The Influence of La Nina on Sri Lanka Rainfall

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ABSTRACT

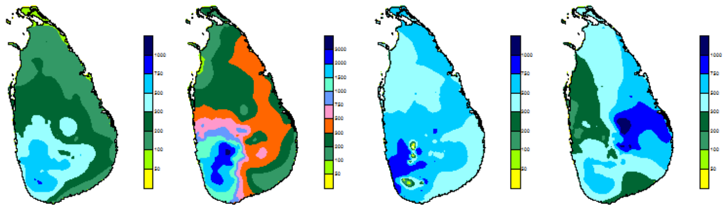
The objective of this study is to identify the relationship between La Niña events and the corresponding rainfall anomalies observed in the 25 districts of Sri Lanka in the last sixty years. Based on Southern Oscillation Index (SOI), district wise rainfall anomalies during the La Niña years for the period of 1951-2011 were investigated by utilizing correlation coefficients and Pearson's level of probability values.

It revealed that the La Niña has a strong influence on the rainfall in Sri Lanka when the La Niña commences in April or May and, prevails for consecutive five or more months with SOI values greater than 8. The seasonal effect of La Niña on rainfall is more pronounce than monthly effect. Negative rainfall anomaly is observed during second inter-monsoon especially in the dry zone. The impact of La Niña in the southwest (SWM) is limited to the wet zone with above normal rainfall. The strongest impact of La Niña is evident during Northeast Monsoon (NEM) with positive rainfall anomaly. These findings may be incorporated in to the process of probabilistic seasonal rainfall forecast

1. Introduction

Sri Lanka is located in the Indian Ocean between latitudes 5^0 55'N to 09^0 50'N and longitude 79^0 42'E and 81^0 52'E. The central part of the island is mountainous and the remaining part of the island is practically lowlands. The climate in Sri Lanka can be characterized as tropical and monsoonal and is divided into four seasons. The South West Monsoon (May-Sep) and North East Monsoon (Dec-Feb) are major monsoons that are highly depending on wind pattern. Between those two periods there are another two weather patterns namely First Intermonsoon (March-April) and Second Intermonsoon (Oct-Nov). South West monsoon basically affect for South Western parts of the country and Eastern and North Eastern winds contribute for North East Monsoonal showers and that affects Eastern and North Eastern parts of the country. During the intermonsoon periods, the Island experiences afternoon or evening thundershowers. These two periods affect for entire Island. However the second intermonsoon receives more rainfall comparing with the first intermonsoon. According to the spatial distribution of annual rainfall, Sri Lanka can be divided in to 3 major climatic zones as Wet zone (rainfall >2500mm), Dry zone (Rainfall<1750) and Intermediate zone (2500mm<Rainfall<1750).

The average rainfall patterns during each monsoon seasons are showed in the figure 1. However the average conditions can be changed due to the prolonged atmospheric phenomenon such as El Nino, La Nina, Indian ipole Index etc.



(a) (b) (c) (d)

Fig 1: Spatial rainfall distribution during climatic seasons (a) First Inter-monsoon (b) Southwest Monsoon (c) Second Inter-monsoon (d) Northeast Monsoon

El Nino and La Nina are coupled atmospheric ocean systems that originate in the tropical Pacific Ocean with unusually warm (El Nino) and cold (La Nina) episodes. Both events develop in association with swings in atmospheric pressure between the tropical indo –Pacific and Eastern Pacific (Mcphaden, Michael, J., 2004). The zonal circulation associated with this pressure pattern is known as the 'Walker Circulation' (Bjerknes, 1969). The system oscillates between cold (La Niña) to neutral (or warm El Niño) conditions with an average every 3-4 years. World Meteorological Organization (WMO) has considered as La Niña occur on average every 3 to 5 years. However, National Oceanic and Atmospheric Administration (NOAA) determined an interval between events vary from 2-7 years (Hanley et al .2003) according to the historical records. La Niña conditions typically last approximately 9-12 months. Nevertheless, some episodes may persist for as long as two years.

The world's climate has always been influenced by El Niño and La Niña. Drought and flood events occur over different parts of the Globe due to El Niño and La Niña (Ropelewski, et al.1989; Rasmusson et al.1983). Rainfall patterns in different parts of the world shifts during the La Niña conditions. Impact of La Nina on seasonal and monthly rainfall provides important information for seasonal rainfall predictions.

The Walker Circulation is characterized by a pronounced seasonal cycle and interannual variability, and it is an integral component of the El Niño Southern Oscillation climate system (Lau et al.2003). Fluctuations of the Walker Circulation can lead to extreme weather conditions in different parts of the world. El Nino and La Nina Generally known as El Nino Southern Oscillation (ENSO), ENSO affects the Walker circulation; it is much stronger (weaker) during the La Niña (El Niño) conditions because of the strong trade winds due to upwelling in the Eastern Pacific Ocean.

There are many indices used to define La Niña and El Niño. Except Southern Oscillation Index (SOI) and Multivariate ENSO Index (MEI), the rest of the indices are based on Sea surface Temperature (SST) anomalies in different regions in the tropical Pacific Ocean. Where SOI and MEI are calculated on the change of atmospheric pressure pattern in `Tahiti and `Darwin. There is no single method to identify El Nino and La Niña events. Different definitions have been used to identify both events in previous studies (International Research Institute, NOAA earth system research laboratory). The indices used by different countries to identify both events are listed in WMO Catalogue_12062006. Australian Bureau of Meteorology is using different Indices such as SOI, Nino SST, MEI and compares with other factors to Identify La Niña and El Niño events (WMO Catalogue_12062006). La Nina events identified by the Australian Bureau of Meteorology are used in this study.

The objective of this study is to identify and characterize the changes in rainfall anomalies such as temporal, spatial variation during the La Niña years in Sri Lanka. The remainder of the paper is organized as follows. Descriptions of the data and analysis method used are presented in section 2. In section 3, the variation of monthly and seasonal rainfall anomaly, and spatial and temporal patterns during La Nina years are investigated. Finally, a summary and conclusions are presented in section 4.

2. Data and Methodology

For the analysis, La Nina years are taken from the Australian Bureau of Meteorology for the period 1951 - 2011 (Table 1). District average rainfalls were collected from the Department of Meteorology. Hence total rainfall for two monsoon and two inter-monsoon periods were considered and rainfall anomaly were taken to identify the behavior with the La Nina condition.

1954/57	1970/72	1988/89	2007/08	2010-2011
1964/65	1973/76	1998/2001	2008/09	

Table 1: La Niña years during the 1951-2011period

Spatial and temporal rainfall variations were analyzed for the La Niña years. The correlation between rainfall and SOI were identified.

2.1 Monthly Southern Oscillation Index Data (SOI data)

Table 1 indicated nine La Niña episodes during the period 1951-2011 and those nine cases have different characteristics in the monthly SOI values. According to the Bureau of Meteorology in Australia, significant La Nina events are defined when monthly SOI values are higher than +8 (http://www.bom.gov.au/climate/glossary/soi.shtml) and persisting for more than five months. There are four similar cases identified with persistent (more than 5 months) periods of SOI greater than +8 such as 1954-57, 1988-89, 1998-2001 and 2010-2011. Out of these four cases, three La Nina episodes started in the month of April while the fourth one started in May (Table 2).

Table 2 represents nine La Niña years, La Niña periods and period of SOI greater than +8. According to table 2, La Niña episodes initiated in April or May have similar SOI characteristics. Quantitative analyses on the relationship between SOI and rainfall anomalies will be presented in the following sections.

La Niña years	La Niña period	SOI >8 and persistent period
1954-1957	April 1954- Jan 1957	May 1955- August 1956
1964-1965	February 1964-January 1965	
1970-1972	June 1970-March 1972	
1973-1976	June 1973-March 1976	August 1973-May 1974, June 1975-February 1976
1988-1989	April 1988-July 1989*	July 1988-Feb 1989*
1998-2001	May 1998-March 2001*	June 1998-April 1999*
2007-2008	June 2007-April 2008	November 2007-March 2008
2008-2009	August 2008-April 2009	August 2008-February 2009
2010-2012	April 2010-March 2012*	July 2010-April 2011*

Table 2: La Niña episodes, characterizing with La Niña active period and persistent months of monthly SOI above 8

* Highlighted periods are La Niña episodes initiated in April or May with similar SOI characteristics

2.2 Rainfall Anomaly and SOI

2.2.1 Monthly Rainfall Anomaly and Monthly SOI

Monthly SOI data and district monthly rainfall anomaly data were analysed during the nine La Nina episodes listed in the table 2. The analysis was focused to identify the correlation between monthly district rainfall anomalies and monthly SOI values. The analyses were conducted on a zonal basis (i.e. dry zone, wet zone and intermediate zone). Twelve districts are found within the dry zone, nine within the wet zone and four within the intermediate zone. The levels of significance of the correlation were tested using Pearson's r level of probability with the $p \leq 0.05$ significance level for those four La Niña episodes.

3. Results and Discussion

3.1 Impact of La Nina on monthly Rainfall anomaly using correlation coefficient for different climatic zones.

Strong correlation between SOI and district rainfall anomalies during the La Niña years is evident in Ampara, Batticaloa, Trincomalee, Anuradhapura and Polonnaruwa districts located in dry zone, Rathnapura and Kandy districts situated in western slope of the Central hills and Badulla district located in eastern slopes of the central hills. The Table 3 represents summary of correlation coefficient which are higher than 0.5.
Table 4 represents summary of districts that has correlation coefficients with $p \leq 0.05$, level of significance. Most of the districts show statistical significance for the 1954-57 La Nina events (Table 4). According to the table 4, only Ampara and Badulla district rainfall anomalies are statistically significant in 1988-1989 La Nina episodes. In 2010-2011 La-Nina episode district rainfall anomalies of Hambantota and Kilinochchi are statistically significant. None of the districts show statistical significance for the 1998-2001 La Nina events. Considering Pearson's significance test, the correlation between monthly district rainfall anomaly and monthly SOI is not significant for three La Nina events that persistent with SOI values above +8 during 1988-1989, 1998-2001 and 2010-2011 because the number of data pairs is limited during these events (12, 4, 7 and 6 episodes).

Correlation coefficient of 5 months running averages of Monthly SOI(>8) and corresponding monthly rainfall anomaly (1954-57, 1988-89, 1998-2001 and 2010-2011)		
Dry zone (>0.6)	Wet zone (>0.5)	Intermediate zone (>0.5)
• Eastern province (Ampara, Batticaloa and Trincomalee) • North central province (Anuradhapura and Polonnaruwa)	• Rathnapura and Kandy districts	• Badulla district

Table 3: District summary, which has higher correlation coefficient during 4 La Niña episodes

correlation coefficients with $p \leq 0.05$ significance level; (significant positive correlation is accepted at $p \leq 0.05$)				
	1954-1957	1988-1989	1998-2001	2010-2011
Dry zone	Ampara, Batticaloa, Anuradhapura, Jaffna, Mannar, Mulativu, Vavuniya, Puttalam, Kilinochchi	Ampara		Hambantota Kilinochchi
Wet zone	Colombo, Kaluthara, Galle and Kegalle			
Intermediate zone	Badulla, kurunegala and Monaragala	Badulla		

Table 4: Districts summary: for correlation coefficients with $p \leq 0.05$ significance level (Similar 4 La Niña episodes)

3.2 Impact of La Nina on Seasonal Rainfall Anomaly

Influence of La Nina on seasonal rainfall anomaly with the genesis period of the La Nina event is discussed in this section. The influence of seasonal rainfall is analysed for La Niña start month April/May (4 cases), June (3 cases), February (one case) and August (one case) cases separately with SOI greater than +8 at least 5 consecutive months period. But only 1964-65 and 1970-72 episodes do not have SOI greater than +8 at least 5 consecutive month period.

It is found that the influence of La Nina on seasonal rainfall except during First inter-monsoon is significant when the initiation of the event occur in month of April or May.

This study also focused on district seasonal rainfall anomalies during the La Niña years that had started in February as well as August. Influence of La Nina events that initiated in February and August are different from those initiated in April or May and difficult to conclude with considering one episode.

3.2.1 North East Monsoon (NEM-December to February)

The Figures 2a, 2b and 2c represent district NEM rainfall anomalies for first NEM during the La Niña active period initiated in April or May in dry zone, wet zone and intermediate zone respectively. These are accumulated rainfall anomalies during December to February season.
Three NEMs (1955, 1999 and 2011) have positive rainfall anomalies (except 1989) in dry zone, wet zone and Intermediate zone.

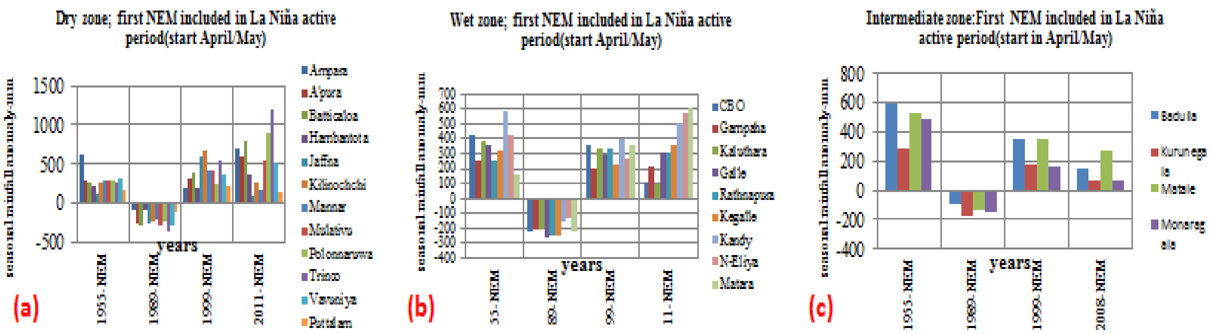


Figure 2: District NEM rainfall anomalies during La Niña episodes that had started in April or May for (a) Dry zone, (b) Wet zone and (c) Intermediate zone.

There are three cases that are started in June and it is different with four similar cases that had started in April or May. There is no clear relationship with genesis year for NEM district seasonal rainfall anomalies during the La Niña period that usually starts in June.

However for NEM, except of four similar episodes (1954-57, 1988-89, 1998-2001, and 2010-2011) other episodes do not show clear pattern at all. These similar episodes show positive NEM (except of 1989 NEM) district rainfall anomalies that are included in the genesis year.

3.2.2 South West Monsoon (SWM-May to September)

Figures 3a, 3b, and 3c represent district SWM rainfall anomalies during the La Niña years that had started in April/May in dry zone, wet zone and intermediate zone respectively.

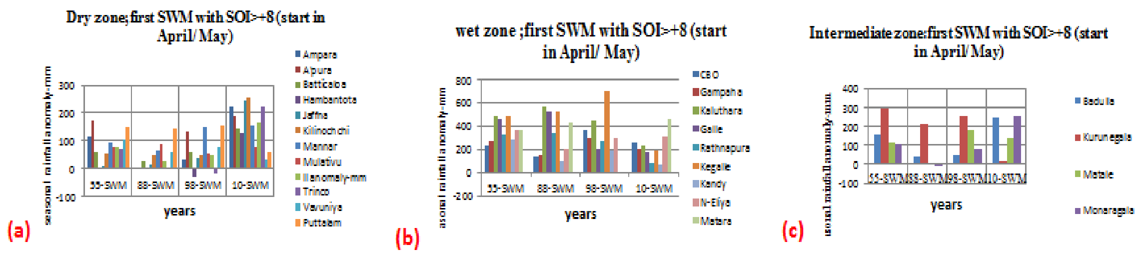


Figure 3: District SWM rainfall anomalies during the La Niña episodes that had started in April/May

As seen in Table 2 that SWMs in 1955, 1988, 1998 and 2010 are included in the La Niña period which is initiated in April/May and the early part of SWM is also included in persistent period of monthly SOI values above +8. Positive rainfall anomalies are evident in some districts of dry zone (Figure 3a) and all districts in wet zone (Figure 3b) during those years. Only Trincomalee (-15.4mm) and Hambantota (-28.1mm) districts in dry zone have negative rainfall anomalies in 1998 SWM. All districts have positive SWM rainfall anomalies, except Monaragala district (in 1988 SWM, -11.7 mm) in intermediate zone (Figure 3c). However, these positive SWM rainfall anomalies that can be found in the first SWMs included in persistent period of higher values of monthly SOI (> 8).

The 1970-72, 1973-76 and 2007-08 La Nina episodes were initiated in June and SWMs in 1970, 1971, 1973, 1974, 1975 and 2007 are included in the La Niña period. There is no persistent period of more than 5 consecutive months with SOI greater than +8 for 1970-72 episodes (Table 2). SWM seasonal rainfall anomalies for La Nina episodes initiated in June are different from those of initiated in April/May. Even though the 1973-76 La Nina episodes have persistent period of monthly SOI values above +8, district rainfall anomalies are different from those of initiated in April/May.

Finally, La Niña influence on SWM district rainfall anomalies has better relationship with those episodes that had started in April/May and some months of that SWM are included in persistent period of SOI greater than +8.

3.3.3 First Inter-monsoon (FIM- March and April)

There is no clear contrast between district seasonal rainfall anomalies in FIM during the La Niña years. For these 9 cases, district FIM rainfall anomalies have different characteristics even in genesis year. However, La Niña influence on FIM doesn't show clear contrast at all.

3.3.4 Second Inter-monsoon (SIM- October and November)

Figures 4a, 4b and 4c represent SIM district rainfall anomalies during La Niña episodes that had started in April/May in dry, wet and intermediate zones respectively.

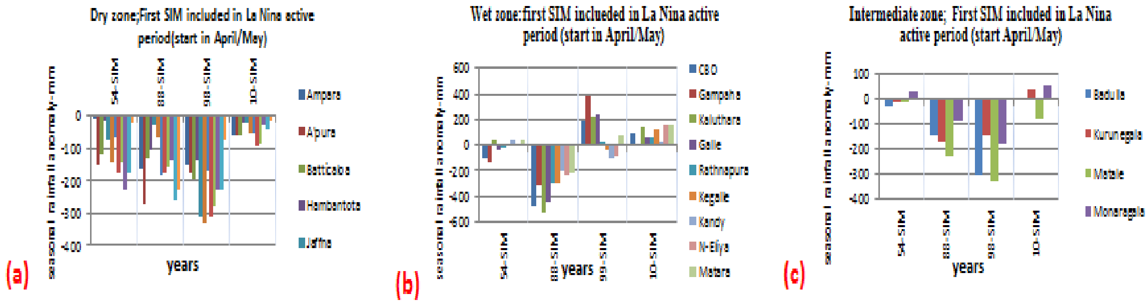


Figure 4: District SIM rainfall anomalies during the La Niña episodes that had started in April/May

All districts have SIM negative seasonal rainfall anomalies in dry zone (Figure 4a) that is included in first SIM during the La Niña active period (genesis year). These results were found with 4 similar episodes (1954, 1988, 1998 and 2010 SIMs) which were identified with SOI (at least five consecutive months of period>+8). SIM districts rainfall anomalies in the intermediate zone and wet zone do not have similar characteristics during those 4 episodes.
So La Niña influence on SIM is limited for dry zone and it has to be started in April/May.

3.4 La Niña influence on temporal and spatial pattern

The NEM (genesis year) is the most influenced season by La Niña because it has positive district monthly rainfall anomalies for all districts (including in dry zone, wet zone and intermediate zone) (Fig 6 a). The SWM has positive rainfall anomalies in all districts in wet zone and some districts in dry zone except Trincomalee and Hambantota, and all districts in intermediate zone except Monaragala district during the La Niña episode (Fig 6 b). But it is the first SWM which is included in the period of SOI>8 persistent months. The SIM is influenced by La Niña with negative rainfall anomalies especially districts in dry zone (Fig 6 c). NEM and SIM influenced by La Niña in the genesis year. The above discussed temporal and spatial results figure out in a Sri Lanka map. The Figure 5 represents climatic zones including districts.

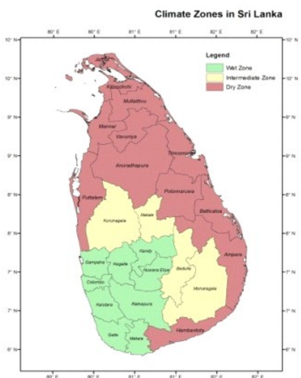


Figure 5. Climatic zones in Sri Lanka including districts

The Figure 6a, Figure 6b and Figure 6c represent the La Niña influence on district seasonal rainfall anomalies. It is obvious that the La Nina influence is strongest during NEM season in temporally (Fig 6 a). Spatially the most influence region is Dry zone because the impact can be seen during all 3 seasons namely NEM, SWM and SIM over the dry zone (Fig 6 a, b ,c).

a) NEM (DJF) **b) SWM (MJJAS)** **c) SIM (ON)**

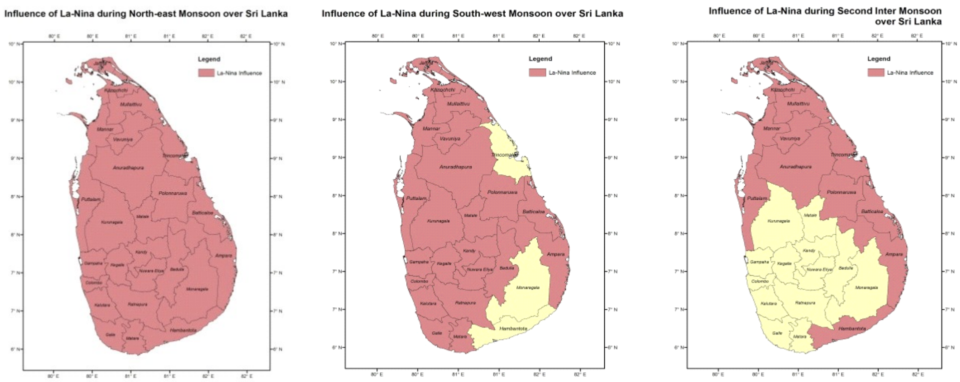


Figure 6: Spatial and Temporal influence of La Niña on district rainfall anomalies

4. Summary and Conclusion

The seasonal district rainfall anomalies are more influenced by La Niña than monthly district rainfall anomalies. The similar district seasonal rainfall anomalies are found during 4 similar episodes in 1954-57, 1988-89, 1998-2001, 2010-2011 that are identified with SOI values greater than +8. Positive district rainfall anomalies are evident during the NEM period especially the first NEM that included in La Niña period. But for the 1989 La Niña, NEM has negative rainfall anomaly. It might be caused by the Negative Indian Ocean dipole (IOD) occurred simultaneously with La Nina episode in 1989. 1989 is the only year among the four La Niña episodes analyzed in this study that has negative IOD activities together with La Niña. The relationship between IOD activities and ENSO is still in debate, but IOD is another atmosphere and Ocean interaction happening in the Indian Ocean, which can affect the climate in the region.

For the South West Monsoon (SWM) season the influence is limited to the wet zone only. This relationship, however, it is only apparent when the SOI is greater than +8 for at least 5 consecutive months. Some districts in the dry zone and all districts in intermediate zone, except the Monaragala district are similarly influenced by La Niña during the SWM period. On the other hand, negative rainfall anomalies were observed during the second Intermonsoon (SIM) period for districts within the dry zone during La Niña active period. There is no clear relationship between the rainfall anomalies and La Niña during the FIM. Generally, La Niña influence on district seasonal rainfall anomalies are found during the developing phase of La Niña episode.

La Nina influence is strongest during NEM season in temporally. Spatially the most influence region is Dry zone because the impact can be seen during all 3 seasons namely NEM, SWM and SIM over the dry zone. However, the overall conclusion of this analysis is: the seasonal district rainfall anomaly is influenced more by the La Niña episodes than the monthly district rainfall anomaly.

It revealed that the La Niña has a strong influence on the rainfall in Sri Lanka when the La Niña commences in April or May and, prevails for consecutive five or more months with SOI values greater than 8.

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