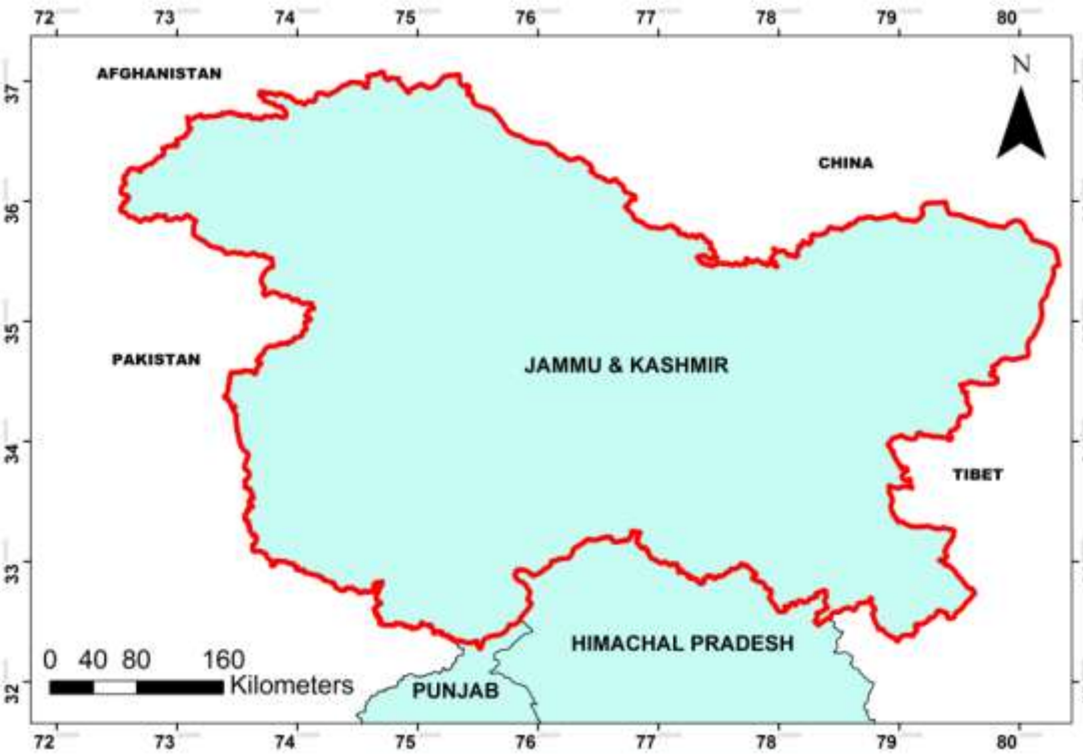
TREND ANALYSIS OF HYDROLOGICAL VARIABLES IN WESTERN HIMALAYAN REGION – PHASE I (JAMMU & KASHMIR)



National Institute of Hydrology

Western Himalayan Regional Centre

Satwari, Jammu Cantt. – 180 003

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ABSTRACT

Western Himalayan region is the main stay of the Himalayan water tower holding more than 90% of glacier and cryospheric resources in India and abundant monsoon rainfall along its foothills. Major rivers of the region; Ganga, Yamuna, Sutlej, Beas, Chenab, Jhelum, Zanskar, Indus, Shyok and Nubra all originate from the mighty Himalayas and contribute immensely to the development of our country and our neighbouring countries. As these rivers carry abundant water to the northern Indian plains and sustain millions of people, mountain population are solely dependent on precipitation, springs and groundwater. Mountain ecosystems are identified as most vulnerable under the climate change regime and mountain communities are already facing numerous challenges to adapt with the uncertainties in the weather pattern exacerbated by the changing regime. Lack of data and knowledge in the mountain region is impacting both adaptation as well as water resources development of the region. In many areas of the western Himalayan region, water resources are under-developed and have enormous possibilities whereas many areas are facing problems related to water availability.

The region has diverse hydrological regimes ranging from monsoon dominated lesser Himalaya and Shivaliks, snow dominated middle Himalayas and snow and glacier dominated higher Himalayas. A cold- arid region of Ladakh is another unique hydrological regime of the Western Himalaya. Water resources issues of the region are also varied reflecting the various hydrological regimes of the area. Available data relevant to the water research in these areas are highly localized and many basins have very poor data network. The western Himalayan region is spread across three states i.e. Jammu & Kashmir, Himachal Pradesh and Uttarakhand. In Stage – I, an attempt has been made in the present study to prepare a database of J&K State and to determine the trend of the various hydrological variables on seasonal and annual time scale in this data sparse region (J&K) over a long time span using non-parametric methods.

Precipitation and discharge are the two major driving forces of a hydrologic regime of any river system, and changes in its pattern could have direct and indirect impacts on water resources. Changing climate due to rising GHGs concentration and subsequently global warming may alter the spatial and temporal pattern of precipitation. Change in its distribution would influence the spatial and temporal distribution of runoff, soil moisture, groundwater reserves and would alter the frequency of droughts and floods. To understand and track these changes, it is very important to analyze the trend of these hydro-meteorological variables.

There are many different ways in which changes in hydrometeorological series can take place. A change can occur abruptly (step change) or gradually (trend) or may take more complex form. Climate change is often recognized as a progressive trend. Studies of precipitation change are typically complicated by factors such as missing values, seasonal and other short-term fluctuations (climate variability) and by lack of homogeneity of the data (e.g. due to changes in instrument and observation techniques).

There are many approaches that can be used to detect trends and other forms of non-stationarity in hydro-meteorological data. In deciding which approach to take, it is necessary to be aware of which test procedures are valid (i.e. the data meets the required test assumptions) and which procedures are most useful (likely to correctly find a change when it is present).

Chenab Precipitation

The present study indicates a significantly decreasing average annual and seasonal precipitation trend over the last 40 year in Chenab basin. 20 out of 24 precipiation are supporting the declining precipitation trend in basin. It is showing a negative trend of precipitation of -6.62 mm/annum for period of 1967-2007 on annual time series basis. Only two station namely Paoni and Mou is showing increasing trend with 90% singificance level on annual basis.

Chenab Discharge

The discharge of the Chenab basin as a whole is showing a rising trend in winter (all 9 sations) and spring season (7 out of 9). The basin is showing a rising trend of discharge of 1.24 Cumec/annum for period of 1967-2007 on annual time series basis. Only the outlet sation Akhnoor is showing declining trend in discharge at the rate of -3.82 Cumec/annum in annual series. The maximum magnitude of positive trend was found at Premnagar (15.16 Cumec/annum) in Monsoon season. This contrary may be due to the reason that the Chenab river has a large number of glaciers in its basin, which have played a regulatory role in controlling its discharge. As the smaller glaciers have receded at a relatively faster rate than the larger ones, this may ultimately lead to their desertion in the near anticipated future.

Kashmir Precipitation

Annual rainfall at four stations, namely Kulgam and Handwara (during the period 1903–1982) and Qazigund and Kukarnag (during the period 1962–2002), was found to be decreasing. Srinagar station experienced a decreasing trend in annual rainfall during the period 1903–1982, whereas it experienced an increasing trend during 1962–2002 and also during 1901–2002. None of the observed trends in annual rainfall were found to be statistically significant. Rainfall in the winter season (the season which receives maximum rainfall) decreased at Kulgam, Handwara, Qazigund, Srinagar (1903–1982) and increased at Kukarnag and Srinagar (1962–2002 and 1901–2002). The decreasing winter rainfall at Kulgam and Handwara was found to be statistically significant at the 95% confidence level.

Srinagar and Handwara showed similar trends (decreasing) in annual rainfall and rainy days during the period 1903–1982, whereas opposite trends (decreasing rainfall and increasing rainy days) were found at Kulgam. Observed trends in annual rainy days were not found to be statistically significant. Winter rainfall and rainy days experienced the same direction of trend (decreasing) at all three stations during the period 1962–2002. The decreasing trend in rainy days at Handwara was found to be statistically significant.

The study indicates decreasing rainfall at four stations and increasing rainfall at one station in the Kashmir Valley over the period of record. If this widespread decreasing trend in rainfall is sustained, it will adversely impact the economy of the Valley. There is a need to incorporate the changing climate in planning and management of water resources of the Valley. The study also provides some scenarios of patterns of rainfall change, which may be used for sensitivity analysis of water availability in Kashmir Valley. Finally, although there are uncertainties about the magnitude and direction of future climate change at various places, measures must be initiated to minimize the adverse impacts of these changes on society.

Tawi Discharge

Tawi river is experiencing the declining trend in annual as well as seasonal discharges. The rate of decrease in discharge in Tawi is -0.731 cumec/annum for annual series, -0.163 for winter, -0.639 for spring and -1.070 for monsoon season at significance level of 90%.

Ground water level

May 2010 with respect to May 2000 – May 2009

Out of 104 wells showing decline, 78 wells (66.10 %) are showing decline less than 2 m. Decline from 2-4 m is shown by 15 wells (12.71%) and 9 wells (9.32%) are showing decline more than 4 m. Out of 12 wells, which are showing rise, all are in the range of 0-2 m.

August 2010 with respect to August 2000 – August 2009

Out of 88 wells showing rise, 78 wells (59.09 %) wells are showing rise less than 2 m, 8 wells (6.06 %) are showing rise from 2-4 m and 2 wells (1.52%) are showing rise more than 4 m. Out of 44 wells, which are showing fall, 34 wells (25.76%) that have shown fall in water level are in the range of 0-2 m, 6 wells (4.55%) have shown fall between 2-4 m and Fall in the range of 2-4 m is shown by 3 wells (2.27%).

November 2010 with respect to November 2000-November 2009

Out of 78 wells showing rise, 74 wells (57.36 %) wells are showing rise less than 2 m, 4 wells (3.10 %) have shown rise from 2-4 m and no well have shown rise more than 4 m. All the 19 wells, which are showing fall, are in the range of 0-2 m.

January 2011 with respect to January 2001 – January 2010

Out of 83 wells showing rise, 73 wells (56.15%) wells showing rise less than 2 m, 9 wells (6.92%) have shown rise from 2-4 m and only a well has shown rise more than 4 m. A total of 39 wells (30%) have shown fall in water level in the range of 0-2 m. Six wells (4.62%) have shown fall between 2-4 m and 2 wells (1.54%) have shown fall in the range of 2-4 m.

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CHAPTER – 1
INTRODUCTION

1.1 General

Climate is perceived to be changing worldwide and there has been growing concern as to the direction and effects of these changes. Impact of changing climate and global warming on water resources of the Himalayan region is undeniable fact. Particularly the temporal changes in precipitation and discharge are becoming important in climate change scenario studies because of their socio-economic impacts. To outline the changes in these variables, it is necessary to look at the historical trends of statistical properties of precipitation and discharge. Hydrology of many Himalayan rivers is controlled by monsoon and winter precipitation and hydro-meteorological changes induced by climatic impacts are affecting the social and economical aspects of the community and inhabitants residing in the region.

Precipitation and discharge are the two major driving forces of a hydrologic regime of any river system, and changes in its pattern could have direct and indirect impacts on water resources. Changing climate due to rising green house gases (GHGs) concentration and subsequently, global warming may alter the spatial and temporal pattern of precipitation. Change in its distribution would influence the spatial and temporal distribution of runoff, soil moisture, groundwater reserves and would alter the frequency of droughts and floods. To understand and track these changes, it is very important to analyze the trend of these hydro-meteorological variables.

There are many different ways in which changes in hydro-meteorological series can take place. A change can occur abruptly (step change) or gradually (trend) or may take more complex form. Climate change is often recognized as a progressive trend. Studies of precipitation change are typically complicated by factors such as missing values, seasonal and other short-term fluctuations (climate variability) and by lack of homogeneity of the data (e.g. due to changes in instrument and observation techniques). There are many approaches that can be used to detect trends and other forms of non-stationarity in hydro-meteorological data. In deciding which approach to take, it is necessary to be aware of which test procedures are valid (i.e. the data meets the required test assumptions) and which procedures are most useful (likely to correctly find a change when it is present).

Western Himalayan region is the main stay of the Himalayan water tower holding more than 90% of glacier and cryospheric resources in India and abundant monsoon rainfall along its foothills. Major rivers of the region, such as Ganga, Yamuna, Sutlej, Beas, Chenab, Jhelum, Zanskar, Indus, Shyok and Nubra, originate from the mighty Himalayas and contribute immensely to the development of our country and our neighbouring countries. As these rivers carry abundant water to the northern Indian plains and sustain millions of people, mountain population are solely dependent on precipitation, springs and groundwater. Mountain ecosystems are identified as most vulnerable under the climate change regime and mountain communities are already facing numerous challenges to adapt with the uncertainties in the weather pattern exacerbated by the changing regime. Lack of data and knowledge in the mountain region is impacting both adaptation as well as water resources development of the region. In many areas of the western Himalayan region, water resources are under-developed and have enormous possibilities whereas many areas are facing problems related to water availability.

The region has diverse hydrological regimes ranging from monsoon dominated lesser Himalaya and Shivaliks, snow dominated middle Himalayas and snow and glacier dominated higher Himalayas. A cold-arid region of Ladakh is another unique hydrological regime of the Western Himalaya. Water resources issues of the region are also varied reflecting the various hydrological regimes of the area. Available data relevant to the water research in these areas are highly localized and many basins have very poor data network. The western Himalayan region is spread across three States, i.e. Jammu & Kashmir, Himachal Pradesh and Uttarakhand.

1.2 Scope of the Present Study

The present study is undertaken with the objective to determine the trend of the various hydrological variables on seasonal and annual time scale in Jammu & Kashmir (J & K) over a long time span using non-parametric methods. The other major objective of the study is to generate possible database and meta-database for the State of J & K. It was planned to gather long-term hydro-meteorological data of Western Himalayan Region and to review its adequacy for water resources management studies. The objectives of the study are:

a) To collect/procure and computerize available long-term hydro-meteorological and hydrological data for the J & K State from different Organizations (IMD, CWC, CGWB, State Department, NHPC etc.)

b) To collect and organize various data relevant to water resources management of the region such as population, cropping pattern, irrigated areas etc.

c) To digitize network of rivers, water bodies, hydrological/hydro-meteorological stations, and water resources projects.

d) Based on the availability of data, to evaluate the monthly/seasonal/annual hydrology of the region (basin-wise and district-wise) in terms of rainfall, snowfall, surface water flow, evaporation, groundwater conditions etc.

e) To evaluate the trend of hydrological variables (such as rainfall, snowfall, temperature, no. of rainy days, snow cover area, surface water flow, peak flows, low flows, groundwater levels etc.) over the available period of record.

f) To identify data gaps for effective hydrological analysis of the State and designing a hydrological data collection strategy.

* * *

CHAPTER – 2
ADMINISTRATIVE AND SOCIO-ECONOMIC PROFILE

2.1 Location

Jammu and Kashmir is the northernmost State of the Union of India. It lies within the latitudes of 32° 17’ to 36° 58’ N and longitudes of 73° 26’ to 80° 30' E. The total area of the State of Jammu and Kashmir is 2,22,236 sq. km, of which 78,114 sq. km are under the illegal occupation of Pakistan and 37,555 sq. km under China. In addition to this, 5,180 sq. km of J&K were illegally ceded to China by Pakistan under the March 1963 Sino-Pak Boundary agreement. The State has international border with Pakistan in the west, Afghanistan and China in the north, and Tibet in the east. The States of Punjab and Himachal Pradesh form its southern border. The State shares a 221 km international boundary with Pakistan in the Jammu region and 365 km with China in its Ladakh sector. The line of control (LoC), which divides the Indian and Pak-occupied parts of the State, is 1001 km long (Jammu - 205 km, Valley - 460 km and Ladakh/Siachin area - 336 km). The border with China is 465 km long.

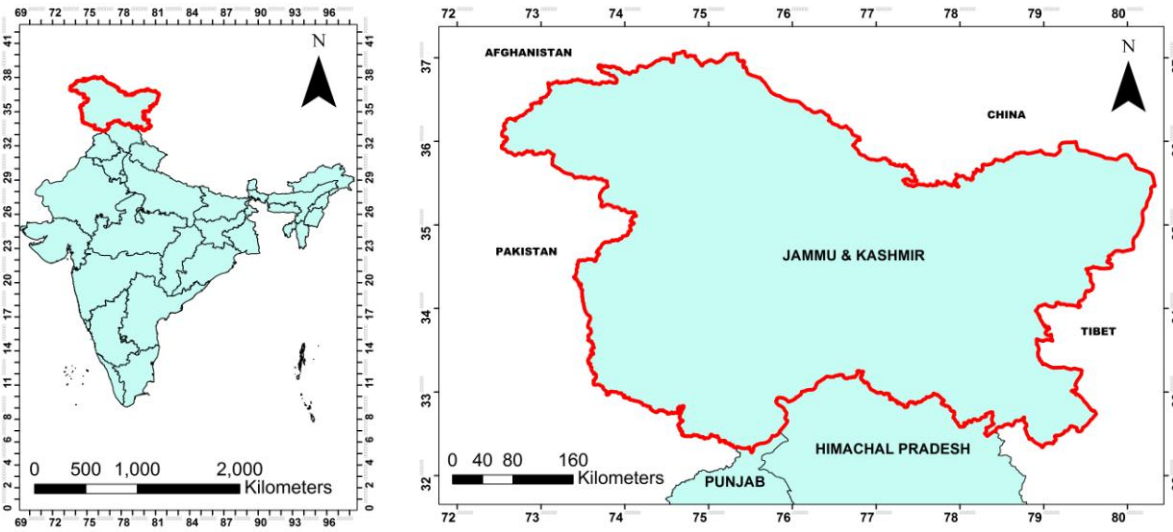

Figure - 2.1: Location of the Jammu and Kashmir State

2.2 Administrative Divisions and Population

Jammu and Kashmir is a multi-lingual, multi-religious and multi-racial State and each group has its own distinct and peculiar cultural ethos, further deepened by geographical divisions created by formidable mountain ranges. Jammu and Kashmir comprises of three natural divisions, namely, Jammu, Kashmir, and Ladakh. The Siachen Glacier (although under Indian military control) does not lie under the administration of the State of Jammu and Kashmir. For administrative purposes, the State is divided into two main divisions, i.e. Kashmir and Jammu provinces. A Divisional Commissioner heads the administration of each division. The two districts of Ladakh region, namely, Leh and Kargil are part of the Kashmir

Division for purposes of administration. In the Ladakh region in 1995, the ‘Autonomous Hill Development Council’ was established as part of decentralized administration.

Prior to 1971, the two provinces consisted of 10 districts only. Between 1971 and 1981, four new districts were created taking the total number of districts in the State to 14. The Kashmir province comprises the districts of Srinagar, Budgam, Pulwama, Anantnag, Kupwara, Baramulla, Leh and Kargil. The Jammu Province comprises the districts of Jammu, Kathua, Poonch, Rajouri, Udhampur and Doda (Figure – 2.2). Further newly formed districts include Kishtwar, Ramban, Reasi, Samba, Bandipora, Ganderbal, Kulgam and Shopian.

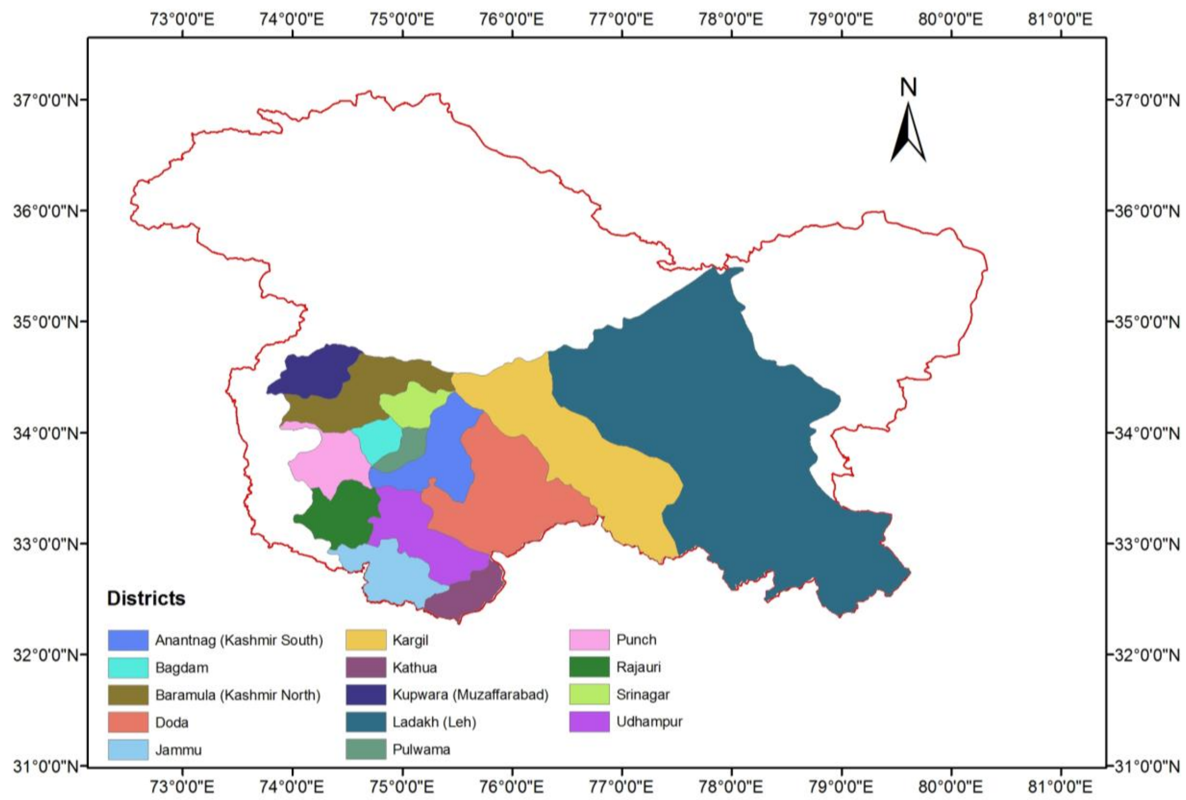

Figure - 2.2: Districts of Jammu and Kashmir

Jammu and Srinagar are the most populous and major cities of J&K. Srinagar functions as summer capital and Jammu serves as winter capital of the State. A Deputy Commissioner, who is also district Development Commissioner, heads each district. A brief description of three regions of J & K State is as follows:

2.2.1 Jammu Region

This region comprises the plains, hills and mountains south and west of the mighty Pir Panjal range that separates Kashmir valley from the plains of the subcontinent. The Jammu region comprises of 10 districts, namely Kathua, Jammu, Samba, Udhampur, Reasi, Rajouri, Poonch, Doda, Ramban and Kishtwar.

Kathua town is situated on the Jammu - Pathankot National Highway at a distance of about 87 km east of Jammu and about 25 km west of Pathankot. The district shares its boundary with Punjab in the south, Himachal Pradesh in the east and Udhampur in the north. The geographical area of the district is 2,651 sq. km with four tehsils namely, Basholi, Bilawar, Kathua and Hiranagar. The majority of the population of Kathua district is dependent on agriculture. About 80 per cent of agricultural land in the district is non-irrigated. A large section of the population depends on wage labour and government employment.

Jammu district is extended along the whole length of the international border with Pakistan. It shares its border with Rajouri district in the north, Udhampur district in the east, and Kathua district in the southeast. The geographical area of the district is 3097 sq. km with 5 tehsils, namely, Jammu, Samba, Akhnoor, R.S. Pura and Bishnah. The rural population depends mainly on agriculture. Except for the Kandi area, the land is irrigated and fertile. Recently, Samba has been formed as a new district.

Udhampur is the third largest district of Jammu and Kashmir and is situated at an altitude of 2,134 feet above sea level. It is located at a distance of 66 km from Jammu on the Jammu-Srinagar National Highway. Rajouri bounds this district in the west, Jammu in the southwest, Doda in the east and Kathua in the southeast. It also shares its boundary with Anantnag in the north. The geographical area of the district is 4,550 sq. km with 5 tehsils, namely, Udhampur, Chenani, Ramnagar, Reasi and Mahore. The principal occupation of the people is agriculture. There are few industries in the district. Recently, Reasi has been made a new district.

Doda is the largest district in the Jammu region. Doda town, after which the district is named, is situated at an altitude of 5,000 feet above sea level. The Khilani village of the district is situated on the National Highway at about 45 km from Batot linking the Kashmir valley with Jammu and other parts of the country. The district shares borders with Anantnag district of Kashmir valley and the Chamba district of Himachal Pradesh. The entire area is hilly. The area of the district is 11,691 sq. km. The district comprises six tehsils, namely, Doda, Kishtwar, Bhaderwah, Gandoh, Ramban and Banihal. The people, in general, are poor due to inadequate production of food grains in the district. The majority of the population depends on ration supply through government shops (PDS). The widespread unemployment has further increased after the government banned leasing of forest to the contractors. Recently, Kishtwar and Ramban have been created as new districts.

Rajouri district was carved out of Poonch district in 1968. It shares a long border from Sunderbani to Bhimbergali with PoK in the west. It is bounded by Udhampur district in the east and by Jammu in the southeast. The northern part of the district consists of hilly terrain. The geographical area of the district is 2,630 sq. km. It comprises of six tehsils, namely, Thanamandi, Rajouri, Budhal, Kalakote Sunderbani and Nowshera. About 80 per cent of the population of the district depends on agriculture. There is no industry in the district. Rearing livestock is another main source of income. Economic condition of the people is generally poor.

Poonch town, the headquarters of the district by the same name, is situated at a distance of 246 km northwest of Jammu. The town is at a height of 3,287 feet above sea level. It is surrounded by the Line of Control (LoC) on three sides and is separated from Kashmir Valley by the mighty Pir Panjal range in the north. The geographical area of the district is 1,674 sq. km, comprising three tehsils, viz., Mendhar, Surankote, and Haveli (Poonch). The people of Poonch district are mainly dependent on agriculture and government jobs. There are no industrial units in the district. The terrain is hilly with little fertile land and therefore, there is great dependency on government jobs.

2.2.2 Kashmir Region

The Kashmir region or valley, is a significant part of the J &K State. The valley is an ancient lake basin 140 km long and 32 km wide. The average elevation of the valley is 5,300 feet above sea level. The tall mountains that surround the valley rising up to 16,000 feet ensure that the weather here is pleasant for most part of the year. Its rich alluvial soil, well-drained by rivers and streams, yields rice, saffron, vegetables and a variety of fruit. It comprises of 10 districts, namely, Anantnag, Kulgam, Pulwama, Shopian, Budgam, Srinagar, Ganderbal, Bandipora, Baramulla and Kupwara.

Anantnag is the southernmost district of the valley. It shares its border with district Pulwama in the west. From south to east, it is attached to Rajouri, Udhampur and Doda districts. It borders with Kargil in the north. The district is criss-crossed by a network of perennial rivers, streams and waterfalls. The geographical area of the district is 3,984 sq. km with five tehsils, namely, Pahalgam, Anantnag, Doru, Kulgam and Bijbehara. Agriculture and livestock rearing are the main sources of livelihood. The district is also well known for traditional handicraft like Gabbas and wooden craft. The district, enriched with perennial streams with clean water, has developed commercial fishing activities with a scattering of trout farms. Sericulture industry has earned a good name among all the small household industries in the district. Recently, Kulgam has been created as a new district.

Baramulla district completely surrounds the district Kupwara and shares the border with PoK at two places in the west as well as in the northeast. The average height of the district is 5187 feet above sea level. It also shares its border with Srinagar, Budgam and Poonch districts in the south and with Kargil in the east. The district has a flat topography, salubrious climate and scenic beauty. The geographical area of the district is 4,588 sq. km with six tehsils, namely, Bandipur, Sonawari, Sopore, Baramulla, Gulmarg and Uri. Bulk of the district’s population depends on agriculture for their livelihood. Sopore tehsil is very famous for its apples. Rearing of livestock is one of the important occupations in the district. It has been the first district to generate and provide electricity to large parts of the State from Mohara Power House. Recently, Bandipur has been created as a new district.

Budgam district was carved out from Srinagar on 1 July, 1979. It is centrally located in the Kashmir valley. It is bounded by Srinagar in the northeast, south and west by Poonch and in the north and northwest by Baramulla. Although the district has several high mountains, its average height is just 5,281 feet above sea level. The geographical area of the district is 1,371 sq. km with three tehsils, namely, Chadura, Budgam and Beerwah.

Kupwara district is situated at an altitude of 5,300 feet above sea level and is the northern-most district of the Kashmir valley. It shares a long border with PoK in its north and western side and is totally enclosed by the Baramulla district on the other side. This district is endowed with rich dense forests. The river 'Kishan Ganga' originating from the Himalayas flows through the outer areas of the district from east to west. Some well-known passes located in the district are Gabhra Pass, Sadham Pass and Nastuchan Pass. The geographical area of the district is 2,379 sq. km with three tehsils, namely, Handwara, Karnah and Kupwara. Although the district is considered deficient in natural irrigation, about 90 per cent of the population depends in one way or other on agriculture for their livelihood. Walnuts are the major horticultural produce in the district. Rearing of livestock is also an important occupation of the people.

Pulwama district came into existence in July 1979. It is situated in the southeastern part of the valley. It shares its borders with Srinagar and Budgam in the northwest and is bounded by the Anantnag district in the south and east. The geographical area of the district is 1,398 sq. km with three tehsils, namely, Shopian, Pulwama and Tral. Agriculture is the main source of livelihood in the district. About 0.73 lakh hectares of land is available for cultivation. Mushroom cultivation and horticulture are of great importance to the economy. Livestock rearing is also an important occupation. Recently, Shopian has been created as a new district.

Srinagar district is located to the southeast of Baramulla. It shares its border with Baramulla, Budgam, Pulwama, Anantnag and Kargil districts from the west to east. The valley is surrounded by the Hurmukh mountain (16,903 feet) in the east, Tosh Maidan (4,000 feet) in the north and Snony Kazi Nag (12,125 feet) in the northwest and also the Mahadev Mountain. The valley is a land of lakes, clear streams, green meadows and magnificent trees. The river Jhelum dissects the district diagonally from the southeast to the northwest. Srinagar is the State's summer capital. The geographical area of the district is 2,228 sq. km with two tehsils, namely, Srinagar and Ganderbal. It has developed all the characteristics of a tourist paradise, with tremendous growth in the development of handicraft and cottage industries, hotels, houseboats, guest houses and tourist transport. The handicrafts of the district have become famous worldwide. Livestock rearing is another important occupation in the district, engaging about 5.25 per cent of the work force. Animal husbandry and sheep breeding have received special attention. Rice and maize are the main crops of the district. Recently, Ganderbal has been created as a new district.

2.2.3 Ladakh Region

Ladakh constitutes the eastern-most part of the State of Jammu and Kashmir. It comprises two districts, namely, Leh and Kargil. This is one of the most beautiful parts of the State and its surreal landscape has often been termed as 'moonscape'. Ladakh covers about 117,000 sq. km and includes the Karakoram Range and the upper Indus River valley. Ladakh is one of the highest places on Earth with the average altitude being above 12,000 feet. Situated on the leeward side of the mountain, it hardly gets any rain. People live a very traditional life, herding sheep and yak, and growing barley near the riverbeds in summer.

Leh district is the northern as well as the easternmost part of Jammu and Kashmir. It is linked with the Kashmir valley by the Zojila pass (10,098 feet) and forms part of the outer

Himalayas. It is one of the highest regions of the earth (altitude 8,800 feet to 18,000 feet approximately) with mountains running along parallel ranges. The climate is very cold and in winter, temperatures dip to minus 40 degrees centigrade. The district is bounded by the international border or LoC with China in the north and east, and with PoK in the north.

The geographical area of the district is 45,110 sq. km with Leh as the district headquarters. The district has two assembly constituencies, namely Nubra and Leh and five blocks namely, Leh, Khaisi, Nubra, Nyoma and Durbuk. Agriculture and animal husbandry are the main sources of livelihood. Cultivation is possible only during summer; barley, vegetables and fruits like apple and apricot are the main crops. Forestry is also one source of income and Leh abounds in medicinal herbs. This district is the source of origin of pashmina goat which produces fibre used for high quality fabric pashmina wool. The district is also rich in water resources like ponds, streams and rivers, which can be utilised for fisheries.

Kargil town is located at a distance of 204 km from Srinagar almost midway on the Srinagar - Leh National Highway. Most of the villages of the district are located at an average height of 10,000 feet above sea level. It shares the Line of Control (LoC) with PoK in the north and borders with Leh in the east and the Kashmir valley in the west. The geographical area of the district is 14,036 sq. km. The district has two tehsils as well as two assembly constituencies, namely, Kargil and Zanskar. The climate is very cold and in winter, the highway is blocked for more than six months, from December to June every year. The snowfall around the Zojila pass and Drass region is very heavy. Agriculture is the main occupation and about 91 per cent of the population is engaged in it. Wheat and millet are the major crops. The Baltal-Kargil road, linking Kargil with Srinagar, is the lifeline of the district. Construction of 230 km Kargil - Padam and Bodh Khushboochaktan roads are in progress. Tourism is being promoted as an industry after Ladakh was opened to foreign tourists in 1974. Horticulture and forestry are being given special attention.

As per the census records for the year 2001 and 2011, the population of all districts is presented in Table – 2.1 while the population in major cities of the State is shown in Table – 2.2.

Table - 2.1

District-wise population of Jammu and Kashmir

Name of district	Headquarters	Population (2001)	Population (2011)
Jammu Division			
Kathua	Kathua	550,084	615,711
Jammu	Jammu	1,343,756	1,526,406
Samba	Samba	245,016	318,611
Udhampur	Udhampur	475,068	555,357
Reasi	Reasi	268,441	314,714
Rajouri	Rajouri	483,284	619,266
Poonch	Poonch	372,613	476,820
Doda	Doda	320,256	409,576
Ramban	Ramban	180,830	283,313

Name of district	Headquarters	Population (2001)	Population (2011)
Kishtwar	Kishtwar	190,843	231,037
Total		**4,430,191**	**5,350,811**
Kashmir Division			
Anantnag	Anantnag	734,549	1,069,749
Kulgam	Kulgam	437,885	423,181
Pulwama	Pulwama	441,275	570,060
Shopian	Shopian	211,332	265,960
Budgam	Budgam	629,309	755,331
Srinagar	Srinagar	990,548	1,250,173
Ganderbal	Ganderbal	211,899	297,003
Bandipora	Bandipora	316,436	385,099
Baramulla	Baramulla	853,344	1,015,503
Kupwara	Kupwara	650,393	875,564
Total		**5,476,970**	**6,907,622**
Ladakh Division			
Kargil district	Kargil	119,307	143,388
Leh district	Leh	117,232	147,104
Total		**236,539**	**290,492**
Total population in J & K State		**10,143,700**	**12,548,925**

Table - 2.2

Population of major cities of Jammu and Kashmir

Name	Rank	Population (2011)	Region
Srinagar	1	11,92,792	Kashmir
Jammu	2	9,51,373	Jammu
Anantnag	3	2,08,505	Kashmir
Udhampur	4	1,82,778	Jammu
Baramulla	5	1,67,986	Kashmir
Kathua	5	1,62,988	Jammu
Sopore	6	66,963	Kashmir

2.3 Economic Profile

2.3.1 Agriculture

Jammu and Kashmir State is full of natural resources of great economic potential. The physiographic location imposes a number of constraints, particularly in agriculture and allied sectors. The initial land-use pattern in the State was purely agriculture. It has changed over a period of time to agri-horticultural and silvi-pastoral. Although the net area sown has remained more or less same (7.31 lakh hectare in 1990-91 to 7.33 lakh hectare in 1999-2000), the area under fruit and vegetable cultivation has marginally increased over the same period of time. In respect of fruit, it has gone up from 176.30 thousand hectare in 1990-91 to 213.73 thousand hectare in 1998-99. Vegetables have shown a marginal increase, from 14,000 hectare in 1990-91 to 14,930 hectare in 1999-2000. Rice, the staple crop, is planted in May and harvested in late September. Maize is the second-most important crop. The best soil for maize is reclaimed swamp and enormous crops are raised from the black peaty land, which lies under the banks of river Jhelum. In the high villages occupied by the Gujjar grazers, very fine crops of maize are grown. Other important summer crops are millet, pulses (legumes such as peas, beans and lentils), cotton and tobacco. Wheat and barley are the chief spring crops. Food-grain production has shown an increase from 13664 thousand quintals in 1990-91 to 15253 quintals in 1998-99.

Many temperate fruits are also grown. Large orchards in the valley of Kashmir produce apples, pears, peaches, walnuts, almonds and cherries. In addition, it is the largest producer of saffron in the Indian subcontinent. Artificial floating gardens on the lakes are favourable for the cultivation of flowers and vegetables. In Ladakh, there is only one cropping season, i.e. Kharif, which extends from March to October. Cultivation in Ladakh is restricted to near the main valleys of Indus, Shyok and Suru rivers, where barley, buckwheat, turnips and mustard are grown. Recently, strawberry cultivation has also been introduced in Ladakh. Pastoral and cattle breeding have long been the vital features of the Ladakh economy. The Kashmir goat raised in the region provides Pashmina for the production of fine fabrics.

2.3.2 Industries

The thick forests of Kashmir provide raw material for several industries. Important industries dependent on forests are*:*

- Poplar wood available in the Kashmir valley is mainly used by match industry. A large number of Government match factories were established in Baramulla but these are not functional for more than a decade.
- Wood of poplar and willow trees is used for making cricket bats. Bringi wood is used for making hockey sticks.
- Walnut trees are grown in abundance in Kashmir. Walnut wood is suitable for woodcarving. The carved goods are exported to foreign countries also. Baramulla also manufactures walnut wood rifle-butts.
- At Pampore (Kashmir) and Bari Brahmana (Jammu); plywood, hardboard and chipboard manufacturing factories have been established. Pulp required for the manufacture of hand-made paper, strawboard and cardboard is also obtained from the forests.

People of Kashmir have won a great reputation as artisans. The chief center of Kashmiri industries is Srinagar, but other localities are famous for their special crafts. Kulgam is famous for its lacquered woodwork and Bijbihara has a reputation for woodcarving. The basket industry is also important and most villages have artisans who make baskets for agricultural purposes. The lacquered work, which had a great reputation, is now declining. The other industries that have developed from the rural crafts include handloom weaving of local silk, cotton, carpet weaving and woodcarving. Such industries together with silver and copper work got impetus in the past by the presence of the royal court and later by the tourist trade; they also owe something to the important position achieved by Srinagar in the west Himalayan trade. Handicraft manufacture is also important in Ladakh, particularly production of Pashmina shawls, carpets and blankets.

The State is rich in water resources, which can generate electricity on a large scale. The other natural resources include fruit, timber, minerals and herbs which are found in abundance. As far as the social sectors are concerned, education is free for all. The State has two major institutes of higher education, namely, University of Kashmir and University of Jammu. As far as primary and secondary education is concerned, the number of primary and high/higher secondary schools has increased from 9242 and 1220 in 1990-91 to 10515 and 1466 in 1999-2000 respectively. The health sector, hospitals and dispensaries are scattered throughout the State. Unani is popular in Srinagar, while Amchi is popular in Ladakh. Ladakh has an excellent network of health care delivery system throughout the district. Srinagar has a highly specialised institute of Medical Sciences, founded in 1982. A total of 6466 villages have been covered by safe drinking water by 1999-2000.

*** * ***

CHAPTER - 3
PHYSICAL CHARACTERISTICS OF J&K STATE

3.1. Climate

Climate exerts a profound influence on the inhabitants of any region. Their social, cultural, economic and other aspects of life are directly or indirectly governed by climate. The climate of the state ranges from the burning and the scorching heat of the plains (of Jammu Division) to the snow-capped heights of Gulmarg (Kashmir) and the mud peak of Mount Godwin Austin (Ladakh) which is 21,265 feet above sea level and the second highest in the world. All these represent three different climatic zones in the State.

From alpine (Ladakh region) to the sub-tropical (Jammu region) climate, the extreme variants of climate in Jammu and Kashmir are due to their location and topography. The sheltered valley of Kashmir, however, exhibits an exception to its peripheral region. Broadly, the State of Jammu and Kashmir comprises three distinct climatic regions: cold arid desert areas of Ladakh, temperate Kashmir Valley, and the humid sub-tropical region of Jammu.

The temperature in the region varies spatially. Leh is the coldest (-28°C average) while Jammu is the hottest. Mean monthly temperature is lowest in January and highest in July except in Jammu where highest temperature is experienced in June. Mean monthly temperature in January varies from –17°C in Drass to 14°C in Jammu; Kargil and Leh being other stations of below freezing average. Considering the overall distribution of climatic elements, four units become obvious:

- The windward (Jammu region)
- The leeward (Ladakh region)
- The high altitude Kashmir (Himadri, Pir Panjal)
- The Kashmir valley

The climate of the valley of Kashmir has its own peculiarities. The seasons are marked with sudden change and the climate can be divided into six seasons of two months each. The aforementioned climatologic divide does not apply only to Kashmir Valley but to parts of Jammu, which like Kashmir valley, are subjected to snowfall and a severe winter. Many parts of the Ladakh region are also subjected to heavy snowfall while other parts are subjected to severe dry cold. There is such heavy snowfall on the way from Kashimr valley to Ladakh that it remains cut off by road for about 5 - 6 months every year.

3.2 Physiography

Physiography of the Jammu & Kashmir State is highly varying. There are the highest mountain ranges of the world, extensive plateau, enormous valleys, deep gorges and large canyons in middle and trans-Himalayan regions. The individual ranges have the characteristic of steep slopes towards south and much gentle slope towards north. The northern slopes are covered with thick and dense growth of vegetation while the southern slopes are mostly bare with thin sparse forest cover. The Zanskar range separates Ladakh region with Kashmir valley while Pir Panjal divides Jammu region and Kashmir valley. The State can be divided into six distinct physiographic units as discussed below:

Sirowal Belt

The Sirowal belt covers an area of about 1000 km^2 and has an average topographic gradient of 1:250 to 1:300 in southwest direction. The land elevation of Sirowal belt above msl is normally within 320 m. Southern parts of Jammu and Kathua districts fall in this belt.

Kandi Belt

The elevation of Kandi belt ranges between 320 m and 400 m above mean sea level. The average topographic gradient varies between 1:60 and 1:100. Kandi belt covers an area of about 1500 km^2 and occupies parts of Jammu and Kathua districts north of Sirowal belt.

Kandi is synonymous to the Bhabhar of Uttar Pradesh. Kandi belt in Jammu & Kashmir State runs in northwest - southeast direction as a narrow strip between rivers Munnawar Tawi in the west and Ravi in the east. The belt is occupied by reworked Siwalik debris, which has master slope towards south-west.

Siwalik Region

Land elevation of Siwalik region ranges between 400 m and 750 m above mean sea level. Ridges and small independent valleys are the prominent features of Siwalik region, which covers parts of Kathua, Jammu, Udhampur and Rajouri districts.

Kashmir Valley

The elevation of valley floor above mean sea level ranges between 1500 m to 2000 m. Kashmir valley covers an area of 5600 km^2 and comprises parts of Badgam, Pulwama, Srinagar, Anantnag, Baramulla and Kupwara districts.

Hilly Mountains

High mountain ranges have the elevation between 2000 m to 5000 m above mean sea level and form parts of Udhampur, Anantnag, Baramulla, Srinagar and Kupwara districts.

Trans-Himalayan Zone

Trans-Himalayan zone constitutes inaccessible terrain of Kargil and Leh districts in Ladakh region. The elevation of this zone varies between 5000 m to 8000 m above msl. However, along lower reaches of Indus and Shyok rivers the elevation is less than 5000 m.

3.3 Soils

The soils of the Jammu and Kashmir State have been classified into 8 groups. They are: (1) Brown forest salls, (2) Degraded soils, (3) Red yellow podzolic soils, (4) Hill forest soils, (5) Mountain meadow soils, (6) Lithosols (7) Saline - alkali soils, (8) Alluvial soils. Details of each group of soil are discussed here. Soil map of the State is given in Figure–3.1 (Source: http://www.inseda.org). Additional information about soils have been obtained from Agriculture and Environment Education/69-Soil Science (SSS)/Soils of Jammu and Kashmir – 382)

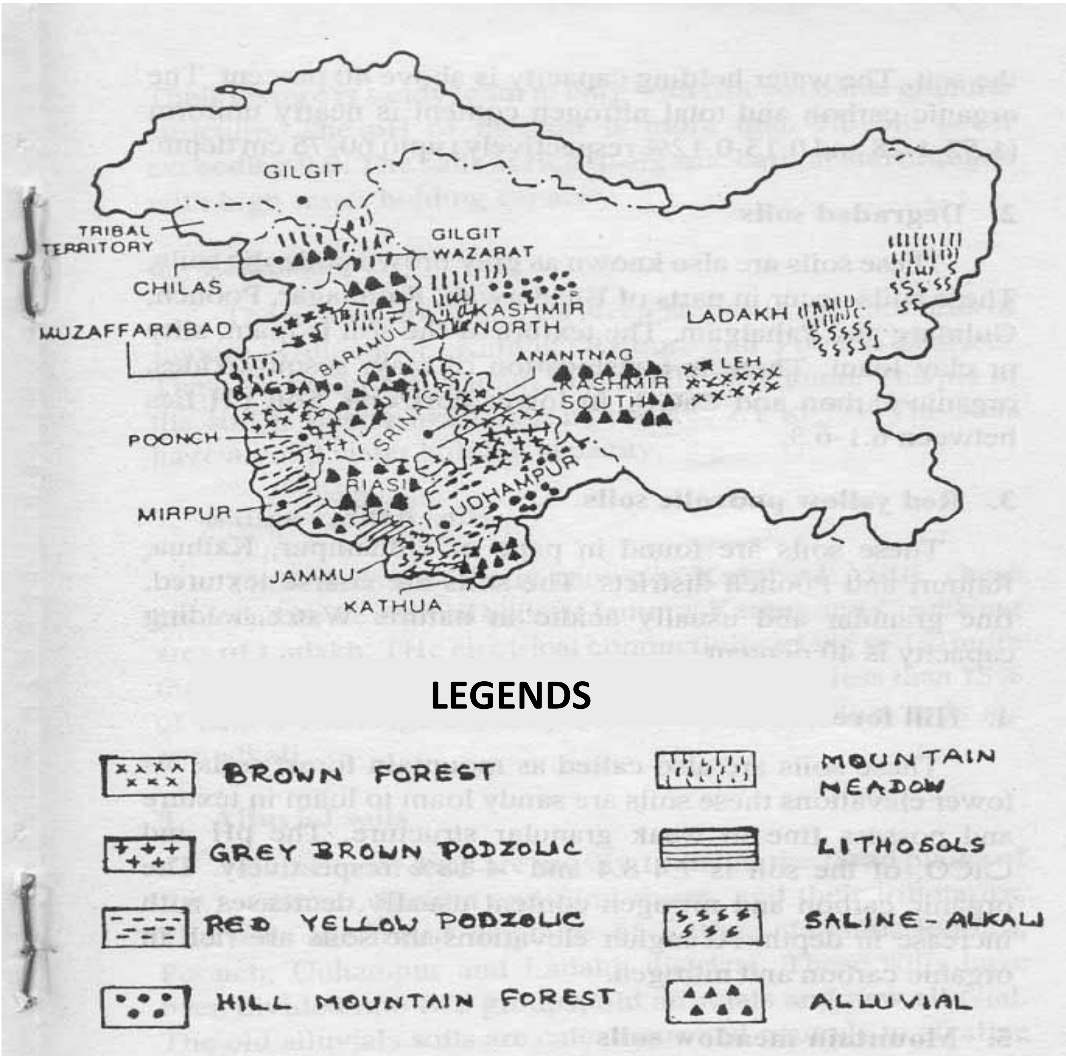

Figure - 3.1: Soils of Jammu and Kashmir

Brown forest soils

This type of soil is also known as brown earth soil. These soils occur in parts of Kathua, Udhampur, Dada, Poonch, Rajouri, Anantnag and Baramula districts. The soils are silty loam to clay loam in texture and posses fine granular sub-angular blocky structure. pH of this soils varies between 7.8 -8.3. $CaCO_3$ is as high as 10% in the soil. The water holding capacity is above 40 percent. The organic carbon and total nitrogen content is nearly uniform (1.52 - 1.28 and 0.15 - 0.12% respectively) up to 60-75 cm depth.

Degraded soils

These soils are also known as grey brown podzolic soils. These soils occur in parts of Bhaderwah, Ramnagar, Poonch, Gulmarg and Pahalgam. The texture of these soils is loam, silty or clay loam. There is translocation of clay, sesqui-oxides, organic carbon and $CaCO_3$ in lower horizons. Soil pH lies between 6.1 - 6.3.

Red yellow podzolic soils

These soils are found in parts of Udhampur, Kathua, Rajouri and Poonch districts. The soils are coarse textured, fine granular and usually acidic in nature. Water holding capacity is about 40 percent.

Hill forest soils

These soils are also called as mountain forest soils. At lower elevations these soils are sandy loam to loam in texture and possess fine to weak granular structure. The pH and $CaCO_3$ of the soil varies between 7.4 - 8.4 and 4 - 18% respectively. The organic carbon and nitrogen content usually decreases with increase in depth. At higher elevations, these soils are rich in organic carbon and nitrogen.

Mountain meadow soils

These soils occur under the pastures found in Gulmarg, Pahalgam, Lolab, Gurez, Baramula, Sonamarg and Chanthang. Their texture is sandy loam to clay with fine to coarse granular structure. The pH of the soil is more than 7.0 but never exceeding 9.0. The soils are rich in organic carbon and nitrogen with high water holding capacity.

Lithosols

These soils are found on steep slopes in the foot hills of Jammu, Udhampur, Kathua, Rajouri and Poonch districts. The soils are gravelly loam to gravelly silty loam. The pH of the soil is nearly neutral in nature, i.e. 7.1 to 7.8. These soils have a good water holding capacity.

Saline alkali soils

These soils are locally known as Kalar Ali Mitti. These are found in the alluvial belts of Jammu, Kathua and Chanthang area of Ladakh. The electrical conductivity of these soils is more than 4 mmhos/cm. Sodium content is generally less than 15% of cation exchange capacity (CEC) indicating that soils are non-alkali.

Alluvial soils

The alluvial soils are mostly found in the flood plains of Ravi, Chenab, Jhelum and Sind rivers, and their tributaries. The soils are found in plains of Kathua, Jammu, Rajouri, Poonch, Udhampur and Ladakh districts. These soils have been divided into two groups: old alluvial and new alluvial. The old alluvial soils are calcareous and neutrals to alkaline in their reaction (pH 7.6 - 8.4) and low to medium in organic carbon and nitrogen. The pH of the new alluvial soil ranges between 7.0 - 7.7 and is calcareous with low in organic carbon and nitrogen.

3.3.1 Texural Classification

The textural classes of soils of the state are represented by the soil texture map as shown in Figure–3.2 (Source: http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116).

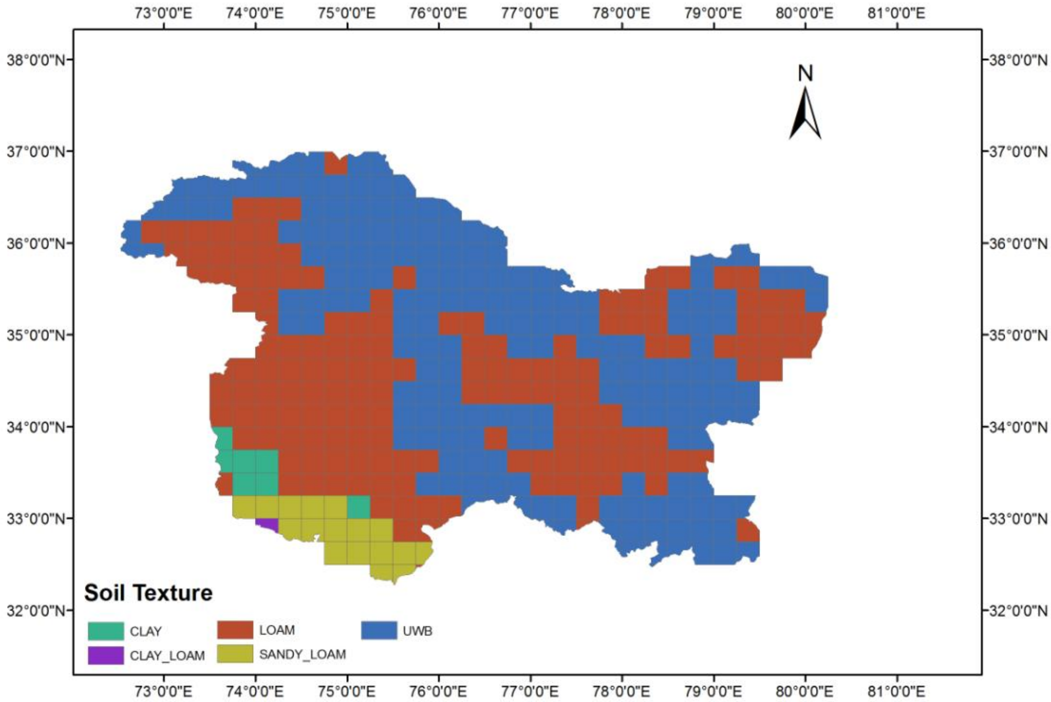

Figure - 3.2: Soil texture map of Jammu and Kashmir

3.4. Land Use and Land Cover

The Land Use Land Cover (LULC) information has been collected from NRSC publications and NRSC website. The Figure – 3.3 below shows the LULC of the J&K State (Source: http://www.nrsc.gov.in). J&K State under Indian control is mostly (around 90%) hilly area. Percentage of various LULC is shown in the Figure – 3.4. The figure clearly indicates that around 46 % of the total state area is Barren Rocky and covered with unweathered bedrocks.

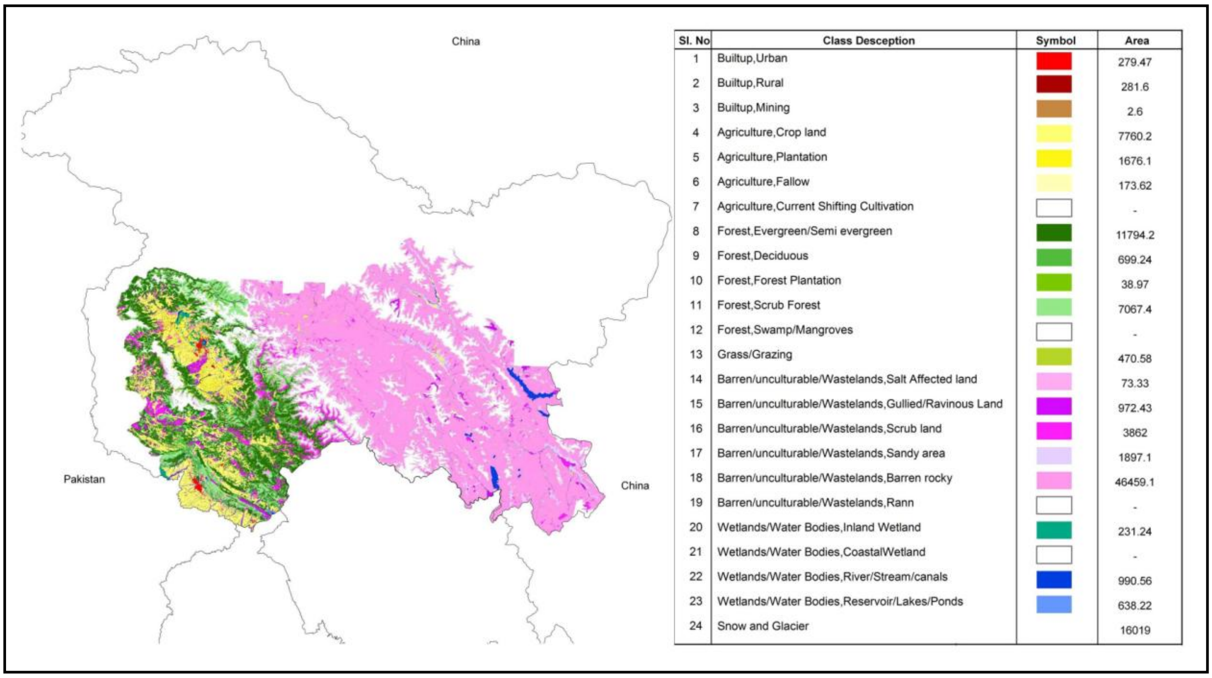

Figure - 3.3: LULC map of Jammu and Kashmir

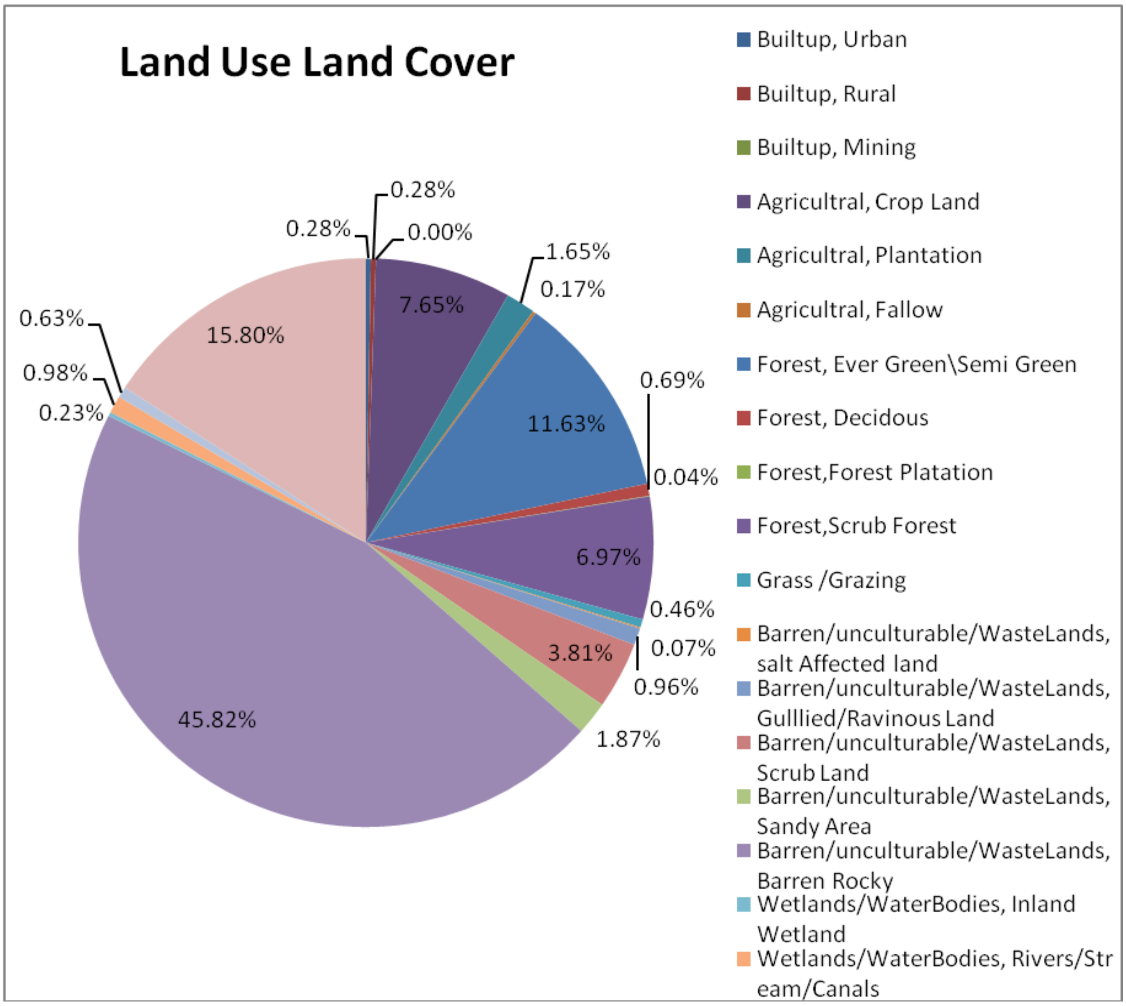

Figure - 3.4: Percentage distribution of various land uses in Jammu and Kashmir

3.5 Hydrogeology

The hydrogeological set up in the State is very complicated owing to varied geological settings and ground water conditions. All the three regions of Jammu & Kashmir State, viz. Ladakh, Kashmir and Jammu, represent entirely different ground water regimes. Based on geology and aquifer characteristics, the area of the State can be divided into two broad hydrogeological units:

1. Porous formation
2. Fissured formation

3.5.1 Porous Formation

Porous formations are best suitable for the exploration and development. Potential zones are encountered in these formations. These formations are:

Jammu Region

In outer plains of Jammu region, extending between River Ravi in the east to Munnawar Tawi in the west, the ground water occurs in Piedmont deposits belonging to upper Pleistocene to Recent age. The deposits comprise unconsolidated sediments in the form of terraces and coalescent alluvial fans developed by the streams debauching out of Siwalik Hills. The sediments consist of coarse clastics ranging in size from boulders to gravel in the loose clay matrix and occasionally alternating bands of clay of varying thickness. Kankar is also intercalated with these sediments at different intervals and in variable quantity. These deposits are graded into finer sediments from north to south in that order. Down south it comprises alternate bands of sands of all grades and clay with subordinate peck of gravels and pebbles.

Kandi Formation

The typical Kandi formation comprises very coarse material with little clay but in the outer plains of Jammu & Kashmir State, the typical Kandi formations are not seen. Instead, they comprise boulder, gravel, pebble and coarse sand with substantial amount of clay, sometimes hard and sticky, of varying thickness. The clay proportion increases towards southwest. Occurrence of perched water bodies is a common phenomenon in the Kandi belt of Jammu & Kashmir State. The ground water generally occurs under unconfined conditions in Kandi formation.

Sirowal Formation

The Kandi formations coalesce into Sirowal formations in the south, which are finer outwash of Siwalik debris, brought by streams. Ground water occurs under both the confined as well as unconfined conditions in Sirowal formation. A spring line demarcates the contact between Kandi and Sirowal formations because the water table oozes out along this line causing marshy conditions. The spring line has undergone deformation due to decline of water table resulting from development of ground water in Sirowal area. However, the base flow could be seen in streams south of this line.

The Dun Belt separates the Siwalik hills in the middle Himalayas and runs as a series of river terraces between Basohli (32°30' N, 76°49'30" E) in the east to Riasi (33°05' N, 74°50' E) and beyond in the west. The sediments are in the form of isolated sub-recent to recent valley-fill deposits ranging in thickness between a few meters to a few tens of meters. These deposits are often dissected as a result of the present day drainage pattern. The deposits comprise of coarse clastics, such as boulders, cobbles and pebbles etc. inter-bedded with lenticular clays.

Isolated Valley Fills in Middle Himalayas

There exist a number of isolated valleys in middle Himalayas where ground water occurs in valley fill deposits comprising of lacustrine to fluvio-glacial sediments. A few meter thick layer of loess overlies these deposits, which is windblown. Ground water in such valleys generally occurs under confined conditions. One of the prominent isolated valleys in middle Himalayas is Kishtwar valley (33°18' 30" N, 75°46’ E) in Doda district of Jammu region.

Kashmir Region

Kashmir valley covers an area of 5600 km^2 and is occupied by Karewas which consist of a huge pile of alternating bands of sand, silt and clay interspersed by glacial boulder beds. The sands are mostly fine to very fine grained and it is very rare that they are medium to coarse grained. There is considerable lateral variation in the nature of the sediments. The aggregate thickness of these sediments is of the order of 2500 - 3000 m. Ground water in the Karewas of Kashmir valley occurs under both, confined as well as unconfined conditions.

Ladakh Region

In Leh plain of Ladakh region, the sediments consist of moranic and fluvio-glacial boulders and cobbles underlain by lacustrine deposits consisting of clay and silt. The Leh plain covers an area of about 100 km^2 between Phayang Nala in the west to Sabu Nala in the east. Ground water generally occurs under unconfined conditions.

3.5.2 Fissured Formation

About 15000 km^2 area in Jammu region is occupied by hilly terrain. It comprises rocks ranging in age from the Precambrian (Salkhala series) to Miocene or even Pliocene (Murees and upper-middle Siwaliks). The rock types range from soft or friable sandstones, clays, shales, conglomerates to hard traps and metamorphic such as quartzite and crystalline limestone. In the Siwalik terrain, groundwater is tapped mainly either from the weathered mantle or from the joints or cracks of these rocks. Friable Siwalik sandstone does possess primary but are not very potential aquifers.

* * *

CHAPTER – 4
WATER RESOURCES OF J&K STATE

4.1 River Basins

Entire State of Jammu and Kashmir is flown by the rivers of Indus River System and the only exception is the small area in the extreme north-east which is part of Qura qush River basin. River basin map of Jammu and Kashmir State is shown in Figure – 4.1.

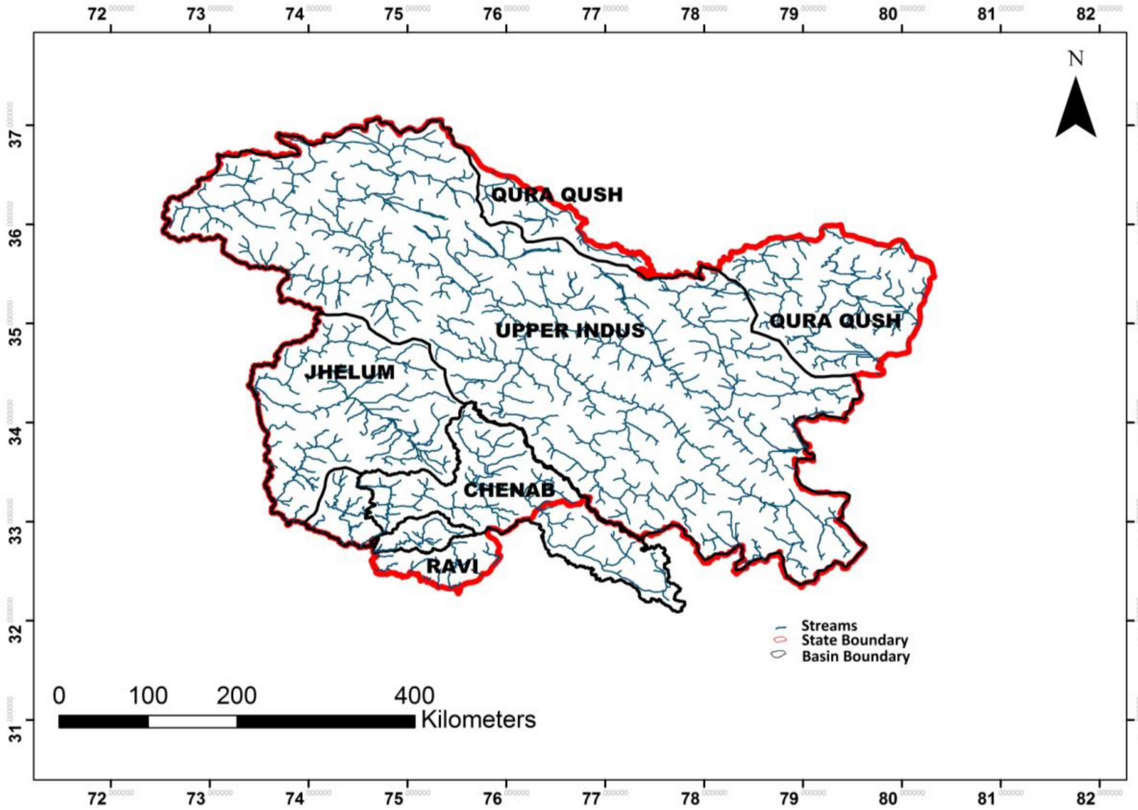

Figure - 4.1: River basin and drainage network map of Jammu and Kashmir

4.2 Indus River Basin

The total drainage area of Indus River basin is 11,78,440 km^2 out of which an area of 4,53,250 km^2 falls in high Himalayan mountains and the remaining 7,25,190 km^2 falls in the plains. Of the drainage area in plains, a total of 3,21,290 km^2 area of Indus basin falls in India whereas only 1,31,960 km^2 area falls in Pakistan.

The Indus River (Sanskrit-Sindhu, Greek-Sinthos, Latin-Sindhus) originates from Lofty Mountains near Mansarovar Lake at an elevation of 5182 m and traverses for several hundred km through Tibet and India before reaching Suleiman mountains in Pakistan. A part of the Indus Basin is above the permanent snow line, which varies in altitude from 4268 m in the eastern parts to 5792 m on the western parts. In Ladakh region, the snow line is at 5488 m above mean sea level, which recedes during summer.

The hydrographic system of the Indus basin is very extensive. The river initially runs along the strike of the mountains and then suddenly makes an acute bend to the south and flows directly across the mountain. The Gilgit River joins the Indus at its great bend to the south. The Indus flows initially under the name of Singee Khabab until it is joined by Ghar river at about 257 km from its source. After short distance downstream, it enters Kashmir at an elevation of 4206 m and flows over a long flat plain in Tibet plateau. It skirts Leh at 3200 m and is joined by Zanskar River while still flowing north but more westerly. The Indus passes near Skardu and reaches Haramosh Mountain (7407 m). Here it takes a turn southwards at an acute angle and passing near Hattu Pir, enters Kohistan. After flowing through wilds of Kohistan and at about 1450 km from its source, the Indus is joined by Kabul and Swat Rivers from Afghanistan. At this point, the elevation of the Indus falls to about 610 m. After leaving Attock in Pakistan, the river flows southwards, parallel to the Suleiman Range. At about 805 km from the Arabian Sea and at an elevation of 79 m, the Indus receives waters from all of its five major tributaries, viz. Jhelum, Chenab, Ravi, Beas and Satluj and here, it is known as Panjnad (five rivers). The river finally joins the Arabian Sea through its mouth, which form a big delta covering 7770 km^2 and a vast coastline of about 201 km.

The drainage basin of the Indus river system, in India, extends from the Naga Parbat in the extreme north-western part of the country to the western slopes of the Shimla ridge in Himachal Pradesh. It includes the whole of Jammu and Kashmir State and most of Himachal Pradesh State. The extreme northern tract of the Indus basin comprises of the cold desert of Ladakh, Lahaul-Spiti and Pooh. South of this tract lies the higher Himalayan mountain wall. Lower and middle Himalayas occupy the central part of the Indus basin. The low rolling Shivalik hills occur along its southern periphery. Climatic conditions in the Indus river system vary from arctic to sub-tropical. The cold desert area remains devoid of precipitation and experiences heavy snowfall. The important rivers of this system are the Satluj, the Beas, the Ravi, the Chenab and the Jhelum. A brief account of sub-basins of Indus System in Jammu & Kashmir State is given below.

4.2.1 Jhelum Sub-Basin

The Jhelum is known in Kashmir as the Veth River. Most parts of Kashmir valley are drained by Jhelum River, which flows in northwesterly direction. The Jhelum River (Sanskrit-Vitasta, Greek-Hydaspes, Latin-Bipaspes) originates from Verinag Spring. The river has various tributaries in the valley, several of which come from the everlasting snows of the Liddar valley. Near Srinagar, it is received by the Sind River, and then forms the Wular lake. The Wular Lake in Baramulla district is, in fact, a delta of Jhelum river. Below Baramulla, the river leaves the fertile banks of the valley and rushes headlong down a deep gorge at Khadnayar and joins the Chenab River at Trimmu in Pakistan.

4.2.2 Chenab Sub-Basin

The Chenab River is one of the most important main rivers of the great Indus System. The Chenab River or Asikin, as it was known in Vedic times, is formed by two important tributaries, the Chandra and the Bhaga, which join near Keylong in Himachal Pradesh to form Chandra-Bhaga or the Chenab River in Himachal Pradesh. The Chandra and Bhaga originate at about 5412 m and 4891 m from the north and south faces of Baralacha pass respectively in Lahaul Spiti Valley and merge together near Tandi in Himachal Pradesh. The Chandra initially flowing south-east for about 88 km sweeps round the base of mid – Himalayas and joins Bhaga. The Chenab River then flows through the Kashmir Himalayas to emerge into the plains at Akhnoor in Jammu district, at about 250 km from its source. Ranbir canal takes off from its left bank in Akhnoor tehsil. The majority of Chenab catchment lies in India while its lower reach, including the confluence with Indus River, is in Pakistan. In India, the Chenab basin is located in western Himalayas between latitude 30º - 34º N and longitude 74º - 78º E.

The Chenab basin in India is spread over the two states, Himachal Pradesh and Jammu and Kashmir, which comprises the extreme western sector of Himalayas. Upper catchment lies in Lahaul area and Pangi Tehsil of Chamba district of Himachal Pradesh. This region is roughly rectangular in shape with main Himalayas on the north, and mid Himalayas on south. These hills rise to a mean elevation of about 5480 m. The total catchment area of the basin up to Akhnoor is about 22,770 km^2. On an average, about 70% of the total drainage area is covered by snow in the month of March/April and about 25% remains under permanent snow cover. The Chenab valley is a structural trough formed by the great Himalayan and Pir Panjal ranges.

4.2.3 Ravi Sub-Basin

Very small parts of the J&K State, mainly the extreme south-eastern parts, fall under the Ravi Sub-basin. The Ravi River rises from the northern face of Rohtang Pass in Himachal Pradesh at an elevation of 4116 m. After passing through Dhauladhar hill ranges, the river emerges from the foothills near Madhopur where the headworks of the Upper Bari Doab Canal exist. It has the smallest catchment area among the rivers of the Indus System. An important tributary of Ravi River, the Ujh River, originates from the Basohli hills of Kathua district which joins the mainstream to its right at Lassian.

4.3 Glacier Resources

Glaciers and snow cover are key to the water resources of the State of Jammu & Kashmir. Out of 9575 glaciers in the Indian Himalaya, more than 5500 glaciers are in the State of Jammu & Kashmir which constitutes more than 67% of the glacier cover of the Indian Himalaya. Major river basins with significant number of glaciers in the State are Chenab, Jhelum, Drass, Suru, Zanskar, Indus, Shyok and Nubra. The State has two distinct glacio-hydrological regimes, such as Alpine and Cold-arid systems. Geographically, the Kashmir region represents the Alpine regime and the major part of Ladakh region represents the cold- arid regime (Figure - 4.2). These glaciers are spread across Pir Panjal range, Great Himalayan range, Zanskar range, Ladakh range, and Karakkoram range. Lidder, Sind, Rembiara and Shali Ganga basins are the main glacier bearing basins of the Kashmir region which together have 133 glaciers as compared to 5211 glaciers in the Ladakh region. While these 133 glaciers cover an area of 94.3 km^2 in the Kashmir region, the total glacier cover area of the Ladakh region is an astounding 17779 km^2. The importance of the Ladakh region in the water resources of the State is evident from these statistics. As there is sparse monsoon precipitation in the Ladakh region, glacier and snow melt water sustain the population. Glaciers of Ladakh range and those in the northern slopes of the Zanskar range constitutes around 227 small cirque glaciers and most of the villages in this region are located along the glacial streams which directly impact the socio-economic activities of the region. The Nubra and Shyok basins have a number of big glaciers including the famous 73 km long Siachen glacier. Some of the most important surging glaciers like Chong Kumdan, Kichik Kumdan and Aktash glaciers are in the Shyok basin. Following sections describe the summary of glacier resources in the major river basins of Jammu and Kashmir. Source of the data is the glacier inventory of Geological Survey of India (GSI) and Glacier Atlas of India (2008).

Table - 4.1

Summary of glaciers in the Indus basin

Name of Basin	Basin Code	No. of glaciers	Glacierised area (km^2)
Shyok	5Q 121	2658	7106
Indus	5Q 122	1796	2165
Gilgit	5Q 11	535	8240
Kishenganga	5Q 2111	222	174
Jhelum (Uri)	5Q214	133	94.18
Chenab	5Q 212	1278	3059
Ravi	5Q 2102	172	193
Beas	5Q 2201	277	599
Satluj	5Q 22	926	1251
Total		**7997**	**22881**

Table - 4.2

Distribution of glaciers in the Sub-Basin of Upper Indus Basin

Name of sub basin	Basin Identification Code	Total area (km^2)	Glacier covered Area (km^2)	Glacier covered Area (%)	No. of Glaciers	Mean glaciation level (above msl)
Shyok	5Q 131	36,676	10,810	29.47	2562	6,000
Nubra	5Q 13105	4,278	1,536	36	204	5,760
Indus	5Q 132	48,884	8,320	17.02	1796	5,564
Gilgit	5Q 11	26,884	8,240	30.65	535	5,500
Kishanganga	5Q 2111	7,256	163	2.25	156	4,700
Total Number of glaciers : 5,253						

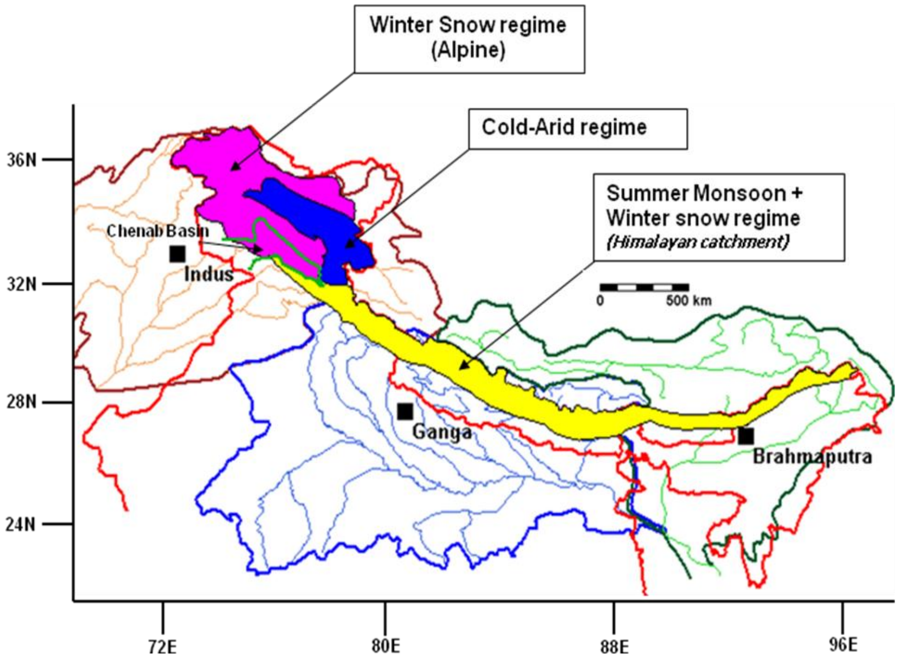

Figure - 4.2: Glacio-hydrological regimes of the Himalaya

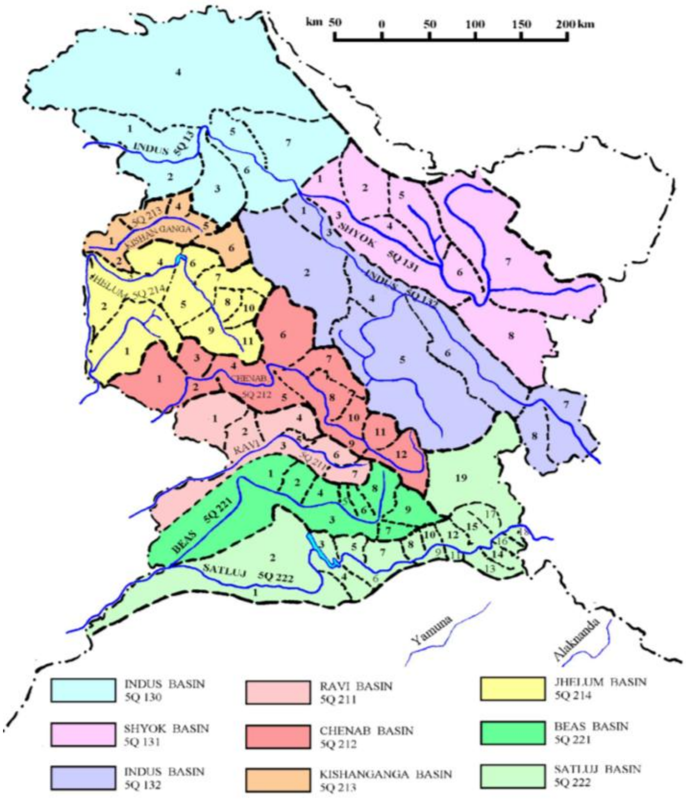

Figure - 4.3: Glacier bearing basins of Indus River

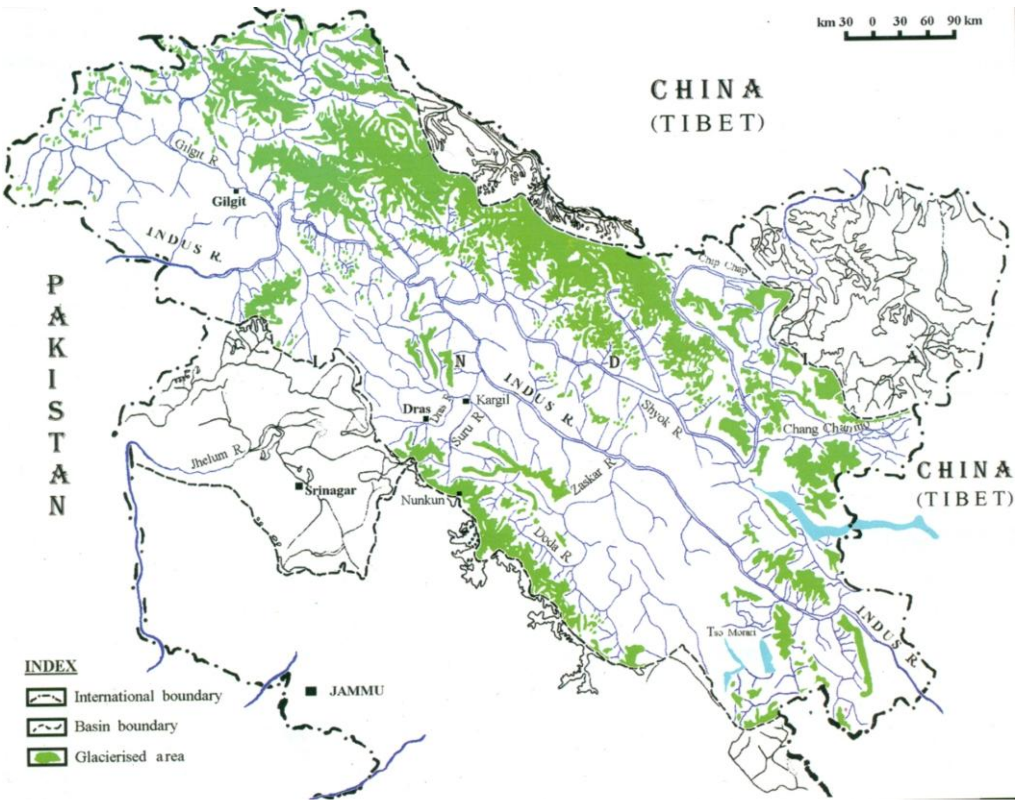

Figure - 4.4: Distribution of glaciers in the Upper Indus basin

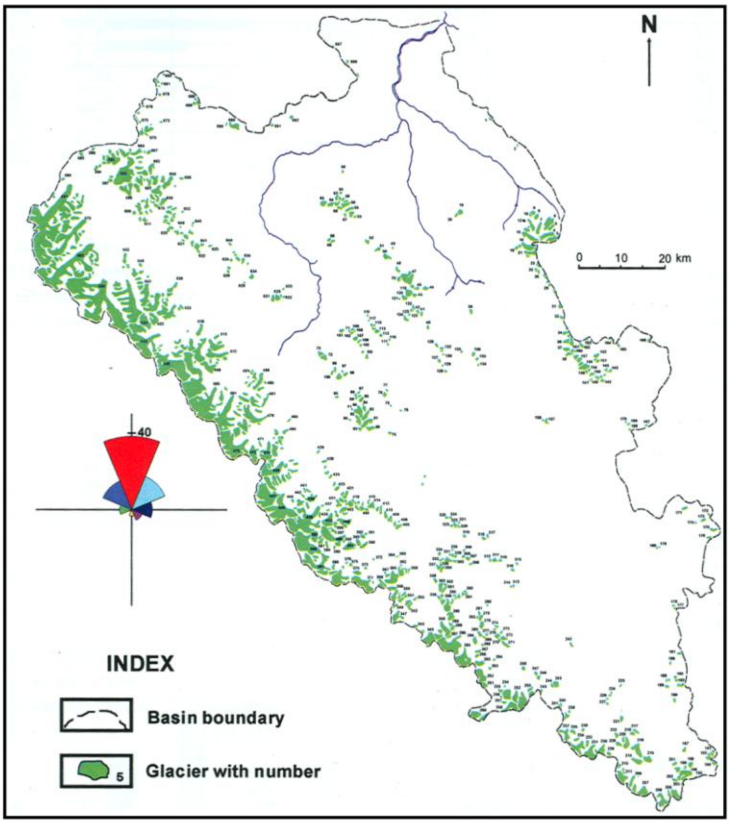

Figure - 4.5: Glacier distribution in Zanskar basin

Table - 4.3

Summary of glacier inventory data of Shyok basin (5Q131), J&K, Himalayas

Basin Name	Shyok		Chumchar		Nubra		Saltoro	
Basin identification	5Q 131 07		5Q 131 08		5Q131 05		5Q 131 02	
Basin area (sq. km)	14509		6842		4278		3493	
No. of Glaciers	1263		491		204		108	
Glaciers Covered Area (sq. km)	2857.36		344.41		1536.37		1194.17	
Glaciers Covered area (%)	19.69		5.03		35.91		34.19	
Total ice volume (cubic km)	261.54		12.04		199.45		84.94	
Orientation	No.	%	No.	%	No.	%	No.	%
N	424	33.57	136	27.70	43	21.08	10	9.26
NE	244	19.32	158	32.18	26	12.75	21	19.44
E	113	8.95	72	14.66	15	7.35	9	8.33
SE	110	8.71	23	4.68	20	9.80	5	4.63
S	101	8.00	18	3.67	39	19.12	13	12.04
SW	47	3.72	6	1.22	14	6.86	23	21.30
W	68	5.38	25	5.09	23	11.27	14	12.96
NW	156	12.35	53	10.79	24	11.76	13	12.04

Table - 4.4

Summary of Glacier inventory of Indus basin

Basin Name	Indus Basin	
Basin Identification	5Q 132	
Basin area (sq. km)	43334.61	
No. of Glaciers	1796	
Glacierised area (sq. km)	2225.57	
Glacierised area (%)	5.135	
Total ice volume (cubic km)	119.7	
Largest glacier		
Identification Number	5Q132 05 582	
Length (km)	23.10	
Area (sq km)	72.53	
Volume (cubic km)	7.25	
Orientation	Number	%
N	583	32.46
NE	453	25.22
E	162	9.02
SE	99	5.51
S	41	2.28
SW	24	1.34
W	74	4.12
NW	360	20.04
Length wise distribution (km)	Number	%
>=5	54	3.01
>=1	776	43.21
<1	966	53.78
Area wise distribution (sq. km)	Number	%
>10	27	1.5
>5	49	2.72
>1	353	19.65
<1	1367	76.11

Table - 4.5

Details of glacier distribution in the sub-basins of Indus

Basin	No. of glaciers	Basin area (km^2)	Glacierised area (km^2)	Ice volume (km^3)
Katicho basin (5Q132 01)	69	928.25	18.75 (2.02)	0.38
Suru basin (5Q132 02)	284	5136	718.85 (14.02)	46.15
Leh basin (5Q132 03)	222	6138	81.32 (1.32)	1.76
Sanglemo Chu basin (5Q132 04)	89	2883	65.33 (2.27)	2.01
Zanskar (5Q132 05)	697	14831.4	1079.26 (7.28)	62.02
Chabbe Nama basin (5Q132 06)	260	6437	170.52 (2.65)	4.67
Indus basin (5Q132 07)	74	3383.9	17.05 (0.50)	0.3
Hanle basin (5Q132 08)	101	3597.06	74.49 (2.07)	2.44

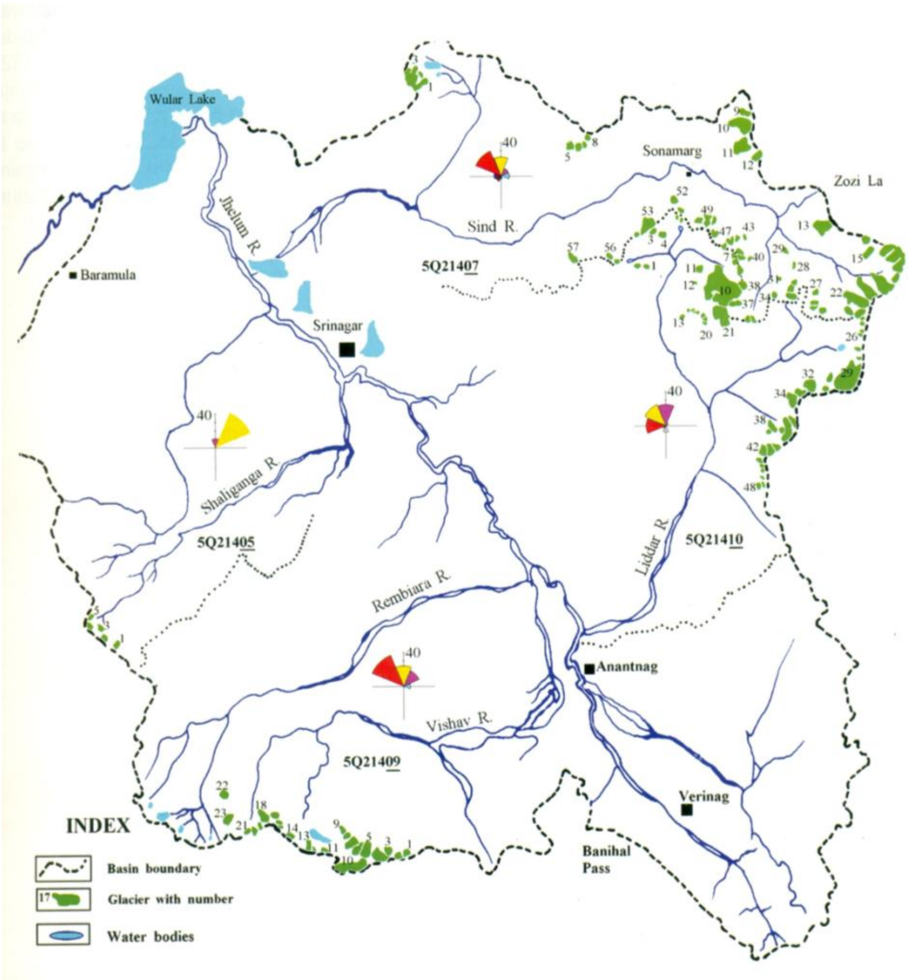

Figure - 4.6: Glacier distribution in Jhelum basin

Table - 4.6

Summarised glacier inventory of Jhelum basin (Q 214), Kashmir, Himalayas

Basin Name	**Shakuganga-Sookhmag**		**Sind**		**Viahav-Rembiara**		**Liddar**	
Basin Identification	5Q 214 05		5Q 214 07		5Q 214 09		5Q 214 10	
Basin Area(km^2)	1516.00		1142.00		1579.00		1282.55	
No. of Glaciers	5		57		23		48	
Glacier cover area (km^2)	1.75		39.94		13.54		38.95	
Glacier cover area (%)	0.12		3.50		0.86		3.04	
Total ice volume (km^3)	0.02		1.40		0.39		1.49	
Largest Glacier			**Nehnar**		**Konsar Nag**		**Kolahoi**	
Identification	5Q 201		5Q 214 07		5Q 214 09 018		5Q 214 01 010	
Number	050001		022		0.80		6.20	
Length (km)	0.95		2.75		2.55		11.50	
Area (km^2)	0.77		2.48		0.10		0.58	
Volume (km^3)	0.02		0.10					
Area wise distribution (km^2)	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
>10	0	0.00	0	0.00	0	0.00	1	2.08
>5	0	0.00	0	0.00	0	0.00	1	2.08
>1	0	0.00	13	22.81	5	21.74	5	10.42
<1	5	100.00	44	77.19	18	78.26	41	85.42

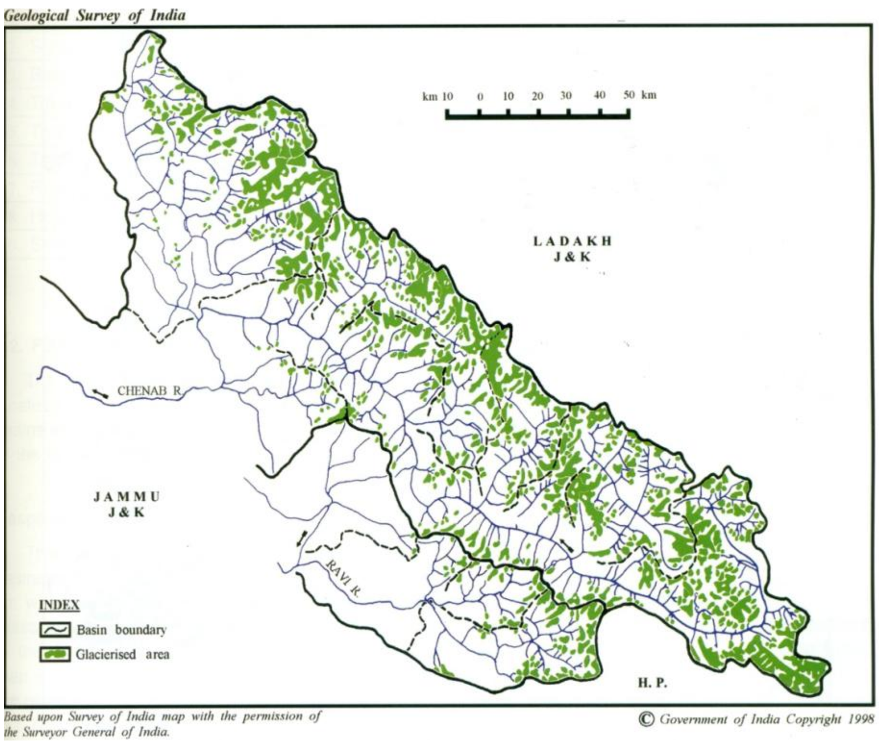

Figure - 4.7: Glacier distribution in Chenab basin

Table - 4.7

Distribution of glaciers in the Chenab basin

Area-class (km^2)	Number	Area (km^2)
<1	127	42
1-5	159	269
5-10	48	240
>10	25	559
Total	**359**	**1110**

4.4 Lakes

A number of lakes are found in the State of Jammu and Kashmir. Most of them are of glacial origin. Some of the important lakes of the State are as follows:

The ***Wular lake*** in Kashmir is the largest freshwater lake in India. It is about 16 km long, 9.6 km wide with ill-defined shores. This lake lies between Bandipore and Sopore at a distance of 75 km.

The ***Dal Lake*** is a beautiful lake near Srinagar. It is 8 km long and 6.4 km wide. It is the flood-lung of the Jhelum. The famous Mughal gardens are situated around it. Floating gardens found in this lake grow a large variety of vegetables. Dal Lake is one of the most beautiful lakes of India and the second largest in the State of Jammu & Kashmir. The lake is surrounded by majestic mountains from three sides and a large number of gardens and orchards have been laid along the shores. The University of Kashmir also stands along the shores of the Dal Lake. The hundreds of uniquely decorated houseboats which floats on the Dal lake afford an opportunity to tourists to reside on the lake in an atmosphere of peace and tranquillity.

The ***Anchar Lake*** is a swampy area. The Sind Nullah enters this lake from one side and flows out from the other. It is about 8 km long and 3 km wide. Gandarbal is a famous township on its northwest bank.

The ***Mansbal Lake*** is at a distance of 29 km from Srinagar and is situated at Sopore. It is 5 km long and 1 km wide. It is connected with Jhelum by a canal near Sumbal.

The ***Harwan Lake*** is situated at a distance of 21 km from Srinagar. It is 278 m long, 137 m wide and 18 m deep. This lake is a source of water supply to Srinagar city.

The ***Hokarsar Lake*** lies on the Baramulla road about 13 km from Srinagar. It is about 5 km long and 1.5 km wide. Willow trees are grown in abundance around its banks.

The ***Konsarnag* or *Vishno Pad Lake*** is situated in the Pir Panjal range at a height of 13124 feet (4000 m) above sea level to the south of Shopian. It is about 5 km long and 3 km wide and is the source of the river Vishav. It is at a distance of 34 km from Shopian.

The ***Gangabal Lake*** is situated at a height of 11713 feet (3,570 m) on the peak of Harmukh Mountain.

The ***Sheshnag Lake*** is situated near Vavjan, enroute to Shri Amarnath cave. It is at a distance of 28 km from Pahalgam.

The ***Neelang Lake*** is situated in tehsil Budgam at a distance of 10 km from Nagam. It is bounded by dense forest.

There are two more lakes – ***Tarsar*** and ***Marsar*** that lie on the northern slope of the Harmukh mountain. Marsar Lake is the origin of the canal Sharab Kohl that provides water to the fountains that play in the Mughal Gardens. Marsar Lake flows into the Lidar, which is one of the largest tributaries of Jhelum.

Sokh and ***Dokh*** are two frozen lakes situated in Harmukh mountain. These are said to be two tear-drops of Parvati – one a warm drop indicating happiness and another a cold one showing grief.

The ***Pangong*** is a salty lake in Ladakh. It is about 6.4 km long and 3.2 to 6.4 km wide at a height of 4,267 m above sea level. The other lakes of Ladakh are ***Patlong, Thaled, Longzang, Pangor*** and ***Tso moriri***.

Mansar Lake is situated 62 km from Jammu. Mansar is a beautiful lake fringed by forest-covered hills, over a mile in length by half-a-mile in width. There are also some ancient temples on the lake's shores, which are visited by devotees in large numbers. With all religions belief and heritage behind, the Mansar Lake is also picking up its fame among the tourists with all its flora & fauna. The lake has cemented path all around with required illumination, with projected view decks to enjoy flickering of seasonal birds, tortoise and fishes of different species. There is a wild life Sanctuary housing jungle life like Spotted Deer, Neelgai etc. besides other water birds such as Cranes, Ducks etc.

Surinsar Lake, a smaller lake that is linked to Mansar, 24 km from Jammu (via a bypass road).

4.5 Springs

Kashmir Valley abounds in numerous springs of which Verinag (the source of Jhelum), Martand (Anantnag), Achhabal (Anantnag), Kokernag (Anantnag), Chashma Shahi (famous for its fresh and digestive water situated near Srinagar on one side of the Boulevard road), Tullamulla or Khirbhawani (a sacred spring), Vicharanag, Sukhnag, Alpathar, Kicharnag,Vishnosar and Harmukat Ganga in Srinagar area and Chirnagand Vasaknag in Anantnag are very famous.

*** * ***

CHAPTER – 5
HYDROPOWER DEVELOPMENT IN J&K STATE

5.1 Hydropower Development in Various Sub-basins

Jammu and Kashmir State is blessed with abundant scope for hydropower generation due to existence of large river basins, viz. Upper Indus (Zanskar, Nubra, Shyok, Sindh, Dras etc.), Jhelum, and Chenab (including Tawi basin). However, hydropower development in the State has not progressed with significant pace. Existing and proposed hydroelectric projects in different basins (Source: http://www.sandrp.in) are shown (Figure - 5.1 to Figure - 5.4).

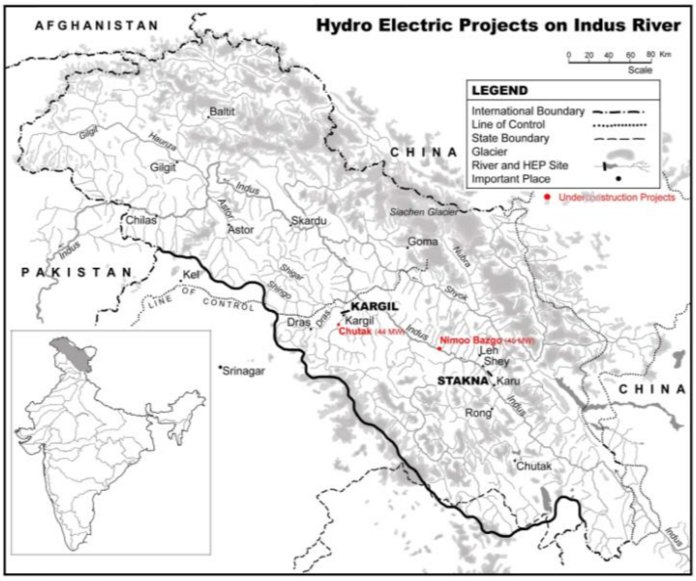

Figure - 5.1: Hydroelectric projects in upper Indus basin

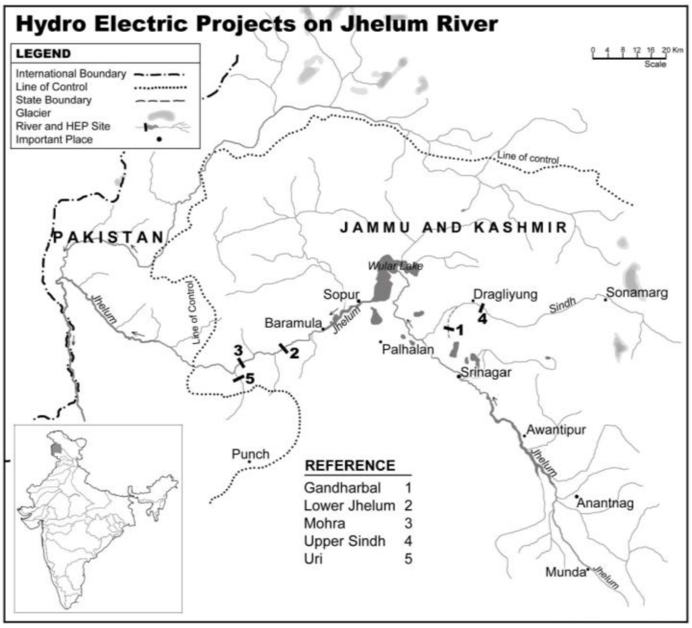

Figure - 5.2: Hydroelectric projects in Jhelum basin

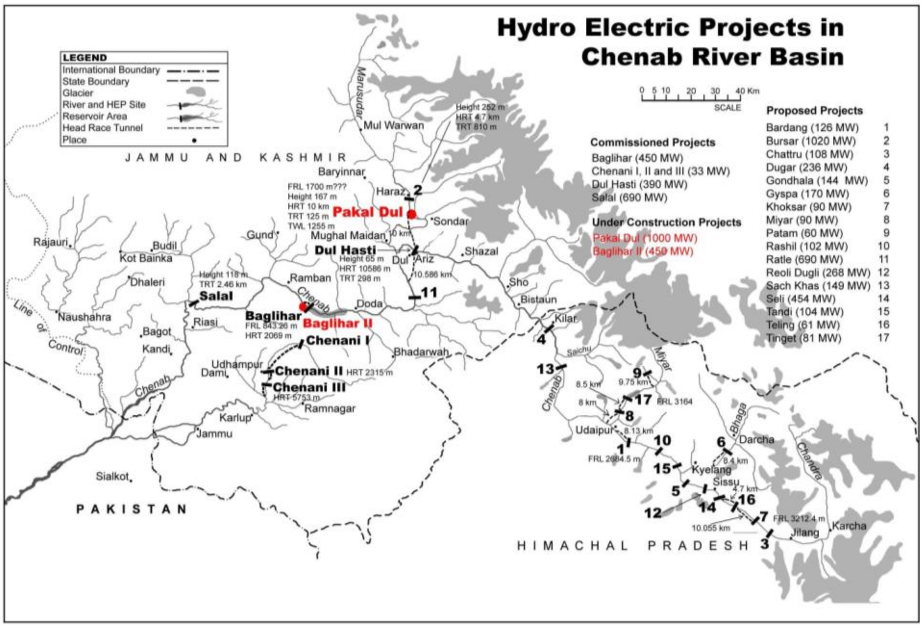

Fig. 5.3: Hydroelectric projects in Chenab basin

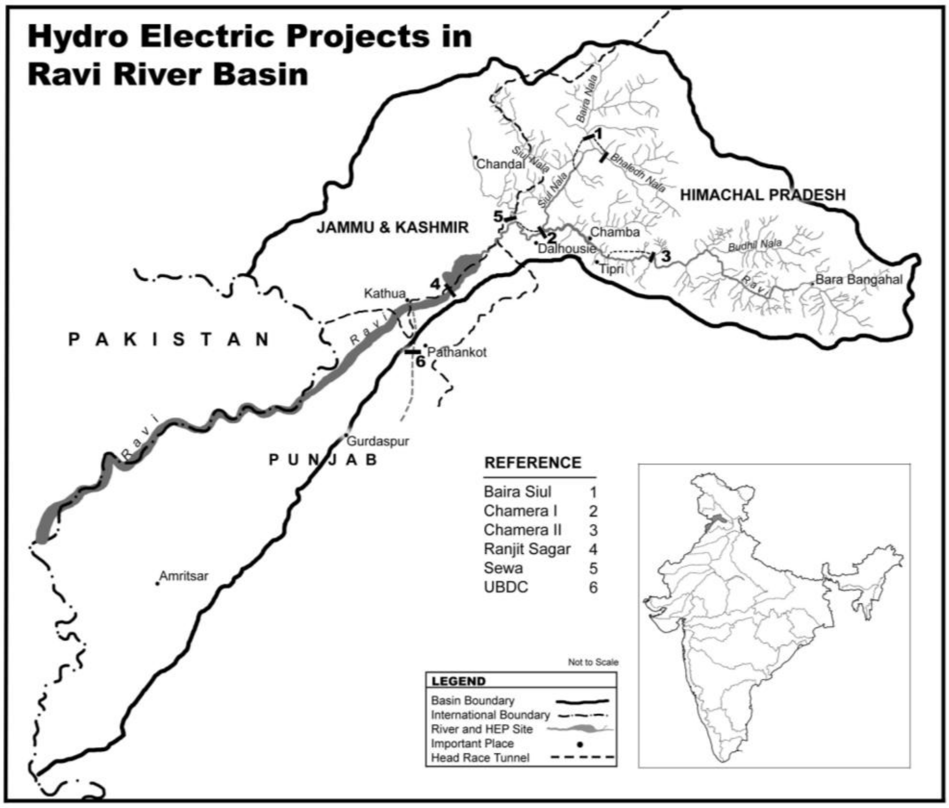

Figure - 5.4: Hydroelectric projects in Ravi basin

5.2 Brief Description of Some Existing HEPs in J&K State

The brief description of the existing hydroelectric projects is given here. The information has been taken from the websites of National Hydroelectric Power Corporation Limited and J&K Power Development Corporation.

5.2.1 Salal Hydroelectric Project

Salal Hydroelectric Project Stage-I of 345 MW (115 x 3) and Stage-II of 345 MW (115 x 3) are constructed on river Chenab in the State of J&K. The project was conceived in the year 1920. The investigations on the project were started in the year 1961 by the Govt. of J&K and construction was started in 1970 by Central Hydroelectric Project Control Board under Ministry of Irrigation and Power, Govt. of India. In 1978, construction of the project was entrusted to NHPC. After completion of the project, it was handed over to NHPC on ownership basis for Operation and Maintenance. Stage-I of the project was commissioned in 1987. First unit of Stage-II of the project was commissioned in 1993, while second unit was commissioned in 1994 and third unit was commissioned in 1995.

Salient Features of Salal Project	
Location	Distt. Udhampur, J & K
Approach	Nearest Rail Head - Jammu
Capacity	690 MW
Annual Generation	3101 million units
Project Cost	Rs. 9288.9 million
Beneficiary States	U.P, J&K, Punjab, Haryana, Delhi, H.P. Chandigarh & Rajasthan
Year of Commissioning	Stage-I 1987 Stage-II 1st unit-1993 2nd unit-1994 3rd unit-1995. Finally Commissioned in 1996
TECHNICAL FEATURES	
• 118 m high, 630m long rockfill dam. • 113 m high, 450 m long concrete dam • 11 m dia, 2.46 km long tail race tunnel. • 6 nos. Penstocks 5.23 m dia, 279 m long each. • Sub-surface power house containing 6 units of 115 MW each.	

5.2.2 Dul Hasti Hydroelectric Project

Dul Hasti Power Station is the second project to be executed by NHPC in the State of Jammu and Kashmir after Salal Stage-II. It is a run-of-the-river scheme which will produce 390 MW of power. The project is constructed on river Chenab. The project headquarter is located at Kishtwar in district Doda of J&K. The concrete gravity dam is situated in village Dul and the Power house is located in village Hasti. The project has generated 1907 million units of power in a 90% dependable year. The commercial production started on 07/04/2007.

Salient Features of Dul-Hasti Project	
Location	Distt. Doda in J & K
Approach	Nearest Rail Head / Airport - Jammu
Capacity	390 MW (3x130 MW)
Annual Generation	1928 MUs
Project Cost	Rs. 3559.77 31 Crores
Beneficiary States	J&K, H.P., Punjab, Haryana, Delhi, U.P, Rajasthan & Chandigarh, Uttaranchal
Year of Commissioning	March 2007
Technical Features	
• 65 m high, 186 m long concrete gravity dam. • 7.46 m & 7.7 m dia., 10.586 km long head race tunnel • 7.46 m dia., 298 m long tail race tunnel. • Underground power house containing 3 units of 130 MW each.	

5.2.3 Uri Hydroelectric Project (Phase-I)

Uri Hydroelectric Project is a run-of-the-river scheme, located on the downstream of Lower Jhelum Power Station, which utilises a head of 252 m. The project has an installed capacity of 480 MW (4 x 120 MW) under Phase-I, with a provision to install an identical capacity under Phase-II. The water conductor system upto the tunnel intake, has been designed to cater to both Phase-I & II. The annual generating capacity of Uri Project Phase-I is 2587.38 million units of energy in 90% dependable year.

Salient Features of Uri-I Project	
Location	Uri Tehsil, Baramulla Distt, J&K
Approach	75 km from Srinagar on Srinagar-Uri National Highway. Nearest railhead-Jammu(380 KM), Nearest airport-Srinagar
Capacity	480 MW
Annual Generation	2587.38 MU
Project Cost	Rs. 3300 Crores
Beneficiary States	J&K, Punjab, Haryana, Delhi, Himachal Pradesh, Rajasthan, Uttar Pradesh & UT of Chandigarh.
Year of Commissioning	January 1997
Technical Features	
• 93.5 m long barrage. • 10.64 km long head race tunnel. • 2 km long tail race tunnel. • Underground power house containing 4 units of 120 MW each.	

5.2.4 Uri Hydroelectric Project (Phase-II)

Uri-II HE Project is located in Uri Tehsil of Baramulla District. The nearest railhead is Jammu, which is, connected to the project site via Srinagar and Baramulla by NH 1A (about 400 km). The project is planned immediately downstream of Uri-I and will pick up its tail water to make use of the gross head of about 130 m available in the course of the river between Uri-I tailrace outlet and a place located about 1.25 km downstream of the confluence of Goalta Nallah and Jhelum River, close to the Line of Actual Control. The project is estimated to generate 1123.76 MU of energy in a 90% dependable year.

Salient Features of Uri-II Project	
Location	Uri Tehsil of Baramulla district in Jammu & Kashmir
Approach	Nearest Rail Head - Jammu, Nearest Airport - Srinagar.
Capacity	240 MW (4 x 60 MW)
Annual Generation	1123 MUs (90% dependable year)
Project Cost	Rs.1724.79 Crores. (Feb. 2005 price level)
Year of Commissioning	February 2013 (Anticipated)
Technical Features	
• Concrete gravity dam 50 m high, 148 m long with 4 nos. of spillways of 9.0 m each • 4.235 km long , 8.4 m dia of HRT (Horse Shoe Type) • Restricted orifice type surge shaft of 25 m dia. • 2 Nos. steel lined penstock 5m dia and 4 Nos. of bifurcated steel lined penstocks of 3.5 m dia. • Underground power house of 133 m length x 15 m width x 40 m height to accommodate 4 units of 60 MW capacity each. • 3.615 Km. long horse shoe type TRT.	

5.2.5 Chutak Hydroelectric Project

Chutak HE Project would harness the hydropower potential of river Suru in Kargil district of Jammu & Kashmir. The barrage of the project is located near village Sarzhe and the power house is proposed on right bank of river Suru near village Chutak. The project envisages to utilize a gross head of 63.4 m to generate 212.93 million units in a 90% dependable year with an installed capacity of 44 MW.

Salient Features of Chutak Project	
Location	Village Minji in Kargil District of Jammu & Kashmir.
Approach	Nearest Rail Head - Jammu (515 km). Nearest Airport- Leh
Capacity	44 MW (4 x 11 MW)
Annual Generation	212.93 MU (in a 90% dependable year)
Project Cost	Rs. 621.26 Crores (December 2005 Price Level)
Beneficiary States	J&K
Year of Commissioning	October 2012
Technical Features	
• 47.5 m long barrage • 5.9m dia, 4.776km long Horse Shoe shaped Head Race Tunnel • 19m dia, 59m high, Orifice type Surge Shaft • 2 Nos., 4.0m dia, 30m long, vertical RCC, each bifurcating into two Penstocks of 2.3m dia each circular steel lined. • Underground Powerhouse , with 4 units of 11 MW each, Francis Turbine • 5.9m dia, 50m long, Horse Shoe shaped Tail Race Tunnel.	

5.2.6 Sewa-III Hydroelectric Project

Sewa river is a tributary of river Ravi, originating from Sartha hill range and traverses a short course of 53 km down to its junction with river Ravi at an altitude of 578 m. The details of this project are as follows.

1.	**Year of commissioning**	**2002**
2.	**Installed capacity**	**3 x 3 = 9 MW**
3.	**Head**	**38 m**
4.	**Length of Canal**	**2.89 km**
5.	**Location**	**365.83 m**
	State	Jammu & Kashmir
	District	Kathua
6	**Hydrology**	
	Catchment area at diversion area	494 sq. km
	50% dependable discharge	24.13 cumec
	75% dependable discharge	6.94 cumec
7.	**Diversion Structures**	
	Type	Barrage 113.50 m between flanks
8	**Intake Structure**	
	No. & width of bays	One bay of 5 m
	Crest level	590 m
	Design discharge	36.62 cumec
9.	**Penstock**	
	Number	3
	Size	1.9 m dia. each
	Length	62 m
10.	**Power House**	
	Location	Near Sudha Nallah on right bank of river Ravi
	Type	Pit type
	Gross Head	42.80 m
	Net Head	38.00 m

5.2.7 Sewa-II Hydroelectric Project

Sewa-II Power Station is a run-of-the river project having installed capacity of 120 MW. The power house is located in a village called Mashka near the junction of Sewa and Ravi. It is located in Murree formation, Panjal volcanics and Tnawal/Bhadrawah group of rocks in lower Himalayas. The project will generate 533.52 million units in a 90% dependable year and also provide 120 MW peaking capacity in the power system of northern region.

Salient Features of Sewa-II Project	
Location	State - J&K, District - Kathua, River - Sewa (a tributary of Ravi)
Approach	Nearest Rail Head - Pathankot & Nearest Airport - Jammu.
Capacity	120 MW (3 x 40)
Annual Generation	533.52 MU (90% dependable year)
Project Cost	Rs. 665.46 Crores.
Year of Commissioning	July 2010
Technical Features	
• 53 m high Concrete Gravity Dam • 6.0 m Horse Shoe Shaped, 289 m length Diversion tunnel • 3.3 m Horse Shoe Shaped concrete lined Head Race Tunnel (HRT), 10.02 Km length. • 3 x 40 MW, vertical Pelton turbine Rated Net Head = 560 m, Max. Gross Head = 599 m • Rated Net Head = 560 m, Max. Gross Head = 599 m	

5.2.8 Nimoo Bazgo Hydroelectric Project

The proposed Nimoo Bazgo HE Project is a run of the river scheme to harness the hydropower potential of river Indus in Leh District of Jammu & Kashmir. The region of Ladakh combines the conditions of both arctic and desert climate. The present available electricity are grossly inadequate. The project is under construction and will generate 239 MU in a 90% dependable year.

Salient Features of Nimoo Bazgo Project	
Location	Village Alchi in Leh District of Jammu & Kashmir
Approach	Nearest Rail Head - Jammu (740 Km.). Nearest Airport- Leh
Capacity	45 MW (3 x 15 MW)
Annual Generation	239 MUs (in a 90% dependable year)
Project Cost	Rs.611.01 Crores (December 2005 Price Level)
Beneficiary States	J&K
Year of Commissioning/Completion Schedule	January 2013 (As per MOU 2012-13)
Technical Features	
• 57m high, Concrete Gravity Dam • 3 Nos., 3.3m dia, each 63m long Penstocks • Surface Power House with 3 units of 15 MW each, Francis Turbine • 35m long Tailpool	

5.2.9 Miscellaneous Other Hydroelectric Projects

Lower Jhelum Hydroelectric Project

Year of Commissioning	1978-79
Installed capacity	3 x 35 = 105 MW
Present rated Capacity	90 MW
Head	202.72 feet

Length of the water conductor	28670 feet
Carrying capacity of water conductor	7700 cusec

Upper Sindh Hydroelectric Project (Phase-I & II)

Year of commissioning	1973-74
Installed capacity	2 x 1.30 MW = 2.6 MW
Present derated capacity	14 MW
Head	149 m
Length of water Conductor	11 km
Design discharge capacity	425 cusec

Ganderbal Project

Year of commissioning	1956
Installed capacity	2 x 3 + 2 x 4.5 = 15 MW
Present derated capacity	8 MW
Head	137 M (Unit I & II) 140 M (Unit III & IV)
Length of Power canal	15 km
Designed discharge Capacity	473 cusecs

Karnah Project

Year of Commissioning	1991 (Unit-I) 1997 (Unit-II)
Installed capacity	2 x 1 = 2 MW
Present Capacity	1 MW
Net Design Head	36 m
Length of the Diversion Structure	315 m
Maximum Discharge Capacity	8.496 Cumec

Chenani Hydroelectric Project (Phase-I)

Year of commissioning	1971 (Unit I, II, III) 1975 (Unit IV & V)
Installed capacity	5 x 4.66 = 23.30 MW
Present derated Capacity	17 MW
Length of canal	18.64 km
Net head	365.83 m

Chenani Hydroelectric Project (Phase-II)

1.	**Year of commissioning**	**1996**
2.	**Installed capacity**	**2 x 1 = 2 MW**
3.	**Location**	
4.	**District**	**Udhampur**
		Latitude 32 Deg-55' N Longitude 75 Deg-09' E
5.	**Hydrology and climate condition**	
	River	Tawi
	Catchment area upto power house stage-I	652 sq. km
6.	**Water Conductor System**	
	Total Length	2.315 km
	Carrying Capacity	7.12 cumec
7.	**Penstock**	
	Feeder Penstock	50 m
	Diameter	2600 mm
	Bifercation	
	No. of pipes	2
	Length of each pipe	18 m
8.	**Power House**	
	Location	Upstream of Salmey Aqueduct on left bank of river Tawi
	Installed Capacity	2 Units of 1 MW each
	Type	Surface
	Size	26 m x 11.4 m
	No. of Units	2 No.
	Gross Head	32.50
	Net head	32.50
	Type of turbine	Francis
	Rated output	1 MW
9.	**Generator**	
	No. and type	2 x 1000 KW
	Generating Volt.	415 V

Chenani Hydroelectric Project (Phase-III)

1.	**Year of commissioning**	**2001**
2.	**Installed capacity**	**3 x 2.5 = 7.5 MW**
3.	**Head**	**74.4 m**
4.	**BR Capacity**	**16560 cusec**
5.	**Length of canal**	**5.753 km**
6.	**Location**	

	District	Udhampur
	Stage-II	Latitude 32 Deg 52 Mn Longitude 75 Deg 10 Mn
7.	**Hydrology and climate condition**	
	River	Tawi
	Catchment area upto power house stage-I	625 sq. km
8.	**Water Conductor System**	
	Total Length	5.753 km
	Carrying Capacity	
	Diversion to desailting tank	15 cumec
	Desilting tank onwards	13 cumec
9.	**Power House**	
	Location	On the right bank of river Tawi at Kawa
	Installed Capacity	3 Units of 2.5 MW each
	Type	Surface
	Size	45.30 m x 12.15 m
	No. of Units	3 No.
	Gross Head	80 m
	Net head	74.7 m
	Type of turbine	Francis
10.	**Generator**	
	No. and type	3 X 1000 KW Synchronous.

Iqbal Hydroelectric Project

Year of commissioning	1956
Installed capacity	3 x 1.25 = 3.75 MW
Head	15 m
Length of water Conductor	1.5 km

Hunder Hydroelectric Project

Year of commissioning	1995
Installed capacity	2 x 200 KW = 400 KW
No. of Units	2
Type of turbine	Francis
Net Head in meter	32.01
Output at Generator terminals	200 KW

Sumoor Hydroelectric Project

Year of commissioning	1993
Installed capacity	2 x 50 KW = 100 KW
Make	Jyoti Ltd., Baroda
No. of Units	2
Type of turbine	Turbo
Net Head in meter	58
Output at Generator terminals	150 KW
Mounting	Horizontal
Cooling	Water cooled
Type of Governor	Hydro Mechanical Bell Drive.

Bazgo Hydroelectric Project

Year of commissioning	1994
Installed capacity	2 x 150 KW = 300 KW
Make	Jyoti Ltd., Baroda
No. of Units	2
Type of turbine	Turbo
Net Head in meter	58
Output at Generator terminals	150 KW
Mounting	Horizontal
Cooling	Water cooled
Type of Governor	Hydro Mechanical Bell Drive

* * *

CHAPTER – 6
HYDRO-METEOROLOGICAL CHARACTERISTICS

6.1 General

Precipitation and discharge are the two major variables of a hydrologic regime of any river system, and changes in their pattern could have direct and indirect impacts on water resources. Changing climate due to rising GHGs concentration and subsequently global warming may alter the spatial and temporal pattern of precipitation. Change in its distribution would influence the spatial and temporal distribution of runoff, soil moisture, groundwater reserves and would alter the frequency of droughts and floods. To understand and track these changes, it is very important to analyze the trend of these hydro-meteorological variables. This chapter deals with the hydro-meteorological characteristics of the Jammu and Kashmir State.

6.2 Precipitation Characteristics in Chenab Basin

There are 24 precipitation measuring stations of Central Water Commission (CWC) located in various parts of the Chenab basin. In addition, there are two meteorological stations of IMD in the basin at Batote and Bhaderwah. The data at these stations are available up to 2001. The precipitation data on daily basis from 1967-2007 has been acquired from CWC. Locations of these stations are shown in Figure - 6.1. The precipitation characteristics of Chenab basin for annual and seasonal time scales are summarized in Tables 6.1 to 6.3.

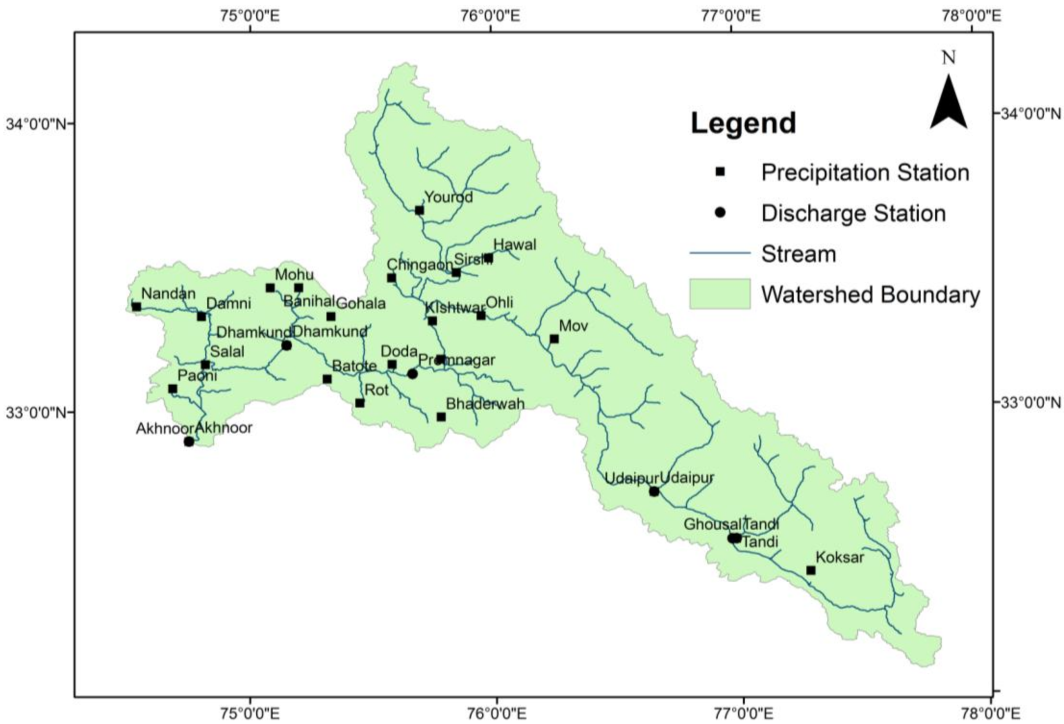

Figure - 6.1: Precipitation and Discharge gauging stations in Chenab basin

Table - 6.1
Annual precipitation characteristics of Chenab Basin

S. No.	Station	Elevation (m)	Average	Stan. Dev.	Max	Min	Skewness	Kurtosis
1	Akhnoor	305	1431.92	356.16	2351.30	679.80	0.22	0.12
2	Banihal	1625	1107.80	350.82	1991.60	485.60	0.16	-0.12
3	Batote	1570	1315.91	336.37	2000.30	529.35	-0.26	0.06
4	Bhaderwah	1830	1116.52	327.28	1737.60	379.20	-0.16	-0.22
5	Chingaon	1840	1593.92	563.77	3179.30	513.00	0.30	0.68
6	Damni	885	1860.03	458.81	2665.10	892.40	-0.40	-0.86
7	Dhamkund	640	1178.41	340.17	1797.50	245.60	-0.32	0.10
8	Doda	1140	784.50	297.44	1218.90	188.40	-0.38	-0.77
9	Drabshala	1095	723.53	228.88	1247.72	342.60	0.41	-0.40
10	Gohala	2400	712.08	406.85	1666.60	78.20	0.72	0.07
11	Hawal	2745	1701.58	885.81	5373.30	629.10	2.63	8.36
12	Kishtwar	1615	909.34	377.00	1917.10	277.71	0.92	1.06
13	Koksar	3615	929.32	409.48	1969.00	378.50	0.74	-0.01
14	Mohu	2440	1456.28	672.43	2958.90	113.20	0.15	-0.12
15	Mou	2900	1020.62	374.09	1825.10	307.50	0.22	-0.34
16	Nandan	1910	2774.88	835.51	4982.70	765.10	0.10	0.59
17	Ohli	1585	1043.32	353.90	1908.00	162.40	0.18	0.82
18	Paoni	600	2341.78	660.44	3796.90	1217.90	0.68	0.25
19	Rot	1375	1249.67	406.81	2628.20	530.90	0.91	1.98
20	Salal	610	1494.26	562.17	2351.50	109.40	-0.50	-0.65
21	Sirshi	1675	1032.45	271.35	1614.10	514.70	-0.05	-0.56
22	Tandi	2600	751.07	439.81	2703.60	73.00	2.66	9.60
23	Udaipur	3100	672.39	230.09	1246.60	176.10	0.14	0.71
24	Yourod	2165	721.35	572.11	1919.10	40.20	1.05	-0.19

Table - 6.2
Precipitation characteristics of Chenab Basin during Monsoon/Summer (Jun-Sep) season

S. No.	Station	Elevation (m)	Average	Stan. Dev.	Max	Min	Skewness	Kurtosis
1	Akhnoor	305	1113.08	335.14	2104.20	395.80	0.57	0.94
2	Banihal	1625	337.20	158.66	719.80	74.40	0.43	-0.03
3	Batote	1570	562.17	172.57	1043.30	33.25	-0.04	2.16
4	Bhaderwah	1830	524.11	201.06	965.60	53.40	0.25	0.34
5	Chingaon	1840	563.57	214.76	1043.80	193.20	0.36	-0.43
6	Damni	885	918.50	276.47	1574.30	427.60	0.32	-0.20
7	Dhamkund	640	447.56	195.36	894.80	41.80	0.30	-0.21
8	Doda	1140	288.28	139.11	584.60	29.00	0.28	-0.35
9	Drabshala	1095	310.92	130.90	631.00	44.90	0.27	0.02
10	Gohala	2400	378.96	263.57	1017.10	75.60	0.84	-0.36
11	Hawal	2745	698.03	400.83	2206.00	68.60	1.88	5.44
12	Kishtwar	1615	307.38	161.65	728.80	19.00	0.46	0.04
13	Koksar	3615	599.40	324.72	1368.00	151.90	0.93	-0.02
14	Mohu	2440	402.36	283.25	1310.90	18.80	1.10	1.30
15	Mou	2900	386.11	189.17	944.80	18.80	0.69	0.83
16	Nandan	1910	1880.84	637.18	3384.70	69.00	-0.41	1.27
17	Ohli	1585	365.34	157.58	915.70	82.40	1.05	2.74
18	Paoni	600	1834.10	601.37	3625.00	761.70	0.96	1.54

S. No.	Station	Elevation (m)	Average	Stan. Dev.	Max	Min	Skewness	Kurtosis
19	Rot	1375	516.04	299.31	1489.20	114.80	1.47	2.71
20	Salal	610	901.59	386.66	1660.60	49.00	-0.06	-0.40
21	Sirshi	1675	332.00	150.11	657.70	48.70	0.12	0.02
22	Tandi	2600	238.86	106.29	542.00	66.10	0.73	0.48
23	Udaipur	3100	235.54	129.46	631.20	55.30	1.52	2.70
24	Yourod	2165	328.42	337.82	1180.30	17.80	1.38	0.84

Table - 6.3

Precipitation characteristics of Chenab Basin during winter season (Nov-Apr)

S. No.	Station	Elevation (m)	Average	Stan. Dev.	Max	Min	Skewness	Kurtosis
1	Akhnoor	305	316.54	152.74	818.10	49.90	0.85	1.88
2	Banihal	1625	779.36	315.44	2077.20	273.80	1.78	6.31
3	Batote	1570	753.36	317.26	1700.40	218.00	0.70	0.72
4	Bhaderwah	1830	598.34	230.76	1014.40	101.50	0.34	-0.36
5	Chingaon	1840	1029.58	561.39	3411.60	241.60	2.26	9.01
6	Damni	885	915.53	357.02	1592.00	134.50	-0.29	0.06
7	Dhamkund	640	731.14	232.48	1392.40	233.40	0.23	0.51
8	Doda	1140	492.62	247.35	1041.40	100.00	0.49	-0.42
9	Drabshala	1095	409.24	183.31	1064.40	72.30	1.30	3.06
10	Gohala	2400	338.11	170.20	803.30	78.20	0.64	0.52
11	Hawal	2745	977.78	529.54	2372.50	300.38	1.88	4.69
12	Kishtwar	1615	617.90	298.40	1775.50	70.63	1.36	5.06
13	Koksar	3615	366.45	138.73	605.00	103.00	0.02	-0.74
14	Mohu	2440	1036.94	598.28	2357.20	19.50	0.61	-0.33
15	Mou	2900	635.04	246.70	1195.00	149.50	0.10	-0.42
16	Nandan	1910	893.69	415.48	2094.80	325.50	0.92	0.59
17	Ohli	1585	709.72	250.06	1281.20	206.50	0.24	-0.18
18	Paoni	600	521.22	281.54	1208.40	63.00	0.64	0.08
19	Rot	1375	733.30	248.15	1313.30	386.40	0.54	-0.26
20	Salal	610	628.81	308.68	1382.30	128.83	0.53	-0.17
21	Sirshi	1675	698.51	235.46	1350.10	264.80	0.29	0.14
22	Tandi	2600	515.69	418.00	2511.60	118.00	3.38	13.90
23	Udaipur	3100	440.65	172.39	885.40	59.50	0.22	0.63
24	Yourod	2165	405.45	264.22	1252.90	96.00	1.41	2.54

The precipitation data of Tawi sub-basin is available at the following stations:

STATION	PERIOD
Jammu (I.A.F)	January 1961 onwards
Jammu (NIH-WHRC)	1991 onwards
Udhampur (I & FC)	January 1961 to December 1972
Udhampur (I.A.F)	1975 to 1980, 1987 to 1989
Chennani (I & FC)	1961 to 1973
Ramnagar (I & FC)	1961 to 1972

6.3 Precipitation Characteristics in Kashmir Region

Long-term rainfall data in the Kashmir region is available at five stations of the India Meteorological Department (IMD), namely Srinagar (34° 05’N, 74° 50’E, Elevation 1586 m), Kulgam (33° 38’ N, 75° 01’ E, Elevation 1770 m), Handwara (34° 24’ N, 74° 17’ E, Elevation 1596 m), Qazigund (33° 36’ N, 75° 10’ E, Elevation 1727 m) and Kukarnag (33° 35’N, 75° 18’E, Elevation 1890 m).

Mean seasonal, mean annual and the coefficient of variation of the annual rainfall and rainy days are given in Table - 6.4. The mean annual rainfall varies from 667 mm at Srinagar (for the period 1903 – 1982) to 1234 mm at Qazigund (for the period 1962 – 2002). The coefficient of variation (CV) of the annual rainfall varies from 22% (Srinagar) to 31% (Kulgam). Mean annual rainy days varies from 56 (Srinagar) to 65 days (Handwara), with a mean of 60 days. Looking at the amount of rainfall in different seasons, it is evident that all the stations receive maximum rainfall in winter season. The high amount of rainfall in the winter season in the Kashmir Valley is due to the western disturbances. The cold fronts associated with these disturbances generate thunderstorms in the pre-monsoon season in Kashmir Valley. The Valley is generally cut off from the south western monsoon by the high ranges of Pir Panjal, but sometimes under favourable conditions, monsoon winds are pulled into the Kashmir Valley (Katiyar, 1987). The contribution of pre-monsoon rainfall varies from 25% (Qazigund) to 30% (Kukarnag), while contribution of monsoon rainfall varies from 15% (Handwara) to 26% (Kulgam). The post-monsoon season is the season of minimum rainfall. The winter season experiences the maximum number of rainy days, followed by the pre-monsoon season.

Table - 6.4

Seasonal distribution of rainfall and rainy days at different stations in Kashmir region (Source : Kumar and Jain, 2010)

S No	Location	Data period	Annual		Pre-monsoon		Monsoon		Post-monsoon		Winter	
			Mean	CV	Mean	% of Annual	Mean	% of Annual	Mean	% of Annual	Mean	% of Annual
Rainfall(mm)												
1	Srinagar	1903–1982	667.0	0.22	186.2	27.9	156.8	23.5	49.3	7.4	274.6	41.2
2	Kulgam	1903–1982	902.3	0.31	239.6	26.6	233.6	25.9	60.5	6.7	368.5	40.8
3	Handwara	1903–1982	1077.7	0.29	305.4	28.3	61.8	15.0	89.4	8.3	521.0	48.3
4	Srinagar	1962–2002	688.3	0.22	202.6	29.4	149.3	21.7	57.8	8.4	278.6	40.5
5	Qazigund	1962–2002	1233.8	0.25	306.6	24.9	249.6	20.2	89.0	7.2	588.6	47.7
6	Kukarnag	1962–2002	1010.4	0.25	297.8	29.5	254.3	25.2	74.4	7.4	384.0	38.0
7	Srinagar	1901–2002	675.8	0.22	192.5	28.5	155.8	23.1	50.5	7.5	276.9	41.0
Rainy days												
1	Srinagar	1903–1982	56	0.15	17	30	13	23	4	7	23	40
2	Kulgam	1903–1982	58	0.21	16	28	15	26	4	7	23	39
3	Handwara	1903–1982	65	0.21	19	29	12	18	5	8	29	45

6.4 Discharge Characteristics in Chenab basin

There are nine river gauging sites of Central Water Commission (CWC) in the Chenab basin up to Akhnoor. Long-term data at these sites are available at daily time step. The Irrigation and Flood Control Department, Govt. of J & K also has one river gauging station at Akhnoor. Locations of these stations are shown in Figure - 6.1. The annual and seasonal discharge characteristics in the Chenab basin have been summarized in Table - 6.5.

Table - 6.5

Discharge characteristics of Chenab basin for annual and seasonal time scales

Annual						
Station	**Max (m^3/s)**	**Min (m^3/s)**	**Av. (m^3/s)**	**Stan. Dev.**	**Skewness**	**Kurt**
Akhnoor	1147.03	522.98	833.96	140.72	0.09	-0.18
Dhamkund	1534.65	482.25	835.91	147.69	1.31	4.03
Premnagar	885.66	293.28	660.63	112.54	-0.72	1.85
Ghousal	146.82	52.64	105.16	17.38	-0.27	2.24
Udaipur	310.64	87.79	228.11	44.24	-0.79	2.05
Benzwar	559.80	259.65	418.44	65.15	-0.40	0.51
Tandi	81.43	25.68	56.77	10.51	-0.13	1.68
Miyar Nalah	57.38	15.04	32.22	8.64	0.81	1.51
Sirshi	207.79	56.70	144.21	38.22	-0.46	-0.33
Spring (Mar-May)						
Akhnoor	1004.69	363.13	683.59	164.84	0.01	-0.72
Dhamkund	1277.22	386.75	697.22	209.89	0.85	0.86
Premnagar	832.83	297.12	464.01	119.79	1.11	1.71
Ghousal	97.63	27.84	50.62	18.79	1.05	0.21
Udaipur	193.34	59.77	115.50	38.96	0.64	-0.68
Benzwar	349.96	140.24	226.57	63.08	0.73	-0.60
Tandi	49.87	13.39	26.13	9.46	1.02	0.46
Miyar Nalah	31.93	8.05	15.64	6.19	0.97	0.36
Sirshi	172.29	18.55	101.75	32.08	0.05	0.70
Monsoon/Summer (Jun-Oct)						
Akhnoor	1969.50	908.69	1427.70	232.39	0.35	0.41
Dhamkund	2036.02	1060.70	1452.62	215.87	0.43	0.26
Premnagar	1661.17	865.64	1214.87	176.63	0.22	0.09
Ghousal	284.61	142.19	207.72	30.11	0.11	0.66
Udaipur	573.01	288.68	446.92	71.09	-0.35	0.04
Benzwar	1257.55	461.54	818.20	148.84	0.25	1.62
Tandi	164.14	53.28	110.78	19.94	0.00	2.09
Miyar Nalah	106.88	43.21	63.62	13.87	0.93	1.51
Sirshi	362.14	73.01	265.62	72.15	-0.70	0.01
Winter (Nov-Feb)						
Akhnoor	312.25	147.30	213.73	42.59	0.49	-0.12
Dhamkund	386.65	114.47	197.18	52.27	1.31	3.38
Premnagar	286.16	91.41	136.11	34.39	2.83	10.76
Ghousal	54.36	13.94	23.84	8.23	1.75	4.52
Udaipur	82.75	19.95	51.34	14.59	-0.05	-0.78
Benzwar	133.74	59.43	83.27	17.73	1.11	1.07
Tandi	28.34	8.20	13.34	4.46	1.35	2.39
Miyar Nalah	15.78	4.23	7.70	3.34	1.54	1.38
Sirshi	55.92	15.76	33.69	9.14	0.10	-0.11

6.5 Ground Water Characteristics

The ground water information of the J&K State has been collected from the north western Himalayan regional centre of the Central Ground Water Board (CGWB), Jammu. The department monitors the water levels in observation wells in the State of Jammu and Kashmir for four times in a year, viz May (between 20th and 31st), August (between 20th and 31st), November (1st and 10th) and January (1st and 10th). Water samples from the observation wells are collected once in a year, during May for quality testing. The water level and chemical analysis data, thus collected, are analyzed and interpreted by Global Environmental Monitoring System (GEMS) and Map Info software and the Ground Water Year Book is issued annually by the CGWB with interpreted data and thematic maps depicting the ground water scenario. Most of the information presented here is sourced from the CGWB Ground Water year book (2010-11).

6.5.1 Status of hydrograph network stations

In Jammu & Kashmir, there are 201 National Hydrograph Network Stations (NHNS) besides 19 numbers of piezometers of CGWB. 143 NHNS exist in Jammu province and 58 stations in Kashmir valley. Due to Law and Order problem, the 58 NHNS of Kashmir Valley are not functional. After revival of work in Kashmir Valley in the year 2006, efforts were started to relocate the earlier NHNS but some of the wells were filled up and some could not be located. To establish the network, some NHNS are identified and established to monitor the ground water regime in the valley. Till now, 25 wells have been established. District-wise number of hydrograph Network Station existing in March, 2011 are given Table - 6.6 and locations of NHNS of Jammu province are shown in Figure - 6.2.

Table - 6.6

District wise number of hydrograph Network Station in March, 2011

S. No	District	No. of NHS	Remarks
Jammu Province			
1	Jammu	63	
2	Kathua	42	
3	Udhampur	13	
4	Rajouri	25	
Sub Total		**143**	
Kashmir Province			
5	Srinagar	3	Effort to revive in progress
6	Badgam	0	
7	Pulwama	4	
8	Kupwara	10	
9	Baramulla	06	
10	Anantnag	02	
Sub Total		**25**	
Grand Total		**168**	

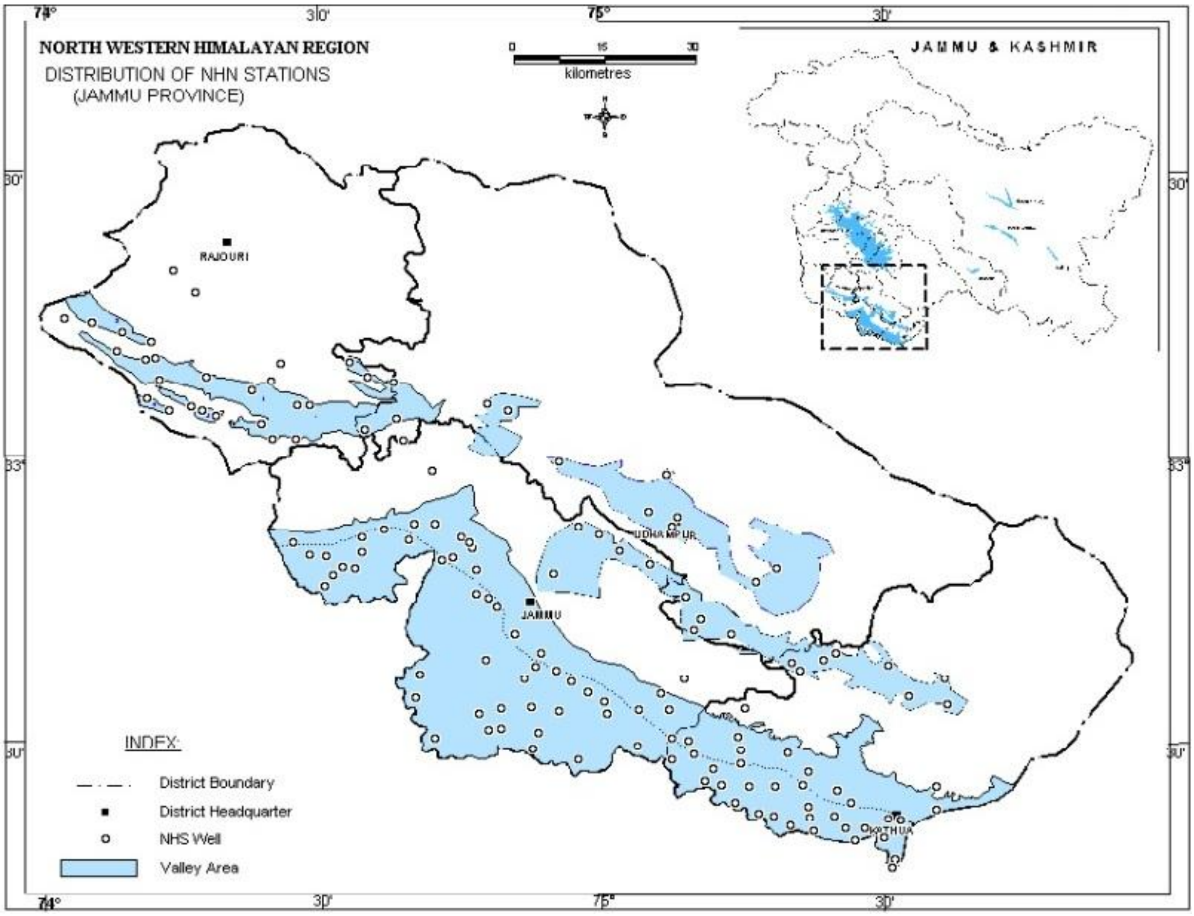

Figure - 6.2: Location map of the NHNS in Jammu Province of J&K

6.5.2 Depth to Groundwater Level in Jammu Province

The latest data of ground water depth for Jammu province for all 143 NHNS for the year 2010-11 for month of May-2010, Aug-2010, Nov-2010 and Jan-2011 are discussed in coming sections. These data have been taken from the ground water year book 2010-11 of NWHR, CGWB, Jammu.

Depth to Water Level in May 2010

The water level data, in respect of 116 out of 143 NHNS for the month of May 2010, was analyzed. The depth to water level ranges from 0.99 in Kathua district to 37.50 m below ground level (bgl) in Jammu district. Water level less than 2.0 m bgl is recorded in 5 wells (4.31%), in 35 wells (30.17%) in the range 2-5 m bgl. whereas, 41wells (35.34%) of the total wells analyzed, have shown water levels in the range of 5-10 m bgl, 17 well (14.66%) and 10 wells (8.62%) are showing the deeper water level, i.e. 10-20 m bgl and more than 20 m bgl respectively. Out of 143 NHNS, 27 wells could not been entered in GEMS because the wells have been deepened and water levels have gone down.

Most of the areas of valley in Udhampur and Rajouri district show water levels between 2-5 m bgl. In outer plain areas, most of the water levels recorded are more than 5 m bgl. Some parts of Udhampur and Rajouri valley also show water levels less than 5 m bgl. However the deep-water level more than 20 m bgl is observed in Kandi area of Jammu & Kathua districts (Figure - 6.3).

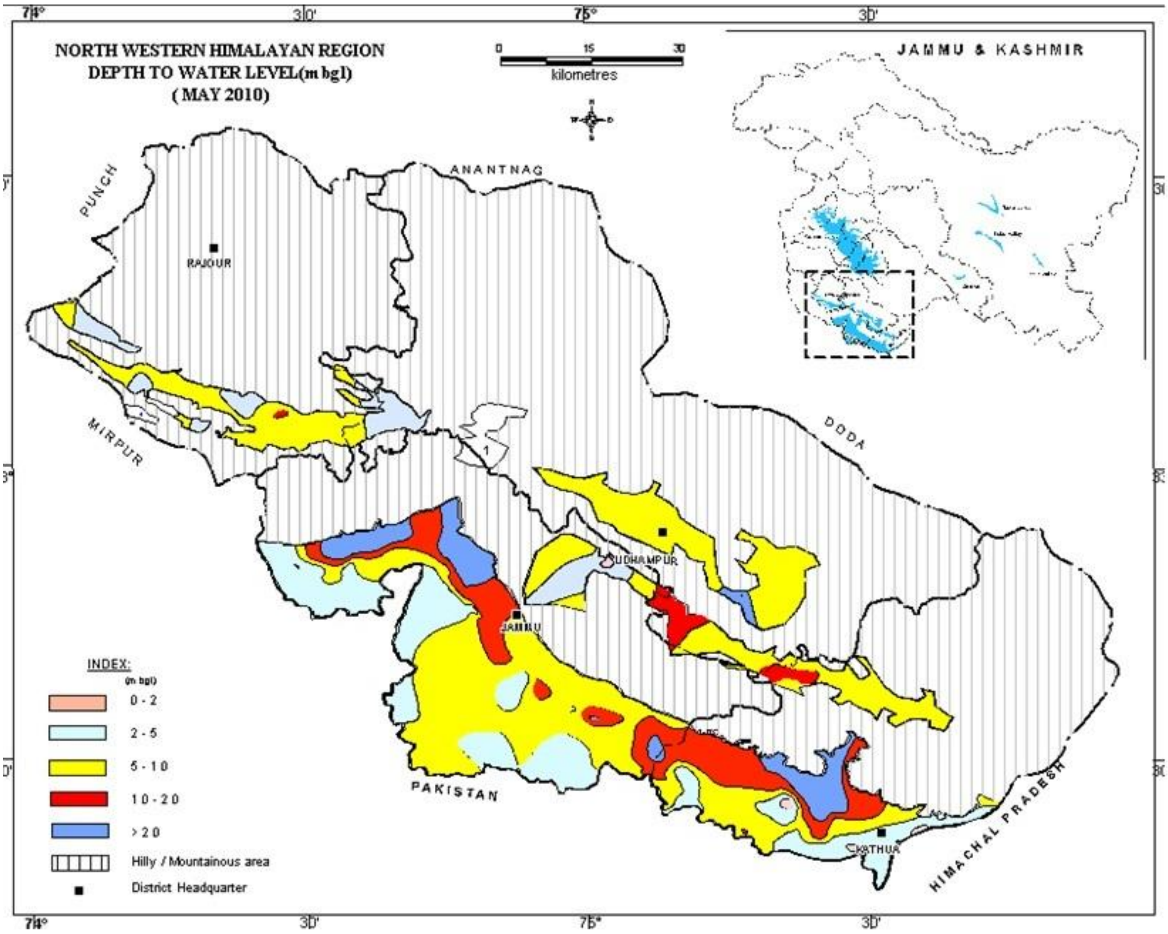

Figure - 6.3: Depth to Groundwater Level in May 2010

Depth to Groundwater Level in August 2010

The water level data, in respect of 132 out of 143 National hydrograph Network Stations for the month of August 2010 was analyzed. The depth to water level ranges from 0.03 to 35.05 m bgl in Jammu district.

Majority of the wells, i.e. 70 wells (53.03%) have recorded the water level in less than 2.0 m bgl, 33 wells (25%) of the total wells analyzed, have shown depth to water level in the range 2-5 m bgl. whereas 13 wells (9.85%) of the total wells analyzed, have shown water levels in the range of 5-10 m bgl. Deeper water level that is more than 20 m bgl is recorded in 6 wells (4.55%) and 10-20 m bgl in 6 wells. Some wells could not been entered in GEMS because the wells have been completely damaged and alternate wells are to be established.

All of the areas of valley in Udhampur and Rajouri districts show water level between 0-2 and 2-5 m bgl. In Outer Plain areas most of the water levels recorded are less than 2 m bgl. Some parts of Jammu and Kathua districts have water level records between 2-5 and 5-10 m bgl. However the deeper water levels viz. 10-20 m bgl are shown in outer plain area of

Jammu and Kathua districts. Deepest water levels that are more than 20 m bgl are observed in Kandi area of Jammu district (Figure - 6.4).

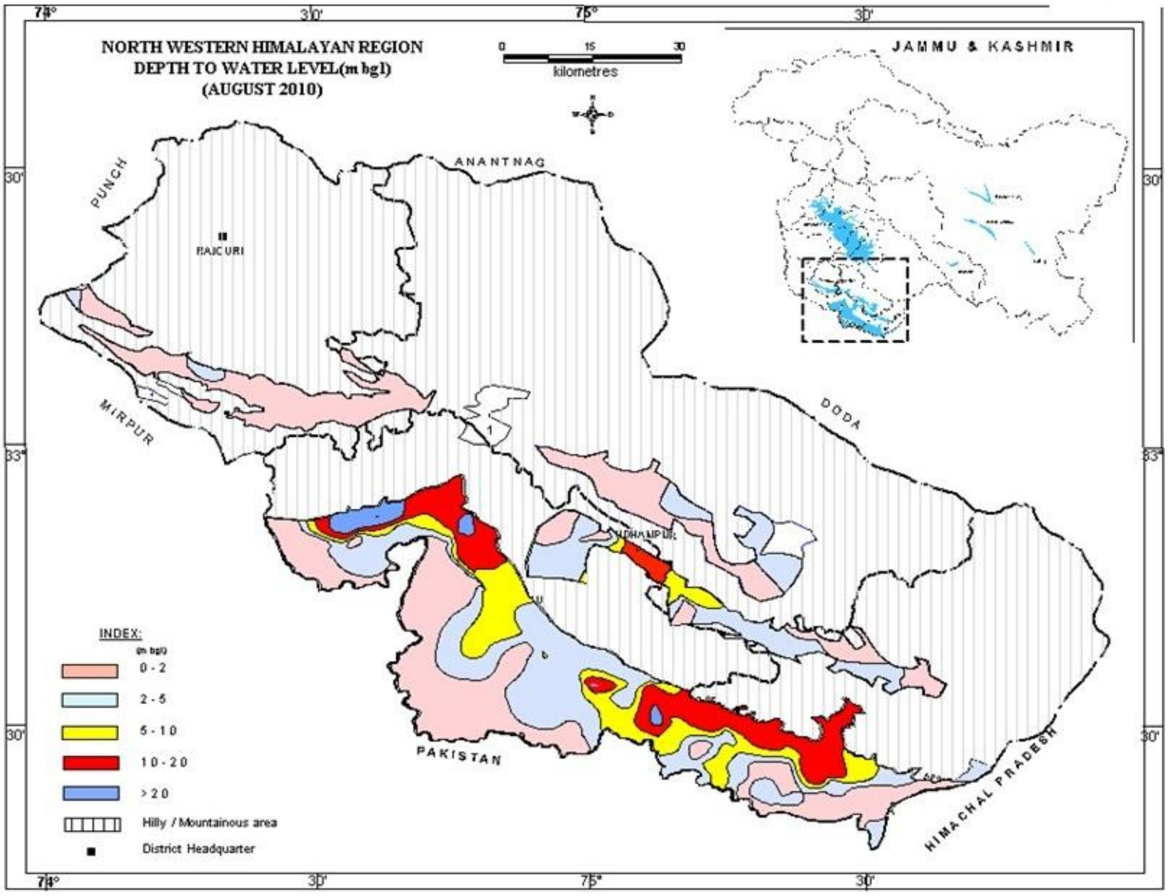

Figure - 6.4: Depth to Groundwater Level in August 2010

Depth to Groundwater Level in November 2010

The water level data, in respect of 128 out of 143 National Hydrograph Network Stations for the month of November 2010 was analyzed. The depth to water level ranges from 0.13 (in Rajouri district) to 34.50 m bgl (in Jammu district). 43 wells (33.59%) have recorded the water level in less than 2 m bgl. Majority of the wells that is 49 wells (38.28%), of the total wells analyzed, have shown depth to water level in the range 2-5 m bgl. Whereas 19 wells (14.84%) of the total wells analyzed, have shown water levels in the range of 5-10 m bgl. 10 wells (7.81%) are showing the deeper water level i.e. 10-20 m bgl. Deepest water level that is more than 20 m bgl is shown by 7 wells (5.47%). Some wells could not been entered in GEMS because the wells have been completely damaged and alternate wells are to be established.

All of the areas of valley in Rajouri and Udhampur district show water level between 0-2 and 2-5 m bgl except some places in Dun valley where water level is between 10 m bgl. In Outer Plain areas most of the water levels recorded are 2-5 m bgl. Some parts of Jammu and Kathua districts water levels are recorded between 2-5 and 5-10 m bgl. However the deeper water level 10-20 m bgl are shown in Outer Plain area of Jammu and Kathua district.

Deepest water levels that are more than 20 m bgl are observed in Kandi area of both Jammu and Kathua districts (Figure - 6.5).

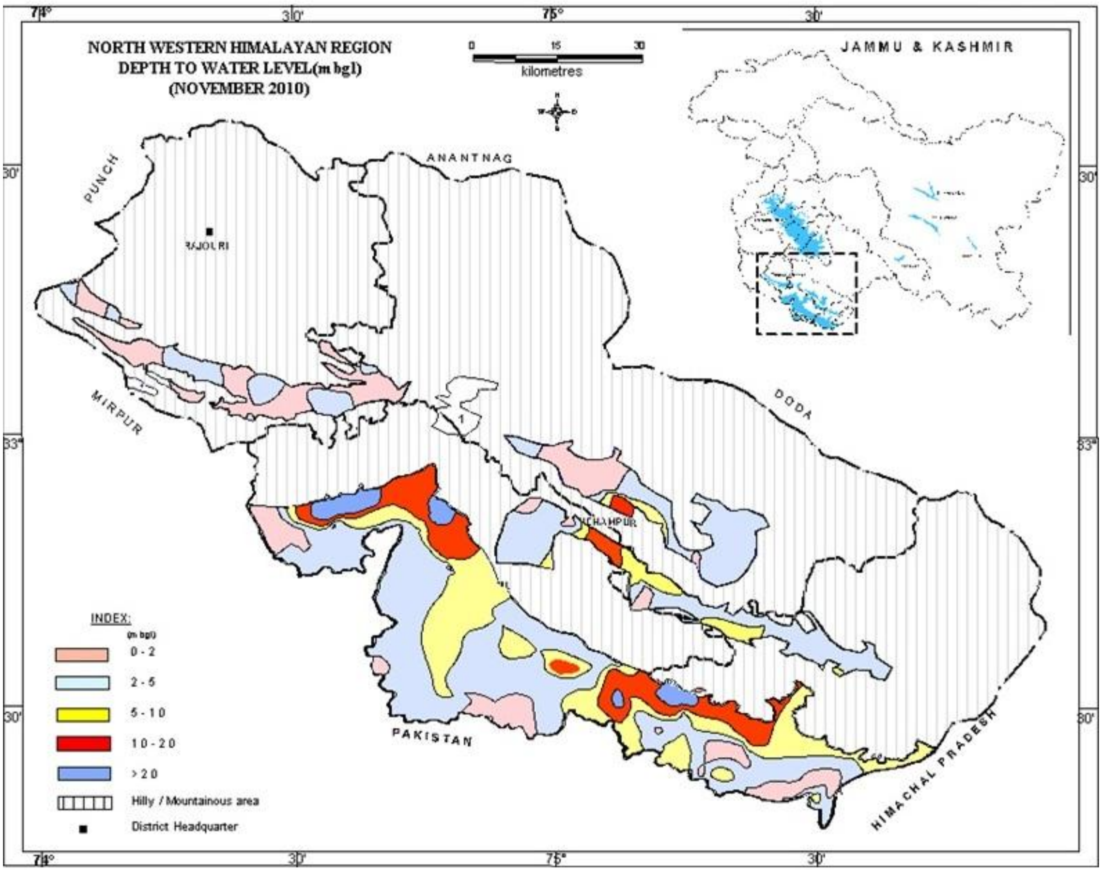

Figure - 6.5: Depth to Groundwater Level in November 2010

Depth to Groundwater Level in January 2011

The water level data, in respect of 128 out of 143 National hydrograph Network Stations for the month of January 2011, was analyzed. The depth to water level ranges from 0.43 (in Udhampur district) to 36.60 m bgl (in Jammu district).

Water levels less than 2 m bgl is recorded in 33 wells (25.78%). Majority of the wells that is 51 wells (39.84%), of the total wells analyzed, have shown depth to water level in the range 2-5 m bgl. Whereas 24 wells (18.75%) of the total wells analyzed, have shown water levels in the range of 5-10 m bgl. 9 wells (8.59%) are showing the deeper water level i.e. 10-20 m bgl. Water level, more than 20 m bgl, is shown by 9 wells (7.03%). Some wells could not been entered in GEMS because the wells have been completely damaged and alternate wells are to be established. All the areas of valley in Rajouri and Udhampur district show water level between 0-2 and 2-5 m bgl except some places in Dun valley where water level is between 10 m bgl. In outer plain areas, most of the water levels recorded are 2-5 m bgl. Some parts of Jammu and Kathua districts water levels are recorded between 2-5 and 5-10 m bgl. However the deeper water level 10-20 m bgl are shown in Outer Plain area of Jammu and Kathua district. Deepest water levels i.e, more than 20 m bgl observed in Kandi area of both Jammu and Kathua districts (Figure - 6.6).

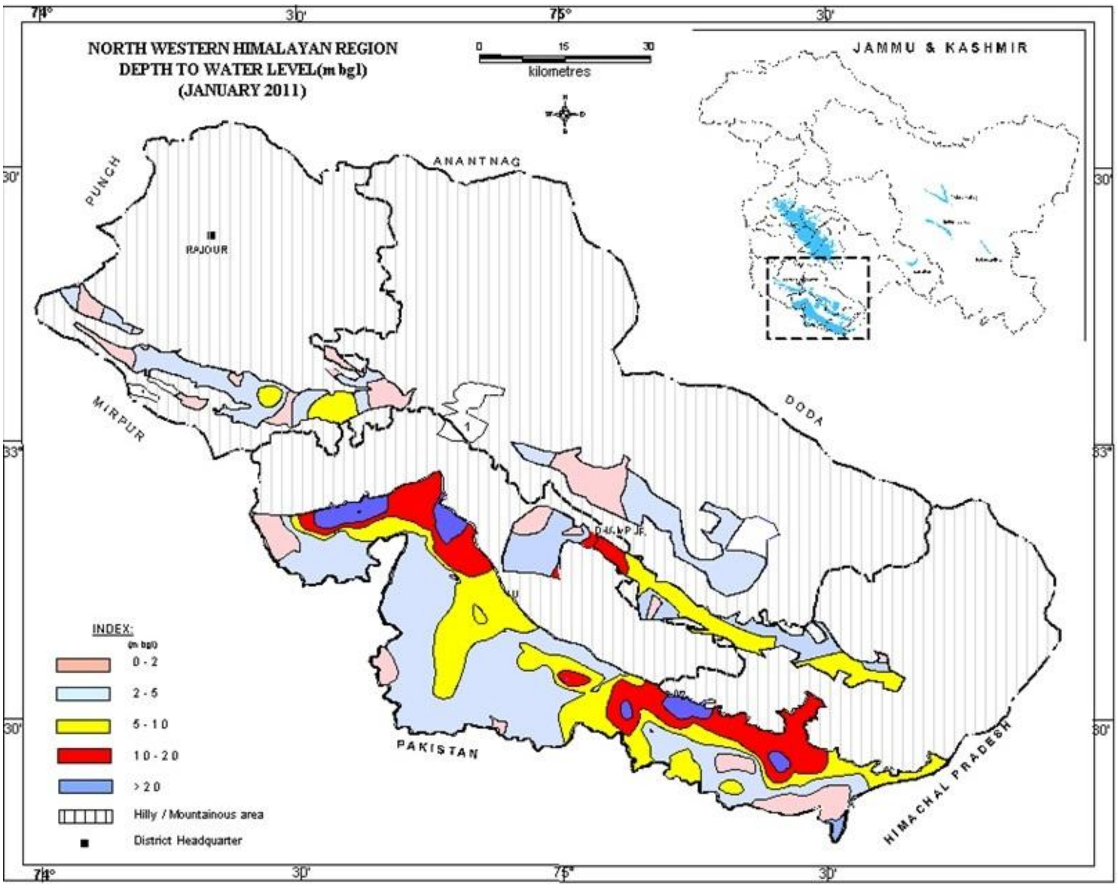

Figure - 6.6: Depth to Groundwater Level in January 2011

6.5.3 Hydrochemistry of Groundwater in Jammu Province

The quality of shallow ground water in the State of Jammu & Kashmir has been evaluated on the basis of 111 water samples collected from shallow ground water aquifers, during pre-monsoon season, i.e. May 2010 by CGWB. All the collected samples were analysed by adopting standard methods of analysis (APHA). The chemical analysis of water samples was done quite late, thus the effect can be seen in terms of considerably high values of pH, carbonates etc. Summarized results of ground water samples are given in Table - 6.7.

Table - 6.7

Ground water quality in NHNS in May, 2010

S. No.	Parameters	Permissible limit	Ranges	No. of Samples	Percentage
1	Sp. Conductance µs/cm at 25^{o}C	-	<750 751-2250 2251-3000 >3000	95 15 01 00	85.6% 13.5% 0.9% 0.0

2	Chloride (mg/l)	250-1000	<250 251-1000 >1000	108 03 00	97.3% 2.7% 0.0
3	Fluoride (mg/l)	1.50 mg/l	<1.00 1.01-1.50 >1.50	110 01 00	99.1% 0.9% 0.0
4	Nitrate (mg/l)	45 mg/l	<45 46-100 >100	105 03 03	94.6% 2.7% 2.7%
5	Iron (mg/l)	1.00 mg/l	<1.00 1.01-1.50 >1.50	92 05 15	82.1% 4.5% 13.4%

Nitrate Concentration

Nitrate is also an important parameter for evaluating ground water quality. In majority of samples (94.6%), concentration of nitrate is less than 45 mg/l. Only 2.7% of samples (3 from Jammu district and 01 from Kathua district) are associated with nitrate concentration more than 45 mg/l, but less than 100 mg/l. Rest 3 (2.7%) samples have reported nitrate concentration more than 100 mg/l. None of the samples of Rajouri and Udahmpur district are associated with Nitrate concentration more than maximum permissible limit of BIS for drinking water purpose. The samples having nitrate concentrations more than maximum permissible limits of BIS, i.e. 45 mg/l is given in Table - 6.8.

Table - 6.8

Samples associated with nitrate concentration > 45 mg/l

S. No.	District	Location	Nitrate (mg/l)
1	Jammmu	Devipur	94
2		Samba	88
3		Bisnah	187
4		Gho Brahamana	230
5	Kathua	Nagrota Gujroo	86
6		Jandi	217

Total Hardness

Hardness of the water is the capacity of water to neutralise soap. Hardness is mainly caused by Carbonate & Bicarbonates of Calcium and Magnesium. This classification is based on the value of total hardness. Ground water may be classified in to four types, Soft, Moderate hard, Hard, and Very Hard (Table - 6.9).

Table - 6.9

Ground water samples as per classification of hardness (in mg/l)

S. No	District	No. of Samples	Soft (0-60)	Mod. Hard (61-120)	Hard (121-180)	Very Hard > 180 mg/l
1	Jammu	50	01	12	17	20
2	Kathua	29	00	14	05	10
3	Rajouri	17	00	09	06	02

4	Udhampur	15	00	09	03	03
	Total	111	01	44	31	35
	%	100%	0.9%	39.6%	28.0%	31.5%

As per the classification, Ground water is moderate hard and very hard. About 39.6% and 31.55% of samples belong to moderately hard and very hard categories respectively. In hard category, 28.0% of samples fall. Only 0.9 % of samples belong to soft category. None of the sample of Kathua, Rajouri and Udhampur belongs to soft category. The range of total hardness of samples is calculated district-wise and summarized in the Table - 6.10.

Table - 6.10

District-wise range of hardness of NHS in May, 2010

S/No	District	Range of Total Hardness (as $CaCO_3$) in mg/l
1	Jammu	60-700
2	Kathua	70-570
3	Rajouri	90-240
4	Udhampur	70-340

From the table, it is very clear that for the samples collected from Jammu district, value of total hardness varies from 60-700 mg/l. As per the BIS norms, 300 and 600 mg/l is the limit for desirable and maximum permissible limit for drinking water purposes. All samples are within the maximum permissible limit (600 mg/l) except Suchetgarh (700 mg/l).

* * *

CHAPTER – 7
TREND ANALYSIS OF HYDRO-METEOROLOGICAL VARIABLES

7.1 General

Climate change and global warming arising from the anthropogenic-driven emissions of greenhouse gases have emerged in the last two decades as one of the most serious environmental issues ever to confront humanity. Although the subject of climate change is vast, the changing pattern of precipitation deserves urgent and systematic attention as it will affect the availability of food supply (Dore, 2005) and the occurrence of water related disasters triggered by extreme events. Precipitation is the major driving force of the land phase of the hydrologic system, and changes in its pattern could have direct impacts on water resources. According to the IPCC (2007), future climate change is likely to affect agriculture, increase risk of hunger and water scarcity and lead to more rapid melting of glaciers. A higher or lower rainfall or changes in its distribution would influence the spatial and temporal distribution of runoff, soil moisture, groundwater reserves and would alter the frequency of droughts and floods.

It is understood that changes in precipitation levels will be accompanied by altered evaporation rates as temperatures rise. The combination of these changes will have profound effects on soil moisture. Soil moisture levels regulate the flow of moisture into rivers, with, for example, saturated soils able to absorb only limited rainfall, thus increasing the likelihood of flooding (Gleick, 1986). Dam planning and operation might also be affected by changing precipitation. In some regions, increased precipitation infers increased energy benefits if the storage capacity exists and if annual distribution of rainfall is favourable. Otherwise increased storm events may mean higher flood flows affecting downstream populations and potential consequences for dam safety. Decreased precipitation will reduce hydropower generation, will provide less water for irrigation and other uses, and increasing competition and conflicts for a dwindling resource.

Global averaged precipitation is projected to increase, but both increases and decreases are expected at the regional and continental scales (IPCC, 2001). Similar trends were reported in rainfall by various authors in the plain of India (Jagannathan and Parthasarathy, 1973; Parthasarathy and Dhar, 1975; Mooley and Parthasarathy, 1984; Thapliyal and Kulshrestha, 1991; Rupa Kumar et al., 1992; Kothyari and Singh, 1996; Srivastava et al., 1998; Sinha Ray and De, 2003; Singh et al., 2008a). Various authors, such as Dhar and Narayanan (1965), Dhar and Farooqui (1973), Dhar et al. (1984), Pant and Borgaonkar (1984), Pant et al. (1999), Shrestha et al. (2000), Sharma et al. (2000), Singh and Sen Roy (2002), Archer and Fowler (2004) and Kumar et al. (2005) have made attempts to study rainfall trends over various parts of the Himalayas. Pant and Borganonkar (1984) did not find any trend in rainfall over the hill region of Uttar Pradesh. Seasonal and annual rainfall did not show any significant trend over western Himalaya during the period 1893–1990 (Pant et al., 1999). Shrestha et al. (2000) found no trend in monsoon precipitation between 1948 and 1994 in the Nepalese Himalaya.

Sharma et al. (2000) found an increasing trend in rainfall at some stations and a decreasing trend at other stations in the Kosi basin in eastern Nepal and Southern Tibet. Similar trends in rainfall were found by Kumar et al. (2005) for the state of Himachal Pradesh. A slight downward trend in monsoon rainfall and a slight upward trend in winter rainfall during 1964–1992 was analysed for the Beas catchment by Singh and Sen Roy (2002). Archer and Fowler (2004), who studied the precipitation at 17 stations in the Upper Indus Basin have found no statistically significant long-term trend in annual or seasonal precipitation over the last century. Khan (2001) detected no trend in Jhelum flows at Mangla reservoir (in Pakistan) and precipitation at three stations in the Jhelum catchment.

7.2 Methodology

For seasonal analysis, each year was divided into four seasons namely, pre-monsoon (April-June), monsoon (July-September), post-monsoon (October-November) and winter season (December-March), depending upon climatic conditions prevailing over the region. Seasonal and annual anomalies of rainfall and rainy days for each station were computed with reference to the mean of the respective variable for available records. These anomalies were plotted against time, and trends were examined by fitting a linear regression line to the data. Linear trends represented by the slope of the simple least-square regression line provided the rate of rise/fall in the variable. Using the value of rate of change, the total change over the last century was computed.

To identify the trend in climatic variables, the Mann-Kendall test has been employed by a number of researchers (Yu et al., 1993; Douglas et al., 2000; Yue et al., 2003; Burn et al., 2004, Singh et al., 2008a, b). In the present study also, the commonly used nonparametric Mann-Kendall test was applied to determine monotonic trends in different variables. Before applying the Mann-Kendall test, data series were tested for serial correlation. If lag-1 auto-correlation (r1) was found to be non-significant at the 95% confidence level, then the Mann-Kendall test was applied to the original data series ($x_1,x_2,.,x_n$), otherwise, the Mann-Kendall test was applied on 'pre-whitened' series obtained as ($x_2-r_1x_1,x_3-r_1x_2,., x_n -r_1x_{n-1}$)(Von Storch and Navarra, 1995; Partal and Kahya, 2006).

7.3 Trend Analysis of Precipitation in the Chenab Basin

The Chenab basin is an important Himalayan sub-catchment of the Indus Basin. Precipitation and runoff process of Himalayan catchments are complex phenomena controlled by a large number of climatic and physiographic factors that vary with both time and space. To identify the long-term trend of precipitation of the basin available records of the 24 precipitation station of CWC has been analyzed in this study. First of all the daily time series were aggregated into seasonal and annual time series and standardized in order to bring uniformity and facilitate comparison between the hydrological responses of these stations, yearly Standardized Precipitation Index (SPI) were computed by subtracting the mean and dividing by the standard deviation of the discharge data series (Shreshtha et. al. 2000; Pant & Kumar 1997). The SPI data series were subjected to trend analyses by two established statistical techniques: standard parametric technique, such as linear regression analysis (Borgaonkar & Pant, 2001) and non-parametric test such as Kendall–Manny's test (Kendall & Stuart 1961).

The precipitation data of two seasons namely, winter (from November of the last year to April of the current year) and monsoon (June to September) and total annual precipitation, were used to study the trends and temporal fluctuations in climate over the Chenab basin. The plots between SPI Vs the respective years of all 24 precipitation gauging station of Chenab are being presented in form of graphs in Fig 2, Fig 3 and Fig 4 for annual, summer/Monsson (MAR-OCT) and winter (NOV-FEB) time series respectively. Simple linear curve fitting was also performed to find the trend of the precipitation. The positive and negetive trends for each precipitation gauging station are also presented in Table - 7.1.

Table - 7.1

SPI Linear trend analysis for annual, monsoon and winter precipitation in Chenab basin

S. No.	Station	Elevation (m)	Season		
			Annual	Summer	Winter
1	Akhnoor	305	(-)	(+)	(+)
2	Paoni	600	(+)	(+)	(+)
3	Salal	610	(-)	(-)	(-)
4	Dhamkund	640	(-)	(-)	(+)
5	Damni	885	(-)	(-)	(-)
6	Drabshala	1095	(-)	(-)	(-)
7	Doda	1140	(-)	(+)	(-)
8	Rot	1375	(-)	(-)	(-)
9	Batote	1570	(+)	(+)	(-)
10	Ohli	1585	(+)	(-)	(-)
11	Kishtwar	1615	(-)	(-)	(+)
12	Banihal	1625	(-)	(-)	(+)
13	Sirshi	1675	(+)	(-)	(-)
14	Bhaderwah	1830	(-)	(+)	(-)
15	Chingaon	1840	(-)	(-)	(-)
16	Nandan	1910	(-)	(-)	(-)
17	Yourod	2165	(-)	(+)	(+)
18	Gohala	2400	(-)	(-)	(-)
19	Mau	2440	(+)	(+)	(+)
20	Tandi	2850	(-)	(-)	(-)
21	Hawal	2745	(-)	(-)	(-)
22	Mohu	2900	(-)	(-)	(-)
23	Udaipur	3100	(+)	(+)	(+)
24	Koksar	3615	(+)	(+)	(+)

The long term trends in SPI series were evaluated by using standard parametric simple linear trend and non-parametric statistical technique i.e. the Mann-Kendall test. Table - 7.1 shows the results for precipitation simple linear trends of SPI series of various precipitation stations of Chenab Basin. The results for the non-parametric Mann-Kendall test for trend detection along with the Z- values of the individual precipitation station are shown in Table - 7.2. Changes in pattern for each precipitaion station of Chenab basin is depicted in

Figure - 7.2, 7.3 and 7.4. It is evident from the Tables - 7.1 &7.2 and Figures - 7.2, 7.3 & 7.4 that there are declining trend of precipitaion over the last 3-4 decades in most of the rain and snow gauge stations. As 20 out 24 numbers of stations are showing decreasing trend on annual basis and out of 20, eleven stations having deceasing trend with more than 90% confidence level, eight staion with more than 95% and five sations with more than 99% confidence level. More over 17 out of 24 stations are also nine number of stations out of those 17 stations having decreasing trend with more than 90% confidence level for summer and winter season respectively.

Table - 7.2

Results of Mann-Kendall Test for annual, monsoon and winter precipitation in Chenab basin

S. No.	Station	Elevation (m)	Z - Value		
			Annual	**Summer**	**Winter**
1	Akhnoor	305	-0.35	-0.85	0.67
2	Paoni	600	2.48**	2.18**	1.12
3	Salal	610	-3.24**	-3.51**	-1.32+
4	Dhamkund	640	-0.78	-1.18	-0.10
5	Damni	885	-0.82	-0.88	-0.44
6	Drabshala	1095	-1.8*	-0.25	-1.75*
7	Doda	1140	-1.82*	-0.56	-1.58+
8	Rot	1375	-0.52	-1.59+	0.30
9	Batote	1570	-0.88	0.49	-0.82
10	Ohli	1585	-0.36	-0.80	1.11
11	Kishtwar	1615	-1.34+	-0.80	0.68
12	Banihal	1625	-1.22	-2.1*	-0.29
13	Sirshi	1675	-0.3	-0.94	0.59
14	Bhaderwah	1830	-1.52+	-0.03	-1.83*
15	Chingaon	1840	-3.1**	-1.87*	-3.11**
16	Nandan	1910	-2.19**	-2.53**	-0.36
17	Yourod	2165	-0.96	-0.42	-0.63
18	Gohala	2400	-1.56+	-2.55**	-1.3+
19	Mohu	2440	-2.88**	-5.12**	0.90
20	Tandi	2600	-2.17*	-0.40	-2.46**
21	Hawal	2745	-2.57**	-1.07	-3.39**
22	Mou	2900	1.27+	0.84	-1.44+
23	Udaipur	3100	0.15	0.93	-1.25
24	Koksar	3615	0.21	0.61	0.72

** Existance of trend with 99% Confidence Level

* Existance of trend with 95% Confidence Level

+ Existance of trend with 90% Confidence Level

Only two stations, namely Paoni and Mou, are showing increasing trend with 90% singificance level on annual basis and two other station udaipur and koksar have the increasing trend. Paoni sation showing significant incresing trend in all seasons.The figures indicates there is a declining trend of precipiation over the year in Chenab basin.

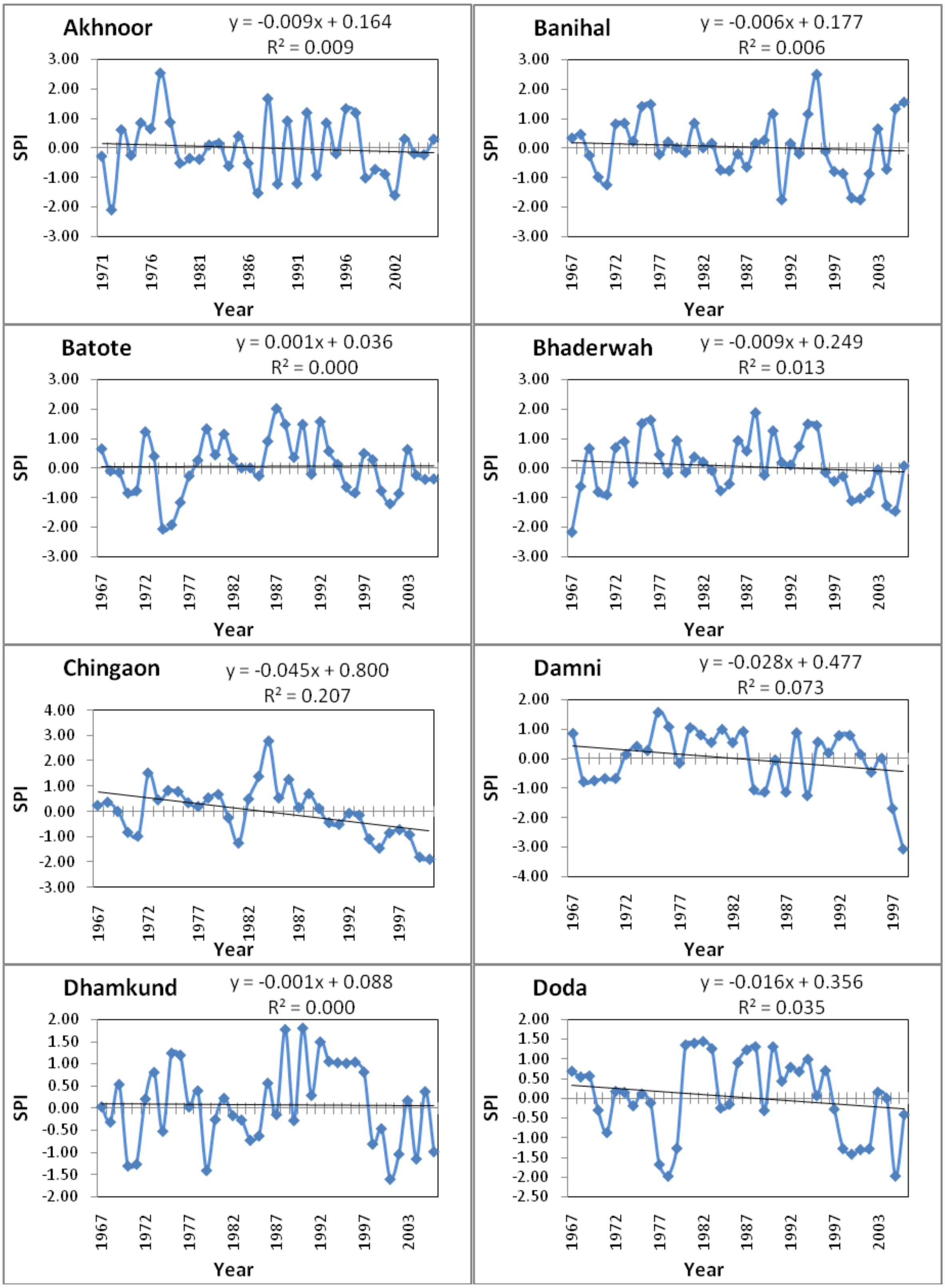

Figure - 7.2(a): Linear trends of Annual Precipitaion at stations of Chenab Basin

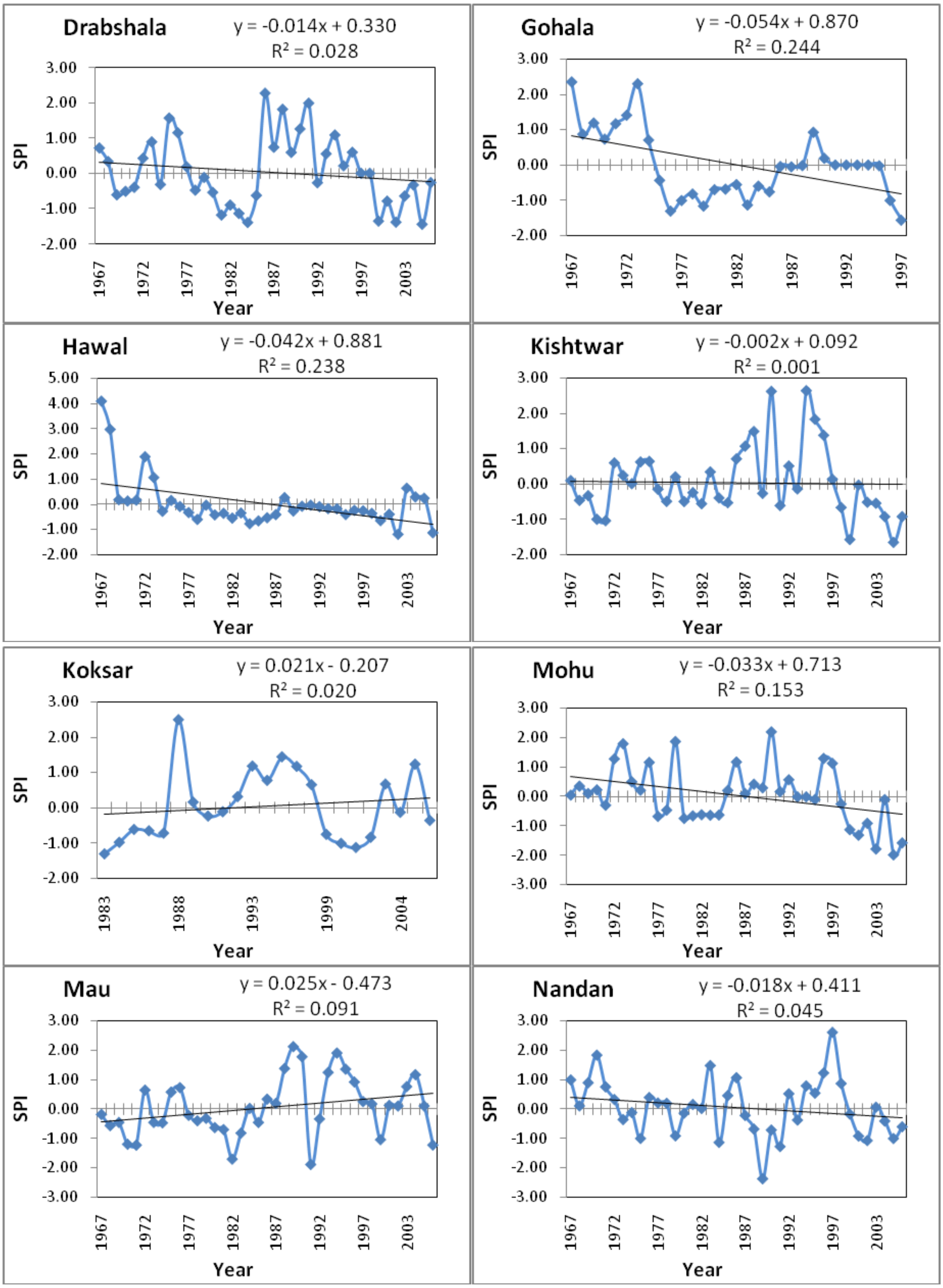

Figure - 7.2(b): Linear trends of Annual Precipitaion at stations of Chenab Basin

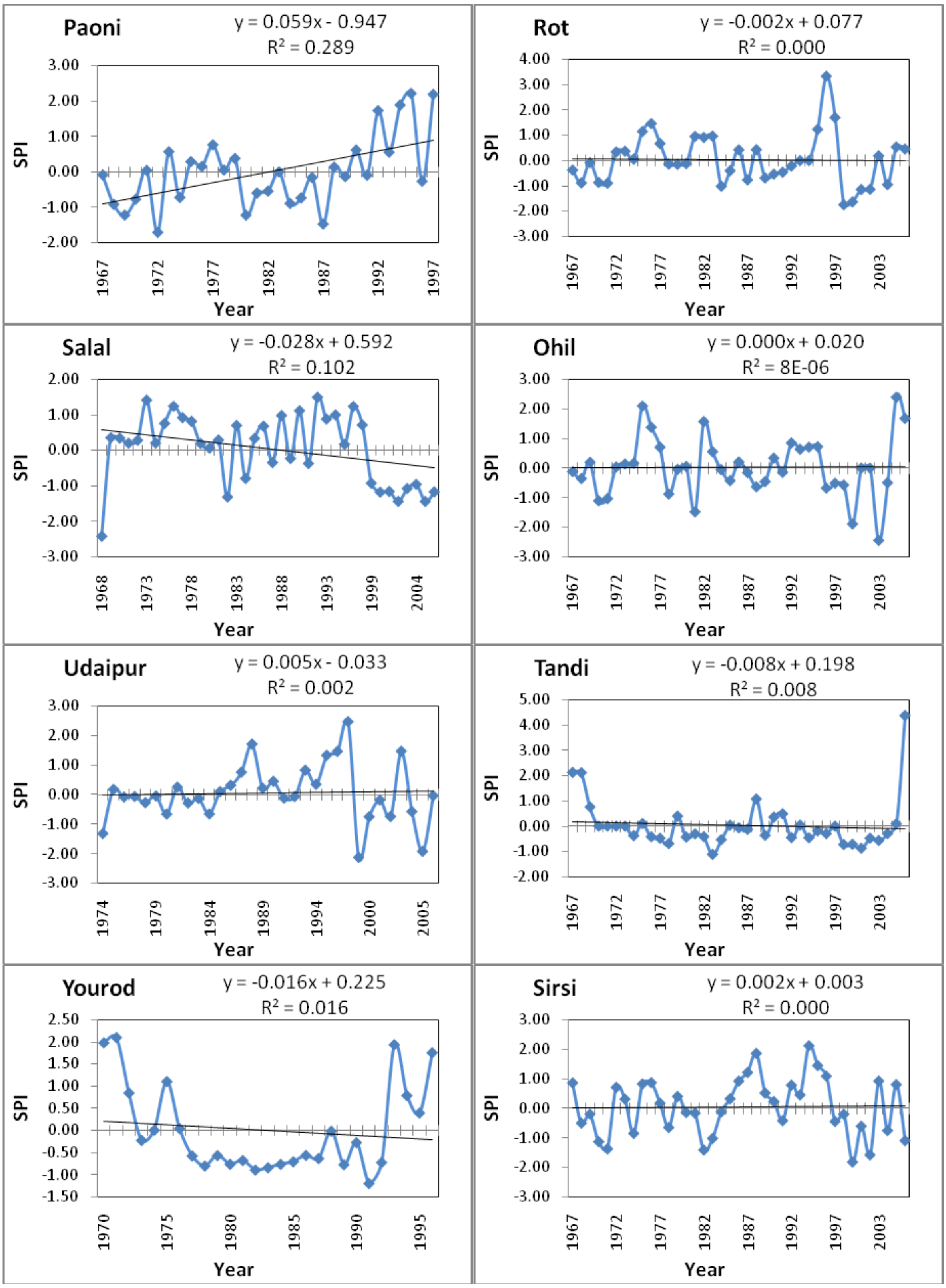

Figure - 7.2(c): Linear trends of Annual Precipitaion at different stations of Chenab Basin

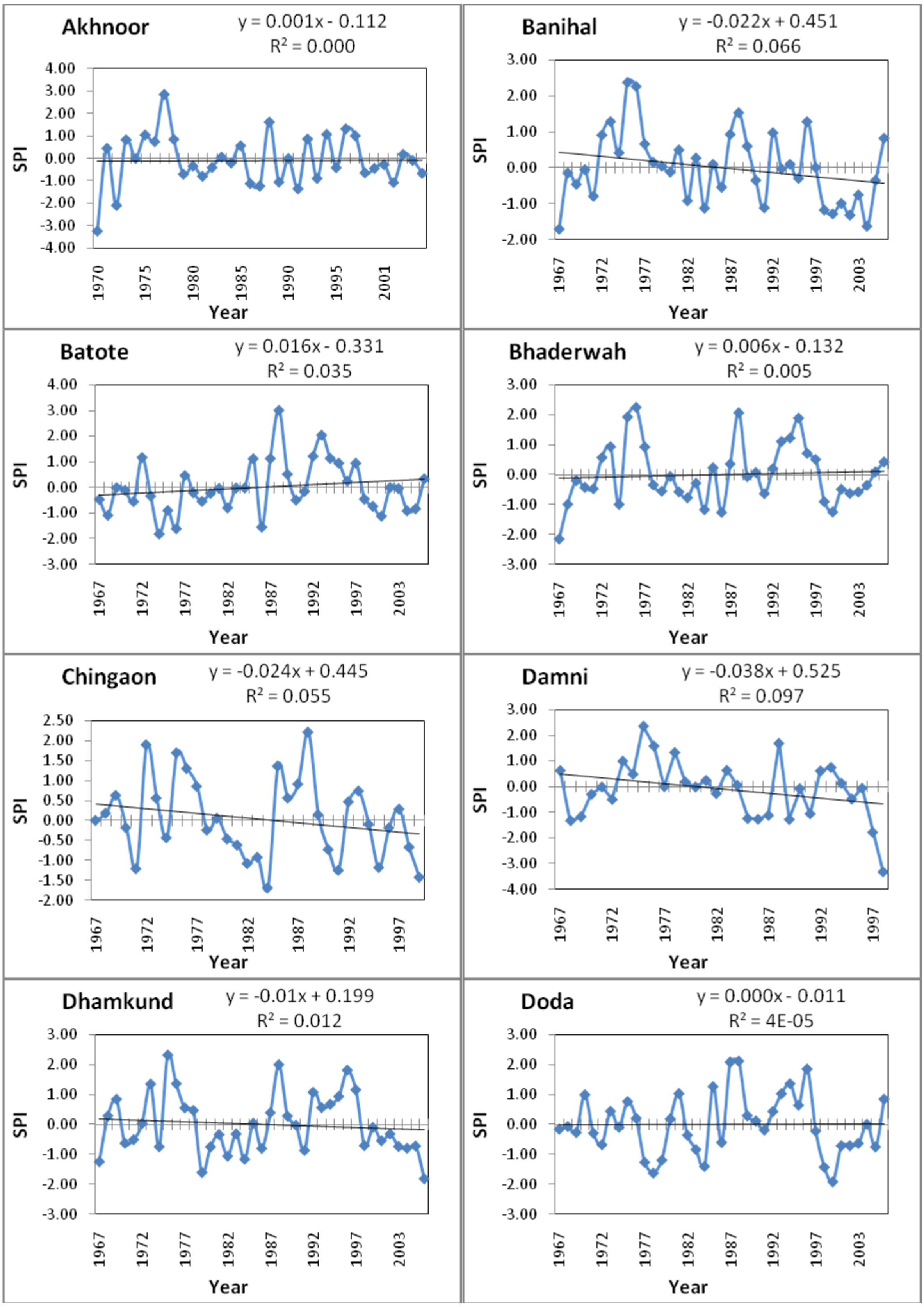

Figure - 7.3(a): Linear trends of Summer Precipitaion at different stations of Chenab Basin

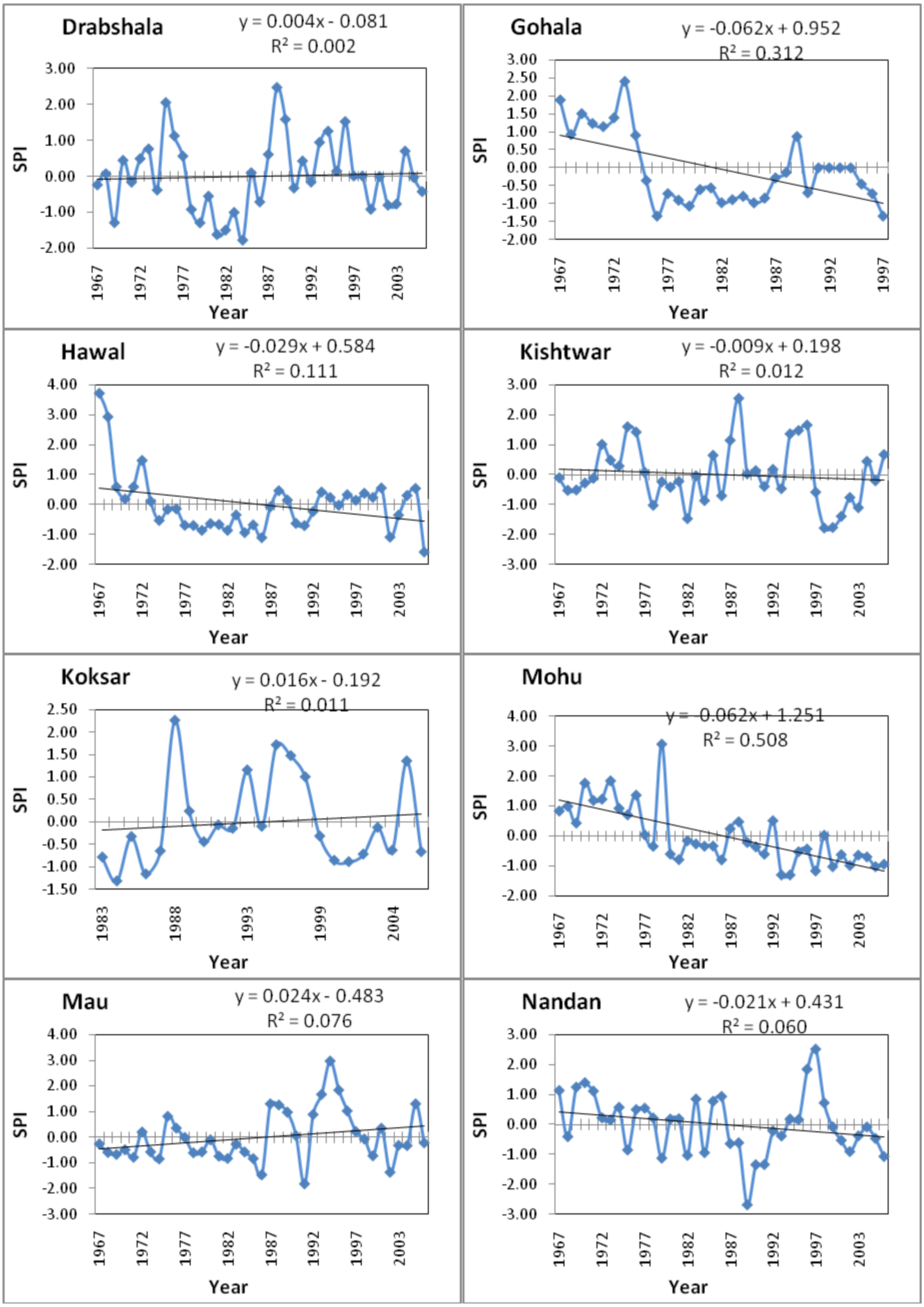

Figure - 7.3(b): Linear trends of Summer Precipitaion at different stations of Chenab Basin

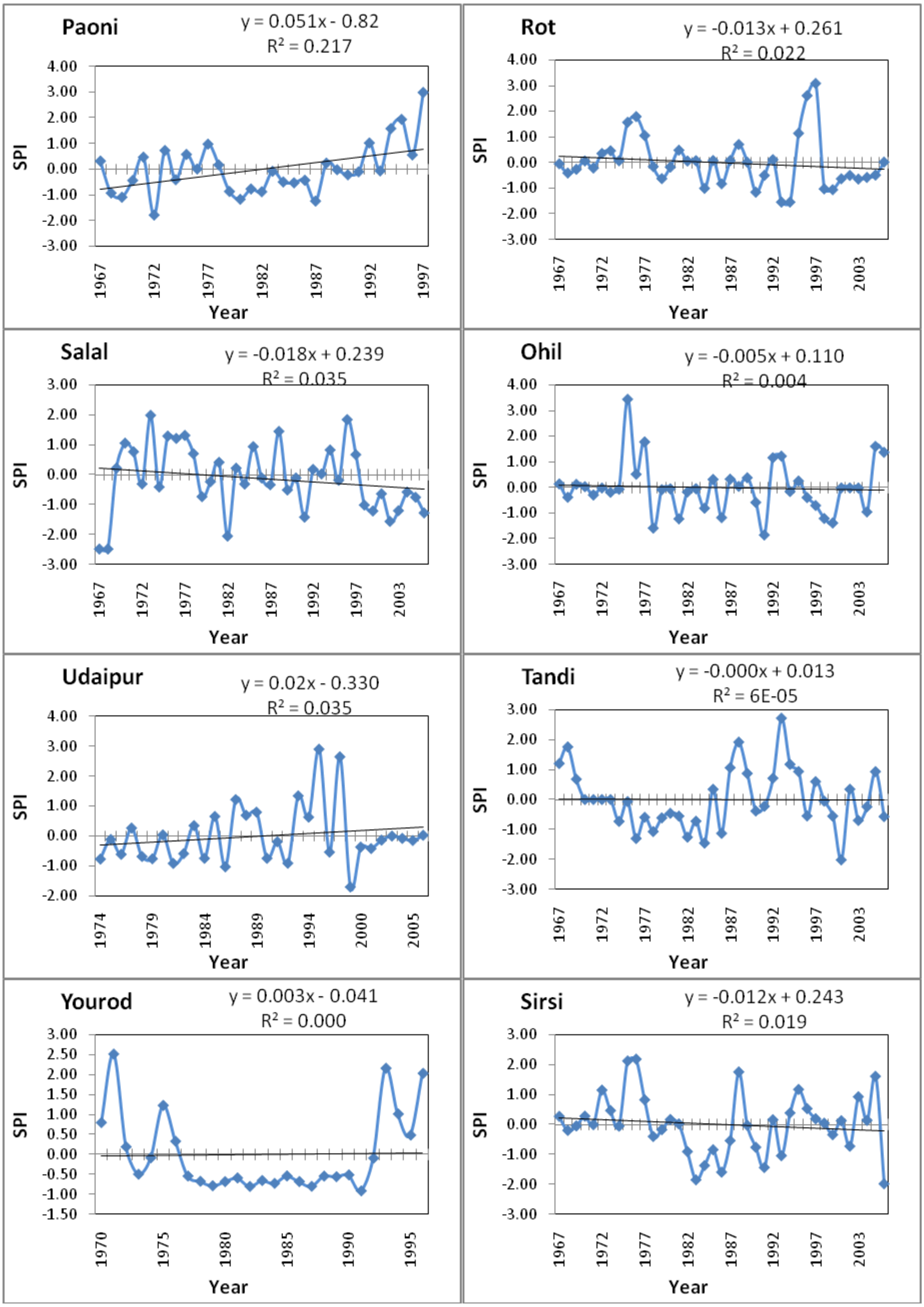

Figure - 7.3(c): Linear trends of Summer Precipitaion at different stations of Chenab Basin

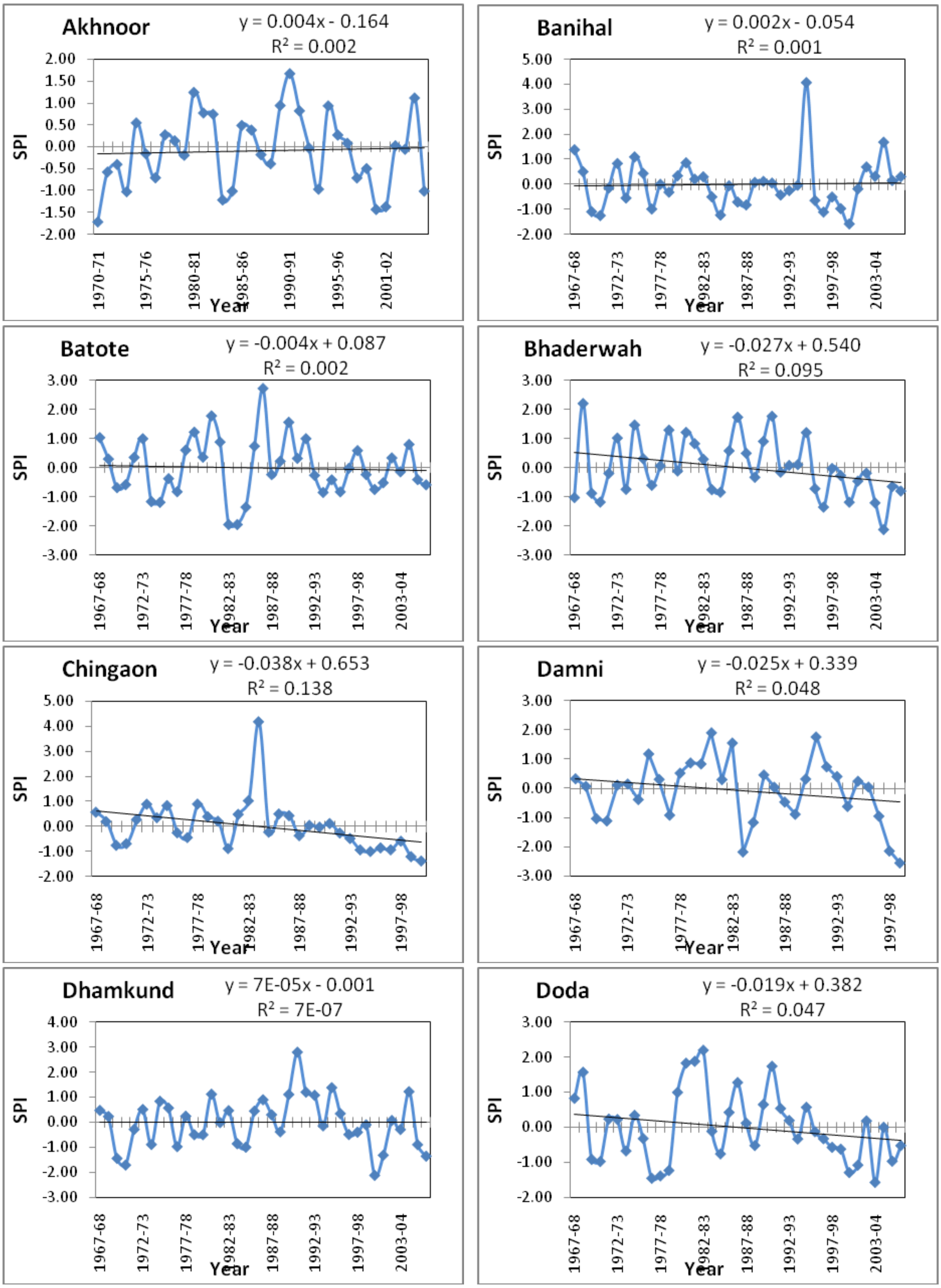

Figure - 7.4(a): Linear trends of Winter Precipitaion at different stations of Chenab Basin

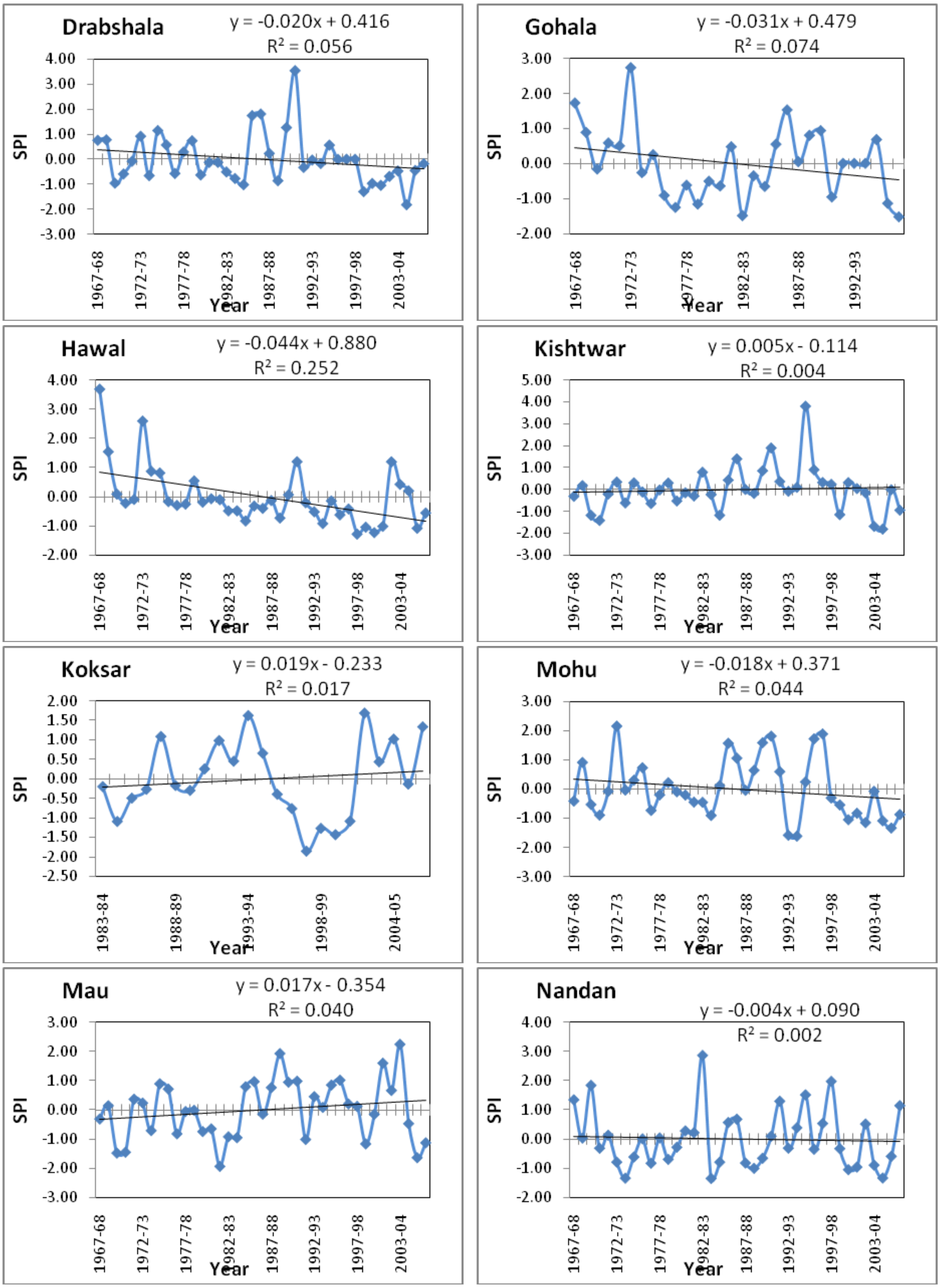

Figure - 7.4(b): Linear trends of Winter Precipitaion at different stations of Chenab Basin

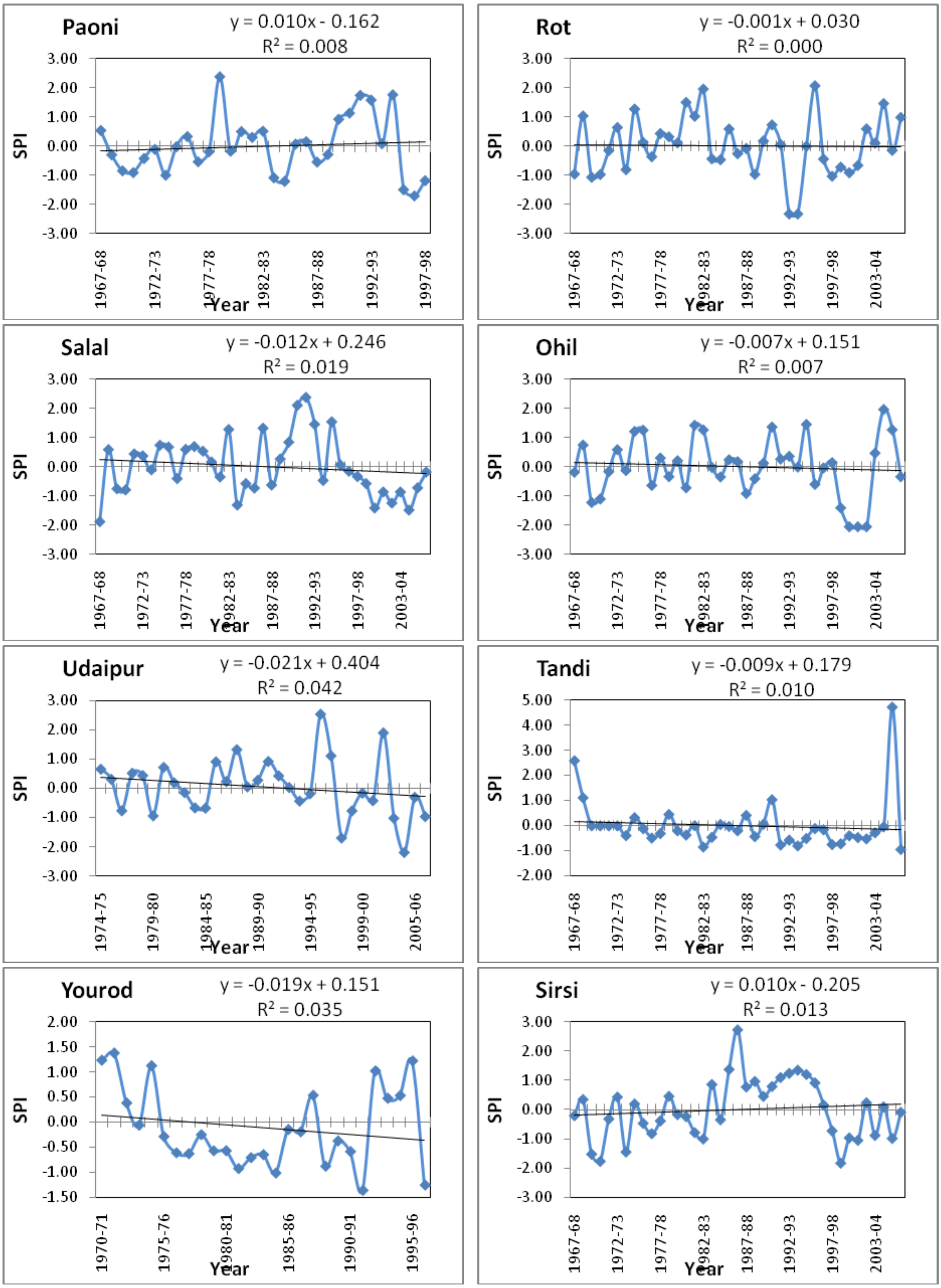

Figure - 7.4(c): Linear trends of Winter Precipitaion at different stations of Chenab Basin

The magnitude of the trends at all 24 precipitation stations has also been determined with Sen' Slope estimator method the results are been displayed in the Table 7.3.

Table - 7.3

Magnitude of trends at various precipitation station of Chenab basin for annual, monsoon and winter seasons by Sen's slope estimator method

S. No.	Station	Elevation (m)	Slope (Q), mm/annum		
			Annual	Summer	Winter
1	Akhnoor	305	-3.02	-4.74	1.72
2	Paoni	600	38.19	31.14	8.69
3	Salal	610	-23.88	-19.05	-8.61
4	Dhamkund	640	-3.92	-3.38	-0.18
5	Damni	885	-9.13	-5.47	-1.62
6	Drabshala	1095	-5.54	-0.48	-4.12
7	Doda	1140	-7.13	-0.99	-5.56
8	Rot	1375	-2.71	-4.25	0.80
9	Batote	1570	-3.96	0.73	-4.05
10	Ohli	1585	-1.50	-0.94	3.43
11	Kishtwar	1615	-5.23	-2.06	1.64
12	Banihal	1625	-5.59	-4.08	-1.38
13	Sirshi	1675	-1.22	-1.75	2.83
14	Bhaderwah	1830	-7.55	-0.07	-6.96
15	Chingaon	1840	-28.78	-7.26	-23.20
16	Nandan	1910	-23.41	-19.11	-1.20
17	Yourod	2165	-9.49	-1.31	-4.12
18	Gohala	2400	-14.18	-14.13	-4.91
19	Mohu	2440	-24.84	-15.26	-10.76
20	Tandi	2600	-6.62	0.00	-6.71
21	Hawal	2745	-20.33	-4.20	-17.94
22	Mou	2900	6.96	1.84	3.21
23	Udaipur	3100	0.34	1.85	-3.68
24	Koksar	3615	3.74	4.92	3.27

7.3.1 Discussion of Results of Trend Analysis

It can be easily observed from Table - 7.2 that the results of Mann-Kendall test are coinciding with the results from Sen's Slope estimator method. From the above table, it can be seen that 20 out of 24 precipitation stations are having declining trend in annual precipitation series with maximum decrease of -28.78 mm/annum at Chingaon station and four precipitation stations are having increasing trend with maximum increase of 38.19 mm /annum at Paoni station. Eventually, Paoni station is showing maximum increase in summer as well as in winter series also. The magnitudes for increasing trend at Paoni are 31.14mm / annum and 8.69mm/annum for summer and winter time series respectively for the last 40 years. The precipitation station, named Nandan, have highest declining trend of 19.11mm/ annum in summer season series and again Chingaon shows the peak rate of decline in winter season series of 23.20 mm/annum. As a whole, Chenab basin is showing a negative trend of precipitation of 6.62 mm/annum for period of 1967-2007.

The studies indicate a significantly decreasing average annual and seasonal precipitation trend over the last 40 year in Chenab basin. 20 out of 24 precipiation are supporting the declining precipitation trend in basin. It is showing a negative trend of precipitation of 6.62 mm/annum for period of 1967-2007 on annual time series basis. Only two stations, namely Paoni and Mou, are showing increasing trend with 90% singificance level on annual basis.

7.4 Trend Analysis of Discharge in the Chenab Basin

Chenab is a glacierized basin, particularly south-eastern part of the basin is heavily cover with glaciers and permanent snow. Usually, there are three components of discharge in a glacierized basin; snow-melt run-off, glacier melt and run-off due to monsoon rainfall. (Singh & Jain, 2002). Because of sparse database, an accurate assessment of the contribution by each component of the discharge is impracticable. However, based on the yearly, daily discharge values from 1967 to 2007 of nine discharge gauging stations, namely Akhnoor, Dhamkund, Premnagar, Benzwar, Sirshi, Udaipur, Miyar Nallah, Ghousal and Tandi, the following periods have been identified to estimate the contributions by various components:

(a) Winter discharge (largely base flow from sub-glacial melting and groundwater storage): November– February.

(b) Spring discharge (base flow + seasonal snow-melt): March–May.

(c) Monsoon discharge (base flow + monsoon rainfall + glacier melt): June–October.

Although seasonal snow cover is an important parameter in the hydrological regime of a basin, its contribution is confined to the spring season when snow-melt and baseflow constitute two components of the discharge. Once the summer sets in, it is the exposed glacier ice in the ablation zone which is the main contributor to the melt along with monsoon rainfall. The contribution by snow cover above the equilibrium line to the discharge is insignificant in this period (Bhutiyani, 1999).

To detect the trend in the stream flow of Chenab basin, all the discharge data are first converted into discharge flux. Then those discharge flux were standardized arithmetically by subtracting the means and dividing with the standards deviations to get the SDI (Standardized Discharge Index) series for all the 9 gauging stations for the period from 1967 to 2006. The discharge data sets from various stations also have been analyzed on seasonal as well as on annual basis. Discharge data has been divided into three seasons namely, spring (March to May), monsoon (June to October) and winter (November to February).

The long term trends in SDI series were evaluated by using standard parametric simple linear trend and non-parametric statistical technique, i.e. the Mann-Kendall test. The plots between SDI vs the respective years of all 9 discharge gauging station of Chenab are being presented in form of graphs in Figure - 7.5(a), Figure - 7.5(b), Figure - 7.5(c), and Figure - 7.5(d) for annual, spring, summer, and winter time series respectively. Simple linear curve fitting was also performed to find the trend of the discharge. The positive and negative trends for each precipitation gauging station are also presented in tabular form in Table - 7.4.

Table - 7.4

Results of SDI Linear trend analysis for annual, spring, monsoon and winter season discharge at various gauging stations in Chenab basin

S. No.	Station	Elevation (m)	Season			
			Annual	Spring	Monsoon	Winter
1	Akhnoor	305	(-)	(-)	(-)	(+)
2	Dhamkund	600	(+)	(+)	(+)	(+)
3	Premnagar	896	(+)	(+)	(+)	(+)
4	Benzwar	1135	(+)	(+)	(+)	(+)
5	Sirshi	1675	(-)	(-)	(-)	(+)
6	Udaipur	2584	(+)	(+)	(+)	(+)
7	Miyar Nallah	2700	(+)	(+)	(+)	(+)
8	Ghousal	2850	(+)	(+)	(+)	(+)
9	Tandi	2850	(+)	(+)	(+)	(+)

7.4.1 Discussion of Trend Analysis of Discharge in Chenab Basin

There are increasing trends in the discharge at almost all the gauging stations in Chenab basin. Out of 9 stations, 7 are showing the increasing trends out of which two, viz. Akhnoor and Sirshi, have declining linear trends for annual SDI series. The monsoon trends are analogous to the annual trends for all the stations. There are 6 stations which are showing increasing trend in all the seasonal as well as annual basis, viz. Dhamkund, Premnagar, Udaipur, Miyar Nallah, Ghousal, and Tandi. In these stations, expect Dhamkund and Premnagar, other four stations are located at higher altitude where snow-melt and glacier-melt is the major component of the stream flow and these are experiencing the increased discharge throughout the year.

Table - 7.5

Results of Mann-Kendall Test for annual, spring, monsoon and winter season discharge at various gauging stations in Chenab basin

S. No.	Station	Elevation (m)	Z Value			
			Annual	Spring	Monsoon	Winter
1	Akhnoor	310	-1.36+	-0.18	-1.53+	1.73*
2	Dhamkund	600	1.48+	2.29*	1.94*	3.17**
3	Premnagar	896	1.34+	2.85**	1.38+	2.62**
4	Benzwar	1135	0.59	2.00*	-0.19	5.22**
5	Sirshi	1680	-2.62**	-1.04	-2.23*	0.03
6	Miyar Nallah	1710	3.52**	2.60**	2.96**	4.86**
7	Udaipur	2584	1.96*	1.87*	2.25*	3.29**
8	Ghousal	2850	1.12	0.31	0.51	4.86**
9	Tandi	2850	2.27*	1.73*	1.86*	3.72**

** Existance of trend with 99% Confidence Level

* Existance of trend with 95% Confidence Level

+ Existance of trend with 90% Confidence Level

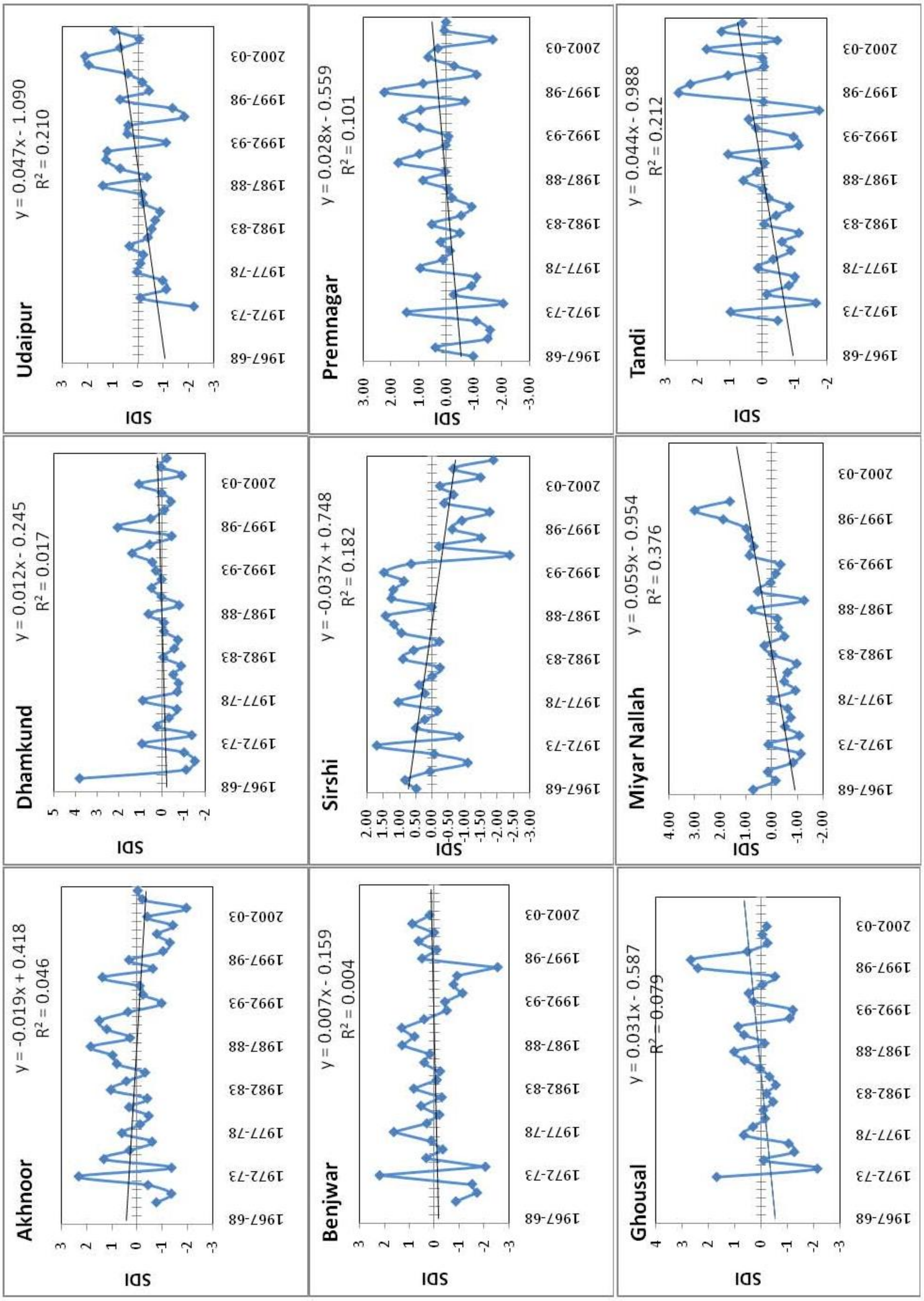

Figure - 7.5(a): Linear graph showing annual trends of discharge Flux at different stations of Chenab Basin

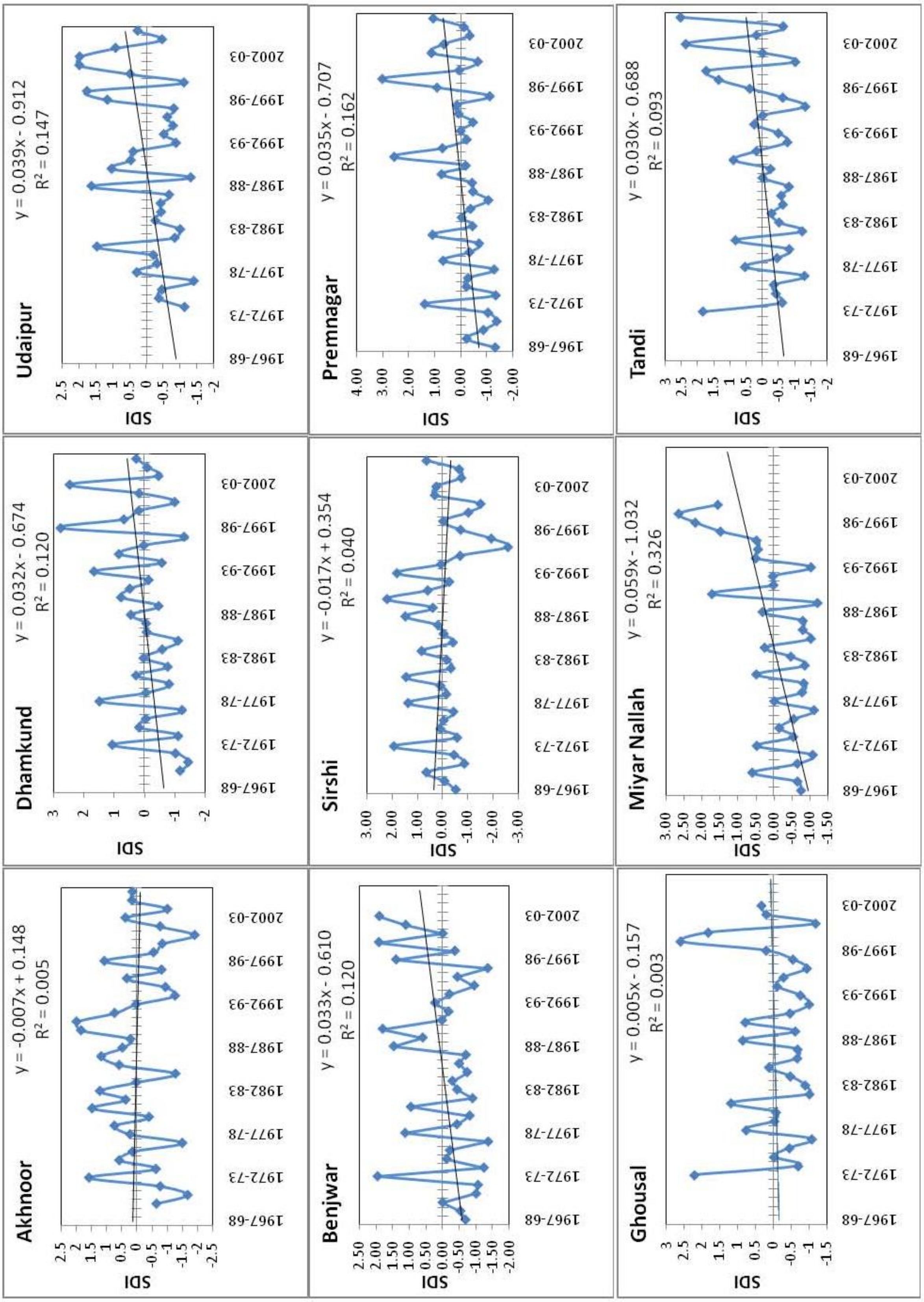

Figure - 7.5(b): Linear graph showing spring trends of discharge Flux at different stations of Chenab Basin

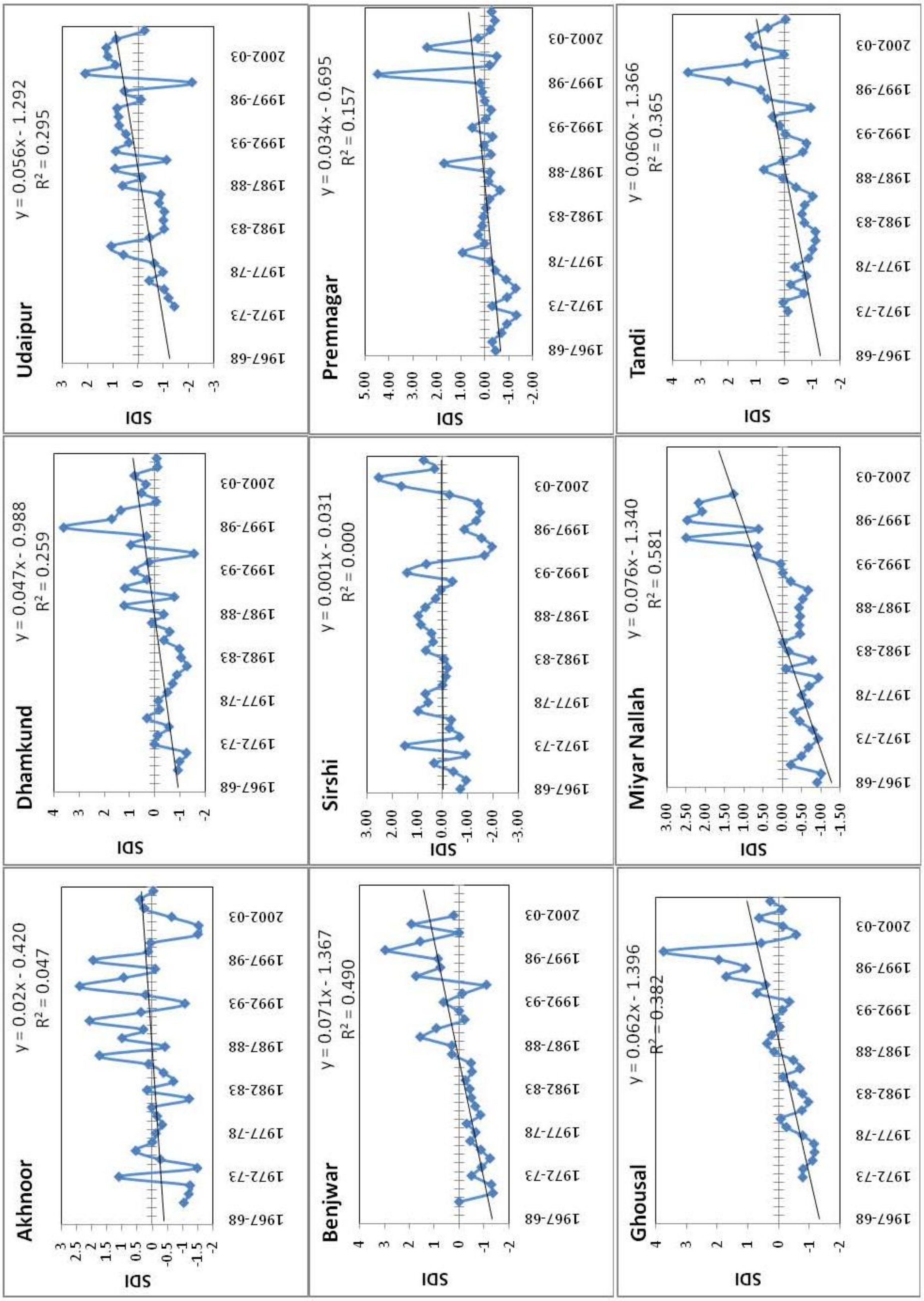

Figure - 7.5(c): Linear graph showing winter trends of discharge Flux at different stations of Chenab Basin

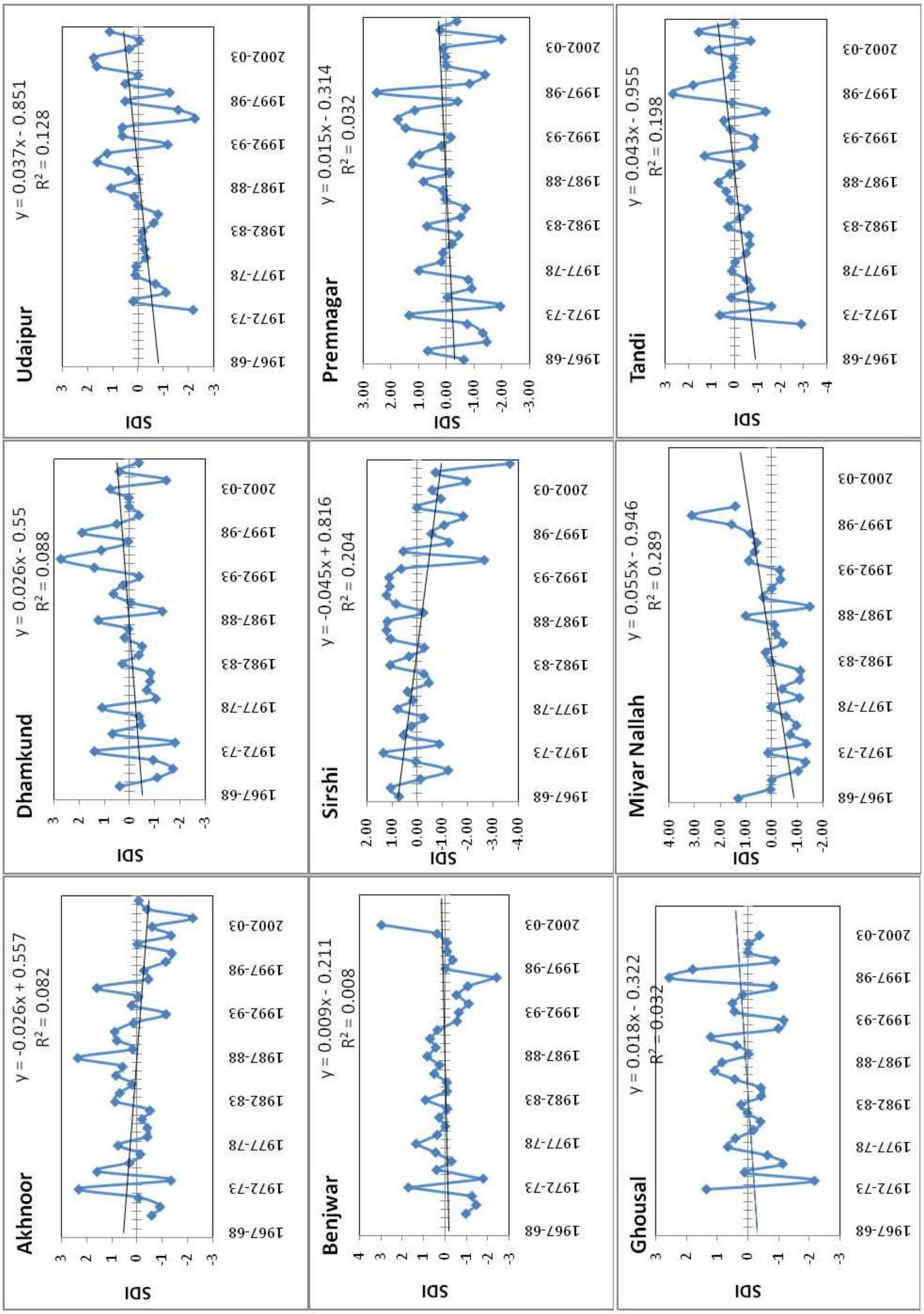

Figure - 7.5(d): Linear graph showing monsoon trends of discharge Flux at different stations of Chenab Basin

On analyzing the results of Mann-Kendall test (Table - 7.5), it is evident that winter seasonal discharge is rising in all 9 gauging stations as well as eight of them having trend with significance level of more than 95% and seven gauging stations having a rising trend at 99% significance level. Spring season also support the increasing discharge trends in the basin as only two out of nine stations show declining trend. Six gauging sites are having positive trend at 95% significance level and for two stations, viz. Premnagar and Miyar Nallah, the significance level is 99% for positive trend. In case of annual time series, all stations, except Akhnoor and Sirshi, are showing rising discharge trends, five out of the nine station having positive trend with 90% significance level. Understanding of the contradictory trends in precipitation and discharge of Chenab basin needs in-depth evaluation and study.

Table - 7.6

Magnitude of trends at various discharge station of Chenab basin by Sen's slope estimator

S. No.	Station	Elevation (m)	Slope (Q) (Cumec/Annum)			
			Annual	Spring	Monsoon	Winter
1	Akhnoor	310	-3.82	-0.47	-5.71	1.05
2	Dhamkund	600	5.01	6.96	6.92	2.03
3	Premnagar	896	8.52	3.87	15.16	1.40
6	Benzwar	1135	0.35	1.79	-0.57	1.02
9	Sirshi	1680	-1.21	-0.26	-2.16	0.10
8	Miyar Nalah	1710	0.41	0.29	0.82	0.19
5	Udaipur	2584	1.46	1.29	2.95	0.88
4	Ghousal	2850	0.05	0.23	0.03	0.46
7	Tandi	2850	0.37	0.31	0.60	0.25

The magnitude of trend in annual and seasonal rainfall and rainy days as determined by the Sen's estimator as given in Table - 7.6. It can be easily observed from the table that maximum increasing discharge trend with a magnitude of 15.16 Cumec/annum is at Premnagar in monsoon season. This station also has highest positive magnitude of 8.52 Cumec/annum in annual time series. For spring and winter season series, gauging site Dhamkund has observed maximum rising positive trend with magnitude of 6.96 Cumec/ annum and 2.03 Cumec/annum. The increase in annual discharge series varied between 0.05 Cumec/annum (for Ghousal) to 8.52 Cumec/annum (for Premmnagar). The decreasing trend was found maximum for Akhnoor for annual (3.82 Cumec/annum), spring (0.47 Cumec/ annum) and monsson (5.71 Cumec/annum).

Thus, discharge in the Chenab basin as a whole is showing a rising trend in winter (all 9 stations) and spring season (7 out of 9 stations). On annual basis, Chenab basin is showing a rising trend of 1.24 cumec/annum. However, Akhnoor is showing declining trend in discharge with some significance level and at the rate of 3.82 cumec/annum in annual series, where as the maximum magnitude of positive trend was found at Premnagar (15.16 cumec/annum) in monsoon season. This is contrary to the precipitation trend which may be due to the fact that the Chenab basin has a large number of glaciers, which have played a regulatory role in controlling its discharge. As smaller glaciers have receded at a relatively faster rate than larger ones, this may ultimately lead to their desertion in the near future.

7.5 Trend Analysis of Precipitation in the Kashmir Region

Kashmir valley lies in the temperate zone, characterized by wet and cold winter and relatively dry and moderate hot summer. Srinagar is relatively warmer, with a mean daily temperature varying between 1^0C to about 8^0C during November to March and 3^0C to 25^0C during April to October. The daily maximum temperature goes up to 31^0C in summer and the minimum down to -5^0C in winter. Horticulture, agriculture and handicraft manufacturing are the main occupation of the Kashmir population, and many fruits and nuts are grown here. The agro-based socio-economy of the region is vulnerable to climate change.

No detailed study on precipitation and discharge trends for the Kashmir region has been reported in the literature. While studying the climate and its long-term variability over the western Himalayas, Pant et al. (1999) included only one station, namely Srinagar from the Kashmir Valley. This study indicated a non-significant decreasing trend in annual rainfall at Srinagar during the period 1983-1990. Archer and Fowler (2004) in their study on spatial and temporal variation in precipitation in the Upper Indus Basin also included only the Srinagar station from Kashmir Valley. They found a non-significant increasing trend in annual rainfall at Srinagar between 1894 and 1999, with an increase of 10% of mean per 100 year between 1961 and 1999. Pant et al. (1999) reported that the mean temperature at Srinagar has increased at the rate of 0.8^0C/100 years between 1893 and 1990. Fowler and Archer (2006) have reported a significant increase in annual mean temperature at Srinagar at the rate of 0.07 ^{0}C/decade during the period 1894–2000. Talib (2007) and Jeelani (2008) have reported that the water level in almost all the streams and rivers of Kashmir has decreased; many springs have dried up; snow fall has reduced over the years; and many of the glaciers have shrunk in size. Talib (2007) states that, due to dwindling water resources, there is a clear trend involving switching from paddy and other traditional irrigation-based crop cultivation to rain-fed fruits and cash crops in Kashmir.

In the present study, seasonal and annual rainfall and rainy days data of Srinagar, Kulgam, Handwara, Qazigund and Kukarnag stations in Kashmir Valley have been analysed to study the variability of seasonal and annual rainfall and rainy days and to evaluate the existence or otherwise of long-term trends in the 20th century. Long-term rainfall data of only five stations of the India Meteorological Department (IMD), namely Srinagar (34^0 05’ N, 74^0 50’ E, Elevation 1586 m), Kulgam (33^0 38’ N, 75^0 01’ E, Elevation 1770 m), Handwara (34^0 24’ N, 74^0 17’ E, Elevation 1596 m), Qazigund (33^0 36’ N, 75^0 10’ E, Elevation 1727 m) and Kukarnag (33^0 35’ N, 75^0 18’ E, Elevation 1890 m) are available in the Kashmir valley. These stations are well distributed in the valley, and thus we assert that the results of this study are representative of the whole of the Kashmir valley.

Due to the varying length of data at these stations, analysis has been performed for three different periods: 1903-1982 (80 years) at Srinagar, Kulgam and Handwara; 1962-2002 (41 years) at Srinagar, Qazigund and Kukarnag; and 1901–2002 (102 years) at Srinagar. Trend analysis of rainy days was carried out at three stations for the period 1903-1982.

Time series of annual rainfall and their linear trend at different stations are shown in Figure - 7.6. The calculated linear trend values (by linear regression) in seasonal and annual rainfall are presented in Table - 7.7. During the period 1903–1982, the annual rainfall at

Srinagar showed a negative trend over the years. Seasonally, rainfall showed an increasing trend in the pre-monsoon and post-monsoon season and a decreasing trend in the monsoon and winter season. The data at Kulgam indicated a decreasing trend in annual, monsoon and winter rainfall and an increasing trend in pre-monsoon and post-monsoon rainfall. Winter, monsoon and annual rainfall had a decreasing trend, and pre-monsoon and post-monsoon season had an increasing trend at Handwara. During this period (1903–1982), the maximum decrease in annual rainfall was found for Kulgam (20.61% of mean/100 years) and the minimum for Srinagar (2.47% of mean/100 years). Handwara showed a decreasing annual rainfall at the rate of 17.8% of the mean/100 years, respectively.

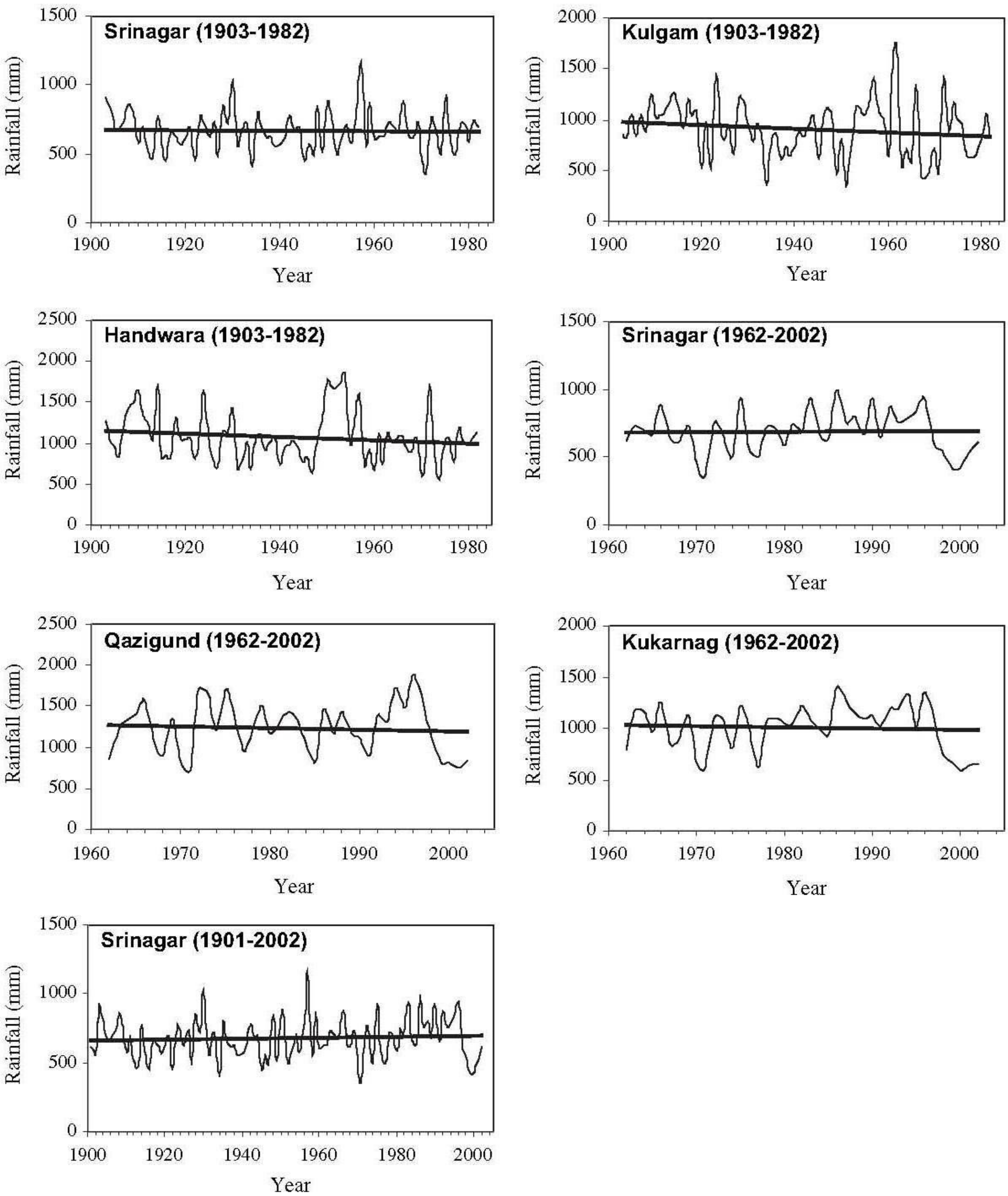

Figure - 7.6: Linear trend in annual rainfall at different stations in Kashmir Valley

For the period of 1962–2002, the analysis of rainfall at Srinagar indicated an increasing trend in the annual, monsoon and winter season and decreasing trend in the pre-monsoon and post-monsoon season. This trend at Srinagar, both at the seasonal and annual level is opposite to the trends detected during the period 1903–1982. Upon scrutiny of the data, it was found that this reversal is due to continuous above-mean rainfall received during the period 1992–1996. Qazigund had decreasing rainfall during the pre-monsoon, post-monsoon, and winter seasons and for the whole year whereas Kukarnag experienced decreasing rainfall during the annual period and in all seasons except winter season.

When 102 years (1901–2002) of rainfall data at Srinagar station were analysed, an increasing trend in annual rainfall was detected. This trend in annual rainfall is opposite to the trend detected for the period 1903–1982 (due the reason explained above) and in the same direction as those for the period 1962–2002. This result of a reversal in trend is consistent with the results reported by earlier investigators. Pant et al. (1999) found a decreasing trend in Srinagar rainfall for the period 1893–1990, whereas Archer and Fowler (2004) have found an increasing trend in Srinagar rainfall during the period 1894–1999. Seasonal analysis of 102 years of rainfall data shows an increasing trend except in the monsoon season. The trend direction for 80-year data and 100-year data is the same except for winter rainfall. During 1903–1982, the winter rainfall had a negative trend, whereas between 1901 and 2000, it had an increasing trend.

The Mann-Kendall test was employed on the seasonal and annual rainfall series, and the results are presented in Table - 7.7. During the period 1903–1982, only decreasing winter rainfall at Kulgam and Handwara was found to be statistically significant at the 95% confidence level. The increasing/decreasing seasonal and annual rainfall at Srinagar, Qazigund and Kukarnag during the period 1962–2002 and at Srinagar during 1901–2002 was not found to be statistically significant.

Table - 7.7

Trends and magnitude of change by linear regression (% of mean/100 years) in rainfall

Time period	Period:1903–1982			Period:1962–2002			Period:1901–2002
	Srinagar	Kulgam	Handwara	Srinagar	Qazigund	Kukarnag	Srinagar
Pre-monsoon	6.24	16.79	1.91	-9.36	-27.94	-46.68	9.87
Monsoon	-21.84	-6.8	-36.21	35.69	35.03	-50.21	-10.95
Post-monsoon	71.49	50.29	55.44	-69.38	-64.9	-6.24	43.91
Winter	-10.62	-65.31*	-36.17*	9.80	-19.11	40.80	4.47
Annual	-2.47	-20.61	-17.78	3.13	-13.65	-11.35	5.40

* Significant at 95% confidence level as per the Mann-Kendall test

Analysis of rainy days during the period 1903–1982 indicates that rainy days at Srinagar increased in the post-monsoon season and decreased in all other seasons and for the annual cycle (Figure - 7.7). Annual and seasonal rainy days at Kulgam were found to be increasing except for the winter season. At Handwara station, rainy days had a decreasing trend for the annual period and all seasons, except the post-monsoon season. The decreasing trend in winter rainy days at Handwara and the increasing trend in post-monsoon rainy days at Kulgam were found statistically significant (Table - 7.8).

7.5.1 Discussion of Trend Analysis of Precipitation in the Kashmir Region

Climate-change projections using various Global Climate Models (GCMs) and Regional Climate Models (RCMs) over India show increasing temperature and changing patterns in rainfall during the 21st century (Rupa Kumar et al., 2006; Rajendran and Kitoh, 2008). PRECIS (a regional climate modelling system) simulations under scenarios of increasing greenhouse gas concentrations and sulphate aerosols indicated a marked increase in both rainfall and temperature towards the end of the 21st century over Jammu and Kashmir (Rupa Kumar et al., 2006). On the other hand, Rajendran and Kitoh (2008), using a super high-resolution global model, have predicted reduced rainfall over Jammu and Kashmir in the future. According to these authors, this reduction is associated with low precipitable water, reduced evaporation, lack of inflow of low-level moist air or transport of dry air from the Arabian region. Thus the two studies referred to above have projected opposite trends in future rainfall for Jammu and Kashmir.

In mountainous areas, the effect of changes in precipitation suggested a linear increase/decrease in snowmelt runoff and total streamflow, while glacier melt runoff was found to be inversely related to changes in precipitation (Singh and Kumar, 1997). Singh et al. (2006) have simulated a 3.5% decrease (increase) in summer runoff due to a 10% decrease (increase) in precipitation for a glacierized Himalayan basin. They have also concluded that the influence of temperature change is greater than the rainfall change on river discharges in glaciated basins. In spite of the uncertainties about the precise magnitude of future climate change and its possible impacts, measures must be taken to anticipate, prevent or minimize the causes of climate change and mitigate its adverse affects (Mall et al., 2006).

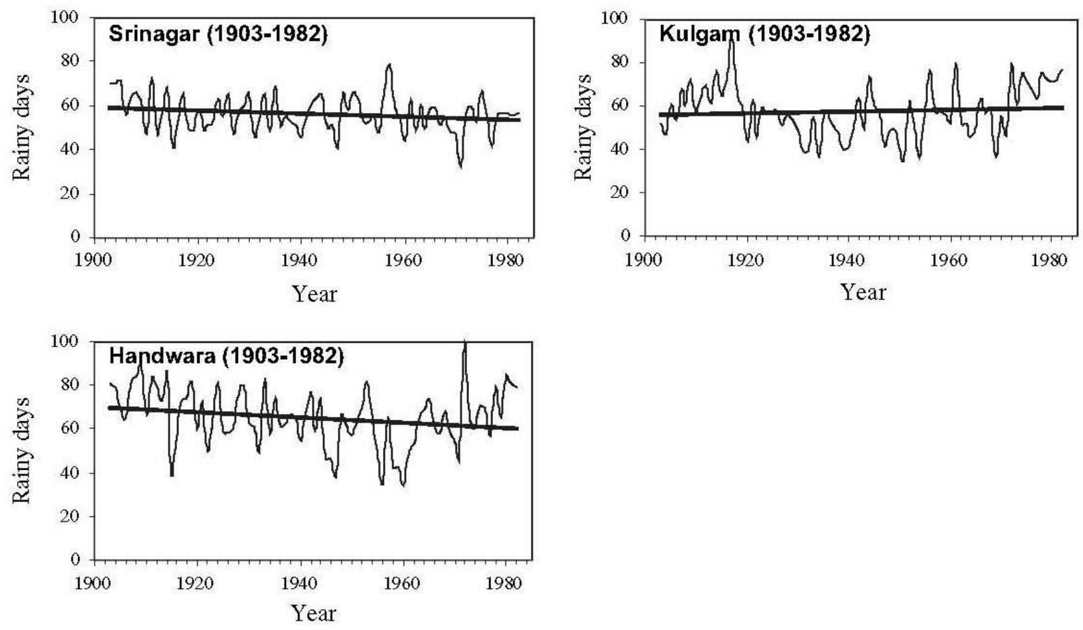

Figure - 7.7: Annual rainy days at different stations in Kashmir Valley

Table - 7.8

Trends and magnitude of change by linear regression (% of mean/100 years) in rainy days (1903–1982)

S. No.	Time Period	Srinagar	Kulgam	Handwara
1	Pre-monsoon	-4.19	13.46	-11.46
2	Monsoon	-21.99	10.20	-20.03
3	Post-monsoon	20.37	105.32*	17.74
4	Winter	-20.36	-17.5	-29.25*
5	Annual	-13.04	7.32	-18.62

* Significant at 95% confidence level as per the Mann-Kendall test

Based on the data for three stations for the period 1903–1982, the Kashmir Valley gets about 880 mm annual rainfall in about 60 rainy days. The seasonal distribution of rainfall is 28%, 21%, 8% and 43% for pre-monsoon, monsoon, post-monsoon and winter seasons respectively.

Annual rainfall at four stations, namely Kulgam and Handwara (during the period 1903–1982) and Qazigund and Kukarnag (during the period 1962–2002), was found to be decreasing. Srinagar station experienced a decreasing trend in annual rainfall during the period 1903–1982, whereas it experienced an increasing trend during 1962–2002 and also during 1901–2002. None of the observed trends in annual rainfall were found to be statistically significant. Rainfall in the winter season (the season which receives maximum rainfall) decreased at Kulgam, Handwara, Qazigund, Srinagar (1903–1982) and increased at Kukarnag and Srinagar (1962–2002 and 1901–2002). The decreasing winter rainfall at Kulgam and Handwara was found to be statistically significant at the 95% confidence level.

Srinagar and Handwara showed similar trends (decreasing) in annual rainfall and rainy days during the period 1903–1982, whereas opposite trends (decreasing rainfall and increasing rainy days) were found at Kulgam. Observed trends in annual rainy days were not found to be statistically significant. Winter rainfall and rainy days experienced the same direction of trend (decreasing) at all three stations during the period 1962–2002. The decreasing trend in rainy days at Handwara was found to be statistically significant.

The study indicates decreasing rainfall at four stations and increasing rainfall at one station in the Kashmir Valley over the period of record. If this widespread decreasing trend in rainfall is sustained, it will adversely impact the economy of the Valley. There is a need to incorporate the changing climate in planning and management of water resources of the Valley. The study also provides some scenarios of patterns of rainfall change, which may be used for sensitivity analysis of water availability in Kashmir Valley. Finally, although there are uncertainties about the magnitude and direction of future climate change at various places, measures must be initiated to minimize the adverse impacts of these changes on society.

7.6 Trend Analysis of Discharge of Tawi River

The trend analysis of the stream flow pattern of Tawi River at Jammu Tawi Bridge Site has been performed using the similar methodology which was adopted for the discharge of Chenab basin. The discharge data series at Jammu Tawi bridge was first converted in to discharge flux. Then those discharge flux were standardized arithmetically by subtracting the means and dividing with the standards deviations to get the SDI (Standardized Discharge Index) series. The length of the data available for this analysis is 31 years i.e. 1976 to 2007. The discharge data had been analyzed on seasonal as well as on annual basis.

The long term trends in SDI series were evaluated by using standard parametric simple linear trend and non-parametric statistical technique i.e. the Mann-Kendall test for three seasons namely, spring (March to May), Monsoon (June to October) and winter (November to February) and annual basis. The plots between SDI Vs the respective years at Jammu Tawi bridge gauging station are being presented in Figure - 7.8 for annual and seasonal time series respectively. Simple linear curve fitting was also performed to find the trend of the discharge. The positive and negative trends for each discharge gauging station are also presented in Table - 7.9.

Table - 7.9

Trend Analysis of Tawi River at Jammu Tawi Bridge site for annual and seasonal time series along with the magnitude of trend

Season	Z-Value	Mann–Kendall's non-parametric test	Linear regression coefficient b	Sen's Slope Estimate (qmec/annum)
Annual	-1.33	(-)*	(-)	-0.731
Winter	-0.71	(-)	(+)	-0.163
Spring	-1.33	(-)*	(-)	-0.639
Monsoon	-1.21	(-)	(-)	-1.070

*Significant at 90% confidence level. (+), Increasing; (–), Decreasing

From the Table and Figure, it is clear that Tawi river is experiencing the declining trend in annual as well as seasonal discharges. The rate of annual decrease in discharge in Tawi is -0.731 cumec/annum and annual and spring season are showing the falling trend of discharge at significance level of 90%.

7.7 Trends in Ground Water Fluctuations

Fluctuation between decadal mean water level and water level of year 2010-11 has been discussed and presented in the following sub sections.

May 2010 with respect to May 2000 – May 2009

The water level fluctuation for the month of May 2010 with respect to the mean water level of May 2000 to May 2009 has been worked out in respect of 118 observation wells.

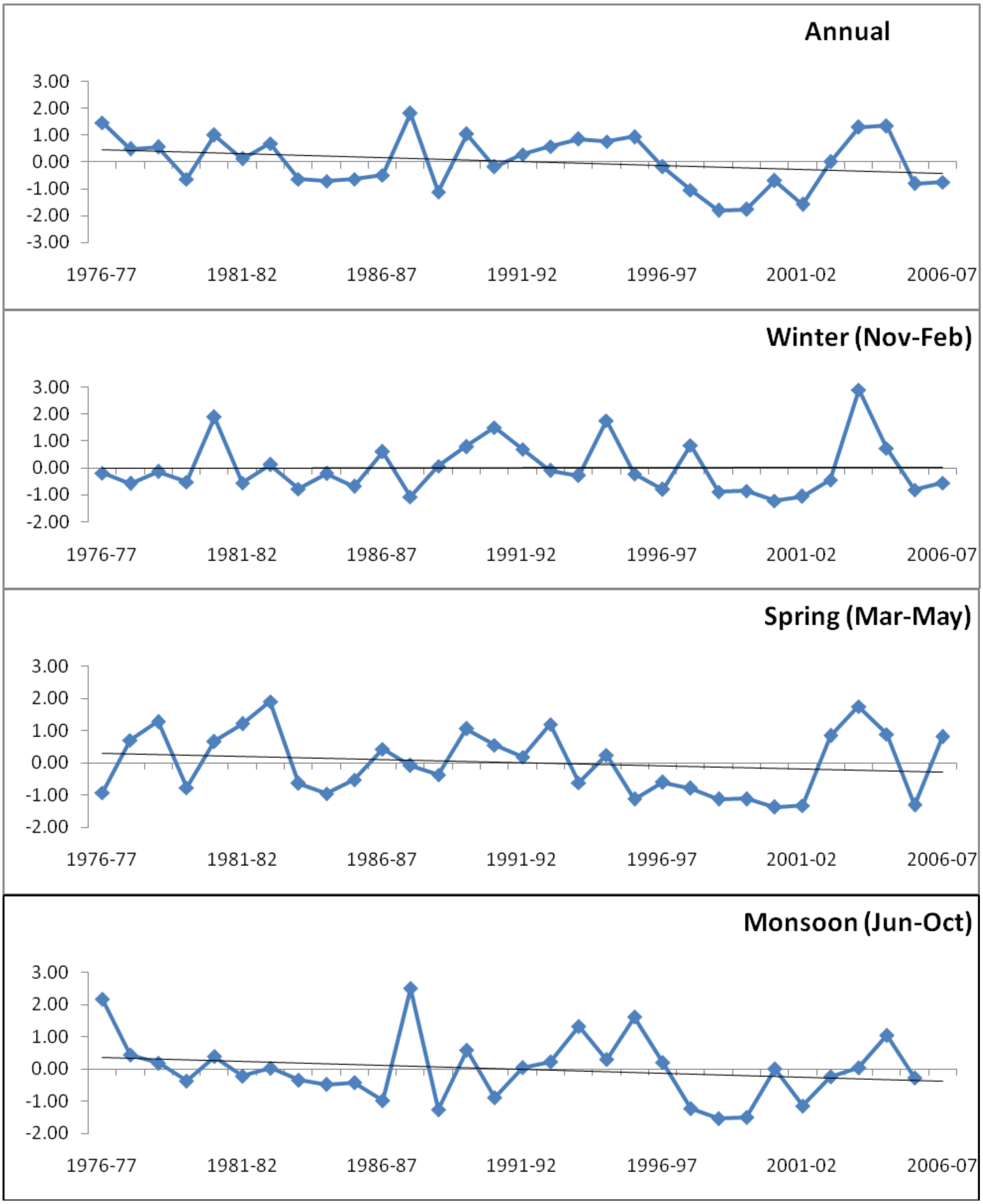

Figure - 7.8: Temporal variation and linear trends in average discharge in annual, winter, spring and monsoon seasons in the Tawi river (1976–2007)

It is observed that a total of 104 wells (88.13%) have shown decline and 12 wells (10.16%) have shown rise in water level.

Out of 104 wells showing decline, 78 wells (66.10 %) are showing decline less than 2 m. Decline from 2-4 m is shown by 15 wells (12.71%) and 9 wells (9.32%) are showing decline more than 4 m. Out of 12 wells, which are showing rise, all are in the range of 0-2 m. Most of the areas monitored have shown decline in water levels. The rise in water level in the range of 0.0 to 2.0 m is observed mainly in parts of outer plain in Jammu district, except in a localized pocket where rise in >4 m bgl. Rest all parts of Kathua district, Rajouri valley and valley area of Dun belt have shown decline (Figure - 7.9).

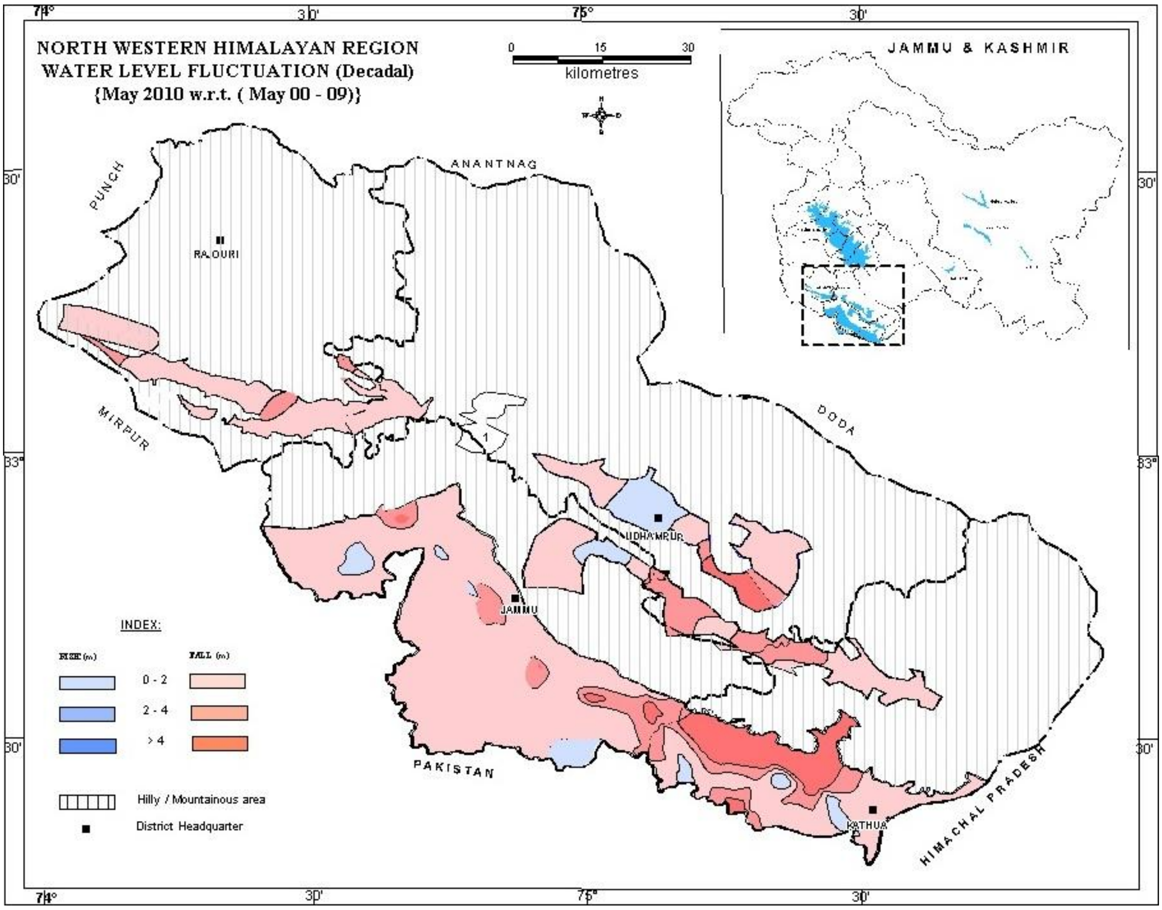

Figure - 7.9: Decadal Fluctuation (May 2010 w.r.t 2000 - 09)

August 2010 with respect to August 2000 –2009

The water level fluctuation for the month of August 2010 with respect to the mean water level of August 2000 to August 2009 has been worked out in respect of 132 observation wells. It is observed that a total of 88 wells (66.66%) have shown rise and 44 wells (33.33%) have shown decline in water level (especially in Kandi areas of outer plains)

Out of 88 wells showing rise, 78 wells (59.09 %) wells are showing rise less than 2 m, 8 wells (6.06 %) are showing rise from 2-4 m and 2 wells (1.52%) are showing rise more than 4 m. Out of 44 wells, which are showing fall, 34 wells (25.76%) that have shown fall in water level are in the range of 0-2 m, 6 wells (4.55%) have shown fall between 2-4 m and fall in the range of 2-4 m is shown by 3 wells (2.27%).

Most of the areas monitored have shown rise in water levels. The rise in water level in the range of 0.0 to 2.0 m is observed mainly in parts of outer plain in Jammu district, Rajouri valley except in a localized pocket where rise in >4 m bgl. A big part in Kathua district and Jammu district have shown decline (in Kandi area) (Figure - 7.10).

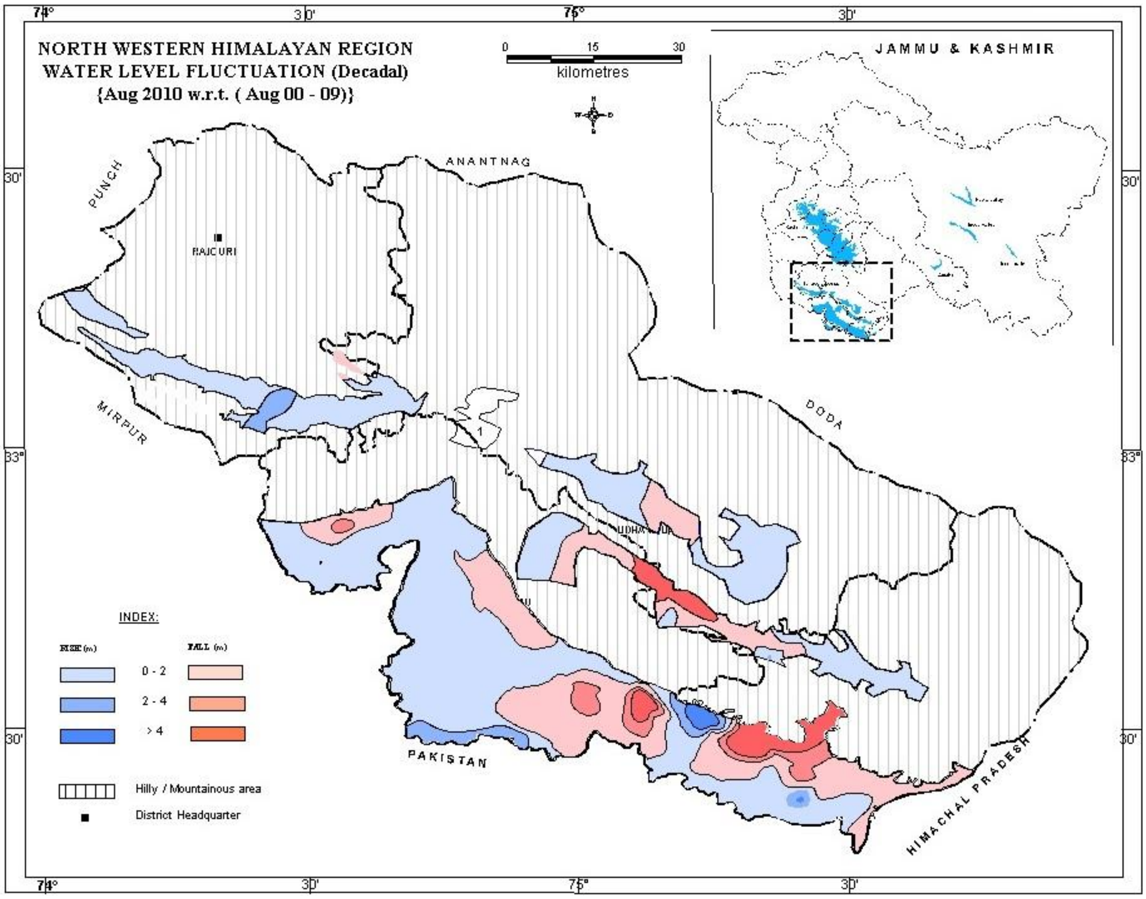

Figure - 7.10: Decadal Fluctuation (August 2010 w.r.t 2000 - 09)

November 2010 with respect to November 2000 - 2009

The water level fluctuation for the month of November 2010 with respect to the mean water level of November 2000 to November 2009 has been worked out in respect of 129 observation wells. It is observed that a total of 78 wells have shown rise and 19 wells (15.57%) have shown decline in water level (especially in Kandi areas of Outer Plains)

Out of 78 wells showing rise, 74 wells (57.36 %) wells are showing rise less than 2 m, 4 wells (3.10 %) have shown rise from 2-4 m and no well have shown rise more than 4 m. All the 19 wells, which are showing fall, are in the range of 0-2 m.

All the districts for November 2010 are showing rise and fall when compared with decadal mean. All of the areas monitored have shown rise in water levels in Rajouri district. The rise in water level in the range of 0- 2.0 m. Udhampur, Jammu and Kathua districts, both rise and fall are between 0-2 m except some localized pockets where fall is more than 4 m (Figure - 7.11).

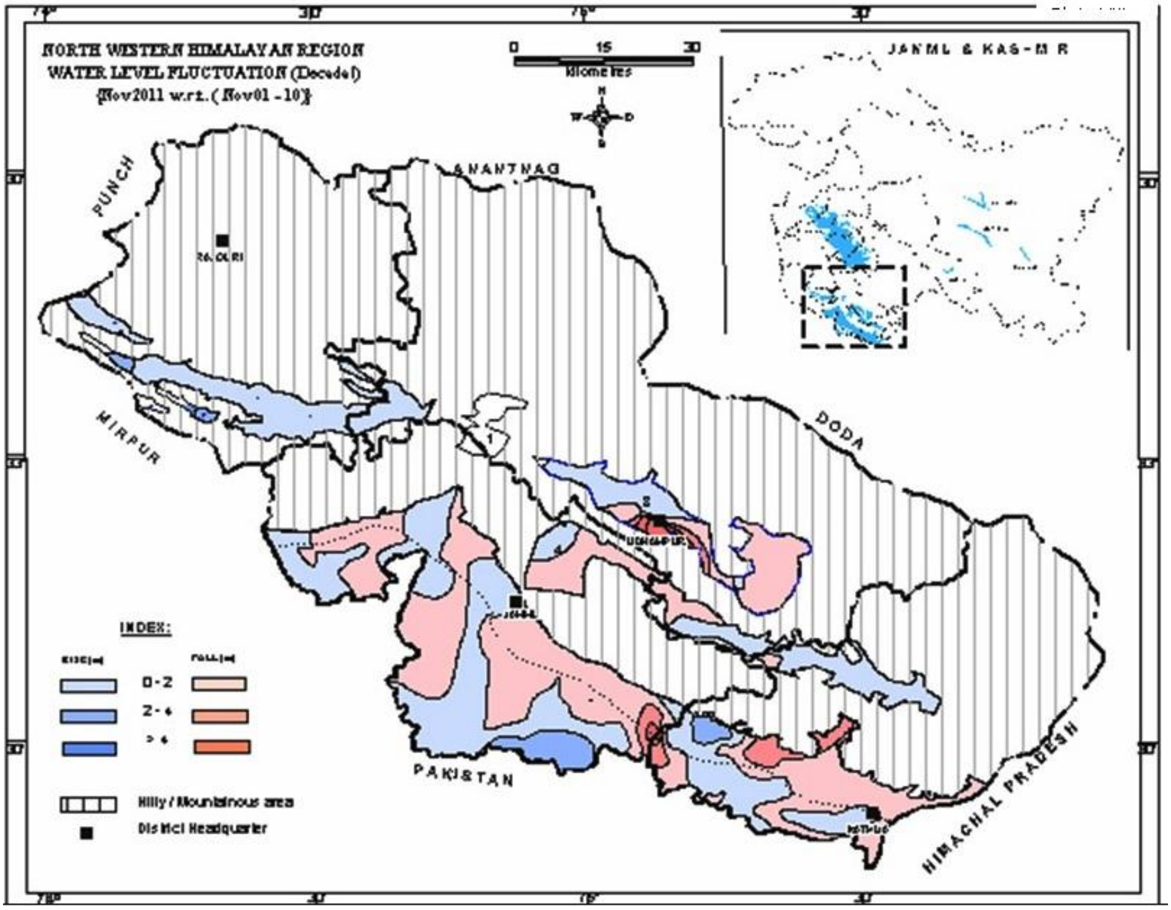

Figure - 7.11: Decadal Fluctuation (November 2010 w.r.t 2000 - 09)

January 2011 with respect to January 2001 – 2010

The water level fluctuation for the month of January 2011 with respect to the mean water level of January 2001 to January 2010 has been worked out in respect of 130 observation wells. It is observed that a total of 83 wells have shown rise and 47 wells have shown decline in water level (especially in Kandi areas of Outer Plains)

Out of 83 wells showing rise, 73 wells (56.15%) wells showing rise less than 2 m, 9 wells (6.92%) have shown rise from 2-4 m and only a well has shown rise more than 4 m. A total of 39 wells (30%) have shown fall in water level in the range of 0-2 m. Six wells (4.62%) have shown fall between 2-4 m and 2 wells (1.54%) have shown fall in the range of 2-4 m.

The water level January-2011 have been compared with the decadal mean water level (Jan 2001-10) are showing rise and fall when compared with decadal mean. All of the areas monitored have shown rise in water levels in Rajouri district. The rise in water level in the range of 0- 2.0 m. Udhampur, Jammu and Kathua districts, both rise and fall are between 0-2 m except some localized pockets where fall is more than 4 m (Figure - 7.12).

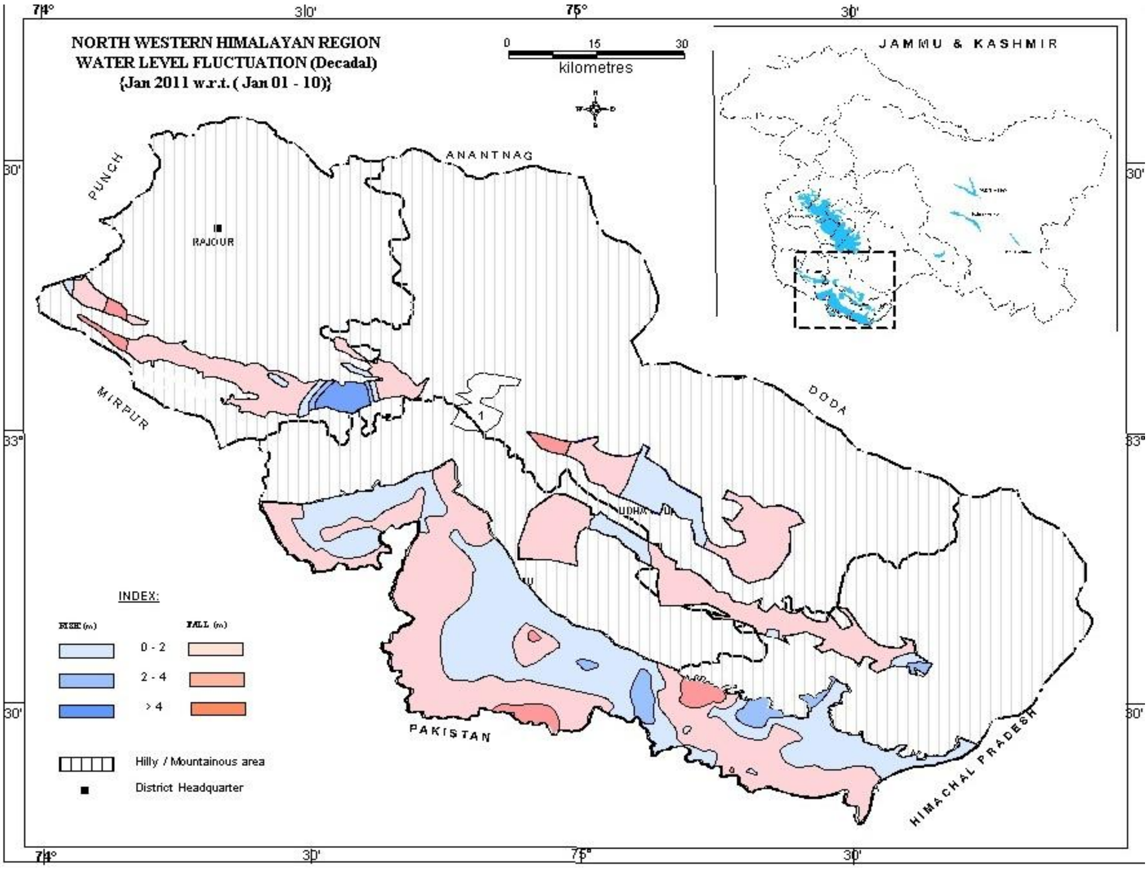

Figure - 7.12: Decadal Fluctuation (January 2011 w.r.t. 2000 - 09)

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