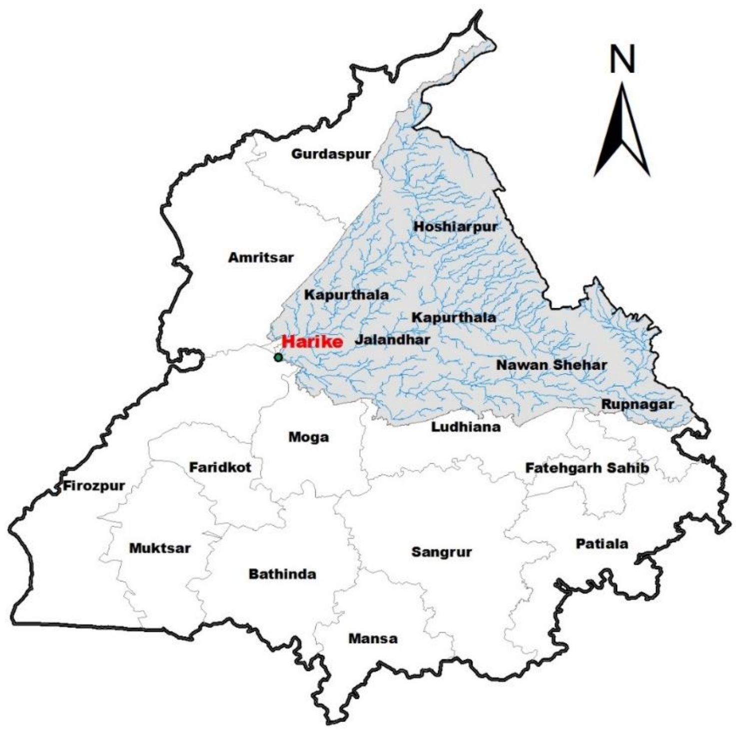
VARIABILITY OF THE HYDRO-CLIMATIC VARIABLES IN PUNJAB PLAINS OF LOWER SUTLEJ



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Chapter 1

1.0 INTRODUCTION

1.1 General

The variability and trends in hydro-meteorological variables has received a wide spread attention among meteorologists and hydrologists across the globe during past several years because of its relevance to climate change. Capturing typical properties of time series, like trends, is highly relevant for the discussion of potential impacts of global warming or flood / drought occurrences. Although, the assessment of trends in climatology and hydrology is a matter of debate due to changing variability and non- stationariness of the variables. These variability in conjunction with climatic change causing significant impacts to agriculture, ecology and infrastructure. The Indian Summer Monsoon (Southwest Monsoon) occurs from June to September and contributes approximately 80% to the total annual precipitation in India. The majority of the Indian agriculture is dependent on it, which is critical for the availability of freshwater for drinking and irrigation. Changes in climatic variable over the Indian region, particularly the SW monsoon, would have a significant impact on agricultural production, water resources management and overall economy of the country. The regions with the rainfed agrarian economy are likely to be worse effected by the changes. Punjab is one of the most critical and important agriculture rich state of India, it holds place of pride among the Indian States for its outstanding achievements in agricultural development. The state has witnessed tremendous increase in the agricultural production during the Green Revolution period, mainly due to healthy mix of institutional and technological factors. On the other hand the extensive use of groundwater through tube wells for irrigation have led to lowering of the groundwater table in most parts of state, and about 98% of the block are under critical to over-exploited (Dark) ground water zones. Agriculture is the largest industry in Punjab; it is the largest single producer of wheat in India. The Punjab state comprising only 1.54 percent of the total geographical area of country now contributes 13-14 percent towards the total food grain production of the country. State has earned a name of granary of India through contributing 35 to 40 percent of rice and 40 to 75 percent of wheat to the central pool in the past two decades. Agriculture and allied sectors are the major contributors (31%) to the state's GDP. For a successful rainfed agrarian economy Monsoon play an important role and a pre-information regarding the changes in the hydro-climatic variable can be ascertained by the analyzing the trends of these hydro-meteorological variables. Keeping this view in mind the present study was undertook to analyze the variability and trend of hydro-climatic variables of Punjab plains of lower Sutlej.

1.2 Background and status of the study

The variation in amount and duration of Indian monsoon rain was reported by many researchers (Satyanarayana and Srinivas, 2008, Kumar et.al. 2010). Significant increasing or decreasing trends in Indian monsoon precipitation led to spatial heterogeneity in precipitation (Krishnamurthy et al, 2009) and temporal variation in trends by aggregating precipitation over large areas receiving varied amounts of rainfall was reported by Goswami et.al., (2006). The spatial distribution of increasing or decreasing trends in extreme rain events across India has been well documented using a variety of statistical methods by different workers (Ghosh et al, 2011). Study conducted for whole India by Kumar et.al. (2010) indicates that in terms of percentage of mean per 100 years, Punjab and Haryana states witnessed a large increasing trend in annual rainfall. Based on duration and recurrence intervals Gill et.al. (2013) studied the spatial and temporal variation of extreme rainfall events in central Punjab and found that recent decade i.e. 2000-2012 showed much variation in rainfall extremes with highest rainfall event in 2011 and lowest during 2002. The land surface of Punjab is one of the most fertile plains of India and understanding of the various hydro-climatic variables shall be very useful for future planning and management of the water resources in optimum way. The Punjab plain of lower Sutlej basin up to Harike Barrage has been selected for the study in views of its important contribution in agricultural production for the country. Groundwater has played a key role in success of Green Revolution in India especially in original Green Revolution states including Punjab. The groundwater withdrawals are the primary source of irrigation (approximately 70-80%) supplemented by the canal water from the dams and diversion of Sutlej River in the region. Thus ground water is under tremendous pressure. With the foresaid context and views the present study was undertook with following objectives:

1. To collect/procure/computerize long-term hydrological and climatic data of study area
2. To create an integrated hydrological database of lower Sutlej
3. To analyze recorded hydro-climatic data for trends or changes in Punjab Plains of lower Sutlej
4. To evaluate monthly/seasonal/annual hydrology of the region

Initially the study was planned for three years, but during one of the internal review meeting as well as working group meeting held in October 2014 it was suggested and accepted that the study period should be reduced to two year. Secondly, due to highly regulated flow regime of the lower Sutlej it was also concluded that the trend analysis of discharge data may not be able to explained the natural variability of the river hydrology and one may not be able to draw much of the significant scientific inferences. Therefore the fourth objective of the study has been dropped. The study commenced in the November 2013, during the first years the rainfall data has been analyzed and presented in the first interim report submitted in March-2014. Further, this second interim report contains the trend analysis of maximum and minimum temperature series. The study is has been completed in time i.e. October 2015.

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Chapter 2

STUDY AREA

2.1 Study Area

The study area comes under the Punjab state which is bounded on the, west by Pakistan, on the north by Jammu and Kashmir, on the north-east by Himachal Pradesh and on the south by Haryana and Rajasthan. This area falls under 9 districts of Punjab namely Amritsar, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Moga, Nawanshehar and Rupnagar (Fig 2.1). The geographic extent of the study area lies between the 30°45'-32°30'N latitude and 74°45'-76°45'E longitude. The study was undertaken actually for the plains of the lower Sutlej of Punjab State, which is also popularly known as Doaba region of Punjab. The Punjab plains are largely flat and featureless and consist of Pleistocene and the sub recent alluvium deposited by the rivers of the Indo-Ganagetic system. The location of the study area is shown in the index map (Fig 2.1).

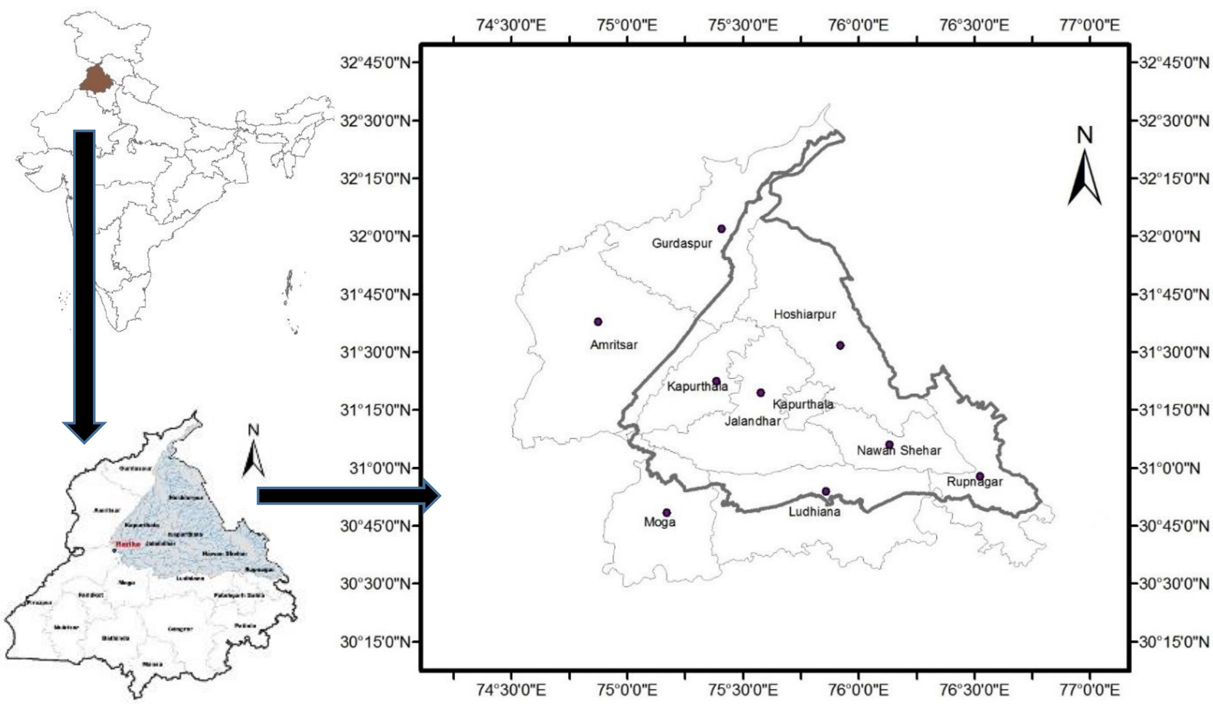

Fig 2.1: Index map of Study Area (Surrounded Portion).

2.2 Climate:

Climate of Punjab is tropical, semi-arid, hot and subtropical monsoon type with cold winter and hot summer. The climate of Punjab is mainly influenced be the Himalayas in the North and the 'Thar' desert of Rajasthan in the south and south-west. Punjab has three well defined seasons, winter season from November to February, pre-monsoon or spring season March to May and Monsoon season from June to October. Late spring and early Monsoon i.e. April to June weather is relatively dry and uncomfortable. Weather tends to be humid during July to September due to increased moisture contents in the air, however these months are comfortable due reduced day temperature.

2.2.1 Rainfall: Punjab receives about 648.8mm of average Annual rainfall with huge variability in space as well as in time. 75% of total rains received during monsoon months. July and August are rainiest month. Rainfall in the state varies from 400mm in extreme southwestern parts to 660mm to the Northern and Northeastern parts. Monsoon reaches eastern part by second last to last week of June which normal onset date of monsoon season and cover entire state by first week of July. During winter state receive about 100mm of average rainfall due to passage of western disturbance which are quite crucial for agriculture operations. State is prone to frequent floods (excess rainfall) and drought (rainfall deficient) during monsoon months (Punjab State Gazetteers). The long term average annual rainfall map of the study area along with the isohyets is depicted in the Fig. 2.2.

2.2.2 Temperature: Day temperature are more or less uniform over the plains except during winter and monsoon season. In general the night temperature are lower in higher latitudes except during the post-monsoon when they are more or less uniform. June is the hottest month with mean maximum temperature of 41 ^{0}C plains with 2 to 5 ^{0}C lower temperatures at elevated places. Highest temperature recorded in the plain is 48.3 ^{0}C, on May 29th, 1944 at Ludhiana. January is the coldest month with mean minimum temperature for the state on a whole is 5.5 ^{0}C, varying from 4 to 5 ^{0}C in the west to 6 to 7 ^{0}C in the east. Lowest temperature recorded in the Punjab is −3.9 ^{0}C, was recorded on January 4th, 1975 at Bhatinda (IMD 2010).

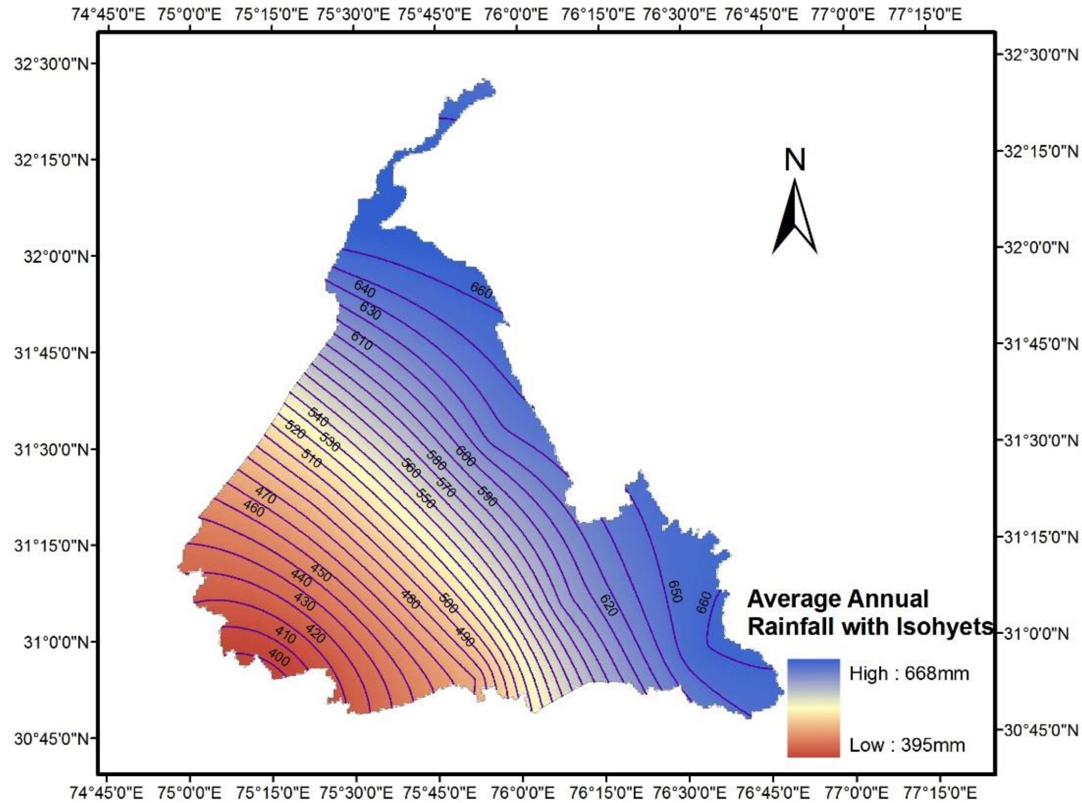

Fig 2.2: Average Rainfall map with Isohyets.

The relative humidity is generally high through the year except during months of April to June. The average humidity remains about 32% in May and 73% during August. Period from October to November May to June is generally cloudless or lightly clouded. July and August are two months when sky remain clouded/overcast for more days.

2.3 Water Resources:

River Systems: The study area is drained by the two of major Himalayan perennial rivers viz. Sutlej and Beas. The region is called Bist-Doab in local language, which literally meaning the area confined between two rivers. The Sutlej and Beas rise in the high Himalayas and after traversing through long courses of several hundred kilometers enter the state of Punjab. The Sutlej enters Punjab near Nangal, moves on to plains at Ropar, passes through district Ludhiana (where the higly polluted Budha Nallah merges with it) and joins Beas at Harike before crossing over to Pakistan. Its total length is 440 km in the state. The Beas enters Punjab near Talwara and enters the plains to meet the Sutlej at Harike. Its total length is 470 km and catchment area is 13,229 km2. The major canal network, Bist- Doab canal arises from River Sutlej at Ropar head-works. Besides these, the Kandi region is full of seasonal streams. The drainage density is high in the north east strip bordering the Siwaliks, but it is moderate to low in the rest of the area with sub-parallel and sub-dendritic patterns. The region is rich in water power. The Pong dam on the river Beas and various powerhouses on the Mukerian Hydel Canal provide power to the region.

Groundwater & Hydro-geology: The study area is mainly underlain by Quaternary alluvium of considerable thickness, which abuts against the rocks of Siwalik system towards North-East. The alluvial deposits in general act as a single ground water body except locally as buried channels. Sufficient thickness of saturated permeable granular horizons occurs in the flood plains of rivers which are capable of sustaining heavy duty tubewells. The Bist- Doab region consists of two aquifer groups. The top layer of the aquifer group-I comprises of coarse sand beds, places gravelly in nature. This layer varying thickness that ranges from 72 m to 94 m. A regionally extensive clay layer with varying thickness from 16 to 32 m separates this aquifer from underlying aquifer group-II. The aquifer group-I comprises of alternating sequences of thin layers of sand and clay beds. Sediments of this aquifer group are chiefly sand, clay, gravel and occasional kankar. The aquifer thickness of group-II below the confining layer up to 250 m has also been worked out. A thick aquifer having a thickness ranging between 81 m to 105 m occur in the area reported by Krishan et al. (2014). Water table elevation is highest in the north-eastern part (Kandi area) and lowest in the south-western part of the region, which in turn reflects the topographic gradient. In the eastern part of the study area, the Sutlej River is effluent in nature while moving to the plains it becomes influent in nature. In the post-monsoon period, depth to water table ranged between 3.59 to 22.27 m BGL.

Existing cropping pattern, cheap credit and free supply of electricity are the main factors behind steep increase in the use of tube wells for irrigation in the study area as well as I the entire Punjab state. Extensive use of groundwater through tube wells for irrigation have led to lowering of the groundwater table in the region. The water table in the districts of study area has also been going down. Most of the centrifugal pumps have been replaced by the submersible pumps leading to additional expenditure along with tremendous increase in energy consumption.

Table 2.1: Distribution of blocks in different categories on basis of ground water resources in Bist-Doab

District	No. of Blocks	Over Exploited (> 100%)	Critical (90-100%)	Semi-Critical (70-90%)	Safe (< 70%)
Hoshiarpur	10	04	-	01	05
Jalandhar	10	10	-	-	-
Kapurthala	05	05	-	-	-
Ludhiana	11	10	01	-	-
Nawanshahar	05	03	-	-	02
Rupnagar	07	03	-	-	04
Total	48	35	01	01	11

2.4 Land Use Land Cover:

Agricultural in the major industry in Punjab, hence the majority of land use belong to agriculture land. As per the statistical abstract (2012) published by Economic and Statistical Organization, Govt. of Punjab the total geographical area of the state is 50.36 lakh ha. During 2010-11, the net sown area was at 4,158 thousand hectare which indicated that about 83 per cent of the area in state is already under cultivation. This is the highest in country and the state is virtually comparable to a farmstead where most of the area is under the cultivation leaving little land for other activities. The forest wealth of state is very poor with only 5.84 per cent (294 thousand hectare) of the total area under the forest cover. Barren, unculturable land, land put to Non-Agriculture use contributes to 532 thousand hectare. The remaining land cover belongs to cultural waste, permanent pastures, other grazing and land under miscellaneous uses which turn out to be 12 thousand hectare. Under the natural resources census mission, NRSC has carried out the national land use land cover mapping using IRS LISS-III satellite data on 1:50, 000 scale for entire country. Fig. 2.4 depicts the Land use land cover map for the study area has been carved from the Punjab state map.

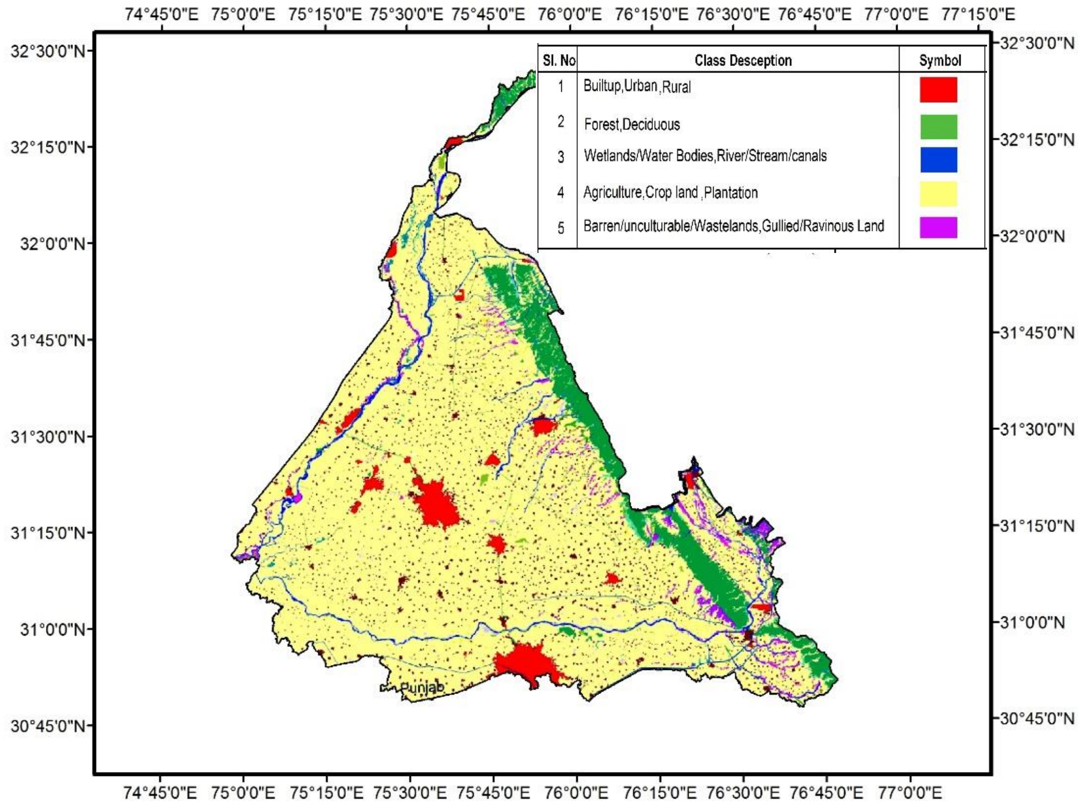

Fig 2.3: Land Use Land Cover Map of study area.

2.4 Districts

This area falls under 9 districts of Punjab namely Amritsar, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Moga, Nawanshehar and Rupnagar (Fig 2.1). The geographic extent of the study area lies between the 30°45'-32°30'N latitude and 74°45'- 76°45'E longitude with a range of altitudinal profile of 106m in the southern to 953m in the northern part. The elevation profile of the study area is shown in the Fig 2.5.The study area is about 13229 km^2 up to Harike Barrage which is the confluence of the Sutlej and Beas. The brief description about the districts falling in the study area are given subsequent sections:

Amritsar: The Amritsar is the second largest (Area 5075 km^2) and most populous (36.11 Lakhs / 3.61 Million) district which falls in the Jalandhar Division of the Punjab including the Tarn Taran district. With Trapezium shape its base resting on the River Beas. It forms a part of a tract known as Bari Doab. The part of the study area which fall in this district is mainly the flood plain of Sutlej and Bluff along the Beas. Soils in the western part of the district are coarse loamy, calcareous soils, where as in the central part of the district soils are fine loamy, calcareous and are well drained.

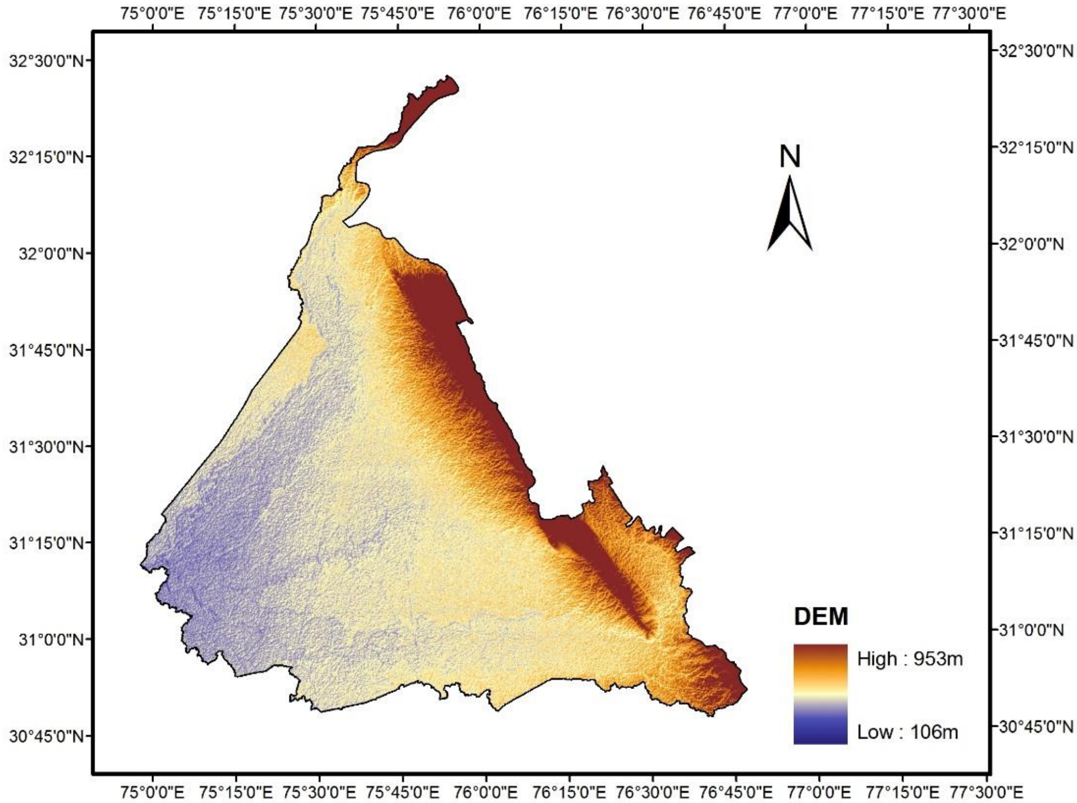

Fig 2.4: Elevation Profile (Digital Elevation Model) of study area.

Gurdaspur: The Gurdaspur district is the northernmost district of Punjab state. It falls in the Jalandhar division and is sandwiched between river Ravi and Beas. The land scape of the district has varied topography comprising undulating plan, the flood plains of the Ravi and the Beas and the upland plain. Its elevation ranges from about 305 meters above sea level in the north-east to about 213 meters above sea level in the south west, with a gentle gradient of about 1 meter in 1.6 km. The ground water in this region is suitable for irrigational and domestic uses. The sub soil water depth ranges from 5 to 8 meters in most part of the district. The soils are loamy with a clay content below 10 percent. The district possesses a fairly dense network of canals of the Upper Bari Doab Canal system which irrigates most of the area of the district. Its main branches are Lahore branch, Kasur branch and the Sabhraon branch. According to the 2011 census Gurdaspur district has a population of 2,299,026.

Hoshiarpur: Hoshiarpur, one of the oldest districts of Punjab, is located in the North-east part of the Punjab state and shares common boundaries with Gurdaspur district in the north-west, Jalandhar and Kapurthala districts in south-west, Kangra and Una districts of Himachal Pradesh in the north-east. Hoshiarpur along with the districts of Nawanshehar, Kapurthala and parts of Jalandhar represents one of the cultural region of Punjab called Doaba or the Bist Doab - the tract of land between two rivers namely Beas and Sutlej. The area along with the Shivalik foothills on the right side of Chandigarh-Pathankot road in Hoshiarpur is sub-mountainous and this part of the district is also known as Kandi area.

Table 2.2: Districts of Punjab with population and geographical area details

S. No.	Name of District	Total population	Decadal growth rate	Density (per km^2)	Area km^2
1	Amritsar including Tarn-Taran	3610961	17.38	709.90	5086.57
2	Gurdaspur	2299026	9.30	649.00	3542.41
3	Hoshiarpur	1582793	6.85	466.00	3396.55
4	Jalandhar	2181753	11.16	831.00	2625.45
5	Kapurthala	817668	8.37	501.00	1632.07
6	Ludhiana	3487882	15.00	975.00	3577.31
7	Moga	992289	10.90	444.00	2234.89
8	Rupnagar	683349	8.67	488.00	1400.31
9	S.B.S. Nagar	614362	4.58	479.00	1282.59

Source: Census of India 2011

Jalandhar: It occupies the southern part of the doab called Bist Jullundur. The climate of this district is on the whole dry except during the brief south-west monsoon season. On an average, there are 36 rainy days (i.e. days with rainfall of 2.5 mm or more) in a year in the district. The number varies from 30 at Phagwara to 45 at Adampur. Being a part of the Doab tract the district is characterized by two distinct features i.e. vast upland plain and Sutlej flood plain. Climate of the district can be classified as tropical and dry sub humid. The area receives normal annual rainfall is about 701 mm which is spread over 35 rainy days. 70% of rainfall occurs during south-west monsoon.

Kapurthala: The climate of Kapurthala is typical of the Punjab plains i.e. hot in summers and cold in winters. It has sub-tropical continental monsoon type climate. Intensive cultivation in the district leaves no scope for forest cover and the wild life is practically nonexistent. The Beas is the main river of district along with two major tributaries west or black bein (stream) and east white bein. Beas while making its way in a south-Westley direction on entering the plains, from its sources near Rohtang pass in the Pir Panjal range of the lesser Himalaya, marks the western boundary of the Kapurthala district. Apart from the natural drainage features, the district is irrigated by the distributaries of the Bist Doab Canal. The area around Kapurthala is underlain by the Indo-Gangetic alluvium which consists of silt, clay, kanker, sand, gravel and pebbles.

Ludhiana: Ludhiana city which is district headquarters is the hub of industry in Punjab. The main industries are bicycle parts and hosiery. Ludhiana is the biggest city of the state. The alluvium deposited by the Sutlej River has been worked over by the wind, which gave rise to a number of small dunes and sand mounds. Most of these dunes have been leveled by farmers of the district. The district can be divided into the flood plain of the Sutlej and the upland plain. About 70% of the rainfall is received during the period of July through September. The rainfall between December and March accounts for 16% of the rainfall the remaining 14% rainfall is received in the other months of the year. The Sutlej and its tributary, the Buddha Nala, constitute the chief hydrographic features of the district.

Moga: Moga became the 17th district of Punjab State on 24 November 1995. It is also known as NRI district. Most Punjabi Non-resident Indians (NRIs) belong to rural areas of Moga district. Moga District is among the largest producers of wheat and rice in Punjab, India. The physiography of the district is broadly classified from south to north into four distinct features i.e. Upland plain, Sand dune tract, younger flood pain and active flood plain of Sutlej.

Nawanshehar: Nawanshahr district also known as Shahid Bhagat Singh (SBS) Nagar district. It is the third least populous and one of the smaller district of Punjab having an area of 1282.59 km^2 consisting of population of 6, 14,362 as per the 2011 census. The land of District Shahid Bhagat Singh Nagar is fertile due to the presence of river Sutlej and irrigated through tubewells and canals except some part of the Balachaur sub-division falling in Kandi Area.

Rupnagar: The town of Rupnagar (formerly known as Rupar or Ropar) is said to the site of an ancient town of the Indus valley civilization. The district headquarters is 42 km from Chandigarh, the state capital. The climate of Rupnagar district is characterized by its general dryness (except in the south-west monsoon season), a hot summer and a bracing cold winter. The soils of the district vary in texture generally from loam to silty-clay-loam except along the Sutlej River where some sandy patches may be found and these are undulating in nature.

Overall the districts of Punjab which falls under the study area of Lower Sutlej up to Harike barrage are having geographically and climatic homogeneity in nature. The soil profile is also alluvial in nature in most of the districts. The area has a very good surface water resources in the form of rivers and canals and the declining ground water table is the common problem in the area.

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DATA AND METHODOLOGY

3.1 Data Used:

This study has been planned to carry out variability and trend test for all the available hydro-meteorological variables. For that the various meteorological data sets from IMD as well as freely available data viz. rainfall, maximum and minimum temperature, Reference Evapotranspiration (ET_0) for the districts (from 1901-2010) which fall under the study area was collected. Ground water level data for the study area was collected from the Ground Water Cell (GWC) of state irrigation department of government of Punjab. Few of the discharge data of Sutlej River was also been collected from the same department. The trend analysis and its attribution along with the assessment of magnitude of trends for aforesaid variables has been performed in the study.

3.1.1 Rainfall Data: The available monthly rainfall datasets for the nine districts (from 1901-2010) which fall under the study area has been taken from the India water portal website for the trend analysis of monthly, seasonal and annual basis. The box plot given blow (Fig 3.1) represents the major statistical characteristics such as shows a data set's lowest value, highest value, median value, and the size of the first and third quartile of the rainfall data from1901-2010 for the concerned districts of the study area.

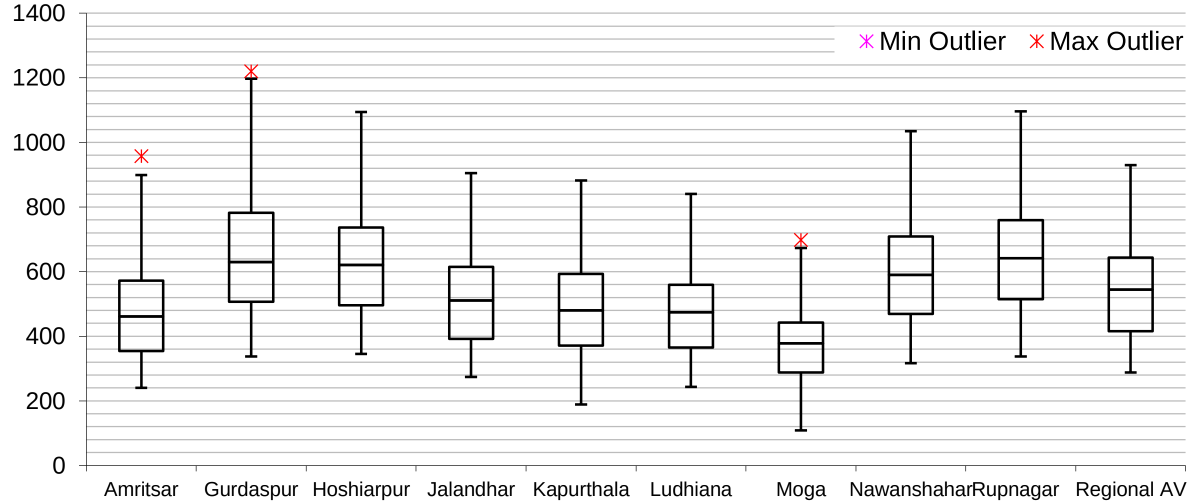

Fig 3.1 Box plot of the rainfall data (1901-2010) for districts of study area.

3.1.2 Temperature Data: The monthly data sets of both maximum and minimum for the districts falling under the study area has processed and annual and seasonal trends and there magnitude has identified. The box plot given blow (Fig 3.2 & 3.3) represents the major statistical characteristics such as shows a data set's lowest value, highest value, median value, and the size of the first and third quartile of the maximum and minimum temperature data respectively from1901-2010 for the concerned districts of the study area.

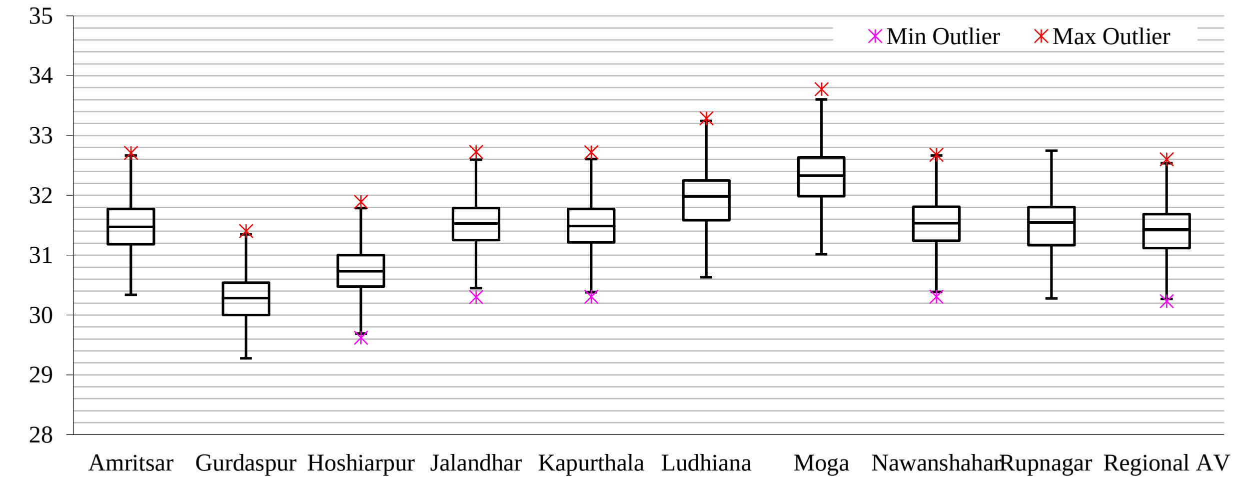

Fig 3.2 Box plot of the Maximum Temperature data (1901-2010) for districts of study area.

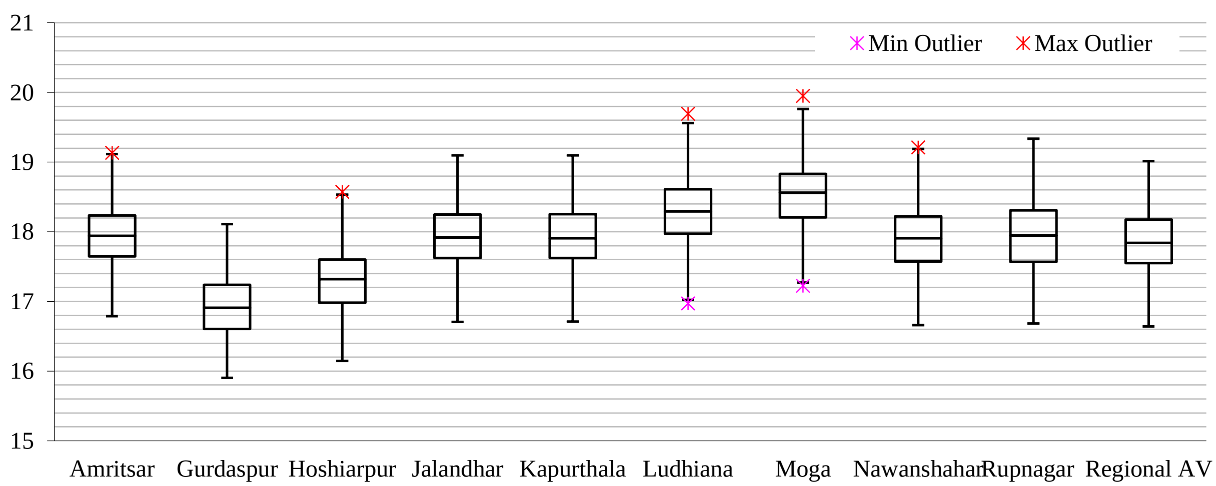

Fig 3.3 Box plot of the Minimum Temperature data (1901-2010) for districts of study area.

3.1.3 Ground water Data: Historic groundwater level data were collected for the study area from the Ground Water Cell (GWC) of state irrigation department of Punjab which is responsible for monitoring the ground water level within the state. The raw data were instantaneous elevation measurements in meter made on pre-monsoonal and post-monsoonal basis. Those measurements were processed for trend detection. Many of the groundwater stations have records shorter than the study period; however, this report only presents the statistical analysis results for the period between 1999 and 2012. The GWC currently has 350 observational wells / piezometers measured bi-annually; 95 of them have long time recorders. Groundwater level data between 1999 and 2012 from these 95 wells in the study area that continuous data with at least 2 measurements per year were analyzed. Fig 3.4 shows the location of these 95 observation point in the study area. GW level in the Bist-doab region of Punjab is highly undulating with a variation from 1m to 33m. Table 3.1 represents the number of observation points in the districts falling in the study area as well as the maximum and minimum ground water table depth below the ground level for pre-monsoon (June) and post-monsoon (October) for the year 2012. Geological Formation of most of the region is reported to be mainly Alluvium to Shiwaliks from south towards north. The stage of groundwater development in almost all the blocks of Bist- Doab region exceeds 100% making the region over exploited in groundwater. Most of the area in the central plains is labeled as 'dark area' from the point of view of ground water.

Table 3.1 District wise GW level Data ranges from GWC, Punjab (Year 2012)

Name of the District	No. of Observation Wells /Piezometers		Ground Water Levels Ranges (m, bgl)			
			Pre - Monsoon		Post-Monsoon	
	Total	With Long-term Data	Min	Max	Min	Max
Hoshiarpur	126	31	4.39	23.30	1.68	22.75
Jalandhar	93	10	6.70	32.80	6.65	32.60
Kapurthala	20	12	6.80	30.10	4.25	27.10
Ludhiana	27	17	3.65	30.92	2.40	31.45
Nawanshahar	15	7	8.20	29.32	7.15	29.32
Rupnagar	69	18	1.75	18.68	1.00	18.28
Total	350	95				

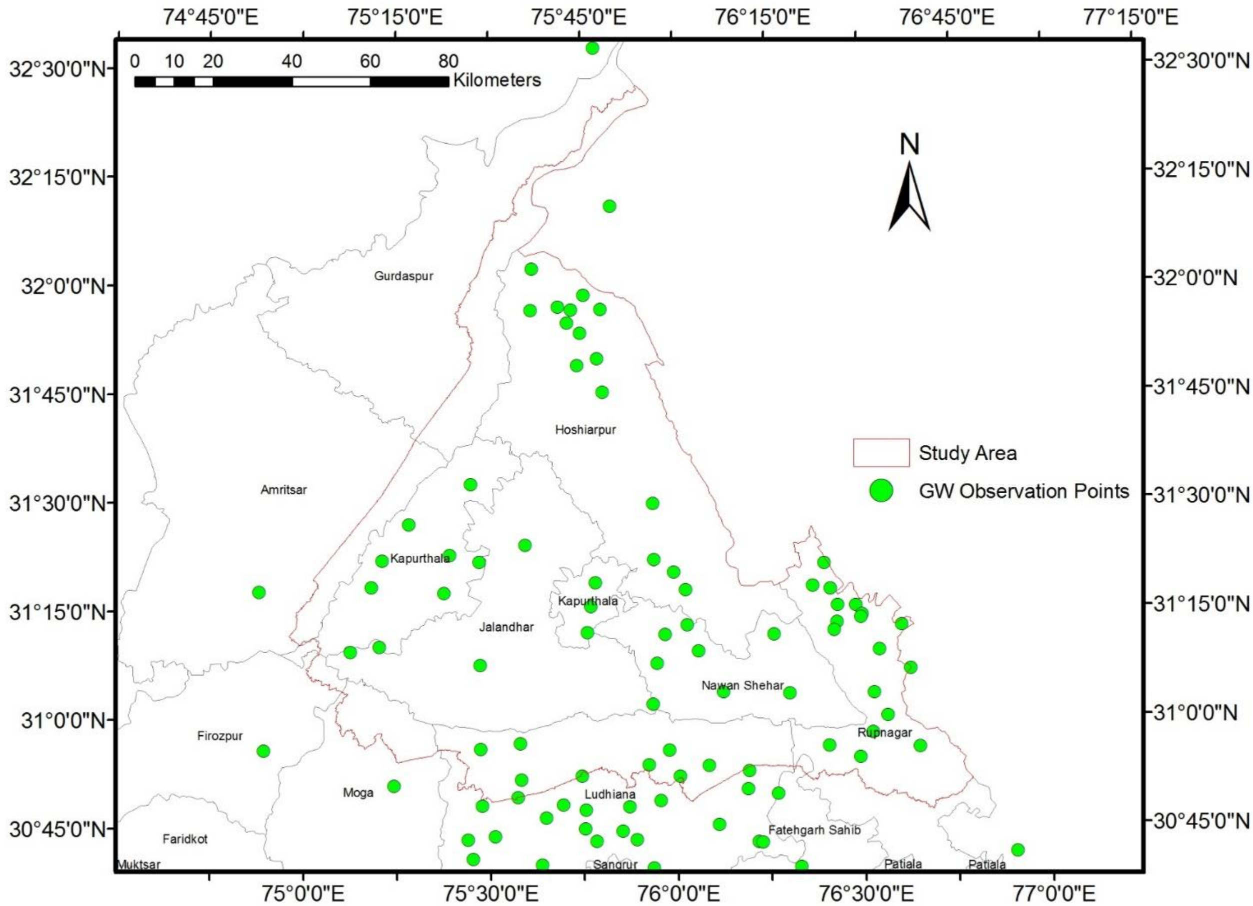

Fig 3.4 Location of Observation Well and Piezometers within Bist-Doab of Lower Sutlej

3.1.4 Reference Evapotranspiration (ET_0) Data: similar to rainfall, the monthly ET_0 data for the study period for aforesaid nine districts has been analyzed for trend detection and its magnitude.

3.2 Purpose of Trend Testing

A series of observations of a random variable (rainfall, temperature, ET, ground water level, etc.) have been collected over some period of time. We would like to determine if their values are generally increasing or decreasing (getting "better" or "worse"). In statistical terms this is a determination of whether the probability distribution from which they arise or its proposition have changed over time. The null hypothesis: H_0 is that there is no trend. However, any given test brings with it a precise mathematical definition of what is meant by "no trend", including a set of background assumptions usually related to type of distribution and serial correlation. The outcome of the test is a "decision" either H_0 is rejected or not rejected. Failing to reject H_0

does not mean that it was "proven" that there is no trend. Rather, it is a statement that the evidence available is not sufficient to conclude that there is a trend.

The inherent variability of any natural time series must be considered whenever attempting to detect trends in a natural time series. There is always difficulty associated with differentiating between natural variability and trends. This argues for the development of a rigorous procedure for detecting trends. The systematic approach that was adopted herein to determine the significance of the detected trends can be followed below:

a. The first step was to choose the variables to be studied. The maximum temperature, minimum temperature, ground water depths data were chosen this time to examine their tend and magnitude of trends to reflect an integrated response of the catchment area as a whole.

b. The second step was to choose the monitoring stations to be investigated. The primary factor on which the choice was based was the availability and length of data record. For temperature time series this point of time monthly temperature data for eight districts of Punjab State which falls within the study area have been examined. And for groundwater level 95 out of total 350 observational wells / piezometers from six districts within study area has been used (Table 3.1).

c. The third step was to check for the presence of trends in the data. This was done using the Mann-Kendall non-parametric test.

d. The fourth step was to determine the significance of the detected trends. This was accomplished utilizing well tested Sen’s slope estimation technique.

Hydrologic and climatic variables are important indicators of climatic change. Precise selection of variables is needed for any trend study as these variables tend to reflect climatic change and can help in understanding the relationships between hydrology and climate. Numerous studies have suggested different variables for detecting climatic change. This report contains the detailed analysis of trend and its magnitude detection of temperature and ground water levels.

3.3 Trend Detection Test

The time series of temperature and ground water level data were analyzed using the Mann-Kendall non-parametric test for trend. Mann (1945) originally used this test and Kendall (1975) subsequently derived the test statistic distribution. This test was found to be an excellent tool to ascertain presence of statistically significant trend in hydrological climatic variables, such as temperature, precipitation and streamflow, with reference to climate change and wildly used by the other researchers in similar applications (Kumar et.al. 2005, Bhutiyani, 2008, Singh et al., 2008a, b Kumar & Jain 2010). Pre-whitening is the most commonly used procedure to eliminate the effect of serial correlation and autocorrelation in any trend analysis, but due to the very large sample size (n >50) and the slope of trend was high (>0.01) pre-whitening of the data series was not carried out as suggested by Bayazit & Onoz (2007). However all the data was standardized before any kind of analysis. Prior to perform the testing the monthly time series of temperature were aggregated into seasonal and annual time series and standardized in order to bring uniformity and facilitate comparison between the hydrological responses of these districts. The rainfall, temperature and ET_0 data of three seasons namely, pre-monsoon or spring season (March – May), southwest monsoon season (June – October), northeast monsoon season or winter season (from November of the last year to February of the current year) and annual average of these variable were used to study the trends and temporal fluctuations in climate over the Punjab plains of lower Sutlej. Standardized Precipitation Index (SPI) and Standardized Temperature Index (STI) series were computed by subtracting the mean and dividing by the standard deviation of the precipitation/temperature series (Shreshtha et al. 2000; Pant and Kumar 1997). The SPI and STI data series were then subjected to trend analyses by two established statistical techniques: standard parametric technique, such as linear trend analysis (Borgaonkar and Pant 2001) and non-parametric test, such as Mann-Kendall test (Kendall and Stuart 1961). In case of Ground water levels two time series viz. pre-monsoon and post-monsoon ground water levels were analyzed for trends similar to other time series.

Mann-Kendall test, which is usually known as Kendall's τ statistic, has been widely used to test for randomness against trend in hydrology and climatology. It is a rank-based procedure, which is robust to the influence of extremes and good for use with skewed variables. According to this test, the null hypothesis H_0 states that the de-seasonalized data ($x_1, . . ., x_n$) is a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all k, j ≤ n with k ≠ j. The test statistic S, which has mean zero and a variance computed by Equation (3), is calculated using Equations (1) and (2), and is asymptotically normal (Hirsch and Slack, 1982):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \tag{1}$$

$$Sgn(x_j - x_k) = \begin{cases} +1 & if\ (x_j - x_k) > 0 \\ 0 & if\ (x_j - x_k) = 0 \\ -1 & if\ (x_j - x_k) < 0 \end{cases} \tag{2}$$

$$Var(S) = \left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5) \right] \Big/ 18 \tag{3}$$

The notation t is the extent of any given tie and $\sum_t$ denotes the summation over all ties. In cases where the sample size n > 10, the standard normal variate z is computed by using Equation (4) (Douglas *et al*., 2000). In a two-sided test for trend, H_0 should thus be accepted if $|z| \leq z_{\alpha/2}$ at the α level of significance. A positive value of ‘S’ indicates an ‘upward trend’; likewise, a negative value of ‘S’ indicates ‘downward trend’:

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S-1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \tag{4}$$

The Mann-Kendall test has two parameters that are of importance to trend detection. These parameters are the significance level that indicates the trends strength and the slope magnitude estimates that indicates the direction as well as the magnitude of the trend. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

3.4 Magnitude of the Trend

The magnitude of the trend in a time series was determined using a non-parametric method known as Sen's slope estimator method (Sen, 1968). This Method assumes a linear trend in the time series. In this method, the slope (T_i) of all pairs are first calculated by

$$T_i = \frac{X_j - X_k}{j-k} \text{ for i } = \text{ 1,2,3} \ldots\ldots\ldots \text{N} \tag{4}$$

Where X_j and X_k area data values at time j and k (j>k) respectively. The median of these N values of T_i is Sen's estimator of slope which is calculated as

$$\beta = \begin{cases} T_{\frac{N+1}{2}}, & N \text{ } is \text{ } Odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right), & N \text{ } is \text{ } Even \end{cases} \tag{5}$$

A positive values of B indicates an upward (increasing) trends and a negative value indicates a downward (decreasing) trend in the time series.

***

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Simple Linear Regression

Standard parametric technique, simple linear regression analysis (Borgaonkar & Pant, 2001) as described in the methodology was applied to standardized the precipitation and temperature series to get SPI and STI of each district for seasonal as well as annual time series. The standardization of the data was performed in order to bring uniformity and facilitate comparison between the hydrological responses of these districts.

The linear regression plots between SPI values of rainfall series versus the respective years of all nine districts of lower Sutlej are being presented in form of graphs in Fig 4.1(a, b, c & d) respectively for annual, Monsoon, winter and spring time series. Similarly the graphs between STI values of both maximum and minimum temperature series are shown in Fig 4.2(a, b, c & d) and Fig 4.3(a, b, c & d) respectively for annual, Monsoon, winter and spring time series. Simple linear curve fitting was also performed to find the trend of the precipitation. The trends for districts under study area are well coinciding with the trend results of the Mann-Kendall test.

4.2 Mann-Kendell Test

The results for the non-parametric Mann-Kendall (MK) test applied to ascertain the significance of trends along with the Z- values of the individual districts for seasonal and annual time series for rainfall, maximum and minimum temperature, ET_0 and Ground water levels represented in the respective tables in the further sub-section. Seasonal trend analysis of the entire monthly rainfall, ET_0 and temperature data (1900-2002) based on the three prominent and distinct seasons viz. pre-monsoon or spring season (March – May), southwest monsoon season (June – October), northeast monsoon season or winter season (from November of the last year to February of the current year) along with annual data series were also carried out for better interpretation and understanding of the trend. Further, in case of temperature, the decadal trend analysis of maximum and minimum temperature was also performed. Pre-Monsoon (June) and Post-Monsoon (October) ground water levels trend data has also reported in this section.

4.2.1 Rainfall Analysis:

The results for the non-parametric Mann-Kendall (MK) test applied to ascertain the significance of trends along with the Z- values of the individual districts for monthly time series and seasonal and annual time series are shown in Table 4.1 and Table 4.2 respectively. The results indicated that, during the primary monsoon month i.e. July seven districts out of total nine districts area showing increasing rainfall at statistically significance level of more than 95% and four of them are supporting this trend at 99% significance level. This is followed by the pre-monsoon month May in which, five districts are confirming rising trend of rainfall with significance level of more than 95% and two districts out of this five are also supporting the trend at 99% significance level. The negative z-values of January and December months' time series for all the districts are depicting the decreasing trend of rainfall but without any significant level. District Gurdaspur is supporting the rising trend of rainfall in all months expect six months of January, April, June, September, November and December.

Table 4.1: Z-Value of MK Test for monthly series of rainfall for lower Sutlej districts

SN	District	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Amritsar	-0.34	2.05*	1.93	-0.48	2.24*	1.56	2.84**	1.94	1.44	1.96*	2.01*	-0.56
2	Gurdaspur	-0.50	2.50*	2.25*	0.31	2.64**	1.11	2.77**	2.28*	0.49	1.96*	1.56	-0.48
3	Hoshiarpur	-0.85	1.45	1.42	-0.35	1.21	0.60	2.37	0.55	-0.29	1.26	0.60	-0.55
4	Jalandhar	-0.74	1.60	1.91	-0.05	1.59	1.22	2.91**	1.61	1.08	1.41	0.31	-0.61
5	Kapurthala	-0.93	1.33	1.52	-0.45	0.75	0.20	2.65**	1.11	1.06	0.22	-0.47	-1.51
6	Ludhiana	-0.40	1.18	1.84	-0.16	2.07*	1.68	2.39*	1.26	1.44	1.88	0.92	-0.38
7	Moga	-0.49	1.21	1.59	-0.84	1.63	0.48	1.90	1.64	1.16	0.78	1.69	-0.65
8	Nawanshahar	-0.57	1.41	1.95	-0.32	2.66**	1.55	1.84	0.89	1.00	1.79	0.44	-0.42
9	Rupnagar	-0.57	1.09	2.05*	0.38	2.24*	1.42	2.33	1.59	1.06	1.03	0.44	-0.16
10	Regional	-0.49	1.63	2.06*	0.01	2.37*	1.37	2.63**	1.81	1.08	1.88	1.37	-0.30
Significance Level: *95%; **99%; ***99.9%													

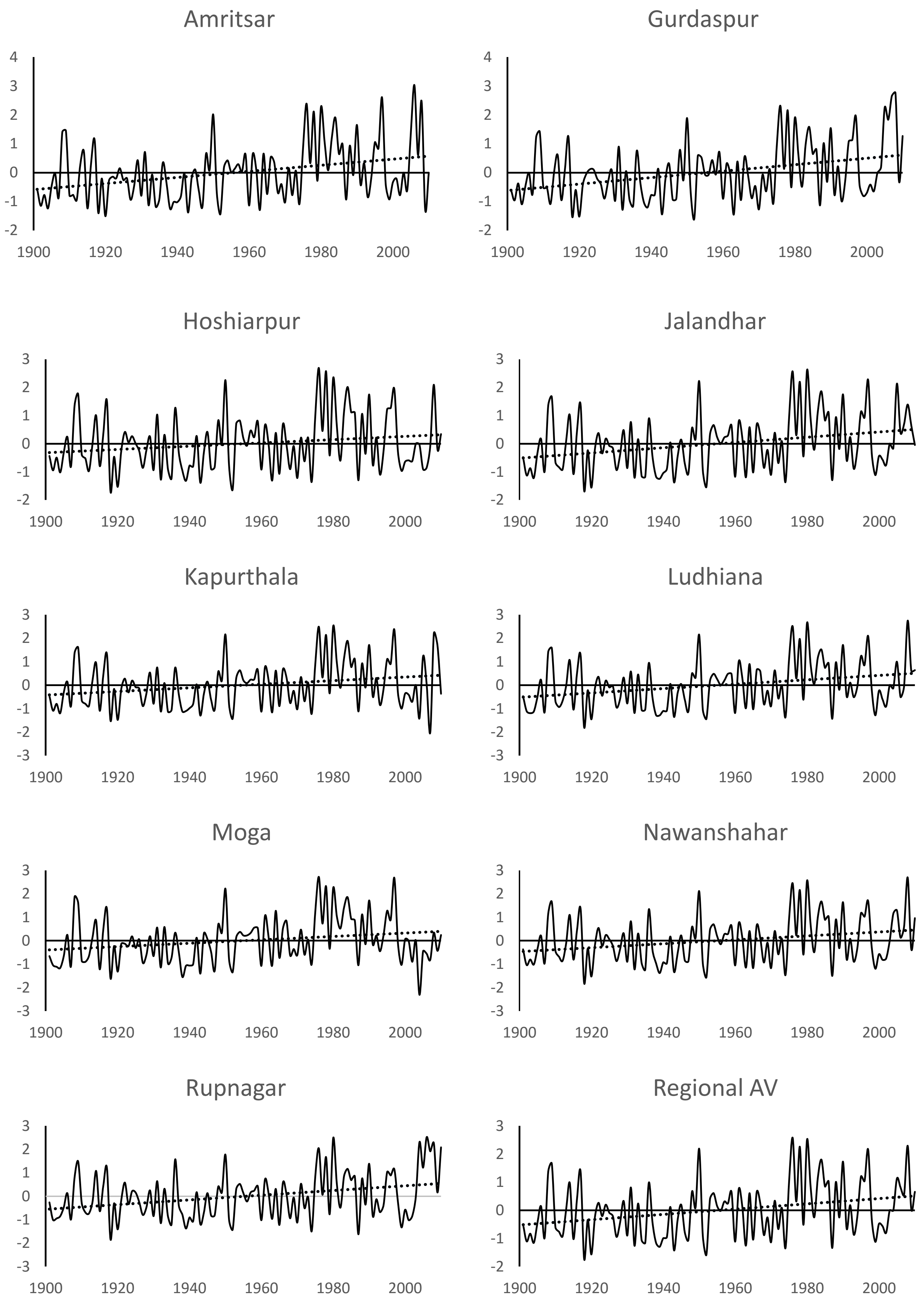

Fig. 4.1(a) Linear Trends of Annnual Rainfall at different districts of lower Sutlej

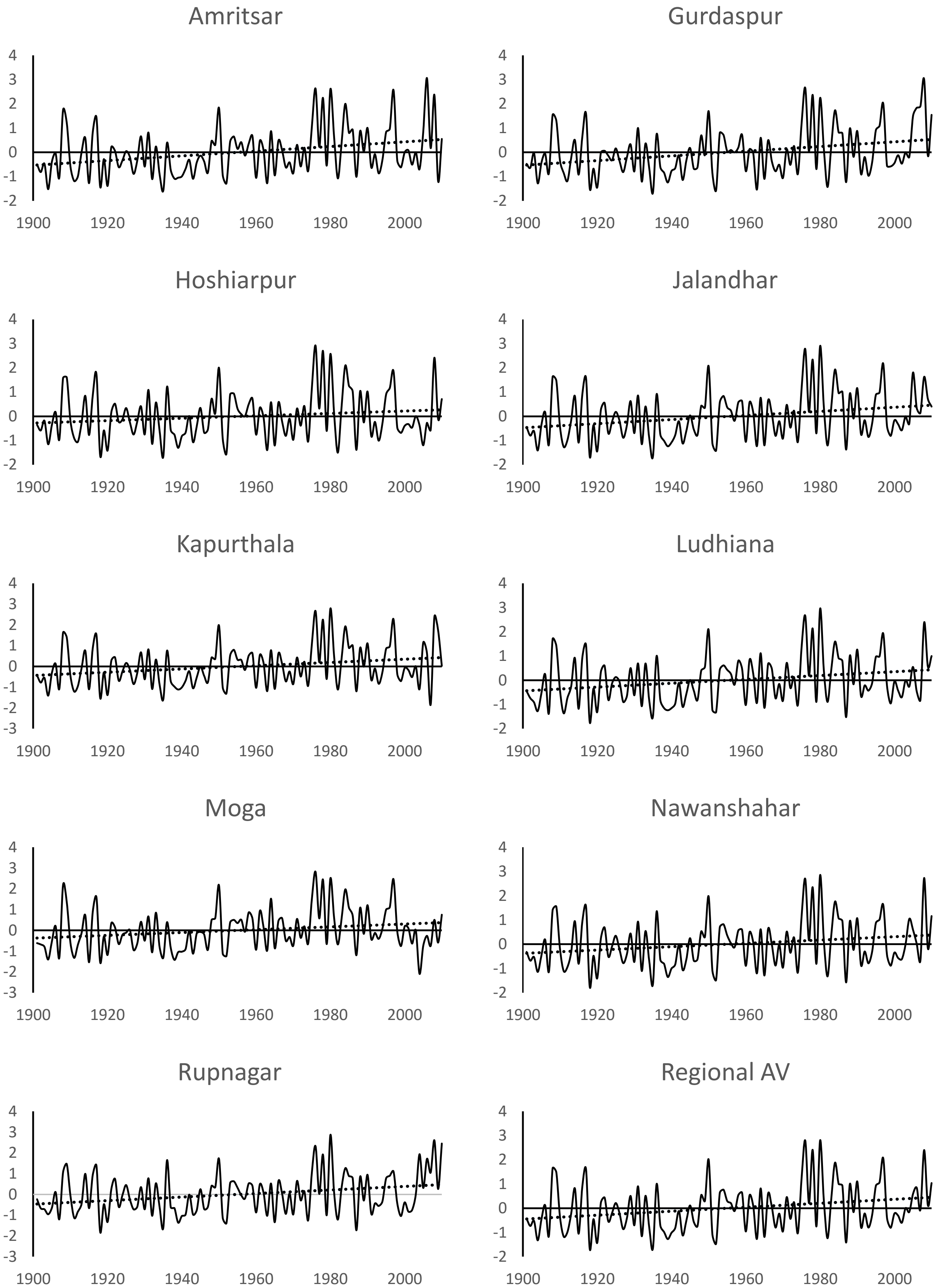

Fig. 4.1(b) Linear Trends of Monsoon Rainfall at different districts of lower Sutlej

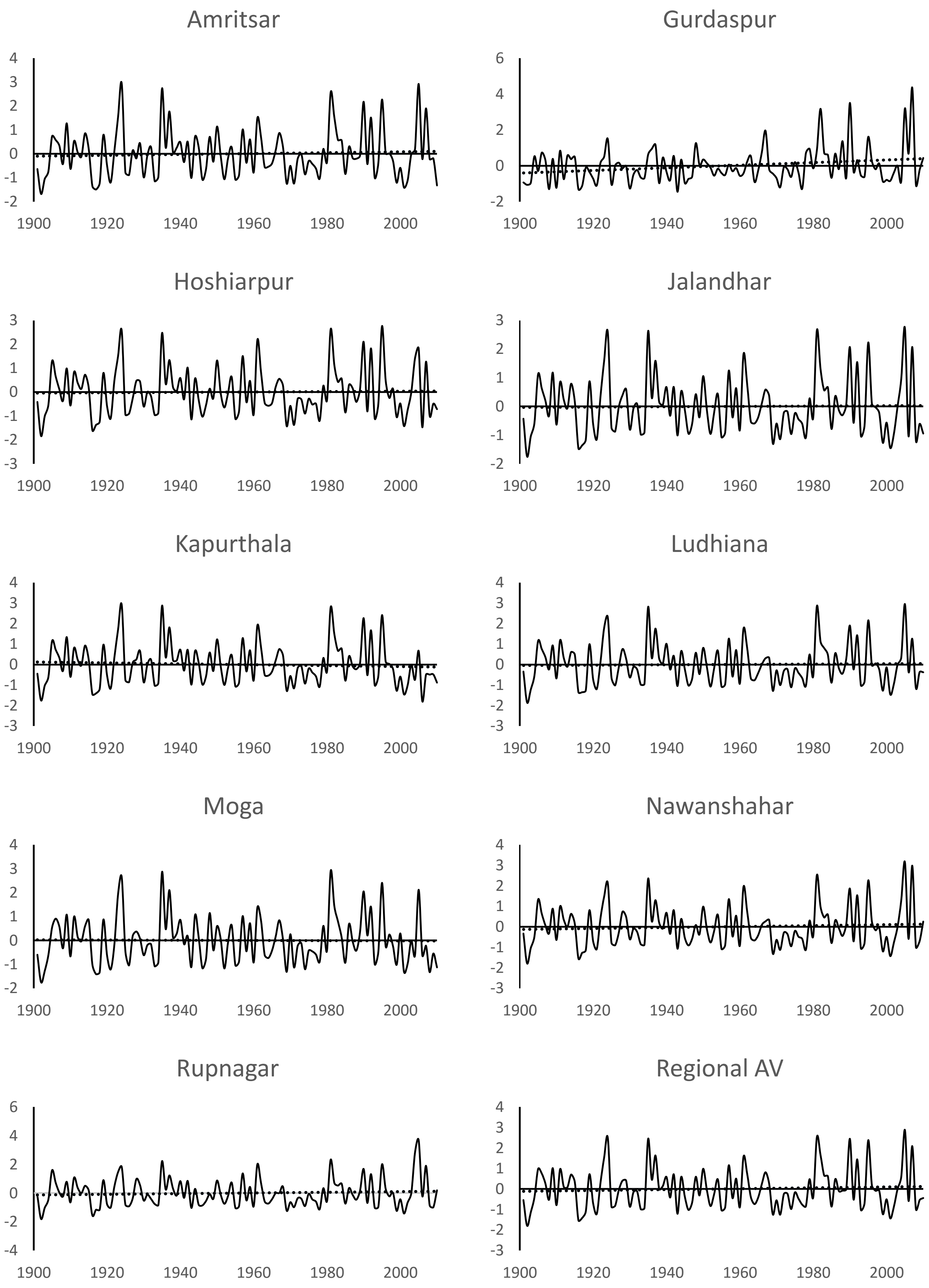

Fig. 4.1(c) Linear Trends of Winter Rainfall at different districts of lower Sutlej

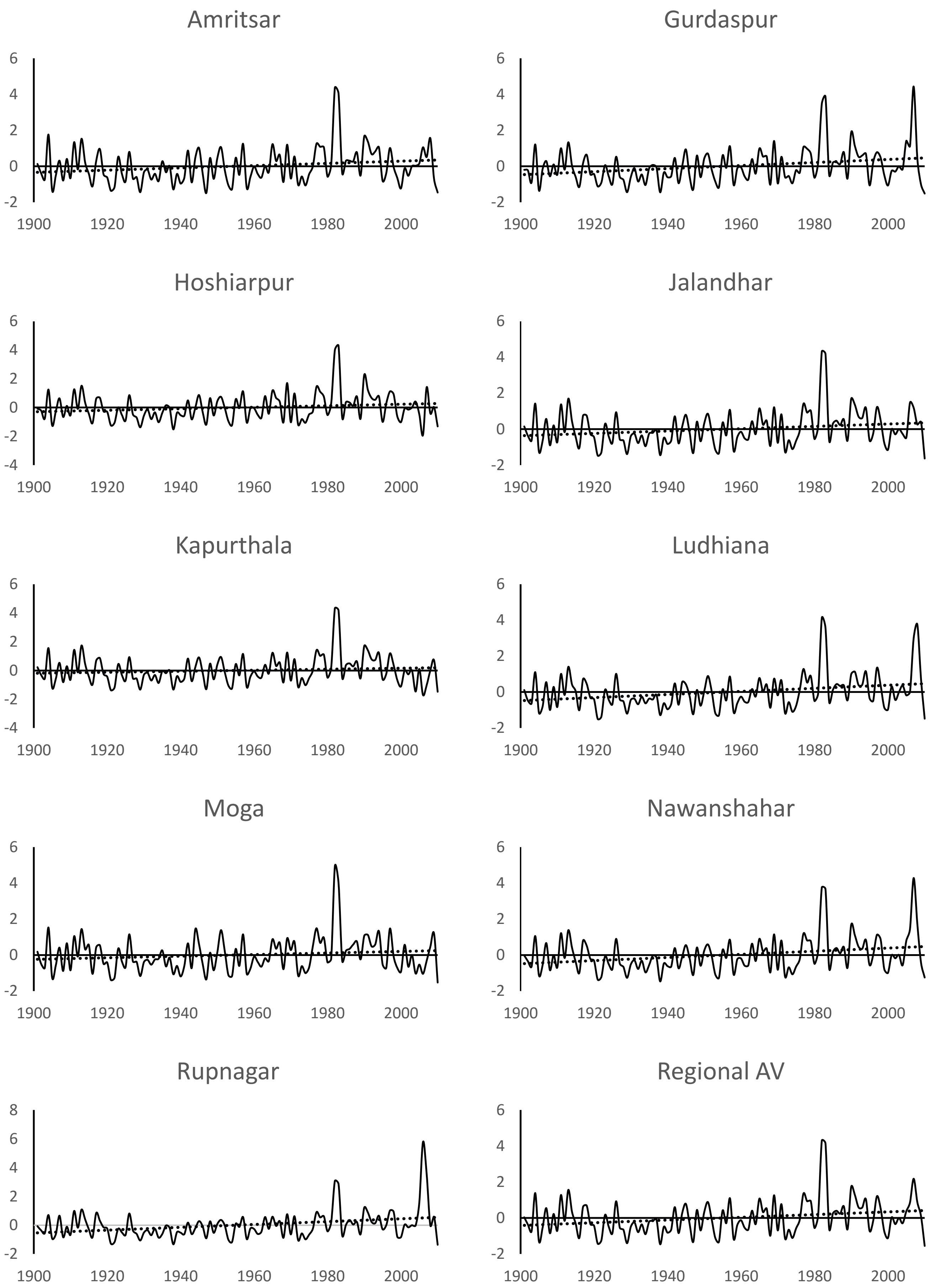

Fig. 4.1(d) Linear Trends of Spring Rainfall at different districts of lower Sutlej

Seasonal analysis of the entire monthly rainfall data (1900-2010) based on the three prominent and distinct seasons viz. pre-monsoon or spring season, southwest monsoon season, winter season along with annual rainfall was also carried out for better interpretation and understanding of the trend (Table 4.2). It is apparent from the results table that the study area as a whole is supporting the rising trend Monsoon season and spring season with statistically significance level of more than 95%. And as monsoon contributes around 80% of total annual rainfall the annual rainfall series also affirming the rising trend. The monsoon season series is having rising trend at 95% significance level for all the districts except Hoshiarpur. Five out of the nine districts have this significance level at 99%. Similarly in the spring season series six out of nine districts having statistically significant rising trend. Although, in the winter season series six districts are showing falling rainfall trend and three are showing rising trend but none of them are statistically significant.

The analysis of annual series is very similar to Monsoon series, as except Hoshiarpur districts all the districts are having statistically significant upward trends. Gurdaspur district is having highest significance level of more than 99.9% for annual series.

It is apparent from the Table 4.1., Table 4.2 and Fig 4.1(a, b, c, d) that there are rising trend of precipitaion over the last century in most of the districts of north-west Punjab plains of lower Sutlej.

Table 4.2: Z-Value of MK Test for Annual and Seasonal series of rainfall for lower Sutlej districts

S. No.	District	Annual	Monsoon	Spring	Winter
1	Amritsar	3.25**	3.07**	2.07*	0.14
2	Gurdaspur	3.47***	2.99**	2.42*	1.53
3	Hoshiarpur	1.75	1.38	1.56	-0.25
4	Jalandhar	3.12**	2.81**	2.20*	-0.46
5	Kapurthala	2.51*	2.56*	1.11	-1.09
6	Ludhiana	3.07**	2.69**	2.45*	-0.09
7	Moga	2.72**	2.56*	1.32	-0.44
8	Nawanshahar	2.68**	2.17*	2.47*	-0.06
9	Rupnagar	2.96**	2.58**	2.81	0.00
10	Whole Study Area	3.07**	2.76**	2.40*	0.16
Significance Level: *95%; **99%; ***99.9%					

In order to get the study area's response the Z-values of annual and seasonal time series also have been interpolated using spline method. The Z-value maps of the study area for annual as well seasonal rainfall trends are presented in the Fig. 4.2 Z-value maps of the area are useful to determine the z statistics of Mann-Kendall test at any point location in the study area. The annual average rainfall of the lower Sutlej is supporting the rising trend with more than 95% significance level in most of the area. The analysis of the rainfall data by parametric and non-parametric statistical test and the magnitude of trends supports the rising trend over the study area. While analysing the results presented in the various tables and figures one can easily conclude that the only winter season is not supporting any trend but the monsoon and the annual rainfall in the region has been increased over the last century.

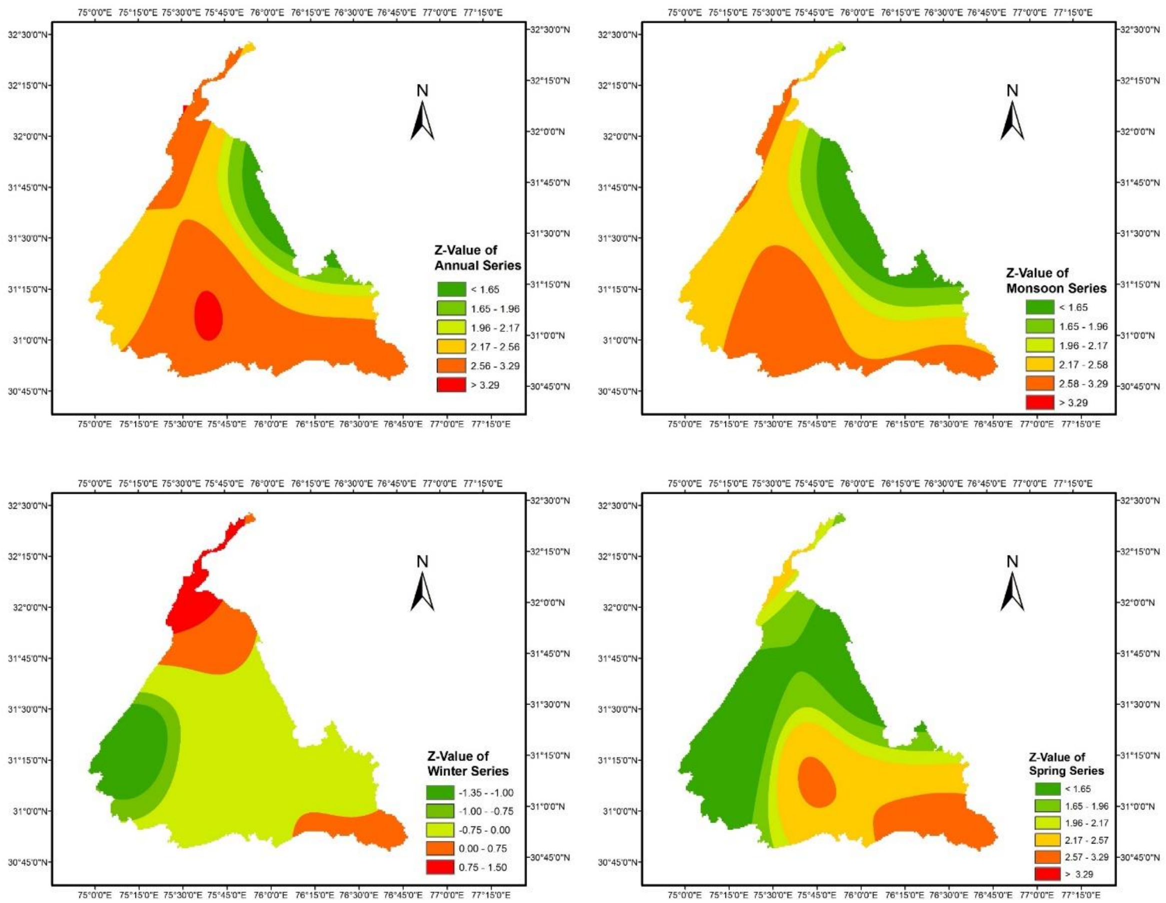

Fig 4.2 Spatial variation of MK trend Z-Statistic for annual and seasonal rainfall at Lower Sutlej

4.2.2 Maximum Temperature

Results in Table 4.3 as well as the linear trend of maximum temperature as depicted in the Fig 4.3 (a, b, c, d) it can be concluded that the study area as a whole is supporting the rising trend in maximum temperature in winter and spring season with statistically significance level of more than 99.9% and 99% respectively in most of the districts. Whereas, the monsoon season at a contrast supporting the decreasing temperature in the region at 99.9% confidence level in most of the districts. Due to this seasonal non-uniformity the annual maximum temperature series does not support any trend in the Bist-doab region for the study period. The monsoon season series is having rising trend at 99.9% significance level for all the districts.

The analysis of annual series does not give a clear indication of any trend although the positive values of Z- statistics support the rise in the maximum temperature over the study period. It is evident from Table 4.3 that winter and spring temperatures have been gone up and Amritsar and Gurdaspur districts are having highest significance level i.e. more than 99.9% for winter series.

Table 4.3: Z-Value of MK Test for Annual and Seasonal series of Maximum Temperature for Lower Sutlej Districts

S. No.	Station	Annual	Monsoon***	Spring**	Winter***
1	Amritsar	0.99	-4.34	2.65	3.66
2	Gurdaspur	1.43	-4.32	2.74	3.78
3	Hoshiarpur	1.21	-4.20	2.72	3.59
4	Jalandhar	1.04	-4.37	2.71	3.65
5	Kapurthala	1.09	-4.46	2.68	3.61
6	Ludhiana	0.88	-4.09	2.77	3.60
7	Moga	0.17	-4.31	2.47*	3.34
8	Nawanshahar	1.27	-4.02	2.78	3.54
9	Rupnagar	1.30	-3.72	2.68	3.46
10	Regional AV	1.06	-4.31	2.66	3.54
Significance Level: *95%; **99%; ***99.9%					

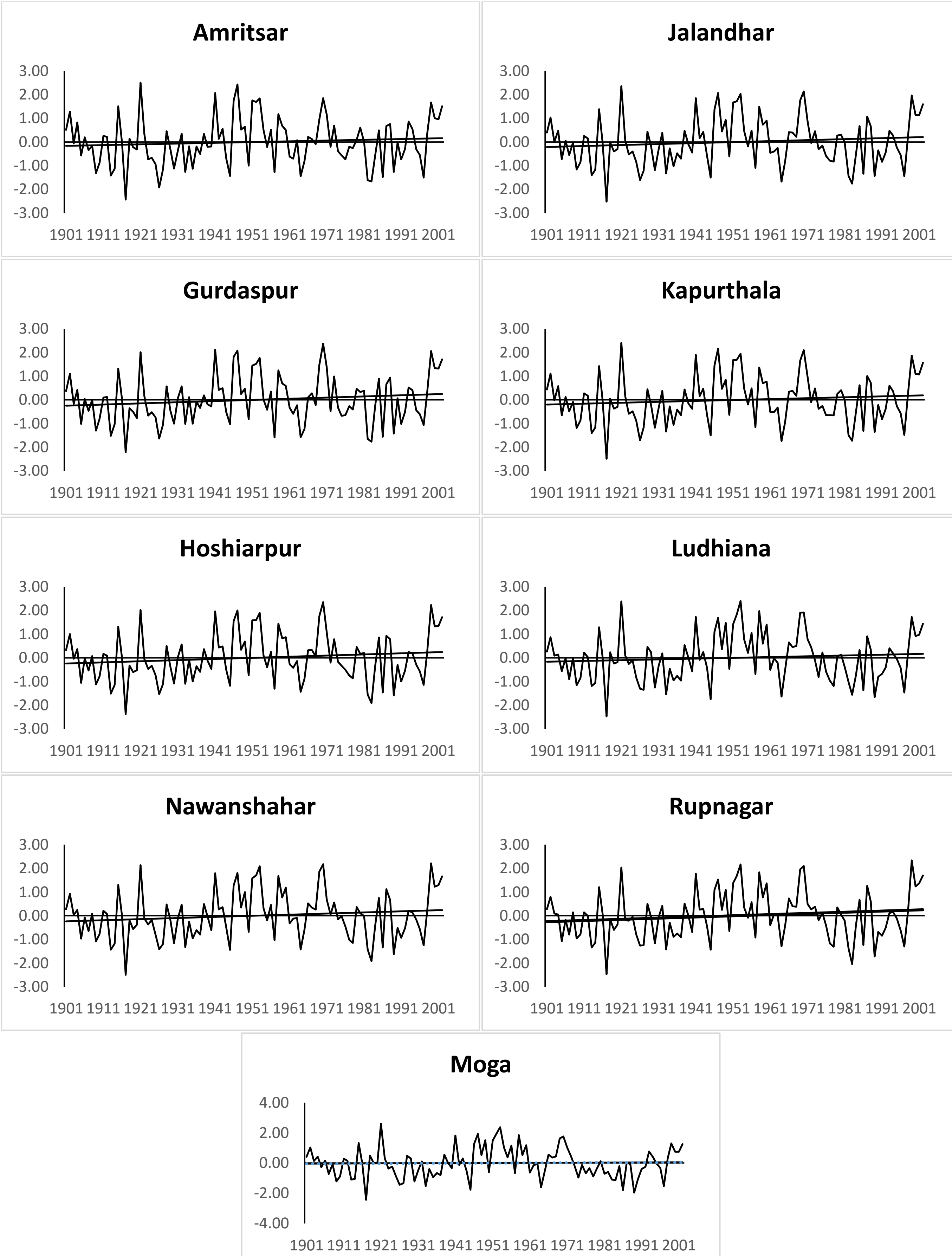

Fig. 4.3(a) Linear Trends of Annual Maximum Temperature at different districts of lower Sutlej

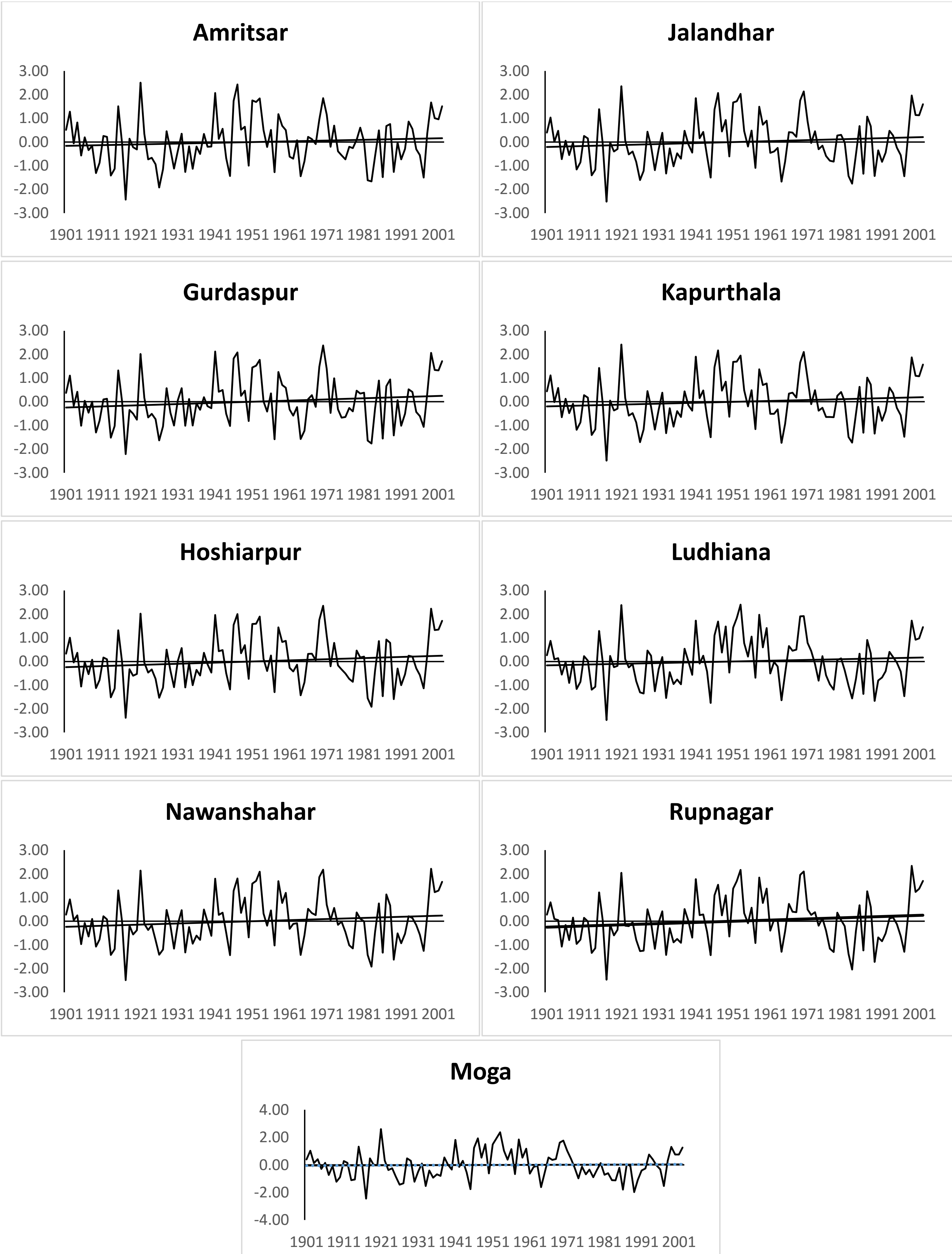

Fig. 4.3(b) Linear Trends of Monsoonal Maximum Temperature at different districts of lower Sutlej

Fig. 4.3(c) Linear Trends of Winter Maximum Temperature at different districts of lower Sutlej

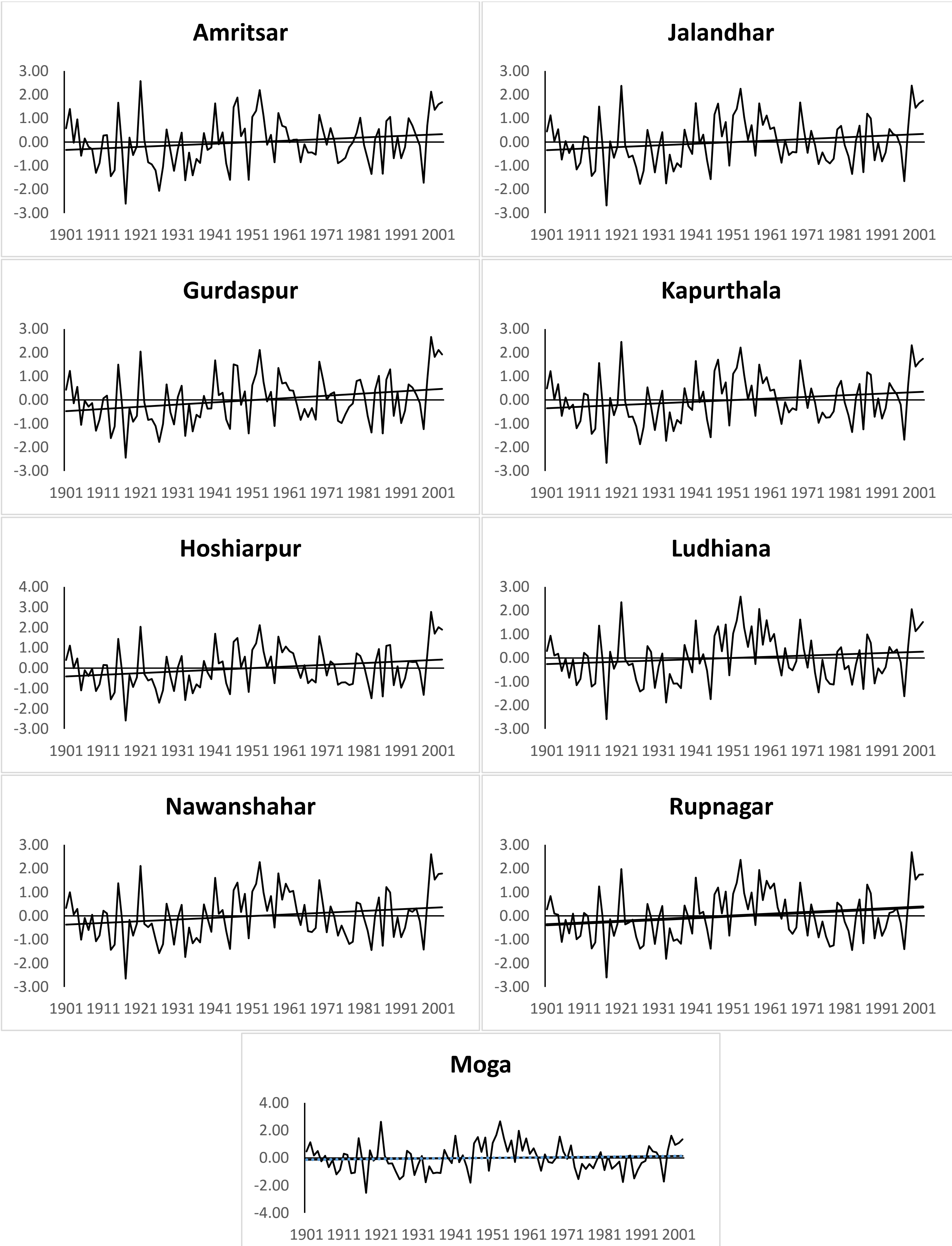

Fig. 4.3(d) Linear Trends of Spring Maximum Temperature at different districts of lower Sutlej

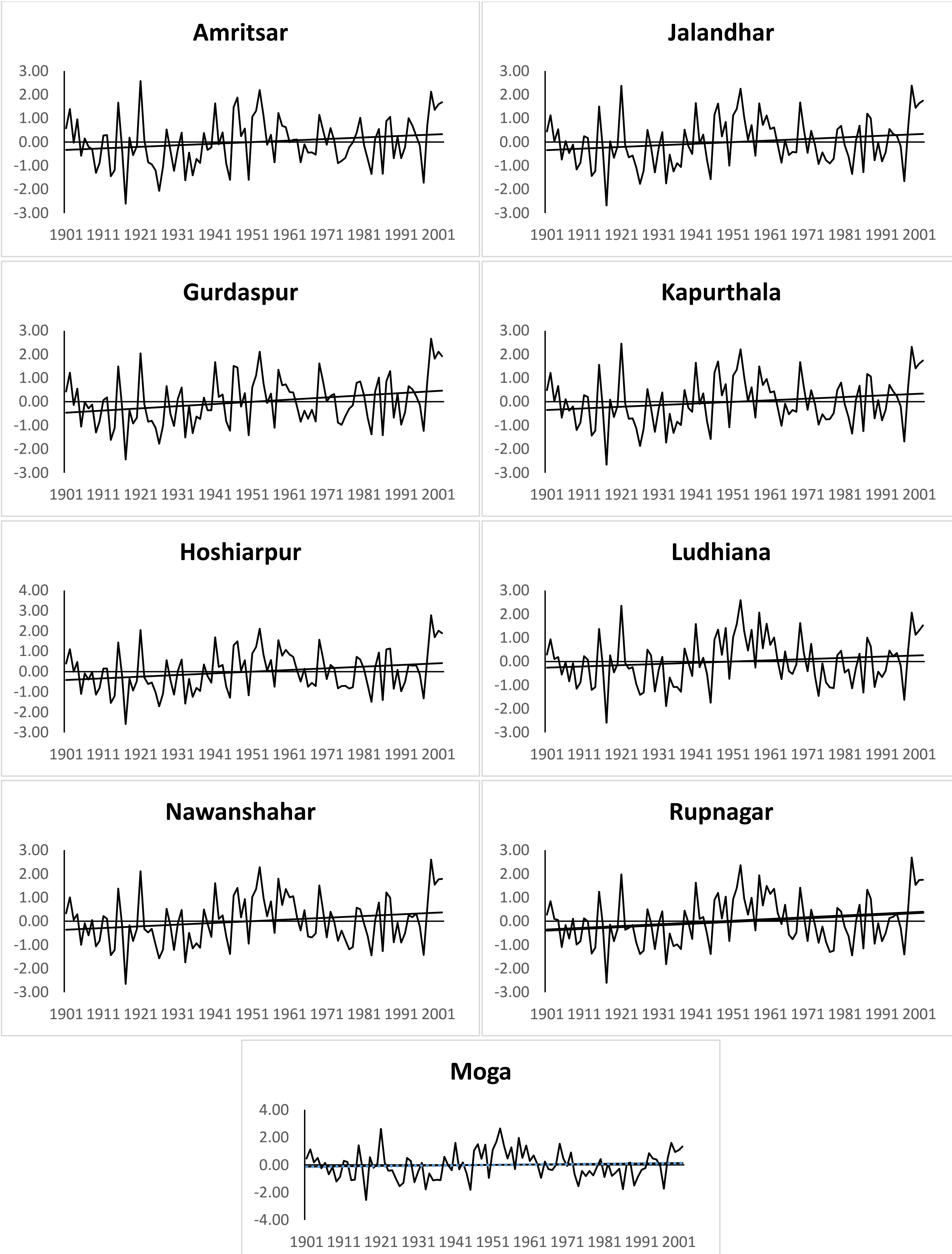

Fig. 4.4(a) Linear Trends of Annual Minimum Temperature at different districts of lower Sutlej

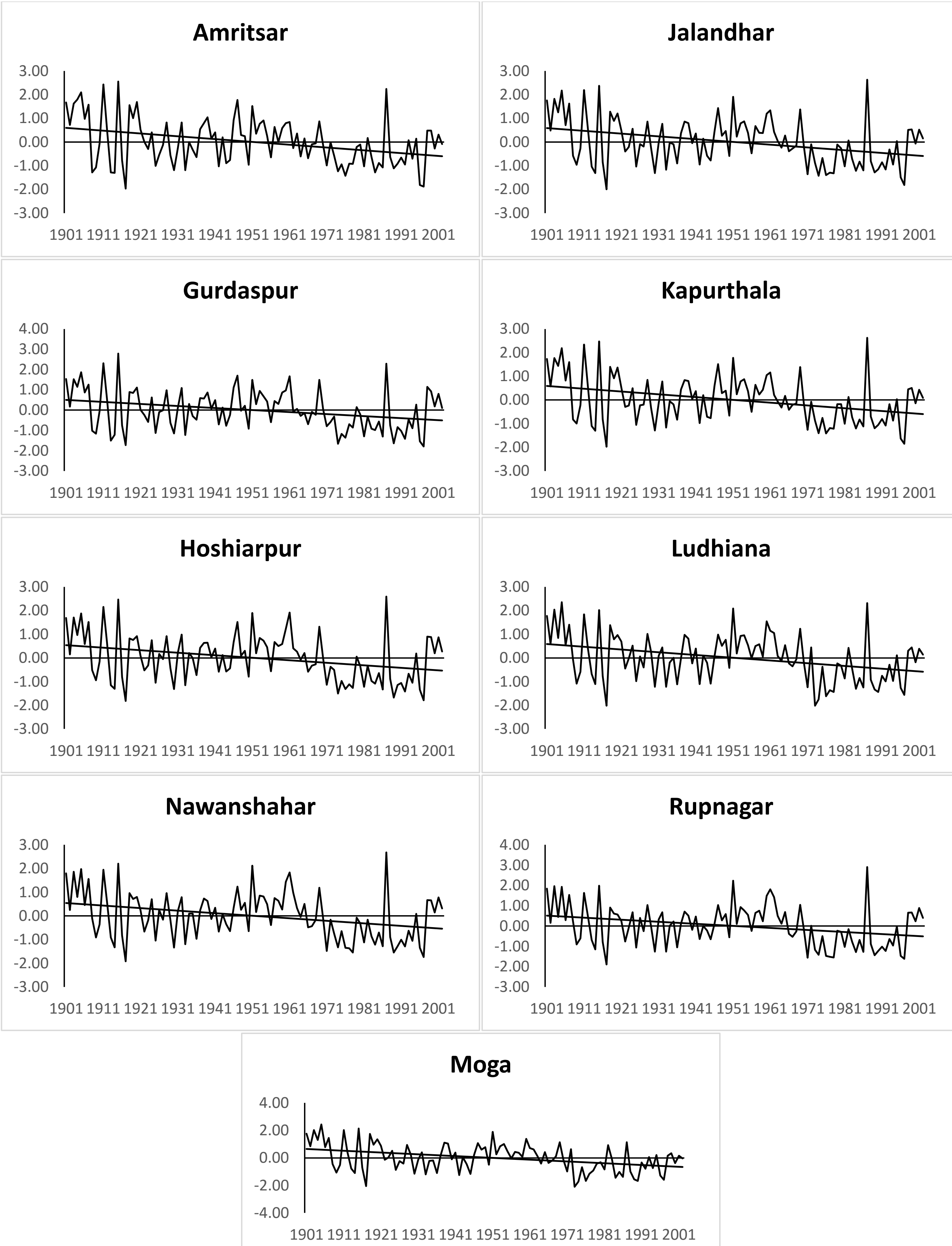

Fig. 4.4(b) Linear Trends of Monsoonal Minimum Temperature at different districts of lower Sutlej

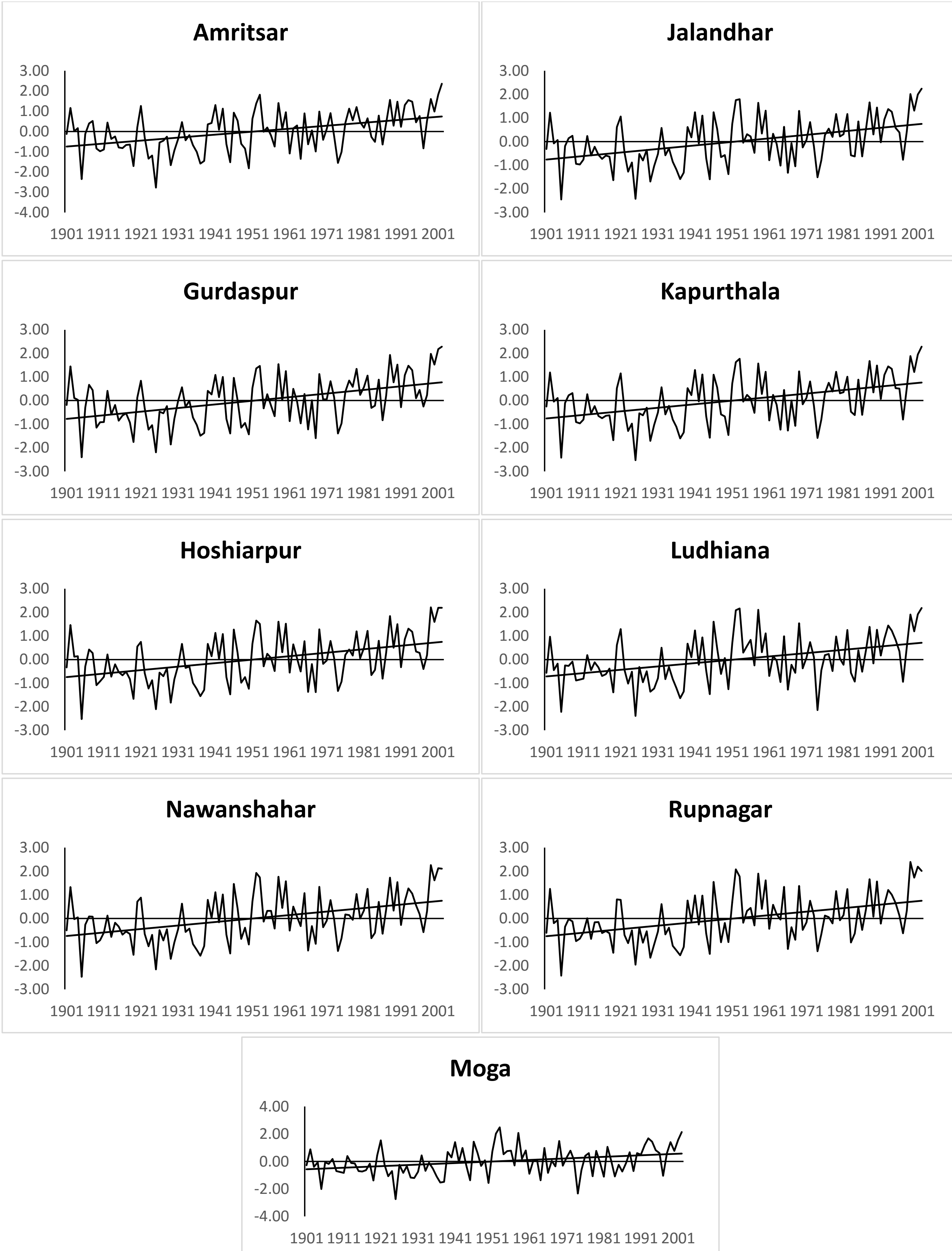

Fig. 4.4(c) Linear Trends of Winter Minimum Temperature at different districts of lower Sutlej

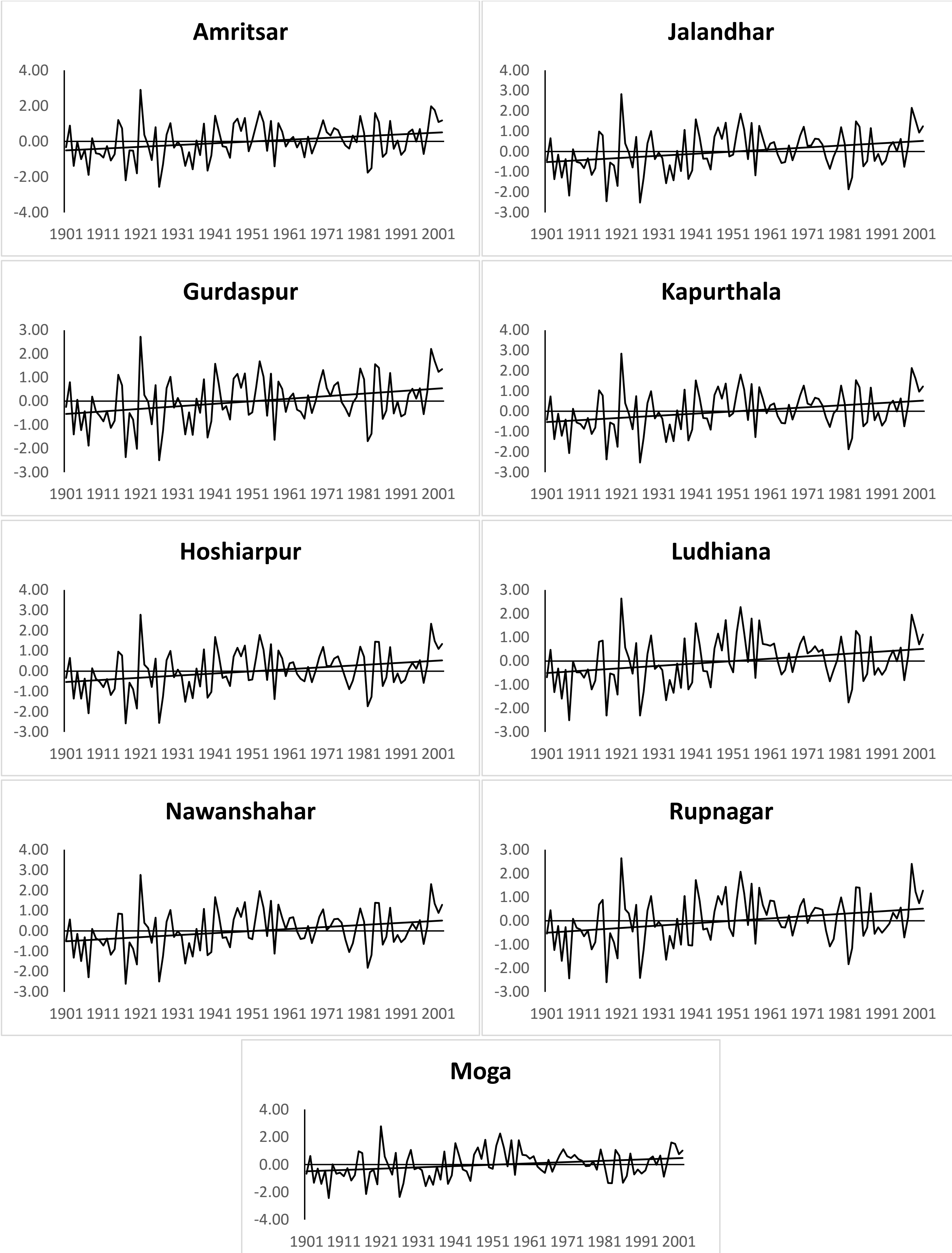

Fig. 4.4(d) Linear Trends of Spring Minimum Temperature at different districts of lower Sutlej

In order to get the study area’s response the z values of annual and seasonal time series also have been interpolated using spline method and these spatial representation is shown in Figure 4.5. Z-value maps of the area are useful to determine the z statistics of Mann-Kendall test at any point location in the study area. from the visual interpretation of these maps one can easily identifies that north to North-Eastern part of the study area is going through a rise in the anuual maximum temperature series as compare to the southern part (Fig 4.3). The Monsoon z-map signifies that there is more rise in the maximum temperature in western part as compare to eastern part of the study area.

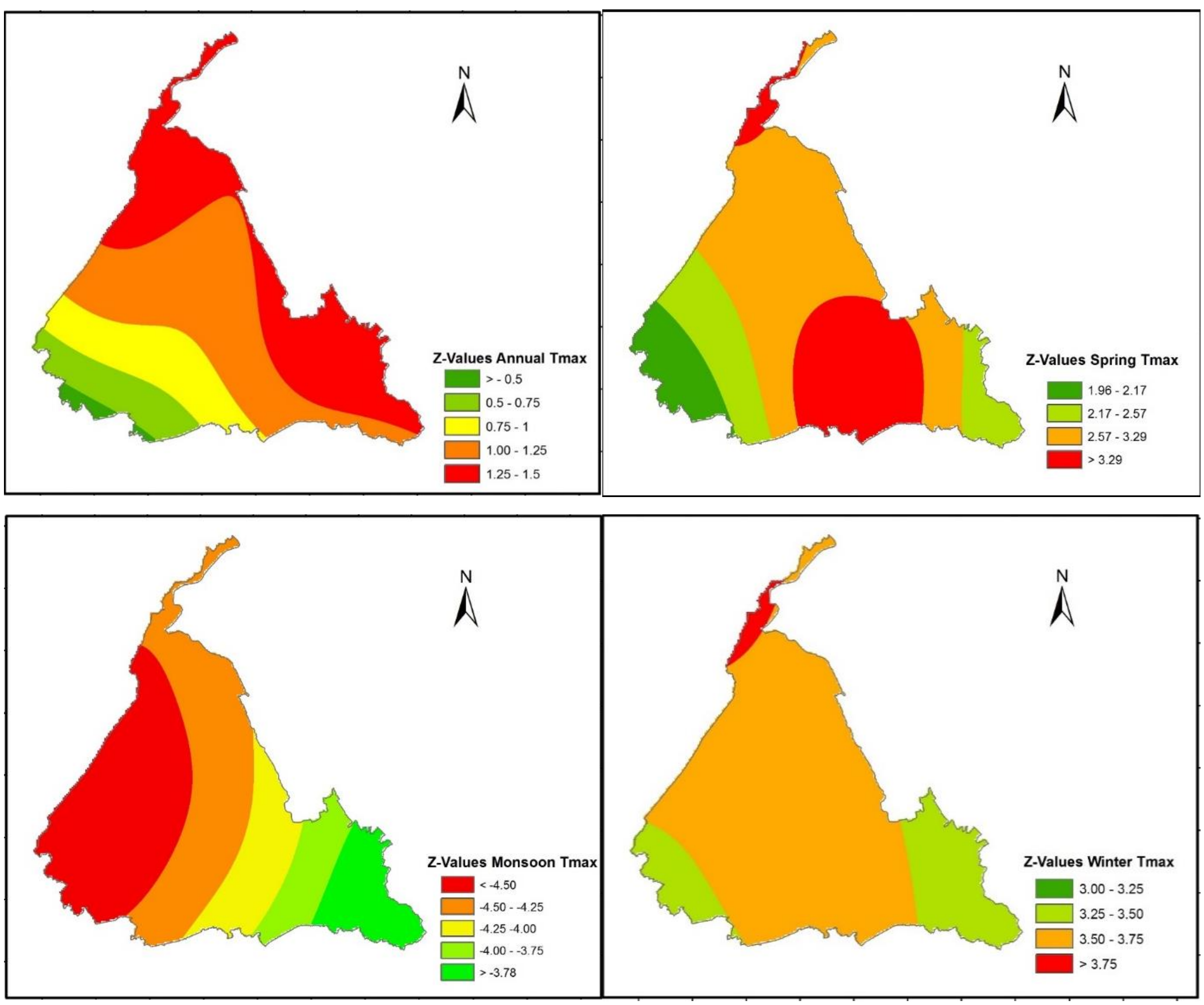

Fig 4.5 Mann-Kendall trends Z-Statistic maps for the Lower Sutlej for annual and seasonal maximum temperature series

4.2.3 Minimum Temperature:

Table 4.4 and Fig 4.4 (a, b, c, d) shows the results of the Mann-Kendal and liners trend test performed for minimum temperature series for the districts falling in study area on annual as well as seasonal basis. It is self-explanatory from the table figures that there is a clear rising minimum temperature trend in the study area in spring and winter season as well annual series is also supporting the risig trend at regional level with more than 90% confidence level. All the districts area supporting increasing temperature trends more than 99.9% confidence level in case of winter season. This means the winters are now becoming warmer as compare to the earlier ones. The monsoon seasonal trends for minimum temperature are following the maximum temperature and showing a falling summer temperatures.

Table 4.4: Z-Value of MK Test for Annual and Seasonal series of Minimum Temperature for Lower Sutlej Districts

S. No.	Station	Annual	Monsoon	Spring	Winter
1	Amritsar	2.04*	-3.4***	3.11**	4.4***
2	Gurdaspur	2.63**	-3.24**	3.06**	4.44***
3	Hoshiarpur	2.09*	-3.37***	3.01**	4.29***
4	Jalandhar	1.86+	-3.49***	3.06**	4.32***
5	Kapurthala	1.83+	-3.46***	3.05**	4.46***
6	Ludhiana	1.35	-3.52***	2.89**	4.18***
7	Moga	0.75	-3.53***	2.83**	3.4***
8	Nawanshahar	1.75+	-3.33***	2.87**	4.26***
9	Rupnagar	1.85+	-3.11**	2.82**	4.16***
10	Regional AV	1.78+	-3.48***	2.98**	4.31***
Significance Level: +90%; *95%; **99%; ***99.9%					

Similar to maximum temperature analysis the Z-value maps of minimum temperature series also have been generated and presented in the figure 4.6. While reading these maps it can be concluded that the north-western part of the study area is strongly supporting the rising minimum temperature during the study period. The winter seasonal minimum temperature is rising in almost about 80% of the total geographical area. In case of annual series of minimum temperature the southern part has low significant level of increasing trends.

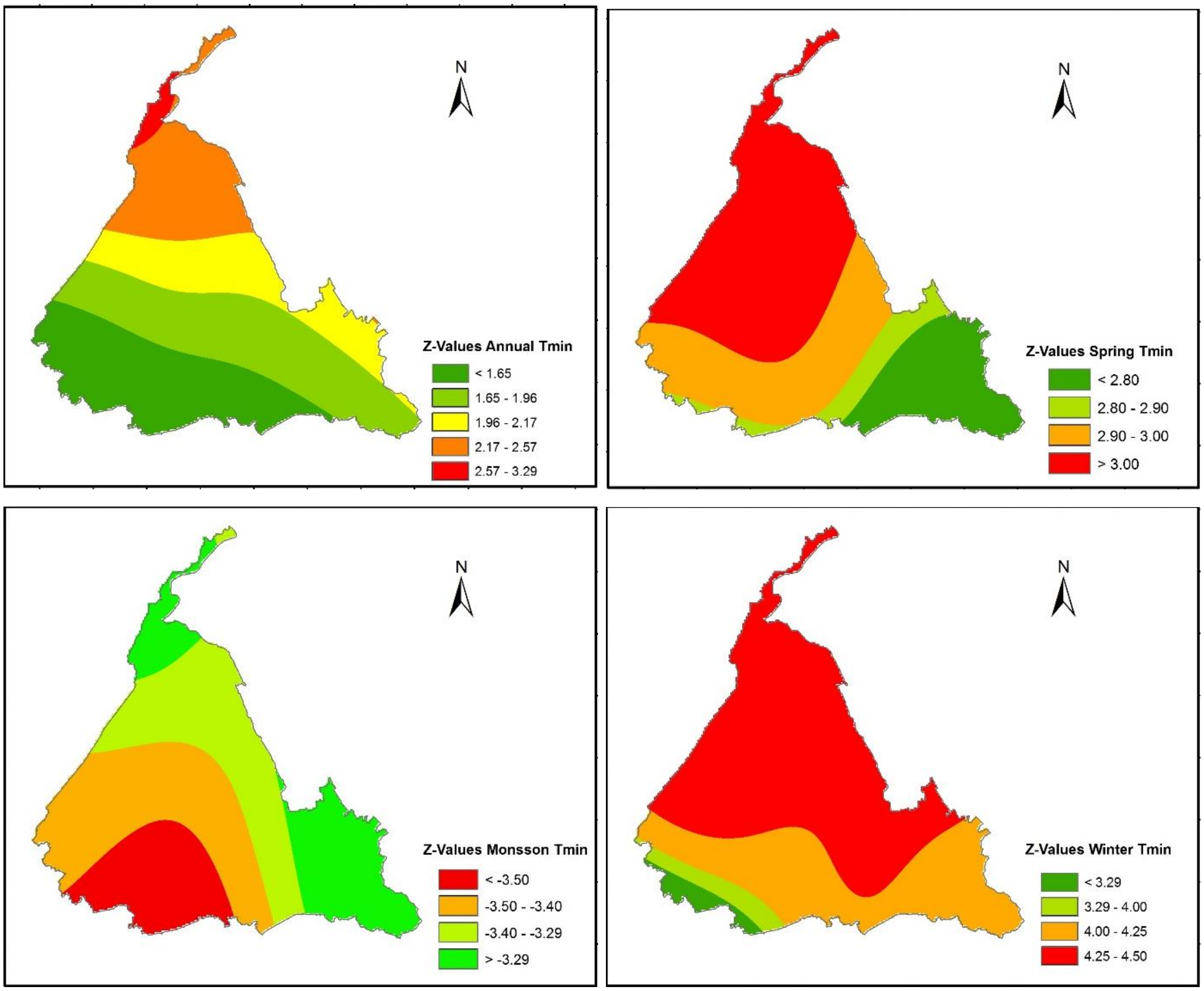

Fig 4.6 Mann-Kendall trends Z-Statistic maps for the Lower Sutlej for annual and seasonal minimum temperature series

4.2.4 Decadal Analysis of temperatures

For in-depth analysis we have also divided the entire annual data length of 102 years (1901-2002) in to four periods: period A (1901-1930), period B (1931-1960), period C (1961-1990) and period D (1991-2002) and performed the trend and magnitude analysis for these periods. The table 4.5 and 4.6 contains the results of these analysis.

Table 4.5: Z-Values of Annual Maximum Temperature series of for different Periods

S. No.	Station	Period-A	Period-B	Period-C	Period-D
1	Amritsar	-1.75+	1.78+	-0.18	1.71+
2	Gurdaspur	-1.43	1.25	0.14	1.85+
3	Hoshiarpur	-1.53	1.57	-0.68	2.26*
4	Jalandhar	-1.78+	2.36*	-0.54	1.99*
5	Kapurthala	-1.68+	2.43*	-0.21	1.85+
6	Ludhiana	-1.21	2.85**	-1.61	2.13*
7	Moga	-1.32	2.75**	-2.28*	1.58
8	Nawanshahar	-1.71+	2.14*	-0.86	2.26*
9	Rupnagar	-1.46	2.48*	-1.46	2.4*
10	Regional AV	-1.61	2.43*	-0.82	1.99*

The annual maximum temperature time series (Table 4.3) is showing falling temperature trends with certain significance levels at many of the stations during period A and period B and D are showing rising temperature trends, whereas the period C is not showing any trend. In case of minimum temperature series (Table 4.4), Period B is significantly supporting the annual minimum temperature rising trend along with period D, whereas Period A is showing decreasing minimum temperatures.

Table 4.6: Z-Values of Annual Minimum Temperature series of for different Periods

S. No.	Station	Period-A	Period-B	Period-C	Period-D
1	Amritsar	-2*	2.28*	0.36	2.26*
2	Gurdaspur	-1.71+	2.14*	0.68	2.26*
3	Hoshiarpur	-1.96*	2.43*	-0.57	2.4*
4	Jalandhar	-1.93+	2.68**	-0.39	2.4*
5	Kapurthala	-2*	2.6**	0.11	2.26*
6	Ludhiana	-1.46	3.43***	-1.32	2.54*
7	Moga	-1.53	3.21**	-2.14*	2.26*
8	Nawanshahar	-1.93+	2.89**	-1.11	2.67**
9	Rupnagar	-1.61	3.18**	-1.32	2.81**
10	Regional AV	-1.89+	2.71**	-0.68	2.4*

Higher positive z-values and higher significance levels in minimum temperature series in these period are also supporting that for the study period these was rise in the minimum temperature

In case of both the temperature time series period A is showing falling temperature trends with certain significance levels at many of the stations and period B and D are showing rising temperature trends, whereas the period C is not showing any trend. Higher positive z-values and higher significance levels in minimum temperature series in these periods are also supporting that for the study period there was rise in the minimum temperature.

4.2.5 Ground Water Levels:

The results of the Mann-Kendal trend test performed for ground water levels series for the study area on pre-monsoon and post-monsoon basis has been performed and results are presented in Table 4.7.

Table 4.7: Z-Values of for Pre-Monsoon and Post-Monsoon Average GWLs for lower Sutlej districts

District	Pre - Monsoon		Post-Monsoon	
	Test Z	Significant	Test Z	Significant
Hoshiarpur	4.05	***	4.05	***
Jalandhar	2.41	*	2.87	**
Kapurthala	6.54	***	6.15	***
Ludhiana	6.37	***	6.38	***
Nawan shahar	4.60	***	3.94	***
Rupnagar	1.31		0.00	
Bist-doab Region	7.65	***	6.91	***
Significance Level: *95%; **99%; ***99.9%				

The entire Bist-Doab region except Rupnagar district is suggesting the falling ground water trend at more than 95% significant levels. Rupnagar (Ropar) not showing any trend may be due to the continuous recharge from the take-off canals and Ropar Headworks which is major diversion structure on Sutlej after Nagal dam.

The spatial Distribution of Mann-Kendall Z-values for Pre-Monsoon and post-monsoon GWLs is shown in Fig 4.7. It can be observed from the Fig 4.7 that the pre-monsoon season is witnessing the more severe falling trend in the GWLs as compare to the post-monsoon season. The centre part of the study area which is more urbanized and industrialized is showing higher significant Z-values.

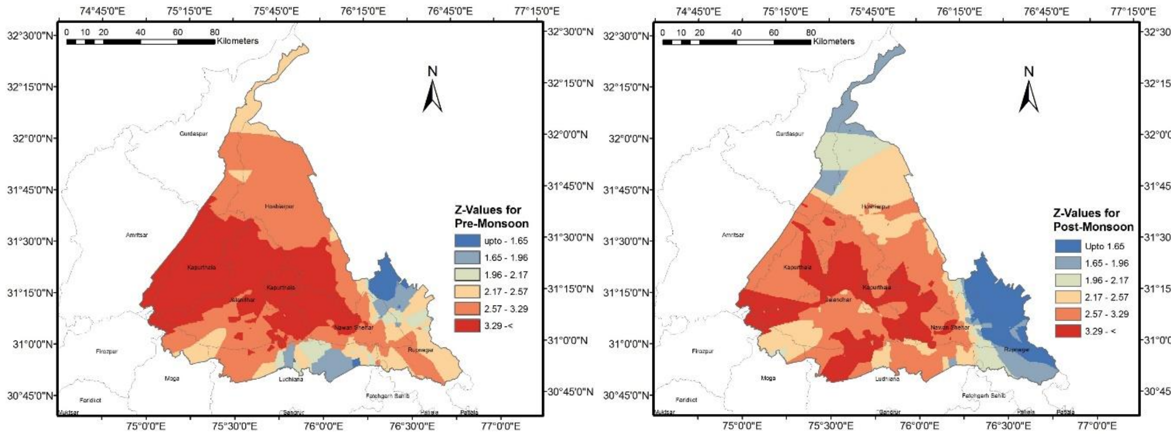

Fig 4.7 Spatial Distribution of Mann-Kendall Z-values for Pre & Post Monsoon GWL

4.2.6 Reference Evapotranspiration:

Being an important meteorological variable from agricultural irrigation point of view the trend analysis of ET0 was also performed. The annual linear trend of the ET0 of study area can be seen in Fig 4.8, which implies that on annual asis no significant trend are present in ET0 series. The statastics of Mann-Kendall test is given in Table 4.8. It can be concluded from the Table 4.8 that the monsoon season series is having falling trend at more than 99.9% significance level for all the districts of Lower Sutlej. And spring and winter season having statistically significant rising trend at 95% and 99% significance levels respectively. But on annual basis the negative sign of z-values showing falling trend but none of the district is having a statistically significant level, so there is no trend annually.

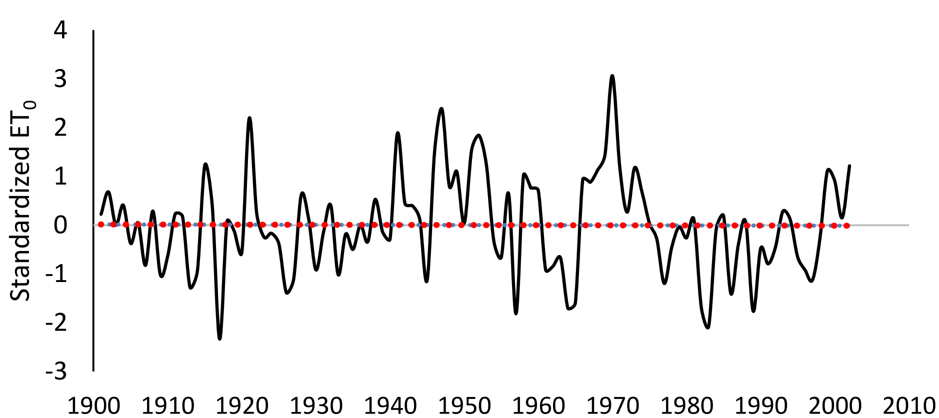

Fig 4.8 Linear Trend of annual reference evapotranspiration (ET_0)

Table 4.8: Z-Value of MK Test for Annual and Seasonal series of Reference Evapotranspiration (ET0) for Lower Sutlej districts

S. No.	District	Annual	Monsoon***	Spring*	Winter**
1	Amritsar	-0.32	-4.80	2.10	2.98
2	Gurdaspur	-0.17	-4.35	2.05	2.93
3	Hoshiarpur	-0.04	-4.01	2.08	3.04
4	Jalandhar	-0.04	-4.33	2.24	3.16
5	Kapurthala	-0.05	-4.50	2.18	3.20
6	Ludhiana	-0.17	-3.90	2.40	3.37***
7	Moga	-0.70	-4.43	2.21	3.15
8	Nawanshahar	0.18	-3.65	2.24	2.96
9	Rupnagar	0.21	-3.59	2.23	2.99
10	Regional	-0.15	-4.40	2.20	3.17
Significance Level: *95%; **99%; ***99.9%					

4.3 Magnitude of trend:

4.3.1 Magnitude of trend: Rainfall

The magnitude of the trend in the rainfall time series, as determined using the Sen Estimator, is given in Tables 4.9 and 4.10. The analysis of trends of rainfall variations by districts shows a large variability in the magnitude and direction of trend from one district to another. Monthly analysis of district rainfall indicated that the majority of the districts have very little or no change in non-monsoon months (Table 4.9) and the monsoon months witnessed increasing rainfall in the majority of districts.

Table 4.9: Sen Estimator of slope (mm/year) for monthly rainfall.

SN	District	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Amritsar	-0.01	0.07	0.08	-0.01	0.07	0.13	0.66	0.36	0.21	0.02	0.00	-0.01
2	Gurdaspur	-0.03	0.14	0.11	0.01	0.09	0.13	0.82	0.53	0.08	0.03	0.00	-0.01
3	Hoshiarpur	-0.04	0.07	0.06	-0.01	0.04	0.07	0.64	0.11	-0.05	0.02	0.00	-0.01
4	Jalandhar	-0.03	0.05	0.07	0.00	0.04	0.11	0.64	0.30	0.18	0.01	0.00	-0.01
5	Kapurthala	-0.03	0.05	0.05	-0.01	0.03	0.02	0.60	0.24	0.18	0.00	0.00	-0.02
6	Ludhiana	-0.01	0.04	0.06	0.00	0.06	0.11	0.49	0.25	0.21	0.02	0.00	0.00

7	Moga	-0.01	0.03	0.04	-0.01	0.04	0.04	0.37	0.28	0.12	0.00	0.00	0.00
8	Nawanshahar	-0.03	0.06	0.07	-0.01	0.08	0.15	0.43	0.20	0.19	0.02	0.00	-0.01
9	Rupnagar	-0.03	0.05	0.08	0.01	0.07	0.15	0.56	0.34	0.21	0.01	0.00	0.00
10	Regional	-0.02	0.07	0.08	0.00	0.07	0.11	0.59	0.33	0.17	0.02	0.00	-0.01

On analyzing the estimates of the slope (mm/year) for annual and seasonal rainfall series of all the districts (Table 4.10), it is implicit that three districts experienced decreasing rainfall in the winter season. The maximum reduction was found for Kapurthala (-0.08 mm/year). The maximum increase out of 9 districts was experienced by Gurdaspur in rainfall (1.95 mm/year annually and 1.56 mm/year Monsoon season) followed by Rupnagar (1.72 mm/year annually and 1.31 mm/year Monsoon season) and Amritsar (1.53 mm/year annually and 1.31 mm/year Monsoon season). Considering the study area as a whole the rate of rise of rainfall over last century is comes out be of an order of 1.42mm/year based on annual time series.

Table 4.10: Sen Estimator of slope (mm/year) for Annual and seasonal rainfall.

S. No.	District	Annual	Monsoon	Spring	Winter
1	Amritsar	1.53	1.31	0.16	0.02
2	Gurdaspur	1.95	1.56	0.23	0.17
3	Hoshiarpur	0.89	0.69	0.11	-0.03
4	Jalandhar	1.37	1.19	0.14	-0.03
5	Kapurthala	1.21	1.13	0.08	-0.08
6	Ludhiana	1.22	0.95	0.14	0.00
7	Moga	0.90	0.78	0.07	-0.02
8	Nawanshahar	1.32	0.99	0.16	0.00
9	Rupnagar	1.72	1.31	0.19	0.00
10	Whole Study Area	1.42	1.18	0.16	0.01

4.3.2 Magnitude of trend: Temperature

Mann-Kendall test has confirmed the rising trend in the minimum temperature and no significant trend in maximum temperature, in order to get the rate of rising or fall the magnitude of the trend in the both the temperature series has been determined using the Sen Slope Estimator as explained in the section 3.4 under chapter 3. The results are given in Tables 4.11 and 4.12. The analysis of trends of temperature variations by districts shows a large variability in the magnitude and direction of trend from one district to another.

On analyzing the estimates of the slope (^{0}C/ 100 year) for annual and seasonal maximum temperature series of all the districts from Table 4.11, it is implicit that all the districts experienced increasing max. temperature in the spring and winter season.

Table 4.11: Sen Estimator of slope (^{0}C/ 100 year) for Annual and seasonal Maximum Temperature.

S.No.	Station	Annual	Monsoon	Spring	Winter
1	Amritsar	0.18	-0.87	1.05	0.80
2	Gurdaspur	0.22	-0.72	0.95	0.81
3	Hoshiarpur	0.20	-0.76	1.01	0.76
4	Jalandhar	0.18	-0.87	1.06	0.80
5	Kapurthala	0.19	-0.89	1.09	0.81
6	Ludhiana	0.17	-0.92	1.17	0.84
7	Moga	0.03	-1.01	1.17	0.73
8	Nawanshahar	0.22	-0.75	1.05	0.81
9	Rupnagar	0.22	-0.74	0.99	0.85
10	Regional AV	0.17	-0.85	1.07	0.78

The maximum increase was found for Ludhiana and Moga (1.17 ^{0}C/ 100 year) with an average rise of 1.07 ^{0}C/ 100 year in spring season. On the other hand in monsoonal season the same Moga have shown a fall in temperature at the rate of 1.01 ^{0}C/ 100 year. Considering the study area as a whole the rate of rise of maximum temperature over last century comes out be of an order of 0.17 ^{0}C/ 100 year based on annual time series.

The Sen Slope estimate results for the minimum temperature series are presented in the table 4.12. Similar to maximum temperature, all the districts are showing rising trend in spring and winter. Amritsar and Ludhiana have highest rate of minimum temperature rise at the rate of 1.21 ^{0}C/ 100 year followed by Kapurthala. In case of the monsoon season, Moga is showing falling minimum temperature at the rate of 0.89 ^{0}C/ 100 year. Overall the study area is experiencing the rising minimum temperature trend and the rate of rise is 0.29 ^{0}C/ 100 year.

Table 4.12: Sen Estimator of slope (^{0}C/ 100 year) for Annual and seasonal Minimum Temperature.

S.No.	Station	Annual	Monsoon	Spring	Winter
1	Amritsar	0.31	-0.68	1.21	0.89
2	Gurdaspur	0.39	-0.55	1.12	0.94
3	Hoshiarpur	0.32	-0.60	1.09	0.89
4	Jalandhar	0.29	-0.70	1.18	0.86
5	Kapurthala	0.31	-0.69	1.19	0.90
6	Ludhiana	0.24	-0.77	1.21	0.81
7	Moga	0.14	-0.89	1.18	0.66
8	Nawanshahar	0.31	-0.65	1.12	0.86
9	Rupnagar	0.33	-0.63	1.11	0.84
10	Regional AV	0.29	-0.67	1.15	0.83

4.3.3 Magnitude of trend: Ground Water Levels

From the Mann-Kendall test it has been confirmed that the study are is having falling ground water levels and that is significant. In order to find the rate of falling Sen's slope method was applied and the results are presented in the Table 4.13.

Table 4.13: Sen Estimator of slope (m/years) for Pre-Monsoon and Post-Monsoon GWL data for lower Sutlej districts

District	Pre - Monsoon		Post-Monsoon	
	Slope (Q)	Constant (B)	Slope (Q)	Constant (B)
Hoshiarpur	0.30	8.56	0.38	6.87
Jalandhar	0.52	11.05	0.45	12.69
Kapurthala	0.15	4.89	0.18	3.71
Ludhiana	0.19	5.98	0.24	6.60

Nawan shahar	0.65	9.91	0.58	9.45
Rupnagar	0.13	6.91	-0.01	6.51
Regional	0.19	4.67	0.18	4.22

The maximum rate of fall of groundwater level was found 0.65m/year and 0.58m/year at Nawanshahar in Pre-Monsoon and Post-Monsoon season. Regionally there is fall in the groundwater level at the rate of 0.18 – 0.19 m/year. The rate of fall for both ethe seasons has also been shown in the Fig 4.9

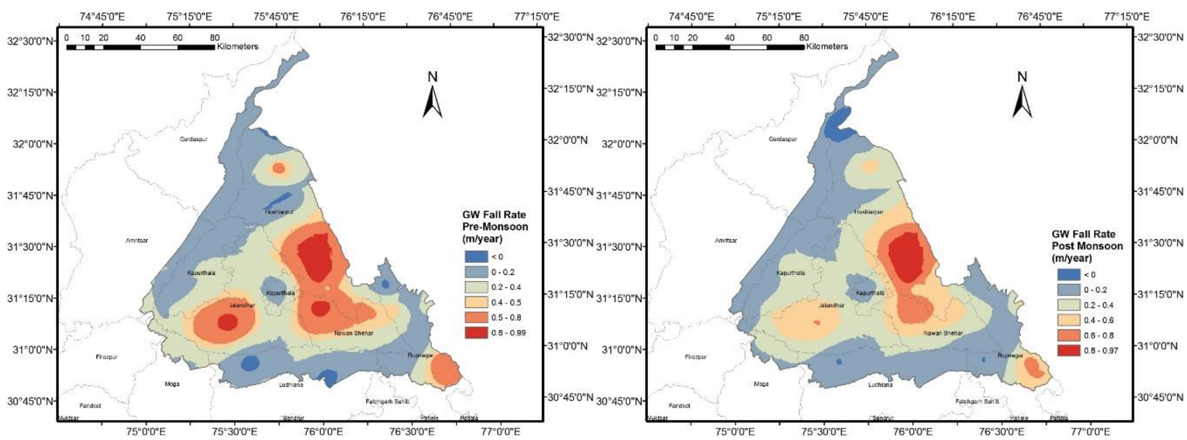

Fig 4.9 Rate of Fall of GWL for Pre-Monsoon and Post-Monsoon seasons (m/year)

4.3.4 Magnitude of trend: Reference Evapotranspiration:

The magnitude of trend for the ET_0 for seasonal as well as annual series has been computed and the results are presented in the Table 4.14.

Table 4.14: Sen Estimator of slope (mm/year) for Annual and seasonal ET_0

S. No.	District	Annual	Monsoon	Spring	Winter
1	Amritsar	-0.31	-2.11	1.16	0.68
2	Gurdaspur	-0.08	-1.93	1.02	0.72
3	Hoshiarpur	-0.05	-1.80	1.09	0.75
4	Jalandhar	-0.04	-1.97	1.17	0.73
5	Kapurthala	-0.03	-2.05	1.20	0.74
6	Ludhiana	-0.15	-1.95	1.43	0.84
7	Moga	-0.58	-2.19	1.36	0.75

8	Nawanshahar	0.15	-1.75	1.22	0.77
9	Rupnagar	0.19	-1.67	1.29	0.81
10	Study Area	-0.09	-1.98	1.15	0.76

The maximum reduction in ET_0 was found for Moga district (-2.19 mm/decade) in Monsoon season. The maximum increase out of 9 districts was experienced by Ludhiana in ET_0 (1.43 mm/decade in spring season). Considering the study area as a whole the rate of fall of ET_0 over last century was estimated -0.09mm/ decade based on annual time series.

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Chapter 5

SUMMARY / CONCLUSION

Punjab state holds place of pride among the Indian States for its outstanding achievements in agricultural development. Agricultural productivity is sensitive to climatic changes and therefore the tracking of theses change in terms of trend is essential to generate variable predictions about impact of change in climate and variability. Various hydro-climatic variables like temperature, rainfall, stream flow etc. are very important, which affect the crop growth and production. This report examined trends in the seasonal and annual maximum and minimum temperature over the nine Punjab districts of lower Sutlej. A long term monthly large data set with the length of data series of 102 years has been used for these districts. Most frequently used non-parametric Mann-Kendall test and simple linear regression technique was used to identify the significant trends of rainfall, ET_0, temperature and ground water levels in this study and the magnitude of the trends were ascertained by the well-established Sen's slope estimator method.

Overall annual rainfall showed increasing trend at almost all the districts with certain significance level. Average rainfall of the study area was 546mm. the highest average annual rainfall is estimated at Gurdaspur district (661mm) and lowest at Moga district (379mm). While looking at the trend analysis part the maximum increase was 1.95 mm/year and the maximum decrease was -0.08 mm/year. Over the complete study area, the annual rainfall showed an increasing trend and the rate of rise was estimated 1.42 mm/year.

Seasonal analysis showed that monsoonal rainfall increased statistically significant over all districts except Hoshiarpur district. Spring rainfall increased over 6 districts with statistically significance levels. Winter rainfall at five districts showed falling trend but these are not at significance levels

Annual and three seasonal (i.e. Monsoon, spring and Winter) analysis of both the temperature series i.e. maximum and minimum has been performed. Annual series of maximum temperature are carrying the positive Z-values of Mann-Kendall test statistics but the trend is rejected at even the significance level of 90%, so no trend in annual maximum temperature series. But, the seasonal analysis showed that winter and the spring temperature are rising over the region as all the district stations are significantly (more than 99%) supporting the increasing trend except Moga district which have a level of 95% in case of spring season. In case of minimum temperature time series, the annual series is supporting rising trend as all the stations having a positive z-values four out of nine stations with 90% significance level, two stations with 95% and one station with 99% significance level. Seasonal analysis of minimum temperature series is bit tricky as winter is following increasing trends of temperature at very significance level (more than 99.9%), whereas, Monsoon season is strongly supporting the decreasing temperature trends (eight station at 99.9% and one station at 99%). Similar to maximum temperature series, the spring season in minimum temperature series also is supporting winter season temperature rising trend at 99% significance level at all stations.

For in-depth analysis we have also divided the entire annual data length of 102 years (1901-2002) in to four periods: period A (1901-1930), period B (1931-1960), period C (1961-1990) and period D (1991-2002) and performed the trend and magnitude analysis for these periods. In case of both the temperature time series period A is showing falling temperature trends with certain significance levels at many of the stations and period B and D are showing rising temperature trends, whereas the period C is not showing any trend. Higher positive z-values and higher significance levels in minimum temperature series in these period are also supporting that for the study period these was rise in the minimum temperature.

The magnitude of the trends in terms of the slope of the linear regression has also been estimated using Sen's slope method. Regionally there is rise in the maximum temperature and the rate of rise is 0.17 ^{0}C/100 years based on annual series. The maximum increase was found in winter series at the rate of 1.17 ^{0}C/100 years at Ludhiana and Moga. And the minimum temperature is rising at the average rate of 0.29 ^{0}C/100 years over the complete study area with the maximum value of 1.21 ^{0}C/100 years at Amritsar and Ludhiana.

An increase in groundwater stress in Bist-Doab region of Punjab due to increase in irrigation demand, domestic requirement and reduction in surface water-bodies has caused a decline in groundwater level significantly. Study suggest an average rate of GWL fall for the region at the order of 0.18 – 0.19 m/year. There is huge range of the water table depth in both pre and post monsoon season ranging from 1m to 32.8m. The stage of groundwater development in almost all the blocks of Bist-Doab region exceeds 100% making the region over exploited in groundwater.

The average annual ET_0 of the study area is about 1721mm with 26 mm standard deviation and coefficient of variation of 0.015. Annually, there is no trend (significant) in the ET_0, but seasonally the study area significantly supporting clear trends. ET_0 in The Monsoon season is showing a falling trends at 99% confidence level, whereas, the winter and spring season are supporting the rising trends at 95% and 90% confidence level respectively. The winter rising trends can be correlated with the rising trends of the winter temperature.

To conclude the annual rainfall trends fully indorsing to the monsoon trend, which implicit the dominance of the monsoon for rainwater arability in the region. The study indicated a clear pattern of rainfall (-1.42 mm/year) and temperature (+0.17 ^{0}C & +0.29 ^{0}C in 100 years for Max. & Min.) trends in the study area with less variability, this could be due to homogeneous geographic and climatic conditions of the districts falling the study area. The ground water levels are ever falling (0.18 – 0.19 m/year) due to over exploitation of groundwater resource.

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