STUDY ON POTENTIAL IMPACTS OF CLIMATE CHANGE ON CROP GROWING AREA SUITABILITY IN SRI LANKA

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KWY WORDS: Sri Lanka, climate change, rainfall, temperature, crop suitability, rice, coconut

ABSTRACT: The objective of this study was to estimate the impacts of climate change on the rainfed rice and coconut cultivation areas in Sri Lanka. Temperature and rainfall in the baseline period (1971 – 2000) were analyzed against projected temperature and rainfall at 2030 and 2050. For the analysis, minimum and maximum temperatures, rainfall data on a monthly basis, crop data, and a crop suitability assessment tool (Ecocrop) were used. The baseline data was prepared using the observed data received from the Meteorological Department of Sri Lanka. Downscaled climate change prediction grids were extracted from the UK Hadley Centre for Climate Prediction and Research Model (HadCM3). These grids were extracted for 2050. The results showed that the area under the dry zone was expected to reduce from 43,734 (baseline) Km^2 to 37,744 Km^2 (2030), a 14% reduction. A further decrease of up to 35,492 Km^2 could be expected by 2050. In other words, an area of 8,242 Km^2 within the dry zone is projected to receive more rainfall (above 1750 mm/year) in the future when compared with the baseline. Further comparisons indicated that rainfall in the months of February, June, July and August would change significantly by 2030 and 2050 compared to the baseline. Under the baseline scenario, the analysis classified 22% of the land area in the country as "highly suitable" for rain-fed paddy cultivation and is expected to increase to 39% and 48% in 2030 and 2050 respectively. The change in bioclimatic suitability by 2030 and 2050 for coconut under rainfed condition indicates increasing trend. The area classified as "highly suitable" is expected to increase from 20% (baseline) to 35% (2030), while the "very suitable" area is expected to increase from 13% (baseline) to 19% by 2050 compared to the baseline period.

1. INTRODUCTION

Climate change has become a major concern to farmers in tropical countries where agricultural practices are climate-dependent. Climate change will result in higher yield variability and a reduction in suitable areas for long-established crops (Olesen and Bindi, 2002). Crops that are grown as rainfed cultivations will especially be affected severely. Changes in climate will modify crop growing areas and early understandings of such changes are important for adaptation and mitigation.

Temperature and rainfall are the two primary factors that affect agriculture in countries situated in the low latitudes. Lower yields occurrence frequency have been higher in the recent past in this region due to reduced water availability and high temperatures. The number of rainy days during a growing season is important for any crop and yield decrease could be attributed to an increase in the frequency of droughts and reduction in the number of rainy days. The temperature outside the naturally expected range during a growing season may have a severe effect on the key growth stage of crops, and adversely affect crop yield. Many studies have highlighted the potential of heat stresses during the blooming stage as a yield reducing factor (Chimenti and Hall, 2001; Morrison and Stewart, 2002). The main objective of this study was to estimate the impacts of rainfall and temperature changes with respect to climate change on growing area suitability of rainfed rice and coconut in Sri Lanka. Baseline period (1970 – 2000) temperature and rainfall were analyzed against projected future (2030 and 2050) temperature and rainfall. For this, baseline and projected climate of minimum and maximum temperatures and rainfall data on a monthly basis, crop data and the Ecocrop model were used.

2. STUDY AREA

Sri Lanka is a tropical island located in the Indian Ocean, next to the southern tip of India, between 5° 55' and 9° 50' North and 79° 42' and 81° 53' East. Its land area is 65,610 km^2. The climate of Sri Lanka is highly influenced by the topography of the island. The island can be mainly divided into central highlands and surrounding low lands depending on the topography. The central highland has complex topographical features such as ridges, peaks, basins, valleys and plateaus. The surrounding low lands are flat except for small hills located in several places. The minimum rainfall, under 900 mm, is recorded in the driest southeastern and northeastern areas. The highest rainfall, over 5000 mm, is recorded in the western slopes and central highlands. There are two wind patterns associated with the two cultivation seasons. The southwest monsoon (SWM) is from May to September and is known as the *yala* season, while the northeast monsoon is from October to December and is referred to as the *maha* season. There are two inter-monsoonal periods from March to April and October to November and are known as the first inter-monsoon and second inter-monsoon, respectively. The mean annual temperature varies between 26.5^0C to 28.5^0C, with an annual temperature of 27.5^0C in the lowlands, up to an altitude of 100m to 150m. The mean annual temperature at Nuwara Aliya located at 1800m above mean sea level is 15.9^0C. The coldest month with respect to mean monthly temperature is generally January, and the warmest months are April and August. The mean annual temperature varies from 27^0C in the coastal lowlands to 16^0C in Nuwara Eliya (Metrological Department of Sri Lanka, 1990).

Rice is the staple food for Sri Lankans. Per capita rice consumption is 97 kg per year (Department of Census and Statistics of Sri Lanka, 2007).There are two main cultivation seasons. *Maha* has the advantage of the annual monsoon rains and usually covers a larger land area. It provide*s* about 70% of the country's annual rice production. *Yala* has reduced water for cultivation resulting in a lower land extent and production. It provides about 30% of the country's annual rice production. Rainfed paddy production contributes 22% of the total paddy production in the country.

The present extent under coconut is around 394,836 hectares. Approximately 75% of the total extent comes under smallholdings. Coconut contributes 5.02% to the total export and earned LKR 72,880 million in 2014 (The Coconut Development Authority (CDA) of Sri Lanka, 2015). Coconut being a smallholder crop, contribution from the coconut industry to the GDP plays a key role in sustaining a viable economy at village, district, and regional levels. To meet domestic demand and industrial needs, Sri Lanka has to increase its coconut production annually. This demand will be further aggravated with the projected population growth.

3. OBJECVTIVE

Temperature and rainfall are key variables of climate change and changes in rainfall and temperature will modify the growing areas of rainfed rice and coconut in Sri Lanka. The modifications as a result of climate change will make rice and coconut cultivation no longer an option in certain areas while new suitable areas may emerge. Therefore, it is vital to study how growing areas may change in the future with respect to climate change. The objectives of this study were to assess the suitability of growing areas of rain-fed rice and coconut in Sri Lanka and to assess the likely changes in the suitability of growing areas in 2030 and 2050 with the predicted changes of temperature and rainfall with respect to climate change.

4. DATA AND METHODOLOGY

Monthly maximum and minimum temperature data from 19 stations and monthly rainfall data for the period 1971 to 2000 (30 years) from 147 stations of the Metrological Department of Sri Lanka were used to quantify the present climate status. Downscaled climate change projections data from outputs of the UK Hadley Centre for Climate Prediction and Research model (HadCM3) distributed by the Research Program on Climate Change, Agriculture and Food Security (CCAFS) of the International Centre for Tropical Agriculture (CIAT) were obtained in ARC ASCII grid format, in decimal degrees and datum WGS84 for both future temperature and rainfall on a monthly basis from January to December of 2030 and 2050. The grid resolution equal to 30 seconds (0.86 km^2) was applied to emission Scenario A1B of A1 family of the IPCC.

Maximum and minimum temperatures on a monthly basis and monthly mean rainfall for the baseline period were estimated by spatial interpolation. The topographically informed IDW interpolation was used to interpolate minimum and maximum temperatures. Since the temperature of the island is heavily dependent on elevation (Muthuwatta et al, 2010), linear regression or simple laps rate theory based on correlation between temperature (minimum and maximum) and altitude were established. Monthly lapse rates are not constant and have a seasonal variations. Wilson and Gallant, (2000) suggested that a DEM at 1-10 km is adequate to represent the elevation dependence of atmospheric phenomena at regional level scales.

Simple Kriging was used to interpolate baseline rainfall data in this study (Muthuwatta and Liyanage). Kinging is based on autocorrelation or the statistical relationship of distance or direction between measured sample points. Spatial autocorrelation explains that things that are closer are more alike than things located at a distance. Future 2030 and 2050 projected monthly minimum and maximum temperature and rainfall of Sri Lanka was estimated based on GCM HadCM3. The projected 2030 and 2050 climates were compared with the baseline climate.

Crop Suitability Analysis – Ecocrop Model

The processed baseline period and 2030 and 2050 data were imported and converted in to DIVA-GIS grids and used to create bioclimatic variables separately for the baseline period and 2030 and 2050. Using these variables, the model computed a suitability index for temperature and rainfall separately to compute a final suitability rating by multiplying temperature and precipitation suitability. The Ecocrop model was adjusted to crop parameters, and model simulations were carried out to estimate crop suitability of baseline and 2030, and 2050. The crop parameters best fitted to Sri Lanka were carefully identified after consulting Agronomists who are experts on each crop (Table 1).

Table 1. Crop parameters used in the suitability analysis

Parameter	Coconut	Rainfed Rice
Minimum temperature at which the crop will die (^{0}C)	10	12
Minimum temperature at which the crop will grow (^{0}C)	20	15
Minimum optimum temperature at which the crop grows (^{0}C)	27	20
Maximum optimum temperature at which the crop grows (^{0}C)	29	30
Maximum average temperature at which the crop will cease to grow (^{0}C) Celsius	35	37
Minimum amount of rain water required for the crop to grow (mm)	1000	1000
Minimum optimum amount of rain water required for the crop to grow (mm)	1250	1400
Maximum optimum amount of water for the crop to grow (mm)	2500	1800
Maximum amount of rain water below which the crop grows (mm)	3500	4500
minimum length of growing season (days)	365	105
maximum length of growing season (days)	365	110

5. RESULTS

Monthly maximum and minimum temperatures for baseline and 2030, and 2050

The analysis of baseline data indicated that April is the warmest month. In the Anuradhapura and Vavuniya Districts maximum monthly temperature ranges between 34^{0}C and 36^{0}C. This warming trend starts in February in the Gampaha, Kurunegala, and Puttalam Districts and continues until end of September spreading further to the Ampara, Polonnaruwa, Batticaloa, Trincomalee, Mullativu and the eastern part of the Badulla Districts. The areas belonging to the Trincomalee, Batticaloa and Ampara Districts experience longer period of high temperature (from May to September). From October onwards, the monthly maximum temperatures show a decreasing trend until the end of January.

The projected monthly maximum temperature for 2030 shows a similar pattern as in the baseline period. However, in every month the maximum temperature shows a higher value compared to the baseline period. As with the baseline period, the warmest month in 2030 will be April. The land area under the maximum temperature of 34^{0}C –36^{0}C is expected to increase notably from March until September. For instance, in the baseline period 11% of the land area experienced maximum temperatures of above 34^{0}C. By 2030 this will likely increase by 33% (Figure 1a).
In Sri Lanka the optimum temperature for many crops ranges between 20-30^{0}C. In the baseline, the area under 30^{0}C is around 83% of the total land mass of Sri Lanka in January, which is projected to decrease by 72%. This indicates that current crop production areas are likely to experience higher temperature levels in the future (Figure 1b).
High temperature during the growing season is a key factor for crop growth. The dominant cropping season (*maha*) of the dry zone of the country is from October to March. The percentage of area between 20^{0}C -30^{0}C, is likely decrease drastically in 2050).

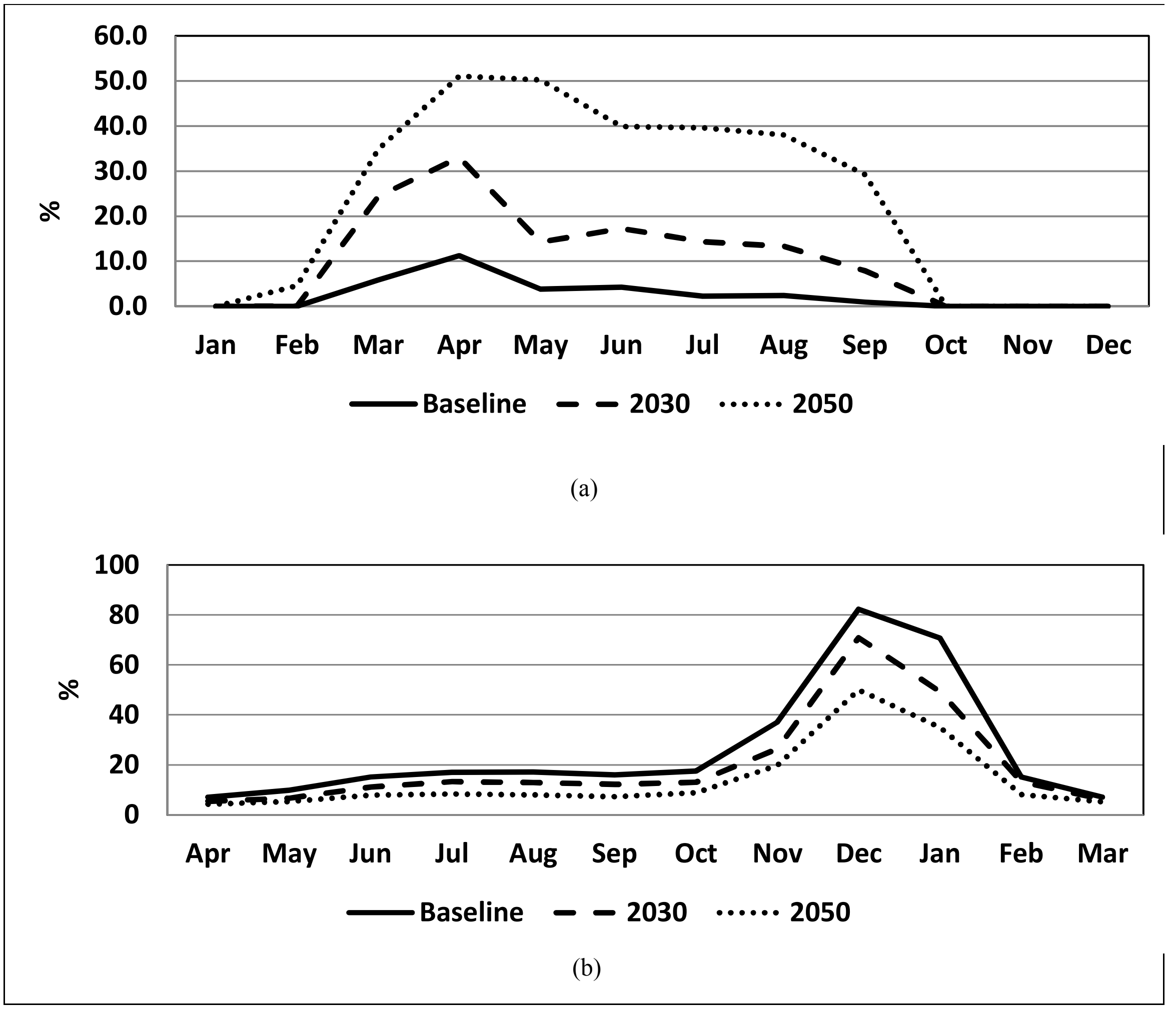

Figure 1: : Percentage change in land extent above Celsius 34 (a) and Percentage change in land extent between Celsius 20 – 30 (b)

The central highlands are the most elevated area in the country where the maximum and minimum temperatures remain low due to its elevation. The baseline data estimated that 1.4% of the total land area remains below 22^{0}C. According to HadCM3 the maximum temperature area below 22^{0}C is likely to decrease by 0.7% (Figure 1b). Baseline data analysis indicates that monthly minimum temperature remains below 26^{0}C in many parts of the island from April to October. From November to March the monthly minimum temperature drops and ranges between 20–24^{0}C. Jaffna, Killinochchi and Trincomalee Districts' monthly minimum temperature during April to September vary between 26–28^{0}C, the highest range in the country.

Compared to the baseline period, the projected monthly minimum temperature is likely to increase in the island. The monthly minimum temperature expected to range even between 28^{0}C – 30^{0}C during period of June to September in 2030. Further, in two districts, Killinochchi and Trincomalee, the highest monthly minimum temperature remains the same as it during the baseline period.

The projected monthly minimum temperature for 2050 is expected to increase further when compared to the baseline and projected 2030. Significantly, from April to September the range in the low lands of the country is likely to be 26–28^{0}C, in contrast to the baseline 24–26^{0}C range.

Mean Monthly Rainfall of Baseline, Projected 2030 and 2050

Traditionally, Sri Lanka is divided into three climatic zones based on spatial and temporal distribution of rainfall. The area with below 1,750mm of annual rainfall is classified as the dry zone, while the area with an annual rainfall of between 1,750-2,500mm is classified as the intermediate and the area with above 2.500mm of annual rainfall is classified as the wet zone. The study indicated following changes of the three climatic zones.

Table 2: Current and projected areas (km2) under three major climatic zones.

Mean annual rainfall		Baseline	2030	2050
< 1,750 mm	Extent Km^2	43,734	37,744	35,492
1,750 – 2,500 mm	Extent Km^2	11,866	13,431	17,312
> 2,500 mm	Extent Km^2	10,278	12,436	12,793

As shown in Table 2, the dry zone is likely to reduce to 37,744 km^2 by 2030 and 35,492 km^2 by 2050, respectively and the intermediate zone is expected to increase by 1,565 km^2 by 2030 and 5,446 km^2 by 2050, respectively. Increase of the area under the wet zone is likely to be 2,158 km^2 and 2,515 km^2 by 2030 and 2050, respectively.

Crop Suitability

The Ecocrop model was used to determine crop suitability due to climate change. The model uses minimum, maximum and mean monthly temperatures, and total monthly rainfall to determine a suitability index based on each parameter separately. Finally, the model determines an overall suitability rating (from 0 to 100) by multiplying both temperature and rainfall indices. The Ecocrop model simulation indicated an increase of suitable areas for both rice and coconut under rain-fed conditions. The results are presented in Table 3.

Table 3. Comparison of suitable areas for rain-fed rice and coconut for baseline, and projected 2030 and 2050

Suitability	Baseline (1970 -2000) (km2)		Projected 2030 (km2)		Projected 2050 (km2)	
	Paddy	**Coconut**	**Paddy**	**Coconut**	**Paddy**	**Coconut**
Not suited	7,243	8,674	563	5,305	332	5,231
Very Marginal	9,550	9,496	7,453	1,711	2,796	697
Marginal	11,600	12,098	8,448	11,274	8,665	9,912
Suitable	11,249	13,706	11,053	13,497	10,292	12,822
Very Suitable	11,589	8,293	12,770	11,132	12,170	12,387
Highly suitable	14,379	13,342	25,322	22,691	31,355	24,561

As presented in Table 3, the highly suitable areas for rainfed paddy will increase from the baseline 14,379 km^2 to 25,322 km^2 in 2030 and 31,355 km^2 in 2050, respectively. For coconut, the 12,342 km^2 of highly suitable area under baseline will increase to 22,691 km^2 in 2030 and 24,516 km^2 in 2050.

For coconut, the areas classified under "Marginal", "Very Marginal" and "Not Suitable" are projected to decrease in the future when compared with the baseline classification. The area under "highly suitable" is expected to increase from 20% to 37%, while the "very suitable" area is expected to increase in 2050 from 13% to 19%. (Figure 1)

Spatial distribution of suitable areas

As shown in Figure 2, Gampaha, Colombo, Kalutara, Galle, Matara, Ratnapura, Kegalle, Kandy, Ampara, Batticaloa, Trincomalee and the windward sides of Polonnaruwa, Moneragala and Badulla Districts are classified as "highly suitable" to "very suitable" for rice under rainfed condition. Puttalam, Mannar Hambantota, Nuwara Eliya and the leeward sides of Anuradhapura and Moneragala Districts are classified as "not suitable or marginal." Further, the distribution of the "highly suitable" category of rain-fed rice suitability is spread over the northern, and eastern provinces. Rainfall is projected to increase in the northern and eastern provinces of Sri Lanka in 2030 and 2050. This rainfall increase will directly affect the suitability of rice crop under rainfed conditions. Additionally, the suitability for rainfed rice in the central high lands is projected to increase compared to baseline. Under the baseline climatic condition, Puttlam, Mannar, Hambantota, Nuwara Eliya and the leeward sides of the Anuradhapura and Moneragala Districts are classified as "not suitable or marginal" based on the results of the Ecocrop model. In contrast to the baseline climate, the suitability of rice cultivation in the future under rainfed conditions is expected to increase in these districts. The area under the "highly suitable" category will increase by 22% in 2030 and by 48% in 2050.

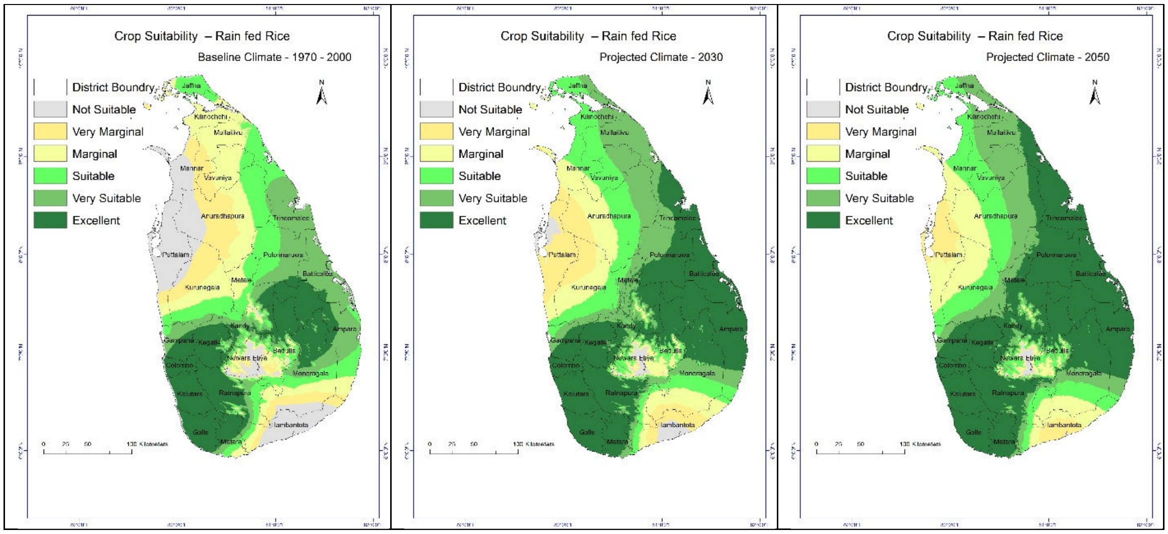

Figure 2: Rainfed rice suitability under Baseline and 2030 and 2050 climate conditions

For coconut, at present, the Gampaha, Colombo, Kegalle, Galle, Matara, Rathnapura, Kandy, Kurunegala, Matale, Moneragala, Badulla Districts are classified as "highly suitable". The Mannar District is classified as "not suitable" to "very marginal." Nuwara Eliya and part of the leeward side of Badulla are also classified as "not suitable," based on rainfall and temperature conditions. The eastern side of Hambantota is classified as "not suitable" and the western side ranges from "marginal" to "highly suitable". The Anuradhapura, Vavuniya, Mullaitivu and Killinochci and Jaffna Districts are classified as being between "very marginal" to "marginal." Part of Ratnapura, Kegalle and Kalutara Districts remain in the "suitable" or "marginal" areas due to very high rainfall experienced in the area. The results of the crop suitability analysis of coconut for the baseline climate are illustrated in Figure 3.

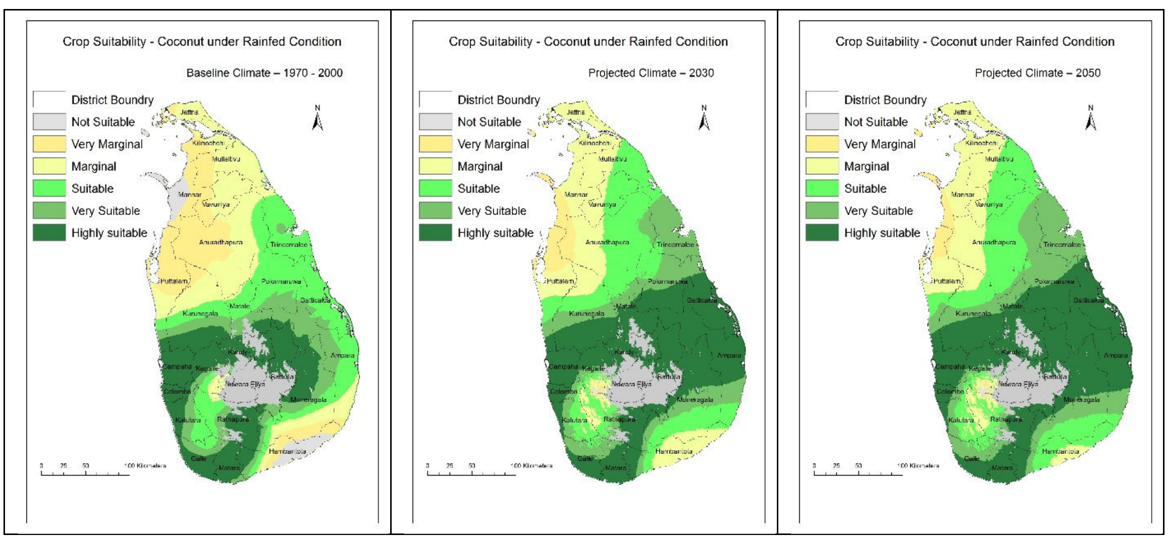

Figure 3: Coconut suitability under Baseline and 2030 and 2050 climate conditions

6. CONCLUSIONS

The bioclimatic suitability of rice and coconut in Sri Lanka was assessed for the baseline (1971 – 2000), 2030 and 2050 climates using the Ecocrop model based on temperature and rainfall. The analysis of crop suitability under the current climate matches current cropping patterns for rice and coconut under rainfed conditions. The change in bioclimatic suitability for the predicted 2030 and 2050 climate is positive for both crops even though the temperatures and rainfall increases. Under the baseline climate, very marginal or not suited area for rainfed rice remains at 26% of the total land area and predicted to decrease up to 12.2% and 4.2% by 2030 and 2050 respectively. The area classified as "highly suitable" for rice cultivation is likely to increase from 22% (baseline) to 39% by 2030 and 48% by 2050. The study indicates rice crop suitability is significantly influenced by rainfall than temperature. The change in bioclimatic suitability for the predicted climate for coconut under rainfed condition also indicates favorable conditions by 2030 and 2050. The area under "highly suitable" is expected to increase from 20% (baseline) to 35%, while the “very suitable” area is expected to increase from 13% (baseline) to 19% (2050). The areas classified under “marginal”, “very marginal” and “not suitable” for coconut cultivation is 30,267 km^2 under baseline conditions and will be decreased to 18,290 km^2 and 15,840 km^2 by 2030 and 2050 respectively.

The study was carried out based on monthly mean temperatures and monthly mean rainfall. The baseline temperature and rainfall was calculated based on 30 year past data from 1970– 2000. The future projections were extracted from the UK Hadley Centre for Climate Prediction and Research Model (HadCM3) and A1B, a subset of the A1 family of Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES). Future studies could examine other scenarios and climate models in order to verify the results. The influence of soil type is not taken into account in this study. Generally, in Sri Lanka coconut is cultivated in all major soil types with certain degrees of suitability except water bodies, rocky lands, steeps etc. The changes in rainfall also may adversely affect soil erosion and crop suitability may change. Further, changes in rainfall and its intensity may trigger adverse climate hazards such as flood, drought and changes in drainage resulting in water logging conditions.

With the change of bio climatic conditions pest and diseases situations may change either favorably or unfavorably affecting crop suitability. The loss of water from the soil, both by evaporation and transpiration from plants, is known as evapotranspiration. Changes in climate seriously change evapotranspiration and results in crop growing areas suitability change. Further studies can examine the impact of climate change on evapotranspiration, soil and soil temperature, changes of probability of hazardous conditions such as flood, drainage, changes of soil erosion, pest and diseases etc.

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