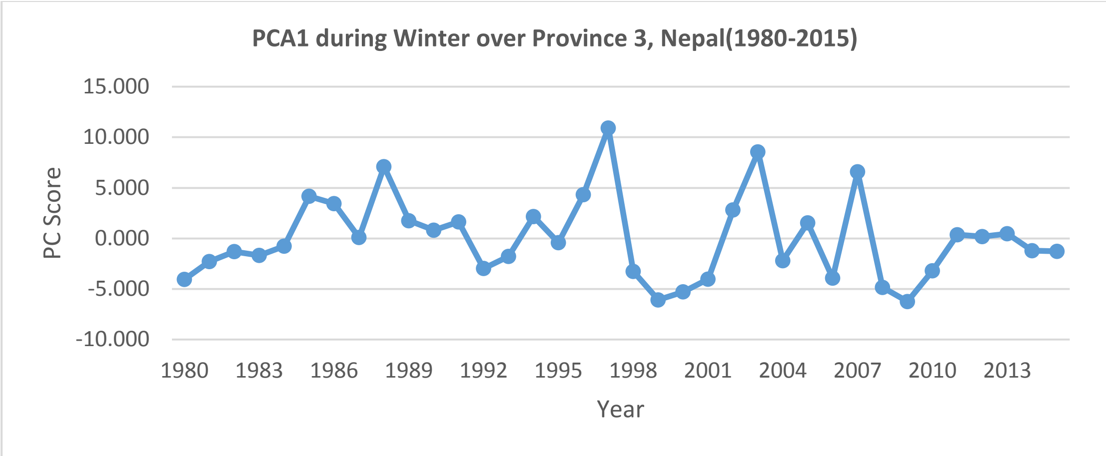

Figure 57: Temporal scores of rainfall covered by Winter Monsoon PCA1 (1980-2015).

About 70.4 percent of variance is explained by the first component (PCA1). The spatial loadings are almost positive having higher values in southwestern and central part of Province (Figure 56). The spatial loadings are high in almost all station except Tamachit, Rasuwa.

The fluctuating time series of the scores of rain gives the information about dry and wet conditions as shown in Figure 57. The temporal scores of rainfall is high in 1997 and 2003 and less in 1999 and 2009. High rainfall occurs with positive/higher spatial loadings and positive time series during Winter season.

This pattern may be associated with western disturbance which is highly concentrated in western Nepal and gets gradual decline in central Nepal as it moves towards east.

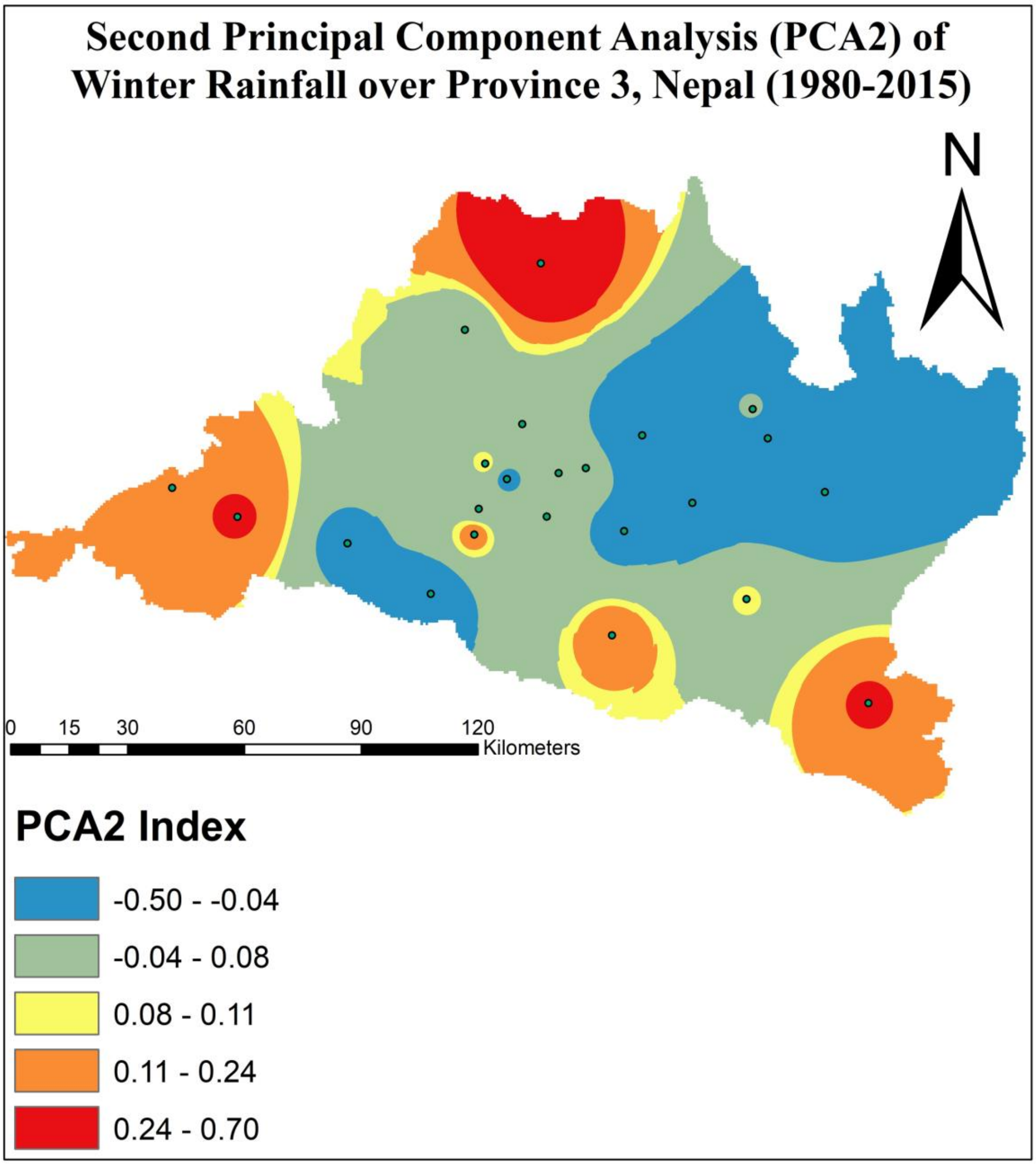

Figure 58: Spatial distribution of loadings covered by PCA2 during Winter.

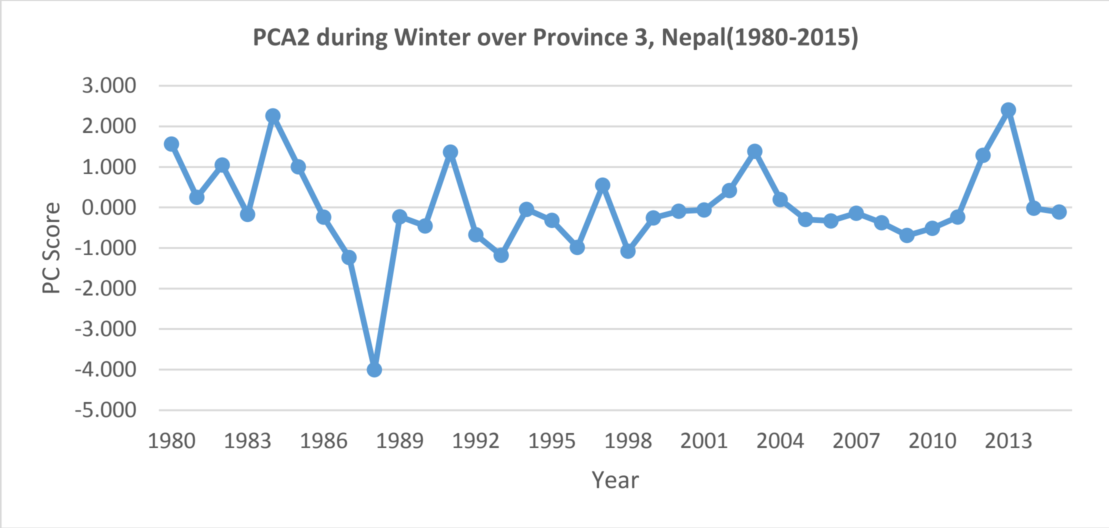

Figure 59: Temporal scores of rainfall covered by Winter PCA2 (1980-2015).

About 5.4 percent of variance is explained by the second component (PCA2). The spatial loadings with positive having higher values are scattered and not concentrated in particular direction (Figure 58). The spatial loadings are high in stations like Tamachit, Rampur, Bahun Tilpung, etc. and low in rest of the Province.

The temporal scores of rainfall is high in 1984 and 2013 and less in 1987 and 1988 (Figure 59).

High spatial loadings are scattered and this might be due to the local effect.

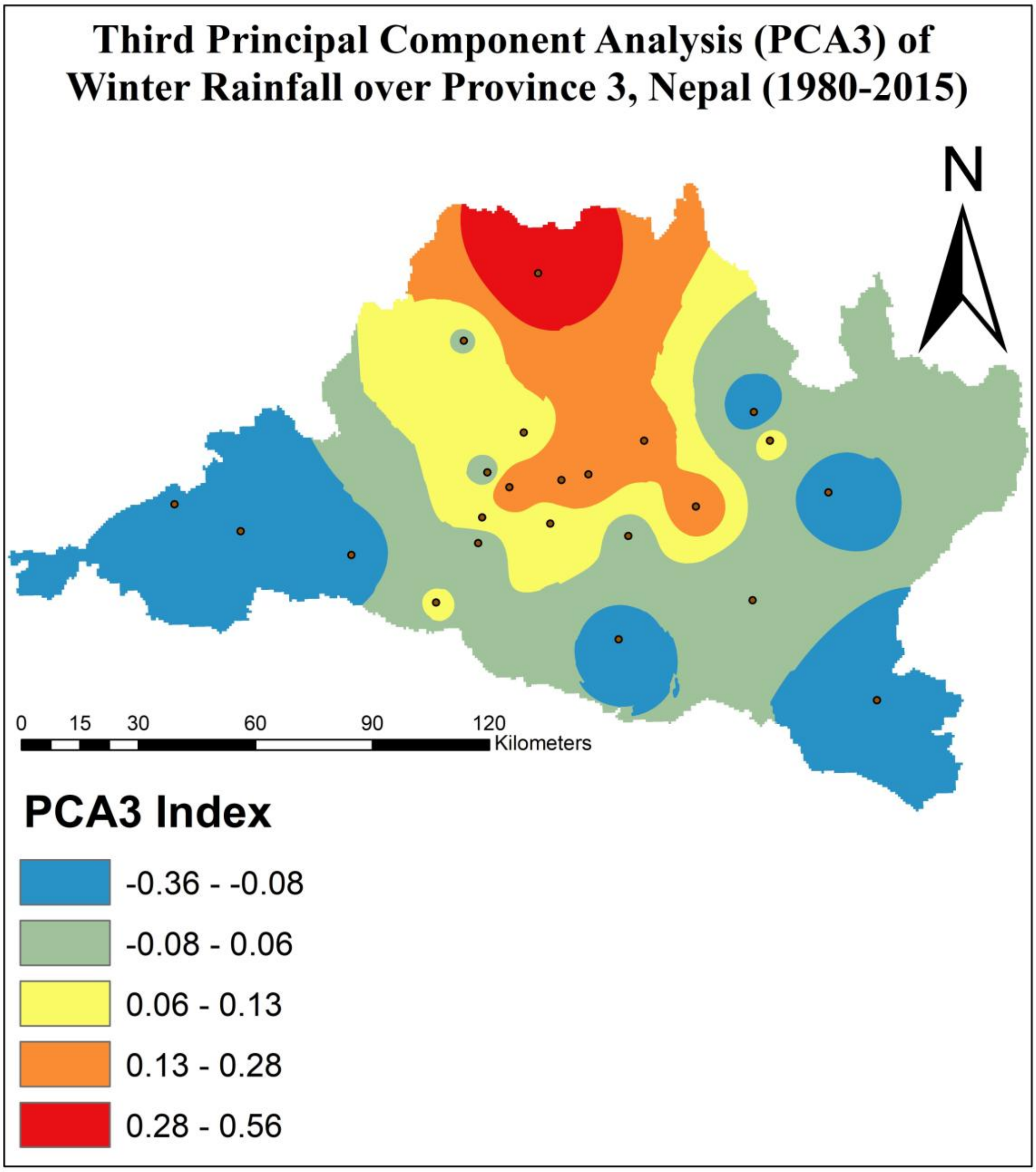

Figure 60: Spatial distribution of loadings covered by PCA3 during Winter Monsoon.

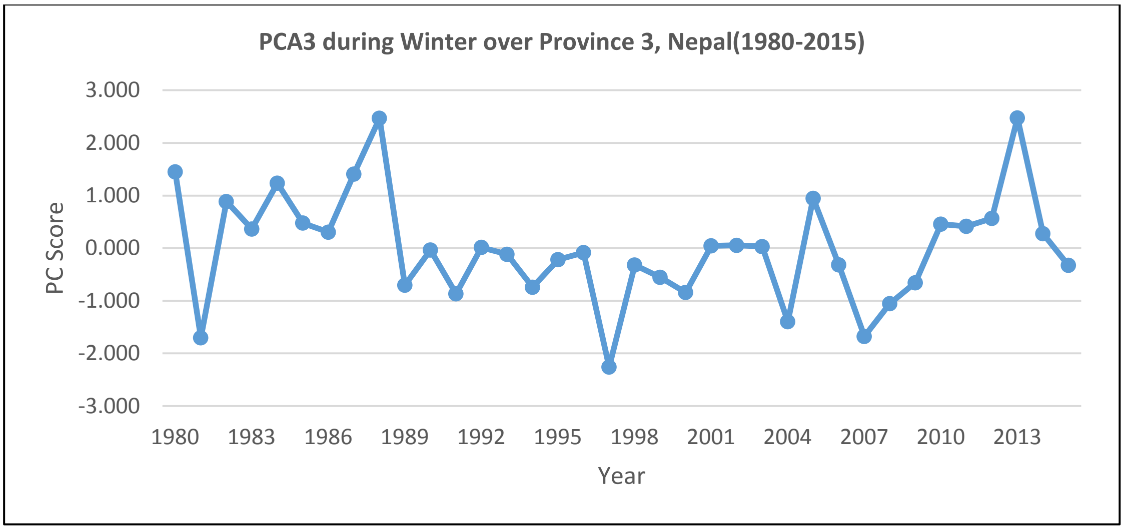

Figure 61: Temporal scores of rainfall covered by Winter Rainfall PCA3 (1980-2015).

About 4.6 percent of variance is explained by the third component (PCA3). The spatial loadings are almost positive having higher values in central and northern part and negative value in rest of the Province (Figure 60). The spatial loadings are high in stations like Thankot, Baunepati, Tamachit, etc. and low in rest of the region.

The temporal scores of rainfall is high in 1988 and 2013 and low in 1981 and 1997 (Figure 61).

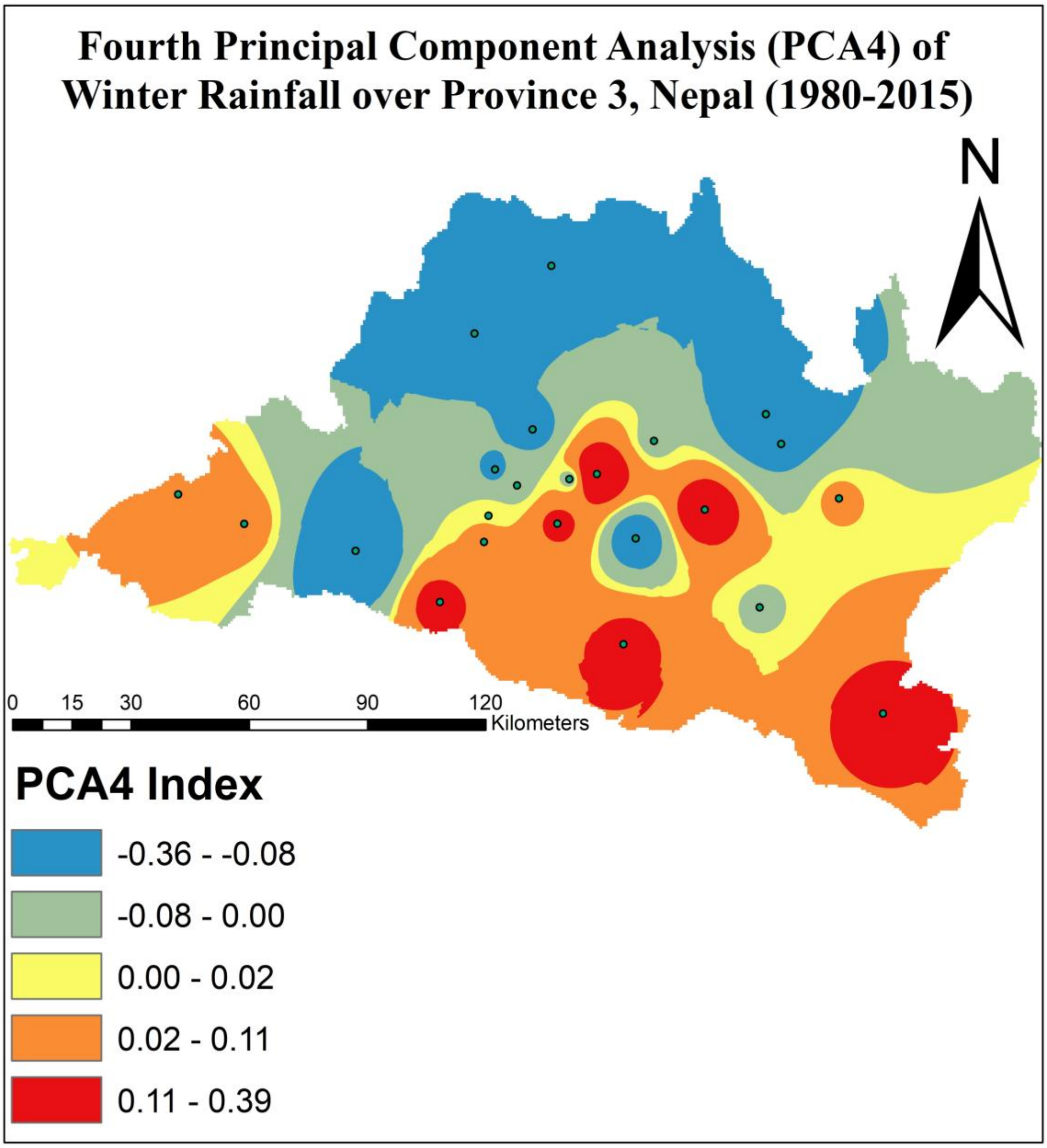

Figure 62: Spatial distribution of loadings covered by PCA4 during Winter.

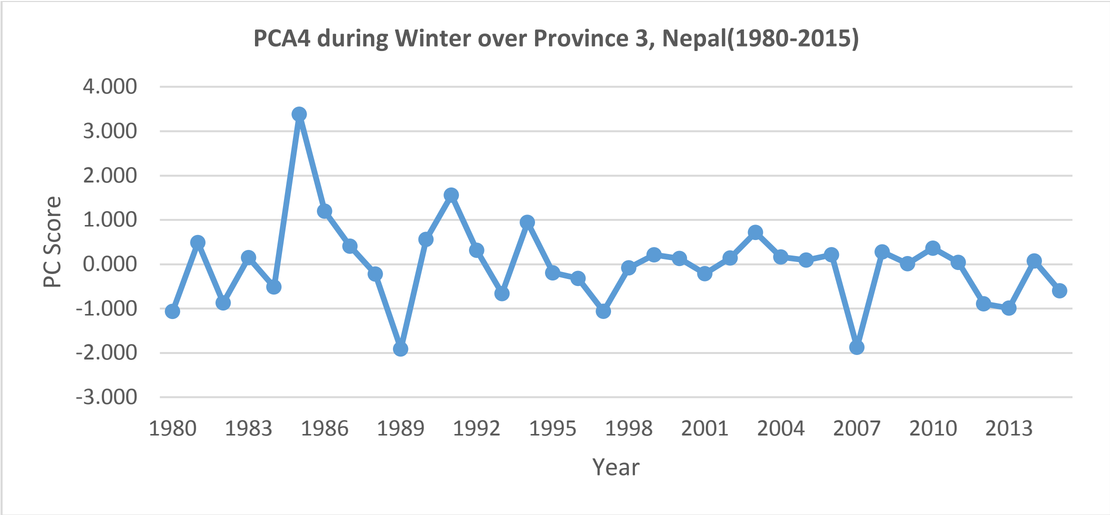

Figure 63: Temporal scores of rainfall covered by Winter PCA4 (1980-2015).

About 3.7 percent of variance is explained by the fourth component (PCA4). Both the positive and negative spatial loadings are scattered without concentrated in particular direction as in Figure 62.

The temporal scores of rainfall is high in 1985 and 1991 and less in 1989 and 2007 (Figure 63).

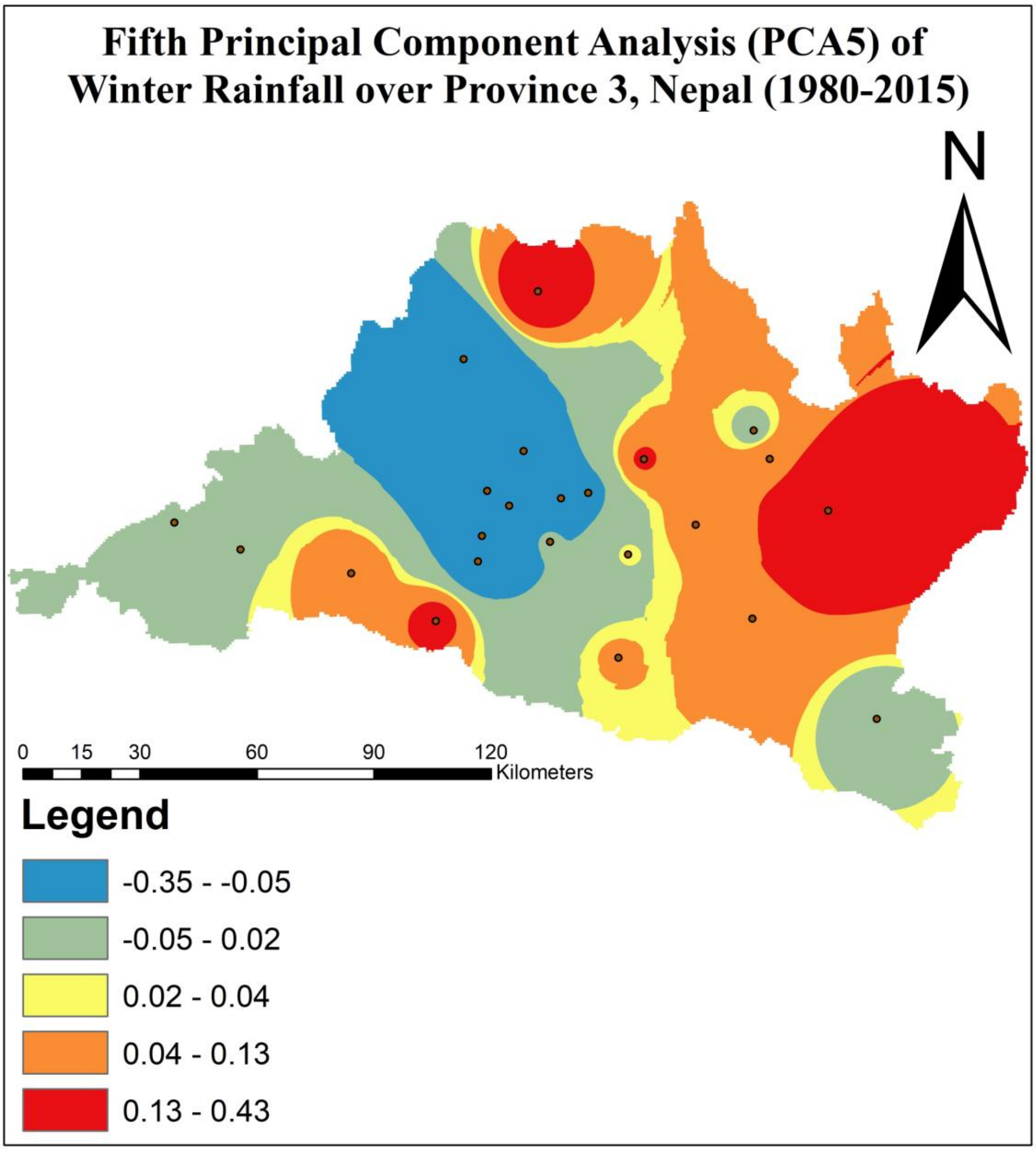

Figure 64: Spatial distribution of loadings covered by PCA5 during Winter.

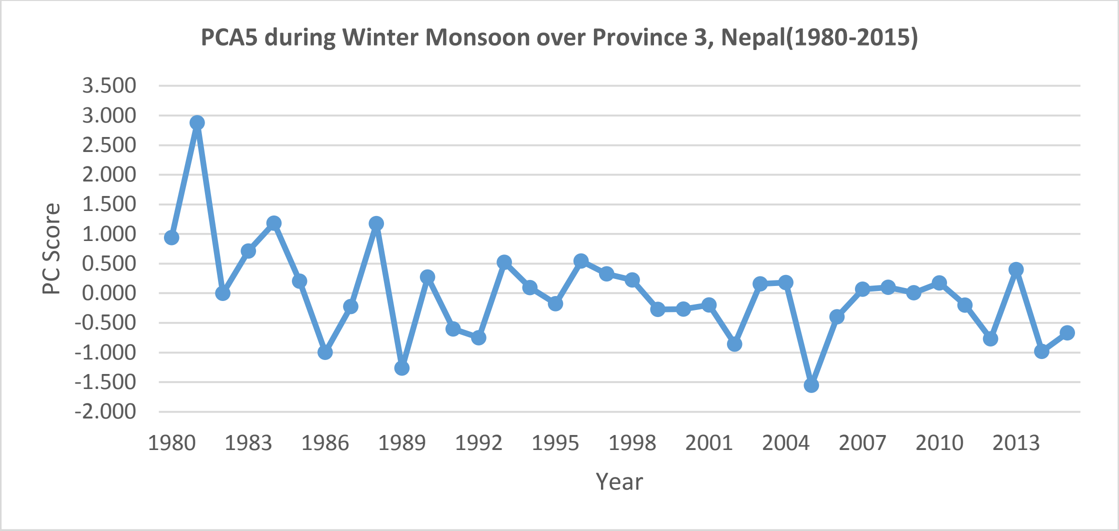

Figure 65: Temporal scores of rainfall covered by Winter PCA5 (1980-2015).

In winter season the variance covered by PCA5 is 2.7%. The spatial loadings are almost scattered without concentration in particular region (Figure 64).

The temporal scores are high in 1981 and 1984 and low in 1989 and 2005 (Figure 65).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion:

The present study shows that annual average rainfall of Province is 1926.69 mm which is accompanied by Pre monsoon 244.94 mm, monsoon 1552.9 mm, Post monsoon 76.8mm and winter 51.94mm where pre monsoon covers 12.71%, monsoon 80.6%, post monsoon 3.98% and winter 2.69%. Monthly rainfall distribution shows that the average rainfall in July is 505.68mm covering 26.24%, August 458.21mm with 23.78% and June 306.25mm with 15.89%. The lowest monthly rainfall occurs in November with 8.67mm rain covering only 0.45% of annual rain followed by December 12.59mm with 0.65% and January 15.37mm with 0.79%. In case of individual stations Gumthang records highest annual rainfall 5526.7mm in 2000 and Tamachit records lowest annual rainfall 184.9mm in 2008. Even though Gumthang is high rainfall region it has highest decreasing trend with -20.7mm/yr. The station at Kathmandu airport has the highest increasing trend of 6.14mm/yr. among the stations considered in present study. Analysis of individual year shows that the highest amount of rainfall was on 2399.4 mm on 1999 which is followed by 2384.7mm in 1985 and 2356.6 mm in 2002. Lowest amount of rainfall was obtained in the year 1992 with rain amount of 1508 mm which is followed by 1546 mm in 1991 and 1573 mm in 2015. While investigating trend it is found that annual average rainfall is decreasing at the rate of -4.58 mm/year. The distribution of rainfall is diverse with maximum pre monsoon rain of 389mm in 2002 followed by 367.4 mm in 1990. Minimum rainfall was obtained 126mm in 1996 and 138.78 mm in 2014. The trend analysis shows that Pre Monsoon rain in this Province is increasing at the rate of 0.17 mm/year. maximum monsoon rain of 1993.8 mm was obtained in the year 1999 which is followed by 1871.68 mm in 2003. Minimum monsoon rainfall of 1204.7mm was obtained in 1991 which is followed by 1225.5 mm in year 2015. The trend analysis shows that Monsoon rain in this Province is decreasing at the rate of -4.17 mm/year. maximum Post monsoon rain of 228.16 mm was obtained in the year 1999 which is followed by 175.5 mm in 1999. Minimum Post monsoon rainfall of 18.65mm was obtained in 1991 which is followed by 21.5 mm in year 1994. The trend analysis shows that Post Monsoon rain in this Province is decreasing at the rate of -0.26 mm/year. Winter Monsoon rainfall of 134.66 mm was obtained in the year 1997 which is followed by 114.6 mm in 2003. Minimum Post monsoon rainfall of 3.53 mm was obtained in 2009 which is followed by 4.7 mm in year 1999. The trend analysis shows that Winter Monsoon rain in this Province is decreasing at the rate of -0.32 mm/year.

Individual station statistics shows that Gumthang has highest annual rainfall of 3828mm and stations like Pansyakhola and Kakani also have high annual rainfall. Tamachit has the lowest annual rainfall of about 720mm and stations like Nepalthok and Dolalghat also have very low rainfall. It is known that station in leeward slope and location near gorge of high hills obtain less rain.

Decadal distribution of rainfall shows that there is not a significant trend in Pre monsoon and Post monsoon rainfall but during Monsoon and Winter season a decreasing trend can be observed. The difference of rainfall in accordance to elevation for the stations lowland stations (below 1000m) and highland stations (above 1000m) shows that annually 75.8mm rainfall variation is seen. In stations above 1000m elevation, average annual rainfall is 1959.6 mm, Pre monsoon rainfall is 256.4mm, Monsoon rainfall is 1567.2mm, Post monsoon 78.5mm and Winter 57.3mm. While, in stations below 1000m elevation, average annual rainfall is 1883.8 mm, Pre monsoon rainfall is 230mm, Monsoon rainfall is 1534.3mm, Post monsoon is 76.6mm and winter is 44.8mm. Among highland and lowland station, the inter annual, Pre Monsoon, Monsoon, Post Monsoon and Winter correlation coefficient are 0.78, 0.89, 0.75, 0.87 and 0.94 respectively.

In strong El Nino year 2015, 2009, 1991, etc. have highest rainfall decline. In strong La Nina year 1985, 1998, 1999, 2011, etc. have highest rainfall incline during Monsoon season. Among 36 years period good correlation is seen in 27 individual year periods during monsoon rainfall and ENSO.

Principal component analysis of rainfall in Pre monsoon season shows that PCA 1 covers variance of 51.3%. For PCA 1 the temporal scores of rainfall is high in 1990, 1998 and 2002 and less in 1992, 1996 and 2014. The spatial loadings are high in 8 stations along central and eastern part of Province in stations like Gumthang, Baunepati, Khopasi, Changunarayan, Kathmandu Airport, Thankot and Kakani.

Spatial loadings are low in 3 stations on northern and southern part in stations like Markhu, Tamachit and Hariharpur Gadhi. The variance covered by PCA 2 is 8.4%. The spatial loadings are high in stations along northern, central and southwestern part of Province.

In monsoon season the variance covered by PCA1 is 39.61%. On PCA1 the temporal scores of rainfall is high in 1999, 2002and 2003 and less in 1991, 1992 and 2009. The spatial loadings are high in central and southern part of Province including stations like Markhu, Changunarayan, Hetauda, Nepalthok etc. and low in northern and southeastern part in stations like Tamachit, Bahun Tilpung, Bahrabise, Baunepati, etc. In monsoon season the variance covered by PCA2 is 11.5%. The spatial loadings are high in almost all stations along southern part of Province.

In Post monsoon season the variance covered by PCA1 is 59.2%. On PCA 1 the temporal scores of rainfall is high in 1985, 1987 and 1999 and less in 1991, 1994, 2000, 2003 and 2012. The spatial loadings are high southwestern and central part in stations like Kathmandu, Chapagaun, Chisapani Gadhi, Dolalghat, Khopasi etc. Spatial loadings are low in northern and southeastern part of Province including stations like Tamachit, Pansyakhola, Gumthang, Bahun Tilpung and Bahrabise. In Post monsoon season the variance covered by PCA2 is 7.2%. The spatial loadings are high in northeastern part.

In winter season the variance covered by PCA1 is 70.4%. On PCA 1 the temporal scores of rainfall is high in 1997 and 2003 and less in 1999 and 2009. The spatial loadings are high in central and southwestern part of Province. Low spatial loadings are observed in north western part mainly concentrated in Tamachit. In winter season the variance covered by PCA2 is 5.4%. The spatial loadings are high in southeastern, northwestern and southwestern part of Province.

5.2 Recommendation:

- The distribution of rain gauge stations including automatic rain gauge stations is very poor all over the Province, sufficient stations network density in accordance with the World Meteorological Organization criteria is recommended.
- Research on Provincial scale is necessary for knowing the climatic state and to identify the vulnerable areas due to water related hazards.

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