Study of the Spatial Variability of Rainfall and Its Impact on Water Resource Sharing In the North Region of India (5, 6, 7)

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***Abstract*-The climate change, as realized through trends of temperature rise and increased CO2 concentration, is a major concern. In the recent past, the number of studies for assessing its impact on agriculture has increased. Crop growth models have been modified and tested for various important crops of this region under different climate change scenarios. But most of the results happen to be region specific and with certain assumptions. Accuracy in assessing the magnitude of the climate change on higher spatial and temporal resolution scale is the prime requirement for accurate estimates of the impact. The extent of inter- and intra-annual variability in climate happens to be large in this region, and the crops respond differentially to these changes. Understanding of this differential behavior can aid in working out the impact of climate change. The vast genetic diversity in crops provides a platform to identify suitable thermal and drought tolerant cultivars for sustained productivity in the changed climate. The main objective of the study is to analyze the spatial and temporal variability rainfall in the humid regions of North region of India within the period 1915-2015. An added objective is to verify the differences in the spatial variability of rainfall in all the three region of the North region of India (5, 6, 7) and how that impact water resource sharing. The flip-flop in annual rainfall was evident in 1914-2015. Similar rainfall trends (increase) was noticed in all the seasons viz., southwest monsoon, post monsoon and winter except in summer during which a marginal decline in annual rainfall was noticed. Recent studies indicated that the increase in average temperature is 0.61 based on the data from 1901 to 2015. It is likely to increase further depending up on the emission of GHGs in the atmosphere. The increase in maximum temperature across India is 0.76°C during the period from 1901 to 2003. Over India, temperatures are increasing.**

***Index Terms*-Monsoon Rainfall; Temporal Variability; Trend; Temporal Variability**

I. INTRODUCTION

Climate (from Ancient Greek klima, meaning inclination) is commonly defined as the weather averaged over a long period of time. Climate encompasses the statistics of temperature, humidity, wind, rainfall, atmospheric pressure, atmospheric particle count and numerous other meteorological parameters in a given region over long periods of time. The standard averaging period is 30 years, but other periods may be used depending on the purpose. Climate also includes statistics other than the average, such as the magnitudes of day–to–day or year–to–year variations. The climate of a location is affected by its latitude, terrain, altitude, ice or snow cover, as well as nearby water bodies and their currents. Climates can be classified according to the average and typical ranges of different variables, most commonly temperature and precipitation. The widely used classification criteria is the one originally developed by WladimirKoppen. The Thornthwaite system, in use since 1948, incorporates evapotranspiration in addition to temperature and precipitation information and is used in studying the potential impacts of climate changes. The Bergeron and spatial synoptic classification systems focus on the origin of air masses defining the climate for certain areas. Climate can be contrasted to weather, which is the present condition of climate parameters over periodsupto two weeks. Meteorology is the interdisciplinary scientific study of the atmosphere that focuses on weather processes and forecasting. Studies in the field stretch back millennia, though significant progress in meteorology did not occur until the eighteenth century. The nineteenth century saw breakthroughs occur after observing networks developed across several countries. Breakthroughs in weather forecasting were achieved in the latter half of the twentieth century, after the development of the computers. Meteorological phenomena are observable weather events which illuminate and are explained by the science of meteorology. These events are bound by the 2 variables that exist in Earth's atmosphere: These are temperature, air, water vapour, the gradients & interactions of each variable, and how they change in time. The majority of Earth's observed weather is located in the troposphere. Different spatial scales are studied to determine how systems on local, regional, and global levels impact weather and climatology. Meteorology, climatology, atmospheric physics, and atmospheric chemistry are sub–disciplines of the atmospheric sciences. Meteorology and hydrology compose the interdisciplinary field of hydrometeorology. Meteorology has application in many diverse fields such as the water resources, agriculture, construction, military, energy production, transport, etc. Climatology is the scientific study of climate, including the causes and long–term effects of variation in regional and global climates. Climatology also studies how climate changes over time and is affected by human actions. Climate models are used for a variety of purposes from study of the dynamics of the weather and climate system to projections of future climate. Various impacts include increase in global average surface temperature, sea levels and decrease in the Northern Hemisphere snow cover. These changes are likely to threaten food production, increased water stress and decrease in its availability, rise in sealevels, which could flood crop fields and coastal settlements, and increase the occurrence of diseases, such as malaria. Given the lack of resources and access to technology and finances, developing countries such as India have limited capacity to develop and adopt strategies to reduce their vulnerability to changes in climate. India is a large developing country with a population of over one billion which is projected to grow to as much as 1.7 billion by 2050 (World Bank, 2012). In India, a significant share of the population is rural, and its dependence on climate-sensitive natural resources is very high. The rural population also depends largely on agriculture and allied activities, for its livelihood. Indian agriculture is monsoon dependent, with over 60% of the crop area being under rainfed agriculture, which is highly vulnerable to climate variability and change.

However, the impacts of climate change will not be uniform across the globe due to differences in bio-physical and socio-economic conditions. For example, it is projected that while crop yields could increase by up to 20% in East and South-East Asia, it could decrease by up to 30% in central and south Asia by the mid-21st century (IPCC, 2007). The magnitude of the impacts of climate change depends on the vulnerability of individual nations and their adaptive capacity to face the consequences. Here vulnerability is the degree to which a system is susceptible and unable to cope with the adverse effects of climate change, including climate variability and extremes. However, developing countries are considered to be more vulnerable to the impact of climate variability and change due to structural weaknesses and low levels of resilience and adaptive capacity. Among regions, south Asia is one of the most vulnerable regions of the world. Observations demonstrate that climate change has affected many sectors in Asia in the past decade and climate change has the potential to exacerbate water resources stress, agricultural productivity, and rise in sea level, jeopardizing millions of people and livelihoods.

The climate of India defies easy generalisation, comprising a wide range of weather conditions across a large geographic scale and varied topography. India is home to an extraordinary variety of climatic regions, ranging from tropical in the south to temperate and alpine in the Himalayan north, where elevated regions receive sustained winter snowfall. The nation's climate is strongly influenced by the Himalayas and the Thar Desert. Four major climatic groupings predominate, into which fall seven climatic zones that, as designated by experts, are defined on the basis of such traits as temperature and precipitation. Groupings are assigned codes according to the Köppen climate classification system. The India Meteorological Department (IMD) designates four official seasons: Winter, occurs during January to February. Summer or pre–monsoon season lasts from March to May (April to July in northwestern India). In western and southern regions, the hottest month is April; for northern regions, May is the hottest month. Temperatures average around 32–40°C in most of the interior. India Climatic Zone Monsoon or rainy season occurs from June to September. The season is dominated by the humid southwest summer monsoon, which slowly sweeps across the country beginning in late May or early June. July is the wettest month. Average daily temperature ranges between 16° C and 28° C. Post–monsoon season lasts from October to December. South India typically receives more precipitation. Monsoon rains begin to recede from north India at the beginning of October. In northwestern India, October and November are usually cloudless. Parts of the country experience the dry northeast monsoon. Average temperature of the season is 17°C. 5 For a country like India, which is still largely dependent upon rain–fed agriculture, availability of freshwater is one of the foremost concerns for the future. Most of Indian plains receive about 80% of their annual quota of rain from the southwest monsoon during the four months, June to September. The coastal areas in peninsular India receive rain from the northeast monsoon during October to December, which includes cyclonic storms.

In this paper we studied and analyze the spatial and temporal variability rainfall in the humid regions of North region of India within the period 1915-2015 and forecasted it for ten year for prediction of the nature of the climate in these region.

II. METHODOLOGY

Middle Gangetic Plain Region:

The Middle Gangetic Plain region includes large parts of Uttar Pradesh and Bihar. The average temperature in July varies from 26 °C to 41 °C and that of January 9 °C to 24 °C average annual rainfall is between 100 cm and 200 cm. It is a fertile alluvial plain drained by the Ganga and its tributaries. Rice, maize, millets in kharif, wheat, gram, barley, peas, mustard and potato in rabi are important crops.

Alternative farming systems, and utilisingchaur lands for pisciculture are some measures to boost agricultural production.

Reclamation of user lands, wastelands, and fallow lands for agriculture and allied activities (agro-forestry, silviculture, floriculture etc.) should be done.

Upper Gangetic Plains Region:

In the Upper Gangetic Plains region come the central and western parts of Uttar Pradesh and the Hardwar and Udham Nagar districts of Uttarakhand.

The climate is sub-humid continental with temperature in July between 26 °C to 41 °C and temperature in January between 7 °C to 23 °C. Average annual rainfall is between 75 cm-150 cm. The soil is sandy loam. Canal, tube-well and wells are the main source of irrigation. This is an intensive agricultural region wherein wheat, rice, sugarcane, millets, maize, gram, barley, oilseeds, pulses and cotton are the main crops.

Besides modernizing traditional agriculture the region needs special focus on dairy development and horticulture. Strategies should include developing multiple mixed cropping patterns.

Eastern Plateau and Hills:

This region includes the Chhotanagpur Plateau, extending over Jharkhand, Orissa, Chhattisgarh and Dandakaranya. The region enjoys 26 °C to 34 °C of temperature in July, 10 °C to 27 °C in January and 80 cm-150 cm of annual rainfall. Soils are red and yellow with occasional patches of laterites and alluviums. The region is deficient in water resources due to plateau structure and non-perennial streams. Rainfed agriculture is practised growing crops like rice, millets, maize, oilseeds, ragi, gram and potato.

Steps to improve agricultural productivity and income include cultivation of high value crops of pulses like tur, groundnut and soyabean etc. on upland rain-fed areas, growing crops like urad, castor, and groundnut in kharif and mustard and vegetables in irrigated areas, improvement of indigenous breeds of cattle and buffaloes, extension of fruit plantations, renovation including desilting of existing tanks and excavation of new tanks, 95.32 lakh ha of acidic lands through lime treatment, development of inland fisheries in permanent water bodies, and adopting integrated watershed development approach to conserve soil and rain water.

RAINFALL TRENDS OVER INDIA

The present study on annual rainfall over the country showed a flip-flop trend, which is significant at 5% level. The flip-flop in annual rainfall was evident in

1914-2015. Similar rainfall trends (increase) was noticed in all the seasons viz., southwest monsoon, post monsoon and winter except in summer during which a marginal decline in annual rainfall was noticed (Table 4.1 and Fig. 4.1). Southwest monsoon rainfall over the Country was significant at 5% level while the post monsoon rainfall was significant at 10% level. However, the trend in annual and southwest monsoon rainfall was declining since 1960 onwards. At the same time, the annual rainfall was increasing in recent decades during post monsoon season. The monthly rainfall also indicated that there was a decline in June while increase in July, August and September during the monsoon season. Such trend was not seen in all the zones studied where rainfall trends differ spatially and temporally. Rainfall trends were uncertain depending upon the time period and season unlike in the case of temperature. However, the annual and monsoon rainfall for the Country as a whole showed declining trend since last 50-60 years though overall increase was seen during the study period of 194 years.

Table 1: All India area weighted monthly, seasonal and annual rainfall in mm (1914- 2015 from the revised series computed using all available rain gauge stations data and from IMD district rainfall data series while the period 2016-2025 are based on the real time DRMS data)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1914	5.0	26.9	25.4	42.8	67.9	157.0	342.0	239.7	191.3	45.5	20.7	21.6	1185.9
1915	19.8	37.5	44.1	33.6	63.9	155.1	227.9	226.9	171.7	90.5	45.2	8.2	1124.4
1916	4.6	20.1	11.0	35.2	59.4	232.0	265.0	309.7	199.6	139.2	46.3	2.9	1324.8
1917	7.6	37.9	20.5	40.1	74.0	230.7	282.7	292.8	278.1	161.3	29.1	9.3	1463.9
1918	11.8	4.0	36.6	35.8	103.6	212.3	183.8	240.9	111.8	19.5	44.7	15.5	1020.2
1919	48.8	20.2	19.1	32.7	59.5	194.7	304.6	285.3	163.1	91.5	50.1	18.2	1287.9
1920	23.9	21.3	55.1	38.2	52.5	163.7	295.7	191.6	123.0	45.9	25.2	3.0	1039.1
1921	37.6	7.4	17.8	43.9	51.2	193.9	293.7	274.4	203.3	70.5	16.1	15.3	1225.0
1922	28.9	9.8	14.3	33.0	48.8	204.9	314.9	218.9	199.8	62.0	55.6	13.3	1204.2
1923	21.6	38.9	21.2	31.0	58.1	102.0	337.8	272.8	173.8	58.0	17.6	15.8	1148.6
1924	21.1	21.9	14.0	30.7	61.4	136.8	328.7	255.4	238.4	65.8	57.1	14.6	1245.9
1925	13.0	11.2	15.3	44.1	100.8	204.7	300.9	234.5	140.2	67.2	41.5	16.1	1189.5
1926	28.3	10.3	55.7	39.4	57.8	98.7	316.9	330.5	210.1	57.3	10.9	10.3	1226.2
1927	13.1	34.7	22.4	36.3	50.4	177.7	346.6	253.2	173.6	69.3	57.2	10.1	1244.6
1928	20.9	40.3	21.1	34.6	54.4	178.9	303.5	229.0	144.0	127.7	21.6	24.4	1200.2
1929	29.6	18.6	14.4	54.6	65.9	194.1	296.7	241.0	125.5	92.9	19.6	40.1	1193.2
1930	23.5	23.2	28.9	51.0	55.9	181.5	288.6	212.0	174.1	96.7	53.0	10.3	1198.5
1931	12.4	32.9	19.0	37.3	59.4	134.5	319.6	303.9	191.1	120.5	41.4	21.0	1292.8
1932	9.2	22.9	20.1	31.0	85.7	141.7	328.3	237.9	181.9	69.4	60.3	14.4	1202.9
1933	16.5	29.6	25.1	48.1	102.4	215.1	279.7	313.4	211.6	93.6	20.5	16.5	1372.0
1934	23.3	11.5	16.1	46.8	47.3	217.7	284.8	294.4	166.8	65.8	32.4	10.5	1217.5
1935	26.9	20.7	19.0	41.5	36.8	159.4	313.5	246.9	185.3	49.9	16.7	11.2	1127.9
1936	12.3	41.8	37.8	33.5	82.7	245.8	292.5	236.7	193.9	66.4	57.2	21.2	1321.8
1937	6.3	50.6	19.0	56.3	58.0	162.2	336.2	208.2	174.0	94.6	20.3	18.9	1204.4
1938	29.9	30.7	33.4	34.2	70.9	273.4	300.2	249.7	171.6	75.4	16.2	5.0	1290.5
1939	13.3	32.1	30.6	40.7	40.6	172.9	272.4	231.5	154.9	91.2	29.6	1.7	1111.6
1940	13.0	25.8	47.7	26.9	80.8	173.8	308.4	278.1	125.5	63.0	40.9	17.4	1201.3
1941	22.9	16.4	20.4	31.5	81.0	171.8	238.7	228.4	154.0	62.1	26.5	20.3	1073.9
1942	21.4	46.0	20.6	44.7	63.7	191.5	339.6	287.0	182.5	34.5	17.7	23.5	1272.9
1943	56.8	9.8	32.5	47.9	94.3	167.8	308.9	228.4	211.4	89.0	17.1	5.2	1269.2
1944	27.6	37.8	54.9	31.9	61.0	155.6	349.1	287.0	156.2	92.3	29.4	15.6	1298.5
1945	34.2	10.2	20.1	47.1	53.6	159.1	333.3	246.7	214.5	80.6	17.9	4.9	1222.0
1946	4.4	19.1	24.5	48.0	71.3	214.0	318.3	296.3	145.0	84.4	76.0	35.8	1337.2
1947	22.4	18.3	26.0	39.1	55.9	130.1	314.4	290.4	240.0	69.8	7.2	22.6	1236.3
1948	25.2	29.0	39.5	42.5	91.3	164.1	347.7	282.7	178.0	61.2	71.1	10.0	1342.2
1949	12.6	28.8	24.1	53.0	89.3	164.3	316.8	243.2	227.0	95.1	10.6	4.7	1269.6
1950	35.4	25.4	36.7	28.7	49.4	135.7	331.6	235.6	202.6	57.7	27.5	7.9	1174.2
1951	15.7	12.1	44.4	54.4	59.4	163.3	252.7	222.8	124.6	73.9	31.3	5.8	1060.6
1952	10.5	19.8	37.4	32.4	69.7	165.6	286.6	256.6	120.0	79.6	9.2	22.5	1110.1
1953	30.2	10.6	25.3	38.3	47.1	162.2	323.1	299.2	179.9	85.8	12.3	8.0	1222.1
1954	37.6	37.2	17.1	22.8	53.9	145.5	297.2	232.0	246.7	73.8	3.6	13.9	1181.4
1955	20.8	4.1	21.3	30.6	72.6	177.7	236.8	313.8	215.7	146.3	26.4	9.3	1275.4
1956	17.0	11.1	31.5	28.1	85.5	211.0	354.1	254.3	163.9	150.1	44.0	11.9	1362.6
1957	31.1	10.9	24.2	39.5	71.2	153.2	300.8	265.4	131.7	64.0	28.6	11.3	1131.9
1958	12.4	16.5	19.1	36.9	80.5	123.7	316.9	324.9	225.7	114.7	30.0	10.9	1312.3
1959	31.8	23.8	21.3	25.9	75.3	169.8	375.5	265.1	237.3	119.7	26.0	5.3	1376.9

1960	13.8	2.7	35.2	20.0	57.7	157.3	320.0	252.9	184.7	68.5	33.7	8.3	1154.8
1961	26.1	34.8	26.0	28.5	77.6	192.9	336.6	287.6	234.9	122.2	21.7	10.4	1399.2
1962	12.6	21.6	16.0	43.6	70.8	137.1	281.6	276.9	211.0	78.4	18.3	29.9	1198.0
1963	6.8	9.8	41.7	50.6	60.9	168.0	258.6	316.7	164.9	99.1	28.4	15.5	1220.9
1964	18.6	14.1	19.0	40.0	52.1	177.2	345.7	273.7	200.4	67.4	22.8	13.3	1244.4
1965	11.8	28.1	26.7	45.1	52.7	116.1	270.1	192.8	129.5	34.0	18.2	22.2	947.4
1966	13.1	25.4	20.3	30.6	57.2	178.8	252.5	212.5	143.9	56.1	51.0	16.7	1058.0
1967	11.1	14.2	63.3	29.5	42.8	144.0	305.6	264.3	170.3	40.6	12.1	56.1	1154.0
1968	29.4	19.8	27.5	32.6	46.7	149.6	309.9	212.8	129.5	67.1	21.8	12.6	1059.3
1969	12.7	14.5	20.1	39.7	63.4	130.2	317.8	273.4	172.7	55.0	35.8	12.7	1147.8
1970	23.2	27.3	25.9	29.2	69.7	215.9	245.6	313.0	212.7	75.3	15.7	1.6	1255.0
1971	16.1	23.6	10.8	52.8	75.0	229.9	267.2	267.3	146.5	99.9	15.9	12.0	1216.9
1972	10.3	27.6	21.6	37.1	55.3	123.3	204.0	219.5	127.5	65.7	31.4	23.7	947.1
1973	21.0	21.8	21.2	27.5	56.5	149.9	277.4	311.0	182.1	114.6	18.9	17.7	1219.5
1974	16.1	12.9	20.5	33.7	64.2	122.0	283.6	232.5	145.3	101.6	10.7	12.1	1055.3
1975	15.4	20.8	28.7	28.3	50.2	175.6	310.7	292.5	224.6	121.9	22.8	3.3	1294.8
1976	11.5	24.5	25.5	36.3	45.4	160.3	294.1	294.0	144.2	33.0	55.0	7.6	1131.6
1977	21.0	10.2	14.6	68.3	84.4	187.2	323.4	245.4	147.8	85.6	65.8	16.1	1269.7
1978	12.3	27.0	44.2	33.1	60.2	208.8	290.0	282.0	161.9	49.1	49.9	18.8	1237.2
1979	20.9	35.0	28.9	21.2	54.2	140.5	239.6	210.6	136.8	51.8	76.1	14.4	1030.2
1980	12.8	22.3	32.5	34.6	55.3	227.8	295.0	263.8	145.7	49.3	24.2	19.0	1182.3
1981	29.3	20.4	48.0	37.3	67.1	151.3	309.1	237.0	184.5	45.1	27.4	14.0	1170.7
1982	23.8	24.2	45.7	49.8	59.0	137.8	230.8	276.9	124.9	51.7	46.0	13.9	1084.4
1983	18.5	23.3	43.4	57.0	70.1	150.8	282.2	304.3	251.6	85.9	10.8	22.9	1320.9
1984	19.0	35.9	22.8	45.3	60.4	192.3	291.9	256.5	144.6	61.0	15.7	15.3	1160.8
1985	23.2	9.9	20.1	39.5	63.0	156.5	290.1	231.7	149.6	114.1	18.8	28.4	1144.9
1986	15.5	36.6	29.9	50.0	49.4	182.6	264.2	228.3	128.4	74.7	49.6	28.4	1137.6
1987	13.2	23.8	28.8	43.9	67.0	133.9	223.2	242.1	152.2	94.4	44.4	21.9	1088.9
1988	10.4	28.7	53.7	41.7	70.4	161.8	374.8	295.3	217.7	53.6	16.2	17.8	1342.1
1989	15.4	15.3	28.8	34.6	57.5	184.7	302.3	236.2	163.1	51.9	20.3	17.2	1127.4
1990	16.0	44.2	54.0	43.8	112.9	191.3	282.9	293.6	197.4	104.1	30.2	31.0	1401.4
1991	14.3	28.1	27.8	51.7	68.9	184.7	279.2	268.1	140.7	61.8	30.2	14.7	1170.2
1992	16.0	16.5	24.8	26.1	59.3	139.7	262.5	274.0	171.7	64.7	41.6	5.6	1102.7
1993	18.2	25.6	41.6	27.0	71.3	172.1	305.4	203.2	208.5	87.9	30.5	16.5	1207.8
1994	25.0	27.9	25.2	45.9	53.1	205.7	350.0	282.2	149.4	82.8	25.5	22.6	1295.3
1995	31.3	29.4	28.3	32.4	82.4	143.3	323.4	269.0	179.0	78.0	36.8	9.2	1242.4
1996	22.9	23.2	32.1	31.4	56.0	185.7	262.1	292.4	146.1	100.5	13.6	16.9	1182.9
1997	14.3	10.4	30.3	46.0	48.6	171.7	281.5	261.9	151.4	61.1	57.6	48.3	1183.1
1998	16.4	28.2	39.1	36.3	49.2	163.9	278.4	243.8	196.5	107.4	39.3	10.3	1208.8
1999	13.7	11.2	8.8	19.3	94.9	169.9	261.7	213.2	183.0	117.2	20.0	3.7	1116.6
2000	18.4	28.2	17.9	34.7	71.6	179.0	263.5	221.1	134.5	41.9	14.6	10.0	1035.4
2001	6.5	9.6	19.2	43.2	61.1	215.6	278.7	205.2	111.5	100.5	19.0	6.3	1076.2
2002	17.2	20.9	23.1	38.0	58.4	169.9	143.5	244.8	136.6	56.4	15.6	5.5	930.1
2003	7.5	41.6	35.2	35.4	39.7	166.6	305.3	246.7	183.8	92.4	10.8	17.4	1182.3
2004	25.1	11.3	11.6	52.5	76.8	167.7	242.1	254.0	125.8	94.3	17.9	7.0	1086.2
2005	39.8	49.3	43.9	37.8	52.2	148.5	333.7	195.2	201.8	97.7	27.4	11.3	1238.7
2006	20.5	11.7	33.8	29.5	79.0	149.3	294.0	303.5	180.2	52.5	34.3	14.0	1202.4
2007	2.8	36.4	37.6	34.7	51.9	200.1	296.4	257.8	213.9	56.3	15.5	16.4	1219.8
2008	25.8	19.3	37.8	33.0	45.7	210.9	251.9	263.9	164.9	51.4	27.2	12.4	1144.1
2009	13.0	12.8	15.9	25.8	57.3	86.7	282.2	190.8	141.1	70.9	54.1	11.1	961.8
2010	7.7	18.2	17.9	43.8	76.9	138.7	296.3	271.2	194.4	67.2	56.4	23.3	1212.1
2011	6.8	25.8	22.4	41.1	53.1	183.5	246.0	284.9	186.9	38.1	20.1	7.6	1116.3
2012	26.5	12.7	11.3	47.5	31.7	117.8	250.2	262.4	193.5	58.7	30.7	11.7	1054.7
2013	11.3	40.1	15.7	30.3	57.8	219.8	310.1	254.9	152.6	129.3	14.0	6.7	1242.6
2014	19.3	27.4	36.1	22.1	72.9	95.2	261.1	237.4	187.9	60.1	14.4	10.7	1044.6
2015	16.0	16.5	24.8	26.1	59.3	139.7	262.5	274.0	171.7	64.7	41.6	5.6	1102.7
2016	18.2	25.6	41.6	27.0	71.3	172.1	305.4	203.2	208.5	87.9	30.5	16.5	1207.8
2017	25.0	27.9	25.2	45.9	53.1	205.7	350.0	282.2	149.4	82.8	25.5	22.6	1295.3
2018	31.3	29.4	28.3	32.4	82.4	143.3	323.4	269.0	179.0	78.0	36.8	9.2	1242.4
2019	22.9	23.2	32.1	31.4	56.0	185.7	262.1	292.4	146.1	100.5	13.6	16.9	1182.9
2020	14.3	10.4	30.3	46.0	48.6	171.7	281.5	261.9	151.4	61.1	57.6	48.3	1183.1
2021	16.4	28.2	39.1	36.3	49.2	163.9	278.4	243.8	196.5	107.4	39.3	10.3	1208.8
2022	13.7	11.2	8.8	19.3	94.9	169.9	261.7	213.2	183.0	117.2	20.0	3.7	1116.6
2023	18.4	28.2	17.9	34.7	71.6	179.0	263.5	221.1	134.5	41.9	14.6	10.0	1035.4
2024	6.5	9.6	19.2	43.2	61.1	215.6	278.7	205.2	111.5	100.5	19.0	6.3	1076.2
2025	31.3	29.4	28.3	32.4	82.4	143.3	323.4	269.0	179.0	78.0	36.8	9.2	1242.4

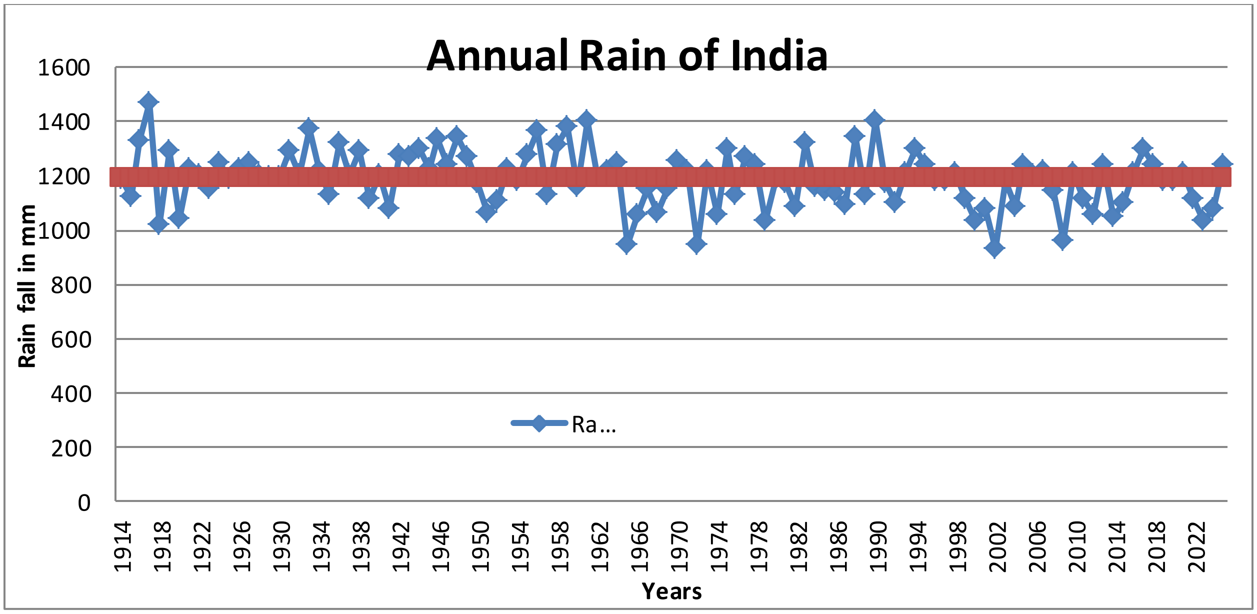

Figure 1: Annual rain fall of India

3. RESULTS AND DISCUSSION

India is due to increase in maximum temperatures. However, during the recent years, minimum temperatures showed some rapid warming suggesting an influence of increase in greenhouse gases. Global precipitation pattern are also changing spatially and temporally. In India also, uncertainties are more in the case of rainfall unlike that of temperature. Studies indicate reduction of annual rainfall over some parts of the Country while increase in some other parts. In this contest, it is relevant to look into the climate variability/change scenarios in different agro climatic zones (4,5 and 7) as it will throw light to take up impact of climate variability with reference to plantation crops, which is one of the objectives of the present study. The trends in rainfall scenarios over the zones have been examined zone-wise viz., 4, 5 and 7.

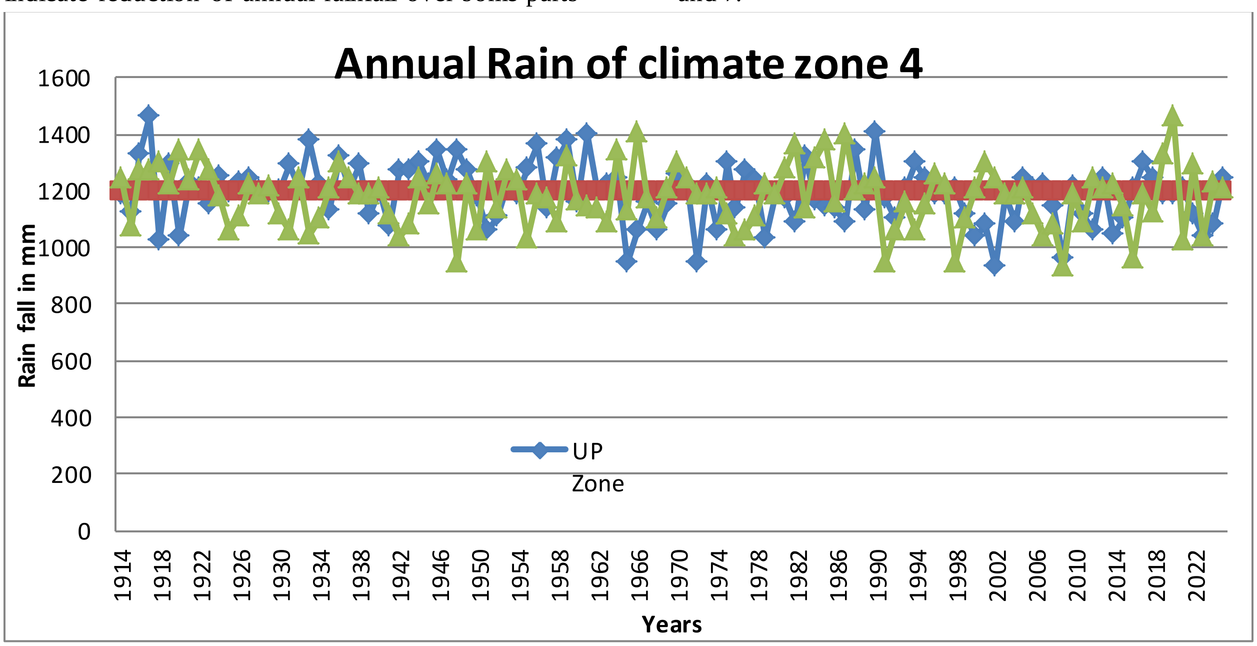

Figure 2: Rainfall trends of Middle Gangetic Plains Region

Decadal rainfall during winter showed a marginal increase at the rate of 0.63 mm per decade over the decades. It is not significant. The highest rainfall was (100.9 mm) was recorded during 1941-50 followed by 86.8 mm during 1911-20. The lowest (41.1 mm) was recorded during the decade 1881-1990. Tri-decadal rainfall also showed an increasing trend (@ 1.53 mm/30 year). In the case of summer rainfall also, the decadal trends indicated an increasing trend at the rate of 3.5 mm/ decade, which is not significant while the tri-decadal increase was 5.3 mm/30 year. The highest rainfall was received during the decade 1951-60 (532 mm) followed by 1931-40 (479.8 mm) while the lowest was 1991-2000 (311.6 mm). The highest rainfall received during the tri-decade 1931-60 (479.3 mm) and the lowest in 1901-30 (360.1mm)

Decadal rainfall during winter showed a marginal increase at the rate of 0.63 mm per decade over the decades. The highest rainfall was (100.9 mm) was recorded during 1941-50 followed by 86.8 mm during 1914-24. The lowest (41.1 mm) was recorded during the decade 1981-1990. The increase is at the rate of 7.6 mm/decade and it is statistically significant at 10% level. The highest rainfall was received during the decade 2001-10 (545.7 mm) followed by 1911-20 (542.5 mm). The lowest was recorded during 1971-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November. The increase is at the rate of 7.6 mm/decade and it is statistically significant at 10% level. The highest rainfall was received during the decade 2001-08 (545.7 mm) followed by 1914-24 (542.5 mm). The lowest was recorded during 1971-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November.

Trends in Rainfall across Upper Gangetic Plains Region

This is among the larger and very thickly populated agro-climatic zones. It covers 32 districts of Uttar Pradesh. A large part of the geographical area is cultivated and is well irrigated. This is the most developed region of the State of Uttar Pradesh. Over 70% of the area is sown and nearly 65% of this is irrigated. The ratio of surface to ground irrigation is about 1 : 2. Agricultural labour and land productivity is high. The zone is characterized by semi-arid and sub-humid conditions. The mean Annual rainfall varies between 700 and 1,000 mm. There are three sub-zones.

The climate of the region is characterized by hot summer and cool winter. Annual rainfall ranges between 700–1,200 mm, 70% of which is received during the months of June to September. The rainfall covers about 70% of the annual PET demand of 1,400 to 1,800 mm and leaves an annual water deficit of 500 to 700 mm during February and June. The growing period ranges from 150–180 days in a year. It experiences dry period from February to June with mean annual temperature of more than 22°C. The areas adjacent to foothills are relatively cooler and experiences thermic soil temperature regime.

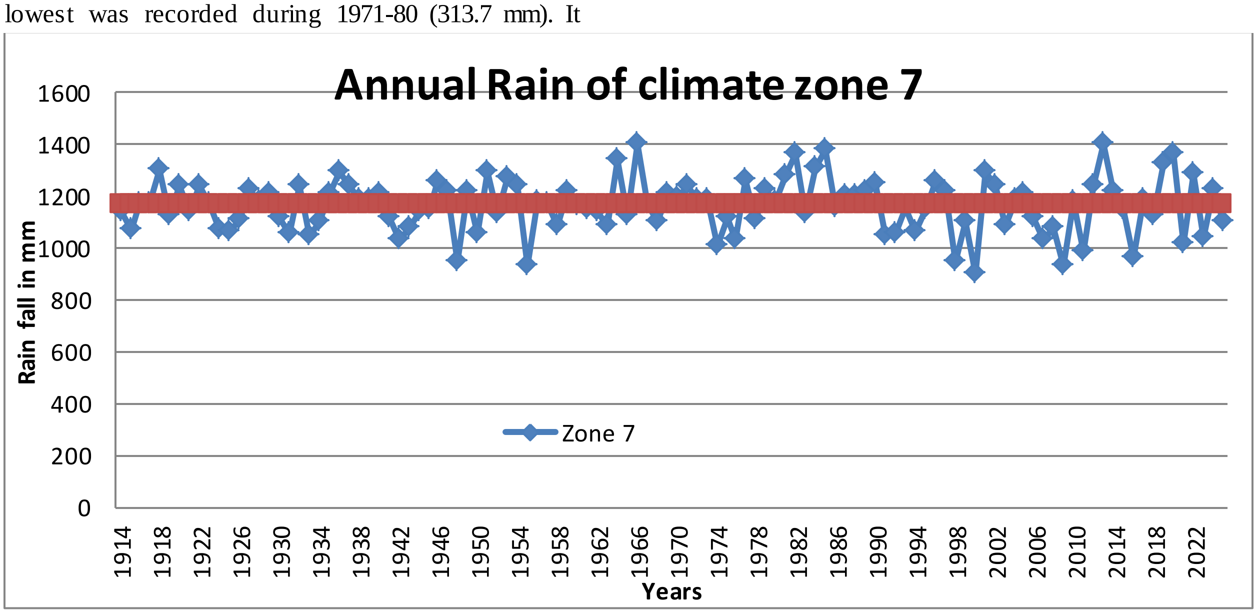

Figure 3: Rainfall trends of Upper Gangetic Plains Region

The highest rainfall was received during the decade 2001-10 (545.7 mm) followed by 1911-20 (542.5 mm). The lowest was recorded during 1971-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November. The increase is at the rate of 7.6 mm/decade and it is statistically significant at 10% level. The highest rainfall was received during the decade 2001-08 (545.7 mm) followed by 1911-20 (542.5 mm). The lowest was recorded during 1971-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November. The increase is at the rate of 7.6 mm/decade and it is statistically significant at 10% level. The highest rainfall was received during the decade 2001-08 (545.7 mm) followed by 1911-20 (542.5 mm). The lowest was recorded during 1871-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November. The increase is at the rate of 7.6 mm/decade and it is statistically significant at 10% level. The highest rainfall was received during the decade 2001-08 (545.7 mm) followed by 1911-20 (542.5 mm). The lowest was recorded during 1871-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November.

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Trends in Rainfall across Eastern Plateau and Hills region

This is the largest agro-climatic zone covering about 400 thousand square kilometres of geographical area. It spans across parts of Maharashtra, Madhya Pradesh, Orissa and West Bengal and is divided into five subzones. The population is largely rural with a concentration of tribals in the Chhattisgarh area in Orissa. The average annual rainfall is about 1,350 mm. Shifting cultivation has been the traditional pattern of farming and the mode of land use among tribals in this zone. Some controls on this practice have been effective in Jharkhand and Madhya Pradesh.

Agricultural productivity is quite low. Over a quarter of the region is covered by forests. In parts of Madhya Pradesh and Maharashtra falling under this zone, nearly half of the geographical area is covered by forests. A gradual decline is noticed in the area covered with forests.

The decadal rainfall was low (2555.7 mm) in 1981-90, which was the warmest decade in Eastern Plateau and Hills region region (Fig. 4.3) It revealed that there was an increase in decadal rainfall till 1950s and thereafter there was a significant decrease in rainfall in recent decades. It was more so in the decade 1981-90. In the case of monsoon rainfall too, it was declining marginally by 2.98 mm/decade. It was high (541.9 mm) in the decade 1921-30, followed by 1901-1920 (521.8 mm) and 1941-50 (503.8 mm). The ever highest flood of 1924 was in the decade 1921-30 (Fig. 4.3). It may be interesting to note that that the lowest average decadal rainfall was observed the decade 2001-10. The vagaries of southwest monsoon in recent years could be attributed to the declining rainfall. It may also be noted that only one year (2009) fell under the category of excess rainfall during the decade 2001-10. It also revealed that decadal rainfall during June and July is declining at the rate of 28.6mm/decade and 13.6mm / decade, respectively. At the same time, decadal rainfall during August and September is in increasing trend - 2.3 mm/decade during August and 7.5 mm/decade in September. Decadal post monsoon rainfall over Middle Gangetic Plains Region showed that the rainfall is increasing over a period of time unlike annual and SWM rainfall.

Decadal rainfall during winter showed a marginal increase at the rate of 0.63 mm per decade over the decades. The highest rainfall was (100.9 mm) was recorded during 1941-50 followed by 86.8 mm during 1914-24. The lowest (41.1 mm) was recorded during the decade 1981-1990. The increase is at the rate of 7.6 mm/decade and it is statistically significant at 10% level. The highest rainfall was received during the decade 2001-10 (545.7 mm) followed by 1911-20 (542.5 mm). The lowest was recorded during 1971-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November. The increase is at the rate of 7.6 mm/decade and it is statistically significant at 10% level. The highest rainfall was received during the decade 2001-08 (545.7 mm) followed by 1914-24 (542.5 mm). The lowest was recorded during 1971-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November.

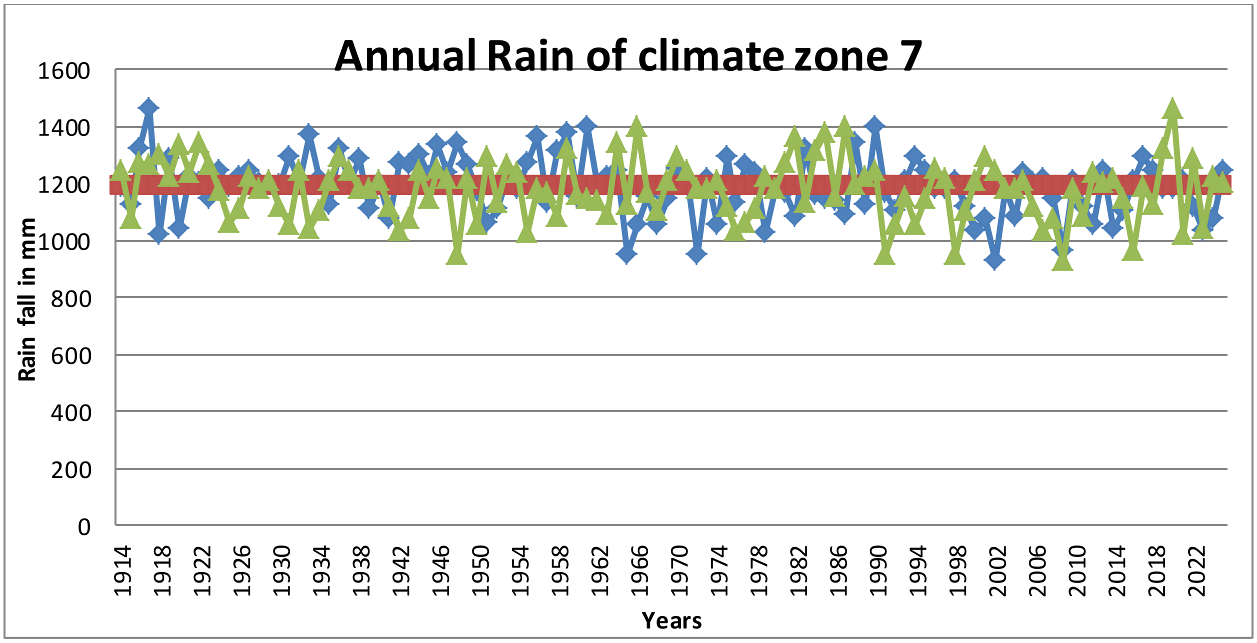

Figure 4: Rainfall trends of Eastern plateau Region

4. CONCLUSION

Studies indicate reduction of annual rainfall over some parts of the Country while increase in some other parts. In this contest, it is relevant to look into the climate variability/change scenarios in different agro climatic zones (4,5 and 7) as it will throw light to take up impact of climate variability with reference to plantation crops, which is one of the objectives of the present study. The trends in rainfall scenarios over the zones have been examined zone-wise viz., 4, 5 and 7. Over the last five decades of the 20th century, the major and minor rainy seasons have undergone varying degrees of drying. This reduction in rainfall is not uniform, either temporally through the rainy seasons or spatially across the study area. Most locations had significant reductions in rainfall during the minor rainy season and at the beginning of major rainy season, and often an increase in rain during the short dry spell. The universal decline of mean rainfalls totals and number of rainy days during the minor rainy season, often associated with greater inter-annual variability, is particularly threatening to the production of a second crop during this time of the year. Meanwhile, increases in means of both variables and reduction in their standard deviations during the short dry spell, only exacerbates these problems.

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