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# RECENT TRENDS OF EXTREME POSITIVE RAINFALL ANOMALIES IN THE DRY ZONE OF SRI LANKA

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## ABSTRACT

**A study was conducted in the Dry zone of Sri Lanka, to identify the trends in occurrence of positive extreme rainfall anomalies, using daily rainfall time series from 1990-2014 collected at 13 rain gauge stations scattered in all major agro-ecological regions of the Dry zone. A trend analysis was carried out, by considering the 95th and 99th percentile of daily time series of annual and seasonal rainfall *viz,* First Inter Monsoon (FIM), South West Monsoon (SWM), Second Inter Monsoon (SIM) and North East Monsoon (NEM) as the cut-off values to designate Heavy and Very Heavy rainfall events of positive anomalies, respectively. The base period to calculate the cut-off values was taken as the 30-year period from 1960-1989. Even though no significant trend in occurrence of Heavy Rainfall (HRF) events or Very Heavy Rainfall (VHRF) events has been observed during last 25-year period from 1990-2014, annually or seasonally, it is revealed that an apparent trend of these extreme positive rainfall anomalies is discernible, especially during SWM and NEM rainfall seasons. This trend has been clearly evident during last 5-year period from 2010-2014. It may likely to inflict significant implications on the agricultural production in the region in terms of both quantity and quality, as SWM and NEM seasons coincide with the reproductive phase of the crops grown in both *Yala* and *Maha* cultivation seasons in the Dry zone. As the climate change is likely to exacerbate extreme rainfall events in future, these apparent trends may even become obvious thus, excess soil moisture stress in rainfed upland crops, flood damages in lowland paddy fields and rapid drying out in cascade of tanks in long-run will be a serious threat to agricultural productivity in the Dry zone of Sri Lanka.**

**KEY WORDS:** Dry Zone, Extreme Rainfall, Heavy Events, Very Heavy Events, Climate Change

## INTRODUCTION

The Dry zone covers about 70 % of the total land extent in Sri Lanka. It is the major agricultural region of the country since the earliest historical times of the island; the dry zone of Sri Lanka consist of thousands of man-made small and large tanks without which human existence in the Dry zone would be difficult as described by Abeyratne (1956) and Ievers (1899). Village tank settlements have always been the back-bone of our Hydraulic Civilization since ancient times. It is also perceived as one of the most appropriate adaptation strategy for climate variability and change in the Dry zone. The annual average rainfall of the Dry zone is less than 1,750 mm with a distinct dry period from May to September coupled with high daily evaporation rates of between 5 to 8 mm due to warm and desiccating winds. Thus, very often annual rainfall represents only a fraction of the water requirements for double-cropped rice and therefore, heavily dependent on supplementary irrigation from aforesaid tanks and reservoirs.

Among the various issues and the threats faced by these tanks, high siltation is of special significance. Continually shrinking catchment area of respective tanks due to encroachment of forests and irrational land use practices on upstream lands, result in more soil erosion leading to rapid siltation of tanks in the Dry zone. Moreover, high-intense rains receiving during convectional rainy periods (March – April and September – October) also increase the soil erosion rate of the Dry zone landscape.

Siltation of tanks not only causes reduction of storage capacity but also leads to alter the tank geometry and ecology. Subsequent rehabilitation works, if any, where the capacity would be increased by raising the spill and tank bund would create a shallow water body spreading over a large surface area. This makes the situation more complicated creating several other problems such as inundation of upstream paddy lands in the cascade, development of salinity conditions in the upper area, increase of tank water losses by evaporation due to increased surface/depth ratio, disappearance of the tree strips in the high flood region (*Gasgommana*) and the grass cover (*Perahana*) and disappearance of some indigenous fish species, which cannot survive in shallow water or do not find a favourable breeding environment. In addition, reduction of capacity of village tanks in the Dry zone also pose additional threats to livelihood, ecosystem services, health and infrastructure, both directly and indirectly resulting web of negative impacts on socio-economic conditions of the Dry zone's peasant community (Anon, 1993).

Global warming is expected to lead to a more vigorous hydrological cycle, including more total rainfall and more frequent high intensity rainfall events (IPCC, 2013), which in turn increases the soil erosion and subsequent siltation of tanks. Climate model simulations (Hennessey *et al.*, 1997) and empirical evidences confirm that warmer climates, owing to increased water vapour, will lead to more intense precipitation events in the future (IPCC, 2007). Recent studies conducted in Central India have confirmed that there are significant rising trends in the frequency and the magnitude of extreme rainfall events (Rajeevan *et al.*, 2008; Goswami *et al.*, 2006). High intense rains were used to be a common feature of the rainfall climatology of the Dry zone only during convectional rainy periods. However, it has been observed in recent times that such rains have become a regular event at any rainy season irrespective of the nature of origin, which may further aggravate the problem of siltation of tank cascade systems in the Dry zone.

Therefore, this study was undertaken to identify whether there is a change in occurrence of extreme rainfall events in the Dry zone enabling policy makers to formulate appropriate risk reduction strategies to conserve the village tank ecosystems in the Dry zone.

## METHODOLOGY

To study the recent trends of positive extreme rainfall events, a 25 year daily time series was taken from 1990 to 2014 from 13 rain gauge stations scattered throughout the Dry zone, representing different Agro Ecological Regions (AER) - (Table 1). The base period was considered from 1960 to 1989 as against to the common standard base period of 1961-1990 due to the availability of data. Even though there are some more rain gauge stations in other agro-ecological regions of the Dry zone, it was unable to employ all of them in the analysis due to presence of large number of missing data and/or being only a short time series. This was particularly true for stations in northern and eastern provinces where data has not been recorded continuously during the period of civil disturbances. The locations of rainfall observation stations in the Dry zone used in the study and their latitude and longitude are shown in Table 1.

**Table 1. Geographical details of rainfall observation stations used in the study.**

| District | Station | AEZ | Latitude (N) | Longitude (E) |
|---|---|---|---|---|
| Anuradhapura | Anuradhapura | DL 1b | 8° 35' | 80° 38' |
| Matale | Pelwehera | DL 1b | 7° 90' | 80° 68' |
| Anuradhapura | Mahallluppallama | DL 1b | 8° 12' | 80° 47' |
| Trincomalee | Kantalai | DL 1c | 8° 38' | 81° 05' |
| Ampara | Ampara | DL 2a | 7° 28' | 81° 67' |
| Trincomalee | Trincomalee | DL 2b | 8° 58' | 81° 25' |
| Batticaloa | Batticaloa | DL 2b | 7° 72' | 81° 70' |
| Jaffna | Jaffna | DL 3 | 9° 68' | 80° 03' |
| Puttlam | Puttlam | DL 3 | 8° 03' | 79° 83' |
| Mannar | Mannar | DL 4 | 8° 98' | 79° 92' |
| Mannar | Murunkan | DL 4 | 8° 83' | 80° 05' |
| Hambantota | Hambantota | DL 5 | 6° 12' | 81° 13' |
| Hambantota | Weerawila | DL 5 | 6° 28' | 81°23' |

In this study, it was an important step to decide an appropriate definition or cut-off value to identify the extreme rainfall events in a time series of daily rainfall data. Even though review of literature revealed that there is no unique definition or method to determine the cut-off value, as quoted by Punyawardena and Premalal (2013) and Shin-Chu *et al.* (2008) have shown that there are three approaches which have been extensively used in identifying extreme positive rainfall anomalies of a data series. The first method is based on the actual rainfall amounts with an arbitrary threshold value. Karl *et al.* (1996) and Groisman (1999) constructed a mean annual number of days which 24-hour accumulation exceeds 50.8 mm (2 inches) as a Heavy Rainfall (HRF) event over the mainland United

States. Similarly, Very Heavy Rainfall (VHRF) climatology is derived when daily precipitation exceeds 101.6 mm (4 inches).

The second way to define extreme positive anomalies is to use specific thresholds such as the 95th and 99th percentiles of daily rainfall values to define HRF and VHRF events, respectively. The third way of defining extreme positive rainfall events is to calculate return periods of the event based on the annual maximum 24- hour precipitation series (Kunkel *et al.*, 1999). However, cursory analysis of rainfall data in the Dry zone of Sri Lanka has revealed that HRF events are more common in recent past and it could be probably attributed to the climate change. Therefore, the return period approach may lead to erroneous conclusions (Punyawardena and Premalal, 2013). The first approach of using an arbitrary threshold value is not appropriate for local conditions as it has been based on empirical evidences of another country where the rainfall climatology is different from the Dry zone's environment. The second method, percentile based approach gives a proper estimation of extreme values with a strong statistical foundation even with recent data. Punyawardena and Premalal (2013) have successfully employed the same approach to identify the trends in extreme rainfall events in the Central Highlands of Sri Lanka. The same approach has been adopted by Shahid (2011) to study the pattern of extreme positive rainfall events in Bangladesh.

The base period for the analysis was taken as the 1960-1989 to capture a period of 30 years to determine the 95th and 99th percentiles in annual and seasonal time series of each station. These two values were then considered as the cut-off values for HRF and VHRF events, respectively. The 25-year period from 1990 to 2014 was taken to determine the trends of HRF and VHRF events by annually as well as rainfall season wise, *viz*, First Inter Monsoon (FIM), South West Monsoon (SWM), Second Inter Monsoon (SIM) and North East Monsoon (NEM). A trend analysis was carried out on extreme positive rainfall events, namely, HRF and VHRF events for annual daily rainfall and each rainfall season, based on the above time periods as the independent variable. Furthermore, the number of days that received positive extreme rainfall events - HRF and VHRF events - were categorized independently in to 5 year time periods (pentad) from 1990 to 2014, namely, 1990-1994, 1995-1999, 2000-2004, 2005-2009 and 2010-2014 to determine whether there is any recent occurrence of such rainfall events.

However, the first pentad period (1990-1994) of stations located in $DL_4$ region, namely, Murunkan and Mannar was dropped from the analysis due to presence of excessive number of missing values. The same remains true with Jaffna data for the period of 1995-1999. The observed apparent increasing trends of HRF and VHRF during last pentad of 2010-2014 in most locations were tested for significance using "CATMOD" procedure in SAS statistical software as these data were not normally distributed.

## RESULTS AND DISCUSSION

Table 2 shows the cut-off values for HRF and VHRF rainfall events for annual time series using 1960-1989 base period. A similar calculation was carried out for all four rainfall seasons independently using the same base period (Values are not shown in the text).

**Table 2.Cut-off values for 95th and 99th percentiles of selected locations of the study for annual time series**

| Station | AEZ | 95th percentile(mm) | 99th percentile(mm) |
|---|---|---|---|
| Anuradhapura | $DL_{1b}$ | 21.5 | 57.2 |
| Pelwehera | $DL_{1b}$ | 25.4 | 67.6 |
| Mahallluppallama | $DL_{1b}$ | 24.1 | 61.7 |
| Kantalai | $DL_{1c}$ | 24.1 | 62.4 |
| Ampara | $DL_{2a}$ | 28.7 | 71.3 |
| Trincomalee | $DL_{2b}$ | 25.9 | 70.4 |
| Batticaloa | $DL_{2b}$ | 27.6 | 70.0 |
| Jaffna | $DL_3$ | 21.5 | 58.6 |
| Puttlam | $DL_3$ | 20.3 | 52.0 |
| Mannar | $DL_4$ | 17.3 | 50.9 |
| Murunkan | $DL_4$ | 19.1 | 50.8 |
| Hambantota | $DL_5$ | 17.0 | 46.0 |
| Weerawila | $DL_5$ | 14.4 | 41.3 |

Table 3 and 4 show the trends of HRF and VHRF events, respectively at study locations for annual daily rainfall time series and four rainfall seasons *viz*, FIM, SWM, SIM and NEM seasons independently. Even though there is an apparent increasing trend of HRF events in annual daily time series in all study locations except Murunkan none of them were statistically significant. However, the increasing trend at Kantalai was significant with a fairly strong relationship ($r^2 = 0.22$). VHRF events in daily time series reveal both apparent increasing and decreasing trends at different locations where the increasing trend at both Anuradhapura ($r^2 = 0.32$) and Kantalai ($r^2 = 0.27$) is significant with a strong correlation (Table 3 and 4).

## Comparison among the seasons

HRF events during FIM season reveal an apparent increasing trend in all study locations except Pelwehera and Murunkan with a significant relationship at Anuradhapura, Kantalai and Trincomalee. Interestingly, VHRF events during FIM season too show an apparent increasing trend at all study locations even though none of them are significant except Trincomalee. Generally, HRF events during SWM season show a decreasing trend at most of the locations except Ampara and Jaffna. However, this decreasing trend was significant only at Weerawila ($r^2 = 0.22$). There was a mixed trend of relationship in VHRF events during SWM season at different locations, but none of them were significant (Table 3 and 4). During SIM season, both HRF and VHRF events show a mixed trend with both positive and negative apparent trends, but it was significant only at Kantalai, Pelwehera and Hambantota with VHRF events (Table 4). Similarly during FIM season, HRF events during NEM season also reveal an apparent increasing trend at all study locations except Ampara and Murunkan. But none of these trends were significant except Kantalai. VHRF events during NEM season too show an apparent increasing trend in all study locations except Hambantota, but the trend was significant only at Anuradhapura ($r^2 = 0.17$).

**Table 3. Trend and significance of Heavy rainfall events in the Dry zone of Sri Lanka**

| Station | AEZ | Annual | FIM | SWM | SIM | NEM |
|---|---|---|---|---|---|---|
| Anuradhapura | DL $_{1b}$ | y = 0.352x - 684.8 | y = 0.120x - 236.5 | y = -0.041x + 89.4 | y = 0.073x - 144.6 | y = 0.190x - 374.6 |
| | | (0.16, 0.050) | (0.25, 0.011) | (0.01, 0.683) | (0.07, 0.185) | (0.12, 0.095) |
| Pelwehera | DL $_{1b}$ | y = 0.141x - 263.9 | y = -0.001x + 4.7 | y = -0.048x + 103.6 | y = -0.054x + 110.7 | y = 0.079x - 153.3 |
| | | (0.04, 0.331) | (0.00, 0.989) | (0.01, 0.667) | (0.07, 0.229) | (0.03, 0.433) |
| Mahalluppallama | DL $_{1b}$ | y = 0.154x - 291.1 | y = 0.056x - 111.3 | y = -0.108x + 223.7 | y = -0.006x + 15.4 | y = 0.092x - 179.5 |
| | | (0.07, 0.189) | (0.06, 0.236) | (0.05, 0.276) | (0.00, 0.898) | (0.04, 0.306) |
| Kantalai | DL $_{1c}$ | y = 0.504x - 984.8 | y = 0.121x - 240.0 | y = -0.063x + 134.8 | y = 0.108x - 212.7 | y = 0.278x - 550.4 |
| | | (0.22, 0.019) | (0.18, 0.033) | (0.03, 0.399) | (0.05, 0.303) | (0.19, 0.031) |
| Ampara | DL $_{2a}$ | y = 0.352x - 684.8 | y = 0.086x - 171.2 | y = 0.003x - 0.9 | y = 0.026x - 50.3 | y = -0.020x + 46.6 |
| | | (0.16, 0.072) | (0.05, 0.256) | (0.00, 0.961 ) | (0.01, 0.676) | (0.00, 0.796) |
| Trincomalee | DL $_{2b}$ | y = 0.169x - 318.8 | y = 0.145x - 288.6 | y = -0.181x + 370.2 | y = -0.017x + 37.6 | y = 0.156x - 307.0 |
| | | (0.04, 0.314) | (0.16, 0.046) | (0.15, 0.057) | (0.00, 0.806) | (0.07, 0.192) |
| Batticaloa | DL $_{2b}$ | y = 0.226x - 430.4 | y = 0.079x - 156.1 | y = -0.114x + 236.9 | y = -0.019x + 42.2 | y = 0.185x - 365.1 |
| | | ( 0.07, 0.191 ) | (0.05, 0.259) | (0.07, 0.198) | (0.00, 0.765) | (0.14, 0.064) |
| Jaffna | DL $_{3}$ | y = 0.117x - 215.7 | y = 0.120x - 237.0 | y = 0.114x - 222.5 | y = -0.085x + 174.9 | y = 0.002x - 0.3 |
| | | (0.02, 0.525) | (0.10, 0.162) | (0.04, 0.419) | (0.13, 0.115) | (0.00, 0.980) |
| Puttlam | DL $_{3}$ | y = 0.352x - 684.8 | y = 0.112x - 222.3 | y = -0.011x + 29.1 | y = 0.045x - 88.1 | y = 0.064x - 123.0 |
| | | (0.16, 0.072) | (0.12, 0.087) | (0.00, 0.906) | (0.04, 0.352) | (0.02, 0.478) |
| Mannar | DL $_{4}$ | y = 0.114x - 209.3 | y = 0.017x - 31.8 | y = -0.083x + 174.5 | y = -0.026x + 56.2 | y = 0.072x - 141.3 |
| | | (0.02, 0.502) | (0.00, 0.873) | (0.01, 0.638) | (0.01, 0.696) | (0.02, 0.554) |
| Murunkan | DL $_{4}$ | y = -0.113x + 248.0 | y = -0.014x + 32.3 | y = -0.054x + 116.1 | y = -0.075x + 154.6 | y = -0.072x + 149.4 |
| | | (0.01, 0.633) | (0.00, 0.909) | (0.00, 0.780) | (0.05, 0.345) | (0.01, 0.619) |
| Hambantota | DL $_{5}$ | y = 0.031x - 44.3 | y = 0.044x - 86.8 | y = -0.080x + 169.1 | y = 0.036x - 70.4 | y = 0.047x - 90.2 |
| | | (0.00, 0.774) | (0.03, 0.402) | (0.05, 0.303) | (0.01, 0.556) | (0.01, 0.631) |
| Weerawila | DL $_{5}$ | y = 0.014x - 5.5 | y = 0.074x - 144.1 | y = -0.303x + 616.9 | y = 0.058x – 112.0 | y = 0.031x - 55.2 |
| | | (0.00, 0.896) | (0.06, 0.252) | (0.21, 0.019) | (0.02, 0.480) | (0.00, 0.737) |

Note: Equation used; $y=mx \pm c$, values given in parenthesis represent $r^2$ and p-value, respectively

Table 4. Trend and significance of Very heavy rainfall events in the Dry zone of Sri Lanka

| Station | AEZ | Annual | FIM | SWM | SIM | NEM |
|---|---|---|---|---|---|---|
| Anuradhapura | $DL_{1b}$ | y = 0.217x - 429.9 | y = 0.069x - 137.4 | y = -0.010x + 22.8 | y = -0.001x + 3.7 | y = 0.089x - 177.5 |
| | | (0.32, 0.003) | (0.24, 0.012) | (0.00, 0.790) | (0.00, 0.933) | (0.17, 0.040) |
| Pelwehera | $DL_{1b}$ | y = 0.015x - 26.9 | y = 0.005x - 8.6 | y = -0.005x + 12.1 | y = -0.034x + 69.6 | y = 0.061x - 122.1 |
| | | (0.00, 0.811) | (0.00, 0.865) | (0.00, 0.887) | (0.21, 0.021) | (0.09, 0.145) |
| Mahallupallama | $DL_{1b}$ | y = -0.018x + 40.4 | y = 0.007x - 15.2 | y = -0.023x + 49.2 | y = -0.017x + 35.9 | y = 0.027x - 54.3 |
| | | (0.00, 0.761) | (0.01, 0.606) | (0.02, 0.507) | (0.03, 0.383) | (0.03, 0.418) |
| Kantalai | $DL_{1c}$ | y = 0.284x - 564.3 | y = 0.060x - 118.8 | y = 0.042x - 82.1 | y = 0.070x - 140.7 | y = 0.049x - 97.0 |
| | | (0.27, 0.008) | (0.15, 0.053) | (0.03, 0.369) | (0.16, 0.045) | (0.04, 0.309) |
| Ampara | $DL_{2a}$ | y = 0.217x - 429.9 | y = 0.032x – 64.0 | y = 0.031x - 61.2 | y = 0.001x - 2.5 | y = 0.026x - 51.7 |
| | | (0.32, 0.191) | (0.05, 0.267 ) | (0.03, 0.432) | (0.00, 0.948) | (0.05, 0.282) |
| Trincomalee | $DL_{2b}$ | y = 0.011x - 19.1 | y = 0.075x - 150.0 | y = -0.051x + 103.3 | y = -0.015x + 29.9 | y = 0.052x - 103.4 |
| | | (0.01, 0.854) | (0.17, 0.039) | (0.05, 0.293) | (0.01, 0.605) | (0.06, 0.230) |
| Batticaloa | $DL_{2b}$ | y = 0.106x - 206.8 | y = 0.027x - 54.5 | y = -0.004x + 10.7 | y = -0.002x + 5.3 | y = 0.058x - 115.6 |
| | | (0.08, 0.181) | (0.04, 0.347) | (0.00, 0.896) | (0.00, 0.913) | (0.07, 0.210) |
| Jaffna | $DL_{3}$ | y = -0.101x + 208.2 | y = 0.050x - 100.7 | y = 0.016x - 31.7 | y = -0.030x + 60.7 | y = 0.8 |
| | | (0.12, 0.141) | (0.10, 0.179) | (0.01, 0.728) | (0.11, 0.142) | (0.00, 1.000) |
| Puttlam | $DL_{3}$ | y = 0.217x - 429.9 | y = 0.025x - 48.9 | y = -0.031x + 64.6 | y = -0.026x + 52.7 | y = 0.031x - 61.9 |
| | | (0.32, 0.930) | (0.10, 0.127 ) | (0.03, 0.391) | (0.091, 0.143) | (0.03, 0.433) |
| Mannar | $DL_{4}$ | y = 0.030x - 58.3 | y = 0.001x - 1.8 | y = -0.029x + 60.4 | y = -0.021x + 42.8 | y = 0.048x - 97.4 |
| | | (0.02, 0.583) | (0.00, 0.981) | (0.01, 0.609) | (0.03, 0.486) | (0.14, 0.098) |
| Murunkan | $DL_{4}$ | y = -0.008x + 21.1 | y = 0.015x - 29.3 | y = 0.017x - 33.0 | y = 0.002x - 3.3 | y = 0.039x - 77.5 |
| | | (0.00, 0.934) | (0.00, 0.784) | (0.00, 0.810) | (0.00, 0.958) | (0.04, 0.382) |
| Hambantota | $DL_{5}$ | y = 0.045x - 86.7 | y = 0.021x - 42.6 | y = 0.003x - 6.4 | y = -0.066x + 134.9 | y = -0.005x + 12.1 |
| | | (0.02, 0.482) | (0.04, 0.324) | (0.00, 0.909) | (0.18, 0.033) | (0.00, 0.873) |
| Weerawila | $DL_{5}$ | y = 0.151x - 297.5 | y = 0.019x - 37.9 | y = -0.035x + 70.9 | y = 0.880 | y = 0.068x - 133.7 |
| | | (0.18, 0.032) | (0.03, 0.404) | (0.03, 0.379) | (0, 1.000) | (0.09, 0.138) |

Note: Equation used; $y=mx \pm c$, values given in parenthesis represent $r^2$ and p-value, respectively

## Variation among the pentad time series

To further explore the apparent increasing trend of extreme positive rainfall events during the last 25- year period, total number of respective HRF and VHRF events occurred during recent 5-year time slots, namely, 1990-1994, 1995-1999, 2000-2004, 2005-2009 and 2010-2014 have depicted in Figure 1 to 10 representing major agro-ecological regions of the Dry zone, namely, $DL_1$, $DL_2$, $DL_3$, $DL_4$ and $DL_5$. It clearly shows that in all major agro-ecological regions of the Dry zone, occurrence of HRF events during NEM season has dramatically increased during the most recent pentad, 2010-2014 at almost all locations of the study. The same is true for the occurrence VHRF events too, except a few instances. The SWM also shows a similar pattern of increasing occurrence of extreme positive rainfall anomalies during most recent pentad at most locations except Ampara and Weerawila.

The increasing trends of extreme positive rainfall anomalies during SWM and NEM seasons at the fifth pentad during 2010-2014 is significant for both HRF ($p<0.0006$) and VHRF ($p<0.0207$) events. It is also pertinent to note that in general, there is no any decreasing trend in either event during most recent pentad of SIM season especially in $DL_1$ and $DL_2$ regions. However, occurrence of both events in the most recent pentad (2010-2014) has decreased during FIM season across all major agro-ecological regions except $DL_1$ region. Even in $DL_1$ region, its neighbouring region to $DL_2$ (Kantalai – $DL_{1c}$) follows the same trend. This trend of FIM is quite contrary to the trend observed in long term data analysis from 1990-2014 (Table 3 and 4) $DL_1$, $DL_2$, $DL_3$, $DL_4$ and $DL_5$ where an apparent increasing trend was observed. The observed spatial variability of trends in different AERs does not reveal any spatial pattern as per the statistical analysis of “CATMOD” procedure in SAS software.

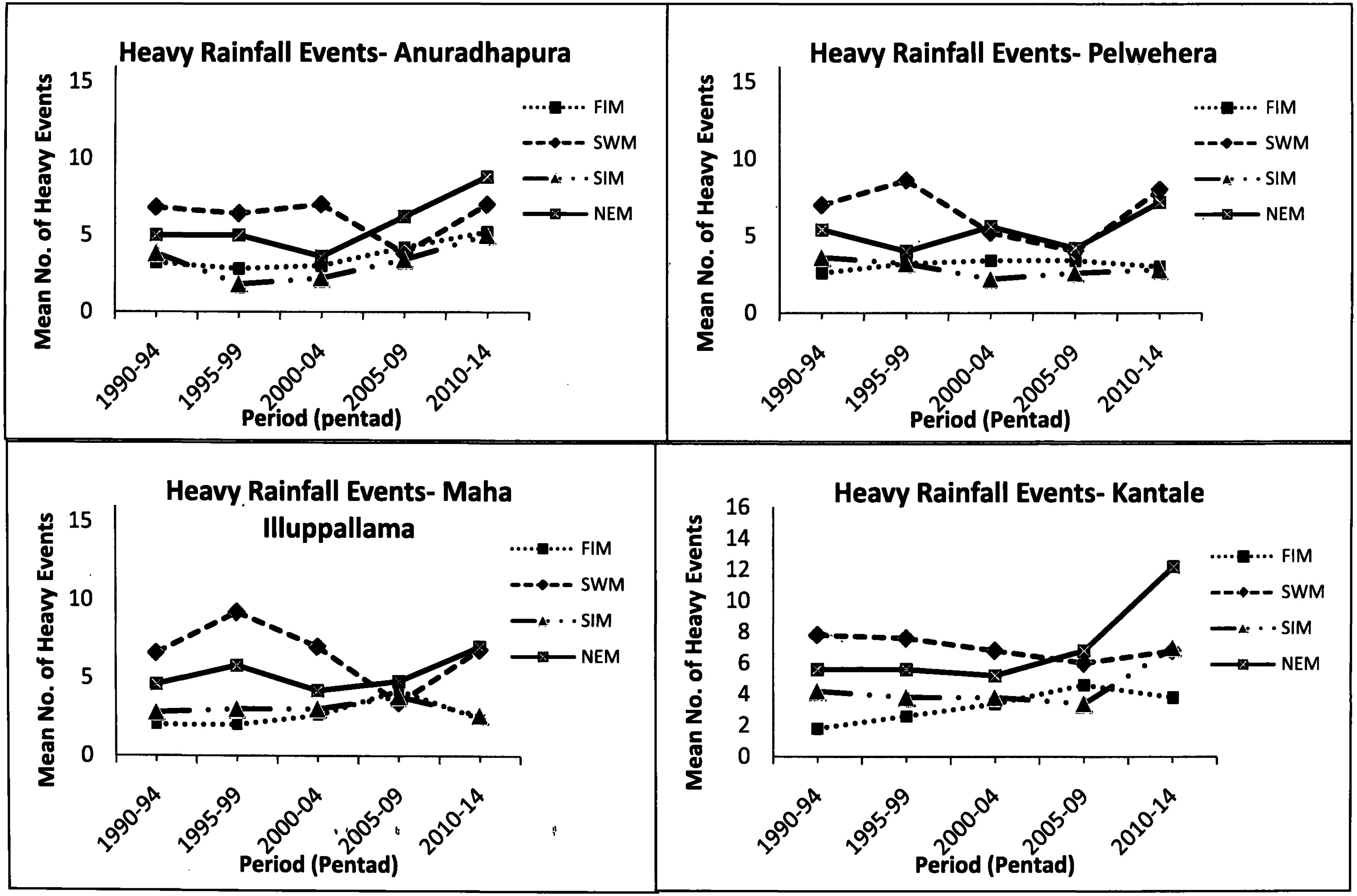


Figure 1: Occurrence of extreme positive rainfall anomalies in the $DL_1$ agro-ecological region of the Dry zone in Sri Lanka – Heavy events

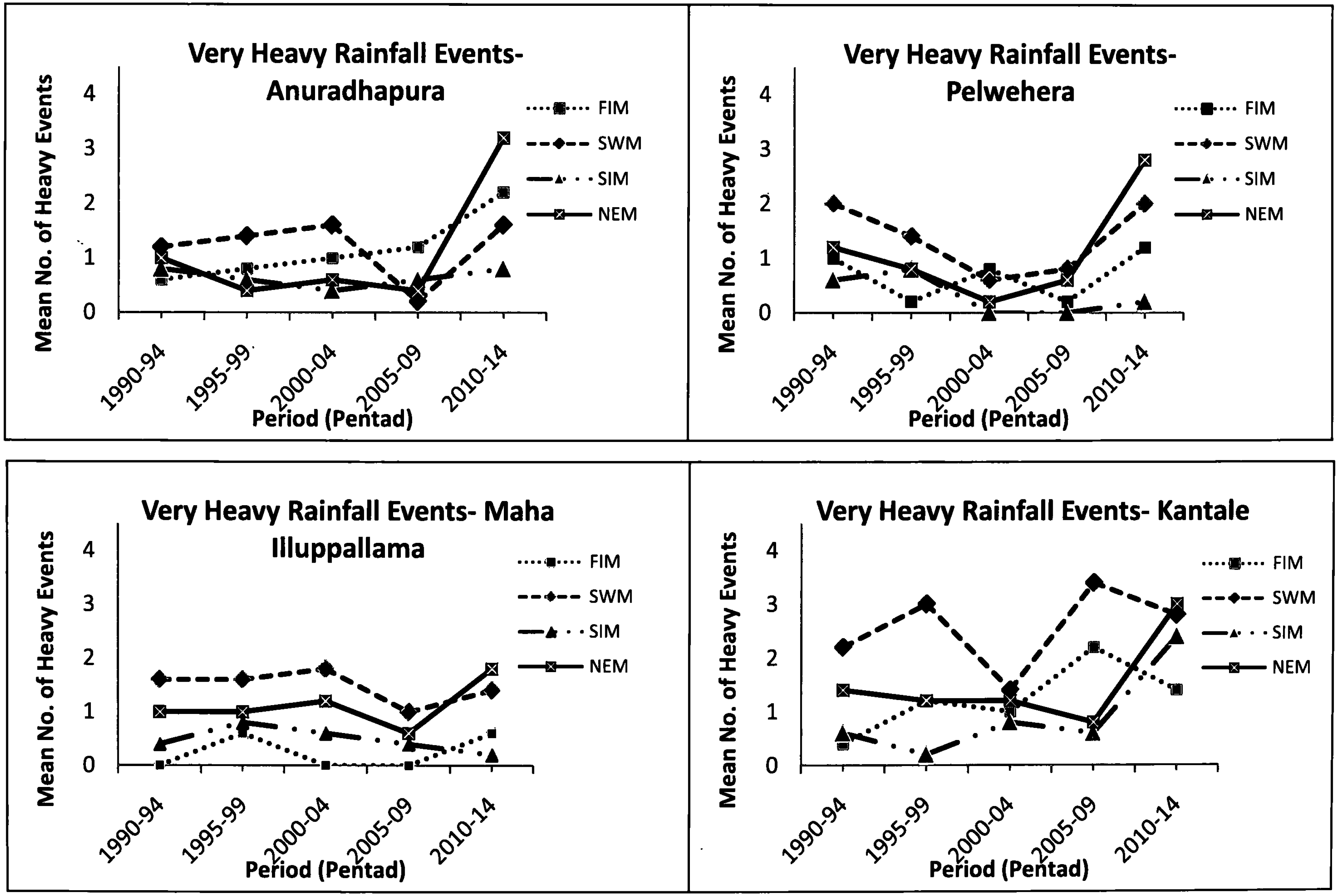
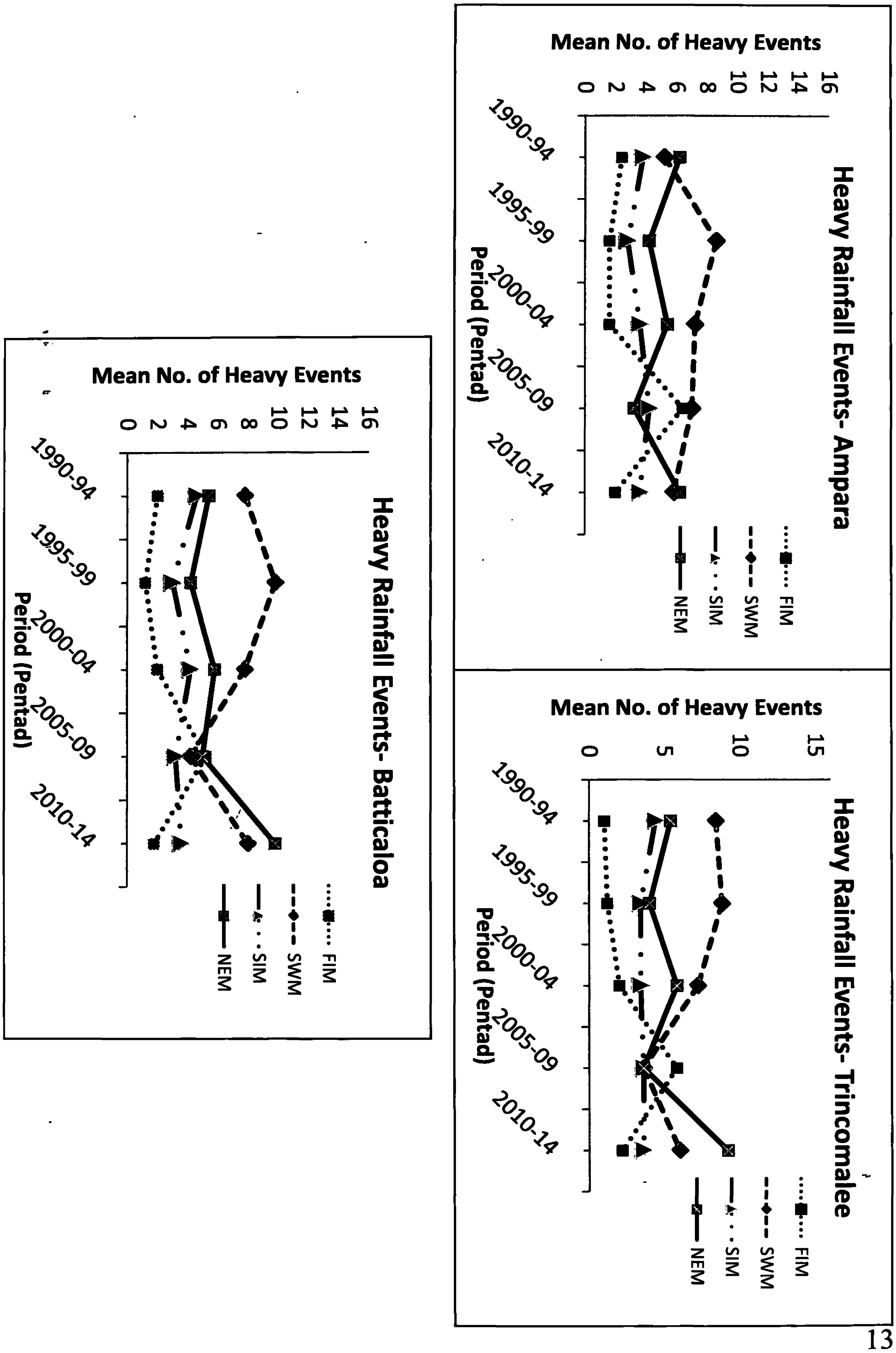


Figure 2: Occurrence of extreme positive rainfall anomalies in the $DL_1$ agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events



Heavy Rainfall Events- Ampara

Heavy Rainfall Events- Trincomalee

Heavy Rainfall Events- Batticaloa

Figure 3: Occurrence of extreme positive rainfall anomalies in the $DL_2$ agro-ecological region of the Dry zone in Sri Lanka – Heavy events

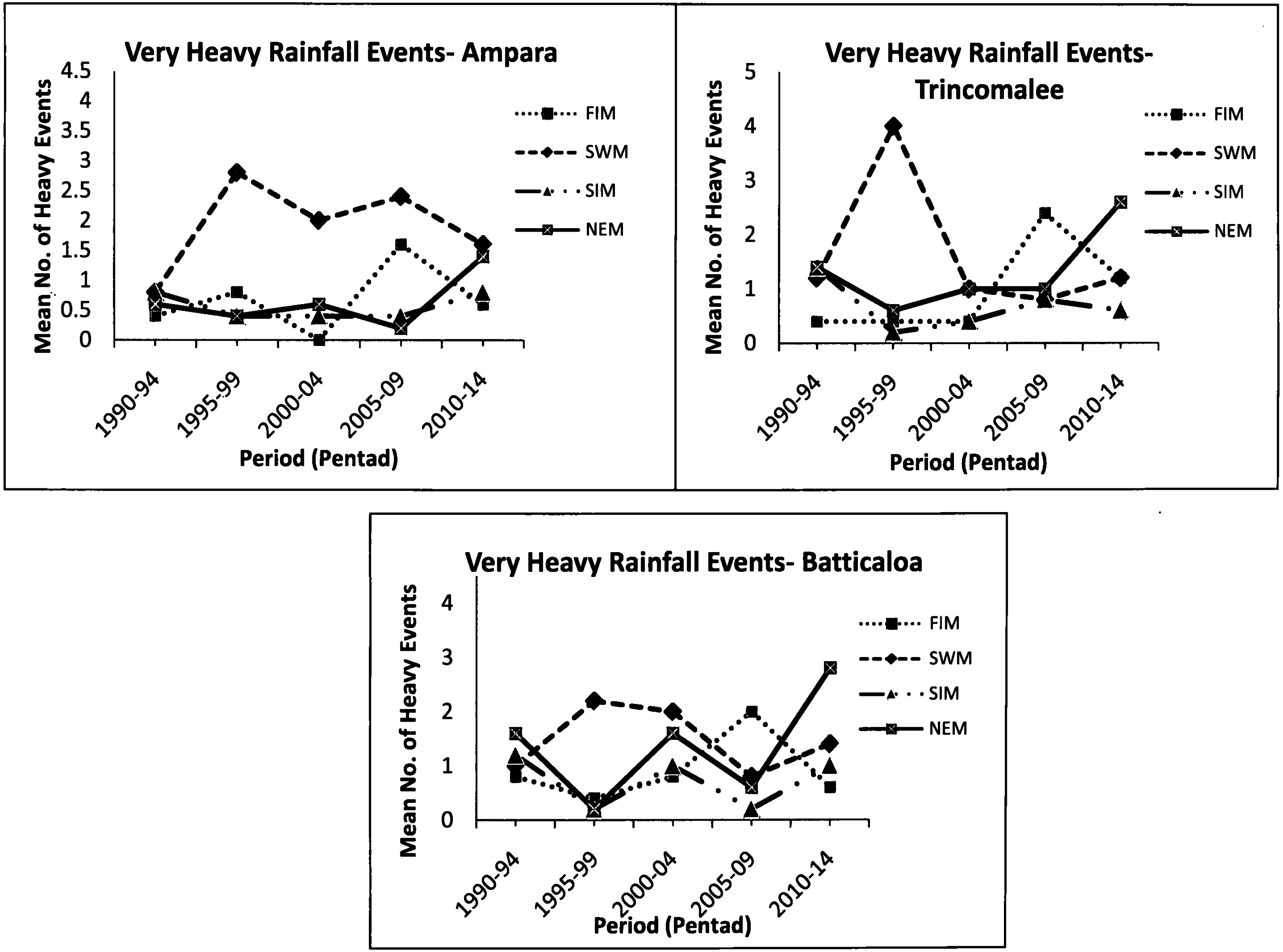


**Figure 4: Occurrence of extreme positive rainfall anomalies in the $DL_2$ agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events**

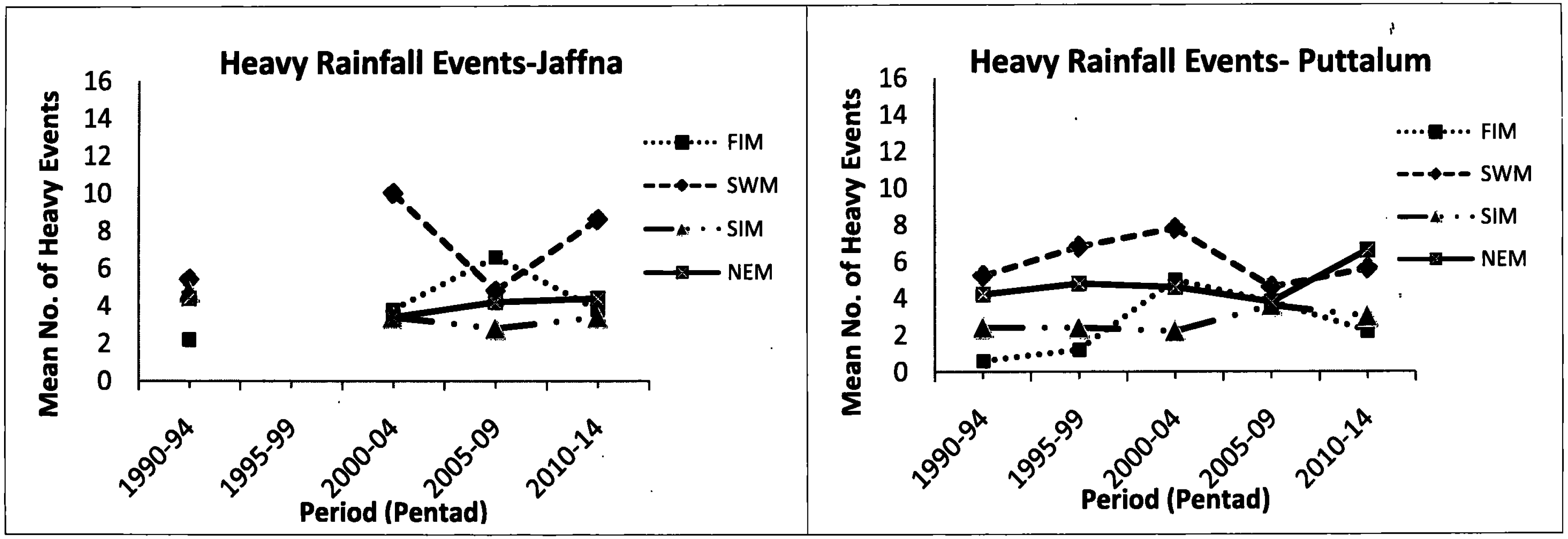


Figure 5: Occurrence of extreme positive rainfall anomaliesin the DL$_3$ agro-ecological region of the Dry zone in Sri Lanka – Heavy events

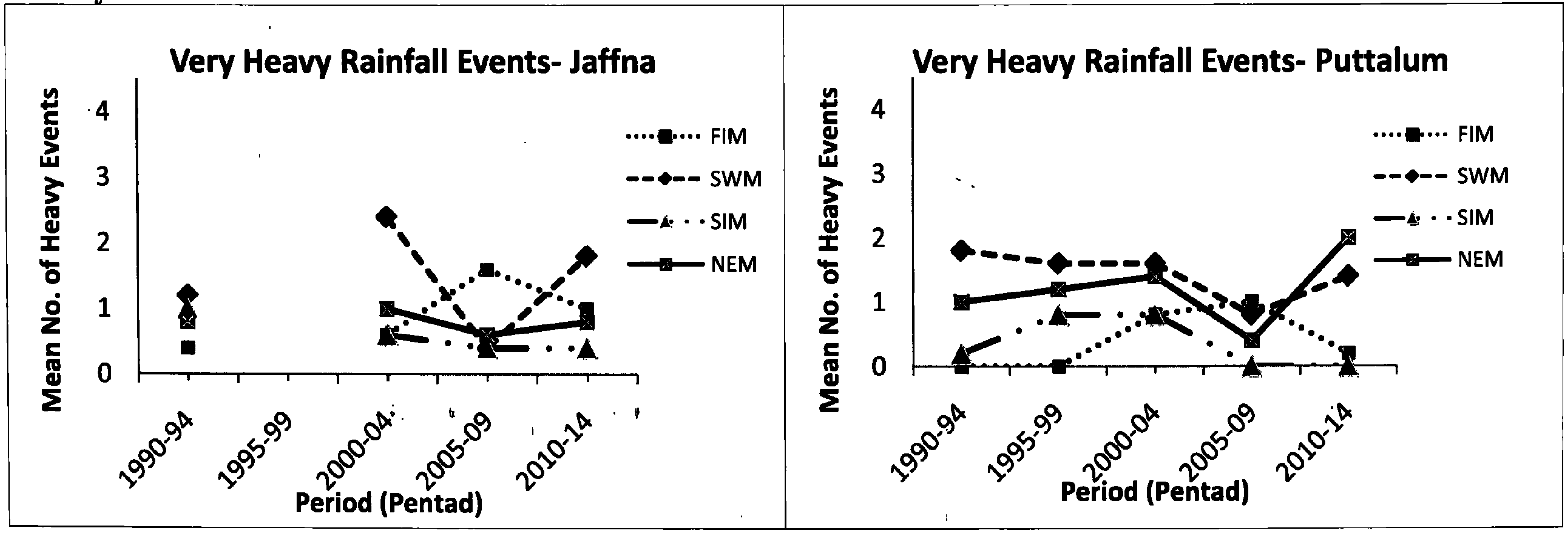


Figure 6: Occurrence of extreme positive rainfall anomaliesin the DL$_3$ agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events

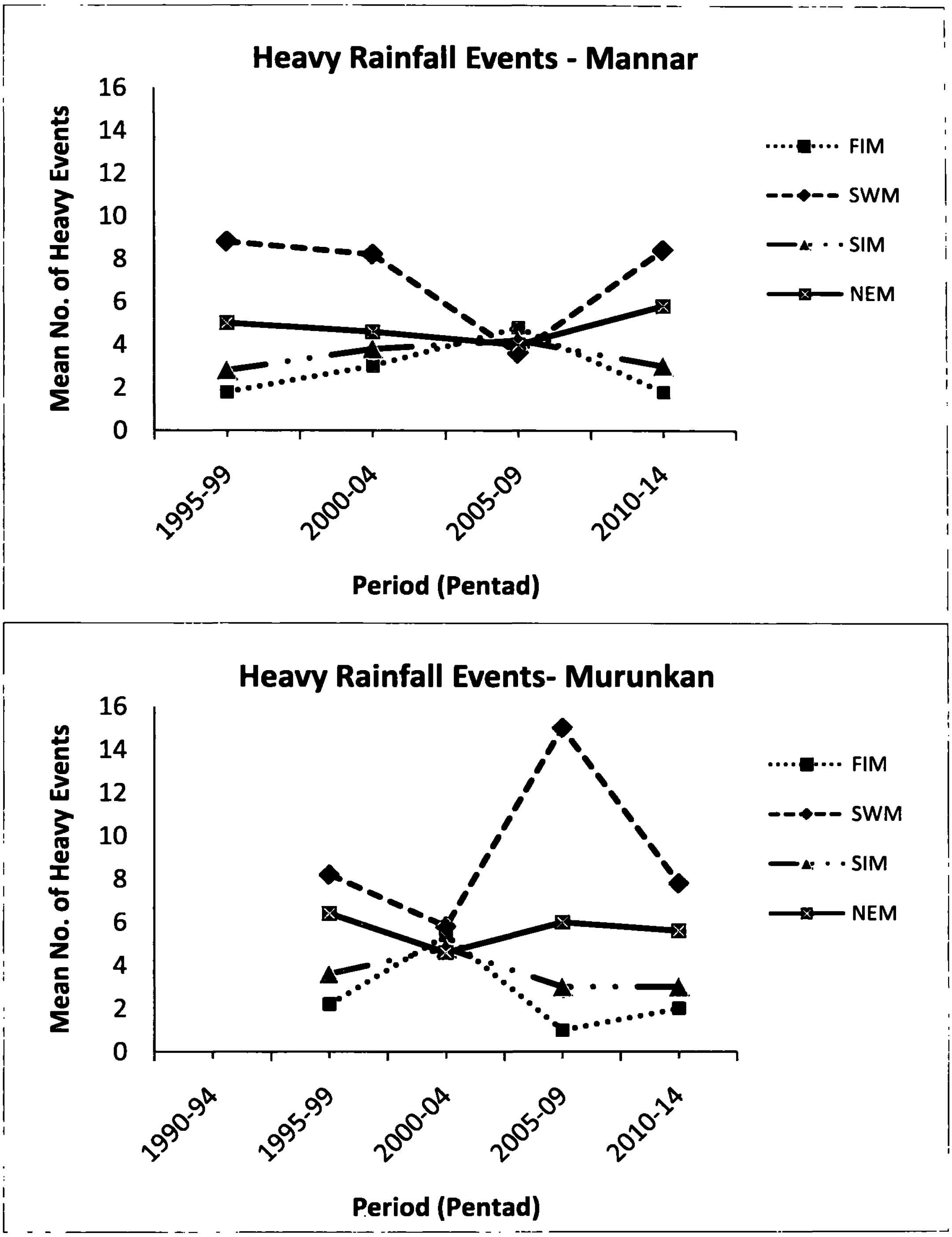
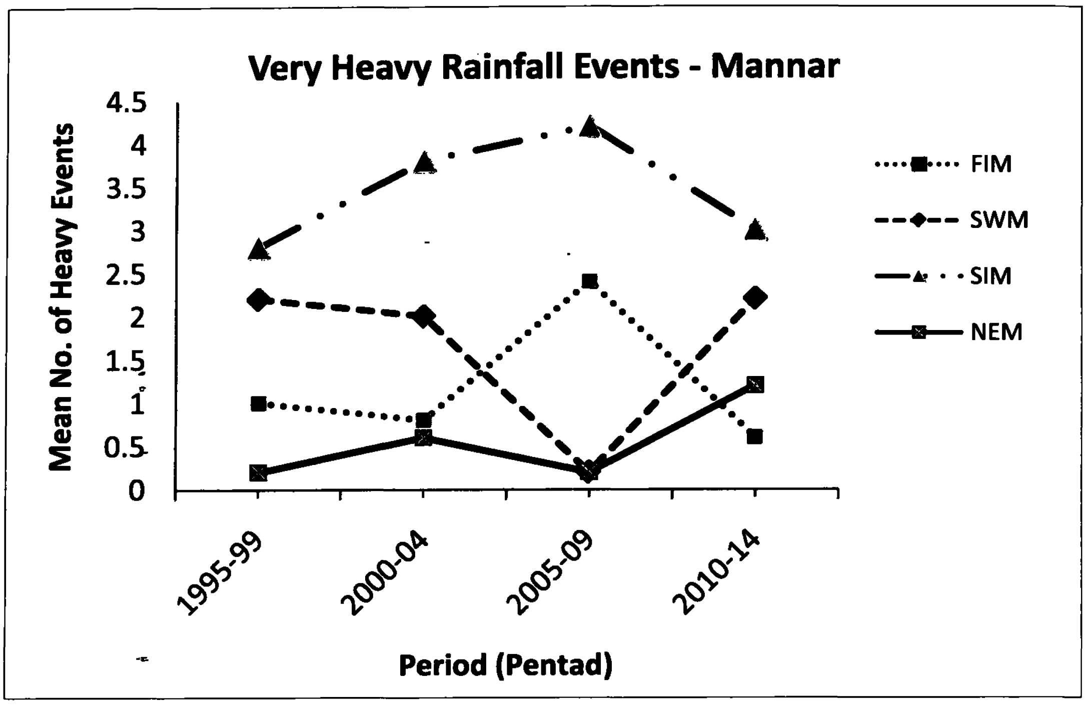


**Figure 7: Occurrence of extreme positive rainfall anomalies in the $DL_4$ agro-ecological region of the Dry zone in Sri Lanka – Heavy events**



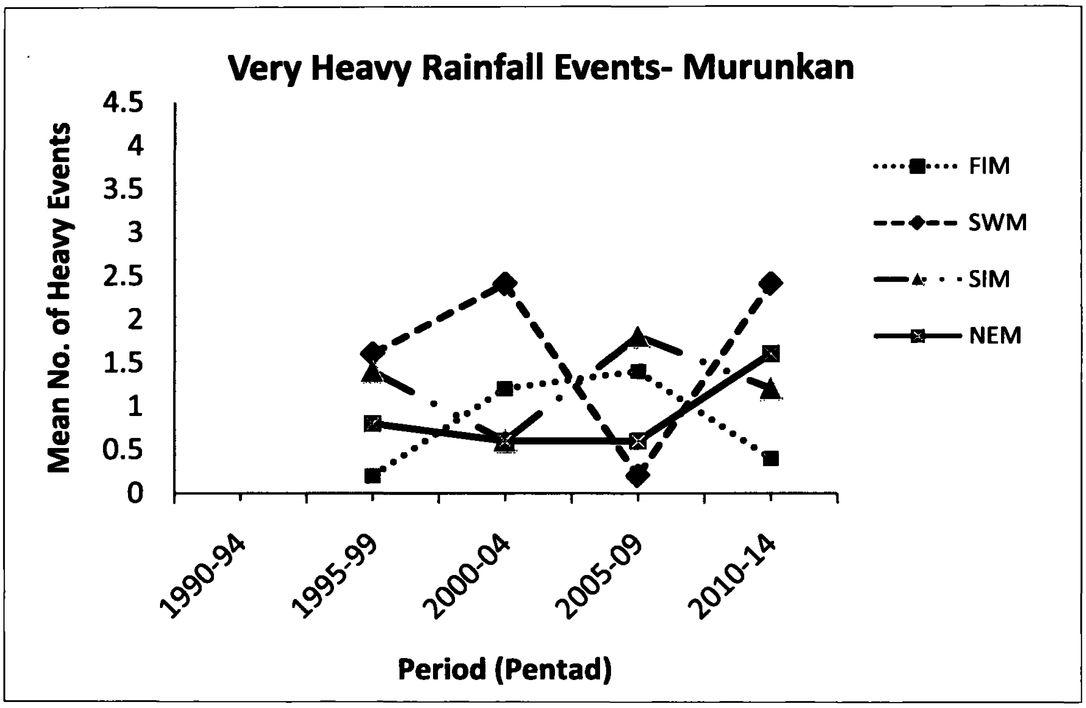


**Figure 8: Occurrence of extreme positive rainfall anomalies in the $DL_4$ agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events**

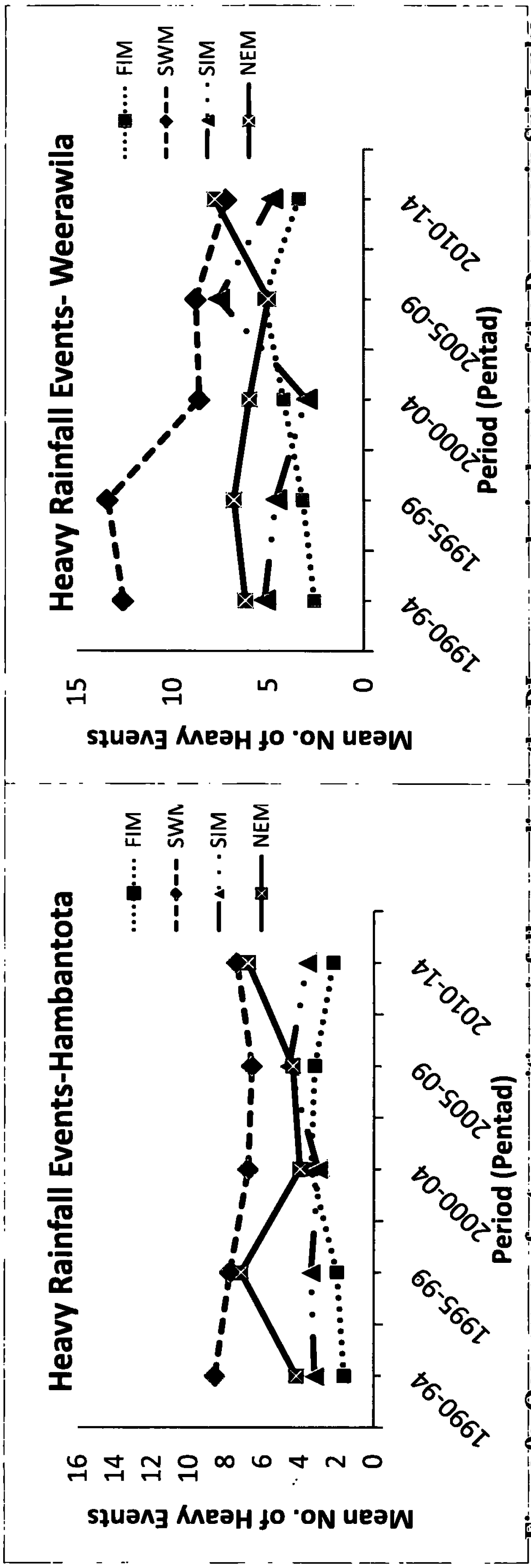


Figure 9: Occurrence of extreme positive rainfall anomalies in the $DL_5$ agro-ecological region of the Dry zone in Sri Lanka – Heavy events

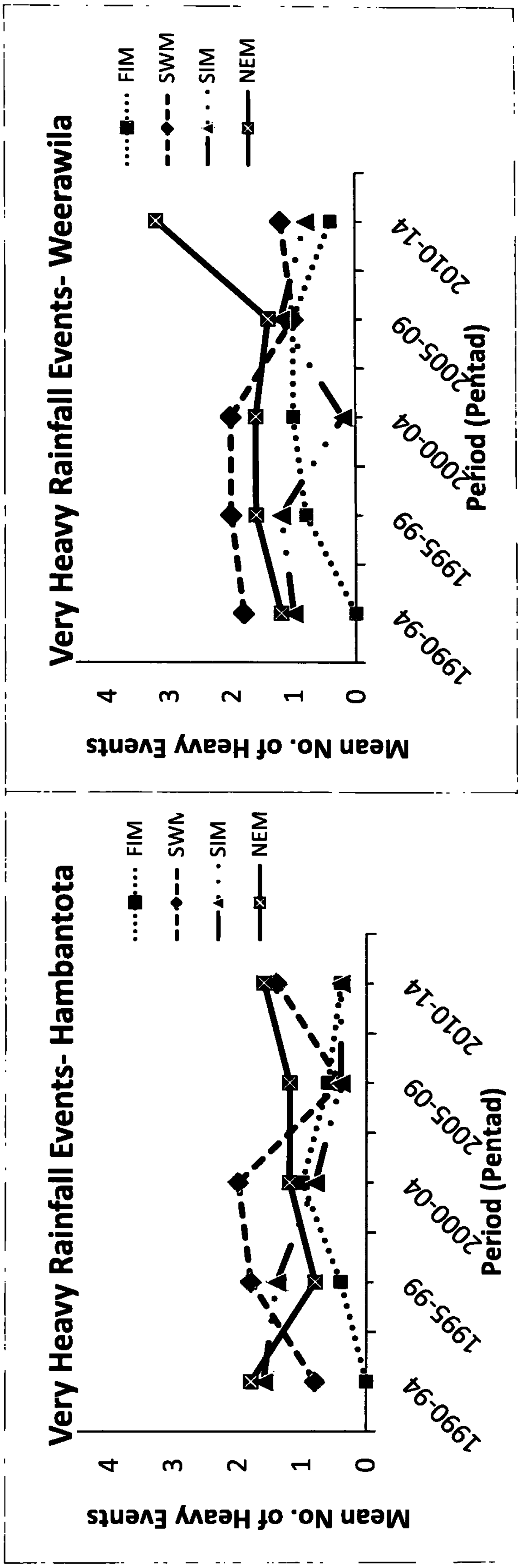


Figure 10: Occurrence of extreme positive rainfall anomaliesin the $DL_5$ agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events

The above results suggest that even though trends in occurrence of HRF and VHRF events during most recent 25-year period of 1990-2014 is not significant, an apparent increasing trend of these extreme events during last 25 year period, last five years in particular signals a change in usual rhythm of rainfall climatology in the Dry zone of Sri Lanka that could be probably attributed to the climate change. With continuing global warming, these extreme events are expected to increase in the future (IPCC, 2013) and thus, current apparent trends could become obvious events in the future. The impacts of these frequent positive extreme rainfall events are already manifested in the Dry zone agriculture during recent times. Meanwhile, increasing trends of extreme positive rainfall anomalies during SWM and NEM seasons during most recent pentad (2010-2014) is quite important aspect to pay attention in the context of crop production in the Dry zone. These SWM and NEM seasons mark the latter half of the two major cultivation seasons in the region namely, *Yala* and *Maha*, respectively. Thus, increasing positive rainfall anomalies in SWM and NEM seasons result in frequent excess moisture conditions in rainfed upland crops and flooding in lowland paddy fields during reproductive phase of both aforesaid cropping systems with subsequent loss of yield both quantitatively and qualitatively.

## Implications of the trend

Moreover, the decreasing trend of extreme rainfall events during FIM season in most places of the Dry zone poses additional threat to crop production under cascade of minor tank systems in the Dry zone. During *Yala* season, these minor tanks are usually fed by ephemeral streams in respective catchments. With the arrival FIM season, aforesaid ephemeral streams become live and feed the downstream tank. Whenever, upstream catchment receives HRF events frequently in a season tanks will come to the full-supply level in a short period of time and therefore, farmers can start the cultivation on-time. Hence, this apparent decreasing trend of heavy rains during FIM season in the Dry zone may lead to frequent insufficient water storage conditions of tanks during *Yala* season for cultivation, drinking, household use and environmental purposes.

Furthermore, the apparent increasing trend of HRF and VHRF events in the Dry zone landscape is detrimental to the existence of the tank cascade system of the Dry zone. If any rainfall event exceeds its intensity greater than 25 mm/hr, such rains result in soil erosion in many landscape of Sri Lanka except closed canopy forests or vegetation with similar ground cover. Thus, increasing trend of HRF and VHRF events in the Dry zone suggests that such erosive rains are becoming more and more frequent in its landscape resulting accelerated soil erosion in already degraded catchments and consequently rapid siltation of downstream cascade of tanks. Siltation of tanks does not only reduce the tank's storage capacity, but also increases the risk of rapid drying out even under a minor dry weather condition. This phenomenon is likely to be aggravated in the future due to climate change. Increased surface to depth ratio of a tank morphology resulted from silting, will increase the evaporative losses from the tank with continually increasing temperature regime of the Dry zone. Punyawardena *et al.* (2013) have shown that average temperature regime of the Dry zone could be in the range of 2 °C to 3 °C higher than that of today at the turn of the 21st century

## Future studies

It is logical to hypothesize that evaporative flux from the Indian Ocean around Sri Lanka should have a direct link with the increased occurrence of extreme positive rainfall anomalies of Sri Lanka. As the evaporative flux from the ocean is a function of Sea Surface Temperature (SST), any ocean-atmospheric phenomenon such as Indian Ocean Di-pole (IOD) and *El Nino* events which alter the SST dynamic around Sri Lanka likely to have a teleconnection with the occurrence of HRF and VHRF events in Sri Lanka. Therefore, further studies are required to establish such teleconnections, if any. So that reliable forecasts on these events could be made with a reasonable lead-time enabling farmers and policy makers to take appropriate risk reduction strategies for such events in approaching rainy seasons.

# CONCLUSIONS

This study was undertaken to ascertain the trends of positive extreme rainfall anomalies in the Dry zone of Sri Lanka where dynamics of seasonal rainfall is an important determinant in agriculture, water resources and livelihood of the people. Even though no significant trend in occurrence of HRF or VHRF events has been observed during last 25-year period from 1990-2014, it is revealed that an apparent trend of these extreme positive rainfall anomalies is discernible, especially during South West Monsoon (SWM) and North East Monsoon (NEM) rainfall seasons. This trend has been clearly evident during last 5-year period from 2010-2014. As these two rainy periods coincide with the reproductive phase of the crops grown in both *Yala* and *Maha* cultivation seasons in the Dry zone, it may likely to inflict significant implications on the agricultural production in the region in terms of both quantity and quality. As the climate change is likely to exacerbate extreme rainfall events in future, these apparent trends could even become obvious thus, excess soil moisture stress in rainfed upland crops, flood damages in lowland paddy fields and rapid drying out in cascade of tanks in long-run will be a serious threat to agricultural productivity in the Dry zone of Sri Lanka.

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