Seasonal Impact of Climate on Tea Production in Sri Lanka

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Abstract: *We investigated the impact of the seasonality of climate (rainfall, minimum and maximum temperature) on seasonality of tea production in Sri Lanka as a step towards an analysis of extreme events. We have taken some safeguards to account for the trends in temperature and production in the recent decades. Monthly averages of variables were taken for 1960-1990 and 1991-2016 to estimate the climatology. Tea production has a bimodal seasonality- the major mode with peak of 25 million MT is from March to June and the secondary mode with a peak is from September to January (22 million MT) for 1960 to 2008. Seasonally tea production peaks one month after rainfall peaks.*

Correlation analysis of the production with rainfall, minimum and maximum temperature (leading by one month) showed very high significance in some months. The February to April production had a highly significant correlation with rainfall and maximum temperature. The production in July to August was correlated with June to July maximum temperature. The October to December production was highly correlated with the minimum temperature from September to November. Thus, there is clear statistical evidence for the substantial influence of rainfall, maximum and minimum temperature on tea production for selected seasons. In work not included here, we find there is a strong regional variation in the seasonality. Thus, the relationships reported on aggregate for production mask the impact of climate on tea. These and other findings reported here shall enable us to identify the impact of extremes and develop climate based statistical models for yield predictions.

Keywords: *Tea, Climate, Seasonality, Sri Lanka, Statistical Analysis, Climate Impact*

1. Introduction

Introduction to Tea in Sri Lanka: Tea (*Camellia sinensis*) is a perennial crop that contributes significantly to the economy of Sri Lanka. Sri Lanka produces tea throughout the year and the total tea production in 2005 has reached a record of 317.2 million kilograms (Zoysa 2015). Tea plantations (Figure 1) are found in varying climatic conditions extending from low to high elevations exceeding 2000*m* (Wijeratne et al. 2011). The pioneer planters had observed the effect of the diverse climate in tea production.

Ecophysiology of Tea focusing on climate: Tea crop depends on air and soil temperature, rainfall, air saturation deficits, soil water, radiation, sunshine hours and evaporation (Carr, 1972, Stephens & Carr, 1991). Fluctuations in the production of tea during the year are a well-documented phenomenon with both short-term

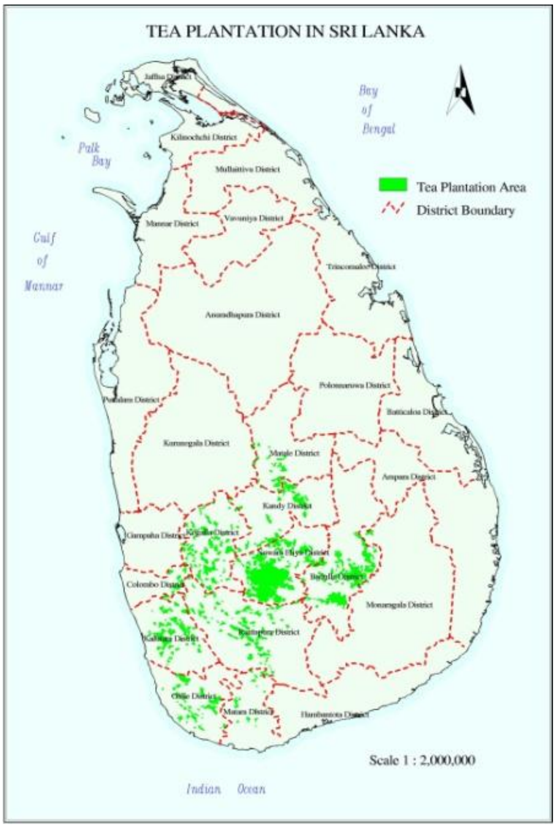

Figure 1-The areas with tea cultivation

variations within a growing season (Fordham, 1970) and variation between seasons of the year (Barua, 1969; Squire, 1979). Climate determines where a crop is grown and the potential yield; the actual yields obtained depend on the prevailing weather (Carr & Stephens 1992, Devanathan, 1975). Changes in temperature, rainfall, and the occurrence of extreme weather events have adverse effects on Tea sector (Gunathilaka, 2017).
Objective of the Research: We have studied the seasonal impact of climate on tea production in Sri Lanka based on seasonal differentiation of climate impacts mainly on analysis of the impacts of rainfall, minimum and maximum temperature. We have taken some safeguards to account for the trends in temperature and production in the recent decades. The role of climate is nuanced, and we need to consider the spatial aspect of both tea and climate production as well.

2. Materials and Methodology

2.1 Regionalization of Tea Growing Areas

The tea regions are broadly grouped according to their elevations, with high grown above 1200*m* elevation, medium grown ranging between 600 *m* to 1200 *m* and low grown from sea level up to 600 *m* (SLTB 2010). Note, the allocation of data for the low, medium and high elevations are for large estates which span elevation tiers appear to be based on the location of the factory or office (Marby, 1972).

2.2 Data:

Monthly data for production

Statistics for tea production are available spanning the 150 years of large scale tea cultivation. Aggregate monthly production data was accessible at national scale (1960 to 2016), and by the 3 tier elevation zones (from 1970 onwards) and at district scale and "tea district" scale for shorter durations.

Monthly Climate data

To construct representative climate indices for the tea producing areas, we used monthly rainfall (Prcp), minimum and maximum temperature (Tmin and Tmax) data for Katugastota, NuwaraEliya, Diyatalawa, Bandarawela, Badulla, Ratnapura and Galle for 1960-2016. These stations of the Department of Meteorology are reasonably well distributed in the tea producing areas. The Diyatalawa station was moved to neighboring Bandarawela in 1993 but since there is high correlation, we use their data in concatenation.

Construction of climate indices

Climate indices were constructed by averaging across all the stations. We have taken safeguards to account for trends in temperature and production in the recent decades.

2.3 Methodology:

2.3.1 Climatology

Averages of the climate and production were obtained for different periods from 1960-2016. As there are significant trends for production and temperature after 1990, we have reported some of the results for 1960-1990. In addition, we have checked that detrended analysis leads to similar conclusions. The IRI Data Library was used for the analysis (http://iridl.ldeo.columbia.edu).

2.3.2 Correlation Analysis

We use Pearson correlation (*r*) to evaluate relations between production and climate variables. We have compared the reported results with Spearman ranked correlation (*r**) so as to discount spurious results due to outliers. As there shall be a lag between the climate influence and its impacts on production, we have undertaken lag analysis from 1-6 months. (http://iridl.ldeo.columbia.edu).

2.3.3 Identifications of consistent seasons

After undertaking a month by month analysis with a lag of one month, we identified adjacent months with high correlations and with a consistent sign. We undertook further analysis for these "seasons" so as to unravel the largest climate influence. (http://iridl.ldeo.columbia.edu).

3. Results and Discussion

3.1 Analysis

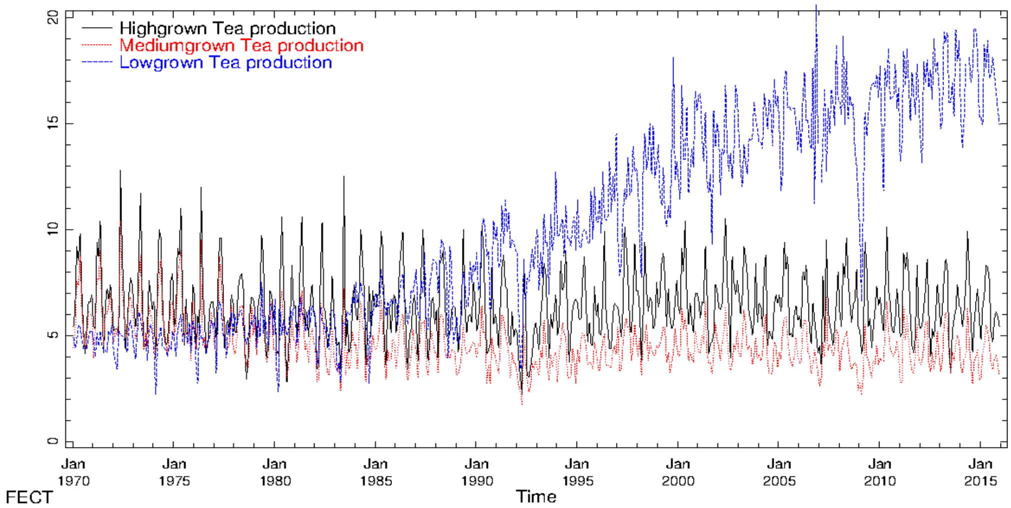

Figure 2- Tea production for low, medium elevation and high elevation from 1960 to 2016.

The mid country production has slightly declined after 1985; the low country production has increased three-fold after 1985 (5MT-15MT). (Figure 2)

3.1.1. Seasonality

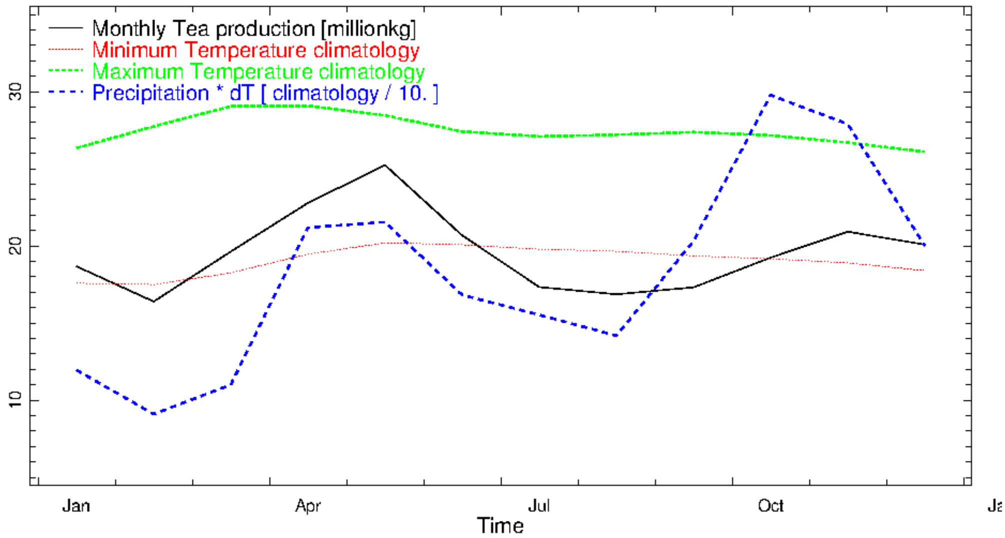

Figure3- The monthly average tea production, rainfall, maximum and minimum temperature from 1960 to 2008.

The seasonality of production from 1960 to 2008 is bimodal with modes from March to June and from October to November and with lower production in February and July to September. Even in these months, the drop of the production is less than 25% of the total.

The rainfall shows a bimodal seasonality with the major modes from October to November and the subsidiary mode from March to June.
The seasonal high temperatures occur in March and April with the lows in the months of December to January. The difference across these months is around 6^0C (figure 3).

Rainfall peaks in relation to the tea production by our analysis has not shown why the peaks of March to May production are more than the October to December peak. This may be due to the reduced solar radiation and cloudiness.

3.1.2 Correlations between Production and Climate

Month	Rainfall			Tmax			Tmin		
	r	*r**	*r-1*	*r*	*r**	*r-1*	*r*	*r**	*r-1*
Jan	-0.045	-0.035	-0.148	0.26	0.268	0.279	0.094	0.021	0.013
Feb	***0.376***	**0.502**	**0.546**	-0.189	-0.206	0.025	**0.599**	**0.558**	**0.496**
Mar	*0.316*	***0.354***	**0.56**	**-0.53**	**-0.528**	***-0.429***	0.061	0.036	**0.521**
Apr	0.249	0.045	**0.618**	***-0.423***	-0.074	**-0.494**	0.06	0.116	**0.466**
May	-0.126	-0.244	*0.30*	-0.061	0.115	*-0.339*	-0.126	-0.084	0.024
Jun	-0.223	-0.142	0.121	**0.512**	**0.475**	***0.393***	**0.507**	***0.378***	0.214
Jul	0.111	0.177	0.002	0.162	0.162	***0.416***	0.257	0.211	-0.154
Aug	0.13	0.033	***0.381***	-0.168	-0.203	-0.069	0.155	*0.121*	*-0.33*
Sep	0.145	0.141	**0.498**	0.193	0.232	0.000	*0.047*	0.040	-0.177
Oct	0.214	0.261	0.006	***0.452***	***0.439***	**0.47**	**0.571**	**0.485**	0.259
Nov	-0.071	0.101	***0.37***	0.296	0.277	***0.306***	0.18	0.276	0.18
Dec	0.105	0.057	***-0.372***	*0.303*	0.249	**0.48**	0.018	-0.013	-0.027

Table 1-Correlation(r), ranked correlation (r), and lag correlation by a month (r-1) of Production with Rainfall, Tmax and Tmin from 1960 to 1990.*

Correlation at each significance level is show with a different font as 90% - 0.30, ***95% - 0.35***, **99% - 0.455.**

The correlation for rainfall and production is strongest in February and March and it shows greater significance for the February to April/May period if production lags rainfall by a month. Lagged correlations also show significance between August and September while November and December show opposing relationships.

Correlation for Tmax and production is negatively stronger in March and April. It shows greater significance for March to May period if production lags Tmax by a month. The correlation shows a strong in June and October while lagged correlations show significance for July, November and December.

The correlation for Tmin and production is stronger in February and it shows greater significance for February to April period if production lags Tmin by a month. It also shows stronger correlations in June and October. (Table 1)

3.1.3 Identification of Consistent Seasons for Rainfall and Tmin, Tmax impact

We have tried to find relationships that are useable for modeling by seasons by considering periods with consistent climate influence on production. Below are results for analysis by such seasons as inferred from Table 1 (Table 2).

Seasons	Rainfall	Tmax	Tmin
Feb-Apr	**0.645**(**0.734**)		**0.561**(**0.611**)
Mar-Apr		**-0.556***(-0.317)*	
Jun-Jul		**0.517***(**0.420**)*	
Aug-Sep	**0.496***(0.337)*		
Oct-Dec		**0.611**(**0.475**)	

Table 2- Correlation (and ranked correlation) of seasonal production with Rainfall, maximum and minimum Temperature from 1960-1990. Notation as in Table 1.

- Rainfall

The rainfall for January to March shows a strong positive correlation with the production of February to April. The relationship between rainfalls in August to September with the rainfall from July to August is significant as well. (Table 2).

- Temperature

Maximum Temperature (Tmax): The maximum temperature of February and March shows a negative correlation with March to April production. The maximum temperature from May to June has a positive correlation with production from June to July. The maximum temperature from September to November has a positive relationship with production from October to December.
Minimum Temperature (Tmin): The minimum temperature in the months of January to March shows a positive correlation with the production in the months of February to April (Table 2).

4. Conclusion

There are discernible climate impacts on tea production in Sri Lanka which is brought out by nuanced analysis. A month by month analysis of 30 years from 1960-1990 and a separate analysis from 1991-2016 shows the relationship between and production and climate variables (Rainfall, Tmin, Tmax) are highly significant in certain months with a month's lag. These significant correlations were retained with rank correlation showing a robust relationship.
There are consistent seasons of climate influence on production (February to April, July to August, October to December) and the relationships for these seasons are skillful enough so that climate indices could be used in a predictive mode.

In work not reported here, we find there is strong regional variation on the seasonality of climate and its impact. Thus, the relationships reported on aggregate for production mask the impact of climate on tea. These findings shall enable us to identify the impact of extremes and develop climate based statistical models for production and yield predictions.

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