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Research Article

CLIMATIC TRANSITION IN PUNJAB SATLUJ FLOODPLAIN

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ABSTRACT

Climatic transition has been noticed at floodplain level with proximate underlying causes. Seasonal and annual phases of climatic conditions have been analyzed for understanding the shift. Thermal and moisture plots have been formed for aligning displacement of months which reflect the shift in identified seasons. Annual average flux in temperature and rainfall regime traced since 1960 to 2011 estimates the annual climatic variation. Change in these variables shows the decrease in average annual temperature by 0.22ºC and increase in average annual rainfall with 89 mm for 2000 to 2011. Although Climatic phenomena's and their underlying natural and anthropogenic causes are having global, regional and local importance. This study is concentrated at local scale i.e. Indian Punjab Satluj floodplain. This area faced 56.55 percent surfacial transition in the form of land use expansion from 1975 to 2011, which in turn affects climatic elements. At this scale it has been noticed that there is a positive link between the spatial distribution pattern of rainfall regime and net irrigated land.

INTRODUCTION

'Weather', 'Season' and 'Climate' explains the variability existed in the temperature, precipitation, humidity, atmospheric pressure and wind etc. in a day, months and years respectively at local, regional and global scale (Veryard, 1963). Climatic homogeneity at global level framed through climatic regions or zones. Wladimir Koppen had done this climatic regionalization based on annual cycle of near surface temperature and precipitation (Lohmann *et al*., 1993). C. Warren Thornthwaite's climatic classification is based on potential evapotranspiration (Thornthwaite, 1948) in 1931(Garnier, 1950). According to Thornthwaite's climatic classification for study area is type D climate i.e. semi arid. Locational attribute of this area characterized it with the continental type of climate. Within broad climatic zones annual and seasonal variations has been noticed with time at local scale. For understanding the climatic variations at local scale 'floodplain' unit has been selected. It is stretched between 30°32' N to 31°35' N and 75°05' E to 76°44' E latitudes and longitudes respectively and spread over 1042.75 km^2 of area. Adjoining the river Satluj, it spreads over parts of eight administrative Blocks of four Districts of Indian Punjab that involved Phillaur Block of Jalandhar District, Aur, Nawanshahr and Balachaur Block of Shahid Bhagat Singh Nagar District, Chamkaur Sahib Block of Rupnagar District and Machhiwara, Ludhiana II and Ludhiana I Block of Ludhiana District.

Variability in the climatic elements with time occurred due to many factors under the genesis of natural and anthropogenic agencies (Rind and Overpeck, 1993; Houghton *et al*., 2001 and Matthews *et al*., 2004). One of the most effectively involved anthropogenic factors is land use and land cover change. It affects rainfall and temperature conditions (Kalnay and Cai, 2003; Pielke, 2005; Brutsaert and Sugita, 1996; Kondoh and Nishiyama, 2000; Arnfield, 2003; Shepherd, 2005; Kaur and Brar, 2013 and Qiao *et al*., 2014). This area faced surfacial transformation in the form of land use and land cover change. Surface transformations, modifications and conversions affects the climatic conditions (Brovkin *et al*,. 2004) through changes in net radiation (Intergovernmental Panel on Climate Change, 2007), division of energy into sensible and latent heat and partitioning process of precipitation into soil water, evapotranspiration and run off (Betts *et al*., 1993 and Foley *et al*., 2005) . This area faced land cover depletion for land use expansion. Importance of studying climatic variation at this spatial unit lies in its vulnerability to further land use and land cover change, which can affect the climatic elements. This study has been based on the following objectives:

To know the climatic transition in Punjab Satluj floodplain from 1960 to 2011 through

a. Seasonal variations and b. Annual variations

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To understand the relevance of local level causes of climatic transition with special reference to surfacial transformations in Punjab Satluj floodplain.

METHODOLOGY

Variation in climatic elements: It has been estimated at two temporal scales i.e. seasonal and annual (Figure 1). Change in temperature and rainfall have been studied from 1960 to 2011.

Source: Temperature data has been taken for Ludhiana station from Statistical Abstract of Punjab and official website of Indian Meteorological Department, Pune. Rainfall data for Rupnagar, Shahid Bhagat Singh Nagar, Jalandhar and Ludhiana Districts has been collected from the Statistical Abstract of Punjab.

Analysis and presentation: Obtained data has been tabulated and analyzed for further interpretation. Hythergraphs has been prepared on the basis of 1960 to 2011 prevailed mean monthly temperature (MMT) and mean monthly rainfall (MMR) values. Threshold limits for thermal and moisture conditions has been set on the basis of empirical understanding and survey results. Climatic variability through time has been estimated from the plot location of combined Mean Monthly Temperature (MMT) and Mean Monthly Rainfall (MMR) values. Sixteen descriptive climatic plots have been generated on the basis of MMT and MMR combinations. These climatic plots area cold and arid (MMT < 5ºC and MMR < 25 mm), cool and arid (MMT 5.1 to 18ºC and MMR < 25 mm), warm and arid (MMT 18.1 to 30ºC and MMR < 25 mm), hot and arid (MMT 30.1 to 40ºC and MMR < 25 mm), cold and semi-arid (MMT < 5ºC and MMR 25.1 to 50 mm), cool and semi-arid (MMT 5.1 to 18ºC and MMR 25.1 to 50 mm), warm and semi-arid (MMT 18.1 to 30ºC and MMR 25.1 to 50 mm), hot and semi-arid (MMT 30.1 to 40ºC and MMR 25.1 to 50 mm), cold and sub-moist (MMT < 5ºC and MMR 50.1 to 75 mm), cool and sub-moist (MMT 5.1 to 18ºC and MMR 50.1 to 75 mm), warm and sub-moist (MMT 18.1 to 30ºC and MMR 50.1 to 75 mm),

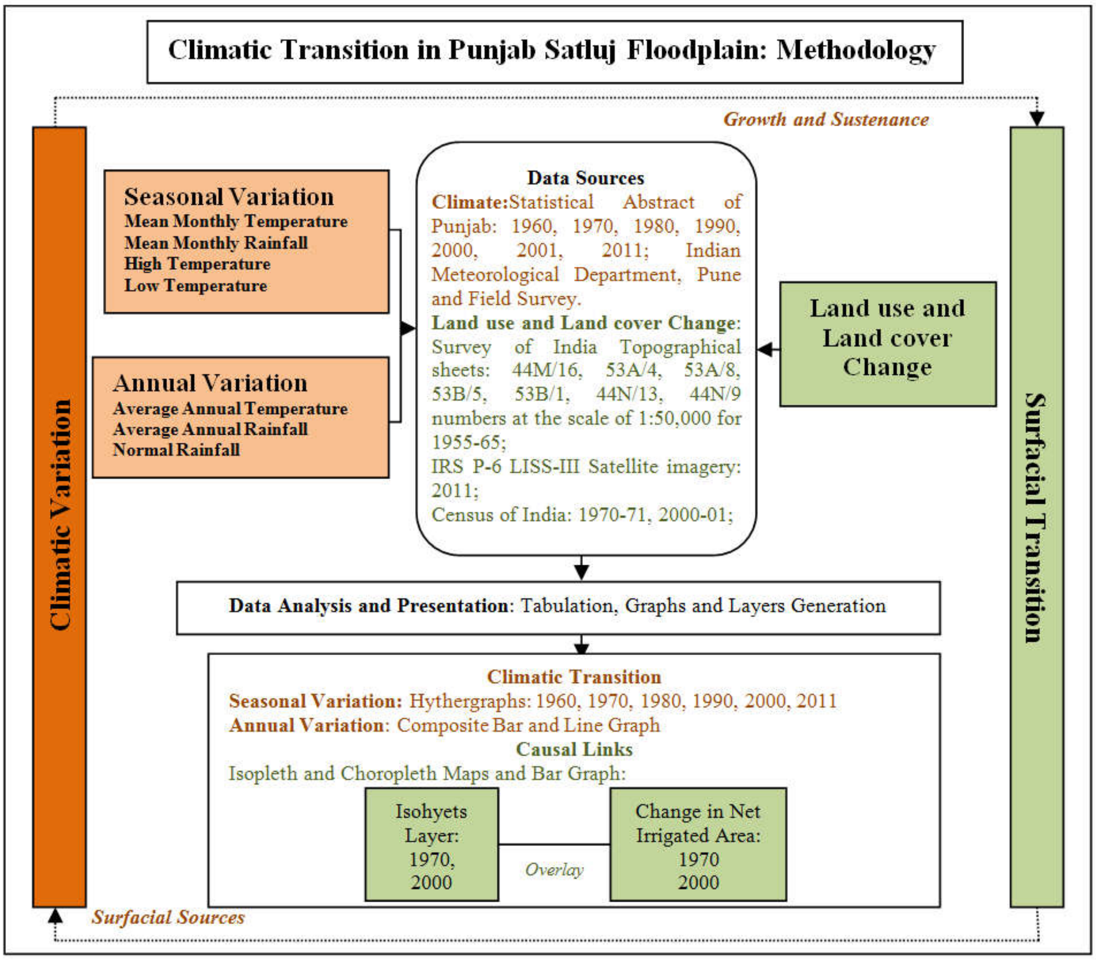


Figure 1 | Transition in Punjab Satluj Floodplain: Methodology. Climatic variation has been studied at seasonal and annual scale with underlying causes specifically surfacial transition. Data set has been prepared from secondary sources and field survey for explaining these variables. Acquired data further tabulated and analysed for generating results and preparing charts and maps. Orange colour depicts the process of climatic data set generation and green reflects the steps involved in preparation of surfacial transition, whereas doted lines established the causal link between both.

Descriptive climatic plots have been generated from the categorized mean monthly temperature and rainfall combinations. Descriptive thermal names has been given, while considering human comfort at sub-tropics estimated from the interview results, which has been done on the fifty persons with normal body temperature. hot and sub-moist (MMT 30.1 to 40ºC and MMR 50.1 to 75 mm), cold and moist (MMT < 5ºC and MMR 75.1 to 300 mm), cool and moist (MMT 5.1 to 18ºC and MMR 75.1 to 300 mm), warm and moist (MMT 18.1 to 30ºC and MMR 75.1 to 300 mm) and hot and moist (MMT 30.1 to 40ºC and MMR 75.1 to 300 mm). Climatic variability has been estimated from the seasonal plot displacements; high temperature, low temperature and mean monthly temperature and rainfall fluctuations and through average annual temperature and rainfall trends.

Annual climatic variations have been estimated from the average annual temperature and rainfall trends shown through composite line and bar graph. Extracted results at these scales with selected parameters reflect climatic transition.

Proximate causes of climatic variation: Climatic transition has been further linked with land use and land cover changes observed in this area as it affects the climate through surfacial processes and get affected from changes in climatic elements as it provide growth and sustenance to land use and land cover activities.

Table 1 Punjab Satluj Floodplain: Climatic Variability. Climatic variability has been depicted in this table through season wise changes in high temperature, low temperature and mean monthly temperature and rainfall values at decadal gaps for Ludhiana station. Variability in these parameters reflects shift in thermal and moisture conditions of identified seasons for this sub tropical area.

Seasons	Months	Climatic Variables	Temporal Variability in Climatic Elements						Seasonal Shift
			1960-1970	1970-1980	1980-1990	1990-2000	2000-2011	1960-2011	1960-2011
WINTER	January	High Temperature (ºC)	4	-6.6	1.1	1.6	DNA	DNA	From Cool and Arid to Cool and Arid
		Low temperature (ºC)	-2	4	-4.6	2.8	DNA	DNA	
		Mean Monthly Temperature (ºC)	-2.5	-0.7	-1.1	0	0.5	-3.8	
		Mean Monthly Rainfall (mm)	-6.6	24.5	8.5	2.3	-34.7	-6	
	February	High Temperature (ºC)	4	-7.8	5.2	-2.4	DNA	DNA	From Cool and Sub Moist to Cool and Arid
		Low temperature (ºC)	-12.6	2.2	-3.2	0.4	DNA	DNA	
		Mean Monthly Temperature (ºC)	1.4	-2.9	0.4	1.8	-1.35	-0.65	
		Mean Monthly Rainfall (mm)	-41.5	53.9	-68.3	2.5	1.4	-52	
SPRING	March	High Temperature (ºC)	0	-5.5	-0.7	6.5	DNA	DNA	From Warm and Semi Arid to Warm and Arid
		Low temperature (ºC)	-8.8	-4.8	0.2	3.1	DNA	DNA	
		Mean Monthly Temperature (ºC)	-1.5	-3.1	-1.8	2	-1.35	-5.75	
		Mean Monthly Rainfall (mm)	-18.2	36.4	-40.3	-7.3	11.4	-18	
	April	High Temperature (ºC)	-0.8	3.8	-6.3	5.7	DNA	DNA	From Warm and Semi Arid to Warm and Arid
		Low temperature (ºC)	-1.6	0.2	-4	1.8	DNA	DNA	
		Mean Monthly Temperature (ºC)	-1.7	0.2	-3.2	4.3	-2.4	-2.8	
		Mean Monthly Rainfall (mm)	-44.6	10.7	-11.1	27.7	7.9	-42	
SUMMER	May	High Temperature (ºC)	0	-2.7	1.2	0.9	DNA	DNA	From Hot and Arid to Hot and Arid
		Low temperature (ºC)	-3.6	5.2	-1.8	2.8	DNA	DNA	
		Mean Monthly Temperature (ºC)	-1.6	-0.7	1.4	0.5	-0.7	-1.1	
		Mean Monthly Rainfall (mm)	-2.5	-0.9	-2.3	-4.9	-38	-16	
	June	High Temperature (ºC)	0.9	-1.5	-2	-2.3	DNA	DNA	From Hot and Sub Moist to Hot and Semi Arid
		Low temperature (ºC)	-0.8	-1.2	-0.8	-0.2	DNA	DNA	
		Mean Monthly Temperature (ºC)	0.2	-1.8	-2.3	-0.3	1.95	-2.25	
		Mean Monthly Rainfall (mm)	-67.5	23.8	10.1	-7	4.6	-36	
RAINY	July	High Temperature (ºC)	1.4	0.4	-2.9	-2	DNA	DNA	From Hot and Moist to Hot and Moist
		Low temperature (ºC)	0.4	0	0.2	-2	DNA	DNA	
		Mean Monthly Temperature (ºC)	-0.7	-0.8	-0.6	-0.3	0.9	-1.5	
		Mean Monthly Rainfall (mm)	21.3	16.3	78.2	51.8	9.4	177	
	August	High Temperature (ºC)	3.4	-3.6	-3.2	0.4	DNA	DNA	From Warm and Moist to Warm and Moist
		Low temperature (ºC)	0.4	-1	-1.6	-0.9	DNA	DNA	
		Mean Monthly Temperature (ºC)	1	-0.2	-2.5	0.6	0.55	-0.55	
		Mean Monthly Rainfall (mm)	-174.5	-47.5	176.1	-136.9	13.8	-169	
	September	High Temperature (ºC)	4.9	-2.5	-3	0.6	DNA	DNA	From Warm and Moist to Warm and Moist
		Low temperature (ºC)	3.4	-3.5	-0.3	4	DNA	DNA	
		Mean Monthly Temperature (ºC)	1.3	-1.8	0.4	0.7	-0.25	0.35	
		Mean Monthly Rainfall (mm)	-58.4	-51.9	-2	12.2	85.1	-15	
AUTUMN	October	High Temperature (ºC)	-0.1	0.5	-1.4	-1.2	DNA	DNA	From Warm and Arid to Warm and Arid
		Low temperature (ºC)	5.4	0	-4.4	2	DNA	DNA	
		Mean Monthly Temperature (ºC)	2.8	-1.8	-0.6	0.1	0.1	0.6	
		Mean Monthly Rainfall (mm)	-6	-2.8	-0.2	1.4	13.6	6	
	November	High Temperature (ºC)	2.6	-3.6	-0.6	3.3	DNA	DNA	From Cool and Arid to Warm and Arid
		Low temperature (ºC)	-0.3	5.5	-4	0.8	DNA	DNA	
		Mean Monthly Temperature (ºC)	2.6	-0.3	-2.1	1.2	-0.6	0.8	
		Mean Monthly Rainfall (mm)	-6	8.2	-10.2	-1.5	-0.5	-10	
WINTER	December	High Temperature (ºC)	-1.9	-3	-0.2	2.3	DNA	DNA	From Cool and Arid to Cool and Arid
		Low temperature (ºC)	1.6	2.6	-0.3	-5.8	DNA	DNA	
		Mean Monthly Temperature (ºC)	1.3	-0.8	-0.5	-0.3	0.1	-0.2	
		Mean Monthly Rainfall (mm)	-6	-0.9	14.9	-10	15	13	

Sources: Land use and land cover data has been extracted from Survey of India Topographical Sheets prepared at 1:50000 scale, 2011 IRS P-6 LISS-III Satellite imagery and Census of India. At floodplain scale causal link between average annual rainfall and net irrigated area has been identified.

Analysis and presentation: Spatial variation in rainfall regime has been shown through isohyets that overlapped by net irrigated land for showing the causal relationship. Further extracted statistical figures of these spatial relationships has been shown through the bar diagram for depicting comparative analysis.

RESULTS AND DISCUSSION

This study discussed what, how, when and why climatic transition took place in Punjab Satluj floodplain through following points;

Estimation of climatic transition

Climatic transition has been estimated through seasonal and annual changes in selected variables. ***Seasonal variations*** have been calculated from the monthly displacement of plots (Figure 2 and Table 1), that shows seasonal shifts with time. In Punjab five seasons have been identified i.e. *Winter season*, which begins in mid November and ends in mid February, *Spring season* (mid February to mid April), *Summer season* (mid April to June), *Rainy season* (July to mid September) and *Autumn season* (mid September to mid November) (Gosal, 2004). Transition in these seasons has been analyzed through their displacement in weather plots formed on the basis of thermal and moisture conditions calculated from Mean Monthly Temperature (MMT) and Mean Monthly Rainfall (MMR) values.

In 1960, ***winter season*** was started with the arid and cool conditions with 10 mm MMR and 18ºC MMT in the month of November and ends in February with the sub moist and cool condition with 60 mm MMR and 15ºC MMT. In 1970, winter came late. It started in December and ends in February. Aridity was decreased in this period. February month experienced 18.5 mm MMR. For this year, lowest temperature was reached at 1ºC, which was observed in the month of January. In 1980, winter season was placed at cool plot with comparatively reduced temperature as MMT for December, January and February months was decreased with 0.8ºC, 0.7ºC and 2.9ºC respectively as compare to previous decade. Highest temperature in this season was declined and lowest temperature was increased. Maximum fall in highest temperature was noticed in February month with 7.8ºC and maximum increase in lowest temperature was observed in January month with 4ºC. In moisture regime, this year was experienced good winter monsoon as January month was placed in semi arid condition and February month was marked in sub moist plot. Winter season of 1990 is less moist as no month was plotted beyond semi arid condition (Figure 2 (D)). Winter season of 2011 was arid and comparatively warm then previous decade. After winter, transitional phase to summer advanced with ***spring season***. It started from March month and continued till April with fluctuated moisture and thermal conditions. Spring season of 1960 was having semi arid and warm climatic conditions. Maximum moisture and warmness was observed in April month. In this season maximum high and low temperature was experienced in the same month i.e. April (Figure 2 A & B). In 1970, this season becomes more arid with 62.8 mm decreased MMR and comparatively less warm. Both March and April month of this season was experienced decreased MMT. Lowest temperature of this season was observed in March and highest temperature was reduced with 0.8ºC. Spring season of 1980 started with comparatively less warm condition.

Whereas spring season of 1990 and 2000 was experienced arid condition as it received 12.9 mm and 0.7 mm MMR respectively. But 2011 obtained less arid condition. In thermal section, 1990 experienced less warm spring with 1.8ºC and 3.2ºC decreased MMT from previous decade for March and April months respectively, but for succeeding decade MMT for these months was increased with 2ºC and 4.3ºC respectively. In 2011 warmness of this season was again decreased as March month experienced reduction in temperature with 1.35ºC, whereas April MMT was declined with 2.4ºC. Existence of ***summer*** season has been measured through degree of hotness. Figure 2 A-F reflects that May and June months have been formulated under this season at thermal scale. In 1960, it started with arid and hot condition and continues till June month, which experienced sub moist and hot conditions. High temperature in this season was noticed in June month. In 1970, Aridity in this season was increased. Maximum high temperature and highest MMT was observed in June month. In 1980, degree of hotness and aridity both were reduced as June month of this season was marked in semi arid plot with 26.3 mm MMR and May month was considered in warm plot with 29.7ºC MMT. Highest temperature of May and June was reduced with 2.7ºC and 1.5ºC respectively. In 2000, Hotness of summer season was experienced a month earlier as maximum MMT i.e. 31.6ºC was observed in May month. Even this season experienced good rain and both months were found in semi arid plot with 42 mm and 29.4 mm MMR for May and June months respectively. In 2011, May month experienced less rainfall and June received more rain than earlier decade. Following summer ***rainy season*** begins with monsoon shower. It has been marked on the basis of moisture regime and consists July, August and September months. Amount of rainfall in these seasons reflects strong and weak monsoon conditions. All months of rainy season was marked in moist plot during 1960. This season received good monsoon shower with 500 mm and maximum rain was occurred in August month with 250 mm MMR. This season transits from hot conditions to warm with 32ºC MMT in July and 28ºC MMT in September. Maximum high temperature was observed in July and minimum low temperature was took place in September month (Table 1 & Figure 2).

Rainy season of 1970 was less moist as compare to previous decade as it received 288.4 mm rainfall. Maximum rainfall was observed in July month. Whereas, at thermal front it was warmer with increased maximum high temperature then preceding decade. In 1980, rainfall for this season was further reduced and aggregately this season received 205.3 mm rainfall. This season was comparatively less hot. Rainy season of 1990 experienced good rain then previous decade with 457.6 mm rainfall. Maximum rainfall was observed in July month. This season faced warmness of weather as all months of this season was marked under warm descriptive plot.

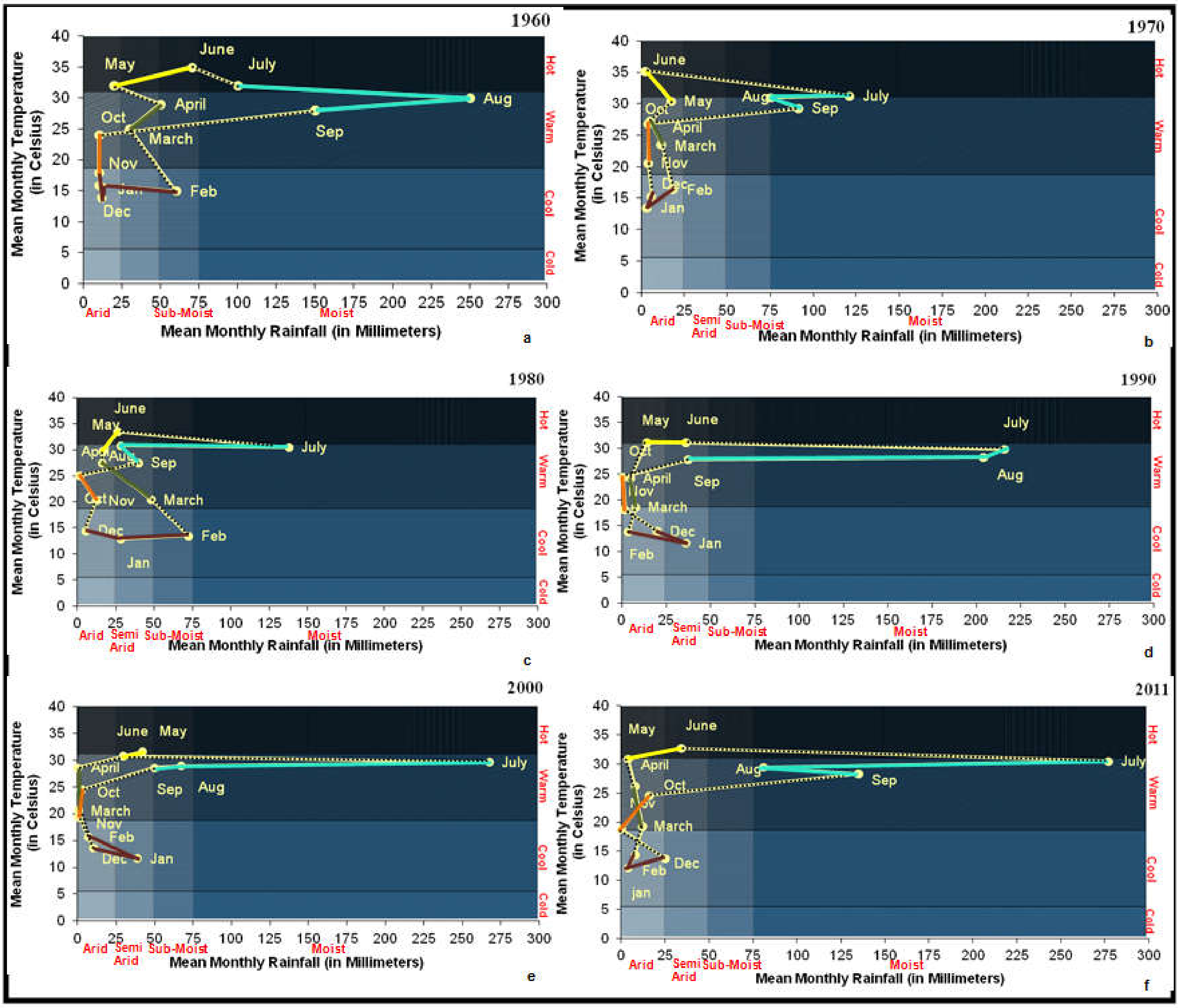


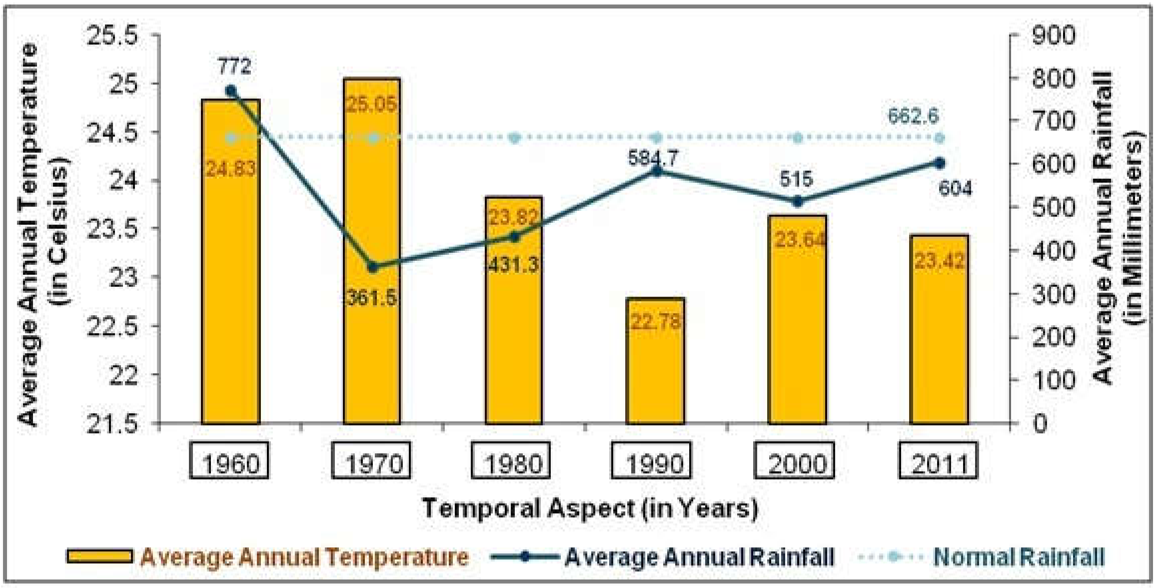
Figure 2 Seasonal Variability in Punjab Satluj Floodplain. Shifts in seasonal pattern has been estimated through displacement of months in formulated thermal and moisture plots based on mean monthly temperature and rainfall respectively. Locational characteristics of identified five seasons i.e. winter season (bold brown lines), spring (bold green lines), summer (bold yellow lines), rainy (bold tourmaline blue lines) and autumn season (bold orange lines) in sixteen descriptive climatic plots depicts change. Transition period between the seasons has been shown through broken black lines. Climatic plots are formed through the combinations of moisture conditions that include arid (<25 mm MMR), semi-arid (25.1-50 mm MMR), sub-moist (50.1-75 mm MMR) and moist (75.1-300 mm MMR) with thermal conditions that involved cold(<5ºC MMT), cool (5.1 to18ºC MMT), warm (18.1 to 30ºC MMT) and hot (30.1 to 40ºC MMT).

In 2000, aggregate showered rain in this season was less as compare to previous decade as it received 384.7 mm rainfall. But noticeably maximum proportion of this rain was happened in July month with 267.6 mm MMR. During this period, maximum MMT was observed in July month. Maximum highest temperature for this season was reduced with 2ºC and it was observed in July month with 36.9ºC. Rainy season of 2011 was received good monsoon rain and placed in moist plot and collectively got 493 mm rainfall. Warmness in this season was increased and maximum MMT was experienced in July month with 30.5ºC. After rainy season, ***autumn season*** begins with arid and warm condition. This season consists October and November month. Autumn season of 1960 was experienced arid condition with 20 mm rainfall. This season proceeds from warm to cool thermal plot with 24ºC MMT for October month and 18ºC MMT in November month. For 1970, aridity was increased.

In 1980, aridity and warmness of this season was reduced as it received 13.4mm rainfall and MMT of October month was reduced with 1.8ºC, which reached at 25ºC and for November month noticed MMT as compare to earlier decade was reduced with 0.3ºC and observed value was 20.3ºC (Figure 2A-F). In this season, maximum highest temperature was observed in October month with 36.4ºC. In 1990, this season become less warm and more arid. From previous decade MMT of October month was decreased with 0.6ºC and reached at 24.4ºC, whereas for November month MMT was reduced with 2.1ºC and absolute figure was 18.2ºC. With decreased warmness, moisture content for this season was also fall and recorded rainfall in this season was 3 mm. This increased aridity was continued till succeeding decade as in 2000, it received 2.9 mm rainfall. At thermal scale warmness was increased as MMT for October and November months was increased with 0.1ºC and 1.2ºC and observed absolute values were 24.5ºC and 19.4ºC respectively. In 2011, aridity was reduced as this season experienced 16 mm rainfall, but it was showered in only one month i.e. October. Thermal status of this season was started with 0.1ºC increased MMT and recorded MMT for October month was 24.6ºC, whereas this season ends with reduced warmness then previous decade with 0.6ºC decreased MMT in November month and absolute temperature for this season was 18.8 ºC. Collectively this seasonal shift affects the annual variability of climatic element at temporal scale.

Annual climatic variations have been estimated through average annual rainfall and temperature flux. During 1960, mean annual temperature for this area was 24.83ºC, which was increased to 25.05ºC for 1970. In 1980 and 1990 temperature was reduced and recorded value was 23.82ºC and 22.78ºC respectively. But for succeeding years temperature was increased with 23.64ºC and 23.43ºC respectively. Rainfall regime of this area was also faced fluctuated situation as average annual rainfall was 772 mm in 1960, 361.5 mm in 1970, 431.3 mm in 1980, 584.7 mm in 1990, 515 mm in 2000 and 604 mm in 2011 (Figure 3). All these selected years received normal monsoon rainfall as it ranged between half to less than one and a half times of the normal experienced rainfall (Arora and Jha, 2015) for this area. Prominent active global phenomena's i.e. El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) has been working behind this monsoon system. For 1960 and 1990 neutral ENSO and IOD phase was noticed, whereas for 1970 and 2000 La Nina and neutral IOD phase was observed. In 1980, neutral ENSO and negative IOD was happened (Gary *et al*., 2007). Along them local factors of climate change has also been noticed for this change.

Punjab Satluj Floodplain: Annual Climatic Transition



Sources: Statistical Abstract of Punjab: 1960, 1970, 1980, 1990, 2000, 2011

Figure 3 Climatic Transition. At decadal gaps comparative average annual temperature and rainfall change had been analyzed for estimating the transition in Punjab Satluj Floodplain.

Climatic Variation: Causes

Variation in climatic elements took place due to extra terrestrial system and ocean, atmosphere, land systems. In this study impact of land system on climatic elements have been discussed with reference to land use and land cover change in study area. As in 1955, ratio of land cover to land use was 64:36, which was drastically changed for succeeding years. In 2011, land cover to land use ratio was reduced and observed values was 6:94. Prominently this land cover was lost for the expansion of agricultural land as this area provides suitable conditions for the development of agro ecological region. Main reason for this change was the presence of natural resources in an integrated form and progressive human efforts that involved damming and channelizing of Satluj river water for utilizing the available resources at best. This results to the agricultural expansion, which covered 362.58 km^2 i.e. 34.77 percent of study area in 1955 and increased to 910.11 km^2 that covered 87.28 percent of study area during 2011. This agricultural increase reflects impact of increased human number and their related demand in this area. In statistical terms this area was inhabited by 2,03,234 in 1961, which was increased to 20,30,635 in 2011. With this number land under built up use was also increased. It consists 1.04 percent of study area in 1955, which reached to 6.24 percent in 2011. Collectively this area faced 56.55 percent transformation from 1975 to 2011.Possible enhancement mechanisms included following processes that can be linked with the land use and land cover change in Punjab Satluj floodplain and its impact on climate:

Surface transformations through land use and land cover change alters the latent and sensible heat input to atmosphere (Mahmood *et al*., 2010 and Stone *et al*., 2013) and affects the temperature regime of an area. In this area surface water in the form of ponds, lakes, drains, canals, Satluj River and wetland covered 195.94 km^2 i.e 18.79 percent of study area during 1960's, which enhanced the evaporation rate and add cooling effect to the weather, which can be noticed from the then prevailing 24 C average annual temperature, which was reduced to 23.42 C in 2011 with reduction in surface water that covered 28.92 km^2 (2.77 percent) of study area.

In *Field Fertilization* process, specifically increased consumption of nitrogenous fertilizers contributes to the addition of green house gases such as nitrous oxide and nitrogen oxides (Mosier *et al*., 1998; Tilman *et al*., 2001; Bouwman, Boumans and Batjes, 2002; World Bank Report, 2010). During 1960-61, 5 thousand tones of Nitrogenous fertilizers were applied on agricultural fields of Punjab, which increased to 1416 thousand tonnes for 2011-12;

Animal domestication and rice growing add methane (Greenhouse Gas) to the environment (Energy Information Administration Agency, 2001; Leroux, 2010 and Government of India, 2013);

Expanded built up areas with varying concrete surfaces are having different thermal properties, which incorporates their storage capability of solar energy that convert into the sensible heat and affects the temperature (Arnfield, 2003);

Transportation modes adds polluted substances into the air (Rizwan, Dennis and Liu, 2008), which elevates the amount of green house gases in atmosphere and increased aerosols acts as a source of cloud condensation nuclei that affects rainfall regime of an area (Molders and Olson, 2004);

Through *Irrigation processes*, water vapor transfer from surface to atmosphere increased (Arnfield, 2003) and affects rainfall regime (Beebe, 1974; Schickedanz, 1976; Schickedanz and Ackermann, 1977; Barnston and Schickedanz, 1984; Ookouchi *et al*., 1984; Mahfouf, Richard and Mascart, 1987; Segal *et al*., 1988; Yan and Anthes, 1988; Brubaker, Entekhabi and Eagleson, 1993; Eltahir and Bras, 1996; Segal *et al*., 1998; Moore and Rojstaczer, 2001). These processes reflect how different surface conditions linked with the climatic elements.

Placed based relationship between increased irrigated land and rainfall pattern has been analyzed for Punjab Satluj floodplain. In this area agricultural expansion took place, which was with time boost up with agricultural intensification. That was possible through Government initiatives taken under different Five Year Plan's and Green Revolution, which resulted to the increased net cultivated area and irrigated area. With time ratio of net irrigated land to net cultivated area was increased, it was 32:44 during 1970-71 and increased to 85:88 in 2000-01. This increased irrigated area contributes to the evaporation rate and further increased the rainfall pattern of this area, which has been visualized through figure 4 and statistically supported by figure 5. During 1970, average annual rainfall for this area was ranged between 361.5 mm to 663.5 mm, which was expanded to 705.1 mm in 2000. It was specifically noticed that the area from low to high rainfall range was expanded with time. In 1970, area experienced 300.1 mm to 400 mm average annual rainfall covered 27 percent area. That consists southern part of Machhiwara Block, western part of Ludhiana I Block of Ludhiana District (Figure 4 (A)).

In this area, villages with having maximum net irrigated land i.e. 75.01 to 100 percent covered 9.6 percent area, which was increased to 69 percent during 2000. In this period area earlier experienced 300.1 mm to 400 mm average annual rainfall was transit to higher rainfall receiving groups with only 10 percent left over. In 1970, maximum rainfall ranged between 600.1 mm to 700 mm was observed in northern parts of Balachaur, Nawanshahr and Aur Block of Shahid Bhagat Singh Nagar

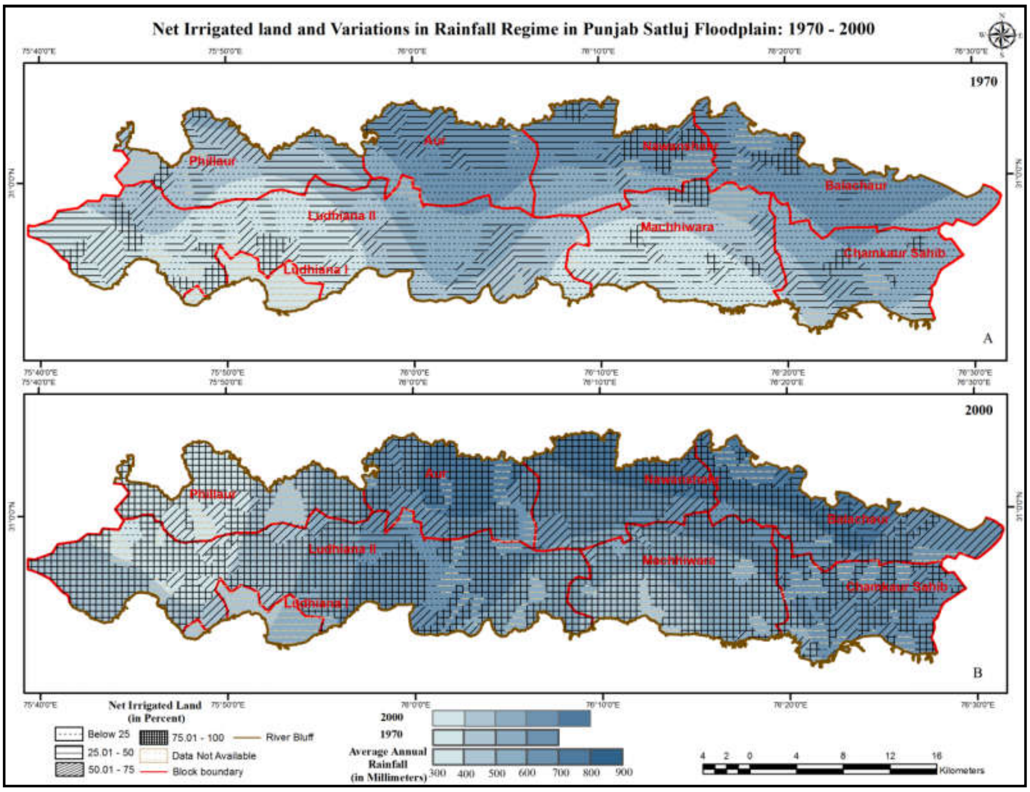


Figure 4 Spatial Causal Relationship between Net Irrigated Land and Rainfall Regime

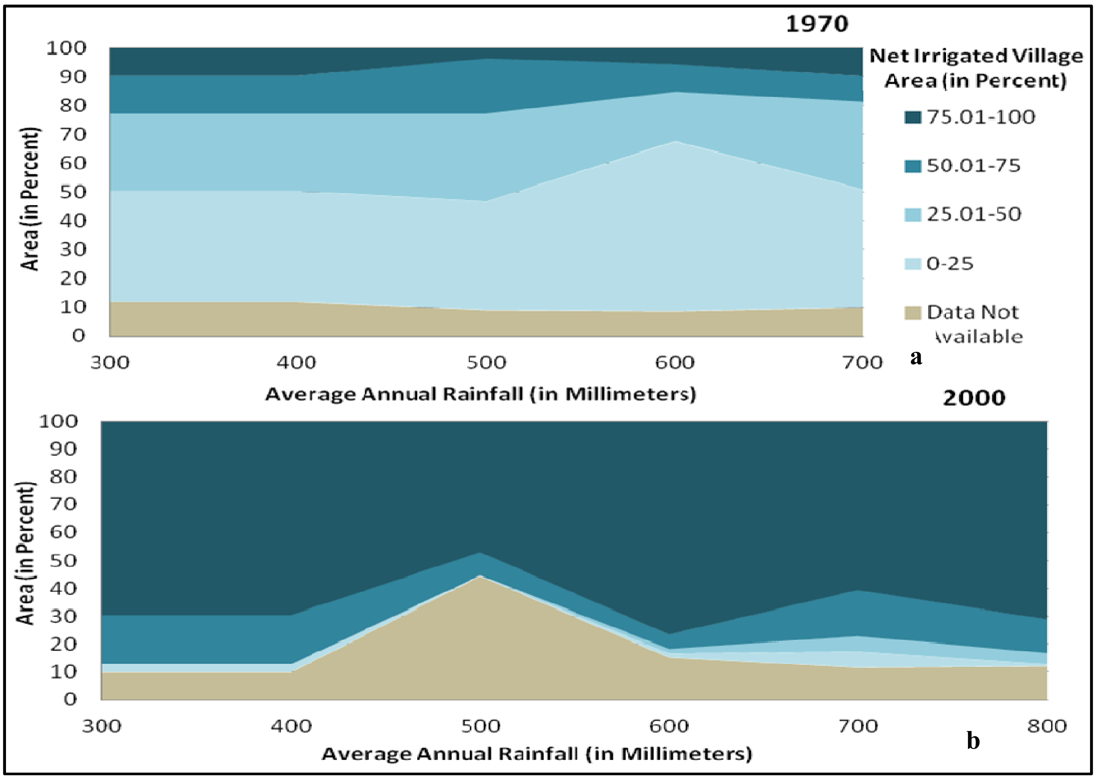
Spatial patterns of net irrigated land and average annual rainfall for the period 1970 and 2000 was overlapped for establishing the causal links.

District and Chamkaur Sahib Block of Rupnagar District and covered 26 percent of study area with its 9.8 percent area consists those villages, which was having 75.01 to 100 percent net irrigated land (Figure 4 & 5 A).

Punjab Satluj Floodplain

Causal Link between Net Irrigated area and Rainfall Regime

tropical area that started from the ***winter season*** that brings coolness to this area. It has been squeezed and came late after 1960. Earlier this season was observed from November to February. Now it limited to December till February with coolest January month.



Sources: Census of India: 1970 and 2000; Statistical Abstract of Punjab: 1970 and 2000

Figure 5 Causal Link between Net Irrigated area and Rainfall Regime. Figure a and b depicts effect of increase in net irrigated area in Punjab Satluj floodplain and its positive effect on the rainfall amount for 1970 and 2000 respectively.

In 2000, 600.1 mm to 700 mm average annual rainfall received area was expanded and covered 40 percent of study area. Villages with their 75.01 to 100 percent net irrigated land covered its 60.37 percent area. In this period highest range of average annual rainfall i.e. 700.1 mm to 800 mm was observed at south eastern part of floodplain area, which involved parts of Balachaur Block (Shahid Bhagat Singh Nagar District), Chamkaur Sahib Block (Rupnagar District) and Machhiwara Block (Ludhiana District) and covered 14 percent of study area. Its 70.87 percent area included those villages that were having 75.01 to 100 percent of its area under net irrigated land (Figure 4 & 5 B).

This analysis clearly depicts the positive relationship between net irrigated land and rainfall. But it is also true that these local causal relationships collectively affects the regional climate (Pielke *et al*., 1998; Chase *et al*., 1999; Pielke, 2001; Pitman *et al*., 2004) and contributes to the global climatic responses and simultaneously global factors made changes to the regional climatic conditions (Foley *et al*., 2005).

CONCLUSION

Variation in climatic elements has been noticed in Punjab Satluj floodplain. This area experienced shifts in its seasonal and annual pattern. Five seasons has been identified for this sub

Aridity of winter season was increased, as in 1960 maximum shower was observed in February month with 60 mm MMR that stretched winter of this year to sub moist condition, but in 2011 maximum received rain was reduced to 25 mm MMR for December month. After winter ***spring season*** came, that consist March and April months. Analysis revealed that from 1960 to 2011, this season shifts from semi arid and warm conditions to arid and comparatively less warm climatic condition. ***Summer season*** was comparatively moist and hot during 1960 as compare to 2011. ***Rainy season*** was moister in 1960, as 500 mm rain was showered in this year, whereas this moisture content was reduced during 2011 as recorded rainfall in this period was 493 mm. From 1960 to 2011 ***autumn season*** for this area was shifted from arid and less warm conditions to more arid and warmer climatic condition. Aggregate change in these seasons for a year reflects annual variability. Recent decadal annual change shows that there is increase in average annual rainfall with 89 mm and decrease in average annual temperature with 0.21ºC. These climatic changes linked here with surfacial transition with underlying applied assumption that these variations also resulted from the factors and forces worked collectively at local to global scale.

Satluj floodplain faced 56.55 percent surfacial transition from 1975 to 2011. This change took place due to the progressive efforts of 19,97,375 increased human number for this area. Maximum expansion was noticed in agricultural land with 52.51 percent. This change affects climate through surfacial processes incorporating thermal flux, addition of Green House Gases, change in water vapour sources, change in evaporation and evapotranspiration rate and added sources of cloud condensation nuclei. Further these changes made affect on the land use and land cover as climatic conditions played very important role in the growth, sustenance and maintenance of natural resources and anthropogenic activities. Ground experiment has been done for analyzing the effect of expanded net irrigated area and increased rainfall. From 1970-2000, net irrigated area was increased with 53 percent. This pattern affects the evaporation rate and thus rainfall regime of this area, which was expanded to 800 mm during 2000-01. So, variations have been noticed in the climatic elements with time in Punjab Satluj floodplain that directly related with local to global level causal factors.

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