SEARCA – FAO Project

"The Impacts of El Nino Southern Oscillation (ENSO) Events on Rice Production, Area and Yield in Sri Lanka"

Samsudeen Zeenas Yahiya, Sumudu Adhikari, Madhura Weerasekara

& Lareef Zubair

Foundation for Environment, Climate and Technology,
Digana Village, Rajawella,
Kandy, Sri Lanka.

+94-81-2376746
climate@sltnet.lk
zeenasy@sltnet.lk

ABSTRACT

Climatic fluctuations have a profound influence on the cultivation of crops such as rice, which is a staple food in Sri Lanka while other cereals such as maize and millet are consumed in more limited quantities. The El Niño / Southern Oscillation (ENSO) phenomenon is a primary mode of climatic variability that affects Sri Lanka. Despite advances in the capacity to predict the evolution of the ENSO phenomenon and advances in understanding the influence of ENSO on rainfall in tropical regions such as Sri Lanka, there has been limited use of climate predictions for agricultural decision-making.

In this study, we analyze the relationship of Sri Lankan rice production, harvested area and yield with rainfall and ENSO, for the "*Maha*" (October to March) and "*Yala*" (April to September) cultivation seasons based on data from 1950-2009. Maha is the primary growing season as it garners much more rainfall; the area under cultivation during Yala is about half of that during Maha. Farmers decide on the extent they cultivate during Yala based on a variety of factors including market conditions, subsidies, available stored irrigation water and gamble on upcoming rainfall. We have used correlation analysis, regression analysis and composite analysis to evaluate the association between rice production, area harvested, yield, ENSO and rainfall, for entire Sri Lanka and separately for three regions as described below.

Previous work has divided Sri Lanka into four regions based on seasonality of rainfall climatology. The "Northern" and "Southern" regions are away from the mountains and are largely not influenced by topographic effects. The southern half of Sri Lanka has an anchor shaped mountain with a North-South ridge that rises to 2.5 km. The Eastern and Western sides of the ridge are identified as two regions as well. We have previously studied the climatic characteristics of these regions.

Rice is cultivated primarily in the lowland areas but there are also regions of cultivation at elevations reaching 1300m. Statistics on aspects of rice production are available for 25 districts – these 25 districts can be allocated among the 4 climatic regions with significant mismatch only in the Southern which is the smallest region. We undertook a cluster analysis of rice production variations of the 25 districts – the results from this exercise too supported a regionalization similar to the climatic regions except in the Southern region. Based on these results, we have reduced the four climatic regions to three by eliminating the small Southern region - the remaining regions are termed Northern, South-Western, and Eastern.

The Production (P), Harvested Area (A) and Yield (Y) data for each of these regions and for "All Sri Lanka" were estimated. The trends in these data which are longer-lived than the typical ENSO-cycle were identified using a 5 point moving average of the data and removed – further analysis were undertaken based on the normalized anomalies. We have repeated this work with detrending undertaken based on 3rd order polynomial fit and based on a first-order differencing scheme. The results are largely consistent with that described below.

Historical monthly rainfall was estimated for All-Sri Lanka and for each of the climate regions based on an average of quality controlled observations from a fairly well distributed network of

synoptic rainfall stations. The sea surface temperature based index of NINO3.4 was used as the ENSO index at a monthly time-step.

Previous work has shown that rainfall in the first half of "Maha" season (October to December) has a consistent positive correlation with NINO 3.4. This relationship is of the opposite sign from that for the correlation between ENSO and rainfall from January to March. Similarly, the rainfall from July to August shows consistent and significant relationship with ENSO. A year-by-year analysis of rainfall climatology under El Nino, Neutral and La Nina conditions supports the above interpretation (Figures 13 (a-d)). For the analysis for Maha, we have used the rainfall during the planting season which is from October to December (OND) as it provides the strongest correlations with Maha PAY data. For the "Yala" season (April to September), we have considered rainfall in both May-August (MJJA) and June to August (JJA) separately. Usually, the rice crop that is chosen for Yala has a shorter growing season of 3-4 months and farmers who do not have assured irrigation await the first seasonal rains in April or May before deciding on the extent of rice cultivation.

The OND rainfall correlates with ENSO and normalized anomalies of Maha season's harvested area and production with a significance of 1% level for entire Sri Lanka. ENSO indices for the Maha season correlates with normalized anomalies of production and yield of this season at 5% level. During Yala, the JJA rainfall shows a strong correlation with ENSO indices (1% significant level). ENSO indices during Yala correlate with normalized anomalies of harvested area and production at 5% significant level.

At the regional level, there are variations to these relationships. During the Maha season, the ENSO/OND rainfall relationships are strong for all regions, but the level of significance for Northern region is relatively lower. Additionally, during Maha ENSO indices shows strong relationships with normalized anomalies of seasonal yield and production in Northern and Eastern regions. The relationships between OND rainfall and normalized anomalies of Maha season's PAY are strong only in the Northern region. During Yala, ENSO indices correlates with JJA rainfall strongly except in Northern region. In addition to JJA rainfall, average of ENSO index for Yala correlates strongly with normalized anomalies of harvested area and production in Eastern region. This relationship is weaker in the Northern and South-Western regions.

This work shows that there is modest predictability of Production, Area and Yield based on ENSO indices – with skill depending on the season and region. Predictions of ENSO indices are available 3-6 months in advance and these may be used in conjunction with the above relationships to provide advance assessment. Planting season rainfall may be predicted with enhanced skill, and this too can inform a prediction system. However, other predictors based on the Indian Ocean and Pacific Ocean sea surfaces should be brought in to augment the skill.

INTRODUCTION

El-Nino Southern Oscillation is a shift in the pattern of oceanic warming and atmospheric circulation centered in the Pacific Ocean with implications across the tropics and elsewhere that recurs typically 2 to 7 years apart. Anomalously warm sea surface temperatures in the equatorial Eastern Pacific is referred to as El Niño phase, and its cold analogue is referred to as La Niña. The influence of ENSO on the South Asian climate system differs by season: while the summer (June to September) rainfall in northern India decreases with the El Niño, it increases in Sri Lanka and southernmost India from October to December. According to our previous studies on rainfall and ENSO it shows that ENSO influence on rainfall differs according to regions and seasons (Zubair *et al*., 2008, Yahiya et al., 2009). Climatic fluctuations have a profound influence on the cultivation of crops such as rice.

Rice in Sri Lanka

Rice is the staple food in Sri Lanka. There has been a steady increase in rice production in Sri Lanka from 1950 to 2009. (Figure 1) The principal cultivation season is from October to March known as "*Maha*". During this season there is usually enough water to sustain the cultivation of all rice fields. The subsidiary cultivation season known as "*Yala*", is from April to September. During Yala usually there is only enough water for cultivation of half of the land extent of that for Maha (Department of Census and Statistics, Sri Lanka, 1991). There is also variability in the sowing dates and duration of cultivation within the island (Yoshino and Suppiah, 1983). Compared to Yala, the harvested area and production is greater in Maha. (Figure 2(a) & figure 2(b)).

Climate in Sri Lanka

The climate of Sri Lanka is tropical with only a modest seasonal variation in temperature (Domroes, 1974). Sri Lanka receives 1,800 mm of rainfall on average annually distributed unevenly ranging from 500 to 5000 mm/year (Figure 3). The rainfall follows a bimodal climatology with the main rains from September to December which coincides with the commencement of the main cultivation season of Maha (October to March) and subsidiary rains from April to June that coincides with the commencement of the subsidiary cultivation seasons of Yala (April to September) (Figure 4).

ENSO impacts on Sri Lankan rainfall

The relationship between ENSO extremes and rainfall in Sri Lanka has been recognized for two decades (Rasmussen and Carpenter, 1983, Ropelewski and Halpert, 1987, 1989, Suppiah, 1986, 1997, 1998, Kane, 1998, Sumathipala and Punyadeva, 1998, Punyawardene and Cherry, 1999).

ENSO influences on rainfall vary over the year. During OND El-Nino leads to enhance rainfall and during JFM El-Nino leads to reduce rainfall (Figure 5).

ENSO has a strong positive correlation with the October-December rainfall in all regions at 1% significant level (Table 1). In previous studies a linkage between rice production and ENSO has been established in Sri Lanka (Zubair, *et al.* (2002). Thus it is evident that El Nino conditions favor rainfall for entire Sri Lanka during OND season. There is a slight drop of predictability in the Eastern Hills region that is subject to orographic rainfall. Based on these correlation values, rainfall in early Maha has high predictability. Apart from the Eastern region rainfall in all the other regions shows significant correlations with ENSO from January – March. While the overall correlation between NINO3 and rainfall for the entire record is modest, an examination of the annual climatology (Figure 7) shows that rainfall during El Niño phases is diminished in comparison to that during the La Nina phase. From April – June, the positive rainfall correlations with NINO3 indices are significant at the 5% level except for the Eastern record (Table 1). In the last three decades correlation has dropped insignificantly due to the drop of ENSO influence on the rainfall of April and June but not May. July – August is generally a dry period in the entire island except in the Southwest region, (Zubair, *et al.* (2009).

Rice Production in Southern Asia and ENSO

Rainfall variations are a principal factor that affects the inter-annual variability of rice production as distinguished from its long-term trends (Yoshino *et al.,* 1983, and Yoshino, 1986). An influence of ENSO extremes on the aggregate rice production and yield of Sri Lanka was reported by Zubair, (2002) with El Nino leading to increased production during the Maha and a reduction in Yala. Gadgil (1999) reported that El Nino was often associated with drop in Indian food grain production during the summer – this result was extended by Selvaraju (2003). Analysis has found that rice production in India was more impacted by ENSO than production of the other crops.

ENSO impacts on rainfall and rice production, area, and yield has been reported in South East Asian countries: China's agriculture compared to that in Indonesia and the Philippines is less climate-sensitive. ENSO has little effect on Chinese rice production despite being well correlated with rainfall (Deng, (2010)). Impacts of ENSO were much greater on areas harvested than on yield in Indonesia (Naylor, (2001)). Lansigan in 2005; Lansigan et al in 2000; Buan et al., in 1996, on El Nino events in the Philippines has identified a negative association between El Nino and rice yields in rain fed production systems (Roberts et al (2009)).

Here in this study we try to identify whether the impact of ENSO affects the rice production in Sri Lanka. Our analysis uses an extended time series and considers finer spatial units than reported in Zubair (2002) and reports on the variability of Area cultivated with ENSO as well. We analyzed 60 years of PAY data and report on correlations between seasonal SSTA and seasonal production, area and yield. Based on these results we also conducted regression analysis of SSTA, rainfall, production, area and yield to assess the relationship between each other for potential skillful predictions for each region and season.

DATA & METHODS

Regionalization

Sri Lanka is a tear-drop shaped island measuring 435 km North-South and a 250 km East to West. The land area is 65,525 square kilometers and is broken into 25 administrative districts and 9 provinces (Figure 6(a), 8).

The island is often demarcated into three principal climatic zones as the Wet, Intermediate and Dry zones based primarily on annual rainfall (Somasekeram *et al*., 1988); however this demarcation does not isolate regions with similar seasonality or influences from the same rainfall generation mechanism. Puvaneswaram and Smithson, 1993) proposed a regionalization base on seasonality which identifies 4 climatic regions (Figure 6(b)) which segregates the island into regions that are dominated by different rainfall mechanisms. The orographic rainfall due to South-West monsoon is dominant in the West; influence of the North-East monsoon is dominant on the East along with cyclonic influences. The Northern and Southern regions have reduced orographic influences due to geography and monsoon wind directions. The Western and Eastern region may be further divided into the coastal (<150 m) and hill (>150 m) (Figure 6(b)).

There is mismatch between the Climatic Zones and Administrative districts by which rice statistics are available. The majority of districts can be assigned to the Northern, Eastern and Western regions – however the districts that overlay the Southern region overlay the Eastern and Western regions as well by Areas that are significant in comparison with Southern region.

Spatial Aggregation

We have obtained rice data (production, area harvested and yield) for all the administrative districts in Sri Lanka. There are some inconsistencies in reporting as there were only 22 districts in 1959; Killinochchi, Mullaitivu and Gampaha districts were created in 1969 and 1978. In addition, some of the production is reported based on irrigation areas after the implementation of the Accelerated Mahaweli river basin development program. A consistent data set was constructed with some assumptions regarding the overlap of new districts with old and irrigation areas with districts. For reducing the 25 districts into a smaller number of regions, we undertook cluster analysis based on correlation value of rice production in each district; the districts were combined into following regions (Northern, South-Western, and Eastern) (Figure 8). The 'Northern' region comprises of Anuradhapura, Vavuniya, Jaffna, Mannar, Killinochchi, Mullaitivu, Kurunegala, Puttalam districts and Mahaweli H irrigation area; the 'South Western' includes the districts of Colombo, Gampaha, Kalutara, Ratnapura, Kegalle, Kandy, Nuwara Eliya, Galle, Matara, Matale ; and the 'Eastern' region with Polonnaruwa, Ampara, Moneragala, Badulla, Batticaloa, Hambantota, Trincomalee districts and Uda Walawe irrigation area.

Unit conversion

Following unit conversions were used.

1 Hectare	= 2.471 acres
1 metric tons	=1000 Kg
1 lb	= 0.45359234 kg
1 kg	=2.20462262 lb
1 bushel	=20.88 kg

Rice Data

Rice data were obtained from the Sri Lanka Department of Agriculture, and the Department of Statistics and Census. Harvested area and Yield data were collected for 22-25 districts of Sri Lanka for the two seasons Yala and Maha for the period of 1950 – 1978; and production, harvested area, and yield (PAY) data were obtained for the same seasons for the period of 1979 – 2009. Since production data was not available from 1950 - 1978 it was calculated by multiplying harvested area and yield (Production = Harvested Area*Yield). There were missing data which were filled by taking the average of the nearest four years.

The district level data was aggregated for the three regions (Northern, South-Western and Eastern regions). Summation of each region was taken for the regional area and production. The following formula was used for the calculation of regional yield.

$$\text{Yield} = \frac{(\text{Area1*Yield1})+(\text{Area2*Yield2})+(\text{Area3*Yield3})......+(\text{Area n*Yield n})}{(\text{Area1+Area2+.......+Area n})}$$

Area 1= harvested area of 1st district
Yield1=yield of 1st district

The amount of Production, and Area harvested in Maha and Yala seasons of the three regions; and all Sri Lanka are shown in (Figure 9 (a-b)).

Consistency check of Rice data

Since sources and units of rice PAY data was not consistent for the entire 60 years, quality checks were carried out. Here two datasets were taken into account; one dataset from 1952-2008 for entire Sri Lanka with largely consistent units; and the other dataset which is calculated for entire Sri Lanka using district wise data. The second dataset was assembled from different data sources, and was associated with several unit conversions. Compatibility of these two datasets is described by the scatter plots. (Figure 12 (a-f)).

De-trending

PAY data is associated with a long term trend, and the following methods were used as the de-trending method.

a) First Difference Method (FD)

In the first difference method the difference is computed by subtracting the previous year's value from the current year's value. For the computation of correlations normalized percentage of the difference is used. In mathematical notation normalized percentage first difference value for production is denoted by

$$P_t = [(P_t - P_{t-1}) / P_{t-1}] * 100$$

b) Third/Second Order Polynomial Method (P3)

The best fitted third or second order polynomial equation of the form either $f(x) = ax^3+bx^2+cx+d$ or $f(x) = ax^2+bx+c$ is obtained for the time series of PAY. Values are predicted using this equation. For the computation of correlation values normalized anomaly is used. In mathematical notation it is denoted as follows.

$$P = (P_{predicted} - P_{actual}) / P_{predicted}$$

c) Five years Centered Moving Average Method (CMA)

Five years centered moving average is calculated for the time series of PAY. Then the normalized anomalies were taken for the computation of correlations. In mathematical notation normalized production anomaly is denoted as follows.

$$P = (P_{actual} - P_{moving\ average}) / P_{moving\ average}$$

The inter annual variation of PAY during Maha and Yala and its five years moving average for all Sri Lanka is shown by (figure 10(a-f)); and the inter annual variation of PAY during Maha and Yala and its five years moving average for regions (Northern,South-Western and Eastern is depicted by (figure 11(a -f)).

Rainfall data - Monthly rainfall data were obtained for the following stations in each region. Regional rainfall index was constructed by averaging monthly data of stations within the region.

Northern - Anuradhapura, Jaffna, Maha Illuppalama, Mannar, Vavuniya, Kurunegala, Puttalam

South-Western - Colombo, Galle, Kandy, Katunayaka, Nuwara Eliya, Ratnapura, Ratmalana

Eastern - Badulla, Batticaloa, Diyatalawa, Hambantota, Ampara, Potuvil, Trincomalee

Seasonal rainfall data were constructed by averaging monthly data for the usual planting and growing phase ((Maha -October, November, December) and (Yala - June, July, August)). Full season rainfall and early season rainfall were used separately for the analysis and better results were found with early season rainfall which is October, November, December for Maha and June, July, August for Yala. Thus specific season rainfall data was used in carrying out the analysis. Rainfall index for entire Sri Lanka was constructed by averaging monthly rainfall of the above three regions.

ENSO Index and El Nino and La Nina

SST based ENSO indices of NINO3 and NINO3.4 have the strongest correlations with Sri Lanka rainfall. Nino-3.4 index has been constructed as the average Sea Surface Temperature Anomaly (SSTA) for the eastern equatorial Pacific Ocean region of (170°W to 120°W and 5°N to 5°S) and obtained for 1950 to 2009 from (NOAA 2010). The El Niño and La Niña years were identified by following Trenberth (1997): El-Niño conditions persist when the average sea surface temperature in the NINO3.4 area exceeds a threshold of 0.4^{o}C, and La Niña conditions are associated with the NINO3.4 index being below –0.4 persisting for at least 5 months . Neutral conditions persists when the Nino3.4 in between -0.4 ^{o}C and 0.4^{o}C. Seasonal ENSO index was constructed by averaging monthly SSTA from October to March for Maha, and from April to September for Yala.

Correlation analysis

The Pearson correlation coefficient was used to identify relationships of PAY with ENSO indices and rainfall (Press *et al*., 1992). A correlation was taken to be significant when the no-correlation null hypothesis was exceeded with a probability of 90 % or 95% and highly significant when the probability was 99%.

Monthly Correlation analysis for Sri Lanka

Correlation analysis was carried out for entire Sri Lanka for each seasonal Production, Area and Yield, and monthly records of rainfall and ENSO. First difference method, third order polynomial method and five years' centered moving average method were used for the computation of correlations.

Seasonal Correlation Analysis for Sri Lanka, and the regions

By considering the results from the monthly correlation analysis seasonal correlation analysis was carried out for entire Sri Lanka and for the three regions separately. Since the sign of the correlation value between ENSO and rainfall is opposite between October to December on one hand, and January to April and June to August on the other, instead of the entire season's rainfall specific parts of seasonal rainfall was considered (Maha: October to December, Yala: June to August). The correlations were computed for entire Sri Lanka as well as for the three separate regions for each season. Correlations have been based on 3-month seasons divided as the first half and second half of both Yala and Maha. Previous work (Yahiya et al. 2009) had shown that these seasons had consistent ENSO influences.

Composite Analysis

El Nino, La Nina and Neutral phases were identified (El Nino: NINO3.4 > 0.4^{o}C, La Nina: NINO3.4< -0.4 ^{o}C, Neutral: NINO3.4< -0.4 ^{o}C). Rainfall anomalies were computed by getting the departure of rainfall from its long term average. Climatology for each ENSO phase was estimated by isolating the rainfall anomaly when a specific ENSO phase prevailed and calculating the climatology using the available values.

Regression Analysis

Regression analysis was carried out where significant correlations are found. Linear regression models were fitted by identifying independent and dependent variables.

RESULTS

- Range of Production, Area and Yield

	Maha	Yala
Harvested Area (Ha)	410362	311984
Yield (kg/Ha)	3753	2418
Production (1000Mt)	2466	1612

- For Entire Sri Lanka

Monthly Correlations - Correlations between monthly rainfall and SSTA are stated in Table 2. February, March, May, August, October, November and December rainfall correlates significantly with ENSO. The sign of the correlation value between rainfall and SSTA is negative for January to April and for June to September. It is positive for May and October to December.

Seasonal Correlations - Maha season rainfall has a high correlation with harvested area, production and ENSO with the values of 0.40, 0.36 and 0.42 respectively. All are significant at 1% level. In addition ENSO in Maha season correlates with yield and production at 5% significant level with the values of 0.27 and 0.29 (Table 3a).

During the Yala season the correlation between rainfall and ENSO is significant at 1% level with the value of -0.38. ENSO correlates with harvested area and production at 5% significant level with the values -0.30 and -0.27 respectively. (Table 3b).

- **For the Regions**

Northern - In Northern region, Maha season rainfall correlations with harvested area and production are 0.50 and 0.47 respectively. Both are significant at 1% level. Yield in Maha is having a correlation of 0.22 with rainfall and significant at 5% level. Also Nino3.4 for that season correlates with yield, production and rainfall at 5% significant level with the values of 0.29, 0.28, and 0.32 respectively (Table 4a).

During the Yala season of Northern region there are no significant correlations of either rainfall or ENSO.

South-Western - In South-Western region during Maha season there is a 10% significant correlation between harvested area and rainfall with a value of -0.23. Also rainfall in that season correlates with ENSO at 1% level of significance with the value of 0.37.

During the Yala season there is a 5% significant correlation between rainfall and ENSO with a value of -0.29. Further correlation between harvested area and ENSO is -0.22 and its level of significance is 10% (Table 4b).

Eastern - In Eastern region Maha season correlation between ENSO and rainfall is 0.43 and significant at 1% level. ENSO correlates with yield and production with values 0.23 and 0.26 and their significance is 10% and 5% respectively.

During the Yala season correlation between rainfall and ENSO is -0.37 which is significant at 1% level. Correlation of ENSO with harvested area is -0.36 where the level of significance is at 1% while the ENSO production corelation is 0.28 and its level of significance is 5%. (Table 4c).

According to the results of the composite analysis during the Maha season Elnino leads to wetter conditions and LaNina leads to drier conditions. Simillarlly during the Maha season normalized rice production anomaly increases under ElNino conditions and decreases under LaNina conditions. The behavior is opposite for the Yala season. (Figures 11(a-d)).

- **Regression Results**

Regression models were built for the significant relationships in Northern, South-Western, and Eastern regions (table 5). Even though the correlations are statistically significant the predictability is low. The highest predictability is for the Northern region Maha production which is based on rainfall where the R^2 value is 22.3%.

CONCLUSION

Data

According to the scatter diagrams and the R^2 values (> 0.96) the PAY data are internally consistent (12 (a-f)) – that is the district-wise data and island-wide data are consistent.

Rainfall Climatology

- During OND El-Nino leads to enhance the rainfall, and during JFM El-Nino leads to reduce the rainfall (Figure 5).
- Among three regions, South-Western region has the highest rainfall (Figure 7)
- The percentage of harvested area and production during Maha is greater than that during Yala. Approximately it is twice as Yala.
- During both seasons, the Northern region has the highest harvested area and the production. The south-Western region has the lowest harvested area, yield and the production during the Maha season.
- During the Yala season the highest harvested area is in South-Western region but the highest production is in Eastern region.

Trends

- There is an increasing trend in PAY data over the time series 1950-2009.

Seasonal Correlations between ENSO, Rainfall, Rice Production, Area, and Yield

- ENSO - Rainfall relationship is statistically significant for parts of both seasons (OND, JJA) and for all three regions with the exception of JJA in the Northern region. ENSO - Rainfall relationship is strong for both seasons and for all the regions except in Yala season of the Northern region.

Maha

- For all Sri Lanka the relationship between OND rainfall and Maha season ENSO is strong and the correlation value is significant at 1% level.
- The correlation between ENSO and rainfall between October to December has opposite signs from that for January to April and June to August. This observation is supported by the analysis of rainfall composites during the three ENSO phases.
- October and November rainfall strongly correlates with month by month ENSO indices from May to December.

- Normalized anomaly of harvested area of Maha season correlates strongly with the May-December ENSO. The Harvested Area-ENSO relationship becomes weaker with January-April ENSO indices.

- Normalized anomaly of production for Maha correlates strongly with the May-December ENSO. The relationship is weaker from January-April.

- Normalized anomaly of yield of Maha season correlates strongly with the September to December ENSO.

- Normalized anomalies of production and harvested area of Maha season correlates strongly with October and November rainfall.

Yala

- Yala season JJA rainfall and ENSO of that season strongly correlates with a significance of 1% level.

- Normalized anomaly of harvested area of Yala season has the highest correlation with the ENSO of May and June.

- Normalized anomaly of production of Yala season correlates strongly with ENSO of June to December.

- Normalized anomalies of production and harvested area of Yala season correlates strongly with January –March rainfall.

- Normalized anomalies of yield of both seasons do not strongly correlate with either monthly ENSO or monthly rainfall.

- In south-Western region we are experiencing poor relationships of production and ENSO in both Maha and Yala seasons. This behavior can be seen in time series of harvested area and

- Production and ENSO relationships are strong for both Yala and Maha seasons for the entire island and the Eastern region; this correlation is weak in Northern region -Yala and South-Western region –both seasons.

- Production and ENSO relationships are strong for both Yala and Maha seasons for the entire island and the Eastern region; this correlation is weak in Northern region -Yala and South-Western region –both seasons.

- The ENSO-production correlation has opposite sense between the two seasons.

- The relationship between production and OND rainfall is strong during the Maha season for entire Sri Lanka. However in the regional analysis this relationship is strong only in the Northern region.

- The relationship between production and JJA rainfall is not statistically significant during the Yala season.

Regional Characteristics during the Maha and Yala Season

- During Maha there is a statistically significant relationship between ENSO and yield for entire Sri Lanka, Northern, and Eastern regions. But this relationship is weaker in Yala.
- During Yala there is a statistically significant relationship between harvested area and ENSO for Sri Lanka, South-Western, and Eastern regions.

DISCUSSION

As per the results of this study there is a significant influence of ENSO on Sri Lankan rainfall as well as rice production, harvested area, and yield. However the influence of ENSO varies by region and season. The ENSO influence in Maha season is the opposite of that for Yala, i.e. El-Nino leads to enhance rainfall and production during the Maha season and vice-versa for the Yala season. We have previously shown that there is a difference in ENSO influence on rainfall in different regions as well as different seasons (Zubair *et al*., 2008, Yahiya et al., 2009).

Apart from rainfall and ENSO there may be other factors influencing the fluctuations in PAY data. Some of these can be, the extent of application of fertilizers, use of high yielding seed varieties, fertilizer prices, civil disturbances, spread of diseases and pests, guaranteed prices for rice, paddy field reclamation, and natural disasters. The correlations reported here could be weakened due to one or more of the above factors. For example, with the increase of rainfall we may expect an increase in harvested area and production, but extreme rainfall may have caused flooding and damaged the crop. Even though we were expecting positive relationship between rainfall and harvested area/production such situations tend to give negative relationships. In 1957 even though Maha season rainfall has increased harvested area and production had declined in both South-Western and Eastern regions; as during this period there was flooding.

Rice production in the South Western region has diminished in recent years in comparison with other areas. South-Western region consists of districts which are becoming urbanized such as Colombo, Gampaha, and Kandy. Urbanization causes paddy field reclamation and reduces the harvesting area and leads to less production.

For the regression we are using only one predictive variable. The correlations are not adequate to give skillful predictions. Thus multivariate regression analysis may be better than simple linear regression analysis.

In this analysis we are not getting strong relationships between production and rainfall in Yala season. But according to Zubair (2002), it should be high. This may be because we used rainfall for JJA as opposed to the April to June considered by Zubair (2002) or because of the longer duration of our data. This may be also because of decadal variability in ENSO-Rainfall relationship as reported in Zubair and Chandimala, 2007.

ACKNOWLEDGEMENTS

Use of rice data from the Department of Census of Sri Lanka, and rainfall data from the Department of meteorology is greatly acknowledged. The research activity is partially supported by The Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA, www.searca.org) and the Food and Agriculture Organization (FAO)-Rome. We are grateful to Dr. Gil C. Saguiguit, JR, the Director of SEARCA, Dr. David Dawe of FAO, Rome, Dr. Mercedita A. Sombilla of SEARCA, for their assistance on this project and we are also thankful to all the others of the project team who helped us in numerous ways.

REFERENCES

1. Chandimala, J. and L. Zubair. (2007). Predictability of Streamflow and Rainfall for Water Resources Management in Sri Lanka, *Journal of Hydrology*, 335 (3-4), 303-312.
2. Deng Xiangzheng, Huang Jikun, Qiao Fangbin, Rosamond L. Naylor, Walter P. Falcon, Marshall Burke, and Scott Rozelle, and David Battisti. (2010). Impacts of El Nino-Southern Oscillation events on China's rice production. Journal of Geographical Sciences. 20: 3-16.
3. Department of Census and Statistics (1991), *Statistical Abstract of the Democratic Socialist Republic of Sri Lanka*, Colombo.
4. Department of Census and Statistics (1993), *Statistical Abstract of the Democratic Socialist Republic of Sri Lanka*, Colombo.
5. Domroes M. (1974). The Agroclimate of Sri Lanka. Franz Steiner Verlag Gmbh: Wiesbaden, 1974.
6. Gadgil, S., Abrol, Y.P., Seshagiri Rao, P.R. (1999). On growth and fluctuation of Indian foodgrain production. Current Science 76: 548-556.
7. Kane R.P. (1998). ENSO relationships to the rainfall of Sri Lanka. *International Journal of Climatology* 18: 859-871.
8. Naylor, R.L., W.P. Falcon, D. Rochberg, and N. Wada. (2001). Using El Nino/Southern Oscillation climate data to predict rice production in Indonesia. Climatic Change 50: 255-265.
9. Press, W.H., S.A. Teukolosky, W.T. Vetterling, and B.P. Flannery (1992). Numerical Recipes in Fortran. Cambridge University Press, New York.
10. Punyawardena B.V.R. and Cherry N.J. (1999). Assessment of the predictability of the seasonal rainfall in Ratnapura using Southern Oscillation and its two extremes. *Journal of the National Science Council of Sri Lanka*. 27 (3): 187-195.
11. Puvaneswaram, K.M. and D.A. Smithson (1993). Controls on the precipitation distribution in Sri lanka. Theoretical and Applied Climatology, 47: 105-115.
12. Rasmusson E.M. and Carpente T.H. (1983). The relationship between eastern equatorial Pacific sea surface temperature and rainfall over India and Sri Lanka. *Monthly Weather Review.* 110: 354-384.
13. Roberts, M.G., Dawe, D., Falcon, W.P. and Naylor, R.L. (2009). El Nino-Southern Oscillation Impacts on Rice Production in Luzon, the Philippines (Notes and Correspondence). Journal of Applied Meteorology and Climatology. 48: 1718-1724.
14. Ropelewski C.F. and Halpert M.S. (1987). Global and Regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Monthly Weather Review* 115: 1606-1626.

15. Selvaraju, R., (2003). Impacts of El Nino-Southern Oscillation on Indian Foodgrain production. International Journal of Climatology. 23, 187-206.

16. Somasekeram, T., Perera , L.A.G., Perera, M.P., De Silva, B.G., Karunanayake, M.M, and Epitawatta, D.S., (1988). *National Atlas*, Survey Department, Colombo

17. Sumathipala W.L. and Punyadeva N.B.P. (1998). Variation of the Rainfall of Sri Lanka in relation to El Niño. *Proceedings of the Annual Sessions of the Institute of Physics, Sri Lanka*, *Colombo*

18. Suppiah. R. and Yoshino, M.M. (1986). Some agro-climatological aspects of rice production in Sri Lanka, *Geographical Review of Japan*, 59 (Ser. B) (2), 137-153.

19. Suppiah R. (1997). Extremes of the southern oscillation phenomenon and the rainfall of Sri Lanka. *International Journal of Climatology.* 17: 87-101.

20. Suppiah, R. (1998) Spatial and temporal variations in the relationship between the southern oscillation and the rainfall of Sri Lanka*, International Journal of Climatology*, 16 (12): 1391-1408.

21. Survey Department, of Sri Lanka National Atlas of Sri Lanka; second edition; 2007:

22. Yoshino, M.M. and Suppiah. R. (1983). Climate and paddy production: A study on selective districts in Sri Lanka, in *Climate, Water and Agriculture in Sri Lanka*, Editors, Yoshino, M.M., Kayane, I., and Madduma Bandara, C.M., Institute of Geoscience, University of Tsukuba, Japan.

23. Yoshino, M.M., Ichikawa, T., Urushibara, K., Nomoto, S., and Suppiah. R. (1983). Climate Fluctuation and its effect on paddy production in Sri Lanka, *Climatological Notes*, Institute of Geoscience, University of Tsukuba, Japan, 33: 57 – 80

24. Zeenas Yahiya; Janaki Chandimala; Manjula Siriwardhana and Lareef Zubair (2009). Sri Lankan Rainfall climate and its modulation by El Nino and La Nina episodes. Engineer Journal – Vol. XXXXII. No. 2, pp. [11 – 24] Apr. 2009. The Institution of Engineers, Sri Lanka

25. Zubair L., (2002). El-Niño -Southern Oscillation influences on rice production in Sri Lanka. *International Journal of Climatology.* 22: 242-250.

26. Zubair, L., M. Siriwardhana, J. Chandimala, and Z. Yahiya, (2008). Predictability of Sri Lankan Rainfall based on ENSO, *International Journal of Climatology*. 28 (1): 91-101.

TABLES, CHARTS, AND FIGURES

Table 1 : The correlation of rainfall with NINO3 from 1869 to 1998, for different regions and entire Sri Lanka. Correlation values that have significance levels for 1% and 5% are 0.22 and 0.17 are shown in bold and italics respectively (n=130)

Region	**JFM**	**AMJ**	**M**	**(JA)**	**OND**
Northern Plains	**-0.23**	**0.23**	**0.28**	**-0.32**	**0.41**
Southern Plains	*-0.17*	*0.2*	*0.17*	-0.1	**0.41**
Eastern	-0.11	0.11	**0.22**	**-0.37**	**0.44**
Eastern Coast	-0.04	0.02	0.09	**-0.3**	**0.4**
Eastern Hills	-0.13	0.07	**0.23**	**-0.31**	**0.34**
Western	*-0.2*	*0.18*	**0.25**	*-0.19*	**0.46**
Western Coast	*-0.18*	0.16	**0.22**	-0.04	**0.45**
Western Hill	***-0.17***	*0.18*	**0.23**	**-0.26**	**0.48**
Sri Lanka	***-0.18***	**0.22**	**0.29**	**-0.29**	**0.51**

Table 2: Correlation values between monthly rainfall and SSTA.

SSTA / Rain	Jan(t)	Feb(t)	Mar(t)	Apr(t)	May(t)	Jun(t)	Jul(t)	Aug(t)	Sep(t)	Oct(t)	Nov(t)	Dec(t)
Jan(t)	-0.21	-0.19	-0.17	-0.15	-0.18	-0.17	-0.01	0.00	-0.06	-0.05	-0.06	-0.07
Feb(t)	-0.27	-0.26	-0.26	-0.28	-0.30	-0.33	-0.20	-0.13	-0.14	-0.16	-0.18	-0.20
Mar(t)	-0.13	-0.17	-0.24	-0.32	-0.32	-0.23	-0.10	-0.08	-0.07	-0.04	-0.02	-0.08
Apr(t)	-0.12	-0.13	-0.11	-0.08	-0.11	-0.15	-0.12	-0.08	-0.08	-0.12	-0.14	-0.17
May(t)	0.20	0.25	0.22	0.24	0.30	0.20	0.19	0.14	0.15	0.17	0.16	0.20
Jun(t)	-0.11	-0.13	-0.14	-0.12	-0.12	-0.17	-0.18	-0.17	-0.13	-0.15	-0.12	-0.09
Jul(t)	-0.05	-0.07	-0.11	-0.10	-0.14	-0.24	-0.19	-0.15	-0.16	-0.19	-0.21	-0.18
Aug(t)	-0.01	-0.02	-0.06	-0.14	-0.22	-0.23	-0.26	-0.20	-0.24	-0.24	-0.22	-0.27
Sep(t)	-0.19	-0.20	-0.14	-0.06	-0.09	-0.04	0.04	0.08	0.13	0.02	0.01	0.01
Oct(t)	0.04	0.10	0.17	0.22	0.30	0.43	0.44	0.43	0.42	0.46	0.43	0.39
Nov(t)	-0.06	-0.01	0.11	0.23	0.28	0.27	0.30	0.30	0.32	0.32	0.35	0.34
Dec(t)	0.05	0.11	0.15	0.18	0.28	0.21	0.16	0.14	0.12	0.13	0.16	0.17

Remark: Correlation values significant at 5% level are indicated by green color.

Table 3a: Correlations of the **Maha** normalized PAY, rainfall and Nino 3.4 for **entire Sri Lanka** for the period of 1950-2009.

	Area	Yield	Production	Rainfall	Nino 3.4
Area	1.00	0.26	0.81	0.40	0.20
Yield	0.26	1.00	0.76	0.18	0.27
Production	0.81	0.76	1.00	0.36	0.29
Rainfall	0.40	0.18	0.36	1.00	0.42
Nino 3.4	0.20	0.27	0.29	0.42	1.00

Table 3b: Correlations of the **Yala** normalized PAY, rainfall and Nino3.4 for **entire Sri Lanka** for the period of 1950-2009.

	Area	Yield	Production	Rainfall	Nino 3.4
Area	1.00	-0.54	0.86	-0.07	-0.30
Yield	-0.54	1.00	-0.14	0.12	0.05
Production	0.86	-0.14	1.00	-0.07	-0.27
Rainfall	-0.07	0.12	-0.07	1.00	-0.38
Nino 3.4	-0.30	0.05	-0.27	-0.38	1.00

Table4 (a): Correlations of the **Maha** normalized PAY, rainfall and Nino 3.4 for **Northern Region** for the period of 1950-2009.

	Area	Yield	Production	Rainfall	Nino3.4
Area	1.00	0.29	0.92	0.50	0.21
Yield	0.29	1.00	0.64	0.22	0.29
Production	0.92	0.64	1.00	0.47	0.28
Rainfall	0.50	0.22	0.47	1.00	0.32
Nino3.4	0.21	0.29	0.28	0.32	1.00

Table 4 (a2): Correlations of the **Yala** normalized PAY, rainfall and Nino 3.4 for **Northern Region** for the period of 1950-2009.

	Area	Yield	Production	Rainfall	Nino3.4
Area	1.00	-0.38	0.97	-0.06	-0.18
Yield	-0.38	1.00	-0.18	-0.04	0.15
Production	0.97	-0.18	1.00	-0.05	-0.18
Rainfall	-0.06	-0.04	-0.05	1.00	-0.16
Nino3.4	-0.18	0.15	-0.18	-0.16	1.00

Table4 (b): Correlations of the **Maha** normalized PAY, rainfall and Nino 3.4 for **South-Western Region** for the period of 1950-2009

	Area	Yield	Production	Rainfall	Nino3.4
Area	1.00	0.00	0.40	-0.23	-0.20
Yield	0.00	1.00	0.90	0.05	0.16
Production	0.40	0.90	1.00	-0.02	0.09
Rainfall	-0.23	0.05	-0.02	1.00	0.37
Nino3.4	-0.20	0.16	0.09	0.37	1.00

Table 4 (b2): Correlations of the Yala normalized PAY, rainfall and Nino 3.4 for **South-Western Region** for the period of 1950-2009.

	Area	Yield	Production	Rainfall	Nino3.4
Area	1.00	-0.05	0.79	0.06	-0.22
Yield	-0.05	1.00	0.57	-0.05	-0.04
Production	0.79	0.57	1.00	0.01	-0.20
Rainfall	0.06	-0.05	0.01	1.00	-0.29
Nino3.4	-0.22	-0.04	-0.20	-0.29	1.00

Table 4 (c): Correlations of the **Maha** normalized PAY, rainfall and Nino 3.4 for **Eastern Region** for the period of 1950-2009

	Area	Yield	Production	Rainfall	Nino3.4
Area	1.00	0.06	0.71	0.02	0.15
Yield	0.06	1.00	0.74	0.13	0.23
Production	0.71	0.74	1.00	0.10	0.26
Rainfall	0.02	0.13	0.10	1.00	0.43
Nino3.4	0.15	0.23	0.26	0.43	1.00

Table 4 (c2): Correlations of the **Yala** normalized PAY, rainfall and Nino 3.4 for **Eastern Region** for the period of 1950-2009.

	Area	Yield	Production	Rainfall	Nino3.4
Area	1.00	-0.08	0.79	-0.06	-0.36
Yield	-0.08	1.00	0.54	0.07	0.05
Production	0.79	0.54	1.00	0.01	-0.28
Rainfall	-0.06	0.07	0.01	1.00	-0.37
Nino3.4	-0.36	0.05	-0.28	-0.37	1.00

* Remarks: In table3a-3b and 4a-4(c2) correlations that are significant at **1%, 5% and 10%** are indicated by **red**, **green** and **blue** colors respectively.

Table 5: Summarized regression results for statistically significant correlations in regions and Sri Lanka.

Region	Season	Variables		Regression Equation	R^2 Value
		Independent (x)	Dependent (y)		
Northern	Maha	Nino3.4	Rainfall	y = 20.63x + 227.5	$R^2 = 0.100$
	Maha	Nino3.4	Production	y = 0.056x - 0.002	$R^2 = 0.077$
	Maha	Rainfall	Production	y = 0.001x - 0.338	$R^2 = 0.223$
South-Western	Maha	Nino3.4	Rainfall	y = 23.26x + 270.4	$R^2 = 0.138$
	Yala	Nino3.4	Rainfall	y = -21.66x + 177.3	$R^2 = 0.084$
Eastern	Maha	Nino3.4	Rainfall	y = 35.54x + 273.1	$R^2 = 0.188$
	Maha	Nino3.4	Production	y = 0.032x - 0.003	$R^2 = 0.067$
	Yala	Nino3.4	Rainfall	y = -12.69x + 57.20	$R^2 = 0.138$
	Yala	Nino3.4	Production	y = -0.052x - 0.004	$R^2 = 0.077$
Sri Lanka	Maha	Nino3.4	Rainfall	y = 26.48x + 257.0	$R^2 = 0.175$
	Maha	Nino3.4	Production	y = 0.036x - 0.002	$R^2 = 0.084$
	Maha	Rainfall	Production	y = 0.000x - 0.186	$R^2 = 0.130$
	Yala	Nino3.4	Rainfall	y = -6.816x + 86.30	$R^2 = 0.101$
	Yala	Nino3.4	Production	y = -0.055x - 0.004	$R^2 = 0.074$

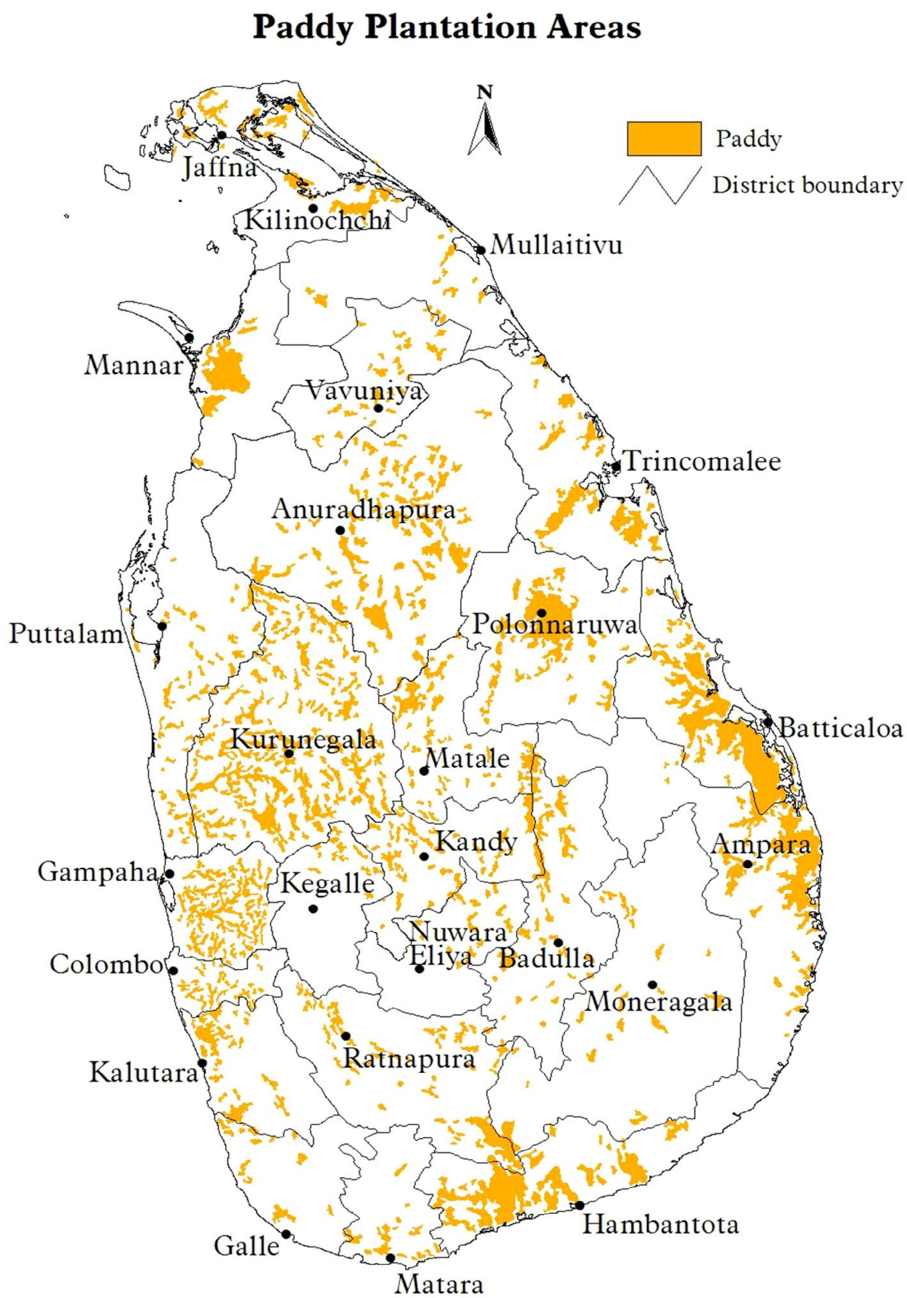


Figure 1: Regions with rice fields in Sri Lanka

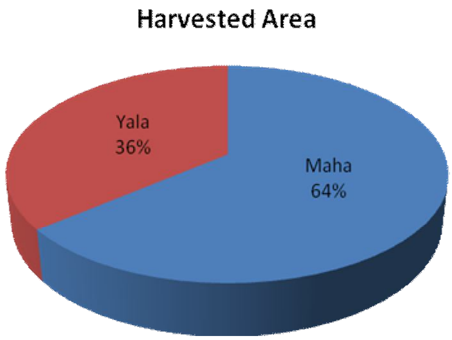


Figure 2(a): Percentage of harvested area in Maha and Yala seasons of Sri Lanka (Considering 1950-2009 as the base period)

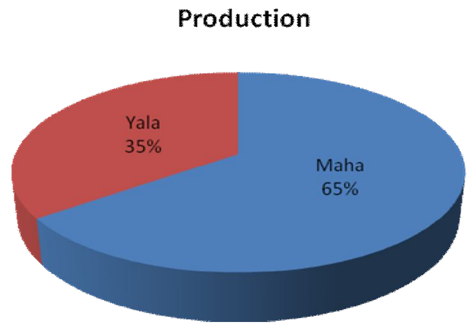


Figure 2(b): Percentage of production in Maha and Yala seasons of Sri Lanka (Considering 1950 -2009 as the base period)

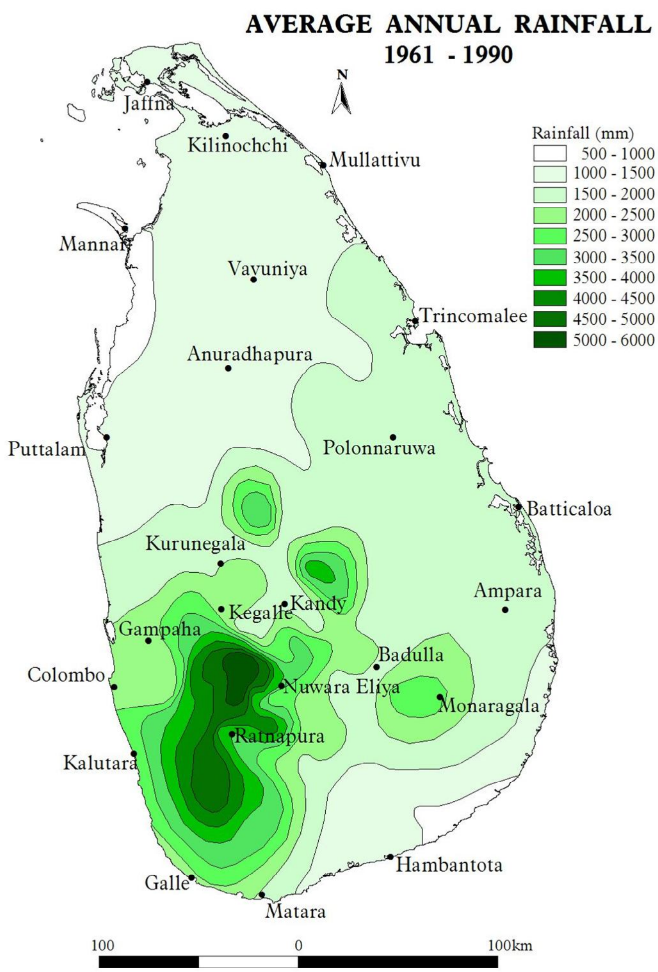


Figure 3: Average of annual rainfall from 1960 to 1990 in Sri Lanka

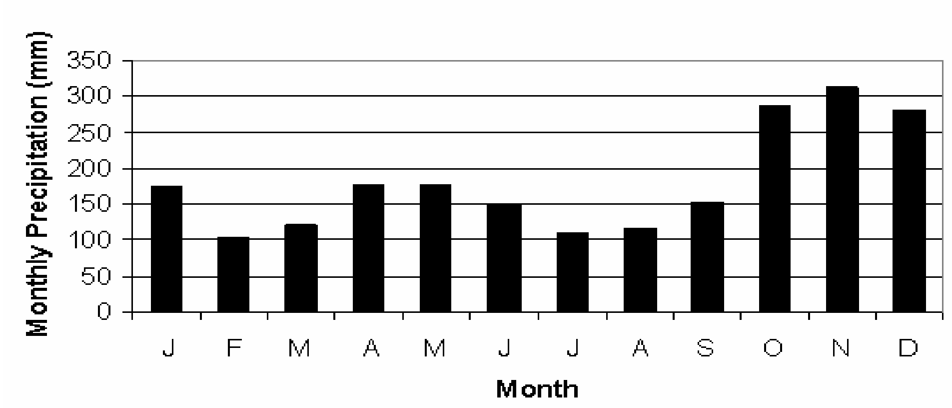


Figure 4: The monthly average rainfall for 1869-1998 for all Sri Lanka

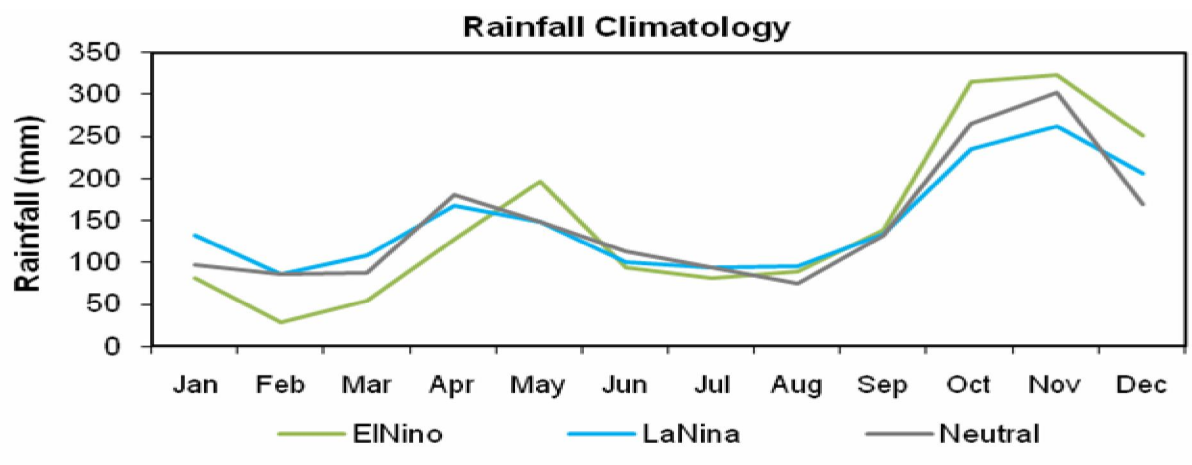


Figure 5: Rainfall Climatology for Sri Lanka during El-Nino, La-Nina and Neutral Phases for 1950-2008 period.

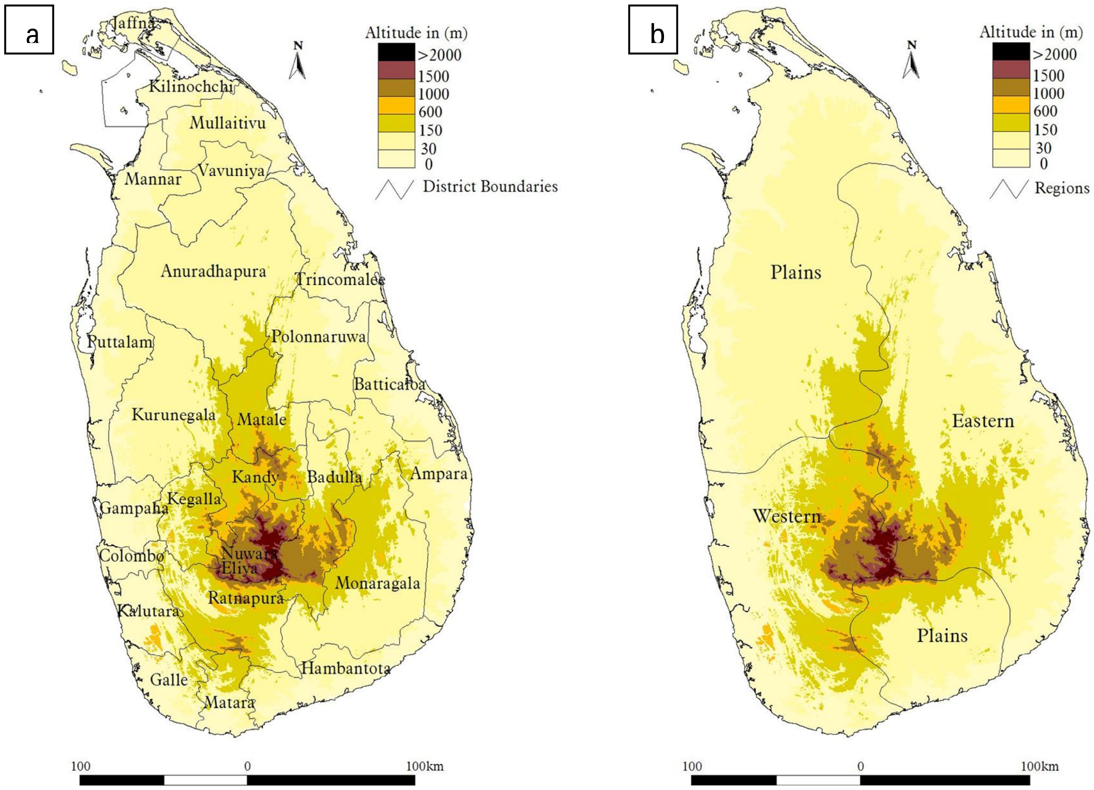


Figure 6(a): District boundaries overlaid on topography.

Figure 6(b): Climate regions overlaid on topography.

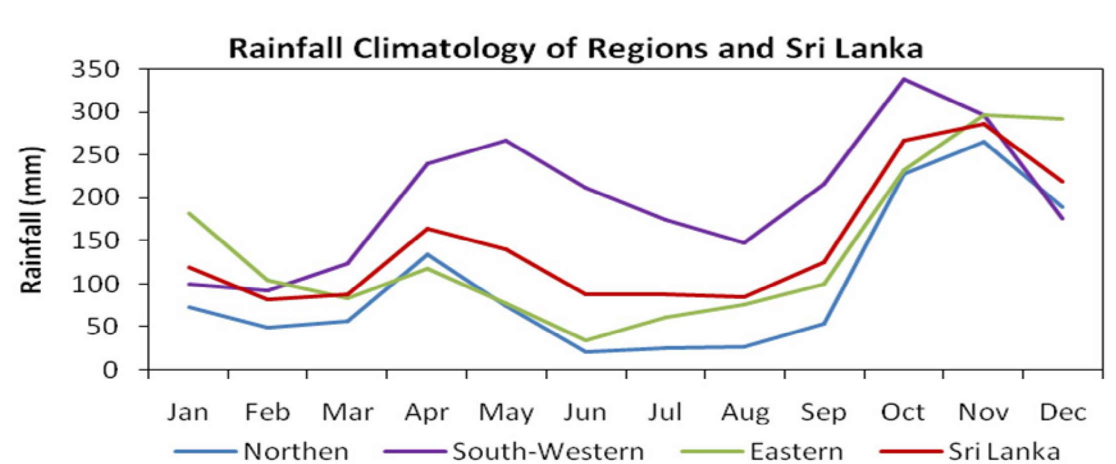


Figure 7: Rainfall Climatology of Northern, South Western Eastern regions and Sri Lanka for the period of 1950-2009.

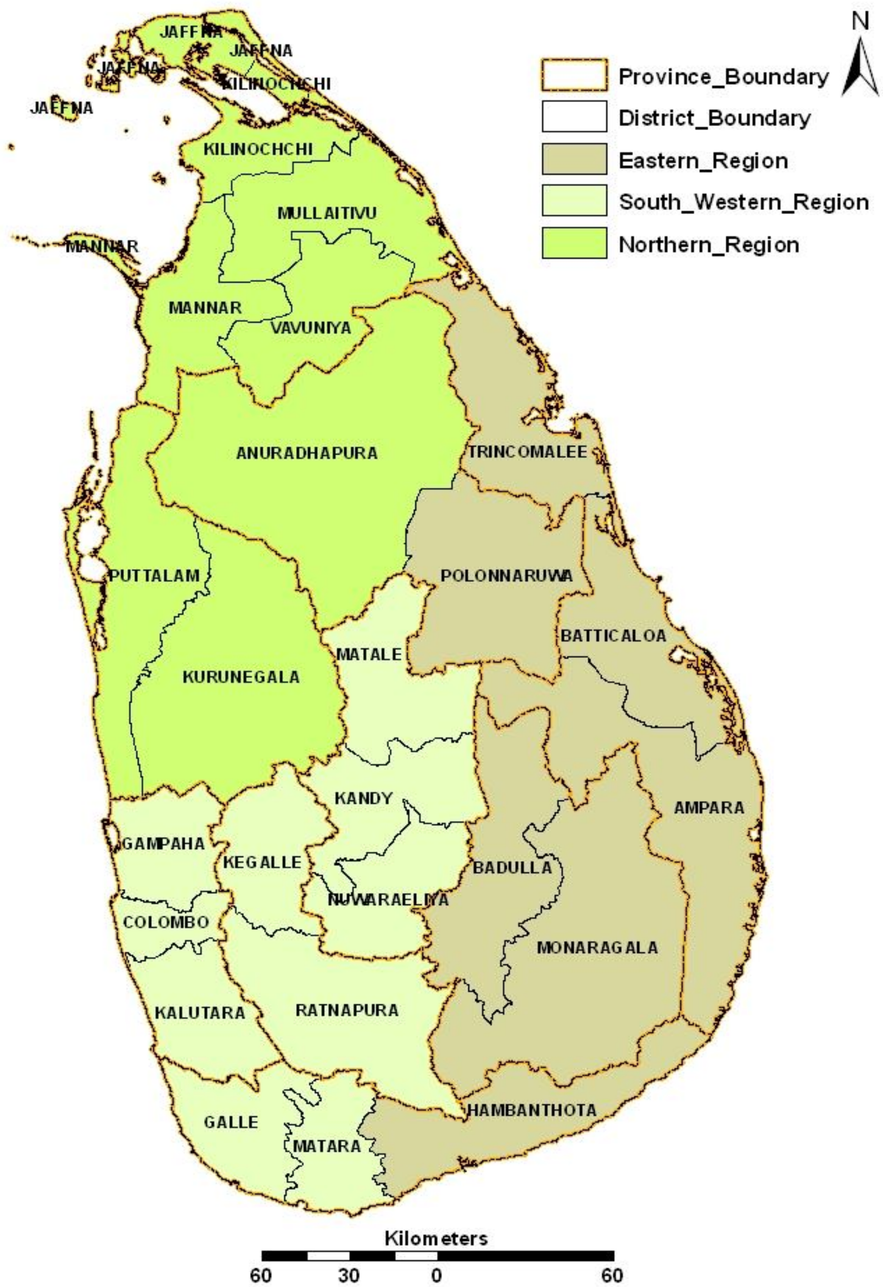


Figure 8: Northern, South-Western, Eastern Regions along with the districts and provincial boundaries.

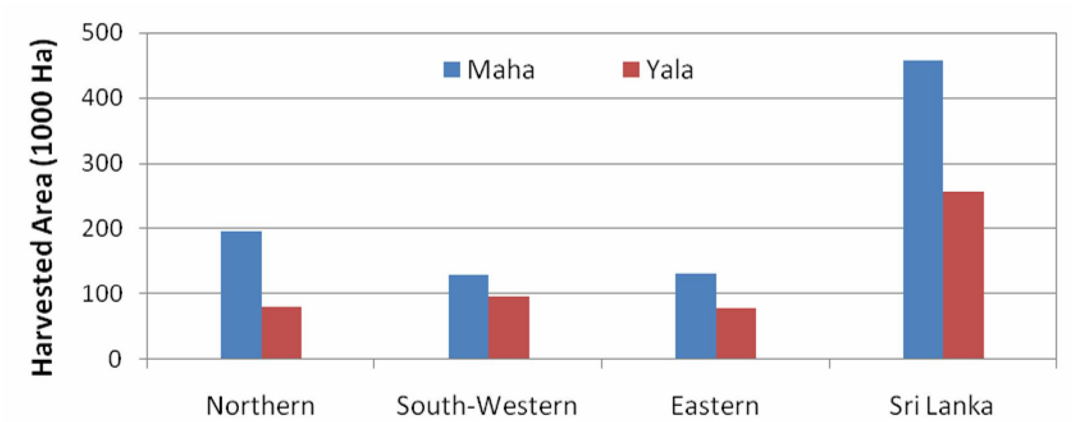


Figure 9(a): Harvested Area in Northern, South-Western and Eastern regions in Maha and Yala Seasons.

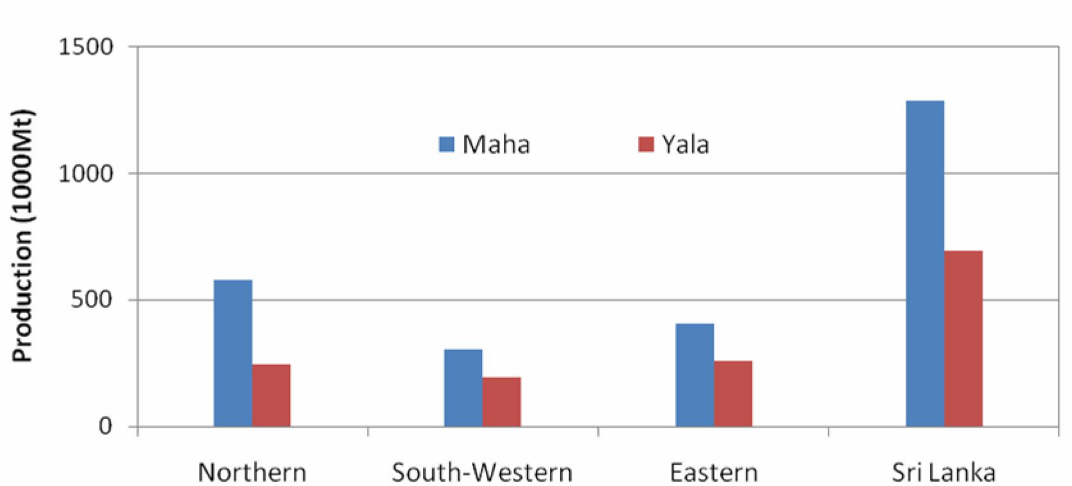


Figure 9(b): Production in Northern, South-Western and Eastern regions in Maha and Yala Seasons.

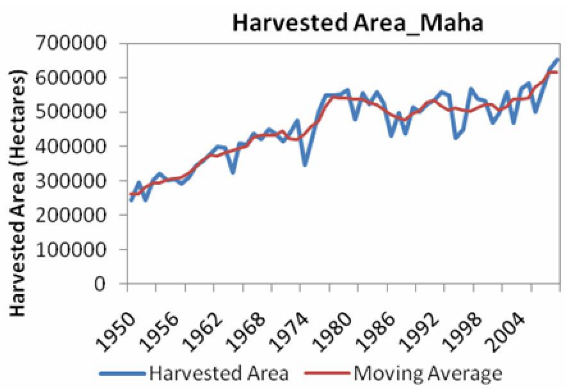


Figure 10(a)

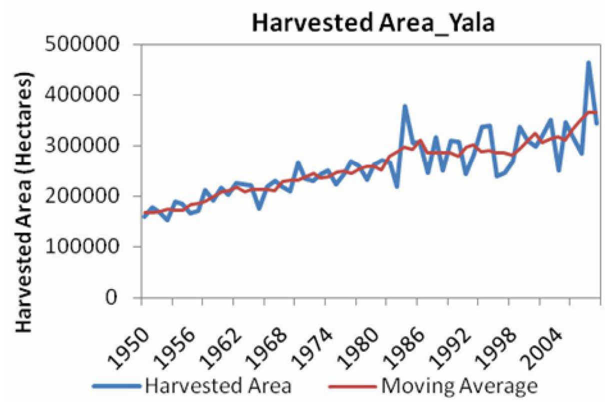


Figure 10(b)

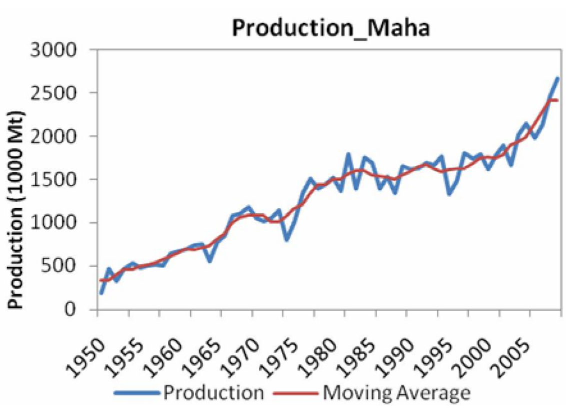


Figure 10(c)

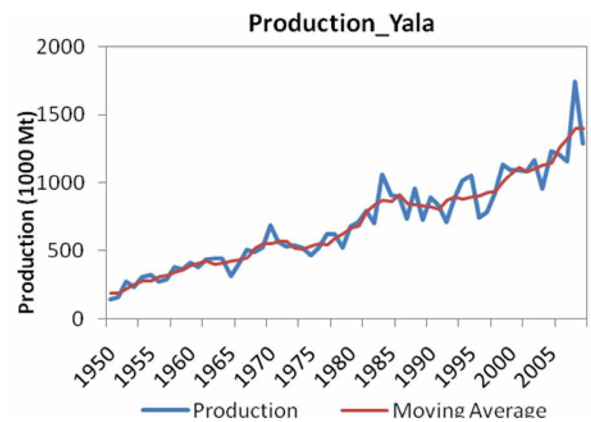


Figure 10(d)

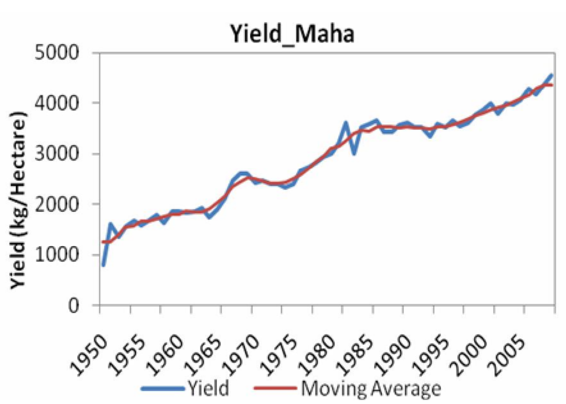


Figure 10(e)

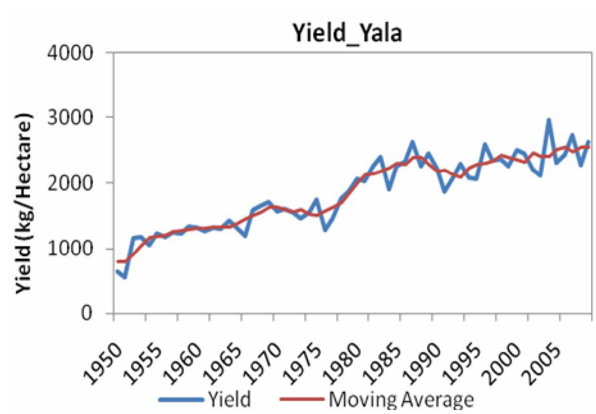


Figure 10(f)

Figure 10(a)-10(f) –The inter annual variation of PAY during Maha and Yala and its five years moving average for all of Sri Lanka .

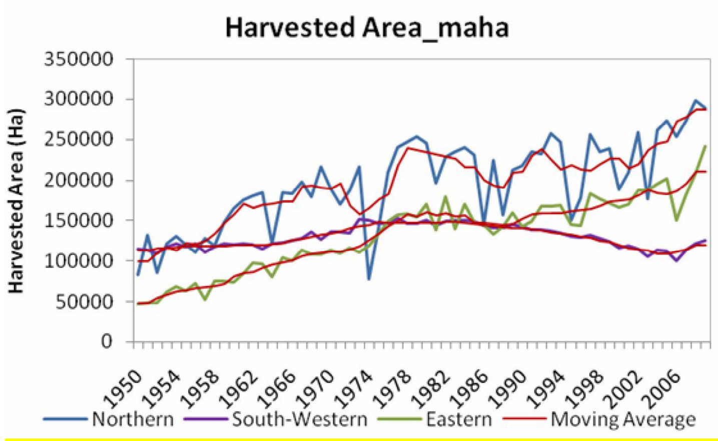


Figure 11 (a)

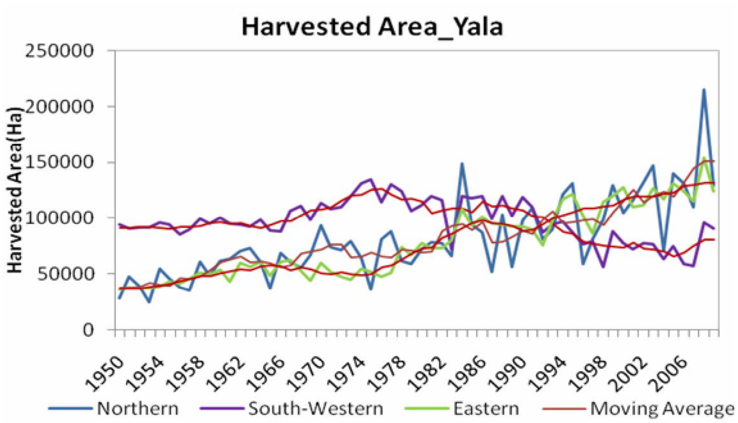


Figure 11(b)

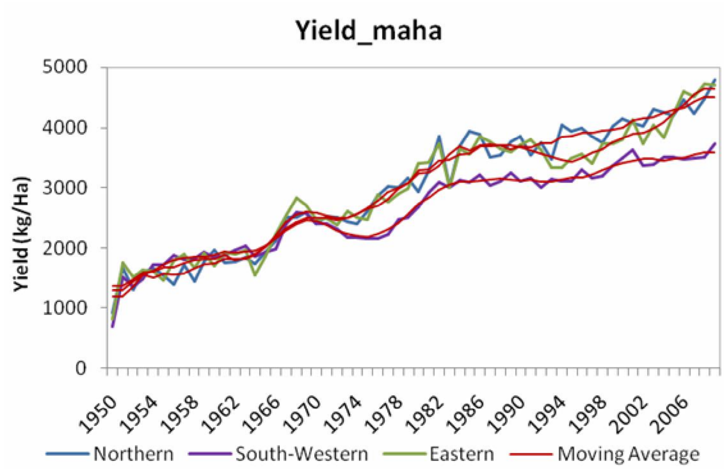


Figure 11(c)

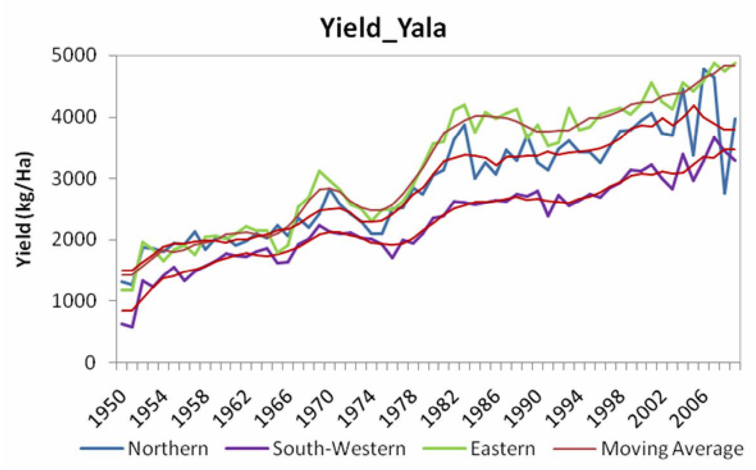


Figure 11(d)

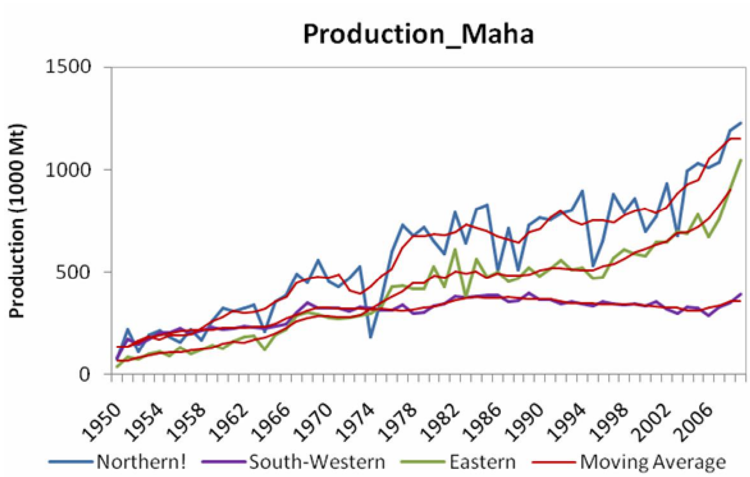


Figure 11(e)

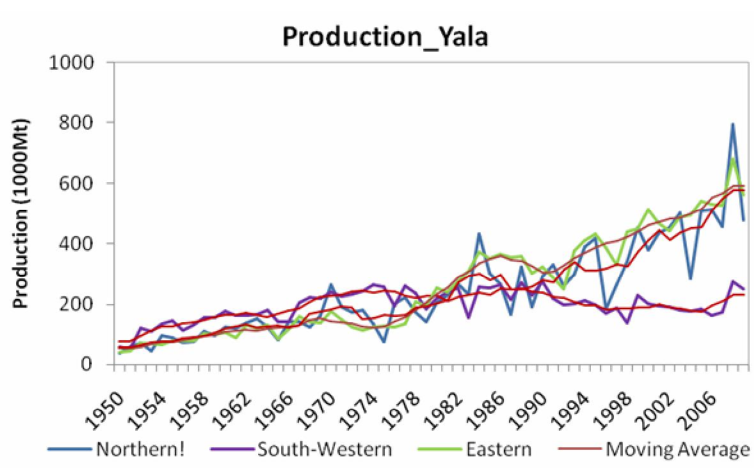
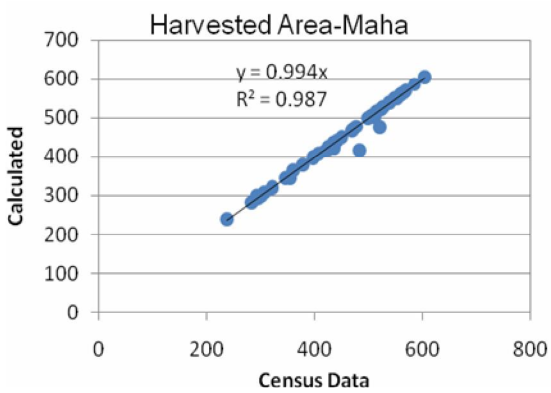
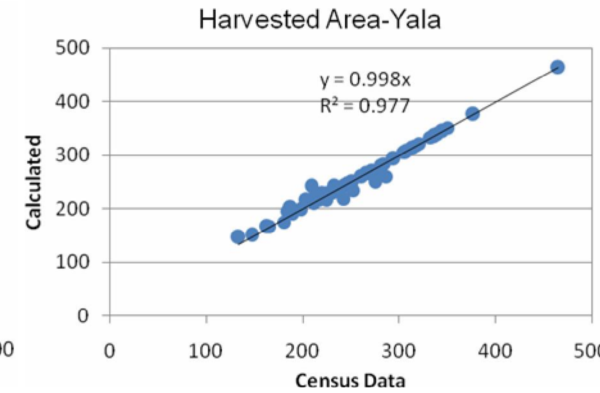


Figure 11(f)

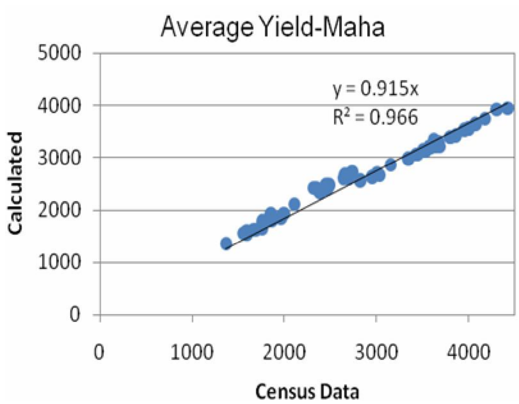
Figure 11(a)-11(f) –The inter annual variation of PAY during Maha and Yala and its five years moving average for regions (Northern, South-Western and Eastern).



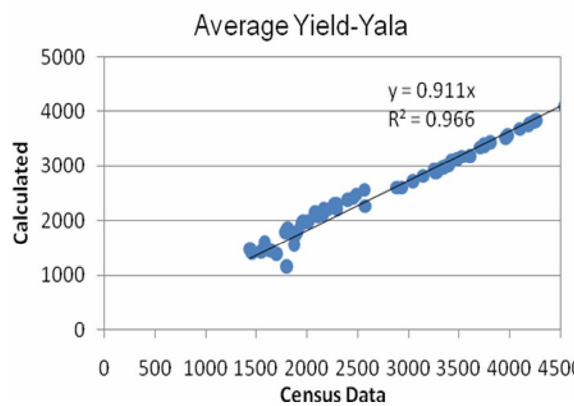
12(a)



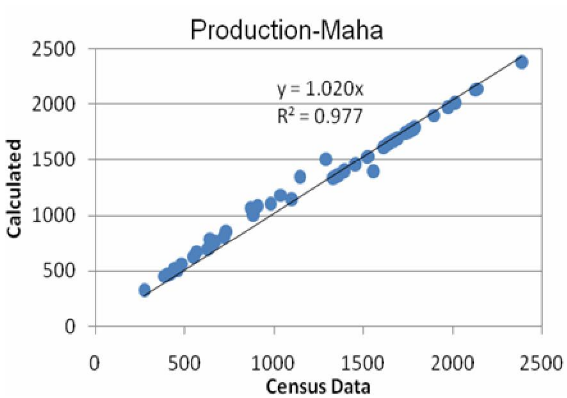
12(b)



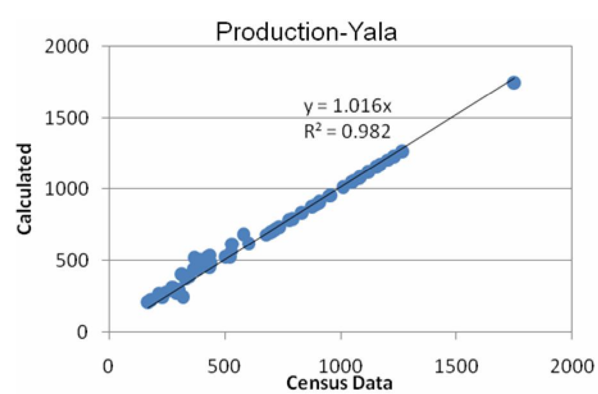
12(c)



12(d)



12(e)



12(f)

Figure 12 Consistency check of PAY data: Consistency between PAY data calculated from District-wise and totals provided by Department of Census for both seasons of entire Sri Lanka for the period of 1952-2008.

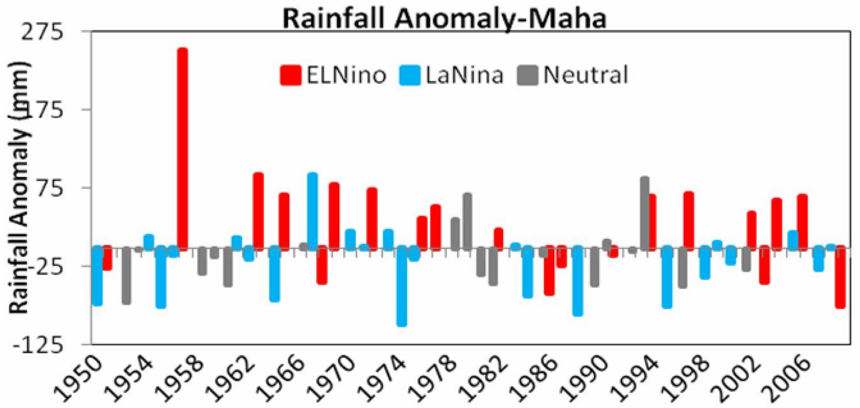


Figure13(a): Inter-annual variation of All Sri Lanka October to December rainfall anomaly during the Maha season from 1950-2009 where ElNino, LaNina and Neutral conditions prevailed.

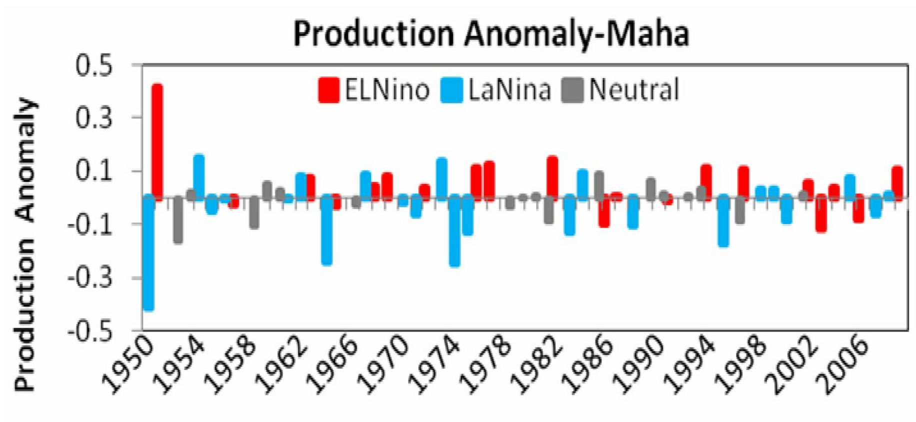


Figure13(b): Inter-annual variation of all of Sri Lanka normalized rice production anomaly during the Maha season from 1950-2009 where ElNino ,LaNina and Neutral conditions prevailled.

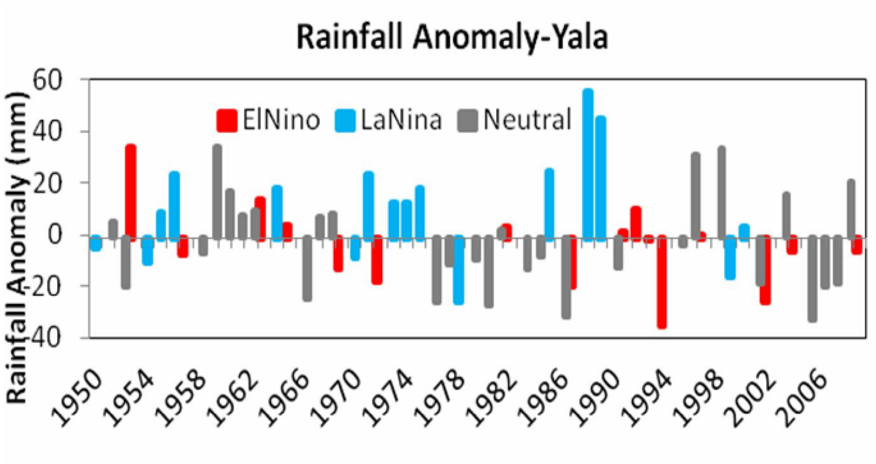


Figure13(c): Inter-annual variation of all of Sri Lanka JJA rainfall anomaly during the Yala season from 1950-2009 where ElNino ,LaNina and Neutral conditions were prevailed.

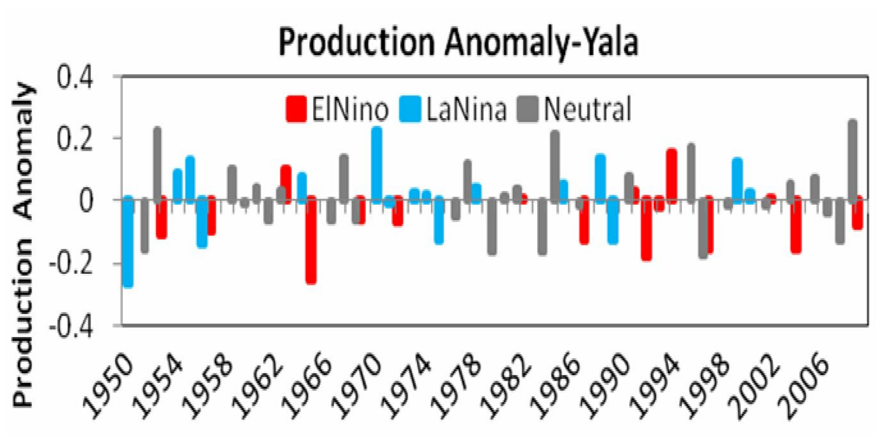


Figure 13(d): Inter-annual variation of all of Sri Lanka normalized rice production anomaly during the Yala season from 1950-2009 where ElNino ,LaNina and Neutral conditions were prevailed.