Impact of Climate Change on Rainfall Pattern in Upper Kumaon Himalaya Region

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Abstract

Every single aspect of environment is affected by climate change. Change in rainfall pattern is an immense important research area in climate-change based study. Rainfall pattern has direct impacts on food production and frequencies natural disasters (landslide, cloudburst, flood, drought etc.). Consequently, that appropriate and systemic consideration since it distresses the most of the human life. Situation in Himalayan region is worst. High altitude, less agricultural area, harsh climate with high fragility makes mountain region more vulnerable in term of climate change. The objective of this study is to identify yearly, seasonal, and monthly rainfall trends in the Upper Kumaon region (UKR). Long-term gridded daily rainfall data (1950–2018) were used. Rainfall data was processed and analyzed for a period of 68 years (1950–2018) at four places (four in each Kumaon division) in the surrounding area of Almora, Bageshwar, Pithoragarh, and Champawat. The regression analysis (parametric) method and variability analysis were used to examine historical trends in daily rainfall. The rising and falling trends in rainfall, as well as anomalies, have been studied using regression. The result shows that rainfall demonstrate statistically significant changes occurred in last 34 years. Rainfall variability is higher in low altitude region than high altitude region of Upper Kumaon region.

Introduction

Climate change has become a hot and global subject of research (Preenu et al. 2017). Climate change, its influences and exposures to mankind, are increasing anxiety worldwide. A soothing and adjustable environment is accountable for life on earth. Minor change in climatic pattern and distribution can create hazardous events for wealth and life. Climate change is truth and it is a biggest crisis of present era (Singh and Gurjar 2011). This climate change crisis is originated from emission of high amount of greenhouses gases by mainly anthropogenic activities and some natural activities (Revadekar et al. 2012). Natural and human activities, entitled “forces” in the climate-based study modify the movement of energy in the atmosphere, cooling and warming Earth by disturbing its heat steadiness. In some area, climate change is forcing warm the earth, while in some area cool it. Greenhouse gases are the primary cause of climate change. As a result of their high efficiency at trapping heat in the atmosphere, the greenhouse effect occurs (Stocker et al. 2013). Climate change is responsible for change in global and local environment. All environmental activities system is being perturbed by climate change. Due to disturbance natural phenomena of an area, anthropogenic activities also get affected. And change in major climatic variable like rainfall, solar radiation and water availability. It is a great deal to the researcher community to understand the climatic change situation and help the mankind to decrease the adverse impact on environment. The varying pattern of rainfall need insistent and appropriate interest, as it will affect whole environmental and human life circle in any geographical region (Dore 2005). Precipitation is main dynamic force of land surface and any type of variability or change in its pattern and seasonality could have direct fluctuation on water resource. Variability in rainfall distribution and amount would stimulate change in spatial-temporal distribution of soil moisture, runoff, and groundwater and could change the frequencies of flood and drought. When, we debate over climate change, the mountain regions stand on the forefront. Mountains occupy around 25 per cent of the land surface of the earth. About 26 percent of the world’s population (about 1.5 billion) lives in montane ecology (Kapos et al. 2000; Meybeck et al. 2001). These are important source of fresh water as they named as water tower. Mountains provide most critical resources water and diverse ecosystem services. Life and livelihood of more than forty per cent population directly and indirectly lie on the mountain resources.

Mountains are one of the most vulnerable climate change ecosystems and are more rapidly affected than other planetary habitats (Beniston 2006). Climate change poses a significant threat to mountain ecosystem services and the populations that rely on them, as well as having significant implications for water resources. Many glaciers are receding as a result of escalating temperatures, making them important climate change indicators. Himalayan region is so fragile. The factors that make these hilly regions most vulnerable are its fast-growing population, depletion of resources, unplanned road construction activities, deforestation, high dependency of population on climate-sensitive sectors like agriculture and forestry, lack of agricultural land (Macchi 2010), livelihood insecurity, high malnutrition population and unskilled population. Change in rainfall pattern, variability and seasonal distribution; create unfavourably modifications in water availability (surface and ground water) (Sharma et al. 2013; Singh and Kumar 2014) frequencies of disaster, cropping pattern, agricultural productivity, vegetation cover (Singh and Mal 2012) and hydropower (Field et al. 2014). Now studies show that Himalayas facing frequently climate change and its induced disaster. Drought, cloudburst, rainfall extremes, landslides etc. are common disaster in mountain region.

This study has been assessed the trends of precipitation in the Upper Kumaon region, India. The Upper Kumaon region is situated in the West Himalayan and it has been selected for the study. This mountain region is highly vulnerable in term of slope, terrain, inaccessibility and scattered settlement and it is important provider of ecological service like water, energy, food, medicine, livelihood etc. except these ecological services, Upper Kumaon region is strategically important for the India. In this region, more than 75 per cent population depends on agriculture and forestry for their livelihood, is likely to be severely affected by climate change. Most of the agriculture activities solely depend on rainfall here. Minor changes in rainfall can devastate life and wealth of the people. Hence, it is very vital to understand the influence of climate change on rainfall pattern and seasonality in Himalayan region for proper forecasting and management of agricultural production and livelihood of the local population. The foremost aim of the study was to analyze the trend of rainfall in the area over the past 68 years. Linear regression method and has been used to analysis trend and moving average have been used.

Materials And Methods

2.1 Data Sources

Mostly IITM Pune data of the observatories, suffer from large data gaps. Therefore, rainfall records of study area (Pithoragarh) were downloaded from Climate Research Unit (CRU) TS2.1 dataset, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia in Norwich (U.K.) from website of India Water Portal (India Water Portal, 2017). It provides district-level observations of rainfall and other variables. Other than this, data series from Global Weather Data for SWAT (U.S.A) (Global Weather Data for SWAT, 2020) and India Meteorological Department (India Meteorological Department, 2019) have been used to analysis rainfall variability in the region.

2.2 Methodology

2.2.1 Trend Analysis

The trend analysis has been done yearly, seasonal and Monthly. It is done by linear regression analysis. Linear trend line of yearly rainfall, monthly rainfall and seasonal rainfall has been computed by the slope value from the linear regression analysis performed (Dash and Hunt 2007; Kothawale and Rupa 2005). A detailed representation of the outcomes was shown using trend line on each graph (Siraj et al. 2013; Addisu et al. 2015) (Rainfall is considered as the dependent variable and the time period is considered as an independent variable such as: Rainfall = t (time), $Y = (\alpha + \beta X + \mu)$. For Y = rainfall, X = periods of time and μ = mistake [21]. For Y = rainfall, X = time period and μ = error (Singh et al. 2013). Furthermore, a non-linear trend had also been established using 6-point moving average filter yearly. Further, the data sets were divided into two halves and trends for the first and second half were also computed accordingly. The flow of trend has been depicted by graphs and tables individually respectively. The confidence level had also been evaluated at 95 per cent. Generally, a 90 per cent confidence level is considered as a standard one. For the low number of data set achieving a higher confidence level is unusual likewise in the study carried out for seasonal data sets have 4 data sets. Thereafter, the 95 per cent confidence level has been computed as it seems to be more feasible throughout the study.

2.2.2 Seasonality Analysis

Seasonality of rainfall had been computed using the ratio-to-moving average method. Implementing the following process had been applied to compute the seasonality (Dash and Hunt 2007). Firstly, the moving average had been calculated. Since the moving average was calculated for the even set of numbers thereafter the centred moving average had been computed and the ratio of the original data set throughout the season had been calculated for the years. Comparatively maximum and minimum values of monthly rainfall were causing the irregularity. Hence, all monthly data values of the entire period had been averaged using the median. Finally, the seasonal indices were computed by multiplying the monthly average ratio to each month.

2.2.3 Variability Analysis

The seasonal and monthly variability has been evaluated using the coefficient of the variance process (Guhathakurta et al. 2020). This denotes the nature of data sets of rainfall and temperature during the period. Further the data sets were divided into two halves and variability for the first and second half was also computed accordingly.

The co-efficient computed for variability is calculated as follows:

$$\text{Coefficient of variation (CV)} = \frac{\text{Standard Deviation (SD)}}{\text{Mean}} * 100$$

3. Study Area

The Upper Kumaon region includes four districts and names are Pithoragarh, Champawat, Almora and Bageshwar. This study area is located between $29^{\circ} 33' - 30^{\circ} 00'$ North latitudes and $79^{\circ} 65' - 80^{\circ} 33'$ East longitudes. Total geographical area is 14,241 sq. km with population of 16,25,491 (Directorate of economics and Statistics, 2016).

Trans-Himalaya is the northern boundary of the region and is also the international border with China (Tibet) and Nepal by most eastern side (Fig. 1). In south side of study area is bound by Nainital district. This area spreads from foothill up to snow cover peaks of Himalayas, constructing the Indo-Tibetan boundary. This region mostly lies in a long arc area of Himalaya, and creates an intermediate zone between dry to sub-humid west Himalaya and per-humid east Himalaya. The average population density is highest in Almora (205 per sq. km) and lowest in Pithoragarh (69 per sq. km). More than 80 per cent people are literate in this region and a primarily an agrarian economy with more than 75 percent of the population depending on agriculture and forestry (Pande et al. 2016).

Results

Distribution of rainfall in upper Kumaon region is so different. The annual mean rainfall among districts of Upper Kumaon region receives from 1950–2018 is highest in Pithoragarh District (1511.97 mm/year) and lower rainfall in Almora (1072.07 mm/year), whereas the average annual rainfall in the Champawat district is 1230.70 mm/year and in the Bageshwar district is 1136.41 mm/year. The average monthly rainfall over the years of 1950–2018 varies from as low as 89.34 mm/month in Almora to as high as 126.00 mm/month in Pithoragarh. The rainfall exhibits the seasonal trends over the years in the region in the rainy season (mostly from June to September) most of the rainfall happened. During the rainy season Champawat district exhibits the maximum rainfall of 281.34 mm/month although Almora has the minimum rainfall 241.42 mm/month during this season. Whereas in the winter season the Pithoragarh district receives the maximum rainfall and the Champawat district has minimum rainfall. Analysing the monthly average the Champawat district has both the extreme of a maximum of 356.91 mm/month and a minimum of 3.84 mm/month rainfall.

4.1 Trend Analysis of Annual, Monthly and Seasonal Rainfall

Trend analysis of 69 years rainfall of Upper Kumaon region reflects variations in rainfall pattern. The trend of linear regression analysis is decreasing with a highest rate of 3.88 mm/year in Bageshwar followed by Almora (3.33 mm/year) and Pithoragarh (2.06 mm/year) whereas Champawat has increasing trend rate of 0.149 mm/year due to the heavy rainfall in recent past and the R^2 value is 0.00006, this shows 0.006 per cent of lowest change in rainfall occurred over

the change of 69 years. Highest percentage of change has been noticed in Bageshwar (6.85 per cent) followed by Almora with 4.58 per cent and Pithoragarh (1.55 per cent) occurred over the change of 69 years. The moving average is also computed which also indicates the rapidly decreasing trend among all the four districts (Fig. 2).

On the basis of trends of seasonal rainfall of Upper Kumaon region, in Almora district, the trend analysis of seasonal rainfall demonstrates (Table 1) that monsoon season i.e. June to August had the most decreasing trend of -3.28 mm/year. But from the observations of the trend analysis of the two-half (1950–1984 and 1985–2018), it has been observed that there is a huge decrease occurred in the monsoon season in last 34 years (1985–2018) with the rate of -2.37 mm/year. One study found that number of rainy days decreased in Almora district during 1992–2003 time spans. Even the seasonal deviation is the highest in monsoon season with the deviation value of 476.42 mm (Joshi et al. 2016). In the district of Champawat, the seasonal analysis reveals that monsoon season i.e. June to August had the most decreasing trend of 0.78 mm/year. But from the observation of the trends of the two-half, it has been observed that there is a huge upsurge happened in the monsoon season in last 34 years (1985–2018) with the rate of 8.16 mm/year. Even the deviation of seasonal rainfall is highest in monsoon season with the deviation value of 343 mm. This increase is due to the heavy rain during monsoon season in the recent past. In the district of Bageshwar, the seasonal analysis shows that monsoon season i.e. June to August had the most decreasing trend of 2.27 mm/year. But from the observation of the trends of the two-half, it has been observed that there is an increase occurred in the monsoon season in last 34 years (1985–2018) with the rate of 2.63 mm/year. The seasonal deviation is the highest in the monsoon season with a deviation of 232.41 mm from 1950 to 2018. In the district of Pithoragarh, the seasonal analysis shows that post-monsoon season i.e. September to November had the most decreasing trend of 1.41 mm/year (Table 1). But from the observation of the trend analysis of the two-half, it has been observed that there is an increase occurred in the monsoon season in last 34 years (1985–2018) with the rate of 5.96 mm/year. The seasonal deviation is the highest in the monsoon.

season with a deviation of 247.28 mm from 1950 to 2018. According to trend of monthly trends the district of Almora, month of August had the decreasing monthly rainfall trend of 2.49 mm/year. And total change from 1950 to 2018 is highest in July (256.11 mm). Moreover, the deviation is highest in July (133 mm). Although month of May exhibits a maximum increasing trend of 0.825 mm/year likewise the total change and the deviation had also exhibit slightly increase, but this increasing nature is very small. In the district of Champawat, month of October had the maximum decreasing monthly trend (0.427 mm) but total change during 1950 to 2018 is high in month of August (234.86 mm). Moreover, the deviation is highest in August (155.44 mm) (Table 2). Although April and May demonstrate a slightly increasing trend likewise the total change and the deviation had also exhibit slightly increase. In the district of Bageshwar, it has been observed that month of August had the decreasing trend of monthly rainfall (1.45 mm/month). And total change from 1950 to 2018 is highest in August (256 mm). Moreover, the deviation is highest in month of July (142.2 mm). Although April and May exhibit a slightly increasing trend likewise the total change and the deviation had also exhibit slightly increase. For the Pithoragarh district, month of October had the decreasing monthly trend of 0.94 mm/month. And the total change from 1950 to 2018 is highest in July (242.72 mm). Moreover, the deviation is highest in month of July (133.19 mm). Although April and May exhibit a slightly increasing trend, likewise the total change and the deviation had also exhibit slightly increase (Table 2).

4.2 Rainfall Variability Analysis of Upper Kumaon Region

The seasonal rainfall analysis reveals in-depth district-wise variability aspect of the rainfall in the Upper Kumaon region. The district-wise analysis of variability in the three consecutive periods (1950–1984, 1985–2018 and 1950–2018) elaborates more insights into the seasonal variability of rainfall over the years. It clearly demonstrated that monsoon season i.e. June to August has least variability throughout. Although in the last 34 years (1985–2018) the variability is highest of in the monsoon season (65.51 per cent). Similarly, the post-monsoon season (i.e. September to November) exhibits the most variability in all three periods. Moreover, the variability is influenced by the variation occurred in the last 35 years (1950–1984). Variability of seasonal Rainfall is comparatively higher in second half (1985–2018) duration than first duration (1950–1984) in all the districts (Table 3). It reflects that rainfall variability has been increased in recent past in Upper Kumaon region which further influences the human life.

As per variability analysis of monthly rainfall it has been found that all the districts are representing that higher variability in month of November and December and lowest variability has been observed in month of July and August. Variability of monthly Rainfall is comparatively higher in second half (1985–2018) duration than duration first duration (1950–1984) in all the districts (Table 4 and Fig. 3). It reflects that rainfall variability has been increased in recent past in Upper Kumaon region which further influence human life. Champawat district is facing highest monthly rainfall variability than other districts. Pithoragarh has least Rainfall variability. It means low altitude district (Champawat) is more prone to rainfall variability than high altitude district (Pithoragarh) in Upper Kumaon region (Table 4 and Fig. 3).

Conclusion

The seasonality, trends and variability analysis conclude the effect of climate change in the Upper Kumaon region. Most of the parts in the world experience an abrupt change in the seasonal phenomenon due to climate change over the years. Upper Kumaon region also faces similar circumstances with the variations in the rainfall and temperature yearly, seasonally and monthly. The mean monthly rainfall seems to be higher during the month of July and August and least during November-December. Although there has been a significant decreasing trend in total yearly rainfall over the

Years with the changing rate of about 2.5 mm/year in the region. The seasonal trend of rainfall also appears to be decreasing in the region the monsoon season had the highest decreasing rate of almost 1.8 mm/year and lowest decreasing rate of nearly 0.6 mm/year during the winter season. The monthly trends of rainfall were decreasing rapidly at the highest rate of almost 1.2 mm/year in August. It has been observed that in the recent past the fluctuation in the rainfall was very extreme, cause the water scarcity or flood conditions (Negi and Joshi 2004). Although the highest seasonal variability in rainfall computed in the region is nearly 73 per cent during the post-monsoon season and the lowest seasonal variability in rainfall computed in the region is nearly 36 per cent during the monsoon season. The highest monthly variability in rainfall computed in the region is nearly 169 per cent mm/year in month of November and the lowest variability in rainfall computed in the region is nearly 42 per cent in month of August. The findings of this study are an incentive to study the impact

effect of climate change in the region's local climate. In addition, the rainfall regime of the Kumaon region with more rainfall station data and the potential implications of climate change must be fully understood for water planning and management for future.

Declarations

Author's Contribution : Conceptualization - AS, RBS, SA, AM ; Writing-original draft preparation – AS, RBS, SA; Writing review and editing – AS, AM, SSD; Methodology and investigation - AS, RBS, SA; Formal analysis- AS, SA,AM ; Supervision- RBS, SA ; Data Curation - AS, RBS, SA,AM; Validation and Visualization- SA, AM, SSD.

AS (Aarti Singh); RBS (R.B. Singh); SA (S. Anand); AM (A. Mohanty); SSD (S. S. Dash)

Availability of data and material: All the data used for this study are available and provided by the public entities (India Water Portal, Global Weather Data for SWAT, and India Meteorological Department).

Code availability: Not applicable

Ethics approval: Comply with all Ethical norms

Consent to participate: Taken consent to Participate

Consent for publication: All Co-Authors given Consent for Publication

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Conflicts of Interest: There is no conflict of interest as per the authors

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Tables

Table 1
District-wise Trends of Seasonal Rainfall in Upper Kumaon Region, (1950–2018)

District	Seasons-wise Rate of Change (in mm/year)				
	Duration	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Almora	(1950–1984)	-0.10	1.08	-0.01	-2.01
	(1985–2018)	0.09	3	-2.37*	-0.67
	(1950–2018)	0.16	1.14	-3.28*	-0.94
Champawat	(1950–1984)	0.09	0.98	-1.12*	-0.67
	(1985–2018)	0.50	1.59	8.16*	2.23
	(1950–2018)	0.39	0.94	-0.78	-0.39
Bageshwar	(1950–1984)	-0.280	1.501	0.718	-0.432
	(1985–2018)	-0.342	0.809	2.6325*	-1.611
	(1950–2018)	-0.034	0.504	-2.2738*	-2.082
Pithoragarh	(1950–1984)	-0.379	1.802	1.69	-0.454
	(1984–2018)	-1.025	1.23	5.966*	0.231
	(1950–2018)	-0.273	0.564	-0.938	-1.411*
Source:Calculated by the Researcher based on data from CRU-TS2.1; Global Weather Data for SWAT and IMD					

Table 2
Trend Analysis of Mean of Monthly Rainfall in Upper Kumaon Region, (1950–2018)

Month	Champawat		Almora		Bageshwar		Pithoragarh	
	Rate of Change (mm/Year)	Total Change (in mm)	Rate of Change (mm/Year)	Total Change (in mm)	Rate of Change (mm/Year)	Total Change (in mm)	Rate of Change (mm/Year)	Total Change (in mm)
January	0.091	-15.139	-0.009	-24.878	-0.305	-39.836	-0.2977	-44.95
February	0.281	-13.571	0.179	-4.768	0.242	-18.496	0.1021	-16.85
March	0.326	-20.585	0.103	-26.797	0.158	-28.737	0.1021	-18.09
April	0.269	43.435	0.213	76.079	0.135	93.037	0.183	85.33
May	0.282	4.299	0.825	22.699	0.213	15.602	0.2791	43.21
June	-0.383	-171.218	0.225	-189.855	-0.478	-152.333	-0.4958	-72.69
July	-0.072	-30.8	1.007	-256.114*	-0.337	198.582	0.0239	242.72*
August	-0.328	234.860*	-2.498*	-83.085	-1.458	255.976*	-0.4662	216.4
September	-0.001	193.605	-0.616	-76.952	-1.103	45.027	-0.4119	70.6
October	-0.427*	0.676	-0.716	-0.85	-0.903	-2.179	-0.9361*	-0.93
November	0.035	9.993	-0.022	11.337	-0.077	8.296	-0.0625	17.41
December	0.017	-1.623	-0.01	-1.681	0.028	-2.605	-0.0774	2.42
Source: Calculated by the Researcher based on data from CRU-TS2.1; Global Weather Data for SWAT and IMD								

Table 3
District-wise Seasonal Rainfall Variability Analysis of Upper Kumaon Region (in per cent)

Districts	Duration	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Almora	1950–1984	46.66	50.43	21.51	96.90
	1985–2018	79.92	100.96	65.51	118.25
	1950–2018	67.18	90.27	46.64	111.96
Champawat	1950–1984	44.15	50.47	21.11	53.54
	1985–2018	71.2	60.24	42.54	80.90
	1950–2018	63	60.22	32.61	66.76
Bageshwar	1950–1984	47.05	49.45	20.4	54.40
	1985–2018	63.02	54.54	39.86	58.19
	1950–2018	55.3	52.14	30.98	60.10
Pithoragarh	1950–1984	46.31	48.81	19.92	51.12
	1985–2018	48.42	56.5	44.93	53.31
	1950–2018	47.05	52.7	33.52	54.10
Source: Calculated by the Researcher based on data from CRU-TS2.1; Global Weather Data for SWAT and IMD					

Table 4
District-wise Monthly Rainfall Variability Analysis of Upper Kumaon Region (in per cent), 1950–2018

District	Duration	January	February	March	April	May	June	July	August	September	October	November	Decem
Almora	1950–1984	67.43	87.66	73.46	86.32	78.01	44.91	35.65	35.27	63.54	111.31	145.14	135.08
	1985–2018	111.8	115.54	104.03	89.73	161.69	82.81	51.83	47.85	70.51	145.68	139.73	142.5
	1950–2018	90.13	106.99	88.95	89.47	153.73	65.65	43.64	43.08	66.86	130.21	144.26	134.84
Champawat	1950–1984	63.57	84.56	75	84	77.55	43.67	34.73	33.25	59.81	112.01	148.39	120.38
	1985–2018	91.98	103.51	149.16	80.05	72.48	66.88	50.71	57.42	70.7	246.88	240.4	152.24
	1950–2018	78.95	100.81	129.66	85.31	76.67	54.82	42.65	45.75	64.68	171.69	214.33	143.91
Bageshwar	1950–1984	66.97	85.31	71.86	83.58	77.87	48.73	32.77	33.97	63.7	107.58	148.1	118.73
	1985–2018	82.68	94.12	104.42	86.76	87.78	64.34	56.49	48.66	63.73	162.38	178.25	150.21
	1950–2018	74.91	91.46	89.8	84.6	83.6	56.26	44.86	41.62	66.14	132.27	160.76	141.67
Pithoragarh	1950–1984	64.75	80.61	73.9	80.28	76.1	53.27	30.06	31.42	59.96	102.76	145.18	115.13
	1985–2018	80.87	67.79	90.09	81.75	80.84	64.59	55.15	47.5	57.5	118.8	173.96	129.58
	1950–2018	72.48	73.69	81.4	80.42	78.97	59	43.31	39.44	59.44	118.66	157.07	123.44

Source: Calculated by the Researcher based on data from CRU-TS2.1; Global Weather Data for SWAT and IMD

Figures

Figure 1

The Study Area

Figure 2

Trends of Annual Rainfall in Upper Kumaon Region (1950-2018) A- Pithoragarh, B- Bageshwar, C- Champaran, D- Almora. Source: Calculated from Data from CRU-TS2.1; Global Weather Data for SWAT and IMD

(a)

(b)

(c)

Figure 3

(a) District wise Variability of Monthly Rainfall from 1950 to 1984 (b) District wise Variability of Monthly Rainfall from 1985 to 2018 (c) District wise Variability of Monthly Rainfall from 1950 to 2018 District wise Variability Analysis of Monthly Rainfall of Upper Kumaon Region *Source: Calculated from Data from CRU-TS2.1; Global Weather Data for SWAT and IMD, Pune