IJASRM International Journal of Advanced Scientific Research and Management, Vol. 1 Issue 10 , Oct 2016.
www.ijasrm.com
ISSN 2455-6378

Seasonal and annual variation of Temperature and Precipitation in Phuntsholing

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Abstract
Bhutan is one of the sensitive regions to climate variation particularly to temperature precipitation changes in the World as there is indication of melting Glaciers in the northern part of country. In this study, trends in precipitation and temperature at annual, seasonal and monthly time scales for the periods of 1996-2014 were examined for the Phunstholing which is located near the Indian Boarder. Non-parametric tests (such as Mann-Kendall and Sen's Slope) to determine climatic trends. In contrast, seasons represent slight precipitation increase (which are not statistically significant) annually, spring and autumn. Temperature data showed slight increase seasonally like spring and summer, even though results are not statistically significant for annually 1996-2014. The temperature data for summer months represent statistically significant increasing trends during the last 18 years. The main objective of this study is to observe the temperature and rainfall trend so far in Phuntsholing .Mann-Kendall's (MK) nonparametric test and Sen's slope estimation techniques were used to quantify the overall statistical significance of the results.

Keywords: ***Climate Variation, Precipitation, Mann-Kendall, Trend, nonparametric***

1. Introduction

Climate of the Earth varies across temporal and spatial scales throughout the planet. Climatic variability can be described as the annual difference in values of specific climatic variables within averaging periods such as a 30-year period. These climatic variations will have unexpected consequences with respect to frequency and intensity of precipitation and temperature variability for many regions of the Earth. Alt-hough the subject of climate change is vast, the changing pattern of precipitation deserves urgent and systematic attention as it will affect the availability of food supply (Dore, 2005) and the occurrence of water related disasters triggered by extreme events.

In the Eastern Himalayas, a substantial proportion of the annual precipitation falls as snow and becomes ice later on. Therefore, the snow is like a natural form of storage, releasing water slowly into the ground or rivers, water is increasingly available only at the time of precipitation. Even in the Himalayan region, inclusive of Tibetan Plateau, has shown some constant warming trends during the past 100 years (Yao et al. 2006). However, little is known in detail about the climatic characteristics of the Eastern Himalayas both because of the paucity of observations and in-sufficient theoretical attention which has been given to the complex interaction of spatial scales in weather and climate phenomena in mountain areas. Long-term data sets are needed to determine properly the degree and rate of climate change, but there are none available for most of the region.

A climate change signal that has been extracted from one single glacier will not a good representative of whole mountain areas as the variation between the mountains are very much. Freshwater availability in many river basins in Asia is likely to decrease due to climate change

The records from the western Himalayan region showing an increase trend in temperature at the rate of around 0.6°C/100 years but no such long-term trend has been recorded in precipitation. With the rise in temperature of mountain region, glaciers are retreating at an alarming rate at present scenario. If the rate of retreating of glaciers remain at this high rate, one day glaciers will disappear and the volume of rivers decreases drastically (WWF Nepal Program, 2005).

Both parametric and non-parametric tests are widely used for trend study. The advantage with a non-parametric test is that it only requires data to be independent and can tolerate outliers in the data (Hameed and Rao, 1998). One of the popular non-parametric tests widely used for detecting trends in the time series is the Mann-Kendall test (Mann, 1945) The two important parameters of this test are the significance level that indicates the trend strength and the slope magnitude that indicates the direction as well as the magnitude of the trend (Burn and Elnur, 2002). The advantage of the test is that it is distribution-free, robust against outliers and has a higher power than many other commonly used tests (Hess et al., 2001)

2. Data and Methodology

Trend analysis of temperature is determined by the historical data records of 18 years from 1996 to 2014 using the method of Mann-kendall (MK) test of non-parametric test.

Mann-kendall (MK) test.

The magnitude of the trend in the seasonal and annual series was determined using the Sen's estimator (Sen, 1968) and statistical significance of the trend in the time series was analysed using Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975).

Magnitude of trend

The magnitude of trend in a time series was determined using a non-parametric method known as Sen's estimator (Sen, 1968). This method assumes a linear trend in the time series. In this method, the slopes (T_i) of all data pairs are first calculated by

$$T_i = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1,2,\ldots\ldots,N \qquad (1)$$

where x_j and x_k are data values at time j and k (j>k) respectively. The median of these N values of T_i is Sen's estimator of slope which is calculated as

$$Qi = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \qquad (2)$$

A positive value of Q_i indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

Significance of trend

To ascertain the presence of statistically significant trend in hydrologic climatic variables such as temperature, precipitation and stream flow with reference to climate change, nonparametric Mann-Kendall (MK) test has been employed by a number of researchers (Douglas et al., 2000; Yue et al., 2003; Burn et al., 2004; Singh et al., 2008a, b; Kumar et al., 2009). The MK method searches for a trend in a time series without specifying whether the trend is linear or non-linear. In the present study the MK test was also applied. MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. The statistics (S) is defined as (Salas, 1993)

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}(x_j - x_i) \qquad (3)$$

where N is number of data points. Assuming $(x_j - x_i) = \theta$, the value of *sign(θ)* is computed as follows:

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & if \quad \theta > 0 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 0 \end{cases} \qquad (4)$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N>10), the test is conducted using a normal distribution (Helsel and Hirsch, 1992) with the mean and the variance as follows:

$$E[S] = 0 \qquad (5)$$

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k (t_k - 1)(2t_k + 5)}{18} \qquad (6)$$

Where n is the number of tied (zero difference between compared values) groups, and t_k is the number of data points in the k_{th} tied group. The standard normal deviate (Z-statistics) is then computed as (Hirsch et al., 1993):

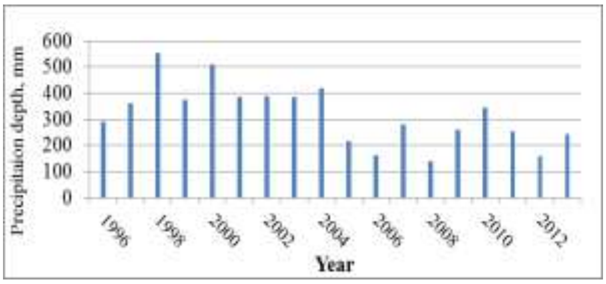
$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \qquad (7)$$

If the computed value of $|Z| > z_{\alpha/2}$, the null hypothesis (H_o) is rejected at α level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level.

Temperature and rainfall record data of phuntsholing for 18 years are shown graphically in the following graphs.

IJASRM International Journal of Advanced Scientific Research and Management, Vol. 1 Issue 10 , Oct 2016.
www.ijasrm.com
ISSN 2455-6378

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Mean annual tempt (0C)	31.2	30.6	31.1	31.9	30.2	30.4	29.2	27.3	30.4	27.8	26.8	27.7	28.9	30	29.8	30.7	30.3	31.4
Precipitaion, mm	292	363	554	375	510	383	388	386	420	217	163	279	138	262	346	253	159	243



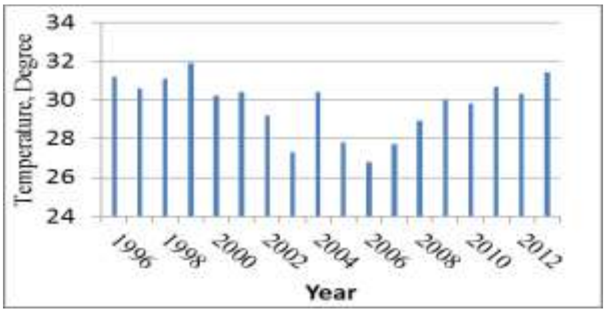


Fig 1: Data record of annul mean temperature and annual precipitation

3. Study Area

The princely Kingdom of Bhutan is a landlocked country, about 300 km long and 150 km wide encompassing an area of 46,500 square kilometers. Located between longitude $88^0 45'$ and $92^0 10'$ East and latitudes $26^0 40'$ and $28^0 15'$ North in the Eastern Himalayas, it is bounded by India in South and South-West and Tibetan autonomous region of China in the North and North-West respectively.

Fig 2: Bhutan map with 20 Districts

4. Results and Discussion

Almost the entire country is mountainous, and elevation ranges from 100m along the Indian border to the 7,554m Kulha Gangri peak on the Tibetan border. These two extremes frame a landscape which stretches from sub-tropical to arctic like conditions. The maximum East-West stretch of the country is approximately 300 km and north-South about 150 km.Chukha is one the District located at the boarder of India.

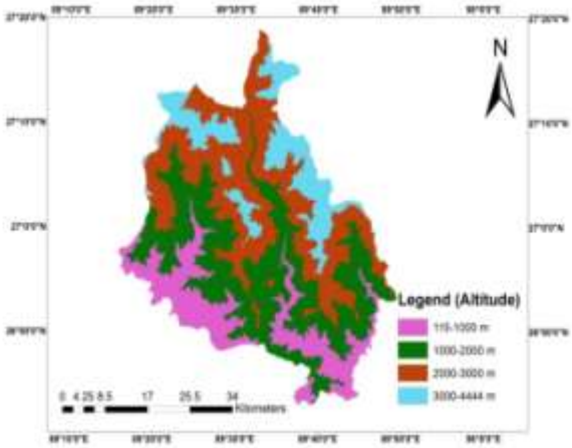


Fig 3: DEM of Chukha District

Phuntsholing region is situated at the latitude of 26o51′ 42.20″ and longitude of 89o22′ 58.01″ in the southern part of country at the 240 m above m.s.l. (mean sea level). This place is very much viable to climate change either by influencing Indian activities as it is located at the boarder of India.

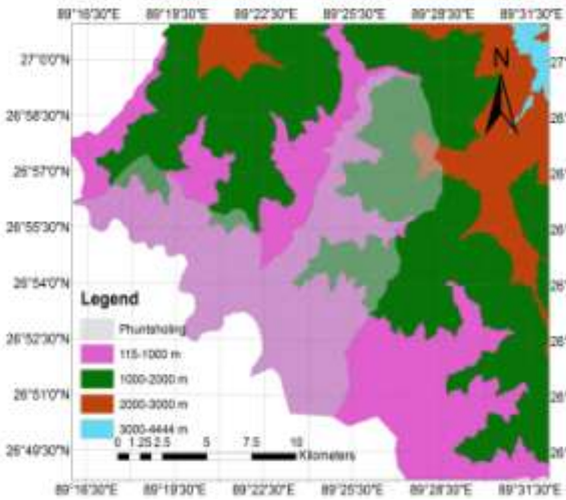


Fig 4: Location of Phuntsholing

International Journal of Advanced Scientific Research and Management, Vol. 1 Issue 10 , Oct 2016.
www.ijasrm.com
ISSN 2455-6378

Fig 5: Location of Study area (Phuntsholing)

5. Result and Discussion

The threat of global warming as of now is real and the resultant of its impact are an alarming as it has observed in and around world. The data availability of high altitude stations is almost negligible and only one meteorology station near by study area. The values of Mann Kendall statistic (Zmk) and Sen's slope (Q) for temperature from 1996 to 2014 are tested at 95% confidence level as indicated table 1. There are four season in Bhutan and it has been analyzed by the statistical method. The negative value shows the decreasing trend and positive value shows the increasing trend but for the temperature, no significant of trend is indicated.

Table 1: Mk test value and Sen's estimator of slope for temperature

Seasons	Test Z	Signific.	Q,Slope	Qmin95	Qmax95
Annual	-0.91		-0.05	-0.217	0.109
Spring	-0.49		-0.03	-0.148	0.143
Summer	0.19		0.03	-0.115	0.124
Autumn	-1.06		-0.08	-0.305	0.082
Winter	-1.52		-0.08	-0.330	0.067

The values of Mann-Kendall statistic Zmk and Sen's slope for short term period of temperature or different season are also represented graphically.

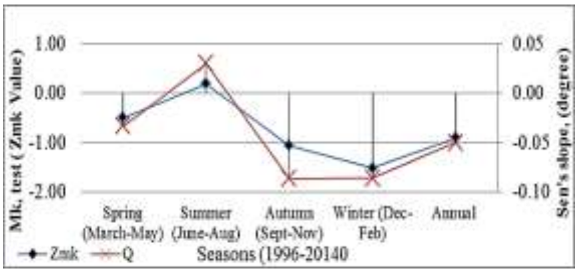


Fig 6: Seasonally value of Mk test and Slope (^{o}C)

According to the Sen's slope winter and autumn give the maximum values of decreasing trend. The only summer season gives positive values and also annual slope is a negative value.

The following graphs indicating the trend analysis for different seasons and annually.

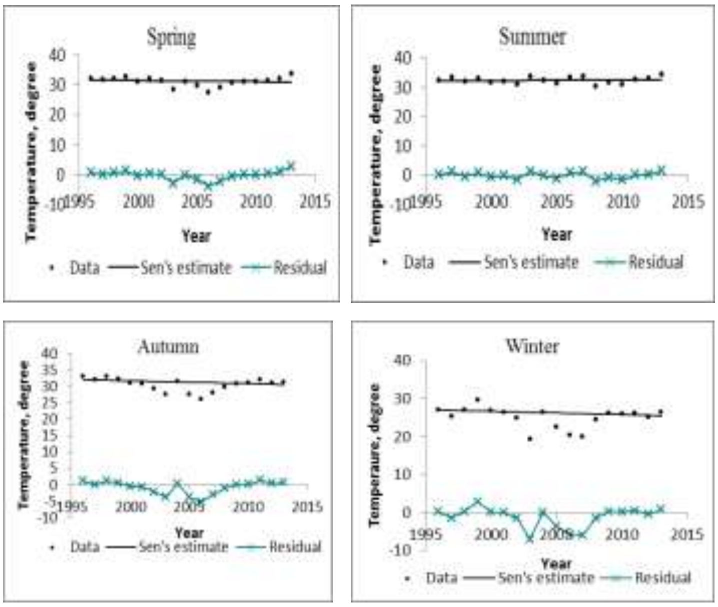


Fig 7: Temperature trend of four seasons (^{o}C)

International Journal of Advanced Scientific Research and Management, Vol. 1 Issue 10 , Oct 2016.
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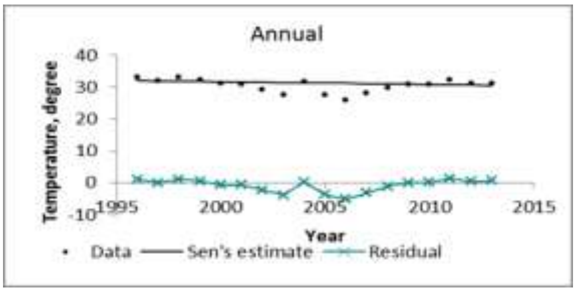

Fig 8: Trend of spring and summer (°C)

This Similarly, the values of Mann-Kendall statistic Zmk and Sen’s slope for short term period for the precipitation are shown below. Annual and summer indicates the most negative value of decreasing trend with significant at 95% confidence levels..

Table 2: Mk test value and Sen’s slope for precipitation

Season	Test Z	Signific.	Q, slope	Qmin95	Qmax95
Annual	-2.42	*	-12.84	-23.24	-2.62
Spring	-1.21		-5.75	-16.05	3.41
Summer	-2.65	**	-32.21	-63.86	-8.23
Autumn	-2.12	*	-6.42	-15.88	-0.93
Winter	-1.94	+	-1.57	-3.60	0.00

The Mann-Kendall test was employed on the seasonal and annual precipitation series. It is indicating the decreasing trends in annual and seasonal precipitation are found to be significant at 95% confidence level.

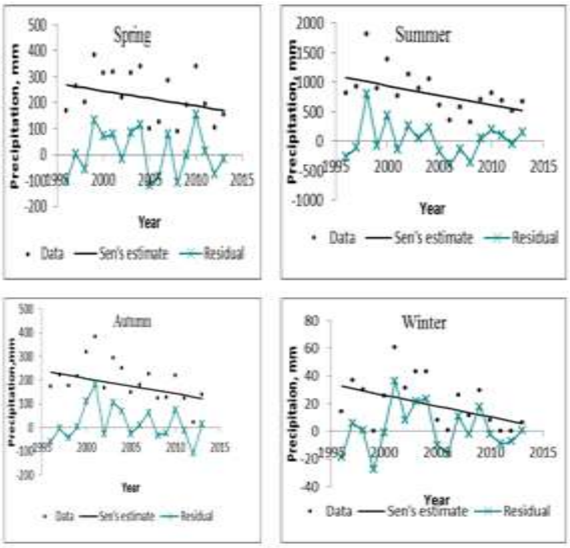

Fig 9: Precipitation trend of four seasons (oC)

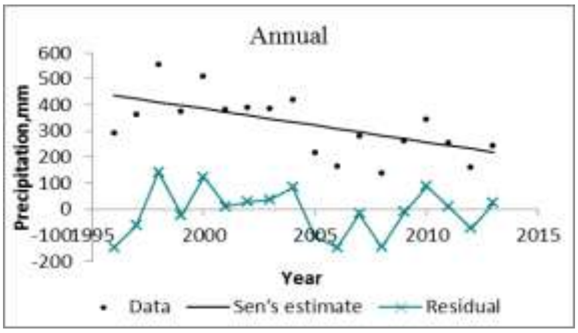

Fig 10: Annual trend of precipitation (mm)

6. Conclusion

The knowledge of spatial and temporal distribution and changing pattern of rainfall is a basic and important requirement for the planning and management of water resources especially in Bhutan. The present study has examined trends in the seasonal and annual rainfall of Phuntsholing area for the period 1996-2014.For temperature, showing the negative Sen’s slope in all the seasons, except in summer but all are indicating insignificant trend. None of seasons were significantly increasing or decreasing trend at 95% confidence level.

For precipitation, all the seasons were found to be a decreasing trend and summer season was most significant of decreasing trend. The overall found to be indicating the decreasing trend annually of 12mm/year. The present study is based on the analysis of temperature and rainfall using non-parametric Mann-Kendall trend test.

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