



ORIGINAL ARTICLE

Climate Change Projections and Their Consequences on Agro-Climates in Sugarcane Growing Areas of *Sevanagala*, Sri Lanka

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Abstract

An analysis was conducted to estimate the agro-climatic changes, which would incur due to projected climate change scenarios on sugarcane cultivation in *Sevanagala*, Sri Lanka over the next 70 years. The general circulation model developed by the Beijing Meteorological Centre was used with Representative Concentration Pathways scenario 6.0 to simulate the climate variables of maximum and minimum temperatures, and rainfall for years 2030, 2050, and 2090. The goodness of fit test was conducted against simulated and observed data using 10-year dataset from 2010 to 2019. The future climate was compared using a baseline data set, which was generated by averaging 10 years of data from 2010 to 2019. The results indicated that by 2090, the average annual minimum and maximum temperatures would increase by 1.2 °C and 1.4 °C, respectively. However, annual maximum and minimum temperatures may remain within the favourable range for sugarcane cultivation. The annual rainfall is expected to increase by 6.0% in 2090 relative to baseline values. The results demonstrated the stability of the effective rainfall. The evapotranspiration would increase by 3.7% by the year 2090 relative to baseline values. The soil moisture deficits for sugarcane planted in the *Yala* and *Maha* planting seasons are also expected to increase by 6.7% and 12.6%, respectively in 2090. As a result of increased evapotranspiration, additional irrigation might be needed to maintain the productivity of sugarcane cultivation indicating the climate-related risks for future rain-fed sugarcane cultivations in *Sevanagala*, Sri Lanka.

Keywords: *Climate change scenarios, Climate projections, General circulation model, Potential evapotranspiration, Soil moisture deficit*

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1. Introduction

The impact of global climate change on crop production is mainly due to changes in rainfall and temperature (Abeysingha et al. 2020). Climate forecasting models are used to study the combined effects of temperature and precipitation changes in future climates. Combined effect due to temperature and rainfall variation will create greater impact on rain-fed crops, while the temperature variation will have a high impact on irrigated crops. (Meng et al. 2017).

Climate change has increased the risk of frequent extreme weather events such as drought, high temperatures, low rainfall, and intense floods, which can be threatened on crop production (Meyer et al. 2011; Zhao and Li 2015). Most climate models have predicted the frequent occurrence of high intensity rainfall events in future (Tammets 2010; de Silva et al. 2007; Zhao and Li 2015) contributing to more runoff and less opportunity for infiltration (de Silva et al. 2007), affecting negatively on soil water balance of the root zone (Ali and Mubarak 2017). Therefore, current climate change would gradually reduce the productivity of most agricultural systems (Bradford et al. 2017). The impact of the

climate change on diurnal variation of temperatures is also reported to be narrowing in elsewhere of the world (Kundu et al. 2017).

Sugarcane is a semi-perennial crop grown in Sri Lanka that has a great risk to expose the adverse effects of climate change (Kumarasinghe and Wijayawardhana 2011). In the tropics, sugarcane ripening perform well at daily maximum temperatures (day time temperature) around 29 °C and daily minimum temperature (night time temperature) around 13 °C (Verma 2004). It is likely that in the areas where the daily minimum temperature increase resulting in decreasing sugar accumulation leading to a low sugar recovery at manufacturing stage (Hussain et al. 2018). The increase of maximum temperature due to climate change would proportionally increase the evapotranspiration rate (Kang et al. 2009), thereby rapidly reduce the available water content in the root zone soil. This scenario will have a high impact on rain-fed cultivation, where soil moisture refills only by the rainfall. Accordingly, increasing evapotranspiration while reducing the effectiveness of the rainfall would results increasing soil moisture deficits in most rain-fed areas of the world (Ali et al. 2017). However, according to Nisansala et al. (2019), the annual rainfall in the southern part

of Sri Lanka is reported to increase during 1987-2017. Thus, it is necessary to determine the climate change impact on the agro-climate of rain-fed sugarcane producing area in Sri Lanka to develop possible adaptation strategies in advance to maintain economic competitiveness of the sugarcane cultivation. It helps to avoid further deterioration of productivity levels of sugarcane plantations and adapt policy decisions while finding of alternative pathways.

The present paper discusses the effect of climate changes on temperature, evapo transpiration, rainfall and soil moisture deficit levels in rain-fed sugarcane plantations in *Sevanagala*, Sri Lanka for the next 70 years period.

2. Materials and Method

The study was conducted in *Sevanagala* sugarcane project, Sri Lanka (6°20'N to 6°26'N and 80°50'E to 80°58'E). MarkSim DSSAT weather file generator was used to simulate and predict daily maximum temperature (°C), minimum temperature (°C) and rainfall (mm) data (Trotochaud et al. 2016; Welikhe et al. 2016). MarkSim software was capable to interpolate coarse grid data, usually between 1 and 2 degrees into smaller grids of 30 arc

seconds using a bi-cubic convolution algorithm of downscaling (Jones et al. 2002). This downscaling procedure provided a reasonably fine data set for a given geographic location (Jones et al. 2002; Reynolds et al. 2018).

General Circulation Model (GCM) developed by Beijing Meteorological Centre of China (BCC-CSM 1.1 m) was used under Representative Concentration Pathways scenario 6.0 (RCP 6.0). RCP scenarios are named according to the radiative forcing level expected in the year 2100. At present, a set of four RCP scenarios were developed based on the radiative forcing levels of 8.5 Wm⁻², 6 Wm⁻², 4.5 Wm⁻², and 2.6 Wm⁻². RCP 8.5 has been developed assuming the highest emissions projections, while RCP 6 available as a medium emission projection (Fujino et al. 2006; Hijioka et al. 2008). Many scientists have pointed out that the RCP 8.5 seems to be an over estimation (Fujino et al. 2006; Larry 2015) and not ideal to be used as a benchmark for future climate change studies (Ritchie and Dowlatabadi 2017). Therefore, this study used RCP 6.0 as a future projection scenario.

Goodness of fit test was conducted between simulated and observed data of monthly rainfall, maximum temperature, and minimum

temperature for 10 years from 2010 to 2019 using root mean square error (RMSE), index of agreement and percent bias (PBIAS) tests as described by Legates and McCabe (1999).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^n (O_i - P_i)^2}{n}} \quad (\text{Eq. 1})$$

$$d = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (\text{Eq. 2})$$

$$\text{PBIAS} = \frac{\sum_{i=1}^n (P_i - O_i)}{\sum_{i=1}^n (O_i)} * 100 \quad (\text{Eq. 3})$$

where, RMSE = Root mean square error; d = Index of agreement, which is varied from 0 to 1 (Willmott 1981); PBIAS = Percent bias; O = Observed values; P = simulated values; n = Number of observations; d values closer to 1 indicates high goodness of fit between observed and simulated data; PBIAS closer to zero indicates better accuracy of the model.

Effective rainfall

There are many methods for estimating effective rainfall, including the soil water balance method and empirical relationships such as the USDA-SCS method. The best estimates of effective rainfall can be obtained by calculating soil water balance. Several studies have proved that the effective rainfall

calculated by the USDA-SCS method under well drained soil closely follows the soil water balance method (Patwardhan et al. 1990). Thus, USDA-SCS method is one of the widely used methods to compute the monthly effective rainfall in many areas of the world (Patwardhan et al. 1990). The USDA-SCS method is used in most of the crop simulation and irrigation scheduling models. As such, the USDA-SCS method was used in this analysis for computing the effective rainfall (Dastane 1978; Rahman et al. 2008; Bos et al. 2008; Ali and Mubarak 2017) as given in the equation 04.

$$P_e = SF (0.70917 \times P_t^{0.82416} - 0.11556) \times (10^{0.2426ET_c}) \quad (\text{Eq. 4})$$

where, P_e = Monthly effective rainfall; P_t = Monthly mean rainfall; ET_c = Average monthly crop evapotranspiration; SF = Soil water storage factor.

The soil water storage factor was calculated by using the equation 05:

$$SF = (0.531747 + 0.295164 D - 0.057697 D^2 + 0.003804 D^3) \quad (\text{Eq. 5})$$

where, D = Usable soil water storage as 50% of the available soil-water capacity in the

sugarcane crop root zone of 90 cm depth which is equal to 60.03 mm for Rhodustalfts (Reddish Brown Earth soil/ RBE) dominant in *Sevanagala* (Wyseure et al. 1994; Wijayawardhana et al. 2014).

Reference evapotranspiration

Reference evapotranspiration (ET_0) was computed using *Hargreaves* procedure as shown in the equation 06 (Mintz and Walker 1993; Yates and Strzepek 1994; Wang et al. 2015; Xiang et al. 2020). R software (4.0.3) was used for the estimation.

$$ET_0 = 0.0023 \times 0.408Ra \times \Delta T^{0.5} \times (T + 17.8) \quad (\text{Eq. 6})$$

where, Ra = Extra-terrestrial radiation which is a function of the latitude, ΔT = Temperature difference (maximum- minimum), T = Mean air temperature ($^{\circ}\text{C}$).

Soil moisture deficits

Soil Moisture Deficit (SMD) depends upon the crop water requirement, the effective rainfall and planting season (Dastane 1978; Bos et al. 2008). Thus, soil moisture deficits for the sugarcane cultivations for the *Yala* and *Maha* planting season's planted crops were assessed. Rain-fed sugarcane in *Sevanagala* is cultivated

basically under two planting seasons of the *Yala* and *Maha* (Wyseure et al. 1994; Wijayawardhana et al. 2014). The *Yala* planting is done from March to April and *Maha* planting is done from September to October, respectively (Wijayawardhana et al. 2014).

Soil moisture deficits were computed using water balance equation (de Silva 2006) as given in the equation 07. Crop evapotranspiration in a given month can be computed with the equation $ET_{\text{crop}} = K_c \times ET_0$ (Allen et al. 1998; Xiang et al. 2020).

$$\text{SMD} = (K_c \times ET_0) - P_e \quad (\text{Eq. 7})$$

where, SMD = Soil moisture deficit in a given month (mm), K_c = Crop factor. Value of the crop factor varies from 0.40, 0.80, 1.25 and 0.75 depending on the growing stages of sugarcane crop namely germination, tillering, grand growth and maturity respectively (Win et al. 2014), ET_0 = Reference evapotranspiration in a given month (mm), P_e = Effective rainfall in a given month (mm).

Percent change

A baseline dataset was produced by averaging a 10-year dataset from 2010 to 2019 in order to estimate relative changes in future climate.

Percent change of annual maximum and minimum temperature, annual rainfall, annual effective rainfall and annual soil moisture deficits for the year 2030, 2050 and 2090 were compared using the equation 08.

$$\text{Percent change} = \frac{x_i - x_{\text{base}}}{x_{\text{base}}} \times 100 \quad (\text{Eq. 8})$$

where, x_i = Annual average maximum temperature, minimum temperature, annual crop water requirement or annual soil moisture deficits in i^{th} year. x_{base} = baseline

which was produced by averaging a 10-year dataset.

3. Results and Discussion

Goodness of fit test

Statistics of the goodness of fit test conducted on maximum & minimum temperatures and rainfall values simulated by the RCP 6.0 with observed data at *Sevanagala* are shown in scatter plot diagrams (Figure 1).

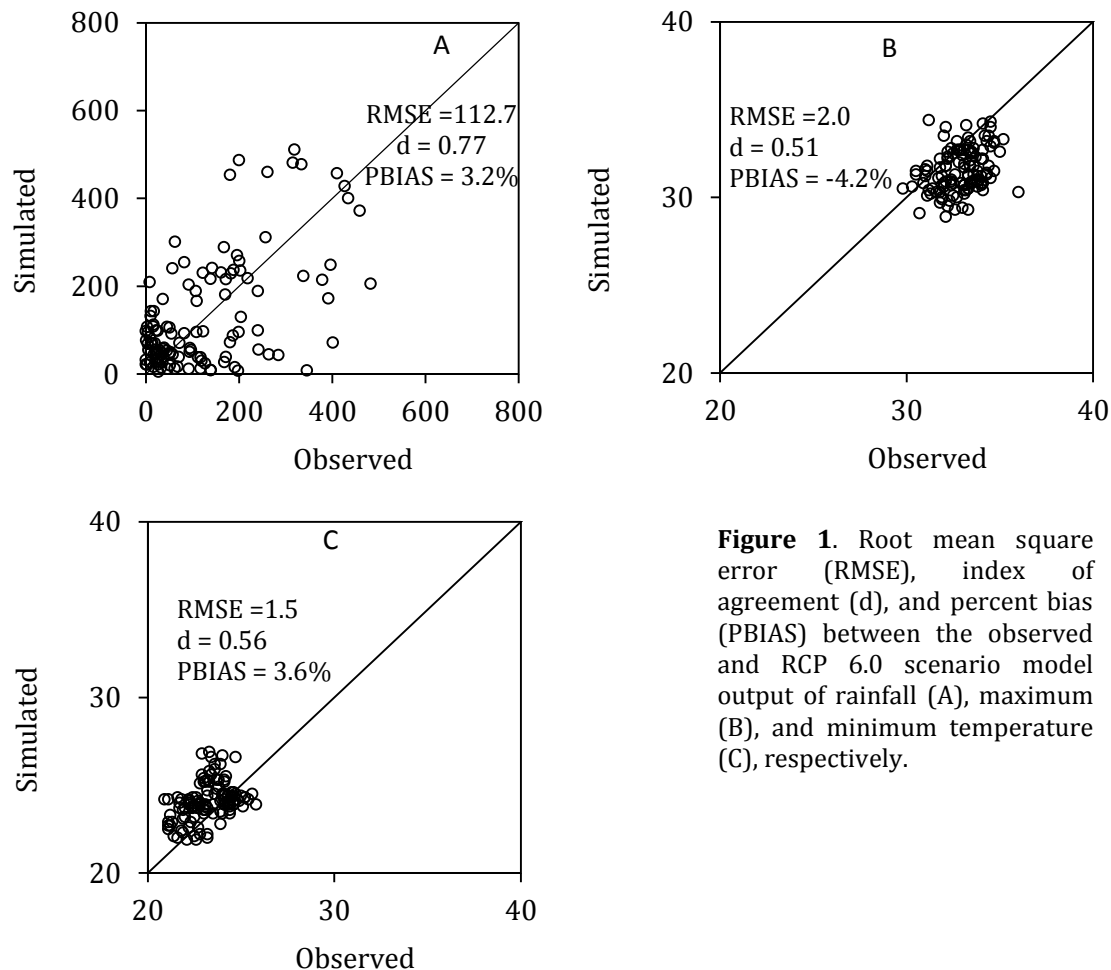


Figure 1. Root mean square error (RMSE), index of agreement (d), and percent bias (PBIAS) between the observed and RCP 6.0 scenario model output of rainfall (A), maximum (B), and minimum temperature (C), respectively.

The calculated percent bias values for monthly rainfall, maximum and minimum temperatures were 3.2%, -4.2%, and 3.6% respectively, which showed satisfactory model accuracy. Nevertheless, the index of agreement for rainfall ($d=0.77$) shows ensured agreement between the simulated data and the actual data, while the maximum and minimum temperatures values showed average accuracy. Fundamentally, amount of rainfall varies greatly on temporal and spatial scale (Wickramagamage 2015). Since the analysis was done using observed data of one agro meteorological station, RMSE calculated against simulated and observed rainfall values showed a considerable variation. The calculated RMSE value for rainfall was 112.7. It reflects the level of uncertainty of RCP 6.0 scenario model output.

Minimum and maximum temperature variation

The variation of monthly mean maximum temperature, minimum temperature and their diurnal variations in 2030, 2050, 2090 and baseline values are depicted in Figure 2.

The annual average maximum temperature shows an increasing trend over time (Figure 2-

D), and it would rise by 1.4 °C by 2090 compared to the baseline value of 31.3 °C.

Nevertheless, it would gradually reach 31.6 °C, 31.9 °C, and 32.7 °C by 2030, 2050, and 2090, respectively. Similar trends (increasing of 1.6 °C) have been observed previously by de Silva et al (2007).

The annual average minimum temperature in 2030, 2050, and 2090 are projected to be 24.4 °C, 24.6 °C, and 25.3 °C respectively (Figure 2). It is expected to increase the minimum temperature by 1.2 °C by the year 2090 compared to the baseline value of 24.1 °C (Figure 2-D), which is compatible with the observation made by de Silva et al. (2007). However, the present analysis reveals that elevated maximum and minimum temperature as shown in Figure 2 in *Sevanagala* would remain within a favorable range of 18 °C -35 °C in terms of climatic requirement of sugarcane crop growth (James 2004).

It is also worth noting that the diurnal temperature variation increase by 0.2 degrees by 2090 relative to the baseline value (Figure 2-D). Usually, increasing diurnal temperature difference enhances the cane quality (Verma

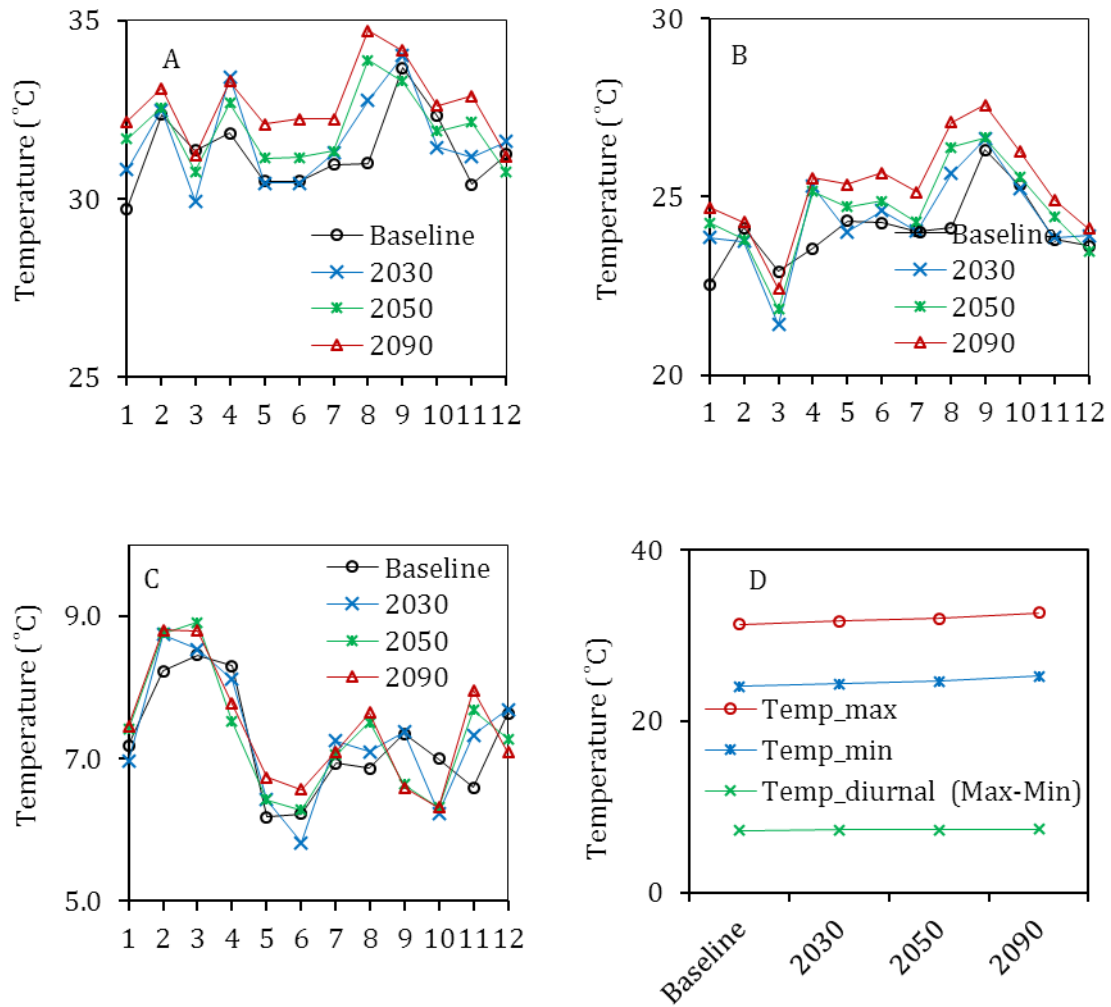


Figure 2. Variation of monthly mean maximum temperature (A), minimum temperature (B), diurnal temperature variations (C) and their annual variation (D). 1-12 in Figures 2A-C are months from January to December.

2004). However, the increase of maximum temperature during the day time would result in increased respiration, contributing to a decrease of number of physiological functions due to heat stress, thus direct benefit due to increasing diurnal temperature variation cannot be expected.

Rainfall and effective rainfall

Variation of monthly rainfall based on the RCP 6.0 scenario model output and calculated effective rainfall in 2030, 2050, and 2090 are plotted in Figure 3.

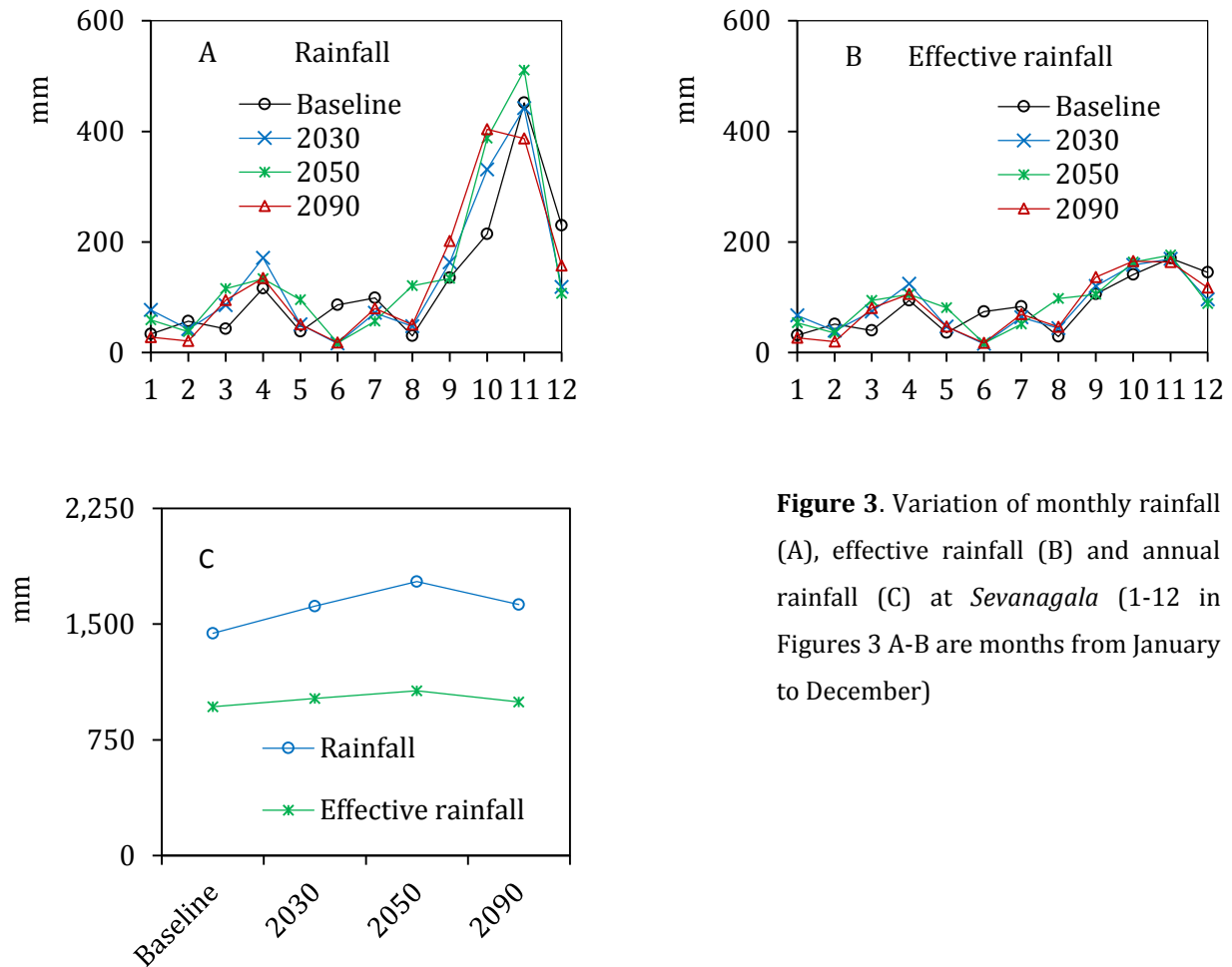


Figure 3. Variation of monthly rainfall (A), effective rainfall (B) and annual rainfall (C) at *Sevanagala* (1-12 in Figures 3 A-B are months from January to December)

The projected annual rainfall in 2030, 2050, and 2090 would be 1,616 mm, 1,776 mm and 1,626 mm respectively. As such, it can be observed that the annual rainfall in 2090 would increase by 6.4% relative to the baseline value of 1,533 mm. An increase in annual total rainfall in Sri Lanka was noticed by Nisansala et al. (2019) and de Silva et al. (2007). It is also worth noting the variation of annual effective rainfall which is estimated to be 1018 mm, 1068 mm, and 995 mm in the years 2030, 2050, and 2090, respectively. Unlike the annual total rainfall,

the effective rainfall would change slightly during the study period (Figure 3-C). This shows that despite the increase in total annual rainfall, annual effective rainfall will not follow a similar pattern. This scenario may closely link to the elevation of high-intensity rainfall events in the future, as reported by Marambe et al. (2015). Since the intense rainfall would reduce the effectiveness of the rainfall contributing more to runoff and less to infiltration. As such, the effective rainfall may not follow the increasing pattern of the total rainfall.

Evapotranspiration

From crop production point of view, evapotranspiration is the main parameter that influences the water requirement of a crop (Weerasinghe 1991; Yin et al. 2010). It gives a sense of the atmospheric water demand and characterizes the pressure created by the atmosphere on the vegetation. Variation of monthly total reference evapotranspiration (ET_0) in the years 2030, 2050, and 2090 at *Sevanagala* is demonstrated in Figure 4.

As per the present analysis, annual ET_0 levels are projected to be 1515 mm, 1525 mm and 1557 mm for 2030, 2050, and 2090 respectively. In 2090, the annual ET_0 level

would increase by 3.7% compared to the baseline value of 1501 mm.

Soil moisture deficits

Soil moisture deficit of the *Yala* (SMD_*Yala*) and *Maha* (SMD_*Maha*) planted sugarcane crop for the years 2030, 2050, 2090, and baseline values are shown in the Figure 5.

Soil moisture deficit for the *Yala* season planted sugarcane would be 467 mm, 426 mm, and 497 mm in 2030, 2050, and 2090 respectively. Similarly, it would be 613 mm, 568 mm, and 716 mm for the *Maha* season crop respectively. Baseline soil moisture deficit values were 466 mm and 636 mm for the *Yala* and *Maha* planting seasons respectively.

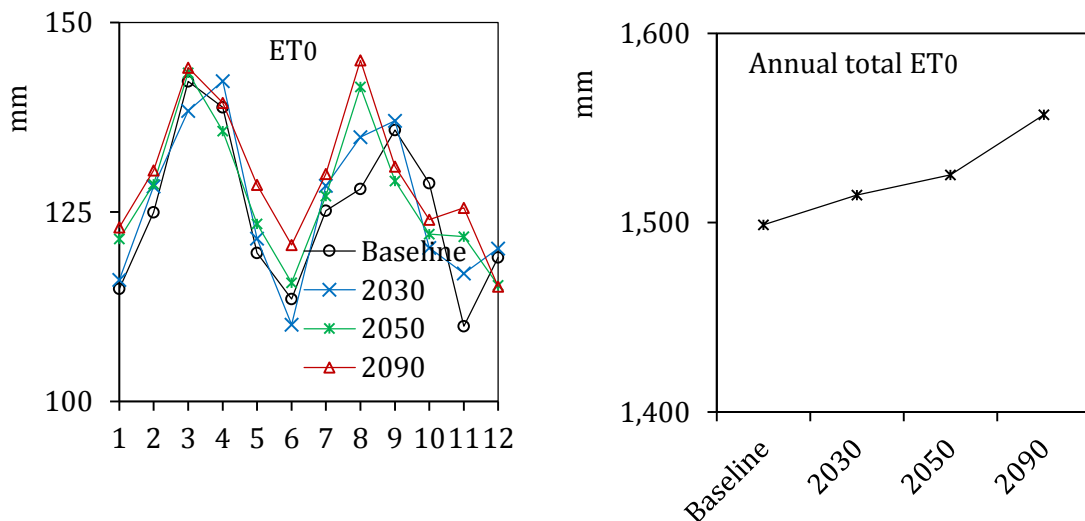


Figure 4. Variation of projected monthly and annual ET_0 in the year 2030, 2050 and 2090 at *Sevanagala* (1-12 in Figure 4 are months from January to December)

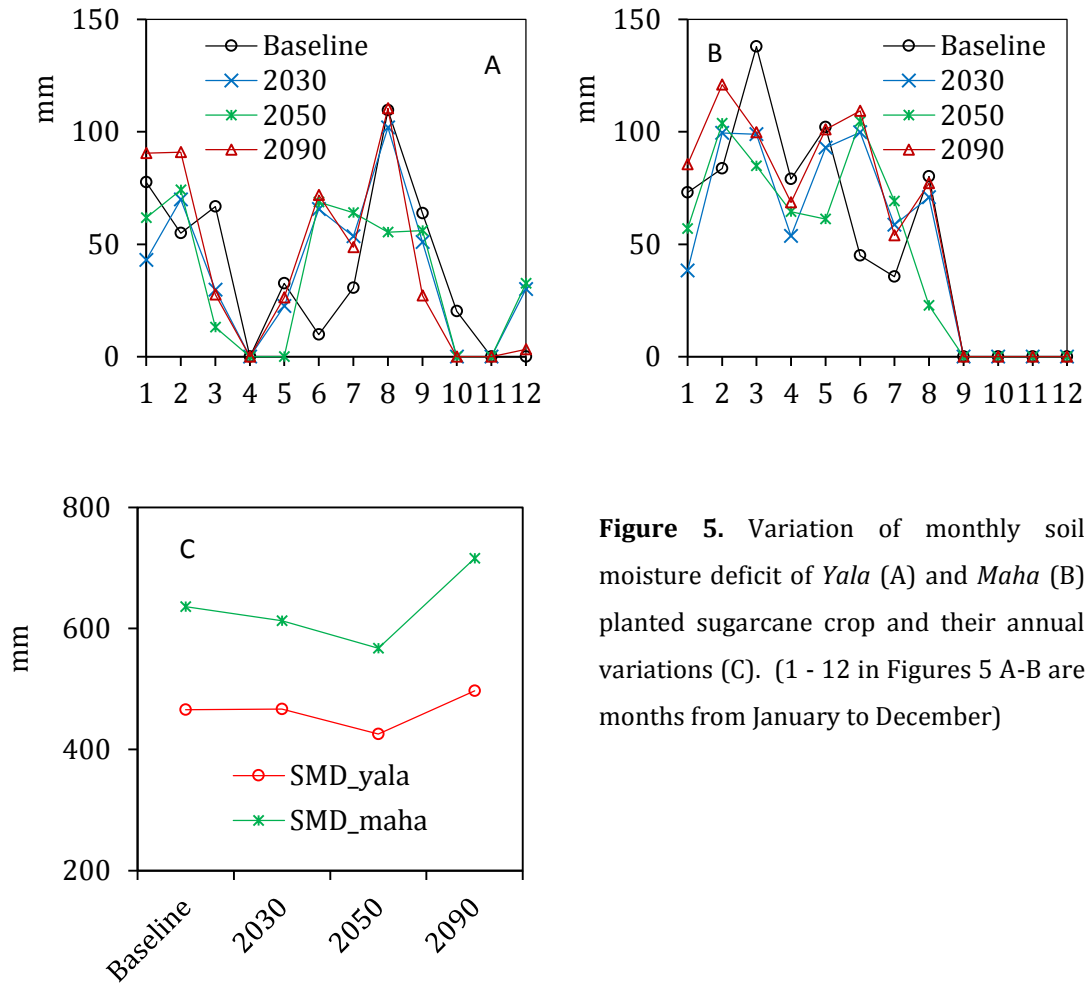


Figure 5. Variation of monthly soil moisture deficit of *Yala* (A) and *Maha* (B) planted sugarcane crop and their annual variations (C). (1 - 12 in Figures 5 A-B are months from January to December)

As shown in Figure 5, soil moisture deficits predicted for the coming 70-year period clearly showed that sugarcane planted in the *Yala* and *Maha* season would increase by 6.7% and 12.6% respectively (Figure 5-C). Nevertheless, predicted soil moisture deficits values clearly showed that sugarcane planted in the *Maha* season would suffer more water shortages than sugarcane grown in the *Yala* (Figure 5-C). The increase of soil moisture deficit would create a threat to rain-fed sugarcane cultivation in

future. Therefore, prior adaption of runoff conservation and increase soil moisture recharging and storage measures with supplementary irrigation facilities can be practical strategies to overcome the issue. Similarly, the development of drought-resistant varieties is also very important to combat the elevated evapotranspiration and soil moisture shortage problems. As the long-term sustainability of the sugar industry, it is needed that funding by government or the sugar

industry's internal capital for establishing new irrigation schemes. One of the possible strategies that can be completed with a limited budget is to construct small-scale runoff water harvesting structures in-situ in the sugarcane plantation (Wijayawardhana et al. 2011).

4. Conclusions

The projected agro-climatic parameters up to the year 2090 revealed that the rain-fed sugarcane cultivation in *Sevanagala* sugar project would be problematic due to elevated evapotranspiration and soil moisture deficit. However, the annual rainfall is expected to increase by 6.0% in 2090 relative to the baseline values. Furthermore, the analysis clearly noticed that the effective rainfall will remain at the current level over the study period.

The annual average maximum temperature will rise by 1.4 °C and minimum temperature by 1.2 °C in 2090 compared to the baseline values. However, over the next 70 years, this rate of increase in temperature will not exceed the physiological desirable limit of 35 °C of the sugarcane crop.

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