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Statistical Analyses on the Seasonal Rainfall Trend and Annual Rainfall Variability in Bhutan

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Abstract:

This study examines the observed seasonal and annual rainfall trend and variability in Bhutan from 1996-2017. Using standard statistical methods, we utilized Mann-Kendall test and Sen's slope estimator to determine the trends in the seasonal rainfall of Bhutan. We analyzed the temporal variability and spatial pattern of rainfall by using the principal component analysis (PCA), Rainfall Anomaly Index (RAI), and Precipitation Concentration Index (PCI). Our results indicate that the summer season contributed to the 73% of the total rainfall in Bhutan while winter season contributed only 1%. Results from the PCI indicate that the rainfall distribution in the northeast part of the country is moderately concentrated while the south to the northwest portion experienced high fluctuation in rainfall distribution. PCA explains the 90.1% of the total variance is linked to the variability of Asian monsoon. The influences of ENSO/La Nina are possible causes for the variability of rainfall in Bhutan though this necessitates more investigations to corroborate.

Key words: Bhutan, rainfall, PCA, Rainfall anomaly index, Precipitation concentration index

1. Introduction

Climate is defined as the average weather of a region over a long period of time. It is the statistical description in terms of the mean and variability of relevant parameters over a period of time ranging from months to thousands or millions of years (IPCC, 2007). The global change in climate may influence long-term rainfall patterns impacting the availability of water (Pal *et al.*, 2017). Rainfall and temperature are vital weather parameters that determine the environmental conditions of a particular region (Girma *et al.*, 2016). Thus, precipitation trend analyses, on different spatial and temporal scales, are of importance (IPCC, 1996).

Given the changes in global warming and the resulting alterations in the hydrological cycle, increasing number of researchers are focusing on the spatial-temporal changes in precipitation and the subsequent outcome on the management of water resources, agricultural irrigation, and flood or drought forecasting (Gu *et al.*, 2017; Mair & Fares, 2011). For instance, rainfall trend analysis carried out in Shaanxi Province of China found that spring rainfall showed significant decreasing trends while summer rainfall showed increasing trends at four stations dispersed over the study area and that autumn rainfall showed a significant trend at two of those stations (Wu & Qian, 2016). Panda & Sahu (2019) also found a statistically significant trend in the annual rainfall during the period of 1980–2017 in Kalahandi, Bolangir and Koraput districts in India. Shrestha *et al.* (2015) reported that precipitation in Hindu Kush Himalayas (HKH) is likely to change, as monsoons are expected to become longer and more erratic and asserted that extreme rainfall events are becoming less frequent, but more violent through increase in intensity. Smadja *et al.* (2015) mentioned that the Himalayan region is one of the most vulnerable regions in the world that has sensitive indicators of climate change.

As a less developed, mountainous and landlocked country, Bhutan's population and ecosystems are vulnerable to climate change (NEC, 2006; UNDP, 2012; UNDP, 2016). Seventy per cent of settlements including infrastructure and agricultural lands are located along the main river basins and are highly prone to flash floods (RGoB & World Bank, 2015). Besides hydropower, agriculture and forestry are key economic sectors influenced by precipitation (NSB, 2020). Thus, droughts and erratic rainfall leave the Bhutanese communities, especially the rural population, highly vulnerable to the impacts of extreme weather patterns (BICMA, 2016). Bhutan, a part of the Hindu-Kush Himalayan region has a wide range of altitudinal zones and prevalence of varied climatic conditions across the country (NSB, 2020). Due to Bhutan's complex terrain and limited data availability, not many studies on seasonal rainfall trend and rainfall variability were carried out.

Despite Bhutan's sensitivity to climatic conditions, the knowledge of key climate variables such as temperature and rainfall in the region is limited (Shrestha *et al.*, 2015). Furthermore, Shahnawaz & Strobl (2015) asserted that unavailability of data at local level is a big obstacle in this process, but generalization of trends over a larger area and for a longer period of time may be misleading in the mountainous regions. Therefore, the purpose of the study is to evaluate the seasonal and annual rainfall trends at a station level to understand the local level observed climate variability. With this objective, we analyze the seasonal precipitation trends of rainfall from 1996 to 2017 using observed data from 14 selected meteorological stations across Bhutan.

2. Study Area, Data and Methodology

2.1 Data and study area

Daily rainfall data from 1996 to 2017 were obtained from the archives of Bhutan's National Center for Hydrology and Meteorology (NCHM) for 20 Class A meteorological stations and quality controlled for accuracy and data length records/consistency. Only 14 stations were found to be robust for data analyses and were used in this study. The map in Figure 1 shows the location of the meteorological stations. For seasonal rainfall trend analysis, seasonal rainfall data were derived from daily rainfall data. The daily rainfall values were averaged into monthly values then accumulated into each season, spring (March, April and May), summer (June, July, August and September), Autumn (October and November) and Winter (December, January and February).

Figure 1. Location of the meteorological stations analysed in this study

2.2 Methodology

We employed Mann-Kendall (MK) test and Sen's Slope Estimator test to determine the climatological trend of the time series. Positive values of Mann-Kendall statistics (S) is an indicator of an increasing trend whereas negative values indicate a decreasing trend. The presence of a statistically significant trend is evaluated using Z value (Longobardi & Villani, 2010). In this analysis, the null hypothesis of no trend is rejected if $Z > 1.96$ at the 95% significance level (Gajbhiye *et al.*, 2016). On the other hand, the Sen's slope (SS) is an indicator of the magnitude of a trend. Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series. A positive (negative) value of Sen's slope indicates an upward (downward) increasing (decreasing) trend in the time series (Sen, 1968). The standard methodologies for MK test and Sen Slope's estimator can be found in Meals *et al.* (2011).

Principal Component Analysis (PCA) was also employed to define the stations' homogenous climatological characteristics. We also calculated the rainfall anomaly index (RAI), and precipitation concentration index (PCI). The Rainfall Anomaly Index (RAI), designed by van Rooy (1965), considers the rank of the precipitation values to calculate positive and negative precipitation anomalies. RAI is calculated to examine the nature of the trends, enables the determination of the dry and wet years in the record and used to assess frequency and severity of droughts (Hansel *et al.*, 2016). The PCI allows quantifying the relative distribution of precipitation spatial patterns. It is also a powerful indicator for temporal precipitation variability for assessments of seasonal precipitation change (Asfaw *et al.*, 2018). PCI values of less than 10 indicates uniform monthly distribution of rainfall (low precipitation concentration), values between 11 and 15 denote moderate concentration of rainfall, values from 16 to 20 indicates an irregular distribution (high

concentration) and values above 20 represent a strong irregularity (very high precipitation concentration) in precipitation distribution (Oliver 1980). The baseline period used for RAI and PCI is 1996-2017.

3. Results and Discussions

3.1 Seasonal rainfall trend

Table 1: Statistics of country-averaged seasonal rainfall. Mann-Kendall test and Sen's Slope were derived at 95% confidence levels.

	Spring	Summer	Autumn	Winter
Minimum	202.89	991.59	16.16	5.11
Maximum	462.41	1577.60	211.89	85.09
Mean	309.09	1187.61	95.77	30.25
STD	59.74	141.23	59.18	21.01
MK	-0.10	0.05	-0.10	-0.26
SS	-23.00	11.00	-23.00	-59.00
p-value	0.54	0.78	0.54	0.10
Sen's slope	-1.29	0.88	-1.19	-0.96
Z-Statistics	-0.62	0.28	-0.62	-1.64

The annual rainfall in Bhutan has a well-defined latitudinal variation that is wettest on the southern part, drier on the central area, and relatively wet on the extreme north (Dorji *et al.* 2016a). On seasonal rainfall, this study revealed that Bhutan received mean spring rainfall of 309.08 mm,

mean summer rainfall of 1187.60 mm, mean autumn rainfall of 95.76 mm and mean winter rainfall of 30.24 mm (Table 1). These results agreed with the report by Shrestha *et al.* (2016), with high seasonal variability in precipitation in Bhutan with about 70% of rainfall occurring in the monsoon months from June to September. The summer rainfall peak was also shown by Sano *et al.* (2013) using the reconstructed rainfall timeseries from tree ring cellulose. The statistical analysis using the Mann-Kendall test and Sen's slope showed that there was a significant trend for the seasonal rainfall on some of the meteorological stations across Bhutan. Generally, there is a decreasing rainfall trend for spring, autumn, and winter seasons while an increasing trend for summer rainfall. However, the Z-statistics shows statistically insignificant trends for all seasons. Shahnawaz & Strobl (2015) also found high variability in monthly precipitation during the rainy season in Bhutan but the variations did not show any trend on a definite direction of change.

Figure 2. Cumulative monthly means of rainfall for Bhutan (in mm/day). Solid black line is the long-term average, dashed black line is the trend line.

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125 Figure 2 shows the time series of rainfall across different seasons. Summer season contributed to
126 the largest amount of rainfall with highest variability (shown in Mean and STD of Table 1) due to
127 the large influence of Southwest monsoon (NCHM, 2019). There is a large spread in the year-to-
128 year variation of rainfall during summer season among other seasons. Highest summer rainfall was
129 recorded in 1998 and 2010.

130 The influence of ENSO to Bhutan's rainfall was highlighted in the study of Sano et al. (2013).
131 They found out that there is a stable teleconnection ($r=0.61$) between ENSO and tree ring data
132 (proxy for precipitation) coinciding with the positive phase of Pacific Decadal Oscillation (PDO)
133 during summer season of 1971-2011. The positive ENSO-rainfall relationship indicates that El
134 Niño (La Niña) events induce dry (wet) conditions in Bhutan. This relationship was also analogous
135 to the study of Adhikari and Sharma (2020). However, Adhikari and Sharma (2020) noted that
136 only the southern foothill stations are teleconnected to ENSO while the northern stations are
137 probably influenced by topography. Nevertheless, additional studies are necessary to corroborate
138 the influence of ENSO on Bhutan's rainfall.

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3.2 Principal Component Analysis (PCA)

Figure 3. First and Second principal components of monthly mean rainfall of Bhutan.

Figure 3 shows the timeseries of the first two principal components (PC) of rainfall. The PCA calculation explains the 95.1% of the total variance accumulated for the two PCs. The first PC is dominantly made up of 90.1% of the variance which largely represent the seasonal cycle of rainfall. This signal also represents the response of Bhutan's rainfall to Asian monsoon system. High signals of rainfall can be observed during summer season whereas low signals can be observed during winter. The second PC only represents the 4.9% of the total variance.

3.3 Seasonal rainfall trend analysis on various stations

Table 2. Seasonal Mann-Kendall Test result of the 14 selected meteorological stations (1996-2017). Values in bold indicate a significant trend.

Stations	season	MK	p-value	Sen's slope	z-statistics
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1.wangdi (Bajo)	1. Spring	-0.039	0.822	-0.005	-0.226
	2.Summer	-0.098	0.398	-0.001	-0.28
	3.Autumn	-0.139	0.98	-0.011	-0.85
	4.Winter	-0.113	0.48	-0.003	-0.706
2.simtokha	1. Spring	0.351	0.024	0.029	2.256
	2.Summer	-0.098	0.778	-0.01	-0.28
	3.Autumn	-0.039	0.822	-0.003	-0.23
	4.Winter	-0.162	0.308	-0.006	-1.019
3.Bhur	1. Spring	-0.325	0.037	-0.127	-2.087
	2.Summer	0.177	0.259	0.299	1.13
	3.Autumn	-0.16	0.31	-0.053	-1.02
	4.Winter	-0.069	0.672	-0.005	-0.423
4.Chamkhar	1. Spring	0.082	0.612	0.012	0.508
	2.Summer	-0.325	0.037	-0.043	-2.087
	3.Autumn	0.013	0.955	0.002	0.06
	4.Winter	0.004	1	0	0
5.Pemagatshel	1. Spring	-0.177	0.259	-0.059	-1.138
	2.Summer	-0.022	0.91	-0.015	-0.11
	3.Autumn	-0.212	0.176	-0.053	-1.35
	4.Winter	-0.117	0.463	-0.006	-0.733
6.Haa	1. Spring	0.203	0.195	0.032	1.297
	2.Summer	-0.221	0.159	-0.046	-1.41
	3.Autumn	-0.03	0.866	-0.006	-0.17
	4.Winter	-0.325	0.037	-0.015	-2.087
7.Kanglung	1. Spring	-0.022	0.91	-0.008	-0.113
	2.Summer	-0.221	0.15	-0.058	-1.14
	3.Autumn	-0.1	0.535	-0.027	-0.62
	4.Winter	-0.152	0.338	-0.006	-0.965
8.Mongar	1. Spring	0.013	0.955	0.002	0.056
	2.Summer	0.77	0.259	0.036	1.13
	3.Autumn	-0.031	0.955	-0.033	-0.06
	4.Winter	-0.013	0.955	0	-0.057
9.Paro	1. Spring	0.186	0.236	0.017	1.184
	2.Summer	-0.048	0.778	-0.007	-0.62

	3.Autumn	-0.134	0.398	-0.011	-0.28
	4.Winter	-0.013	0.955	0	-0.057
10.sipsu	1. Spring	-0.108	0.499	-0.036	-1.466
	2.Summer	-0.013	0.955	-0.018	-0.06
	3.Autumn	-0.091	0.573	-0.039	-0.56
	4.Winter	-0.455	0.003	-0.047	-2.933
11.Trashiyangtse	1. Spring	0.074	0.652	0.017	0.451
	2.Summer	-0.177	0.259	-0.044	-1.13
	3.Autumn	-0.1433	0.367	-0.026	-0.9
	4.Winter	-0.229	0.143	-0.009	-1.476
12.Zhemgang	1. Spring	0.16	0.31	0.027	1.015
	2.Summer	0.117	0.463	0.4	0.73
	3.Autumn	-0.03	0.866	-0.006	-1.17
	4.Winter	-0.195	0.215	-0.013	-1.241
13.Damphu	1. Spring	-0.125	0.429	-0.026	-0.078
	2.Summer	-0.03	0.866	-0.015	-0.03
	3.Autumn	-0.056	0.755	-0.024	-0.09
	4.Winter	-0.023	0.146	-0.01	-1.129
14.Punakha	1. Spring	0.134	0.397	-0.01	0.845
	2.Summer	-0.056	0.735	-0.006	-0.69
	3.Autumn	-0.16	0.31	-0.027	-1.18
	4.Winter	-0.269	0.088	-0.007	-1.703

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155

156 Table 2 displays the calculated seasonal Mann-Kendall Test for the 14 selected meteorological
157 stations in Bhutan. Most stations show insignificant trend but a few shows otherwise. Simtokha
158 and Bhur exhibit significant increasing and decreasing trend of spring rainfall, respectively.
159 Rainfall in Chamkhar is also found significantly decreasing during summer. Winter rainfall shows
160 shortfall in water availability as the trend is seen significantly decreasing in Sipsu and Haa. No

significant increasing or decreasing trend is observed during autumn season in any of the stations in Bhutan.

3.4 Rainfall Variability analysis

3.4.1 Rainfall Anomaly Index (RAI)

Table 3. Annual Rainfall Anomaly Index of the selected stations (1996-2017). Values in bold indicate extremely wet (positive) and dry (negative) years as bold with an underline.

Year	Chamkhar	Bhur	Trashiyangtse	Simtokha	Kanglung	Sipsu	Wangdi
1996	4.42	-1.63	5	-5.14	1.96	-1.76	-1.15
1997	3.88	-2.96	3.76	2.94	1.13	-1.51	0.68
1998	2.11	4.91	1.85	-1.56	-0.91	7.99	0.32
1999	3.05	2.38	4.25	3.49	-0.01	-0.27	3.49
2000	-1.99	-1.32	2.8	-3.4	2.79	5.71	-2.37
2001	-0.53	-5.28	-0.17	4.9	-2.9	-0.14	0.84
2002	-0.81	-4.44	-2.98	7.23	4.02	-0.85	4.92
2003	-4.89	1.39	-2.22	4.74	-0.66	-0.81	2.7
2004	5.2	9.7	-0.54	-1.33	6.9	-0.25	-3.36
2005	-3.22	-1.66	1.69	-3.48	3.47	3.73	-2.01
2006	1.01	-3.61	-0.35	-2.49	-2.8	-3.29	4.49
2007	-0.32	1.85	3.52	-4.84	4.7	-1.52	-2.79
2008	2.03	0.89	0.69	-0.37	0.46	2.83	-0.24
2009	-1.18	1.08	<u>-7.18</u>	-1.07	-1.19	-0.49	-1.34
2010	2.93	3.43	2.1	-0.6	0.07	7.64	6.16
2011	-1.96	-3.07	-6.29	-1.2	-4.71	-5.23	-0.13
2012	-5.23	0.05	-4.07	-0.69	-1.56	-1.65	-5.05

2013	2.56	-0.28	-1.25	0.29	4.51	-6.56	3.44
2014	-2.3	-3.36	-4.5	3.15	-5.33	-3.71	-4.01
2015	-1.38	0.94	2.54	-0.79	-1.91	0.73	2.96
2016	-0.26	1.25	2.18	3.16	-2.46	-1.69	-0.96
2017	2.81	3.07	2.01	0.45	-0.57	1.98	-2.48

168

169 In this study, analysis of the Rainfall Anomaly Index (RAI) of the 7 selected meteorological
170 stations across Bhutan are presented in Table 3. Extremely dry conditions occurred in
171 Trashiyangtse (2009) which was also reported by Pipchu (2018). Contrarily, extremely wet years
172 occurred in Simtokha (2002) and Sipsu (1998, 2010) and the highest inflection point of the
173 extremely wet period occurred in Sipsu in 1998, with RAI of 7.99. The dry and wet years across
174 these stations could be probably characterized by the influence of El Niño and La Niña,
175 respectively, though this needs additional examination. Bhur, which is located in the southern
176 Bhutan with lowest elevation among the stations, also exhibit an extremely wet year which resulted
177 to the 2004 monsoon flood event that also occurred in eastern part of Bhutan (Shrestha *et al.*, 2016).
178 The high RAI in 2004 is attributed to the heavy rainfall induced by monsoon influence (NCHM,
179 2019). Overall, these stations mainly exhibit drier than wet conditions in the recent years.

3.4.2 Precipitation Concentration Index (PCI)

Figure 3. Spatial distribution of precipitation concentration index (PCI) averaged from 1996-2017.

The spatial pattern of the annual average precipitation concentration index (PCI) values shown in Figure 4, depicts substantial differences in Bhutan's distribution of precipitation throughout all the years (1996-2017). The PCI values range from a minimum of 15.07 to 16.08 in some parts of northern and eastern regions to a maximum of 18.94 to 20.79 in most part of the southern regions of the country. The PCI values show increases from east to the west, indicating a clear gradient, where the western and southern parts of Bhutan experience substantial precipitation seasonality. According to An (2000), this may be linked to the summer monsoon winds, which blow from the southwest to the northeast. This is true for Bhutan as the Southwest monsoonal winds bring lot of

moisture to the southern foothills and north part of country receiving less rainfall due to high mountain barriers blocking the moisture carrying winds.

In an annual scale (not shown), the study observed that there were no PCI values of less than 12 in any of the time periods for all stations, indicating the absence of uniform distribution of rainfall throughout the year. Annual PCI values vary across different time periods and different stations with minimum PCI of 12.07 at Wangdi in 2005 and a maximum PCI value of 29.33 at Deothang in 1997. The PCI values are analysed to be sensitive to La Niña, probably. For instance, majority of the stations' PCI are found high during La Niña years 1998, 2000, 2007, 2012 and 2016. El Niño, however, could have only perturbed a few selected stations such as Deothang (1997, 2002) and Dagana (2014).

4. Summary and Conclusions

This statistical study was undertaken to understand the seasonal rainfall trend, annual spatial and temporal rainfall variability across meteorological stations in Bhutan. Our analyses find that the summer season is observed to have the highest contribution (73%) in the total rainfall in Bhutan while winter season contributed the least (1%). Seasonal rainfall trend for Bhutan indicates insignificant decreasing trend for spring, autumn and winter and an insignificant increasing trend for summer. The standard deviation of rainfall in Bhutan reveals that summer (winter) season has the highest (lowest) year-to-year variability among other seasons. The seasonal rainfall trend varies for each station.

Extremely dry and wet years in selected stations are likely to be characterized by the influence of El Niño and La Niña, respectively (Sano *et al.*, 2013; Dorji *et al.*, 2016b; Adhikari and Sharma

2020) but additional studies are warranted to corroborate the teleconnection influence. The first and second principal component explain the 90.1% and 4.9% of the total variance, respectively. The dominant component shows characteristics of Asian monsoon. The PCI analyses indicate the absence of uniform distribution of rainfall throughout the year. Annual PCI values vary across different time periods and different stations. Northeastern regions of the country receive relatively regular precipitation distributions throughout the year while in most of the Southern and Western regions indicate a high irregularity in the rainfall distributions. Overall, Bhutan receives less precipitation in the east compared to the west, of the country.

The influence of ENSO, complex topography, and Asian monsoon are almost certain in the variability of rainfall in Bhutan. While further efforts are underway to increase monitoring and recording of observations, these results provide information on rainfall variability of the districts and could prove beneficial to local authorities as input for the local adaptation planning, planning agricultural activities and development of adaptation strategies.

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