Trends in Dry and Wet Events of Rainfall in Aththanagalu Oya Basin

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Trends in Dry and Wet Events of Rainfall in Aththanagalu Oya Basin

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ABSTRACT

Sri Lanka needs to pay more attention to the climate extremes as the availability and the quality of water resources are directly affected by such changes. Sustainable planning and management of water resources of Aththanagalu Oya that feeds many large and small scale multi-purpose water extraction schemes is vital to cope up with the impacts of climate change. Thus, an analysis of the shifts and trends of climatic patterns with respect to wet and dry events within the Aththanagalu Oya basin was carried out to evaluate the state and the extent of climate change using Standardized Precipitation Index (SPI) Model in Mat Lab R2007b (version 7.5), utilizing 20 *years of daily rainfall data (from January 1991 to February 2011) of six selected sub-catchments (Henarathgoda, Vincit, Chesterford, Kirindiwela, Nittambuwa and Pasyala) of the Aththanagalu Oya basin. The identified events (both wet and dry) were ranked into five classes (normal, mild, moderate, severe and extreme) based on the severity of each event and the variations in climate (with respect to SPI) and were evaluated using Paired Chi-Square method. A decrease in dry events and an increase of the wet events in the climatic pattern of recent years (2001-2011) compared to the past (from 1991 to 2000) in Vincit, Kirindiwela, Nittambuwa and Pasyala could be predicted in accordance with the SPI analysis while an opposite trend is observed in Henarathgoda and Chesterford. Unlike the predictions of many studies which expect significant alterations in climate patterns in the recent years than the past years only the wet events of Pasyala (a significant increasing trend of wetness) and the dry events of Vincit (a significant decreasing trend of dryness) indicate significant alterations in climatic patterns while the climatic variations indicated by the rest of the areas remain statistically insignificant according to the SPI approach.*

INTRODUCTION

Any change in climate that occur over the time whether due to natural variability or as a result of human activity, influencing the composition of global atmosphere has been defined as climate change (IPCC, 2007; UNFCCC, 2008). Similar to many countries in the world, numerous sectors such as environment, health, agriculture, food security, economic activity, natural resources and physical infrastructures etc. of Southeast Asian counties are also experiencing adverse impacts of climate change, which has significantly challenged the sustainable development. Being tropical counties with agriculture based economy, the impacts of climate change that have significantly influenced the quantity and quality of available water resources have resulted severe impacts on agriculture and economy. Sri Lanka which is characterized by three major climatic zones (wet, intermediate and dry) also depends mainly on agriculture in ensuring food security and welfare of the total population of 20 million. The fluctuations in rainfall patterns play a dominant character in defining climatic patterns of tropical countries such as Sri Lanka. Especially the water availability in both lotic and lentic waters, quality of water and the health of associated eco systems are predominantly affected by such rainfall fluctuations while recent observations symbolize the presence of significant alterations in rainfall patterns (in both dry and wet zones) in Sri Lanka. Hence proper planning of water resources should be done in coordination with the specific climatic patterns of the considering regions or the locality rather than focusing on general patterns and trends (overall climate patterns of the country) of dry and wet events.

Since the dawn of 1900s, numerous driving factors such as demographic patterns, economic growth and consumption patterns have caused an increment in water demand for numerous purposes in Sri Lanka (Amarasinghe, 2010). Since the early civilization of humans, lotic waters of Sri Lanka play a key role in catering to the diverse requirements of water by numerous sectors. Yet even though Sri Lanka is blessed with 103 rivers that feed upon around 52 billion cubic meters of annual surface runoff, the predicted decrease in annual runoff from 2,799 cubic meters into 2,232 cubic meters (in terms of per capita) by 2050, could cause severe impacts on economic, social and environmental aspects. Thus the sustainable utilization of water resources, while addressing both recently experiencing alterations in climatic patterns and the increased water requirements by different sectors (agricultural, industrial and domestic etc.), has become a key issue in Sri Lanka (Halwatura *et al.*, 2013). Hence the evaluation of the alterations of climatic change (especially in rainfall patterns) in terms of both severity and frequency of occurrence in dry and wet events of rainfall (that denote the trends in rainfall) in catchments of rivers is of higher importance to assess the future impacts of climatic change on the availability and quality of water in lotic waters to ensure the sustainable and effective planning and management of water resources.

At present, numerous methods, procedures, indices etc. have been developed and are being employed to analyze the wetness, dryness and other weather extremes by using monthly precipitation data, where droughts are considered as precipitation deficits with respect to average values and floods as the opposite. The simplicity, flexibility, effectiveness and capability of acting as an objective measurement of meteorological droughts effectively in dry regions (Hayes *et al.*, 1999; Wu *et al.*, 2001; Morid *et al.*, 2006 and Sternberg *et al.*, 2011) has caused the Standardized Precipitation Index (McKee *et al.*, 1993) to outstand numerous other methods of extreme event (droughts and wet periods) prediction such as Effective Drought Index (Byun and Wilhite, 1999), Palmer Drought Severity Index (Palmer, 1965), Surface Water Supply Index (Shafer and Dezman, 1982) etc. (Udayanga and Najim, 2013). The provision of magnitude, period of occurrence and longevity of climate extremes, enabling the users to identify all the relevant trends of the weather extremes has resulted the SPI to be applied throughout the world in different climatic regions (Lee *et al.*, 2013 and Liu *et al.*, 2011).

Updated and localized study of climate patterns and prediction of climate extremes respecting the shifts, variations and trends of the climate patterns at present with respect to the past (especially focusing on dry and wet events) is vital for the evaluation of impacts of climate change on lotic waters and for the sustainable planning and management of water resources. Aththanagalu Oya is regarded as one of the major six rivers in Sri Lanka which caters for a higher degree of multi-purpose water extractions (drinking water, agricultural and industrial etc.). Thus the evaluation of the trends in dryness and wetness of rainfall patterns in Aththanagalu Oya basin that readily influence the availability and quality of water in the Aththanagalu Oya, is of higher importance for the effective, well-coordinated and sustainable management of water in Aththanagalu Oya while ensuring the provision of water for the diverse extraction schemes without compromising the future state of the river. The emphasis of the importance, effectiveness, reliability and easy applicability of SPI for the quantification of the extent of both the dry and wet events and the incorporation of alterations in climatic patterns (especially the severity and the of occurrence frequency of climate extremes) in formulation of water resources management policies and management plans etc. are also expected through this study.

METHODOLOGY

Study area

The upper region of Aththanagalu Oya river basin which is located in between 7° 6.60' N - 7° 7.88' N and 80° 7.02' E - 80° 5.22' E (covering an area of approximately 337.06 km^2), was selected as the study area. The studied catchment area composes of Aththanagalu Oya and Dee Eli Oya. Laterite, unconsolidated sand, alluvium, peat deposits and crystalline basement rocks could be identified as the main geological formations of the basin area. Four major land use types (agricultural areas, urbanized areas, natural forest patches and scrublands) could be identified within the basin. Considering agricultural areas, coconut which covers about 26% of the land area in the catchment remains as the main agricultural crop. Rubber, which is limited to upper catchment area, covers nearly 18% of the land while paddy lands are intense in the lower part of the catchment covering 16% of land area. Tea and other export crops cover less than 1% of the area. Forest patches occupy diminutive coverage of about 5% from the catchment area and consist of unclassified forests and scrublands, which are restricted to the upper catchment areas. The highest percentage of the land cover occupies home gardens (33.5%) including commercialized areas and industrialized areas, since the considered catchment area is heavily urbanized. The basin lies within the 'low country wet zone' agro ecological zone; characterized by 75% expectancy of annual rainfall of 1700 mm - 3200 mm. Both irrigation and drinking water extractions, which divert and pump water from Attanagalu Oya and Dee Eli Oya catering for the water requirements of a considerable portion of the catchment, are currently in operation within the catchment, making Aththanagalu Oya and Dee Eli Oya, the major sources of water. In view of the irrigation extractions, six major anicuts, four under Dee Eli Oya (Muruthawela, Kumballoluwa, Panugala and Idellawala) and two under Attanagalu Oya (Morenna, Ketawala) with three main drinking water extraction points (Weediyawatta, Mangalathiriya and Kalagedihena) could be recognized within the studied catchment. Approximately 3,261,287 m^3 of water is extracted from Attanagalu Oya annually as drinking water by the Water Supply and Drainage Board.

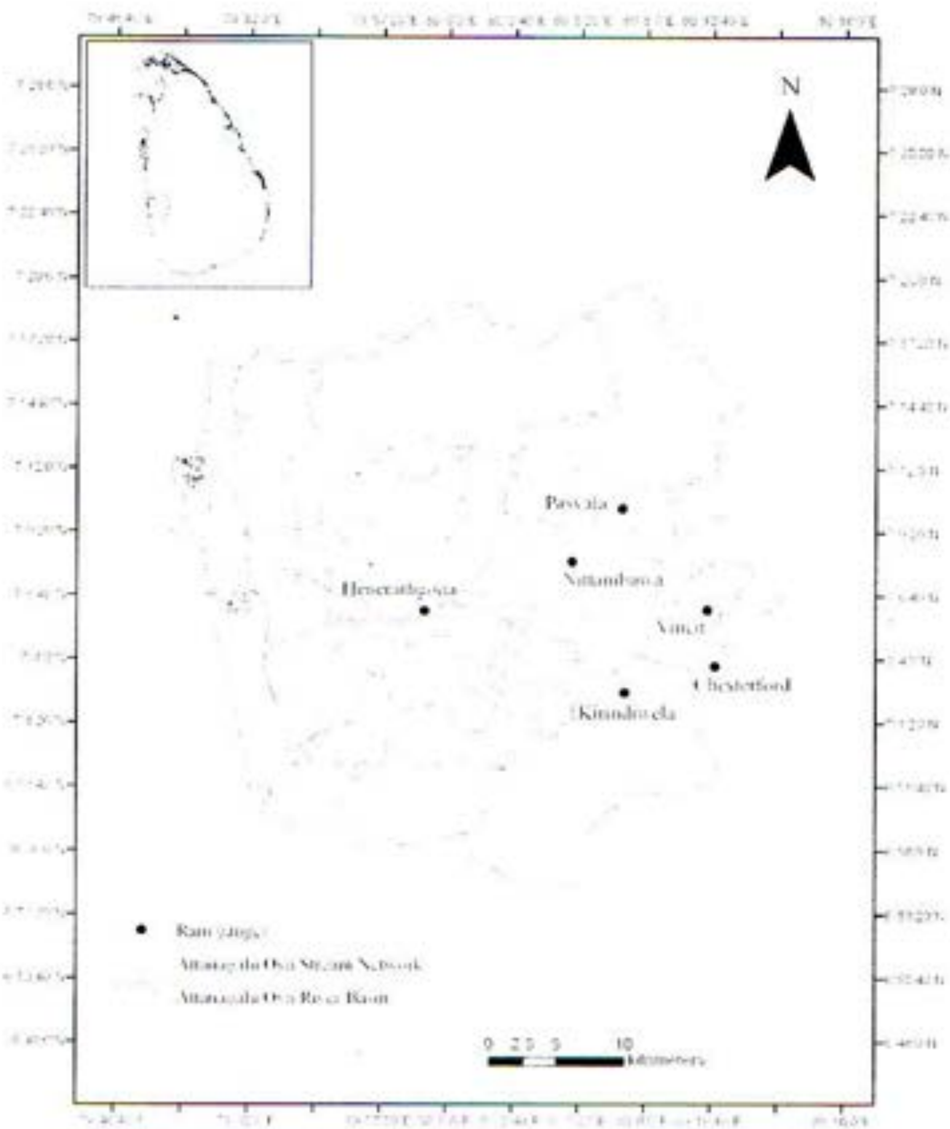

Figure 1: Attanagalu Oya stream network and the distributed rain gauging stations

Data Collection and analysis

Daily rainfall data covering the period from January 1991 to March 2011 of Henarathgoda, Vincit, Chesterford, Kirindiwela, Nittambuwa and Pasyala rainfall gauging stations which are located within the Aththanagalu Oya catchment area were obtained from the Department of Meteorology, Colombo. Monthly precipitation was computed based on the aggregated daily rainfall values for each station and two major data sheets were prepared for each station including monthly cumulative rainfall data ranging from 1991-2000 and 2001-2011.

Standardized precipitation index

SPI values for each month for the time intervals 1991-2000 and 2001-2011 were calculated for each station as the difference between precipitation on a time scale (x_i) and the mean value ($\bar{x}$), divided by the standard deviation (S), as given in the equation 1.

$$SPI = \frac{x_i - \bar{x}}{s}$$

.... Eq. 1

As recommended by Liu *et al.* (2011), a consecutive number of months; where SPI values remain below a threshold of -0.49 was assumed to be a dry period while length or duration of the drought (D) was taken as the number of consecutive months where SPI remains below -0.49. The identified dry periods were classified into five classes as normally dry (0 to -0.49), mild drought (-0.50 to -0.99), moderate drought (-1.00 to -1.49), severe drought (-1.50 to -1.99), extreme drought (-2.00 or lesser) events based on SPI values (Liu *et al.*, 2011). The wet events also were assumed to be present over a consecutive number of months, where SPI values remain over a threshold of 0.49. As recommended by Liu *et al.* (2011), the wet periods were also classified into five classes based on the SPI range, as normally wet (0 to 0.49), mild wet (0.50 to 0.99), moderate wet (1.00 to 1.49), severe wet (1.50 to 1.99) and extreme wet events (2.00 or higher). The generated SPI values in the time intervals were plotted against time on a monthly basis and the observable patterns were compared with each other to identify any similarities, variations and shifts of climate from 1991-2000 and 2001-2011. The generated negative and positive values of SPI were categorized in accordance with the boundaries of different classes of drought and wet events, as proposed by Liu *et al.* (2011). The total number of events in both the periods was calculated and the percentage of each class of events was calculated separately. The significance in variation of the percentage occurrence of the above identified events (in each class) during the respective periods, were statistically assessed in accordance with the Paired-Chi-square test.

RESULTS AND DISCUSSION

Temporal variations of the SPI values in each study locality were plotted where Figure 2 shows the temporal variation of SPI at Pasyala. These plots facilitate the accurate and effective comparison and interpretation of the variations in climatic patterns within the period from 1991-2000 and 2001-2011. The percentage of climatic events belonging to each class that occurred within each time period at different localities are tabulated in Table 2, while the Table 3 represents the summarized results of the Paired Chi-square test, which was performed to evaluate the significance of the alterations in climate patterns (in terms of dryness and wetness) in the studied localities.

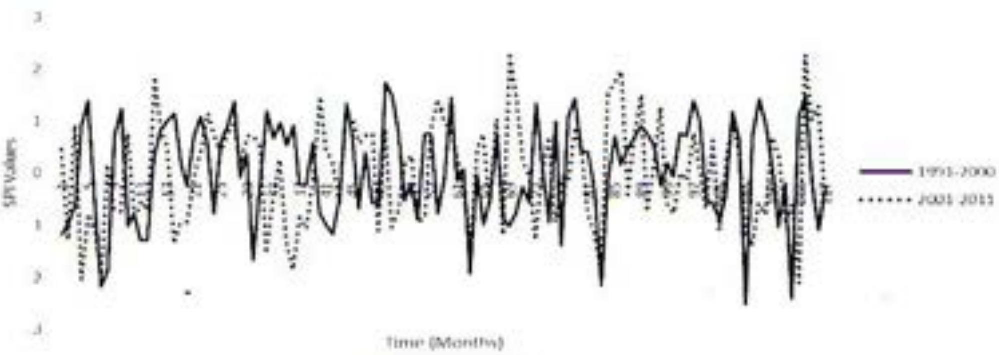

Figure 1: Temporal variation of SPI in Pasyala (a) in 1991-2000 (b) in 2001-2011

Table 1: Percentage occurrence of drought and wet events at different study localities

Periods	Event	SPI Value	Category	Percentage Occurrence of Events %					
				Chesterrford	Henarathgoda	Kirindiwela	Nittambuwa	Pasyala	Vincit
1991-2000	Wet	≥ 2.00	Extreme wet	1.69	6.45	0.00	4.00	0.00	1.59
		1.50 to 1.99	Severe wet	6.78	6.45	17.31	4.00	1.67	6.35
		1.00 to 1.49	Moderate wet	28.81	16.13	19.23	28.00	30.00	23.81
		0.50 to 0.99	Mild wet	32.20	27.42	19.23	34.00	48.33	34.92
		0 to 0.49	Normal wet	30.51	43.55	44.23	30.00	20.00	33.33
	Droughts	0 to -0.49	Normally dry	32.14	38.00	30.43	35.56	36.84	32.73
		-0.50 to -0.99	Mild droughts	10.14	34.00	30.43	24.44	35.09	29.09
		-1.00 to -1.49	Moderate droughts	13.04	18.00	26.09	24.44	15.79	23.64
		-1.50 to -1.99	Severe droughts	3.62	6.00	10.87	11.11	5.26	14.55
		≤ -2.00	Extreme droughts	0.72	4.00	2.17	4.44	7.02	0.00
2001-2011	Wet	≥ 2.00	Extreme wet	0.00	0.00	1.61	1.56	3.17	1.75
		1.50 to 1.99	Severe wet	7.27	9.09	11.29	7.81	7.94	8.77
		1.00 to 1.49	Moderate wet	27.27	27.27	24.19	21.88	19.05	33.33
		0.50 to 0.99	Mild wet	32.73	30.91	14.52	40.63	33.33	21.05
		0 to 0.49	Normal wet	32.73	32.73	48.39	28.13	36.51	35.09
	Droughts	0 to -0.49	Normally dry	34.62	43.86	27.08	29.09	16.67	40.00
		-0.50 to -0.99	Mild droughts	21.15	24.56	27.27	40.00	46.30	35.00
		-1.00 to -1.49	Moderate droughts	28.85	21.05	20.00	14.55	25.93	10.00
		-1.50 to -1.99	Severe droughts	11.54	7.02	12.73	7.27	7.41	6.67
		≤ -2.00	Extreme droughts	3.85	3.51	3.64	9.09	3.70	8.33

Table 2: Paired Chi-square test results for each locality

Locality	Type of the events	Calculated X_2	Interpretation
Chesterford	Wet	0.08	Not Significant
	Dry	0.91	Not Significant
Henarathgoda	Wet	6.52	Not Significant
	Dry	1.23	Not Significant
Kirindiwela	Wet	2.37	Not Significant
	Dry	0.74	Not Significant
Nittambuwa	Wet	2.09	Not Significant
	Dry	4.58	Not Significant
Pasyala	Wet	10.54	Significant Increment in Wetness
	Dry	7.18	Not Significant
Vincint	Wet	3.26	Not Significant
	Dry	10.25	Significant Reduction of Dryness

$X^2_{(df=4, 0.05)}$ =9.448, * Indicate a significant difference among the recorded events in the two periods considered at a confidence level of 95%

The wet events in Pasyala (a significant increasing trend of wetness) and dry events in Vincit (a significant decreasing trend of dryness) indicated significant variations in the recent years (2001-2011) compared to the past (1991-2000) in accordance with the SPI analysis and Paired Chi-square test (Table 3), while the variations in wet and dry events of the other localities (Henarathgoda, Chesterford, Kirindiwela and Nittambuwa) were not significant to be considered as dominant alterations in climate. Still notable variations in terms of severity and occurrence frequency in both wet and dry events in all the studied localities could be identified in accordance with Table 2. When Pasyala is considered, a significant increment in the number of mild, moderate and extreme wet events (except for the normal and severe wet events which indicate no variations) with a reduction in the occurrence of mild and moderate drought events (except for the normal dry events which indicate no variations) in the recent years with slight increments in severe and extreme drought events (which are statistically insignificant) could be observed. Hence when the overall pattern is considered, wetness in the recent years at Pasyala, indicate a significant increasing trend while the dryness of the locality has decreased at a mild level. Meanwhile the dry events of Vincit indicate a significant decreasing trend which also suggests an increase of wetness in the Aththanagalu Oya catchment. In addition a decrease in dry events and an increasing trend of wet events in the climatic pattern of recent years (2001-2011) with respect to the past years (from 1991 to 2000) in both Kirindiwela and Nittambuwa could also be identified in accordance with the SPI analysis (Table 2). Yet according to the Paired Chi-square statistical test (Table 3), only the increment of wetness in Pasyla and Vincit (out of Vincit, Kirindiwela, Nittambuwa and Pasyala) should be respected in terms of significance. In another approach, an increase of precipitation in November that could offset precipitation increases in the other months has been proposed by Seo *et al.* (2005), in accordance with CSIRO and PCM models, while CGCM, CCSR and HAD3 models have predicted an increased overall precipitation in Sri Lanka leading to a profitable yield of agriculture. Among the wet zone areas, the average annual rainfall in Colombo, Galle, Kandy, Nuwara Eliya and Ratnapura is predicted to be increased by 32%, 24%, 12% and 5 %, respectively (De Silva, 2006).

Both Henarathgoda and Chesterford localities symbolize possible increase in dryness with a reduction of wetness in terms of SPI (Table 2) which are insignificant in accordance with results of the Paired Chi-square statistical test (Table 3). According to a frequency analysis of average and maximum rainfall in Attanagalu Oya basin by using the Gumbel approach, the average rainfall in upper, middle and lower catchment areas in 2001 to 2010 compared to 1991 to 2000 has been reported to be slightly decreased. Similarly the maximum rainfall has also slightly decreased in upper catchment areas in 2001 to 2010 compared to 1991 to 2000, while a slight increment in maximum rainfall has been observed in middle and lower catchments in 2001 to 2010. According to the rainfall frequency analysis of average and maximum rainfalls, a change in the rainfall pattern in the Aththanagalu Oya basin has been proposed by Wanigenethti *et al.* (2012). Thus the results of the SPI analysis of rainfall in Aththanagalu Oya basin, also suggest a similar potential alteration of rainfall patterns in terms of severity and occurrence frequency of wet and dry events while only the increment in wetness at Pasyala and Vincit remains highly significant. This study also emphasizes the occurrence of micro climate variations in large geographical areas that should be respected in sustainable planning and management of water resources.

Aththanagalu Oya is one of the major six rivers that significantly contributes to diverse multi-purpose water extractions (including agricultural, drinking water and industrial) that range from medium to large scale in terms of extracted quantity of water. The contribution of the Aththanagalu Oya to paddy cultivation remains significant in the wet zone as approximately an asweddumized land extent of 2,067 ha and 3,586 ha are being cultivated catered by the minor and major irrigation schemes of Aththanagalu Oya, respectively. At present, the agricultural water requirement is predicted to remain more or less constant, while the drinking water extractions are expected to increase exponentially within the Aththanagalu Oya catchment (Halwatura *et al.*, 2013). In addition, a possible reduction in the quantity and spatial distribution of rainfall leading to an increased irrigation water requirement for paddy by 13-23% during the main season compared to that of 1961-1990 by the year 2050 has been predicted by De Silva *et al.* (2007). Hence, any alteration in the amount of received rainfall and seasonality could significantly influence the availability of water for agriculture and other water extractions in Aththanagalu Oya which could result critical outcomes on both economic and social sectors. Thus, even though an increase in wetness with a reduction of dryness could be expected for majority of the Aththanagalu Oya basin (except in Henarathgoda and Chesterford) in the rainfall patterns in present and future, the sufficiency of the flow of Aththanagalu Oya contributed by the increased runoff generated via expected increment in wetness rainfall is doubtful. Thus conducting a well-planned analysis of river flow could be recommended to achieve the goals of sustainable and effective management of water within the Aththanagalu Oya basin while catering for the needs of multipurpose extractions. In addition, shifting of crop species, adjustment of the cropping calendar based on metrological parameters (as recommended by Lee et al., (2005), application of modeling approaches to ensure optimum and sustainable delivery of irrigation water for crops (Haque *et al*., 2004), employment of Smart and Integrated Watershed Management Practices (SIWMP), policies, increasing of public awareness on the sustainable use of water (in both domestic and agricultural requirements) and construction of properly designed and well-functioning water retention structures such as culverts and small scale cascade type reservoirs etc. could be recommended as potential measures to compensate the impacts of climatic change in Aththanagalu Oya basin.

Sri Lanka coupled with Western Ghats produce one of the highly respected and sensitive biological hotspots. Especially the wet zone of Sri Lanka, regardless of its small extent is renowned for its high degree of endemism in terms of both fauna and flora. The micro climate variations in Aththanagalu Oya basin triggered by the alterations in rainfall patterns could result significant impacts on distribution and survival of these flora and fauna (especially the endemic species) via alteration and modification of environmental conditions of the diverse habitats on which many endemic species thrive upon. Hence the evaluation of the trends in climate change such as variations in the abundance, severity of extreme events and the extent of affected area are of higher importance to assess the impacts of climate change on the biodiversity, so that proper and effective remediation and migratory measures (such as drafting of policies, designing of management actions and plans etc.) to preserve biodiversity and ecosystems could be implemented. Significant spatial and temporal variations in climate (especially microclimate variations at regional levels) could be often experienced in the climate patterns in tropical islands such as Sri Lanka. Yet, unlike most of the recent studies that have been conducted to investigate the trends and impacts of climate change at national level in Sri Lanka, *the* current study focuses on the variations and trends in climate at the regional level in Aththanagalu Oya basin which are of higher importance for many aspects such as the degree of bio diversity, agriculture, industrial sector and domestic water extractions etc. As mentioned above, the generalization of the predictions in variations, trends in climate and weather patterns and presenting a common conclusion, remains difficult due to the presence of diverse micro climate variations in target localities at regional scale. Even though many studies such as Seo *et al*., 2005; De Silva, 2006; De Silva *et al*., 2007; Eriyagama *et al*., 2010 and Waniganethti *et al*., 2012 etc. suggest significant alterations in severity and occurrence frequency of climatic events in the recent years throughout the country, according to the SPI approach, only the wet events of Pasyala (increment of wetness) and the dry events of Vincit (reduction of dryness) indicates significant alterations in patterns of rainfall.

CONCLUSIONS

A decrease in dry events and an increase of the wet events in the climatic pattern of recent years (2001-2011) with respect to the past years (from 1991 to 2000) in Vincit, Kirindiwela, Nittambuwa and Pasyala could be predicted in accordance with the SPI analysis while an opposite trend is expected to occur in Henarathgoda and Chesterford. Unlike the predictions of many studies which expect significant alterations in climate patterns in the recent years than the past years, according to the SPI approach, only the wet events of Pasyala (a significant increasing trend of wetness) and the dry events of Vincit (a significant decreasing trend of dryness) indicate significant alterations in climatic patterns while the climatic variations indicated by the rest of the areas remain statistically insignificant. Hence, a significant increase in wetness in Vincit and Pasyala in terms of both severity and frequency of occurrence with variations of rainfall seasonality could be predicted in accordance with the SPI. Thus in general, an increase of wetness within the Aththanagalu Oya basin could be expected according to the overall results generated by the SPI approach.

The impacts and trends in climate change which tends to cause significant impacts in usual climate patterns of tropical countries including Sri Lanka influencing the water availability and flow characteristics of rivers, need to be studied and evaluated to cope up with the impacts of climate change. The planning and management of the water resources in Aththanagalu Oya, should be properly conducted based upon the observed and expected future trends in climate patterns to ensure sustainable planning and management of water resources while catering for multi-purpose uses (agricultural, drinking and industrial etc.). In addition, the evaluation of the micro climate variations in climates is of potential importance in assessment of the future impacts of climate change on the rich biodiversity in the wet zone of Sri Lanka, so that the drafting of conservation strategies, biodiversity management and action plans etc. could be conducted effectively by accounting for such impacts of climate change.

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