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Vulnerability of Tea Sector for Climate Change in the Major Tea Growing Regions in Central Hills of Sri Lanka

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ABSTRACT

The climate change impacts are becoming a prominent issue in the Sri Lankan tea sector. This study has attempted to identify vulnerability of tea sector in the major tea growing district of Nuwara Eliya in the central hills of Sri Lanka. Mean monthly rainfall and temperature, drought conditions and soil erosion of Nuwara Eliya district were considered as major variables in climate vulnerability mapping. Climate vulnerability map was developed using weighted overlay modeling in Geographic Information Systems (GIS) by allocating appropriate weightages for the main variables mentioned above for their influence on tea production. Rainfall data analysis for the study period from 1945 to 2005 revealed significantly higher rainfall variability for months of January, June, July, and August, which highlights the need of special management attention in these months. Around 65% of land extent of the study area possessed an ideal temperature regime (18-25^{0}C) for growth of tea. Land extent of 3.96% under tea was highly vulnerable for soil erosion in the study area. Less and moderately soil erosion vulnerable tea extent were 79.64% and 16.40%, respectively. The climate vulnerability map developed based on all four variables, revealed that 13.15% tea extent as highly vulnerable for current climate change. Land extent of 20.54% and 66.31% were categorized as moderately and less climate vulnerable, respectively, which could also become vulnerable in future, if present trends continues. Necessary adaptation strategies should therefore be implemented immediately to ensure the sustainability of the tea industry in the central hill region of Sri Lanka.

***KEYWORDS**: Climate change, Climate vulnerability, Climate vulnerability mapping, Geographic Information Systems (GIS)*

Introduction

Sri Lanka is an island whose economy is predominantly based on agriculture. Traditional peasant agriculture which had been continuing for centuries was replaced by large scale plantation agriculture in the mid-18th century. Exotic crops such as tea, rubber, coconut, coffee, and cocoa were intensively cultivated mainly in Wet (>2500 mm annual rainfall) and Intermediate (1750-2500 mm annual rainfall) zones of Sri Lanka. These plantation crops together with other agricultural crops contribute 10.6% to Gross Domestic Product (Central Bank of Sri Lanka, 2013). Out of those plantation crops, tea industry is playing a key role in social and economic stability in Sri Lanka. Total extent of tea plantations at present is 203,020 ha and more than 700,000 workers and their families are dependent on the tea industry (Plantation Sector Statistical Pocket Book, 2012).

However, currently the tea sector is facing many constraints such as lack of human resources, frequent fluctuation of prices, problems related to the food safety management certifications, management of natural resources in sustainable manner, impact on climate change *etc*. There is ample evidence to suggest that Sri Lanka's climate has been changed. Time series of annual mean temperature anomalies from 1871 – 1990 show a significant warming trend at most places in the country during the latter half of this period. The rate of increase in temperature from 1961 to 1990 is 0.016 ^{0}C per year (Chandrapala, 1996a; Chandrapala, 1996b; Fernando and Chandrapala, 1992). Sri Lanka's 100 year warming trend from 1896 – 1996 is 0.003 ^{0}C per year. This warming trend is seen throughout the country and could be due to enhanced greenhouse effect and 'local heat island effect' caused by rapid urbanization and land use changes (Basnayake *et al*., 2003; Emmanuel, 2001; Fernando and Basnayake, 2002). There is no significant trend in Sri Lanka's mean annual precipitation change during the last century although higher variability is evident (Jayatillake *et al*., 2005).

Tea is grown as a rainfed plantation crop in Sri Lanka. The changes in rainfall and temperature conditions directly affect tea production. The optimum temperature and rainfall for cultivation of tea are in the range of 18-22 ^{0}C and 223 to 417 mm per month, respectively (Wijeratne *et al*., 2007). Reduction of rainfall by 100 mm per month was found to reduce the productivity by 30-80 kg of 'made' tea/ha/month (Wijeratne *et al*., 2007). The decline of tea production due to the drought in 1992 was about 26% compared to that of 1991 (Central Bank of Sri Lanka, 1992). Extreme events of heavy rains cause severe soil erosion. Stocking (1992) presented erosion hazard ratings developed based on the type of tea cultivation and land slope classes in the central hilly region (The catchment area of major rivers). Under these circumstances, the tea industry in Sri Lanka, especially the Nuwara Eliya district is highly vulnerable to change of climate. It may cause greater economic, social, and environmental problems.

Vulnerability to climate change can be expressed as a function of exposure, sensitivity and adaptive capacity (IPCC, 2001). Advanced modeling capabilities of

Geographic Information Systems (GIS) are used extensively in vulnerability mapping. Limited attempts have been made so far to identify agriculturally vulnerable hot spots within Sri Lanka. Therefore, vulnerability mapping is very essential to design specific adaptation mechanisms to minimize negative impacts of climate change. It also facilitates for future planning purposes in tea industry, ensuring sustainability of the tea sector in the future as well.

The purpose of this study was to identify current vulnerability of tea sector in the major tea growing district of Nuwara Eliya in the central hilly region of Sri Lanka for climate change using four parameters, namely; monthly rainfall, monthly mean temperature, drought conditions, and soil erosion. The specific objectives were to map the variability of those four parameters separately and to develop a composite map of vulnerability of tea sector to climate change in the study area.

Methodology

Study Area

The study was carried out in Nuwara Eliya district of the Upper Mahaweli Catchment area located in central hilly region of Sri Lanka. The location map of the study area is depicted in Figure 1. The study area belongs to rainfall categories of Wet (>2500 mm annual rainfall) and Intermediate (1750-2500 mm annual rainfall) and elevation categories of low (<300 m above mean sea level (msl)), mid (300-900 m above msl) and up country (>900 m above msl) which was further categorized into fourteen different agro-ecological regions (Department of Agriculture, 2003).

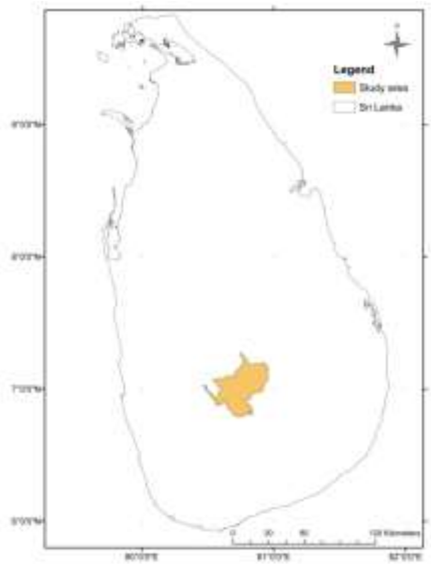

Figure 1: The location map of the study area –
Nuwara Eliya district of the Upper Mahaweli Catchment

Preparation of Rainfall and Temperature Maps of the Study Area

The daily rainfall data of 41 recording stations in and around the Nuwara Eliya district were collected from the Department of Meteorology and Natural Resources Management Centre of the Department of Agriculture. Monthly averages were computed for the study period of 60 years from 1946 to 2005.

Due to limited number of weather stations that record temperature in the study area, island wide temperature recording stations were selected. The Global Positioning System (GPS) locations of those weather stations were used to create a point data layer in the GIS environment. In case of temperature, thematic maps were produced for monthly mean temperature for the study period of 60 years from 1946 to 2005.

Out of different methods available to interpolate point data, the Inverse Distance Weighted (IDW) method was used. The spatial analysis toolbox was used for this purpose. The properties of ArcGIS 9.2 (Arc/Info) software were set as follows; power as two (2), search radius type as variable and output cell size as 100 m.

Determination of Drought Index

Drought severity classification in *Yala season* (south west monsoon and first inter-monsoon rainy seasons lasting from March to August) and *Maha season* (north east monsoon and second inter-monsoon rainy seasons lasting from September to February) seasons was identified using a drought index based on Moisture Availability Index (MAI). MAI is the ratio of the dependable rainfall to potential evapotranspiration. The potential evapotranspiration data were also collected from Department of Meteorology and Natural Resources Management Centre of the Department of Agriculture. A value of MAI less than or equal to 0.33 is considered as a very dry condition and not suited for rain fed agriculture (Hargreaves, 1975).

Preparation of Erosion Hazard Maps

Stocking (1992) presented erosion hazard ratings for different land uses in the hilly region of the Upper Mahaweli Catchment. It was emphasized that these ratings are dimensionless. Erosion hazard ratings were allocated according to the tea category (based on canopy thickness) and the land slope classes. Following classification of soil erosion was adopted in this study (Table 1).

Table 1: Soil erosion categories adopted in the study (Stocking, 1992)

Erosion Hazard Rating	Soil Erosion
0.05 - 1	Low
2 - 8	Moderate
>8	High

Development of Climate Vulnerability Map

The weighted overlaying technique which is available in GIS was used for this purpose. Four major variables were used to develop the climate vulnerability map. The main variables included in the model were mean monthly temperature, mean monthly rainfall, agricultural drought and soil erosion (Figure 2). The weightages were allocated to main variables in the model according to the influence of each variable on tea yield (Productivity). The expert scientist's views from Tea Research Institutes, University of Peradeniya and Department of Agriculture of Sri Lanka were taken by conducting an opinion survey. Once the weightages were allocated to main variables, ranking was done for sub-variables from 1 to 9 (1 was allocated for the best suited condition while 9 allocated for the worst (Highly vulnerable) condition) (Annexure 1). Statistics were generated using GIS, with respect to Divisional Secretary (DS) and *Grama Niladari* (GN) divisions to identify climate vulnerable tea land categories. *Grama Niladari* divisions are the smallest administrative unit in Sri Lanka.

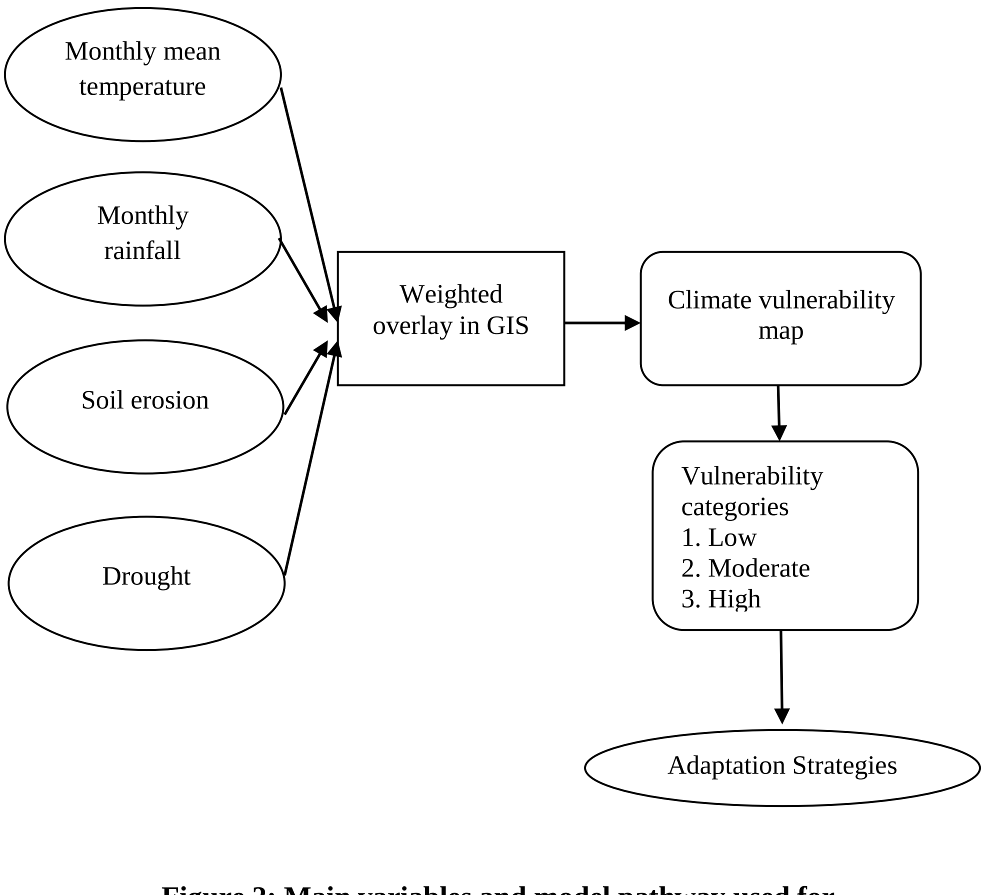

Figure 2: Main variables and model pathway used for climate vulnerability mapping

Results and Discussion

Spatio-Temporal Changes of Rainfall within Nuwara Eliya District

Nuwara Eliya district consists of Wet (>2500 mm annual rainfall) and Intermediate (1750-2500 mm annual rainfall) climatic conditions. The district receives rains from all four rainy seasons with a varying spatial distribution. The summary of the results derived from the spatio-temporal analysis of the rainfall is given in Table 2.

Spatial variations of rainfall (1946 to 2005) for the twelve months are depicted in Figure 3. Rainfall data analysis for the study period revealed that months of January, June, July and August were having high rainfall variability, which emphasis the need for special attention to reduce negative impacts.

Table 2: Summary of the spatial analysis of mean monthly rainfall (1946 to 2005) in Nuwara Eliya district

Month	Minimum Rainfall (mm)	Maximum Rainfall (mm)	Mean Rainfall (mm)	CV (%)
January	65	423	194	55
February	60	207	116	35
March	70	268	121	16
April	149	359	229	12
May	103	620	204	39
June	44	810	242	63
July	66	673	225	55
August	69	618	203	53
September	99	627	207	42
October	232	654	305	19
November	214	405	304	15
December	119	553	270	43

CV – Coefficient of Variation

Minimum rainfall requirement for tea is considered as 100 mm/month (Watson, 2008). Months of January, February, March, June, July and August were recorded less than the minimum rainfall level in some parts of the study region.

Spatio-Temporal Changes of Temperature within Nuwara Eliya District of the Upper Mahaweli Catchment

Spatial variations of mean temperature (1946 to 2005) for the twelve months are depicted in Figure 4. Tea grows well within a temperature range of 18-25 °C, and an air temperature below 13 °C and above 30 °C is found to reduce growth (Watson, 2008). Some parts of the study area were experiencing below 13 °C temperature, except months of April and May.

Most parts of the study area possess an ideal temperature (18-25 °C) for growth of tea. Results revealed that 64.47 % of the land extent comes within the mean annual temperature range of 18 to 25 °C, which considered as an ideal temperature range for growth of tea (Table 3).

Table 3: Mean annual temperature classes in Nuwara Eliya district

Temperature Classes °C	Land Extent (ha)	Percentage (%)
12 to 15	6,160	4.82
15 to 18	35,279	27.60
18 to 25	82,406	64.47
25 to 27	3,976	3.11
Total	127,820	100

Identification of Drought Prone Regions in Nuwara Eliya District

Drought severity classification in *Yala* and *Maha* seasons was identified using drought index based on moisture availability index (MAI) (Table 4) as described in Chithranayana and Punyawardena (2008).

Table 4: Drought severity classification (Hargreaves, 1975)

No. of Months with MAI Less Than or Equal to 0.34	Drought Severity
0	Wet
1	Slightly wet
2	Mild drought
3	Drought
4 or more	Severe drought

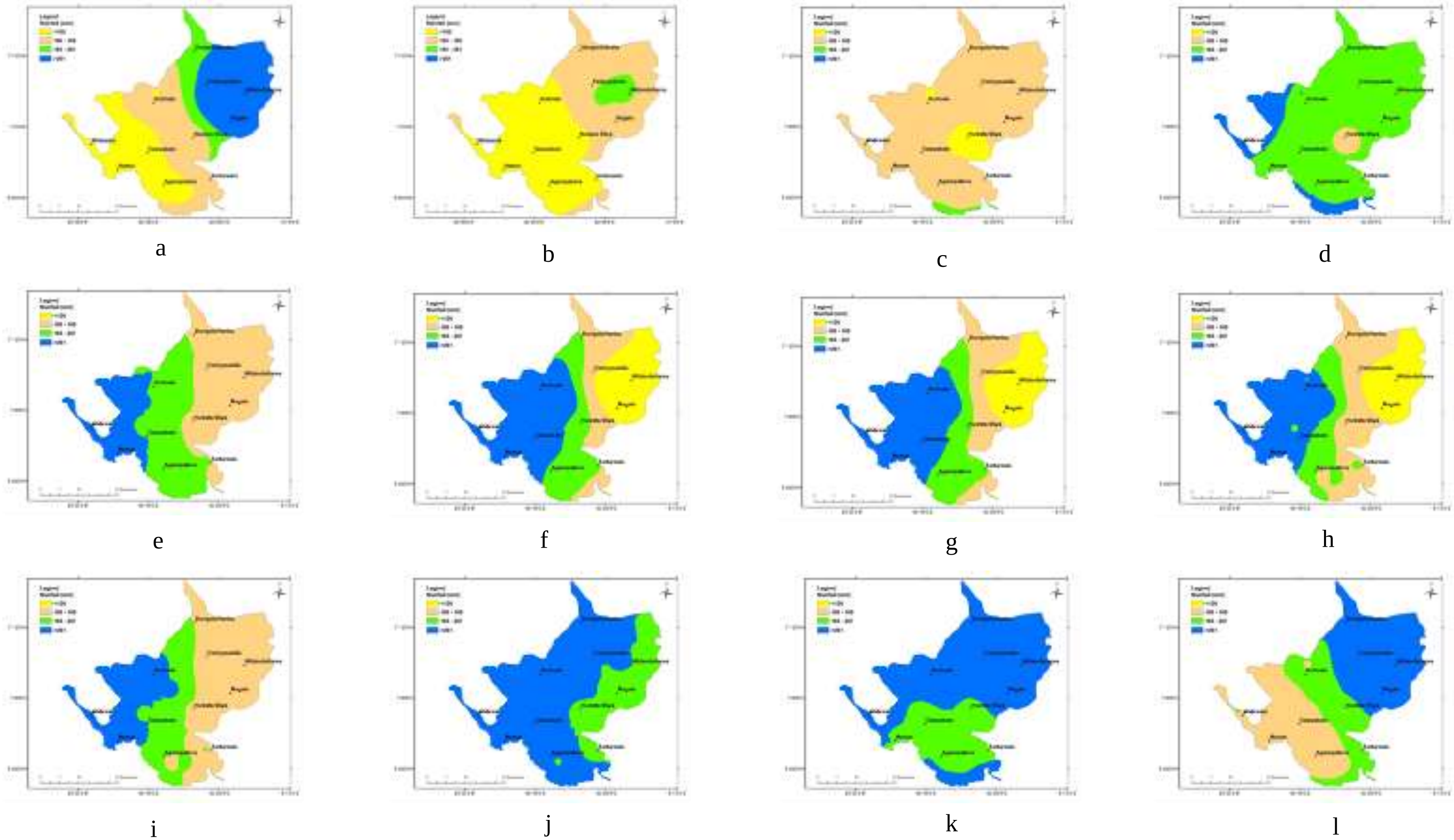

Figure 3: Spatial variation of mean monthly rainfall for the period from 1946-2005 (a) January; (b) February; (c) March; (d) April; (e) May; (f) June; (g) July; (h) August; (i) September; (j) October; (k) November and (l) December

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Spatial Pattern of Drought during Maha Season

The spatial distribution of the drought during Maha Season in Nuwara Eliya district is depicted in Figure 5. All the agro ecological regions in the study area were free from drought hazards during Maha seasons due to the relatively high effectiveness of Second Inter Monsoon rains and low evapotranspiration rates over all agro-ecological regions (Table 5).

Spatial Pattern of Drought during Yala Season

The spatial distribution of the drought during *Yala* Season in Nuwara Eliya district is depicted in Figure 6. Agro-ecological regions in the Up country Intermediate zone (IU) of IU3b and IU3e experience a mild drought conditions compared to wetter regions. However, agro ecological regions in the Mid country Intermediate zone (IM) of IM1a and IM3c are vulnerable to mild drought and drought conditions, respectively (Table 6). Under such situations, tea cultivation is highly vulnerable to water shortage conditions during *Yala* season in above agro ecological regions.

For relatively high drought prone areas, drought tolerant varieties can be used. Planting of shade trees to reduce the drought impacts in IU regions is important (Wijeratne *et al*., 2007).

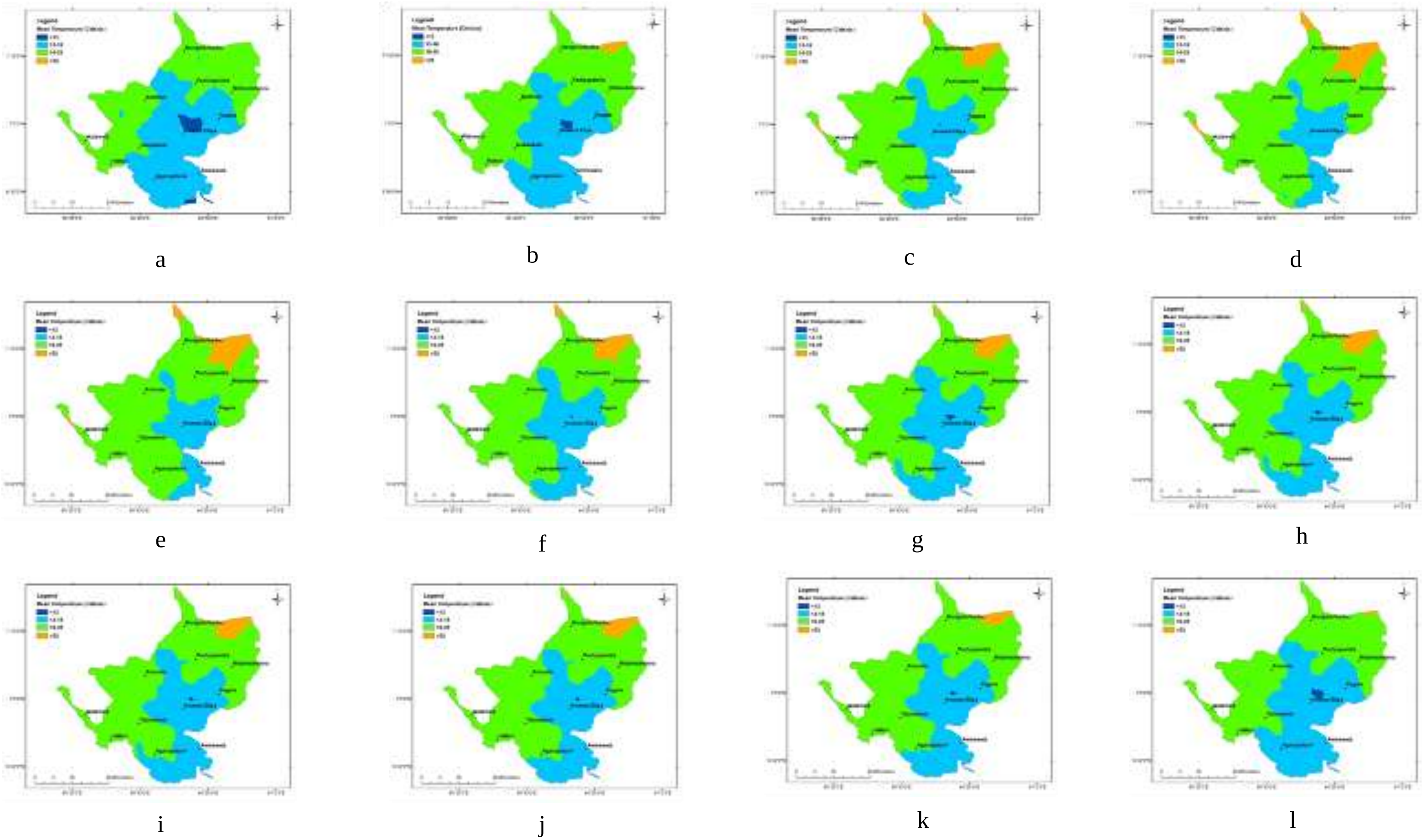

Figure 4: Spatial variation of average monthly mean temperature from 1946 to 2005 (a) January; (b) February; (c) March; (d) April; (e) May; (f) June; (g) July; (h) August; (i) September; (j) October; (k) November and (l) December

Table 5: Drought severity of each agro ecological region during *Maha* season (Chithranayana and Punyawardena, 2008)

Agro Ecological Region	Drought Severity	Dry Months
IL2 (Low country Intermediate)	Wet	
IM1a (Mid country Intermediate)	Wet	
IM1c (Mid country Intermediate)	Wet	
IM3c (Mid country Intermediate)	Wet	
IU2 (Up country Intermediate)	Wet	
IU3b (Up country Intermediate)	Wet	
IU3d (Up country Intermediate)	Wet	
IU3e (Up country Intermediate)	Wet	
WM1a (Mid country Wet)	Wet	
WM2a (Mid country Wet)	Slightly wet	February
WU1 (Up counter Wet)	Wet	
WU2a (Up counter Wet)	Wet	
WU2b (Up counter Wet)	Wet	
WU3 (Up counter Wet)	Wet	

Table 6: Drought severity of each agro ecological region during *Yala* season (Chithranayana and Punyawardena, 2008)

Agro Ecological Region	Drought Severity	Dry Months
IL2 (Low country Intermediate)	Severe Drought	June, July, August, March
IM1a (Mid country Intermediate)	Mild Drought	June, July
IM1c (Mid country Intermediate)	Drought	June, July, August
IM3c (Mid country Intermediate)	Drought	June, July, August
IU2 (Up country Intermediate)	Wet	
IU3b (Up country Intermediate)	Mild Drought	June, July
IU3d (Up country Intermediate)	Slightly Wet	June
IU3e (Up country Intermediate)	Mild Drought	June, July
WM1a (Mid country Wet)	Wet	
WM2a (Mid country Wet)	Wet	
WU1 (Up counter Wet)	Wet	
WU2a (Up counter Wet)	Wet	
WU2b (Up counter Wet)	Wet	
WU3 (Up counter Wet)	Wet	

Soil Erosion Map for Tea Lands in Nuwara Eliya District

To determine soil erosion, erosion hazard ratings which were discussed by Stocking (1992) were used in this study. Results revealed that 3.96% of the tea extent is highly vulnerable to soil erosion (Table 7). The soil erosion map in tea lands for Nuwara Eliya district is depicted in Figure 7.

Table 7: Tea extent under different soil erosion classes in Nuwara Eliya district

Soil Erosion Class	Tea Extent (ha)	Percentage (%)
Low	31,658	79.64
Moderate	6,519	16.40
High	1,574	3.96
Total	39,751	100

Tea lands with less canopy cover were highly vulnerable for soil erosion. Soil erosion is high in poorly managed seedling tea fields (poor ground cover) compared to vegetatively - propagated (good ground cover) tea.

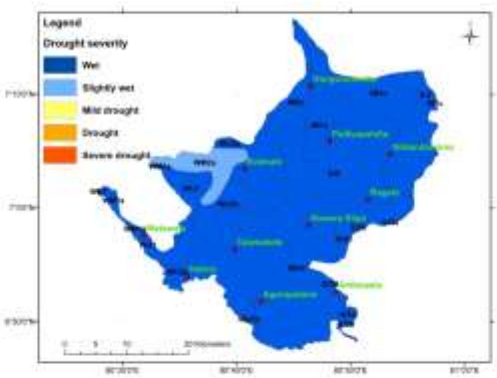

Figure 5: Spatial pattern of drought during *Maha* Season in the study area

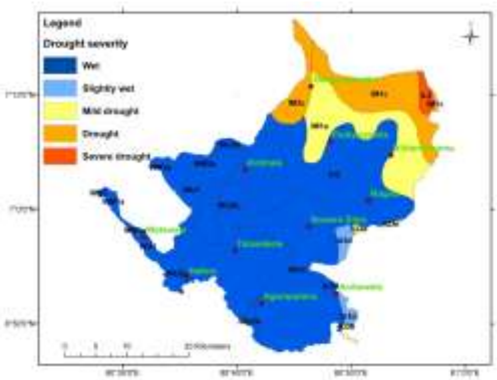

Figure 6: Spatial pattern of drought during *Yala* Season in the study area

Poorly managed seedling tea fields have more open patches which are conducive to soil erosion. Therefore, special emphasize should be given to tea lands in steep slope regions where seedling tea is grown. The area which was identified as highly vulnerable should be given more emphasis on soil erosion and soil moisture conservation measures. Biological strategies such as soil rehabilitation, Slopping Agricultural Land Technology (SALT), cover crops and infilling of tea lands to improve ground cover can be recommended (Wijeratne *et al.*, 2007; Wijeratne, 2009). Implementation of good agricultural practices (GAP) ensures the sustainability of the tea cultivation in the Nuwara Eliya district.

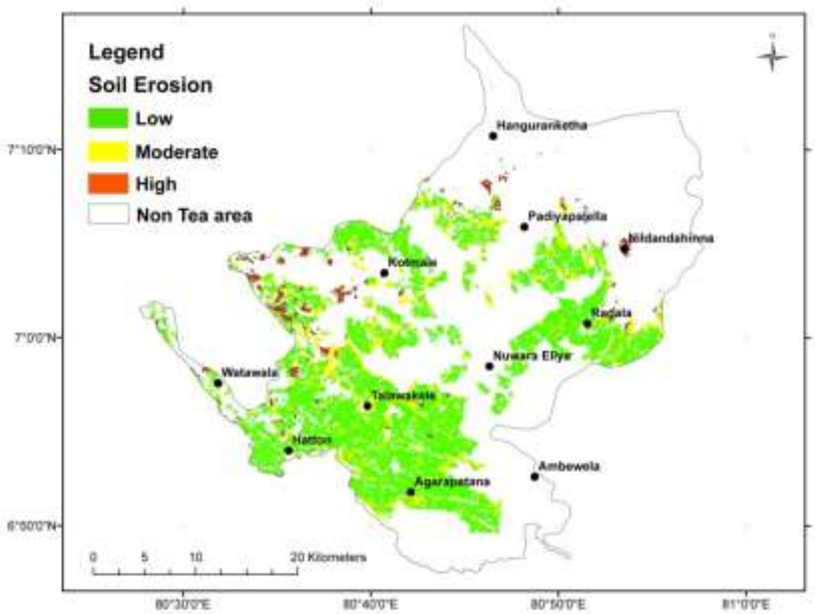

Figure 7: The soil erosion map for Nuwara Eliya district of the Upper Mahaweli Catchment

Climate Vulnerability Modeling

Climate vulnerability map was derived combining the mean monthly rainfall, mean annual temperature, agricultural drought vulnerability and soil erosion vulnerability. In this analysis, weighted overlaying technique was used to derive climate vulnerability map. In order to allocate appropriate weightages for main variables, an opinion survey was carried out with 25 scientists from Tea Research Institute (Talawakelle, Rathnapura, Hanthana), Department of Agriculture (Natural Resources Management Centre) and Crop Science Department (University of Peradeniya). The summary results of the opinion survey are given in Table 8.

Table 8: Summary of the opinion survey on proportional weightage allocation for major variables on the influence on tea production

Variable	Percentage (%) of Weightage out of Total 100 Points
Mean monthly Rainfall (mm/ month)	35
Mean annual temperature (^{0}C)	10
Agricultural drought	10
Soil erosion	45
Total	100

The climate vulnerability map developed based on combination of individual vulnerabilities of rainfall, temperature, agricultural drought, and soil erosion in Nuwara Eliya district was categorized into three broad classes as less vulnerable, moderately vulnerable and highly vulnerable (Figure 8). The Climate vulnerability map revealed that 5,225 ha (13.15%) of tea land extent in the region was highly susceptible for current climate vulnerability. Most of the seedling tea lands (propagated using seedlings) which have less than 40% ground cover (1677 ha) were categorized in to the highly climate vulnerable category. Soil erosion was given the highest weightage in the model (45%), because it has become the major limiting factor in up country tea production. Furthermore, tea land extent of 8,165 ha (20.54%) and 26,361 ha (66.31%) were categorized as moderately and less climate vulnerable, respectively (Table 9).

Table 9: Summary of the climate vulnerability classes identified based on combination of individual vulnerabilities of rainfall, drought, soil erosion and temperature

Climate Vulnerability Classes	Tea Extent (ha)	Percentage (%)
Low	26,361	66.31
Moderate	8,165	20.54
High	5,225	13.15
Total	39,751	100

Distribution of the vulnerable tea classes with respect to Divisional Secretary Divisions (DSD) are given in the Table 10. The results revealed that the highest percentages of highly vulnerable tea extent were distributed in Nuwara Eliya DS division. Distribution of the vulnerable tea classes with respect *Grama Niladari* (GN) divisions are given in Table 11.

Table 10: Distribution of the climate vulnerable tea classes with respect to Divisional Secretary Divisions (DSD)

DSD	Climate Vulnerability (ha)		
	Low	Moderate	High
Ambagamuwa	1956	213	79
Hanguranketha	1836	837	170
Kothmale	5884	1900	854
Nuwara Eliya	12966	4100	2696
Walapane	3719	1115	1426

A few climate vulnerability modeling studies have been carried out in order to assess the climate vulnerability in Sri Lanka. Composite vulnerability index for multi-hazard exposure for each district in Sri Lanka have been developed and results showed that Nuwara Eliya distrct was ranked as 80-100 (high vulnerable) range (Eriyagama *et al*., 2010). Composite vulnerability indices for drought, flood and cyclone also showed that Nuwara Eliya district was considered as highly vulnerable compared to other districts in Sri Lanka (Eriyagama *et al*., 2010). Climate vulnerability modeling studies related to crops and forestry have used geographic information systems and remote sensing as a modeling tool (Omo-Irabor *et al*., 2011, Zhang *et al*., 2006). In this study only the physical vulnerability was assessed with respect to Tea lands. Several climate vulnerability studies have considered the social vulnerability in vulnerability modeling (Eriyagama *et al*., 2010; O'Brien *et al*., 2004). In this study only the potential climate vulnerability was assessed. Adaptive capacity was not considered in vulnerability modeling.

With anticipated climate change in future, moderately vulnerable areas can also become highly vulnerable. Therefore, appropriate adaptation strategies should be taken immediately to protect those lands to avoid further degradation.

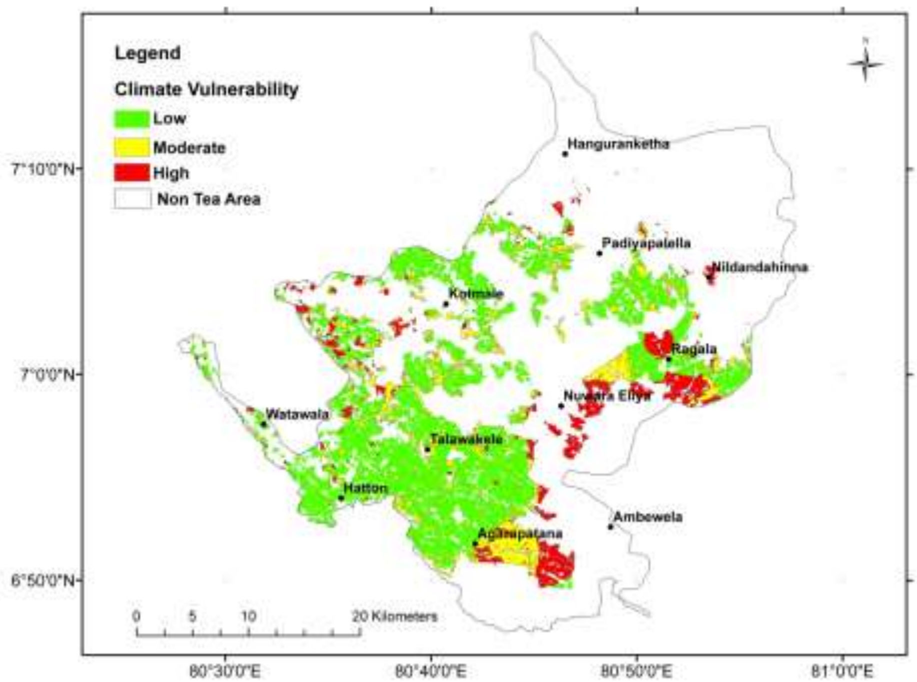

Figure 8: The potential climate vulnerability map for Nuwara Eliya district of the Upper Mahaweli Catchment

Table 11: *GN (Grama Niladari)* divisions in Nuwara Eliya district under different climate vulnerable classes

Climate Vulnerability Classes		
Less	**Moderate**	**High**
Coombewood	Glasgow	Sandrinhem
Albian	Park	Delmar
Nagasena	Weverly	Dayagama West
Waltrim Watta	Dayagama West	Rathnayakapura
Hope Estate	Hope Estate	Brookside
Highforest Watta	Lipakele	Pedro
Eldonhall	Sandrinhem	Ruwaneliya
Stonycliff	Rukwood Estate	Dayagama East
Kirimetiya	Concordia	Concordia
Shanon	Agarapathana	Ketambulawa
Yulefield	Sheen Estate	Park
Dreton	Udapussellawa South	Agarapathana
Dunsinan	Barewell	Udapussellawa South
Frotoft	Rahanwatta	St. Leonard
Great Western	Medakumbura North	Lipakele
Brookside	Dunukedeniya	Ruwanpura
Balmoral	Kurunduoya	Sandathenna
Elbedda	Elbedda	Nildandaheenna
Kudu Oya	Kolapathana	Glasgow
Bangalahatha	Palagolla	Perakumpura
Watagoda	Great Western	Thelissagama
Summerset	Hollyrood	Bulu Ela
Medakumbura North	Binganthalawa	Sooriyagaha Pathana
Bremore	Labukele	Samagipura
Helboda	Perakumpura	Bangalahatha
Lindula	Kudu Oya	Nuwaraeliya Central
Barewell	Watagoda	Bogahawatta
Wedamulla	Summerset	Nuwaraeliya West
Kurunduoya	Lindula	Kalapura
Binganthalawa	Gonapitiya Watta	Katarandana
Henfold	Albian	
Perakumpura	Coombewood	
Rosella	St. Magret	
St. Magret	Wedamulla	
Rahanwatta	Pundaluoya North	
Dimbula	Dunsinan	
Muloya	Watawala	
Thangakele Watta	Senarathpura	
Bogahawatta	Maha Uva	
Ketambulawa	Sooriyagaha Pathana	
Sheen Estate	Mount Vernon	
Karagasthalawa	Muloya	

Conclusions

Rainfall data analysis for the study period revealed that months of January, June, July and August were having high rainfall variability, which emphasis the need for special adaptation attention to reduce climate change impacts tea production. Around 65% of land extent of the study area is possessed an ideal temperature (18-25 ^{0}C) for growth of tea. The entire study area does not exhibit droughts during *Maha* season. However, in almost all agro-ecological regions of the Up country Intermediate zone, the drought proneness is relatively higher, except IU2, during the *Yala* season. There is also a slight possibility of drought conditions occurring in the Wet zone of the study area during *Yala* season.

Land extent of 1,574 ha (3.96%) under tea was highly vulnerable for soil erosion in the study area. Less and moderate soil erosion vulnerable tea extent were 31,658 ha (79.64%) and 6,519 ha (16.40%), respectively.

Overall climate vulnerability mapping considering all four variables revealed that 5,225 ha (13.15%) tea extents were considered as highly susceptible for current climate vulnerability which requires urgent attention. Furthermore, tea land extent of 8,165 ha (20.54%) and 26,361 ha (66.31%) were categorized as moderately and less climate vulnerable, respectively could also become vulnerable in the future if appropriate improvement programs are not implemented.

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Annexure 1: Weights and ranks allocated for main variables and sub categories respectively

Main Variable	Contribution (%)	Sub Category	Rank
Mean monthly rainfall (mm/ month)	35	<100	9
		100-185	6
		185-261	3
		>261	1
Monthly mean temperature (^{0}C)	10	<13	9
		13-18	3
		18-25	1
		>25	4
Agricultural drought	10	Wet	1
		Slightly wet	2
		Mild drought	7
		Drought	8
		Severe drought	9
Soil erosion	45	Low	1
		Moderate	5
		High	9