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Recent Trends in the Onset and Withdrawal of Summer Monsoon over Nepal

Dilip K. Gautam[1]* and Suman K. Regmi[2]

[1] Regional Integrated Multi-Hazard Early Warning System for Africa and Asia, Asian Institute of Technology campus, Klong Luang, Pathumthani 12120, Thailand.
[2] Department of Hydrology and Meteorology, Tribhuvan International Airport, Kathmandu, Nepal.

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ABSTRACT This paper presents the analysis of the onset and withdrawal dates and the duration of summer monsoon over Nepal for last 63 years (1951-2013). The trend analysis revealed that both the onset and withdrawal of summer monsoon are delayed in recent years. The statistical analysis using cumulative deviation and Worsley likelihood tests showed a step jump in mean withdrawal date after the year 1997. The mean withdrawal date after 1997 is later than the normal withdrawal date by 10 days. Although, the trend for onset is statistically insignificant, the trend for withdrawal is significant at 5% level. Stationarity tests for the period of 1951-1996 and 1997-2013 also revealed that both the onset and withdrawal series are non-stationary. A step change in withdrawal date with delayed trend on both onset and withdrawal coupled with longer duration suggests a temporal shift in the monsoon pattern over Nepal after 1997. The temporal shift in the monsoon is consistent with published findings on the effect of global climate change on the dynamics of the South Asian summer monsoon precipitation. The shifting pattern of the summer monsoon exerts a strong stress on agriculture, water resources, ecosystems, human health and the overall economy of the country.

Key words: *Nepal, Monsoon, Onset, Trend, Withdrawal*

1 INTRODUCTION

The economy of Nepal is dominated by agriculture sector providing about 35% of the GDP with about 66% population depending upon it. About two-thirds of agricultural GDP comes from the crops sub-sector and the remainder from the livestock sub-sector. Most agricultural holdings can be classified as subsistence family farms (64%) with only 3.1% classified as actual commercial farming operations (MOAC, 2010).

About 31% of the agricultural land is irrigated and the rest is heavily dependent on summer monsoon rains. Even all the irrigated areas have no access to year-round irrigation. Irrigation water availability also depends upon rainfall as it recharges the groundwater aquifers and provides stable flow in the rivers for the dry season. The summer monsoon is the most important season in Nepal for agriculture with nearly 80% of annual precipitation falling between June and September.

Corresponding Author: Regional Integrated Multi-Hazard Early Warning System for Africa and Asia, Asian Institute of Technology Campus, Pathumthani 12120, Thailand, Tel: +66 82 926 0043, E-mail: dilip.gautam@rimes.int

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The summer crops (paddy, maize and millet) comprise nearly 80% of the total national cereal production. Paddy is the main crop cultivated extensively in the Terai region where more than 70% of the national production is grown. Paddy alone accounts for more than 50% of the national cereal production (GON, 2010). The rice crop requires abundant water for transplanting, and so is sensitive to the onset of monsoon. If the onset of monsoon is delayed, it will also delay the transplantation and ultimately reduce the rice yield (Prasai, 2010). Similarly, heavy rainfall and floods in October may ruin the rice in maturation and harvesting stage. Increasing variability of precipitation patterns will have a significant effect on crop productivity, as farmers will have to adapt to the changing onset and termination dates of the monsoon. The delay in the onset of monsoon significantly impacted the rice crops in 2009, as many seedlings were lost and some did not have enough time to mature enough for a viable yield (WFP, 2010).

Nayava (2008) studied the rice yield and the monsoon rainfall for the last 30 years from 1971 to 2000 and showed that the rice yield in Nepal was badly affected in those years, when the monsoon rainfall was lower than normal. Therefore, the impact of rainfall on rice production is quite evident. Similarly, the delay in monsoon severely affected the maize plantation in the hilly region in 2012, which contributes to 76% of total maize production (Sapkota, 2012). The nature of the rainfall, its amount, seasonal distribution and intensity, frequency of occurrence, variability and areal variation are the major factors affecting the agricultural potential (Nayava, 1980). Hence, timely onset, regular downpour, adequate amount and timely withdrawal of summer monsoon are vital for food security in Nepal.

In recent years, irregular patterns have been observed on the onset and withdrawal of summer monsoon rainfall over Nepal. Eastern Terai received deficit rainfall in 2005 due to shorter monsoon duration because of late onset. As a result, nearly 10% of agricultural lands remained fallow and the crop production decreased by 12.5% on a national basis (Malla, 2008). In 2009, the monsoon rainfall continued even after the normal date of withdrawal and created havoc with heavy rainfall, floods and landslides in the mid and far-western regions of the country. A record rainfall of 221 mm was recorded on 5th October, 2009 at Dipayal station. Similar rainfall event following the landslides and flash floods occurred in far-western region on 20th September 2008 when the monsoon was supposed to be in the withdrawal phase. Thus, the study has been carried out to analyze the existing records on monsoon onset date, withdrawal date and duration of last 63 years (1951-2013) and investigate the randomness, homogeneity and temporal patterns in the data set.

2 MONSOON AND ITS CHARACTERISTICS IN NEPAL

The climate of Nepal is influenced by its location in subtropical latitude; mountainous topography and the South Asian monsoon. The climatological (normal) date of onset and withdrawal of monsoon over Nepal are 10 June and 23 September respectively with the average duration of 105 days (DHM, 2010). Monsoon enters from the eastern parts of Nepal and gradually covers the entire country within a week. The amount of rainfall is much higher in the eastern region and substantially decreases from the east to west. On contrary to onset, the withdrawal of the monsoon takes place from west to east.

The analysis made from the observations of 166 stations rainfall data for the period from 1976 to 2005 by Practical Action (2009) revealed that 79.6% of rainfall occurs in the monsoon period. Figure 1 shows the spatial variation of monsoon rainfall over Nepal. The spatial variation of the monsoon rainfall in the country is highly influenced by the topography and altitude differences resulting in significant local changes. Spatial variation is typical throughout the hills but most evident across the Annapurna range in central Nepal indicating a large spatial variation in monsoon rainfall ranging from less than 150 mm in Mustang and Dolpa to more than 4500 mm in Kaski. The effect of monsoon is prominent in the eastern half of the country. The western half especially the northern parts of mid western development region are generally drier compared to the eastern half (Practical Action 2009). The mean rainfall for Nepal during the monsoon season amounts to be 1422.8 mm with standard deviation (SD) of 132.6 mm and coefficient of variation (CV) of 9.3% (Shrestha, 2000). The aspects of monsoon rainfall event concerning its timing, intensity, duration and spatial coverage are of great interest.

The trend analysis made from the observations of 166 stations rainfall data for the period from 1976 to 2005 by Practical Action (2009) revealed the overall increasing trend in monsoon rainfall with 3 mm per year in the most part of the country. Figure 2 shows the monsoon rainfall trend over Nepal. Baidya *et al.* (2008) found increasing trend in precipitation extremes in total and heavy precipitation vents at most of the stations based on 46 years data from 1961-2006.

The troughs and depressions are the main semi permanent features for monsoon rainfall in Nepal. The monsoon trough is the extension of Inter Tropical Convergence Zone (ITCZ) which is almost parallel to the Himalayas. This trough is responsible for active and break monsoon in Nepal. Nepal receives heavy rainfall when the monsoon trough is close to the foothills of the Himalayas. Depressions or low pressure areas originated in and around the Bay of Bengal also move along the monsoon trough causing rainfall in Nepal.

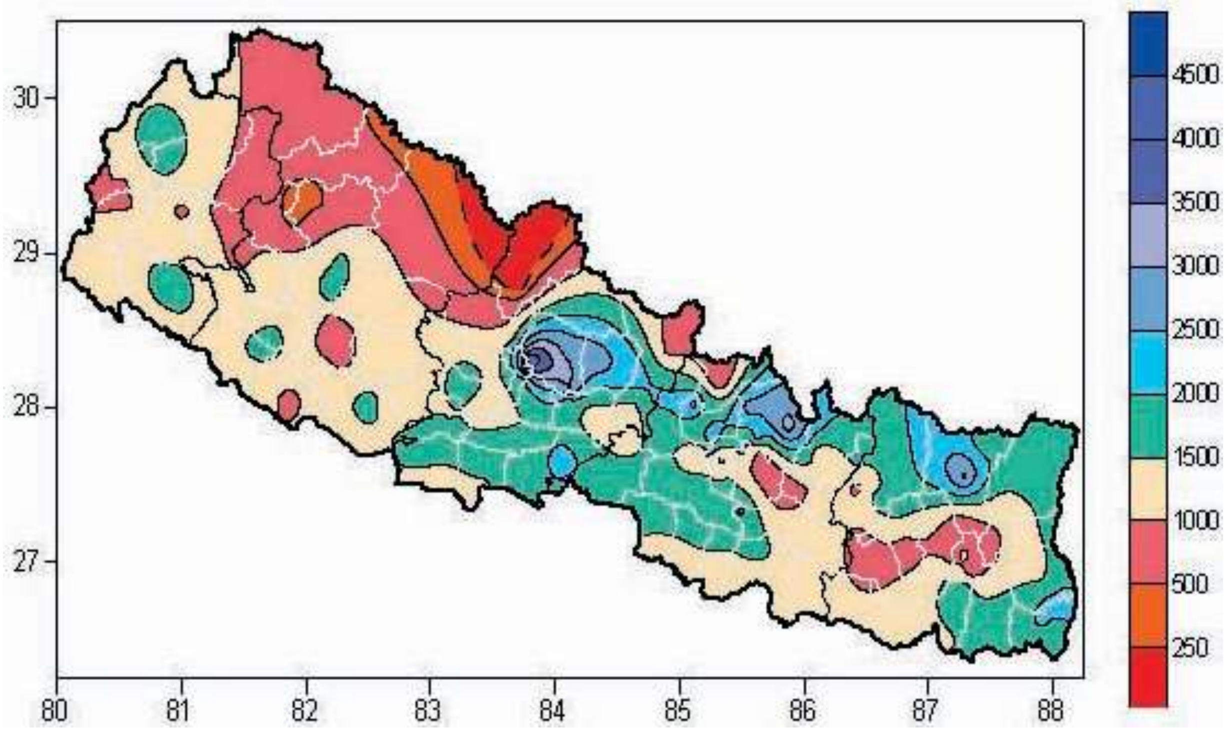

Figure 1 Monsoon mean rainfall (mm) over Nepal (Source: Practical Action, 2009)

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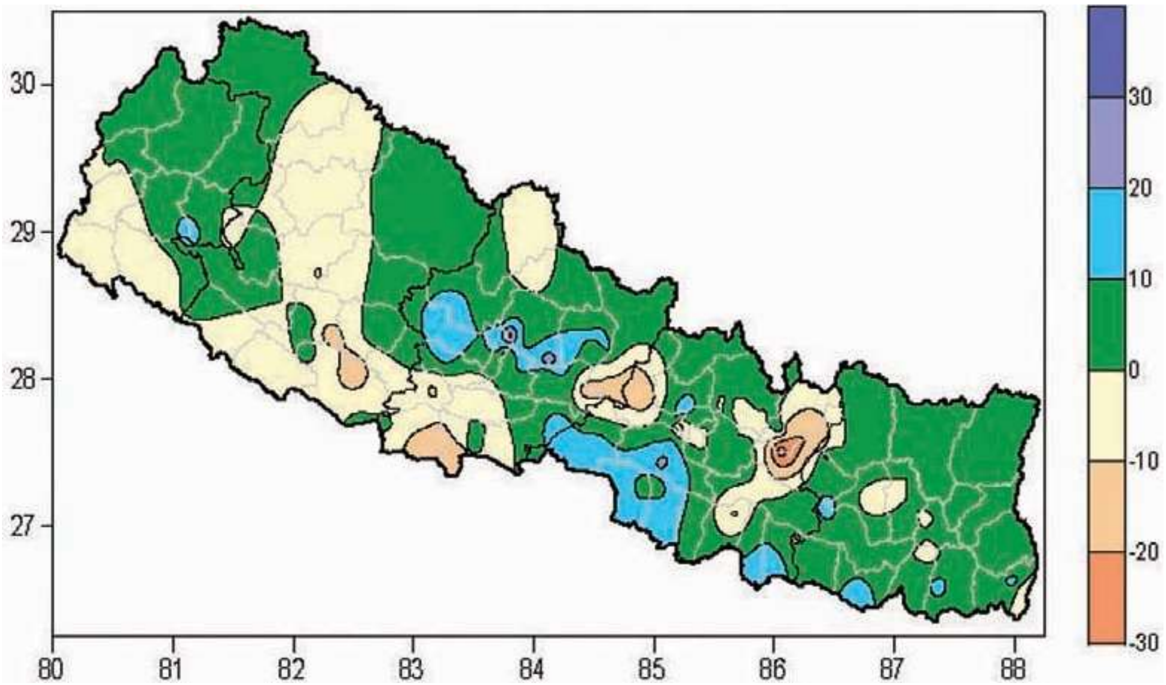

Figure 2 Monsoon rainfall trend (mm/year) over Nepal (Source: Practical Action, 2009)

It is generally believed that the differential heating of land and water surfaces is responsible for the monsoon activities. Monsoon originates as the southeast trades of southern hemisphere which after crossing equator and deflection by Coriolis force approaches the heated continent of South Asia as southwest monsoon (Devkota, 1983). The onset and withdrawal of monsoon are associated with the change in the direction of seasonal winds and the northward and southward movement of the equatorial (monsoon) trough (Ananthakrishnan and Rajagopalachari, 1964). Lang and Barros (2002) analyzed a relatively short record of 5 years (1997–2001) of rainfall data from central Nepal and suggested that the monsoon onset in central Nepal is closely linked to monsoon depressions in the Bay of Bengal. The formation of depressions or low pressure areas is associated with the burst of monsoon. On contrary to this, the formation of low pressure areas intensifying into depression or cyclone just prior to the monsoon onset results delay in monsoon.

The onset date of monsoon each year is determined by a sharp increase and characteristic persistency in rainfall (Ananthakrishnan *et al.*, 1967). Therefore considering the variability of rainfall over short time period, five day's (Pentad) rainfall criteria is also used for the analysis. But in Nepal, thunderstorm activities are highly pronounced and cumulative precipitation shows a sudden increase making the onset quite confusing. In such a case, Department of Hydrology and Meteorology (DHM) decides the onset date by the study of the atmospheric pattern over the region. The following principles are taken into consideration for the determination of the monsoon onset date in Nepal.

- The formation of a strong thermal low over northwest India and Pakistan and decreasing of pressure below 990 hPa.

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- The formation of cyclonic circulation over Rajasthan, Madhya Pradesh, Bihar, Bengal
- Locating of distinct monsoon trough (surface ITCZ) over Indo-Gangetic plane
- Increasing numbers of isobars over the Indian sub-continent resulting in a symmetric pattern of narrow isobars
- Strengthening of cross equatorial flow
- Shifting of the westerly jet stream at 500 hPa over northwest India towards across Himalayan belt at 40^0N and appearance of the easterly jet stream over peninsular India between 200 and 100 hPa, resulting in the establishment of an easterly wind over South Asia at all levels
- Domination of the Tibetan plateau by high pressure cell at 500 hPa and the movement of the subtropical ridge line between 300 and 200 hPa around 30^0N.

There are no objective criteria defined for the withdrawal of the monsoon from Nepal. Most of the times, the withdrawal of the monsoon is linked with the recession of weather activities. Similarly, withdrawal of monsoon is also associated with the shifting of the westerly jet southwards below 40^0N at 200 hPa. Subsequently, the easterly wind also weakens at the mid and lower tropospheric levels diminishing all the monsoon semi-permanent features. Based on these observations, the Meteorological Forecasting Division of the Department of Hydrology and Meteorology declares the withdrawal date of the monsoon. But occasionally, occurrence of the rainfall due to western disturbances immediately after the monsoon makes it difficult for the declaration of monsoon withdrawal.

South Asian monsoon has both interannual and intraseasonal variability. Duan *et al.* (2007) found the evidence of a significant South Asian monsoon variability in the Himalayas over the past 300 years by the study of ice-core. The 300 year accumulation record showed that South Asian monsoon in the Himalayas had weakened in the 18th century and then strengthened between 1795–1850, weakened again during 1850-1875 and strengthened during 1875–1920, after that it has weakened from early 1920 to the present.

3 DATA AND METHODS

Annual data on summer monsoon onset date, withdrawal date and duration for last 63 years (1951-2013) have been obtained from the records of the Meteorological Forecasting Division of the Department of Hydrology and Meteorology (DHM), Nepal. Figures 3(a) – 3(c) in the next section present the time series plots of the onset date (Day-Of-Year), withdrawal date (Day-Of-Year) and duration (days) for 1951-2013 respectively.

The following methods are employed to analyze the randomness, homogeneity and temporal patterns of data.

i. Exploratory Data Analysis
ii. Stationarity test
iii. Various statistical tests for trend, step change and randomness

Exploratory Data Analysis (EDA) is a very powerful graphical technique to explore, understand and present data and is an essential component of any statistical analysis. Its first use is to examine the raw data, check ranges and find any outliers visually. EDA can uncover some of the following aspects of data (Kundzewicz and Robson, 2000):

- Temporal patterns (e.g. trend or step-change)
- Seasonal variation
- Regional and spatial patterns
- Data problems (outliers, gaps in the record etc.)
- Correlations (between variables or sites).

Stationarity test is performed to determine whether the mean values and variances of a series vary with time. Two methods are widely used for testing the stationarity of a time series. These are Kwiatkowski, Phillips, Schmidt and Shin (KPSS) stationarity test (Kwiatkowski *et*

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al., 1992) and Augmented Dickey-Fuller (ADF) unit root test (Dickey and Fuller, 1979).

Statistical tests detect the changes in a time series which can occur steadily (a trend), abruptly (a step-change) or in a more complex form. It may affect the mean, median, variance, autocorrelation or almost any other aspect of the data (Kundzewicz and Robson, 2000; Francis and Lionel, 2005). Various statistical methods to test for trend, change and randomness in the time series data are given in Table 1. The most widely used tests for change look for one of the following:

- Trend in the mean or median of a series
- Step-change in the mean or median of a series.

Mann-Kendall, Spearman's Rho and Linear Regression methods are used to detect trend in the time series. Step change in the mean or median of a series is identified using Distribution Free CUSUM, Cumulative Deviation and Worsley Likelihood Ratio methods. Median Crossing, Turning Points, Rank Difference and Autocorrelation methods are employed to detect randomness.

A statistical test is performed by defining the null and alternative hypotheses, calculating test statistic and comparing with the expected distribution of the test statistic under the null hypothesis. A significance level is defined to measure whether a test statistic is very different from values that would typically occur under the null hypothesis. The significance level gives the probability of a value as extreme as, or more extreme than the observed value, assuming "no change" (the null hypothesis). For example, a 5% significance level means that we will make an error 5% of the time i.e. if the null hypothesis was true then 1 in 20 test results will have a significant (and incorrect) result.

Resampling analysis could be performed with replacement (bootstrapping method) to obtain a good estimate of the critical test statistic values and the significance level of a test statistic. For detecting trend/change of any direction, the critical test statistic value at $a/2$ is used (two sided tail). For detecting trend/change in a pre-specified direction (e.g., an increasing trend), the critical test statistic value at a is used (one-sided tail). The null hypothesis is valid if the test statistic is smaller than the critical values. Otherwise, if the test statistic is higher than the critical values, the alternative hypothesis is valid.

Table 1 Statistical tests for trend, step change and randomness in the time series data

Test Property	Test Method	Remarks
Trend	Mann-Kendall	non-parametric
	Spearman's Rho	non-parametric
	Linear Regression	parametric
Step change in mean/median	Distribution Free CUSUM	non-parametric
	Cumulative Deviation	parametric
	Worsley Likelihood Ratio	parametric
Difference in mean/median	Rank-Sum	non-parametric
	Student's t-test	parametric
Randomness	Median Crossing	non-parametric
	Turning Points	non-parametric
	Rank Difference	non-parametric
	Autocorrelation	parametric

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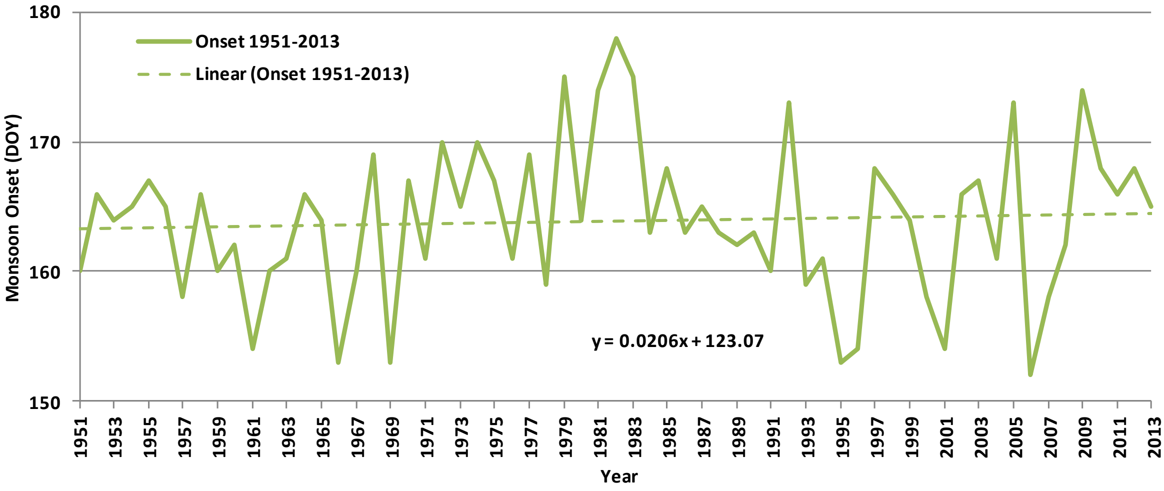

Figure 3(a) Monsoon onset showing overall positive (late) trend for 1951-2013

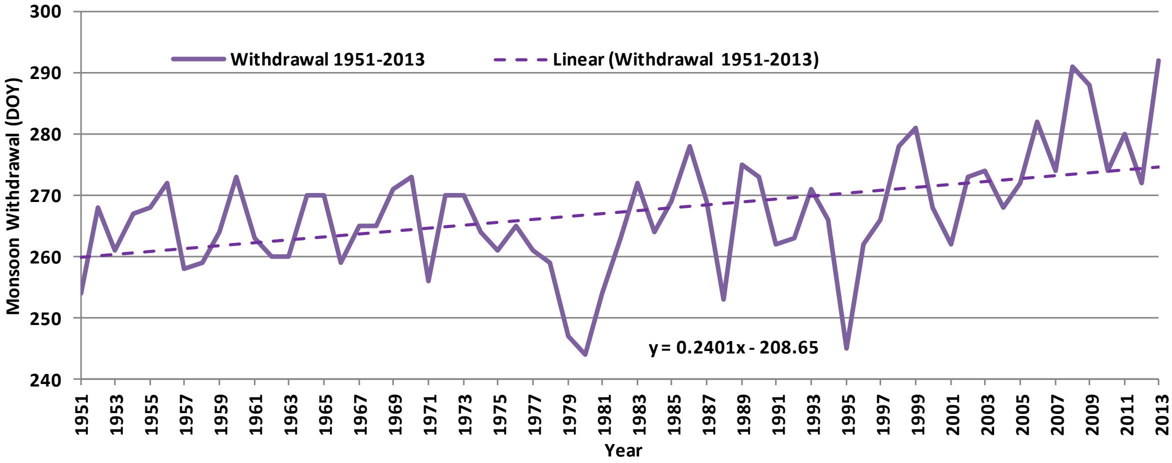

Figure 3(b) Monsoon withdrawal showing overall positive (late) trend for 1951-2013

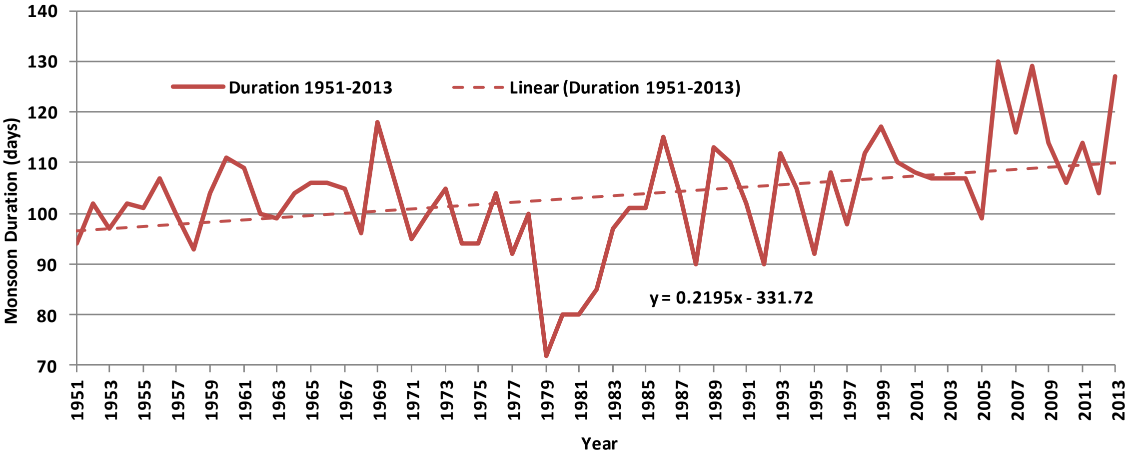

Figure 3(c) Monsoon duration showing overall increasing trend for 1951-2013

4 RESULTS

Exploratory data analysis was performed by examining the time series plot of the onset date, withdrawal date and duration against the year. Figures 3(a) – 3(c) present the monsoon onset date, withdrawal date and duration for 1951-2013 respectively. The plots show high variability on onset and withdrawal dates. The date of onset varies from 1st June to 27th June. Similarly, the date of the withdrawal varies from 31st August to 19th October and the duration of the monsoon period varies from 72 to 130 days. The mean date of the onset is 13th June which is 3 days later than the date fixed by the Department of Hydrology and Meteorology. The mean date of withdrawal is 24th September for 1951-2013. However, for 1997-2013, the mean date of withdrawal is 3rd October which is 10 days later than the normal date. The standard deviations of onset and withdrawal dates are 6 and 10 days respectively.

It is seen that the onset dates are later than mean date in 43% of the years, the maximum delay being 17 days in 1982. The onset dates show slightly delayed trend of 0.02 days per year for the whole data set (1951-2013). Similarly, the dates of withdrawal are also found to be later than the mean date for 50% of years, the maximum delay being 26 days in 2013. The withdrawal dates show delayed trend of 0.24 days per year. A step jump in mean withdrawal date is observed since 1997 (see Figures 4(a) – 4(c)). The durations of the monsoon are also found to be higher than normal for 52% of years, the longest duration being 130 days in 2006. The standard deviation of duration is 11 days. The monsoon durations show significantly increasing trend of 0.2195 days per year for whole data set.

Figures 4(a) – 4(c) present the comparison of monsoon onset date, withdrawal date and duration respectively for 1951-1996 and 1997-2013. The onset dates show delayed trend of 0.2279 days per year for 1997-2013. The withdrawal dates also show sharp delayed trend in recent years, especially after 1997. The delayed trend of withdrawal for recent 17 years (1997-2013) is 0.8873 days per year. The increasing trend of monsoon durations in recent years is 0.6593 days per year.

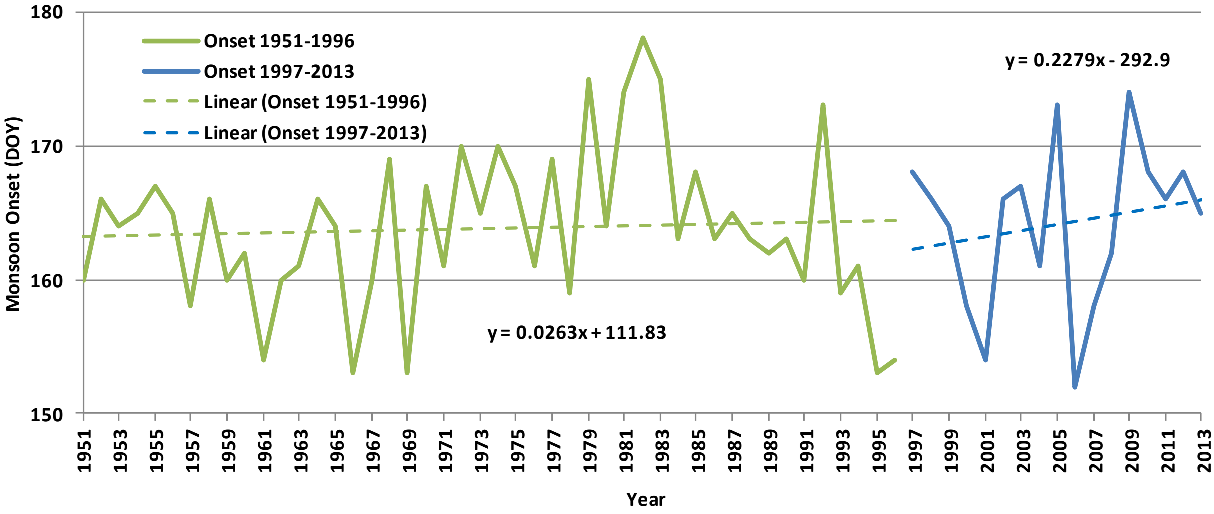

Figure 4(a) Monsoon onset showing significant positive (late) trend after 1997

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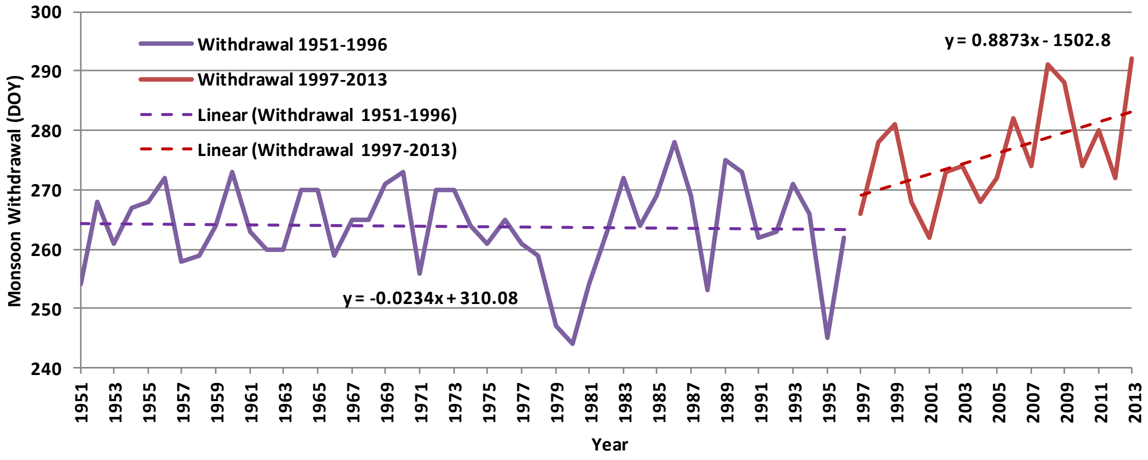

Figure 4(b) Monsoon withdrawal showing significant positive (late) trend after 1997

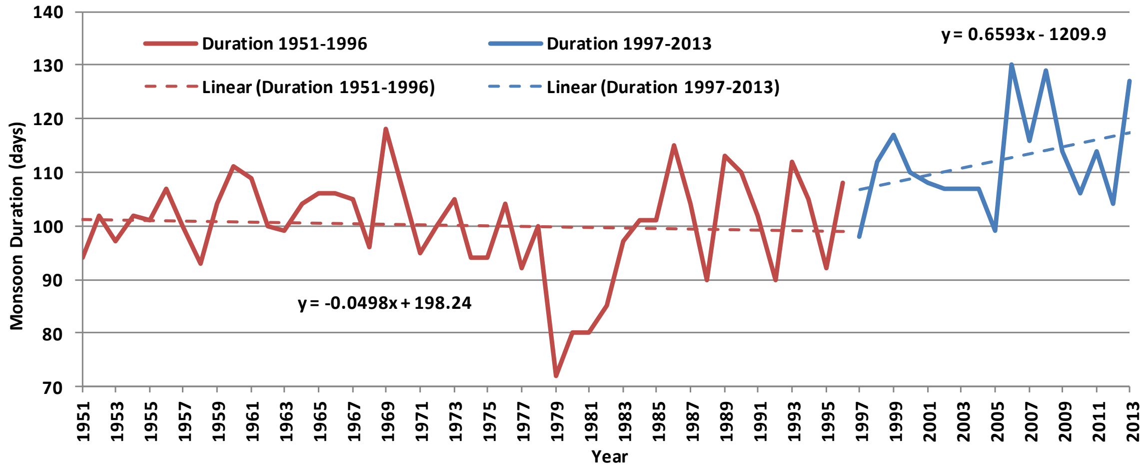

Figure 4(c) Monsoon duration showing significant increasing trend after 1997

KPSS and ADF stationarity tests were performed at 5% significance level on the onset, withdrawal and duration data set using Econometrics Toolbox of MATLAB R2012a. KPSS and ADF tests for the whole series revealed that the series is non-stationary. Since step jump is found in the series after 1997, stationarity tests have been performed for the both parts of the series to evaluate whether the parts of the series are piecewise stationary. Table 2 presents the stationarity test results for onset, withdrawal and duration for the whole series as well as the parts of the series. Both tests suggest that the whole series as well as the parts of the series exhibit nonstationarity. The onset, withdrawal and duration series after 1997 are found trend stationary indicating the presence of deterministic trend.

Further, statistical analysis has been performed using TREND V1.0.2 software developed by Cooperative Research Centre for Catchment Hydrology (CRCCH), Australia (CRCCH, 2005). TREND has 12 different statistical tests for trend, change and randomness in the time series data, based on the WMO/UNESCO Expert Workshop on Trend/Change Detection and on the CRC for Catchment Hydrology publication Hydrological

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Recipes (Grayson *et al.*, 1996). It gives results for a two-sided tail test. Resampling analysis has also been performed with replacement (bootstrapping method) and 1000 replicates were generated to obtain a good estimate of the critical test statistic values.

Table 2 Stationarity test results for onset, withdrawal and duration series

Data type	KPSS stationarity test		ADF unit root test		Remarks
	Test statistics	Critical values	Test statistics	Critical values	
Onset (1951-2013)	0.1543	0.1460	-0.1078	-1.9456	Nonstationary (Autoregressive)
Withdrawal (1951-2013)	0.3389	0.1460	0.3748	-1.9456	Nonstationary (Autoregressive)
Duration (1951-2013)	0.4174	0.1460	-0.0297	-1.9456	Nonstationary (Autoregressive)
Onset (1951-1996)	0.2485	0.1460	-0.2648	-1.9471	Nonstationary (Autoregressive)
Withdrawal (1951-1996)	0.0742	0.1460	0.0061	-1.9471	Nonstationary (Trend stationary)
Duration (1951-1996)	0.2034	0.1460	-0.1566	-1.9471	Nonstationary (Autoregressive)
Onset (1997-2013)	0.0724	0.1460	-0.1868	-1.9553	Nonstationary (Trend stationary)
Withdrawal (1997-2013)	0.0634	0.1460	0.5539	-1.9553	Nonstationary (Trend stationary)
Duration (1997-2013)	0.0549	0.1460	0.3286	-1.9553	Nonstationary (Trend stationary)

Table 3 Test statistics for the date of monsoon onset for 1997-2013

Test method	**Test statistic**	**Critical values**			**Critical values (Resampling)**			**Result**
		a=0.1	**a=0.05**	**a=0.01**	**a=0.1**	**a=0.05**	**a=0.01**	
Mann-Kendall	0.577	1.316	1.568	2.061	1.524	1.812	2.513	NS
Spearman's Rho	1.069	1.316	1.568	2.061	1.775	2.059	2.618	NS
Linear regression	0.755	1.753	2.131	2.947	1.738	2.149	3.111	NS
Cusum	6	5.03	5.607	6.721	8	9	13	NS
Cumulative deviation	0.848	1.085	1.196	1.381	1.07	1.178	1.352	NS
Worsley likelihood	1.958	2.942	3.328	4.244	2.874	3.272	4.559	NS
Rank Sum	-1.107	1.316	1.568	2.061	1.876	2.165	2.55	NS
Student's t	-0.724	1.746	2.12	2.921	1.715	2.018	2.572	NS
Median Crossing	0.5	1.316	1.568	2.061	1.5	2	2.5	NS
Turning Point	-1.217	1.316	1.568	2.061	2.434	3.043	4.26	NS
Rank Difference	-0.665	1.316	1.568	2.061	1.774	2.07	2.587	NS
Auto Correlation	0.535	1.316	1.568	2.061	1.617	1.845	2.375	NS

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Table 4 Test statistics for the date of monsoon withdrawal for 1997-2013

Test method	Test statistic	Critical values a=0.1	Critical values a=0.05	Critical values a=0.01	Critical values (Resampling) a=0.1	Critical values (Resampling) a=0.05	Critical values (Resampling) a=0.01	Result
Mann-Kendall	1.977	1.316	1.568	2.061	1.607	1.895	2.348	S (0.05)
Spearman's Rho	2.049	1.316	1.568	2.061	1.814	2.127	2.804	S (0.1)
Linear regression	2.365	1.753	2.131	2.947	1.734	2.266	2.977	S (0.05)
Cusum	5	5.03	5.607	6.721	7	9	11	NS
Cumulative deviation	1.268	1.085	1.196	1.381	1.08	1.191	1.402	S (0.05)
Worsley likelihood	3.028	2.942	3.328	4.244	2.493	2.875	3.843	S (0.05)
Rank Sum	-2.261	1.316	1.568	2.061	1.78	1.973	2.55	S (0.05)
Student's t	-2.128	1.746	2.12	2.921	1.651	1.869	2.356	S (0.05)
Median Crossing	0.5	1.316	1.568	2.061	1.5	2	2.5	NS
Turning Point	0	1.316	1.568	2.061	2.434	3.043	3.651	NS
Rank Difference	-1.109	1.316	1.568	2.061	1.7	2.07	2.661	NS
Auto Correlation	0.882	1.316	1.568	2.061	1.69	1.935	2.493	NS

NS: Not Significant, S: Significant

CUSUM, Cumulative Deviation and Worsley Likelihood Ratio tests on withdrawal series showed step jump in mean and median with 1997 being the year of change. Hence, the data were divided into two series; 1951-1996 and 1997-2013. The summary of the test results for the date of monsoon onset and withdrawal for 1997-2013 are given in the Table 3 and 4 respectively.

All the test statistics for the monsoon onset, withdrawal and duration for 1951-1996 series did not reveal statistically significant trend. Similarly, all the test statistics for the monsoon onset and duration for 1997-2013 series also did not show statistically significant trend. However, test statistics for the withdrawal for 1997-2013 showed different result. The Mann-Kendall and Linear Regression tests on the date of withdrawal for 1997-2013 showed that the test statistic is higher than the critical value at 5% significance level indicating a very strong evidence of delayed trend (late withdrawal). Spearman’s Rho test showed increasing trend significant at 10% level. However, the randomness tests did not strongly suggest that data do not come from a random process.

5 CONCLUSION

Analysis of 63 years of data revealed a large interannual variation on the dates of the onset and withdrawal of summer monsoon over Nepal. Both the dates of onset and withdrawal of summer monsoon are found to be delayed in recent years. This result is consistent with the finding by Goswami *et al.* (2010) for the onset phase of Indian summer monsoon which has slowed down significantly during the past decade compared with prior decades. Goswami *et al.* (2010) have suggested that the delay on the onset is due to systematic weakening of the vertical easterly wind shear and the north–south gradient of the mean low-level humidity around the equator.

The stationarity tests showed that both onset and withdrawal dates are non-stationary. The Cumulative Deviation and Worsley Likelihood Ratio tests showed a step jump in mean withdrawal date after the year 1997. The mean withdrawal date after 1997 is delayed by 10 days from the normal withdrawal date. There is a delayed trend for both the date of onset and withdrawal over Nepal after 1997. Although, the trend for onset is statistically insignificant,

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the trend for withdrawal is significant at 5% level. A general late onset coupled with late withdrawal and step change in mean withdrawal date suggests a temporal shift in the monsoon pattern over Nepal after 1997.

The substantial variability on onset, withdrawal and duration of the summer monsoon exerts a strong stress on agriculture, water resources, hydropower generation, ecosystems, human health and overall economy of the country. In 2009, late onset of the monsoon and irregular distribution of rainfall caused a reduction in the summer crop production across the country by more than 6%. Paddy production was down by 11% and maize production was down by 4% compared to that of 2008. The withdrawal was also delayed and an excessive rainfall was observed during 4-8 October, which caused floods and landslides in the mid- and the far-western districts. The total amount of rainfall during the four days exceeded total monthly rainfall in some areas, which resulted in a considerable damage to the summer crop production (WFP 2010). This clearly indicates that a delay on withdrawal coupled with heavy rainfall could be devastating.

The monsoon in Nepal is greatly influenced by the monsoon variability with the dynamical parameters representing the circulation of monsoon over the Bay of Bengal. Dash *et al.* (2004) have shown that there is a decreasing trend in the number of monsoon depressions over the Bay of Bengal during the last two decades. The inter-annual variation of monsoon is closely linked with the linear trends of the surface air temperature in the regions in and around the Bay of Bengal.

Shrestha (2000) has shown that the influence of Southern Oscillation (SO) in monsoon rainfall over Nepal is very significant. The years with significant negative (positive) Southern Oscillation Index (SOI) have less (more) rainfall. Sigdel and Ikeda (2012) have also shown that the mechanism which governs strength of the monsoon system over Nepal is the large-scale phenomena such as El Niño Southern Oscillation (ENSO); La Niña for high summer monsoon and El Niño for weak summer monsoon. Positive Sea Surface Temperature (SST) anomalies are related to warm phase or El Niño events and negative anomalies are related to cool phase or La Niña events. The ENSO, SO and SST are highly correlated with each other.

Onset, withdrawal, and season length all show significant correlations with sea surface temperatures (SST) in the Indian Ocean, tropical Pacific, and in the North Pacific regions (Cook and Buckley, 2009; Sabeerali *et al.*, 2011). The changes in SSTs are attributed to anthropogenic forcing both globally and regionally and the increase of SST is likely to increase heavy precipitation events (IPCC 2007). Recently, a Purdue University research group used a high-resolution nested climate modeling system to investigate the response of South Asian summer monsoon dynamics to anthropogenic increases in greenhouse gas concentrations and found that climate change could influence monsoon dynamics and cause less summer precipitation, a delay in monsoon onset and an increase in the occurrence of monsoon break periods (Ashfaq *et al.*, 2009). The shift in the monsoon pattern over Nepal shows consistency with the findings by Ashfaq *et al.* (2009). Further detailed investigation is required to definitely attribute the temporal shift in the monsoon pattern over Nepal to the impact of global climate change and hence recommended for future study.

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روند جدید در هجوم و بازگیری مونسون تابستانی نپال بالایی

دیلیپ ک. گوتام[1]* و سومان ک. رگمی[2]

۱- سامانه جامع هشدار چندمنظوره افریقا و آسیا، کامپوس انستیتوی فناوری آسیا، کلانگ لوانگ، پاتومتانی، ۱۲۱۲۰، تایلند.

۲- گروه هیدرولوژی و هواشناسی، فرودگاه بین المللی تریبوان، کاتماندو، نپال.

تاریخ دریافت: ۱۸ دی ۱۳۹۲ / تاریخ پذیرش: ۲ اردیبهشت ۱۳۹۳ / تاریخ چاپ: ۲۵ خرداد ۱۳۹۳

چکیده این مقاله براساس آنالیز زمان های هجوم و بازگیری دوره مونسون تابستانی پنال بالایی برای مدت ۶۳ سال (۱۹۵۱-۲۰۱۳) تهیه شد. روند آنالیزها مشخص کرد هجوم و بازگیری مونسون تابستانی در سالهای اخیر با تأخیر همراه می باشد. آنالیز آماری با استفاده از انحراف تراکمی و آزمون Worsley like lihood نشان داد، میانگین جهشی در زمان بازگیری بعد از سال ۱۹۹۷ مشاهده شد. میانگین زمان بازگیری بعد از سال ۱۹۹۷ دیرتر از زمان بازگیری نرمال ۱۰ روزه می باشد. اگرچه روند برای هجوم به طور آماری معنی دار نمی باشد روند برای بازگیری در سطح ۵ درصد معنی دار است. آزمون های آماری برای دوره ۱۹۵۱-۱۹۹۶ و ۱۹۹۷-۲۰۱۳ هرچند که آشکار نمود هجوم بازگیری سری های غیر ایستگاهی هستند. تغییر در زمان بازگیری با روند تأخیری، بر هجوم و بازگیری با دوره های طولانی تر تغییر موقتی در الگوی مونسون پنال بالایی بعد از سال ۱۹۹۷ پیشنهاد می شود. تغییر موقتی در مونسون ثابت می باشد. با پایش انجام شده اثر جهانی تغییر اقلیم روی دینامیک بارش مونسون تابستانی آسیای جنوبی، تغییر الگوی مونسون تابستانی را نشان می هد، که کشاورزی، منابع آبی، اکوسیستمها، سلامتی انسان و کل اقتصاد کشورها را متأثر می سازد.

کلمات کلیدی: نپال، مونسون، هجوم، روند، بازگیری
