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Fluctuations in Monthly and Annual Rainfall Trend in the Limbang River Basin, Malaysia: A Statistical Assessment to Detect the Influence of Climate Change

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Abstract: Fluctuations in monthly and annual rainfall trends in the Limbang River Basin, Malaysia were characterized through Cramer's (t_k) test and linear regression (LR) methods. Rainfall measurements from four rain gauging stations having 35 years (1981-2015) of data were grouped in to 10 years non-overlapping and 15 years overlapping monthly and annual rainfall totals for the analysis. Analysis of monthly rainfall in the initial sub-periods of 10 years non-overlapping (1986-1995) indicate significantly decreasing trends in all rain gauging stations during the months January, October, December and 15 years overlapping (1981-1995 and 1986-2000) in the months of January, March, April, October, November and December. Annual rainfall trend in these sub-periods also confirms the same and suggesting dry condition in the region. During the sub-periods (1996-2005 and 1996-2010), the monthly and annual rainfall trends started showing significant increasing trends indicating wet condition in LRB. This period can be considered as a transition period in general rainfall pattern in LRB because the 10 years moving average rainfall also peaked above the long-term average rainfall in all stations. Significant increasing trend in monthly rainfall in 10 years non-overlapping (2006-2015) periods is associated with January, March, November and December whereas in 15 years overlapping period (2001-2015) indicate a significant increase during the months of January, March, April, November and December. Increasing rainfall trend in monthly and annual total revealed by linear regression analysis shows an overall increase of >1000 mm annual rainfall in all rain gauging stations with approximately at the rate 1% per year. However, fluctuation in annual rainfall indicate the influence of regional climatic phenomena on rainfall characteristics of LRB.

Keywords: Cramer's test; Linear regression; Rainfall trend; Climate change; Limbang.

Introduction

Impact of climate change in a region can be best identified by studying the changes occurred in hydrological regime (frequent floods and droughts) and variation in agricultural productivity. The effects of these will vary widely from local to regional scale based on the severity of climatic phenomena occurred in the region (Walther et al., 2002; Patz et al., 2005). The characteristics of climatic variables such as temperature, rainfall and its effect reflected as droughts (agricultural and meteorological) can be identified by the application of well-defined statistical techniques (Middelkoop et al., 2001; Alexander et al., 2006; Immerzeel et al., 2010; Knutsonet al., 2010; Almazroui et al., 2012; Trenberth et al., 2014; Kelley et al., 2015; Onyutha et al., 2016; Brown et al., 2017). However, in order to detect the changes in rainfall, temperature and evapo-transpiration

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caused due to regional climate change, continuous and accurate measurements of these variables are required.

Numerous attempts were reported from different parts of the world to detect the effect of climate change on agriculture and meteorological characteristics especially on precipitation and temperature (Hulme et al., 2001; Hughes, 2003; Longobardi and Villani, 2010; Djaman et al., 2017; Nolan et al., 2017; Thakural et al., 2018). Climate change is a global phenomenon, but its effect varies regionally. Considering the different climatic regions of the world, tropical regions are more susceptible to such changes due to its geographical locations, ecological heterogeneity and environmental richness (Camera et al., 2017). Effects of climate change in tropical regions are well documented and the results indicate long-term as well as short-term changes in biodiversity, rainfall characteristics, stream flow and agricultural productivity (Liu et al., 2009; Sa'adi et al., 2017a, b).

Among the tropical regions, the impact of climate change is more severe in Southeast Asia as a whole and countries situated in the equatorial tropics are more vulnerable to weather related hazards (Yusuf and Francisco, 2009). Studies conducted by different group of researchers on climatic conditions of Southeast Asia suggests high influence of large scale weather phenomena such as El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Madden-Julian oscillation (MJO) on climate of the region, which lead to torrential rainfall, flash floods, and severe storms (Aldrian and Djamil, 2008; Moron et al., 2010; Tangang et al., 2008; Hidayat and Kizu, 2010; Salahuddin and Curtis, 2011; Robertson et al., 2011. Effect of these weather phenomena have high influence on the long-term rainfall (annual) characteristics and monsoonal characteristics of Sarawak state of Malaysia (situated in Northern Borneo), than any other places in the region (Sa'adi et al., 2017a,b). Climatic condition of Sarawak was also affected by intertropical convergence zone (ITCZ), due to its geographical location (equatorial tropic). These make the region experiencing two periods of heavy rainfall in every year (Zhang, 2005; Maloney and Shaman, 2008; Sa'adi et al., 2017a). All these processes have direct influence of local climatic conditions of the region.

During the recent decade (after the year 2000), numerous attempts were made to study the rainfall characteristics and trend pattern in Sarawak, Malaysia (Dindang et al., 2011; Hua et al., 2013). Most studies used selected rain gauges to characterize the rainfall trend, extreme rainfall events and general characteristics of rainfall. Results of these studies identified variability in rainfall characteristics in Sarawak and were controlled by different parameters such as nearness of the ocean, sea-land interaction and highly varying terrain characteristics (Camerlengo et al., 2000). Therefore more detailed study on local basis is required to detect the trend in rainfall and effect of climate change in tropical rainfall regime. Further, no detailed studies on rainfall trend characteristics and effects of climate change on rainfall pattern were reported from the Limbang River Basin (LRB) in Sarawak, Malaysia. In view of this, in the present study, an attempt has been made to statistically detect the fluctuation in monthly and annual rainfall in LRB due to climate change and extreme weather events occurred in the region.

Study Area

Area selected for the present study, the Limbang River Basin (LRB), forms part of tropical equatorial rainfall regime in Southeast Asia. LRB is located in Sarawak state of Malaysia (East Malaysia, Borneo) and enclosed between N latitudes 03° 47′ 7″ to 04° 54′ 47″ and E longitudes 114° 46′ 7″ to 115° 31′ 30″ (Figure 1). The Limbang River flows 196 km northeasterly and the LRB covers a total area of 3687 km^2. LRB receives an annual average rainfall of 3798 mm and experience monsoonal climatic conditions. Dominant monsoon seasons cover more than ten months of the year. The South-West monsoon starts in May and extended to September and the North-East monsoon covers November to March. Each monsoon is separated with a short inter-monsoon month i.e. April and October. Northeast monsoon is the wettest period and southwest monsoon are comparatively dry. The average daily temperature ranges from 18˚C to 35˚C. Dominant land cover in the river basin is the tropical forest and very less area is covered with oil palms. Elevation varies between >1 m in the coastal stretch and <2400 m in the southern portion of the basin. Due to its highly undulating nature and higher terrain slope, runoff with high sediment contents is typical of this region.

Materials and Methods

Estimation of rainfall trend characteristics and its fluctuations need continuous rainfall measurements (monthly as well as annual rainfall) for long periods. In the present study rainfall data from four rain gauging station for a period of 35 years (1981-2015) were collected from the Department of Irrigation

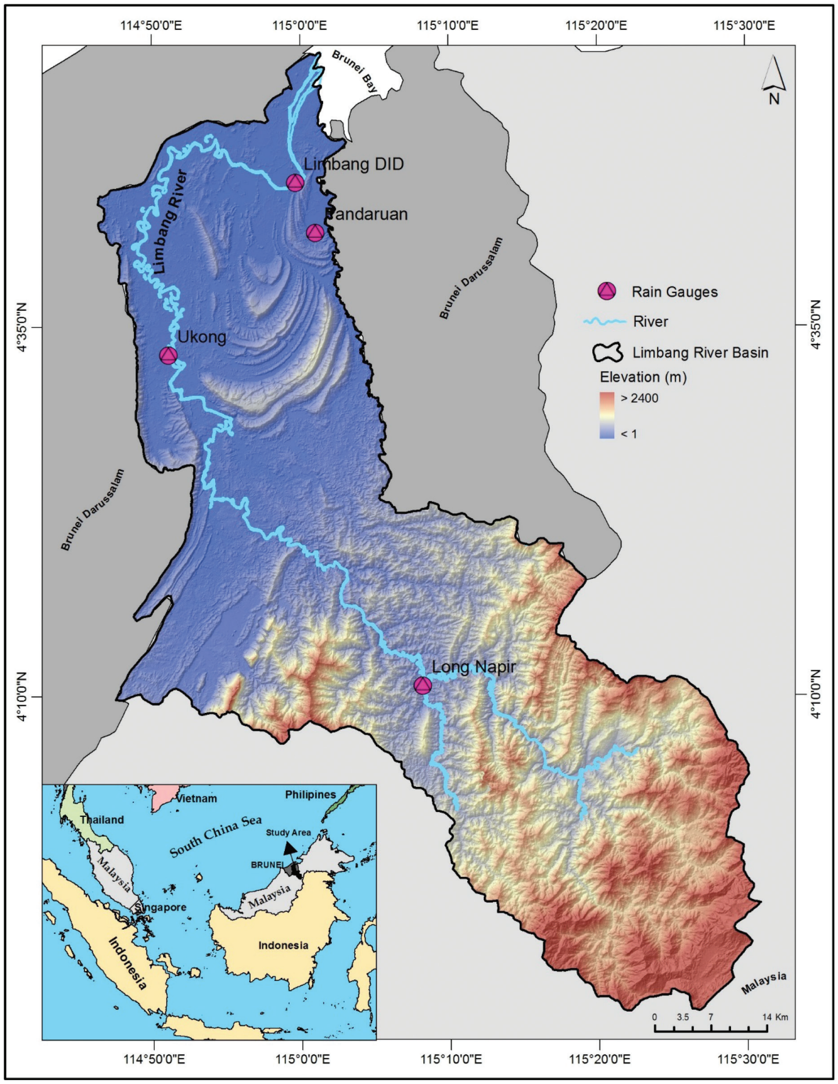

Figure 1: Study area location map with rain gauging stations in the Limbang River Basin.

and Drainage (DID), Sarawak, Malaysia. The rain gauging stations namely Limbang DID, Pandaruan, Ukong and Long Napir were spatially distributed in LRB, representing different terrain conditions. Before analyzing the trend characteristic and its fluctuations, general statistical characteristics such as mean, standard deviation, kurtosis, skewness and coefficient of variation (CV) were calculated for monthly and annual rainfall totals for each station. Further, station-wise monthly and annual rainfall data were divided in to two different groups i.e. 10 years non-overlapping and 15 years overlapping, to detect rainfall trend and nature of the trend. Two different statistical methods such as Cramer's test and linear regression were used to detect the characteristics of monthly and annual overlapping and non-overlapping rainfall.

Cramer's Test

The consistency of rainfall trend over a period was characterized through Cramer's test. The test compares the mean of sub-period with mean of the whole period data and the biggest advantage of the method is that, it allows overlapping of data while determining the trend. Cramer's test can be calculated as (Cramer, 1946; Mitchell et al., 1966):

$$t_{\mathrm{k}} = \left(\frac{n(N-2)}{N-n\,(1+t_{\mathrm{k}}^{\mathrm{z}})} \right)^{1/\mathrm{z}} t_{\mathrm{k}}$$

where N is the total number of observations and n is the number of observations in the sub-period. The value of τ_{k} is the standardised value of the difference between the mean and can be calculated as:

$$\tau_k = \frac{\bar{x}_k - \bar{x}}{S}$$

where $\bar{x}_k$ is the mean of sub-period with n observations and $\bar{x}$ and S are the mean and standard deviation of entire data of N values. The test statistics t_k gives the value of student t distribution with $N - 2$ degrees of freedom. A comparison of student t distribution table at 95% confidence level appropriate to two-tailed test were also carried out to obtain the statistical significance. Application of Cramer's test to detect the rainfall trends and its fluctuation are well documented by Abaje et al. (2010, 2012, 2014 a,b, 2018) and Paliatsos et al. (2005).

Linear Regression

Linear regression is used in the present study to detect the nature of trend by considering the grouped monthly and annual rainfall data of each station. Linear regression is one of the simplest methods to calculate the trend of time series data (Partal and Kahya, 2006; Longobardi and Villani, 2010; Donat et al., 2016). Linear regression equation is:

$$Y = a + bX$$

where Y is the dependent variable, X is the explanatory variable, b is the slope and a is the intercept. The positive and negative nature of the time series data can be described by the slope of the regression line. Assumption of normal distribution is necessary for linear regression. The null hypothesis is that the slope of the line is zero or no trend in the data. The probability value shows the significance of the slope. Positive value indicates an increasing linear trend and negative value a decreasing linear trend. In the present study, annual rainfall of each station and its 10-year moving average was linearly plotted and the trend was detected.

Results of general statistics, trend pattern detected by Cramer's test and the nature of the trend pattern analyzed by linear regression are discussed in detail below.

Results

General Statistical Characteristics of Monthly and Annual Rainfall

Basic statistical properties of monthly rainfall of different rain gauging stations indicate varying characteristics (Table 1). In Limbang DID, the month of January shown the highest mean rainfall (347 mm) and the lowest mean rainfall was noted in the month of July (197 mm). While considering the station Pandaruan, the highest mean rainfall was noted in the month of November (377 mm) and the lowest in July (237 mm). Rain gauging stations Ukong and Long Napir showed highest mean rainfall in the month of November (413 and 268 mm respectively) and the lowest in the month of March (224 and 175 mm respectively). All other months showed mean rainfall higher than 200 mm. In the case of monthly distribution of rainfall, all stations showed a unique pattern of rainfall distribution i.e. higher rainfall totals during the months of November, December, January compared to other months.

Considering the mean annual rainfall, the rain gauging station Pandaruan showed the highest mean (3611 mm) and Long Napir showed the lowest (2574 mm). Deviation of mean rainfall amount was characterized through the assessment of standard deviation. The standard deviation of monthly rainfall measured in Limbang DID vary from 107.55 mm (July) to 205.59 mm (January), whereas SD of Pandaruan ranges between 116.96 mm (July) and 229.76 mm (January). Considering the other two rain gauging stations, SD found to be in the range of 113.64 to 175.25 mm (May-January) and 93.08 to 128.82 mm (July-January) for Ukong and Long Napir respectively. The SD of annual rainfall varies from 676.22 mm (Ukong) to 786.27 mm (Long Napir).

Kurtosis values of monthly rainfall data analysed for Limbang DID ranges from –1.23 (June) to 4.29 (September) and in Pandaruan it varies between –0.97 (January) and 2.41 (November). At the same time, kurtosis value derived for the rain gauging station Ukong vary in the range of –0.84 (June) to 4.55 (March) and Long Napir, it ranges from –1.34 (June) to 3.09 (May). Kurtosis of annual rainfall data ranges from –0.89 (Limbang DID) to 0.40 (Ukong). Skewness value of monthly rainfall data analysed for the rain gauging station Limbang DID ranges from –0.15 (December) to 1.61 (September). Rainfall data of Pandaruan showed the skewness in the range of 0.18 (December) to 1.24 (August), whereas those of Ukong vary between –0.47 (May) and 1.66 (March). Long Napir showed comparatively low skewness values and range from –0.57 (November) to 0.88 (May). Skewness value of annual rainfall data ranges from –0.98 (Long Napir) to 0.40 (Pandaruan).

The coefficient of variation analyzed for monthly rainfall in Limbang DID was found to vary between 0.38 (December) to 0.69 (August) and the CV of monthly rainfall in Pandaruan range from 0.36 (November) to 0.73 (August). Considering the other two rain gauging stations, the CV was found to be ranging between 0.34 (November) to 0.65 (March) and 0.40 (November) to

Table 1: General statistics of monthly and annual rainfall for rain gauging stations considered in the present analysis (1981-2015)

Stations	*Parameters / Months*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual*
Limbang DID	Mean	347.60	253.53	208.57	271.19	300.03	211.14	197.80	233.64	231.50	257.12	314.89	319.34	3146.36
	SD	205.59	144.32	138.27	109.63	143.10	108.41	107.55	161.10	128.57	123.14	137.40	122.02	715.75
	Kurtosis	-0.63	-0.39	1.06	-0.34	0.26	-1.23	-0.62	0.03	4.29	1.67	2.04	-0.92	-0.89
	Skewness	0.41	0.20	0.84	0.60	0.75	0.19	0.69	0.86	1.61	1.26	1.14	-0.15	0.21
	CV	0.59	0.57	0.66	0.40	0.48	0.51	0.54	0.69	0.56	0.48	0.44	0.38	0.23
Pandaruan	Mean	359.54	276.41	249.00	327.87	338.96	251.17	237.20	255.53	290.47	311.44	377.53	336.84	3611.96
	SD	229.76	157.81	151.58	126.19	151.18	139.33	116.96	186.53	152.29	142.77	135.63	135.00	711.50
	Kurtosis	-0.97	1.11	0.67	0.40	-0.01	-0.69	-0.65	1.75	0.11	0.87	2.41	-0.33	0.06
	Skewness	0.45	0.74	0.76	0.56	0.66	0.38	0.42	1.24	0.81	1.09	1.18	0.18	0.40
	CV	0.64	0.57	0.61	0.38	0.45	0.55	0.49	0.73	0.52	0.46	0.36	0.40	0.20
Ukong	Mean	319.13	251.63	224.09	283.89	305.44	253.72	227.72	243.03	285.19	316.93	413.84	350.13	3474.74
	SD	175.25	132.95	145.39	128.82	113.64	122.53	121.59	151.33	148.85	126.14	139.00	132.70	676.22
	Kurtosis	-0.74	-0.31	4.55	0.62	-0.13	-0.84	2.95	0.81	1.68	-0.24	2.67	-0.59	0.40
	Skewness	0.53	0.65	1.66	0.79	-0.47	0.00	1.28	1.04	1.21	0.52	1.15	-0.30	0.31
	CV	0.55	0.53	0.65	0.45	0.37	0.48	0.53	0.62	0.52	0.40	0.34	0.38	0.19
Long Napir	Mean	225.86	176.97	175.72	231.64	223.76	206.14	178.72	201.00	210.62	239.48	268.58	235.87	2574.38
	SD	128.82	118.11	98.60	107.67	102.62	124.97	93.08	128.48	109.98	100.13	108.64	117.31	786.27
	Kurtosis	-0.75	0.22	-0.24	-0.40	3.09	-1.34	1.78	-0.69	-0.89	0.00	0.05	-0.47	0.27
	Skewness	0.10	0.68	0.32	-0.24	0.88	0.05	0.85	0.61	-0.20	-0.03	-0.57	0.30	-0.98
	CV	0.57	0.67	0.56	0.46	0.46	0.61	0.52	0.64	0.52	0.42	0.40	0.50	0.31

0.67 (February). The coefficient of variation analysed for annual rainfall data ranges from 0.19 (Ukong) to 0.31 (Long Napir), which indicates comparatively lower variation in rainfall distribution.

Cramer's Test (t_k) Based Trend in Monthly and Annual Rainfall

Assessment of sub-periods (non-overlapping and overlapping) monthly and annual rainfall trends for the rain gauging station in LRB indicates varying characteristics. Monthly rainfall of 10-year non-overlapping periods showed statistically significant (95% confidence) increasing and decreasing trends (t_k values) in different sub-periods (Table 2). During the first sub-period (1986-1995), significant decreasing trend was noticed in the months of January (–3.108 and –3.179), October (–2.118 and –2.182) and December (–3.799 and –2.363) in Limbang DID and Pandaruan. At the same time, Ukong showed significant decrease in rainfall in January (–2.170) whereas the station Long Napir shown significant decreasing trends in the months of January (–2.411), February (–2.563), May (–2.169) and December (–2.573). Considering the second sub-period of analysis (1996-2006), Limbang DID (2.724), Pandaruan (2.805) and Long Napir (2.740) shown statistically significant increasing trend in the month of October and Ukong shown significant decreasing (–2.052) trend in the month of April.

During 2006-2015, statistically significant increasing trends are shown by Limbang DID in January (2.689), March (2.389), November (3.942) and December (3.00); Pandaruan in January (3.231), March (2.114) and November (2.093) and Long Napir in January (2.970), March (2.824) and April (2.410). No significant trend was associated with Ukong during this period of analysis. Analysis of station-wise 10-year non-overlapping annual rainfall confirms the results by showing similar decreasing and increasing trend characteristics (Table 3). During the first sub-period (1986-1995), three stations namely Limbang DID (–3.665), Pandaruan (–3.076), Long Napir (–2.467) showed statistically significant decreasing trends. Ukong also showed a non-significant decreasing trend (–1.997). In the second sub-period (1996-2005) all stations showed a non-significant increasing trend, in which the maximum increase was shown by Long Napir (1.985). A significant increasing trend was noticed during the third sub-period (2006-2015), in which the station Limbang DID showed the maximum increase (4.160).

Results of month-wise rainfall of 15 years overlapping sub-periods reconfirm the trend characteristics revealed by 10-year non-overlapping periods of analysis (Table 4). During the first sub-period (1981-1995), most months showed decreasing trend in which statistically significant (95% confidence) trends are associated with January (–2.617), February (–2.159), March (–2.441), October (–3.456), November (–3.304) and December (–3.156) in Limbang DID; January (–3.082), February (–2.812) and October (–2.962) with Pandaruan; January (–2.098) with Ukong. Rain gauging station Long Napir showed significant decreasing trend in all months except July and September. Considering the second overlapping time period (1986-2000), rain gauging stations continued to show overall decreasing trend in all months and the significant decreasing trends were noticed in the months of January (–2.518), April (–2.539) and December (–3.910) in Limbang DID; January (–2.626) and December (–3.015) by Pandaruan. Ukong and Long Napir also showed decreasing trends, in which Long Napir in the month of March (–2.461) only showed statistically significant trend. During the third overlapping period (1991-2005), though the trends shown varying characteristic, among the stations, Ukong only showed a statistically significant increasing trend (2.145 in June).

A change in trend characteristic was noted in the fourth time period (1996-2010). During this period of analysis, Limbang DID showed increasing rainfall trend in all months, in which a statistically significant increase was observed in June (2.786) and October (3.623). A similar pattern of trend was shown by Pandaruan with significant increasing trends during June (2.696) and October (3.574). Ukong shown a significant increasing trend in June (2.307) and Long Napir in January (2.236), February (2.706), June (2.375), October (2.959) and December (2.819) showed statistically significant trends. At the same time, the most recent sub-period (2001-2015), statistically significant increasing trend were dominated in all months in all stations. Limbang DID showed statistically significant increase in the months of January (2.372), March (2.837), April (2.385), October (2.028), November (4.068) and December (3.691), in which the maximum increase was noted in the month of November (4.068). Pandaruan showed a significant increasing trend during January (2.867), March (2.872) and November (2.227). In Ukong, though most months shown increasing trend, but none was statistically significant. But in the case of Long Napir, a significant increasing trend was noted in the months of January (2.990), March (4.570), April (2.253), November (2.494) and December (2.486).

Table 2: Results of month-wise 10-year non-overlapping sub-period analysis based on Cramer's test (t_k)

Stations	*Period/ Months*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Limbang DID	1986-1995	-3.108*	-2.027	-1.146	-1.640	0.244	-0.605	-0.389	-0.243	-1.377	-2.118*	-0.967	-3.799*
	1996 -2005	0.173	0.354	0.256	-0.204	-0.057	1.179	0.848	-0.247	1.643	2.724*	-0.113	0.372
	2006-2015	2.689*	1.967	2.389*	1.721	-0.349	0.890	-0.257	1.856	-0.101	0.790	3.942*	3.000*
Pandaruan	1986-1995	-3.179*	-1.946	-0.516	-0.938	0.961	-0.606	-0.587	0.578	-1.577	-2.182*	-0.633	-2.363*
	1996 -2005	0.159	0.946	-0.033	-0.178	-1.545	1.283	0.275	-0.168	1.070	2.805*	-0.364	-0.469
	2006-2015	3.231*	1.934	2.114*	1.045	-0.417	0.330	-0.240	0.589	0.444	0.364	2.093*	1.251
Ukong	1986-1995	-2.170*	-1.144	-0.398	-0.320	-0.418	-0.119	-1.819	-0.215	-0.915	-0.124	-0.073	-1.861
	1996 -2005	0.273	0.771	-0.690	-2.052*	-0.049	1.202	0.261	0.591	0.141	1.651	-0.089	0.977
	2006-2015	1.997	1.093	1.790	1.148	-0.056	0.173	1.104	1.380	0.622	-0.302	0.869	0.637
Long Napir	1986-1995	-2.411*	-2.563*	-1.769	-1.516	-2.169*	-0.616	-1.030	-0.440	0.328	-1.732	-0.499	-2.573*
	1996 -2005	0.785	1.897	0.599	0.273	1.183	0.639	0.618	1.036	0.733	2.740*	1.290	2.021
	2006-2015	2.970*	1.266	2.824*	2.410*	1.135	1.718	0.975	1.151	0.634	0.573	1.810	1.300

* 95% confidence level

Table 3: Results of station-wise 10-year non-overlapping sub-period analysis based on Cramer's test (t_k)

Stations /Period	*1986-1995*	*1996-2005*	*2006-2015*
Limbang DID	-3.665*	1.143	4.160*
Pandaruan	-3.076*	0.727	3.185*
Ukong	-1.997	0.589	2.355*
Long Napir	-2.467*	1.985	2.822*

* 95% confidence level

Similar to the monthly rainfall, the annual rainfall in each station corresponds to the sub-periods showing distinct variation in rainfall trend characteristics (Table 5). During the initial period of analysis (1981-1995), all the stations showed significant decrease in rainfall and Limbang DID showed maximum decrease (–5.854). Considering the second sub-period (1986-2000), the decreasing rainfall trend was continued in all stations, but showed change in significance. Among the stations, Limbang DID and Pandaruan only showed statistically significant decrease (–2.845 and –2.122 respectively) in trend, whereas stations Ukong and Long Napir showed non-significant decreasing trend. Characteristics rainfall trend started showing a shift from a significant decreasing trend to non-significant decreasing trend in the third sub-period (1991-2005) as observed in the monthly rainfall trend.

Rain gauging stations such as Limbang DID, Pandaruan and Ukong showed least level of decrease in annual rainfall (–0267 to –0.960), whereas Long Napir showed a non-significant increasing trend (0.904). Annual rainfall in LRB started showing an increasing trend during the sub-period (1996-2010), with statistical significance. All stations showed increasing trend varying in the range of 2.869 to 3.772 in annual rainfall and the maximum increase was associated with Long Napir (3.772). As noticed in the monthly rainfall trend, annual rainfall also continued to show an increasing trend in the most recent sub-period (2001-2015). Though all the stations showed an increasing trend in annual rainfall, Ukong showed statistically non-significant increase (1.623). The significant increasing trend shown by other stations vary in the range of 3.083 (Pandaruan) to 5.137 (Limbang DID).

Characteristics of Accumulated Annual Rainfall

Linear regression plots facilitated the identification of long-term trend fluctuations in annual rainfall in LRB (Figure 4). Considering the linear regression plot of Limbang DID (Figure 4a), annual rainfall was found to be lower than long-term average rainfall (3146 mm) during the period 1981-1995. In this period, the lowest rainfall was noted around the year 1982 and 1990. After the year 1995, though the annual rainfall shows slight fluctuation, it peaked above the long-term mean rainfall total. 10 years moving average rainfall (>3200 mm) also peaked above the long-term mean rainfall after the year 2000. After this period (year 2000) the annual rainfall showed a drastic increase with minor fluctuations in annual rainfall total. However, in very recent year (after 2010), annual rainfall showed a decreasing characteristic in Limbang DID. The remarkable fluctuations (decreasing) in annual rainfall were noted during the periods 1990-1995 and 2000-2005. Considering the station Pandaruan, the long-term mean shows value higher than 3600 mm and the annual rainfall shows highly varying characteristics than Limbang DID (Figure 4b). The lowest rainfall characteristic in Pandaruan was observed in the period of 1990-1995 in its whole data range. During the period 1995-2000, annual rainfall found to be shown increasing trend and the maximum increase in rainfall was noticed after the year 2005. However, the 10 years moving average shows an increasing trend (>3700 mm) than long-term mean rainfall after the year 2000. Similar to Limbang DID, marked fluctuations in annual rainfall totals are noticed during 1990-1995, 2000-2005 and are showing decreasing trend in rainfall.

Characteristics trend shown by Ukong also suggests definite periods of rainfall fluctuations as shown by Limbang DID and Pandaruan (Figure 4c). Annual rainfall was found to be lower than long-term mean (3474 mm) in selected time periods, which correlate with the decreasing trend characteristics shown by the other stations. The dominant decreasing trend characteristics was observed during the periods 1987-1994, 2001-2005 and very recent time i.e. after year 2014. Peak rainfall (above long-term mean) in this station was recorded during 1996-2000 and 2007-2010. Comparison of 10 years moving average rainfall with long-term mean rainfall, clearly suggests a phase change trend characteristic of annual rainfall after the year 2000. Before the year 2000, the 10-year moving average rainfall was below the long-term mean rainfall and showing a steady increasing trend (>3500 mm) with slight fluctuation in the recent time. In the case of Long Napir, the identified phase change in trend characteristic was well reflected in annual rainfall and 10-year moving average after the year 2000 (Figure 4d). During the period 1981-1999, annual rainfall and 10 years moving average was below long-term mean (2574 mm) and after

Table 4: Result of month-wise 15-year overlapping sub-period analysis based on Cramer's test (t_k)

Stations	*Period / Months*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Limbang DID	1981 - 1995	-2.617*	-2.159*	-2.441*	-1.356	0.370	-1.962	-0.534	-1.429	-1.389	-3.456*	-3.304*	-3.156*
	1986-2000	-2.518*	-1.089	-1.360	-2.539*	-0.165	-0.368	0.130	0.542	-0.992	-0.771	-1.363	-3.910*
	1991 -2005	-1.531	-0.996	-0.673	-0.782	0.257	1.302	1.184	-0.665	0.200	1.201	-0.749	-0.736
	1996 -2010	1.372	1.054	1.859	1.256	0.189	2.768*	1.569	0.823	1.643	3.623*	0.822	1.421
	2001-2015	2.372*	1.385	2.837*	2.385*	0.018	1.751	0.048	0.629	1.126	2.028*	4.068*	3.691*
Pandaruan	1981 - 1995	-3.082*	-2.812*	-1.874	-0.782	1.827	-1.492	-0.032	-0.383	-1.405	-2.962*	-1.513	-0.694
	1986-2000	-2.626*	-0.623	-1.288	-1.016	-0.066	0.027	0.020	1.333	-0.894	-0.248	-1.214	-3.015*
	1991 -2005	-1.533	0.057	-0.775	-0.918	-0.814	1.503	0.274	-0.355	-0.416	1.515	-0.826	-1.483
	1996 -2010	1.170	1.511	1.602	1.484	-0.490	2.696*	0.700	0.734	1.489	3.574*	-0.071	0.659
	2001-2015	2.867*	1.512	2.872*	0.943	-0.818	0.876	-0.523	-0.393	0.870	1.035	2.227*	1.404
Ukong	1981 - 1995	-2.098*	-1.754	-0.947	0.743	0.096	-1.261	-1.256	-1.851	-0.698	-1.198	-0.708	-1.507
	1986-2000	-1.834	0.416	-0.875	-1.648	-0.386	0.203	-1.124	1.556	-0.502	0.841	0.465	-0.981
	1991 -2005	-1.141	0.260	-1.231	-1.792	0.140	2.145*	-0.584	0.445	-0.401	1.133	-0.183	0.471
	1996 -2010	1.680	1.736	0.671	-0.599	0.293	2.307*	1.326	1.974	0.664	1.686	0.010	1.343
	2001-2015	1.971	0.238	1.485	0.558	-0.091	0.933	0.754	0.064	0.369	0.228	0.172	0.817
Long Napir	1981 - 1995	-3.713*	-3.166*	-3.294*	-2.481*	-2.224*	-2.234*	-1.486	-2.086*	-1.268	-3.174*	-3.096*	-3.356*
	1986-2000	-1.625	-0.892	-2.461*	-1.181	-0.996	0.202	-0.437	1.023	0.170	-0.134	-0.016	-1.585
	1991 -2005	-0.451	0.930	-0.184	-0.233	0.164	1.408	0.433	0.359	0.345	1.734	1.123	0.841
	1996 -2010	2.236*	2.706*	1.941	1.555	1.190	2.375*	1.436	0.873	1.791	2.959*	1.902	2.819*
	2001-2015	2.990*	1.574	4.570*	2.253*	1.230	1.358	0.962	0.555	1.408	1.442	2.494*	2.486*

* 95% confidence level

Table 5: Result of station-wise 15-year overlapping sub-period analysis based on Cramer's test (t_k)

Stations / Period	1981-1995	1986-2000	1991-2005	1996-2010	2001-2015
Limbang DID	-5.854*	-2.845*	-0.634	3.767*	5.137*
Pandaruan	-3.856*	-2.122*	-0.960	3.494*	3.083*
Ukong	-2.810*	-0.806	-0.267	2.869*	1.623
Long Napir	-5.643*	-1.054	0.904	3.772*	3.507*

* 95% confidence level

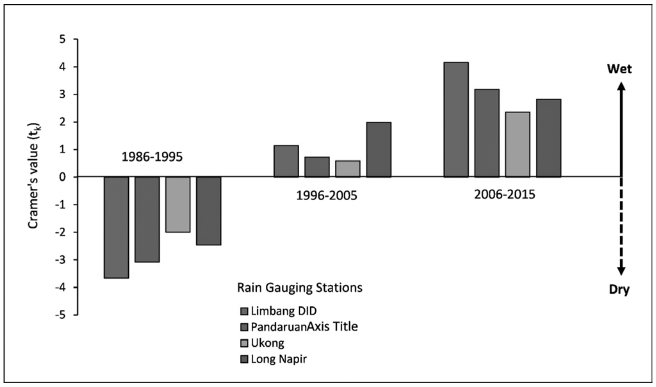

Figure 2: Station-wise annual rainfall trends (10 years non-overlapping sub-periods) showing wet and dry conditions in LRB based on Cramer's statistics.

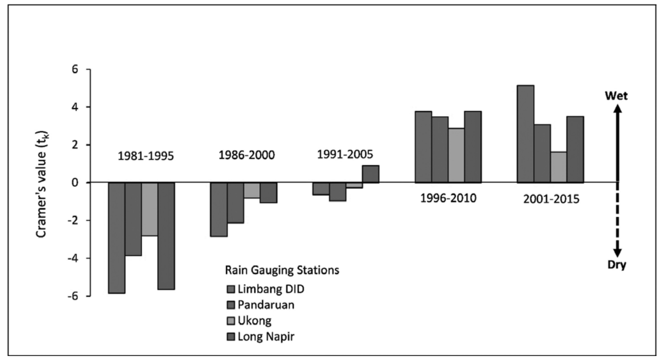

Figure 3: Station-wise annual rainfall trends (15 years overlapping sub-periods) showing wet and dry conditions in LRB based on Cramer's statistics.

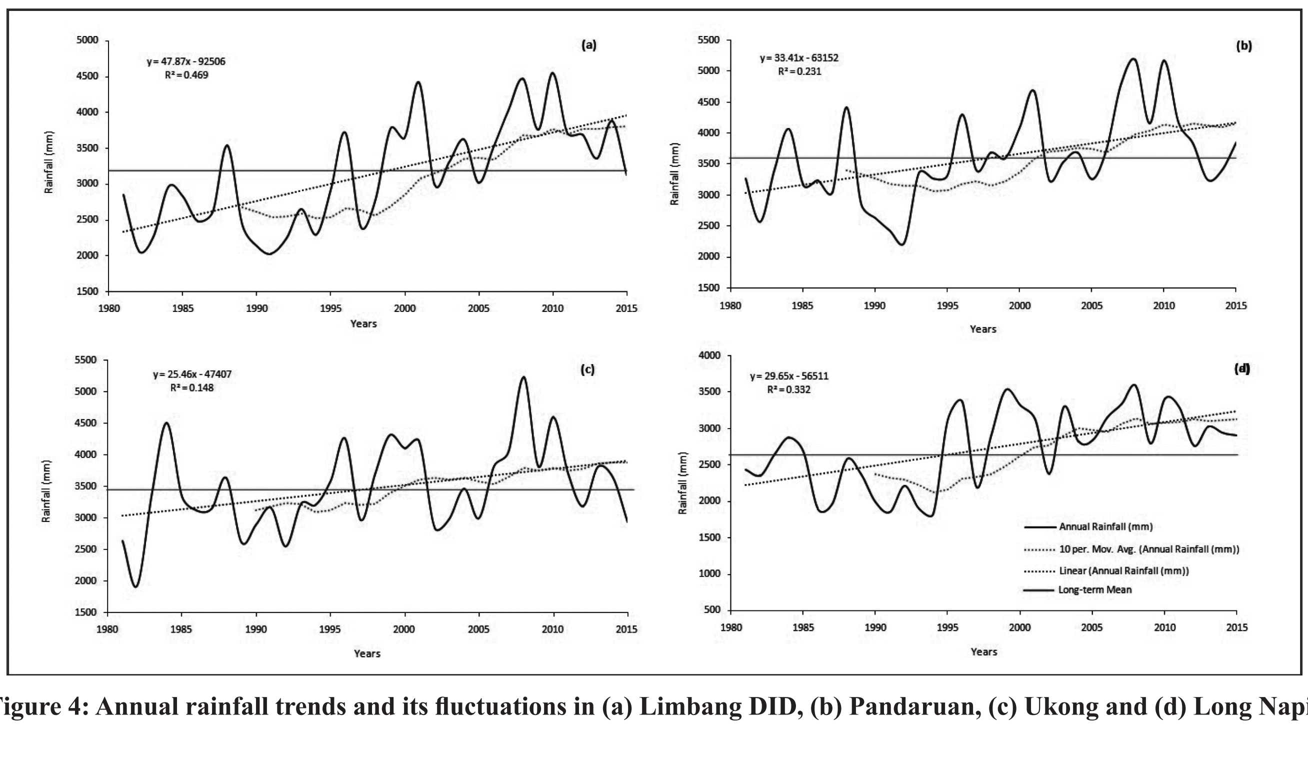

Figure 4: Annual rainfall trends and its fluctuations in (a) Limbang DID, (b) Pandaruan, (c) Ukong and (d) Long Napir.

year 2000, the trend characteristics shown a gentle and steady increase. However, in this station, the prominent low rainfall periods are marked during 1990-1995 only. Though the linear plot shows periods of lower rainfalls, but are not prolonged like other stations.

Discussion

Basic statistical characteristics of monthly and annual rainfall in different stations reveals specific characteristics associated with each rain gauging station.

It has been noted that in most months the region receives a mean rainfall >170 mm which range to the maximum of 413 mm. While considering the monthly rainfall in individual station, Ukong showed the maximum difference between rainfall (≥190 mm) with lowest in the month of March (224 mm) and the highest during November (413 mm). It was also noted that, there was a notable variation in the total monthly rainfall received in each station. In Limbang DID, highest rainfall (>300 mm) are recorded during the months of January, May, November and December whereas in Pandaruan January, April, May, October, November and December show the highest rainfall. In Ukong, the months January, May, October, November and December show the highest rainfall amount (>300 mm). At the same time, in Long Napir, the recorded highest monthly rainfall is 268 mm (below 300 mm) in November and most months show rainfall >200 mm (January, April, May, June, August, September, October and December respectively). Moreover, a common pattern indicated by these stations is, the highest rainfall totals are found to be concentrated in the months of November, December and January than any other months suggesting the role of the northeast monsoon, which carries more rain than the southwest monsoon season.

The variability in monthly rainfall is not well reflected in annual total except Long Napir. Rain gauging stations namely, Limbang DID, Pandaruan and Ukong shows annual mean rainfall >3000 m whereas in Long Napir it was ≥2500 mm. Variation in the total rainfall can be attributed as locational effect (spatial location of rain gauging stations). Limbang DID, Pandaruan and Ukong are situated in comparatively less elevated place and more close to the South China Sea than Long Napir, which was enclosed between high elevated hills. These hills restrict the movement of clouds which carry rain and Long Napir receives comparatively low amount of rainfall. This phenomenon needs to be studied in detail to understand the orographic effect over rainfall in the selected regions in LRB.

Statistical moments such as standard deviation (SD), kurtosis, skewness and coefficient of variation (CV) helped to detect the distributional characteristic of rainfall in each station studied. Among the stations, large difference in SD values observed in Pandaruan and Limbang DID indicate total variation in rainfall received in each month. At the same time, Long Napir with lowest SD (93.08 to 128.82 mm) indicating less variation in distribution of monthly rainfall. Ukong, which received maximum rainfall totals in each month, showed less variation in SD. However, in the accumulated annual rainfall, SD is found to be higher in Long Napir and was very low in Ukong. This indicates the variation in annual rainfall (inter-annual variation in total rainfall), during the period of analysis, in which the annual rainfall totals are more or less similar in Ukong and varying in all other stations. The peakness and flatness of monthly and annual rainfall in different rain gauging stations were assessed through kurtosis indicate infrequent extreme deviations (higher values) and less distinct deviations (lower values).

Overall, all stations show comparatively lower values in most months indicating less deviation. However, in certain months higher values are present and indicating high peaking and flatness caused due to high variation in rainfall distribution. Higher values in kurtosis were observed in the months of August, September, October and November months, indicating more fluctuation in rainfall during end of the southwest monsoon and beginning of the northeast monsoon. At the same time, distributional symmetry of the data revealed by skewness indicating approximately symmetric nature of data distribution by showing most skewness values between ±0.50. Considering individual stations, most stations except Long Napir shows moderately skewed data distribution during the months of February, March, April, May, July and August and highly skewed data distribution in September, October and November. In Long Napir, most months show approximately symmetrical as well as moderately symmetrical rainfall distribution. This indicates comparatively very less variation in amount of monthly rainfall in the region and the assumption was also supported by the results of CV, by showing comparatively lower values suggesting less fluctuation from the average value.

Statistical characterization of monthly and annual rainfall trends at various levels of analysis carried out by Cramer's test revealed distinguishable trend characteristics associated with rain gauging stations and LRB as whole. Considering the 10 years non-overlapping monthly rainfalls, the sub-periods show significant trend characteristics, which identified clustered nature (having a common pattern of trends) of rain gauges. During the sub-period 1986-1995, all the months show decreasing rainfall trend as the dominant character, in which maximum t_k value of –3.799 was shown by Limbang DID in the month of December. A reversal in trend characteristics was noted in the second sub-period (1996-2006). In most months, all the stations showed a general increasing trend in which statistically significant t_k value (increasing trends) were noted in the month of October. Though Ukong showed a similar characteristic of increasing rainfall, statistically significant decreasing trend was noted in the month of April.

The increasing trend characteristics were continued in the last decade of analysis (2006-2015) and statistically significant increasing trends were noted during the months of January, March, April, November and December. The trend pattern shown by the monthly analysis was well reflected in the analysis of station-wise 10-year non-overlapping annual rainfall. Annual rainfall measured in each station showed a continuous nature of an increasing trend from the second sub-period of analysis. Rain gauging stations showed significant decreasing trend during 1986-1995, started showing non-significant increasing trend in 1996-2005 and became significant increasing trend during previous sub-period of analysis (2006-2015). Considering all stations, the highest recorded increase in annual rainfall was associated with Limbang DID (4.160).

A notable correlating characteristic was observed in the Cramer's test results of monthly and annual rainfall of 15 years overlapping sub-periods. Monthly rainfall in all stations showed statistically significant decreasing trends in the initial period of analysis (1981-1995). The decreasing trend with significance and non-significance was continued till third sub-period (1991-2005) of analysis. After this period, during 1996-2010, a drastic change in trend pattern was observed in most months i.e. the t_k value started showing increasing trend characteristics. The result was well correlated with the results of 10 years non-overlapping rainfall trends. During this period of analysis, statistically significant increasing trends with positive t_k values were noted in the months of January, February, June, October and December. As identified earlier, increasing rainfall trend characteristics were dominated in the last sub-period (2001-2015), in all months with maximum t_k value of 4.570 in March. The dominant trend characteristics recognized by the previous analysis were also reflected in the analysis of 15 years overlapping annual rainfall data.

A specific period of trend reversal (1996-2010) was also identified. Before this sub-period, annual rainfall measured in all stations showed significant decreasing trend with t_k value to the maximum of –5.854. However, gradual change in trend characteristics was noted with t_k values close to zero suggesting reversal of annual rainfall trend in LRB during the period of 1991-2005. After this period, annual rainfall showed positive t_k values indicating increasing rainfall characteristics (1996-2010). As discussed earlier, the increasing trend characteristic was continued to vary in the recent sub-period (2001-2015) of analysis with highest t_k value of 5.137. Comparison of long-term mean rainfall (35 years) with 10 years moving average of annual rainfall in linear regression plots clearly explained the variation in trend characteristics. All rain gauging stations in LRB show a common pattern of the trend with a few sub-periods of change in annual rainfall above the long-term average. Among the fluctuations identified from the graph, the notable variation (constant increase) in annual rainfall was marked during the recent time period i.e. after year 2003. Since, this year, the annual rainfall was higher than the long-term mean and 10 years moving average.

Results of monthly and annual rainfall analysis in LRB revealed a dominant reversal of rainfall characteristics after the year 2000. Rainfall trend in all rain gauging stations show increase in rainfall by indicating positive values in Cramer's t_k statistics in monthly as well as annual rainfall. While considering 10 years non-overlapping and 15 years overlapping periods of rainfall, a remarkable change in rainfall trend was noticed from the sub-period 1996-2005 and 1996-2010 respectively (Figures 2 and 3). In the beginning of sub-period, all the station showed a decreasing trend and it gradually changed to increasing trend. The change in pattern from comparatively dry (t_k value is negative) condition to wet (t_k value is positive) in recent years indicate the influence of climate change in overall increase of rainfall in LRB. Overall results show that, the rainfall in LRB showed an increasing trend, though it was affected by various climatic phenomena. The increasing trend characteristics associated with an increase in annual rainfall amount in each station were approximately calculated and are shown in Table 6.

All stations in LRB showed an increasing trend in annual rainfall during the period of analysis (1981-2015). Among the stations, the highest increase in annual rainfall was shown by Limbang DID, followed by Pandaruan and Long Napir. An increase of approximately 1675.6 mm in annual rainfall with 47.87 mm/year; 1169.50 mm with 33.41 mm/year and 978.45 mm with 29.65 mm/year was noted in Limbang DID, Pandaruan and Long Napir respectively. Among the stations, Ukong showed the lowest increase of 891.35 mm in annual rainfall with 25.46 mm/year. In order to identify the percentage increase of annual rainfall each year, a comparison with long-term mean was carried out in the present analysis. The results show that, annual rainfall in Limbang DID increases at a rate of 1.52% per year; 0.93% per year in Pandaruan; 0.73% per year in Ukong and 1.04% per year in Long Napir.

Table 6: Statistics of overall trend of annual rainfall identified through linear regression

Rain gauging station	*Total increase in annual rainfall (mm)*	*Increase in rainfall/year (mm)*	*% rainfall increased/ year*
Limbang DID	1675.6	47.87	1.52
Pandaruan	1169.5	33.41	0.93
Ukong	891.35	25.46	0.73
Long Napir	978.45	29.65	1.04

The increasing trend in annual rainfall amount caused frequent flood in lower parts of the river basin.

These results reconfirm and point towards the remarkable influence of weather phenomena over the rainfall characteristics of the region during 1996-2005. This altered the existing rainfall pattern in the region and provided an increase in overall availability of rainfall. Due to the terrain complexity and equatorial location, the characteristics pattern of weather and its effects on local climate is unpredictable and are highly influenced by in situ synoptic systems and large scale atmospheric phenomena (Tangang et al., 2008). However, studies conducted by Lim et al. (2017), identified an increase in the frequency of the Cold Surges (CS) events between 1980–2001 and 1998–2012 in Southeast Asia and the increase in frequency of CS and Madden-Julian oscillation (MJO) might have caused the increased availability of rainfall (extreme rainfall events) in the region.

Conclusion

Analysis of monthly and annual rainfall from selected rain gauges in the Limbang River Basin shows the effect of climate change in rainfall at the river basin. Cramer's statistics assessed for 10 years non-overlapping and 15 years overlapping rainfall revealed a phase change in overall rainfall trend from decreasing to increasing rainfall characteristics. A notable difference in monthly rainfall characteristics was observed after the year 1996 (sub-period of analysis 1996-2005 and 1996-2010). After this year, the decreasing rainfall trend changed to a statistically significant increasing trend in all stations. Considering the monthly characteristics, it can be concluded that, increase in total rainfall was controlled by the rainfall received during the months of January, February, October, November and December. The impact of increasing monthly rainfall during the analysis period reveals an overall increase in annual total rainfall irrespective of the influence of regional large scale weather phenomena. However, in the end phase of recent time period (after 2014), all the stations in LRB shows a decrease in annual rainfall. All these results point towards the fluctuating trend characteristics of rainfall in LRB, with respect to global as well as regional climate change.

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