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Assessment of Projected Temperature and Precipitation in the Northern Province of Sri Lanka through Statistically Downscaled CMIP6 Projection

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Abstract. The issue of climate change has emerged as a paramount concern for the global community, with several nations grappling with the far-reaching effects thereof on their respective territories. Among these nations, Sri Lanka is ranked as the country facing the greatest potential threat. In the Northern Province of Sri Lanka, which has experienced a rebirth after years of internal conflict with the aid of international agencies, projections regarding climate change indicate a diverse array of potential impacts. To arrive at these projections, a comprehensive analysis was conducted, which leveraged downscaled data derived from the Coupled Model Inter-comparison Projects, Phase 6 (CMIP6), obtained via the grid for the Northern Province. Various models were employed to scrutinize this data, and to validate the findings, an analysis was performed by comparing the model-simulated past climate data to observed data. Multimodal ensembles provided insights into unique temperature and precipitation patterns under varying emission scenarios, including the Shared Socioeconomic Pathways (SSP) 4.5 and 8.5, between 2020 and 2100. Under the SSP2 4.5 scenario, for instance, the temperature increase would total 1.13°C, accompanied by 106.19mm of augmented rainfall. By contrast, under the SSP5-8.5 scenario, temperature would increase by 1.81°C, with a projection of 159.6mm increase in rainfall. Moreover, spatially, the future changes in temperature and rainfall for the Northern Province of Sri Lanka display consequential variations. Specifically, the western part is projected to witness higher rates of temperature and rainfall increase than the eastern part. However, it should be noted that variations exist in the values of the projections of temperature and rainfall across the different models. Regardless, the region must brace itself for elevated temperatures, resulting in heatwaves and an augmented frequency of scorching days, indicating an urgent need for policymakers and communities to incorporate these findings when developing and implementing climate adaptation strategies that aim to mitigate climate change's adverse impact in the area of study.

Keywords: Temperature, Rainfall, Multimodel, Ensemble, Increasing, Northern Sri Lanka

Оцінка прогнозованої температури та опадів у північній провінції Шрі-Ланки за допомогою статистично зменшеного прогнозу CMIP6

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Анотація. Питання зміни клімату стало першочерговим занепокоєнням для світової спільноти, і кілька країн борються з далекосяжними наслідками цього на своїх відповідних територіях. Серед цих країн Шрі-Ланка визнана країною, яка стикається з найбільшою потенційною загрозою. У Північній провінції Шрі-Ланка, яка пережила відродження після багатьох років внутрішнього конфлікту за допомогою міжнародних агентств, прогнози щодо зміни клімату вказують на різноманітний спектр потенційних наслідків. Щоб отримати ці прогнози, було проведено всебічний аналіз, який використовував зменшені дані, отримані з проектів взаємопорівняння об'єднаних моделей, фаза 6 (CMIP6), отриманих через сітку для Північної провінції. Для ретельного вивчення цих даних використовувалися різні моделі, а для підтвердження висновків було проведено аналіз шляхом порівняння змодельованих на моделі минулих кліматичних даних з даними спостережень. Мультимодальні ансамблі надали інформацію про унікальні моделі температури та опадів за різними сценаріями викидів, включаючи спільні соціально-економічні шляхи (SSP) 4.5 та 8.5, між 2020 та 2100 роками. Наприклад, за сценарієм SSP2 4.5 підвищення температури становитиме 1,13°C, випаде 106,19 мм опадів. Навпаки, за сценарієм SSP5-8.5 температура зросте на 1,81°C, а кількість опадів збільшиться на 159,6 мм. Більше того, у просторі майбутні зміни температури та кількості опадів для Північної провінції Шрі-Ланки демонструють відповідні варіації. Зокрема, очікується, що в західній частині спостерігатимуться вищі темпи підвищення температури та кількості опадів, ніж у східній частині. Однак слід зазначити, що існують відмінності в значеннях проекцій температури та кількості опадів у різних моделях. Незважаючи на це, регіон повинен підготуватися до високих температур, що призведе до хвиль спеки та збільшення частоти спекотних днів, що вказує на нагальну необхідність для політиків і громад врахувати ці висновки при розробці та впровадженні стратегій адаптації до клімату, спрямованих на пом'якшення несприятливого впливу зміни клімату на область дослідження.

Ключові слова: температура, опади, мультимодель, ансамбль, зростання, Північна Шрі-Ланка

Introduction

The menace of climate change has proven to be a significant threat to the global economy, and many countries worldwide, with its impacts permeating widely across various primary and sub-sectors of the economic development sphere(Adams & Heidarzadeh, 2022). Climate change is frequently accompanied by an increase in the intensity and frequency of extreme weather events, including heat waves, cold waves, droughts, cyclones, floods, and intense rainfall(Kumar Guntu & Agarwal, 2020). Unfortunately, many parts of Asia, including South Asian countries, are prone to these adverse effects of climate change. For instance, Asian countries stand to experience a 2-4°C increase in sea surface temperature and a 10-20% increase in tropical cyclone intensity between 2020 and 2050(Li et al., 2021). In response, many countries, particularly developing ones, have made climate change mitigation a top priority, providing valuable support to other nations in the form of adaptation or reducing climate change impacts. Yet, severe food cincreases continue to plague many developing countries worldwide due to climate change (Umar et al., 2022).

In Sri Lanka, climate change is also becoming a pressing issue, particularly negatively impacting water resources. The Sri Lankan government is grappling with considerable challenges in mitigating the effects of climate change on the water resources of Sri Lanka (Somasundaram et al., 2020). Climate change-induced uncertainties surrounding surface water resources undermine efforts directed toward improving Sri Lanka's socioeconomic sectors. Climate, being an essential natural phenomenon, practically determines all actions necessary for human survival in Sri Lanka(Shanthi De Silva, 2016). Critical climatic parameters, such as rainfall and temperature, dictate all phases of agriculture in the country. For instance, both irrigation and water supply (for domestic, industrial, and agricultural sectors) significantly depend on rainfall in Sri Lanka. As such, climate change variability profoundly influences Sri Lanka's daily processes (Iresh, 2019).

The Northern region of Sri Lanka, situated near the vast Indian peninsula, is influenced by the peninsula's wind patterns. It is also bounded by the Bay of Bengal (to the East), the Arab Sea (to the west), and the Park Strait of the sea (to the North)(Piratheeparajah, 2016). These sea surfaces change over time, leading to the local climate pattern's variation in the Northern Region of Sri Lanka. The study area in Sri Lanka is affected by southwest Monsoon and North-East Monsoon wind influences, leading to two main seasonal climate changes – short winter and long summer seasons. Unpredictable fluctuations in rainfall and temperature in the Northern region pose a significant threat to traditional and modern agricultural activities. Extended dry spells, particularly during the southwest monsoon season, create drought-prone situations and result in water scarcity (Weerasinghe et al., 2018). This, in turn, induces crop failure. On the other hand, intense rainfall within a short period during the second inter-monsoon season leads to flood vulnerability, severely impacting the region's economic activities. Unexpected extreme weather events also expose many vulnerabilities in all sectors within the region. Sadly, there are no hydro-meteorological studies in the area due to the internal war, leaving the farmers' responsible agents with insufficient information to advise them on rapid hydro-meteorological changes. Therefore, the need for hydro-meteorological studies of the Northern region of Sri Lanka is urgent and necessary for sustainable economic activities in the area (Nagamuthu & Rajendram, 2015).

The Northern Province of Sri Lanka has a population of nearly 1,100,000 people, fulfilling 81% of their daily needs (Northern Provincial Council, 2022). Any threats to the Northern Province's economy, regardless of their sources, present significant challenges to the already marginalized livelihoods of the people in the province. In the event of a climate change disaster, it would significantly affect people's lives, taking more than six months to recover and return to daily living. After thirty long years of civil strife in the Northern part of Sri Lanka, the government has initiated several developmental activities aimed at stimulating economic development in the region (Piratheeparajah, 2015). Sadly, climate change poses significant challenges to both present and future economic development efforts in the Northern region, compounding the economic devastation caused by the internal conflict. All economic activities in the area rely on surface and groundwater resources. The mainland (Vanni) depends on surface water resources such as primary, medium, and minor tanks, rivers, lakes, and springs while people in the Jaffna peninsula, islands, and coastal areas depend on groundwater resources. However, climate change impedes these activities by significantly reducing available water resources (De Silva & Kawasaki, 2018).

In light of the above, it is crucial to undertake studies that identify climate change and its impacts in the Northern Region of Sri Lanka. However, few such studies exist, with many of them mainly focusing on water resources while neglecting the physical, climatic data, and human aspects of Northern Sri Lanka. As such, this study is of utmost importance, particularly in adapting successfully to current and future climate change under various climate change scenarios. The results of this study are anticipated to contribute significantly to future development planning activities of the Northern Region.

Data and Methodology

This study is primarily concerned with the identification of projected climate change anomalies in the study area. Several studies have attempted to project climate change in their respective areas, but this is the first such attempt for the Northern region of Sri Lanka. Future projected climate change data were obtained from the Climate Change Knowledge Portal (CCKP) of the World Bank (Lacombe et al., 2019). Additionally, data for this study were collected from the global coordinates system through intercomparison coupled model phase 6 (CMP6), which is an output of Coupled Atmosphere-Ocean General Circulation Models (CACGCM) based on the IPCC's sixth assessment report (Xiang et al., 2022).

The scientific community uses scenarios to characterize the range of plausible climate futures and to illustrate the consequences of different pathways, policy choices, and technological changes. These scenarios exist as 'what if' cases, chosen to span a wide range without any ties to likelihood. The approach to formulating different scenarios has evolved from a climate-centric to an increasingly societal development-centric concept, providing insight into a range of plausible climate outcomes. Shared Socioeconomic Pathways (SSPs) are used in CMIP6 and replace the Representative Concentration Pathways (RCPs) which were presented in CMIP5. Five SSPs are presented in CMIP6, and they present different societal development pathways. The total radiative forcing level by 2100, which is the cumulative measure of GHG emissions from all sources, is presented at the end of each pathway (Langsdorf et al., 2022)(IPCC, 2017)(IPCC, 2023).

The five SSPs presented in CMIP6 are as follows:

1. SSP1-1.9, the most optimistic scenario, in which global emissions are cut to net zero around 2050. This scenario aligns with the Paris Accord of keeping global warming to 1.5°C by the end of the century.
2. SSP1-2.6, which supports increasing sustainability, with global emissions cut severely but not to zero until after 2050.
3. SSP2-4.5, which presents a 'middle of the road' scenario, in which emissions remain close to current levels, before starting to fall around mid-century, but do not reach net zero by 2100.
4. SSP3-7.0, which presents a pathway considerable value of increase of temperature from current levels by 2100.
5. SSP5-8.5, which presents a future based on an intensified exploitation of fossil fuel resources where global markets are increasingly integrated leading to innovations and technological progress(Li et al., 2021).

CMIP6 is defined by experiment suites divided into three categories: (1) Decadal Hindcasts and Predictions simulations, (2) long-term simulations, and (3) Atmosphere-only (prescribed SST) simulations for highly computationally demanding models.

The IPCC released four emission scenarios in 2022: SSP1-2.6, SSP1-4.5, SSP3-6.0, SSP4-7.0, and SSP5-8.5. However, this study only considered SSP2-4.5 (medium) and SSP5-8.5 (high) scenarios, both of which represent distinguished different scenarios of carbon emission (Ruosteenoja & Jylhä, 2021). Many researchers suggest using both of these scenarios to identify future climate change projections most appropriately. The numbers associated with the SSP represent the global representation of greenhouse gas emissions on different scales. The unit value is measured in watts per square meter achieved in different scenarios on different scales up to 2100. For example, SSP 2.6 represents an extreme mitigation scenario related to the Paris Conference, while SSPs 4.5 and 6.0 represent intermediate stabilization pathways with high emissions but some controls. Finally, SSP 8.5 assumes a continuous increase in greenhouse gas emissions without any control measures (IPCC, 2021).

Numerous grid-based data analysis models catering to various climatic periods have been employed to assess the forecasted climate alterations across the globe in distinct SSPs. Numerous institutions across the globe have developed models to analyze climate data and predict future trends in climate. In this inquiry, the following models were utilized to generate predictions regarding temperature and rainfall patterns in the Northern Province of Sri Lanka. However, it must be noted that the study places special emphasis on multi-model ensembles for interpreting the outcomes (Table 1.) (World Bank Group, 2022).

Each model used in this study requires a sufficient amount of historical data to project into the future. This serves as the reference point for generating future projections and typically spans 30 years. Climate change studies, however, can utilize some preferred periods established by the World Meteorological Institute, such as 1971 to 2000, 1981-2010, and 1990 to 2020, for the entire period. To form each model's reference period, a section of historical simulations is required (Facts, 2022). The IPCC recommended twenty years for recent climate change studies, whereas this study considers the primary climate period as 1986 to 2005 as recommended by the CACGCM. Future projections are made for the years 2020-2039, 2040-2059, 2060-2079, and 2080-2099, with a focus on two basic parameters: mean monthly temperature and monthly rainfall (precipitation). This study considers only two climatic scenarios: 4.5 medium-low emissions and 8.5 high emissions. The Climate Change Knowledge Portal of the World Bank Group was the primary source of grid data for the study. The data was set up at a 1°x1° global grid spacing and produced through bi-linear interpolation. The study employed data downscaled to the geographical coordinates of the Northern region of Sri Lanka situated in the latitudes of 8° 37' 42" N and 9° 49' 00" and longitudes of 79° 41' 35" and 80°57'35".

Data Processing Procedures and Protocol for Future Climate Change Analysis

1. ***Baseline Climatic Periods:*** The CMIP6 model simulations were computed independently to generate a standard dataset for which two complete climatologies for the current and imminent twenty-year intervals (2020-2039, 2040-2059, 2060-2079, and 2080-2099) can be calculated, in addition to their relative variabilities in contrast to their standard reference duration of 1995-2014 (Lacombe et al., 2019). Monthly

Table 1. Future climate change models and the models' originating centers and codes

Model	Institution	Modeling Centre
BCC_CSM1_1	Beijing Climate Center, China Meteorological Administration	BCC
CCSM4	National Center for Atmospheric Research	NCAR
CESM1_CAM5	National Science Foundation, Department of Energy, National Center for Atmospheric Research	NSF-DOE-NCAR
CSIRO_MK3_6_0	Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence	CSIRO-QCCCE
FIO_ESM	The First Institute of Oceanography, SOA, China	FIO
GFDL_CM3	Geophysical Fluid Dynamics Laboratory	GFDL_ESM2G NOAA GFDL
GFDL_ESM2M	Geophysical Fluid Dynamics Laboratory	GFDL_ESM2G NOAA GFDL
GISS_E2_R	NASA Geophysical Fluid Dynamics Laboratory	NASA GISS
GISS_E2_H	NASA Geophysical Fluid Dynamics Laboratory	NASA GISS
IPSL_CM5A_MR	The Institute Pierre Simon Laplace	IPSL
MIROC_ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and the National Institute for Environmental Studies	MIROC
MIROC_ESM_CH	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and the National Institute for Environmental Studies	MIROC
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC
MRI_CGCM3	Meteorological Research Institute	MRI
NORESM1_M	Norwegian Climate Centre	NCC

fundamental data were acquired such that the resulting products represented a twenty-year climatic period. These twenty-year breaks at the grid level are crucial for referencing the diverse variabilities throughout the 21st century. Therefore, each 20-year time window can be linked to the standard "present-day" reference period of 1995-2014, and the corresponding anomalies bear significant correspondence with the IPCC results (Stocker et al., 2013).

2. Re-gridding: Because all original model output is presented on their native grids, the multimodal collection required re-gridding to a common resolution. This was achieved by producing a common 1° x 1° global grid spacing through bi-linear interpolation. The Northern region of Sri Lanka is located in the latitudes of 8° 37' 42" N and 9° 49'00" and longitudes of 79° 41'35" and 80°57'35", and the data was downscaled for these geographical coordinate locations and applied in this study(World bank group, 2021).

3. Climatology: Twenty-year climatologies were formed for each of the four selected essential climate variables for all five SSPs («SSP1-1.9», «SSP1-2.6», «SSP2-4.5», «SSP3-7.0», «SSP5-8.5») and CMIP6's 'baseline' interval (1995-2014) derived from the historical simulations («hist»), while the future climatologies (2020-2039, 2040-2059, 2060-2079, 2080-2099) were computed. These climatologies yielded 12 monthly average values, 4 seasonal average values, and one annual mean value established over the respective time windows. To form the climatologies, all values were computed directly from the absolute temperature and precipitation data taken from the model simulations. Note that each model might exhibit slightly different absolute temperatures and precipitation, and these offsets compared to observational data are generally small, yet they can be significant in some regions. Therefore, to compare changes between models, comparisons of relative changes are more appropriate than absolute values (World Bank Group, 2021).

4. Anomalies: For each model, variable, and for every future twenty-year time window, anomalies for each month, as well as the annual value, were computed and assessed relative to their corresponding historical reference period. These values are ideal for model-to-model inter comparisons as they always refer to the change simulated by each model. For some indicators that represent departures or counts above absolute thresholds, prior bias correction is critical (for example the number of days with minimum night time temperatures above 21°C).

5. Ensemble Information: Ensemble values were calculated from the anomalies for every twenty-year climatological period in the future from each of the models in the collection. These ensembles describe how the collection of up to 31 CMIP6 models projects the climatological changes on average. Different ways of exploring the ensemble distribution are possible, but here, the median across the individual model values was chosen as the primary representation. Additionally, ensemble high (90th percentile) and low (10th percentile) values were generated for all the climatological anomalies to help users recognize the range of probable outcomes driven by different sources of uncertainty. Note that values are available for each model separately, and thus the user could explore the distribution in more detail. Because each model has a slightly different climate sensitivity and simulated different internal climate variability, the projections increasingly differ in the future. Therefore, the ensemble spread generally increases with time. Note that each model's anomalies can be compared with the provided ensemble description that encompasses the range between high (90th percentile) and low (10th percentile) levels of the underlying distribution.

Methodology for the Validation of Data

The validation of future climate change data methodology is crucial to employ this data effectively for further use in this study. To achieve this, a comparative analysis method was implemented to assess the accuracy of future temperature and rainfall data pertaining to the analysis of future climate change patterns in the Northern region of Sri Lanka. This involved utilizing general circulation models to simulate historical data and comparing it against actual observed data to assess its validity. Specifically, actual rainfall data spanning thirty years from 1990 to 2020 was considered for the assessment of both types of data. Multiple models were employed to project future climate change data for the study area under different scenarios. These models simulated temperature and rainfall data for the study area, including ensemble data, which was then compared with actual observed historical data to assess the validation of future climate change data for this study. Validation assessment analysis of future climate change data is crucial to ensure the reliability of data for this study. To achieve this goal, actual observed and model-simulated historical data were compared utilizing the Mean Absolute Deviation (MAD) method, as this is the most effective method for identifying variations in a data set. In this study, MAD was employed to compare the variations between actual observed and model-simulated historical data in the Northern region of Sri Lanka. The MAD was computed utilizing the following formula:

$$MAD = \text{median}\ (|Xi - \tilde{X}m|), \quad (1)$$

where: Xi - the ith value in the dataset;

Xm - the median value in the dataset.

In addition, the historical data that was observed and model-simulated was evaluated through the use of a figure-based comparison method. This involved utilizing trend line graphs to compare the data in question.

To explore future climate change scenarios, multi-models were implemented across two distinct SSP scenarios: SSP 4.5 (medium low emission) and SSP 8.5 (high emissions), which were released by the IPCC in 2021. Regardless of the specific model being utilized, the study area consistently exhibited increases in both temperature and rainfall values. To that end, this section is focused on drawing comparisons between the validation of future climate change data, observed actual data, and model-simulated historical data. As such, the monthly climate change projected by multi models for the Northern region of Sri Lanka, utilizing temperature and rainfall parameters, is analyzed herein.

The validation analysis of future climate change data was carried out using the MAD method. As it pertains to the observed actual rainfall versus the model-simulated historical data, minor differences in the MAD values were observed. An investigation of the annual mean rainfall pattern uncovered a striking similarity between the observed and predicted historical rainfall in the Northern region of Sri Lanka. Specifically, based on MAD, the annual rainfall patterns from the last thirty years in the aforementioned region exhibited a variation of only 3.3mm between the observed actual precipitation and the model-simulated values, which amounted to 129.7mm and 126.4mm, respectively (Fig. 2).

Regarding temperature, the MAD results indicate a strong correspondence between the actual observed data and model-simulated historical data. Specifically, the MAD values for actual observed and model-simulated historical temperatures were found to be 0.57°C and 0.63°C, respectively. Thus, there was only a 0.06°C deviation between the two types of temperature data sets in this study (Fig. 1).

Based on the historical records of both observed

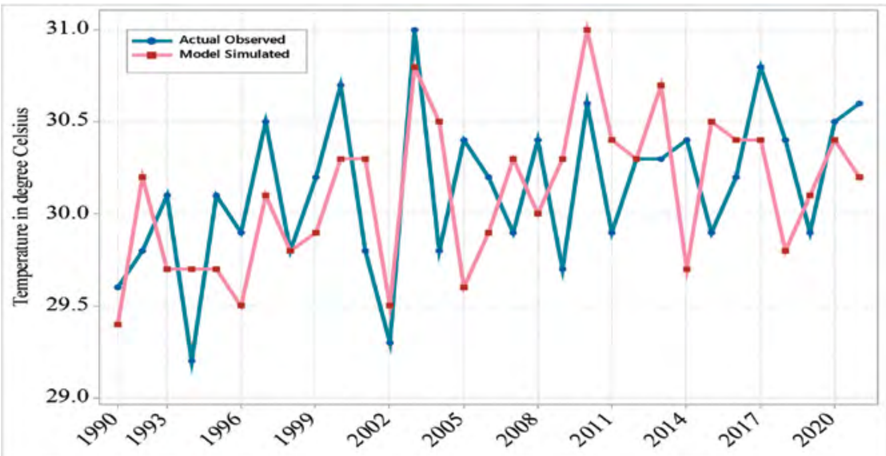

Fig. 1. Observed and Modeled simulated annual mean temperature trend for the period from 1990 to 2022 in the Northern Region of Sri Lanka

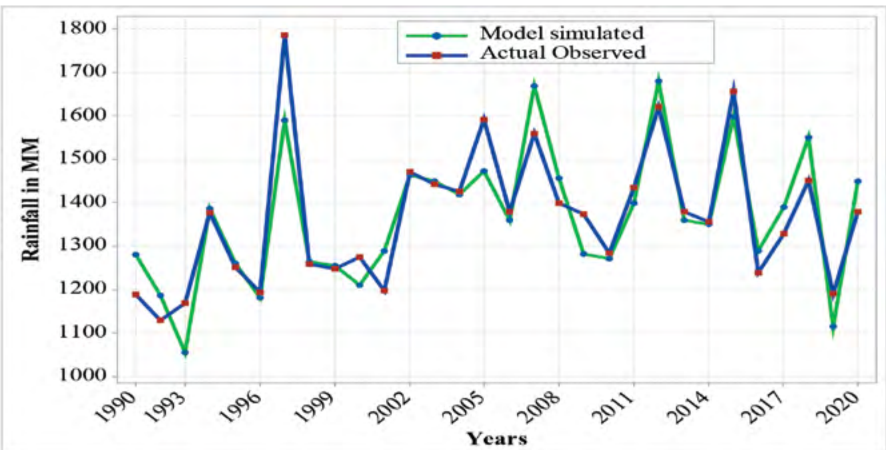

Fig.2. Observed and Model simulated annual total rainfall trend for the period from 1990 to 2022 in the Northern Region of Sri Lanka

and model-simulated data, pertaining to the annual temperature and rainfall of Sri Lanka's Northern region, a consistent trend can be observed. The yearly average temperature has shown a nearly identical pattern, as has the total annual rainfall, over the past thirty years since 1990.

Results and Discussion

The evaluation of the anticipated temperature and precipitation pattern in the Northern Province of Sri Lanka has manifested a noteworthy surge in various SSPs for distinct climatic epochs. Nevertheless, multimodel amalgamations have pointed out an upward trajectory in temperature and precipitation during the climatic span spanning from 2020 to 2100.

Future Temperature Changes under SSP 4.5

Future alterations in temperature have been investigated by analyzing sixteen models during four distinct climatic eras, namely 2020 to 2039, 2040 to 2059, 2060 to 2079, 2070 to 2099, and 2020 to 2100. Temperature alteration anomalies (Mean) for the study region have been analyzed. According to the projections for the climatic period 2020 to 2100, based on the SSP 4.5 scenario, various temperature augmentations are expected to occur in the study area.

The collective model indicates an impending in-

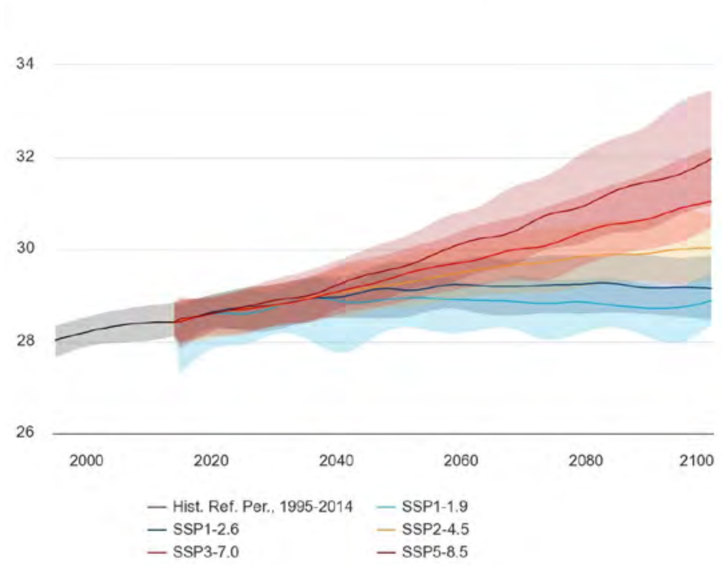

Fig. 3. Projected Multi-model ensemble annual mean temperature of the Northern Province of Sri Lanka for the period from 2020 to 2100 under SSP4.5. Under the SSP5- 8.5, there will be a very significant increase in the temperature in the study area. Compared to other scenarios SSP1-1.9 shows a minimal increase in the study area.

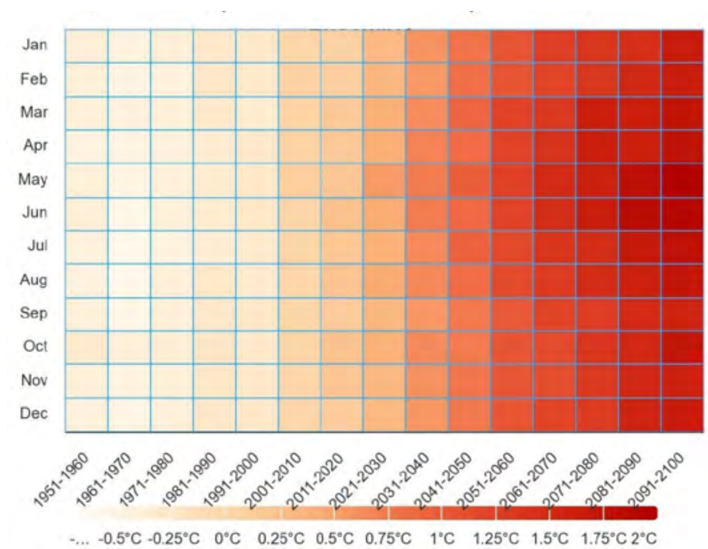

Fig. 4. Projected Multi-model ensemble decadal monthly mean temperature of the Northern Province of Sri Lanka for the period from 2020 to 2100 under SSP4.5

crease in temperature, with an increase of 1.13 °C during this period (Fig. 3,4). The model presents varying monthly fluctuations for different scales concerning temperature escalation. According to the collective model, the maximum temperature increase will occur in April, with a temperature increase of 1.25 °C. Additionally, June and July have projected temperature increases of 1.24°C and 1.23 °C respectively. Nonetheless, the collective model portrays an elevation in temperature of over 1.00 °C every month. It is worth noting that the smallest increase in temperature was recorded in November and December, at 1.01 °C. Furthermore, from 2020 to 2100, February, March, July, and September will experience the greatest temperature escalation. Each discrete model presents distinctive values of future temperature escalation in the study area. Table 2 delineates the monthly temperature changes under the SSP 4.5 scenarios, as projected by the diverse models.

As per the models, the estimated temperature increments exhibit fluctuation every month (refer to Fig. 5, 6, 7, 8). Notably, GFDL_CM3 demonstrates a substantial increase of 2.43 °C in January, while the lowest projection of 1.04 °C is from BCC_CSM1_1_M during the same month. Additionally, other models also provide different predictions of the temperature increase for January. In February, GFDL_CM3 indicates the highest temperature spike of 2.63°C whereas the lowest prediction of 1.01 °C is offered by BCC_CSM1_1_M. March portrays the highest projection of 2.86°C by CSIRO_MK3_6_0 and the lowest of 0.87°C by the FIO_ESM model. April exhibits a peak temperature increase of 3.28°C by CSIRO_MK3_6_0, indicating an upsurge in temperature in the said month during 2020 – 2100. In contrast, FIO_ESM suggests the lowest value of 0.92°C for the same month. Remarkably, GFDL_CM3 displays the

Table 2. Monthly basis projected temperature changes in various models under SSP 4.5 scenarios for the Northern region of Sri Lanka

Types of Models	Increasing average values in °C (2020-2100)
ENSEMBLE	1.13
BCC_CSM1_1	1.22
BCC_CSM1_1_M	1.24
CCSM4	1.23
CESM1_CAM5	2.12
CSIRO_MK3_6_0	2.22
FIO_ESM	1.05
GFDL_CM3	2.53
GFDL_ESM2G	1.14
GISS_E2_H	1.35
GISS_E2_R	1.17
IPSL_CM5A_MR	2.28
MIROC_ESM	1.89
MIROC_ESM_CHEM	1.95
MIROC5	1.55
MRI_CGCM3	1.53
NORESM1_M	1.28

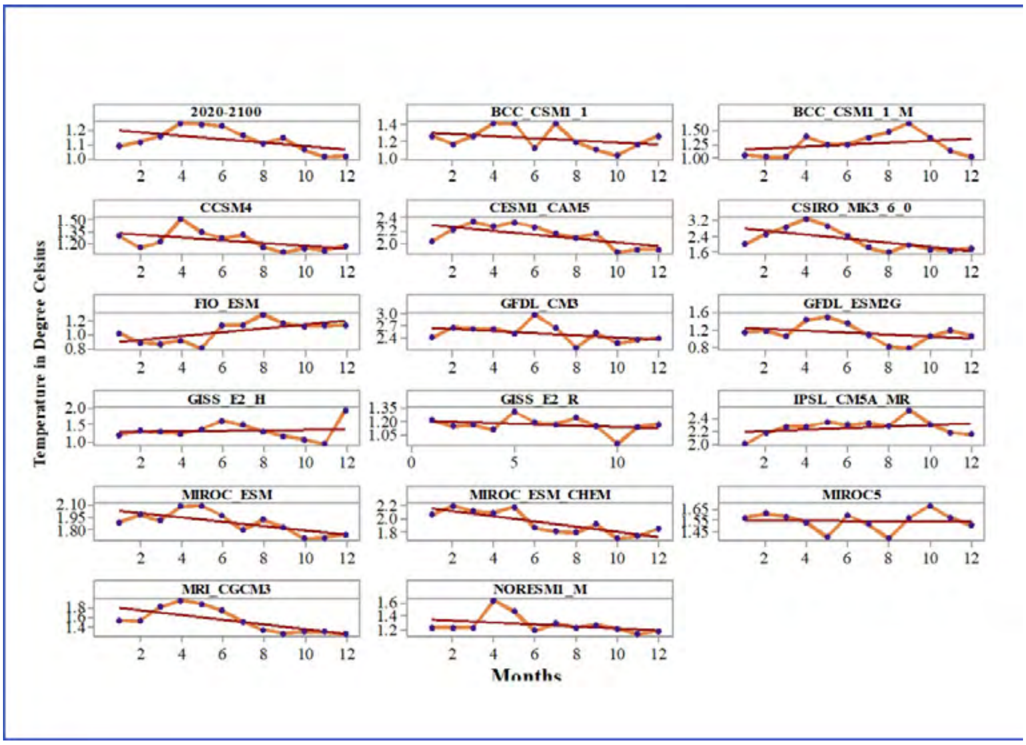

Fig.5. Projected monthly temperature anomalies of each model for the period from 2020 to 2100 under SSP4.5

highest and lowest temperature increases for April, estimating 2.93°C and 0.81°C, respectively. Similarly, in June, GFDL_CM3 projects the highest temperature value of 2.99°C, whereas BCC_CSM1_1's estimated temperature increment is the lowest with a value of 1.11°C. The projected temperature spike in July for GFDL_CM3 is 2.67°C, whereas the minimal temperature increment predicted is 1.18°C by the GISS_E2_R model. The IPSL_CM5A_MR model reflects the highest projection of temperature increases of 2.3°C, 2.55°C, and 2.33 °C for August, September, and October, respectively. However, among the other models, CCSM4 projects the lowest temperature value of 1.16°C for August, while BCC_CSM1_1 provides the minimum temperature spike predictions for September and October. GFDL_CM3 portrays the uppermost temperature projections for November and December, while the lowest projections for November and December are from GISS_E2_H and BCC_CSM1_1_M models, respectively, in the period of 2020 to 2100 in the study area (Figure 7).

The projected temperature in the study area for future climatic periods exhibits monthly variations, as depicted in Fig.6. The ensemble analysis reveals significant fluctuations between two time intervals, namely 2020 to 2039 and 2040 to 2059, in the study region, according to the models.

Projected Temperature under SSP 8.5

The anticipated temperature from 2020 to 2100 according to SSP 8.5 scenarios displays variance across every model. Nevertheless, the Ensemble model denotes an average temperature increase of 1.81°C for the Northern Region of Sri Lanka during that period (Fig. 9, 10, 11). Even so, there is substantial irregularity each month. The analysis suggests that the RC 4.5 scenarios exhibited the highest surge in ensemble temperature in April, which recorded an average val-

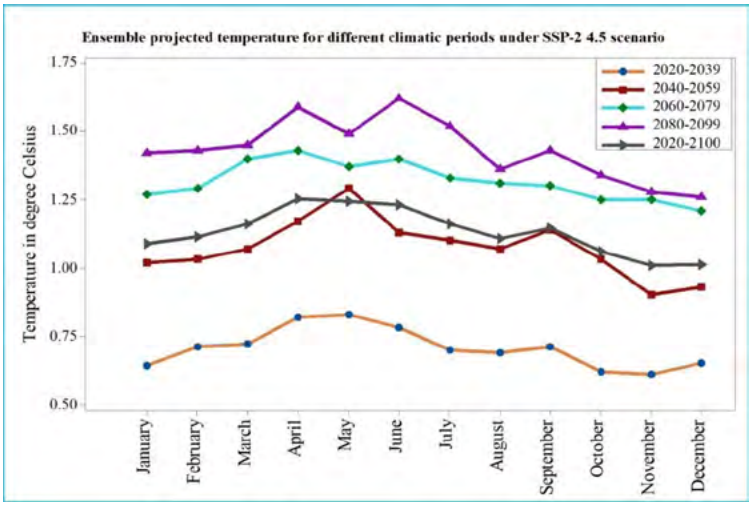

Fig. 6. Ensemble view of projected temperature increases for the Northern Region of Sri Lanka under SSP4.5 in various models for every month

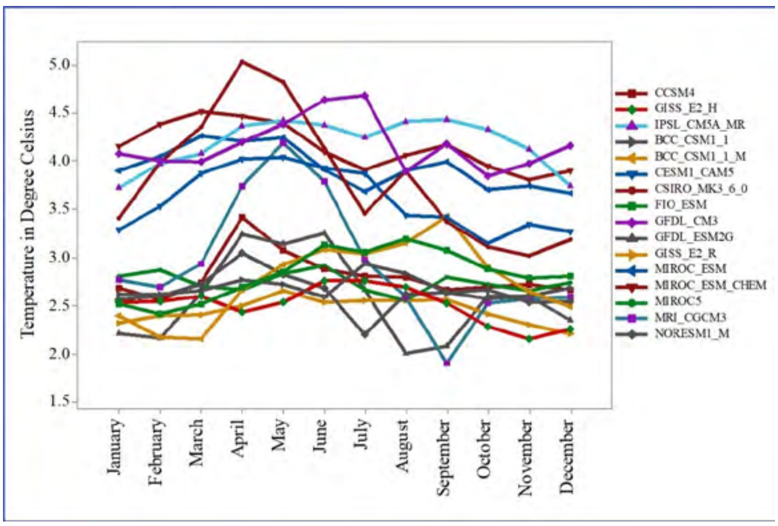

Fig. 7. Various models projected temperature increase under SSP 4.5 from 2020 to 2100 in the Northern Region of Sri Lanka

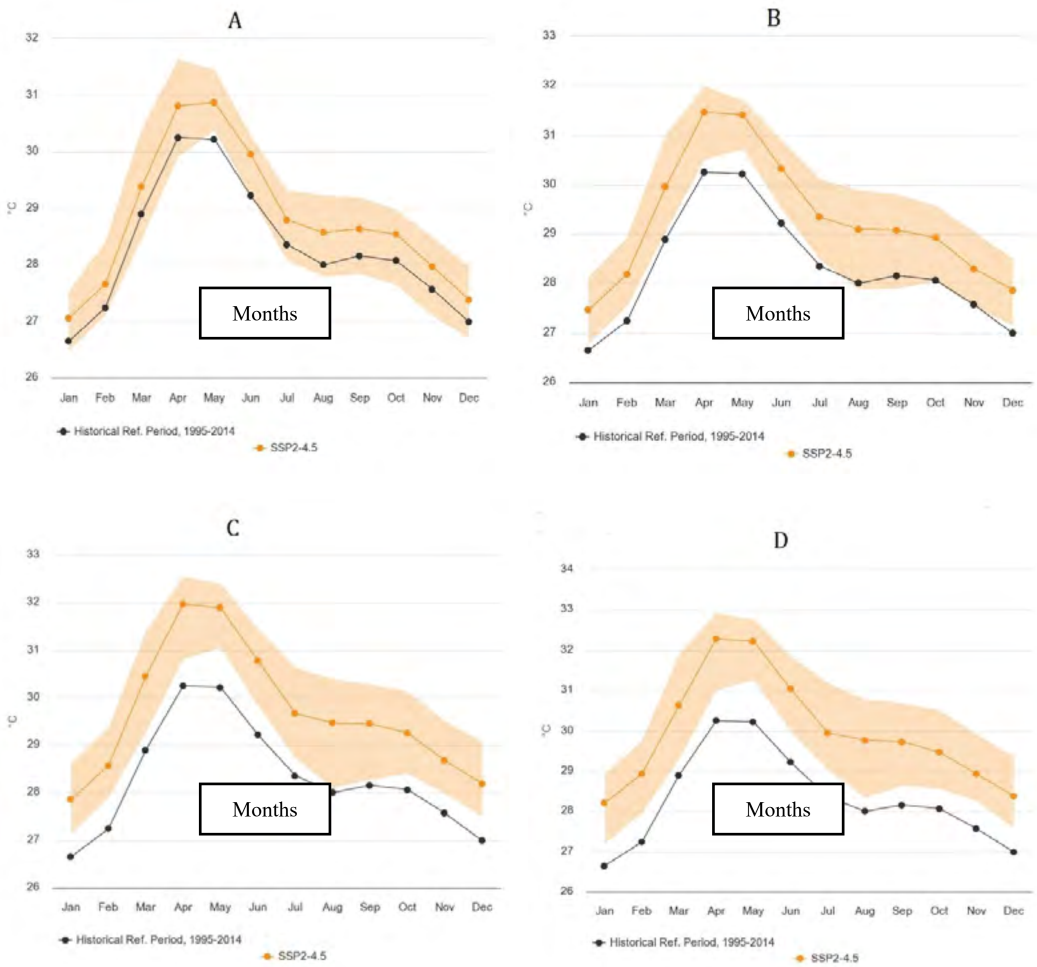

Fig.8. Models projected monthly average value of temperature increase in SSP4.5 for a different climatic period for the Northern region of Sri Lanka (A-2020 to 2039, B-2040 to 2059, C-2060 to 2079, D- 2080 to 2090). These variations in the monthly pattern of temperature in different climatic periods under SSP2-4.5.

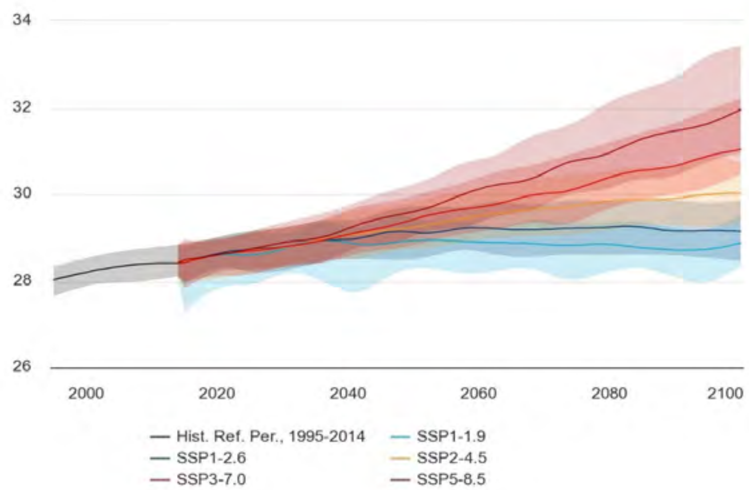

Fig. 9. Projected model ensemble annual mean temperature of the Northern Province of Sri Lanka for the period from 2020 to 2100 under SSP8.5. Compared to other climatic periods, from 2080 to 2100 a very extensive temperature increase has been identified in all scenarios, but it seems very high under the SSP5-8.5 scenarios.

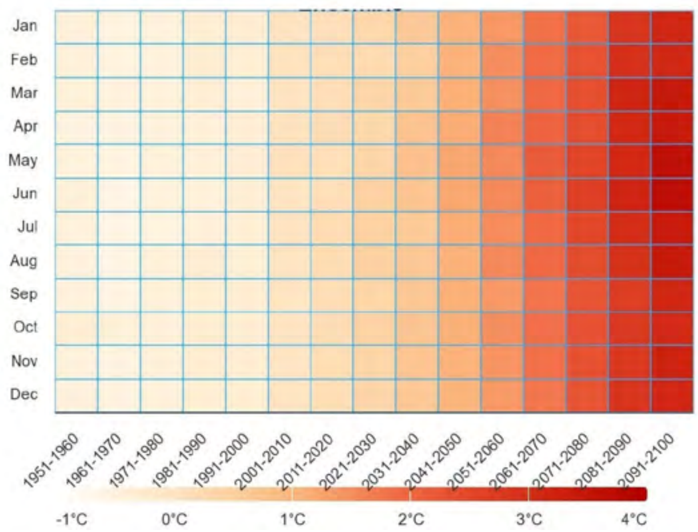

Fig.10. Projected model ensemble decadal monthly mean temperature increase in the Northern Province of Sri Lanka for the period from 2020 to 2100 under SSP8.5

ue of 2.06°C for the same month. Subsequent to April, June exhibited a temprature increase of 1.99°C, while May displayed a temperature increase of 1.96°C.

Furthermore, it is noteworthy that the nadir of temperature increase projections is expected to occur in both November and December, with both months indicating an equivalent value of 1.69°C. Similarly, August and September are projected to record identical values of 1.8°C. It is pertinent to mention that Table 3 provides a monthly ensemble variation of estimated temperature projections for the SSP 8.5 scenarios between the years 2020 to 2100. However, it is essential to point out that the average value of all the models is anticipated to be 3.15°C during the aforementioned time frame under the SSP 8.5 scenario.

Table 3. Monthly basis of projected temperature changes in various models under SSP 8.5 scenarios for the Northern region of Sri Lanka

Month	**Ensemble Average temperature(°C) projection 2020-2100**
January	1.7225
February	1.685
March	1.7075
April	2.0675
May	1.965
June	1.9975
July	1.9125
August	1.845
September	1.8
October	1.7325
November	1.695
December	1.695

As per the analysis of every model, notable variations exist in their respective projections of average temperature increase. Notably, the IPSL_CM5A_MR model records the highest average value of temperature increase at 4.18°C, followed by the GFDL_CM3 model at 4.17°C, and MIROC_ESM_CHEM at 4.15°C. Conversely, the lowest average values of temperature increase are registered in GISS_E2_R at 2.45°C, followed by GISS_E2_H at 2.51°C (as depicted in Tables 3 and 4).

Table 4. Various models projecting the annual mean value of temperature increase for the period of 2020 to 2100 under SSP 8.5 for the Northern region of Sri Lanka

Types of Models	**Increasing annual mean values in °C (2020-2100)**
ENSEMBLE	1.81
BCC_CSM1_1	2.68
BCC_CSM1_1_M	2.75
CCSM4	2.81
CESM1_CAM5	3.16
CSIRO_MK3_6_0	3.81
FIO_ESM	2.87
GFDL_CM3	4.17
GFDL_ESM2G	2.57
GISS_E2_H	2.51
GISS_E2_R	2.45
IPSL_CM5A_MR	4.18
MIROC_ESM	2.74
MIROC_ESM_CHE	3.94
MIROC5	2.74
MRI_CGCM3	2.94
NORESM1_M	2.64

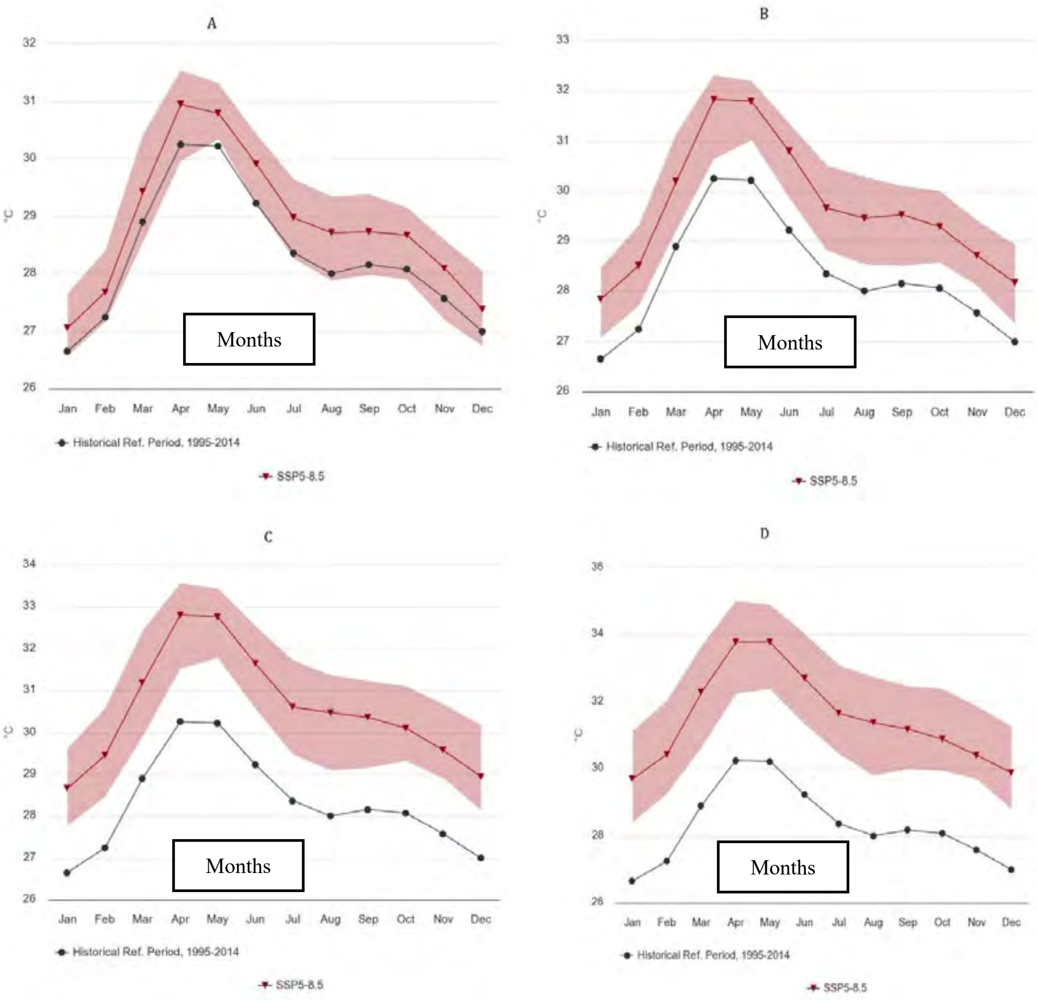

Fig. 11. Models projected monthly average value of temperature increase in SSP8.5 for a different climatic period for the Northern region of Sri Lanka (A-2020 to 2039, B-2040 to 2059, C-2060 to 2079, D- 2080 to 2090). These variations in the monthly pattern of temperature in different climatic periods under SSP5-8.5.

Differences have been observed in monthly average temperature anomalies in the study area. Each model displays various monthly average alterations in Sri Lanka's northern region (Fig. 12 and Fig. 13). In January, the MIROC_ESM_CHEM model registered the highest temperature increase of 4.15°C, while the lowest temperature variation of 2.21°C was recorded on the GFDL_ESM2G model with a predicted temperature average of 2.92°C. In February, the average temperature increase was 2.98°C, with some fluctuations in prediction variations. The MIROC_ESM_CHEM model predicted the highest temperature increase of 4.39°C, while the BCC_CSM1_1_M model recorded the lowest variation with a temperature value of 2.18°C in the study area. The projected average value for temperature increase for March is 3.11°C, with the MIROC_ESM model registering the highest temperature increase of 4.27°C and BCC_CSM1_1_M the lowest temperature increase of 2.16°C. Despite variations in every model's temperature prediction, the CSIRO_MK3_6_0 had the highest expected temperature increase in April of 5.04°C, the highest increase in the study area every month. Conversely, the GISS_E2_H model recorded the lowest projected temperature value of 2.44°C, with an average temperature increase of 3.18°C across all models in April. The average predicted temperature value for May was 3.41°C, but the CSIRO_MK3_6_0 model projected the highest temperature increase of 4.82°C, and the GISS_E2_H value registered the lowest temperature increase of 2.54°C. Several other models also predicted high temperatures this month, including CESM1_CAM5, GFDL_CM3, MRI_CGCM3, and MIROC_ESM MIROC_ESM_CHEM. For June, the models' average predicted temperature value increased to 3.33°C, with the GFDL_CM3 observing the highest temperature increase of 4.64°C, whereas the GISS_E2_R model projected the lowest temperature increase of 2.54°C. The model predicted an average temperature increment of 3.14°C for July, with IPSL_CM5A_MR projecting the highest expected temperature increase of 4.25°C and NORESM1_M forecasting the lowest at 2.2°C. In August, IPSL_CM5A_MR forecasted the highest temperature increase at 4.41°C, while the GFDL_ESM2 G model projected the lowest temperature increase of 2.01°C. The average temperature increase projected by all models for this month was 3.08°C. For September from 2020 to 2100, the models showed an average temperature increase of 3.04°C, with IPSL_CM5A_MR registering the highest expected temperature increase of 4.43°C and MRI_CGCM3 model the lowest at 1.91°C. IPSL_CM5A_MR had the highest temperature projections for October and November at 4.33°C and 4.13°C, respectively, with 2.94°C and 2.90°C average values. Although the lowest temperature increases had differences, the GFDL_ESM2G model predicted 2.6°C for October's lowest value, while GISS_E2_H recorded the lowest value of 2.16°C for November. December had the lowest monthly average projected temperature increase of 2.88°C. In the future, December would still be the coldest month in the study area, according to model analysis. The GFDL_CM3 model had the highest projection of temperature increase of 4.16°C, whereas the GISS_E2_H predicted the lowest temperature increase of 2.26°C. For both scenarios (SSP 4.5 and SSP 8.5), MIROC5 and CESM1_CAM5 models have not shown significant temperature fluctuations. However, the full monthly temperature increase was reported by the GFDL_CM3 model in both scenarios, with BCC_CSM1_1_M modeling the lowest temperature increases for many months in both

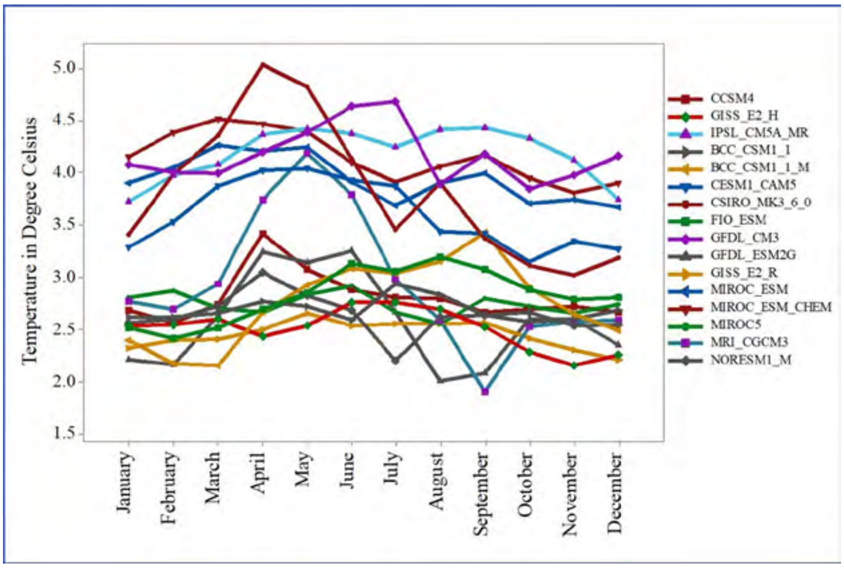

Fig. 12. Various models projected temperature increase for the Northern region (2020 to 2100) under SSP 8.5

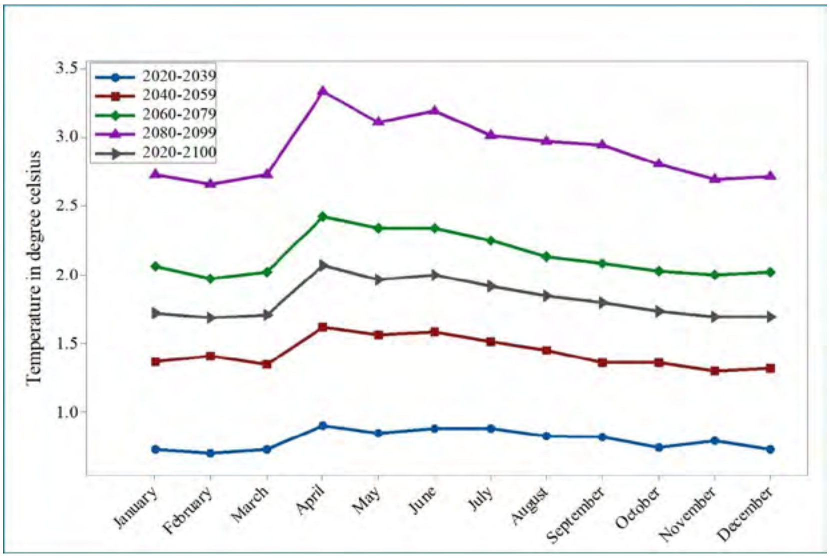

Fig.13. Projected monthly temperature variations for the different climatic periods under SSP 8.5 in the Northern region of Sri Lanka

cases. In SSP 4.5, the GFDL_CM3 model showed the highest temperature increase in the months, while BCC_CSM1_1, BCC_CSM1_1_M, and FIO_ESM models recorded the lowest temperatures for most of the months. For SSP 8.5, IPSL_CM5A_MR had the maximum number of months for the highest temperature increase. The projection models for climate change used in this study area showed variations in the monthly temperature fluctuation during different climatic periods.

Future Rainfall Changes of the Northern Region of Sri Lanka under SSP 4.5 Scenarios

There exist significant variations among the models pertaining to rainfall projections for the duration of 2020 to 2100 under the SSP 4.5 scenario, as mentioned in Fig. 14,15, 16, and 17. While the average ensemble projection for the increase of rainfall in the study area among all models is 106.19 mm, it is characterized by monthly variation across the said ensemble. For instance, the January ensemble depicts a increase from the current January average of 2.8mm. Nonetheless, there exists a decreasing trend in the monthly average rainfall projections from February to May. Thus, in this manner, February decreased by -1.07mm, March decreased by -3.3 mm, April decreased by -2.61 mm, and May decreased by -1.81mm. These months currently fall under the dry period category, and a reduction in rainfall in the future will only increase the drought situation in the study area. However, the models indicate that there will be an upward trend in rainfall post-June. Specifically, a 2.28 mm increase in June, a 14.5 mm increment in July, a 22.5 mm augmentation in August, and a 16.7 mm increase in September are projected. As per the SSP 4.5 scenarios' projection analysis, an intriguing revelation is that the SIMS and NEMS will be the wettest period akin to the present climatic condition, as the ensemble contends that there will be a 55 mm increment in these periods in the future. On the other hand, in October, the average monthly rainfall increased by 27.26 mm, November by 16 mm, and December by 12 mm, as per the models' projections.

The anticipated precipitation amounts between 2020 and 2100 exhibit variations across the models enlisted. The CSIRO_MK3_6_0 model predicts the highest increase in average annual rainfall, estimating the amount to be 342.76 mm, while the FIO_ESM model projects a negative value of -48.05 mm for the average annual rainfall . The projected increase in average rainfall for NORESM1_M is estimated to be 288 mm, while that for MIROC_ESM is anticipated as 269.5 mm and MIROC5 is projected as 249.88 mm. Similarly, the increase for MIROC_ESM_CHEM is predicted as 229.29 mm, and that for GFDL_ESM2G is estimated as 225.25 mm, whereas the increase for BCC_CSM1_1 is projected to be 184.38 mm, and BCC_CSM1_1_M reports an average increase of 190.04 mm. The model IPSL_CM5A_MR projects the lowest increase in the amount of average annual rainfall, valued at 2.85 mm, whereas increase in rainfall for GFDL_CM3 is projected to be 65.8 mm, projecting the lower average rainfall for the SSP 4.5 scenarios from 2020 to 2100.

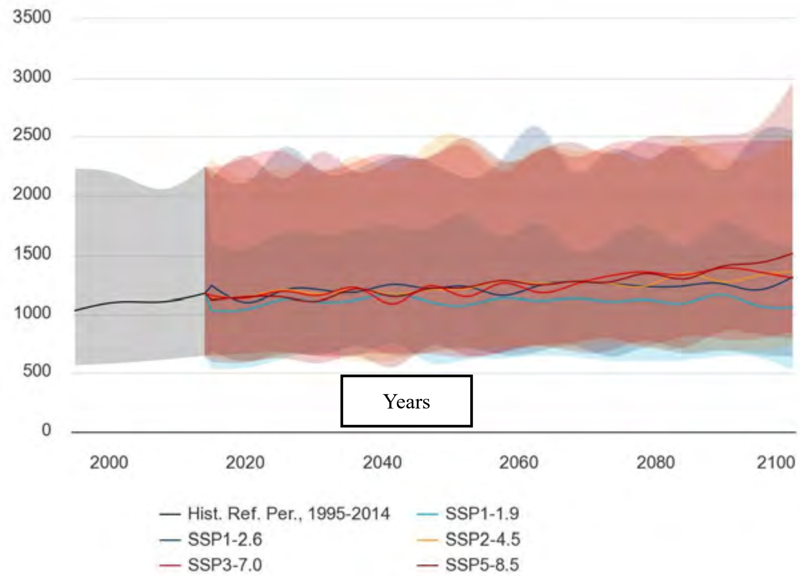

Fig.14. Multi-model ensemble projected rainfall for the period from 2020 to 2100 of the Northern Province of Sri Lanka under different SSPs.There are no big variations in the projected rainfall changes in different scenarios under different climatic periods.

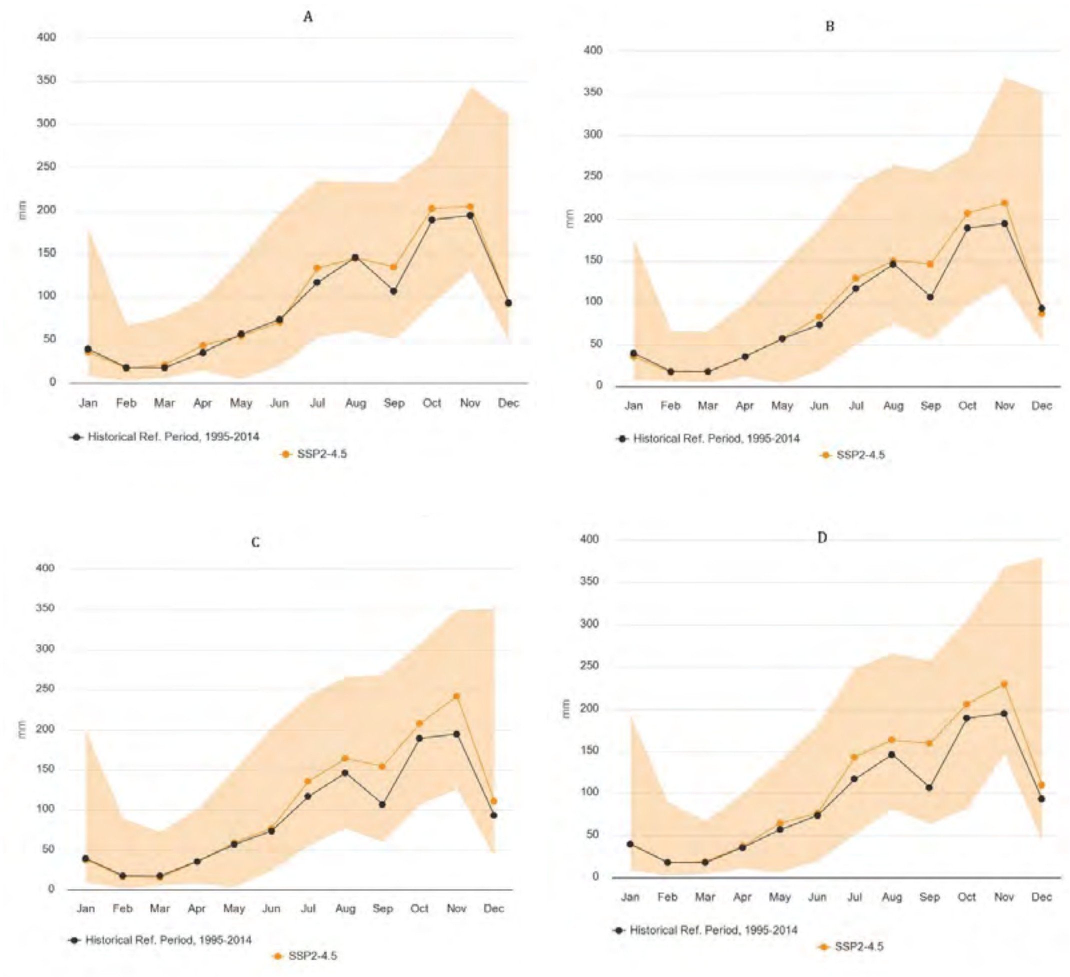

Fig. 15. Multi-model ensemble projected monthly rainfall total for the different climatic periods of the Northern Province of Sri Lanka under SSP4.5 (2020 to 2039, B-2040 to 2059, C-2060 to 2079, D-2080 to 2090). There are variations in the monthly pattern of rainfall in different climatic periods under SSP2-4.5.

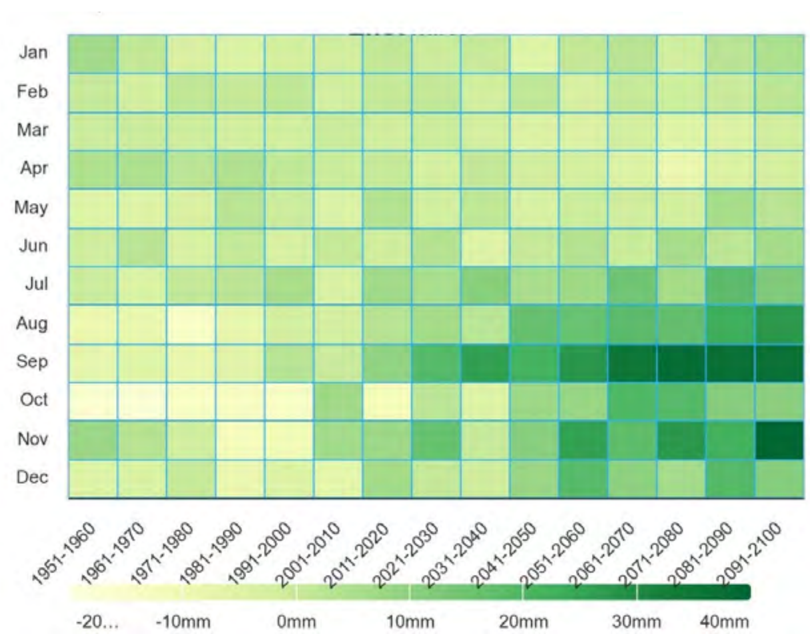

Fig. 16. Projected multi-model ensemble decadal monthly rainfall changes in the Northern Province of Sri Lanka from 2020 to 2100 under SSP4.5

The monthly mean rainfall throughout 2020 to 2100 varies across different models. In January, the projection of the highest increase in mean rainfall is 57.73 mm by the MIROC_ESM_CHEM model while the lowest has been forecasted as -37.15 mm by the IPSL_CM5A_MR model. In February, the GISS_E2_R model predicts an increase of 37.65 mm in the mean rainfall whereas the GFDL_ESM2G model projects a decrease of -18.91 mm. March depicts an increase of 17.08 mm in the mean monthly rainfall according to the GISS_E2_R model while the MRI_CGCM3 model forecasts a decrease of -23.57 mm. The majority of models predict a decrease in the mean monthly rainfall for April; notably, the BCC_CSM1_1_M model predicts a decrease of -67.81 mm. Few models predict an increase in the mean monthly rainfall for April, such as the BCC_CSM1_1_M model which predicts an increase of 93.6 mm whereas the GFDL_CM3 model predicts a decrease of 14.78 mm. The BCC_CSM1_1_M model predicts an increase in the mean monthly rainfall of 37.58 mm while the GISS_E2_H model predicts a decrease of -90.25 mm in June. In July, the BCC_CSM1_1_M model projects the highest rainfall of 39.29 mm whereas the FIO_ESM model projects the lowest, -24.41 mm. For August, all models except the FIO_ESM model predict an increase in the mean monthly rainfall while the BCC_CSM1_1 model places the highest projection at 88.82 mm. The CSIRO_MK3_6_0 model predicts the highest value for rainfall increase for October and December – 71.71 mm and 118.74 mm respectively. The NORESM1_M model projects the highest rainfall increase for December, 122.2 mm, while the MIROC5 model projects the lowest rainfall for October, -17.6 mm. The CESM1_CAM5 model predicts the lowest value of rainfall in November, 62.39 mm while the lowest value of the December month average is projected as -48.92mm by the CCSM4 model (Figures 16, 17, and 18).

Future Rainfall Changes in the Northern Region of Sri Lanka under SSP 8.5 scenarios

Fig. 19 and 20 illustrate the various projected rainfall changes in the study area for the period of 2020 to 2100 under the SSP 8.5 scenario in multi-models. On average, there is an expected increase of 159.46 mm of rainfall in the Northern region of Sri Lanka under the SSP 8.5 scenario across all models (Fig. 19 and 20). However, it is important to note that the ensemble average for this period is 13.28 mm, where there are variations in the monthly rainfall patterns. Under SSP 8.5, there is a decreasing monthly rainfall pattern observed between January to June. In particular, there is a decrease of -3.01mm, -6.01mm, -0.42mm, -6.11mm, 8.23mm, and 4.28mm in January, February, March, April, May, and June, respectively. When compared to the SSP 4.5 scenario, there is a decrease in the average rainfall for certain months. Conversely, the ensemble has an increasing trend in monthly rainfall from July to December. According to the ensemble average, July shows a significant increase of 16.34mm of monthly rainfall compared to July under SSP 4.5 scenarios. Moreover, there is an increase in

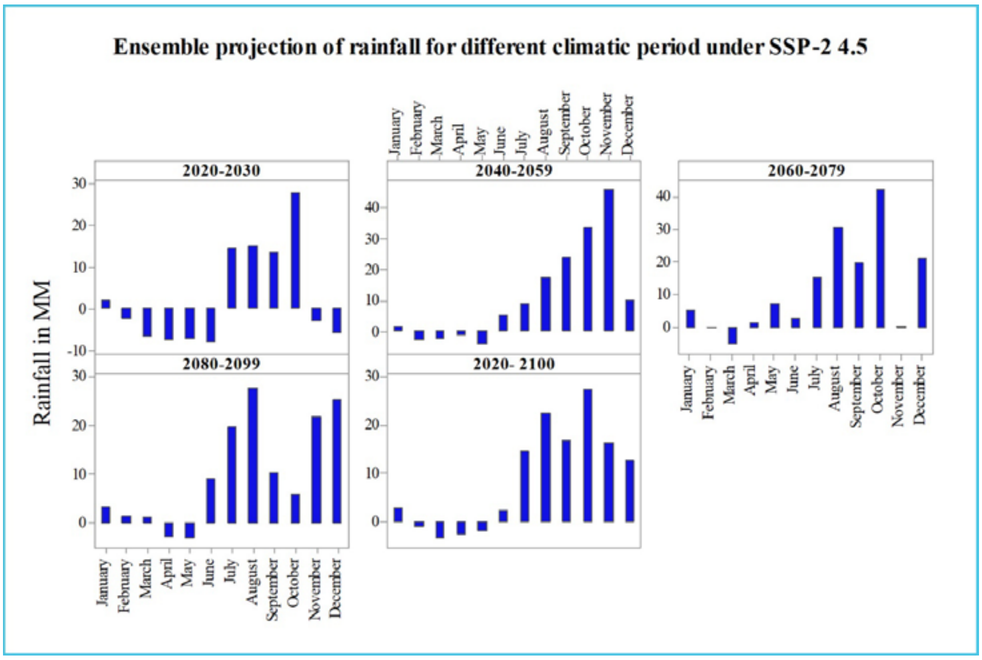

Fig. 17. Projected rainfall changes of Northern region in multi models for the period of 2020 to 2100 under SSP 4.5 scenario

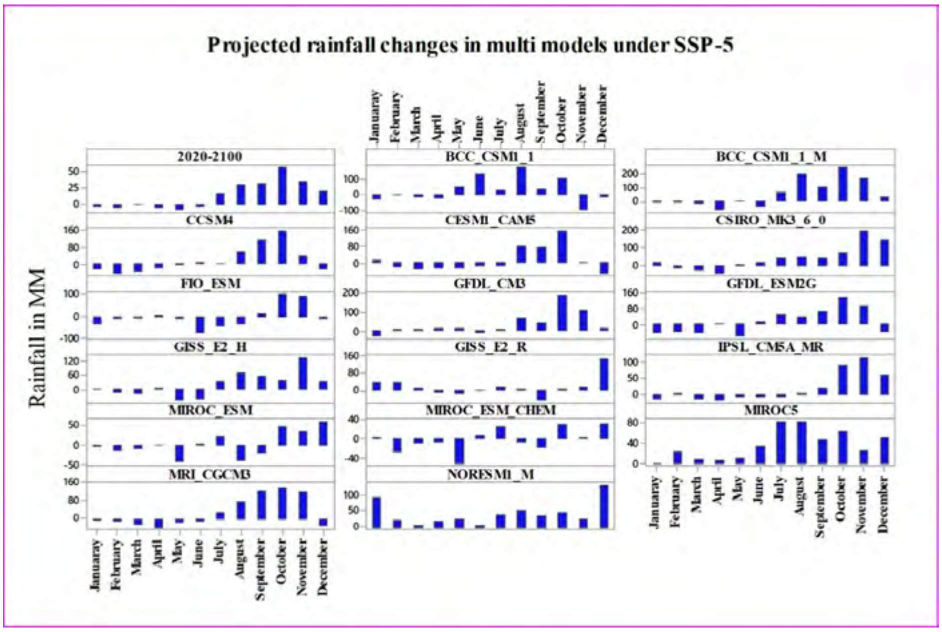

Fig. 18. Ensemble projected rainfall for a different climatic period of the Northern region of Sri Lanka under the SSP 4.5 scenario

monthly rainfall in the ensemble for August, September, October, November, and December. In particular, the ensemble average for August increases by 29.47 mm, and September shows an increase of 30.61mm in monthly rainfall under SSP 8.5 for the period of 2020 to 2100. Notably, the highest increase in the monthly projection for rainfall is observed in October with an increase of 56.57mm in the ensemble. November also shows an increase of 34.82mm, while December shows a smaller increase of 19.73mm.

The models projected variations in the average rainfall under the SSP 8.5 from 2020 to 2100. The

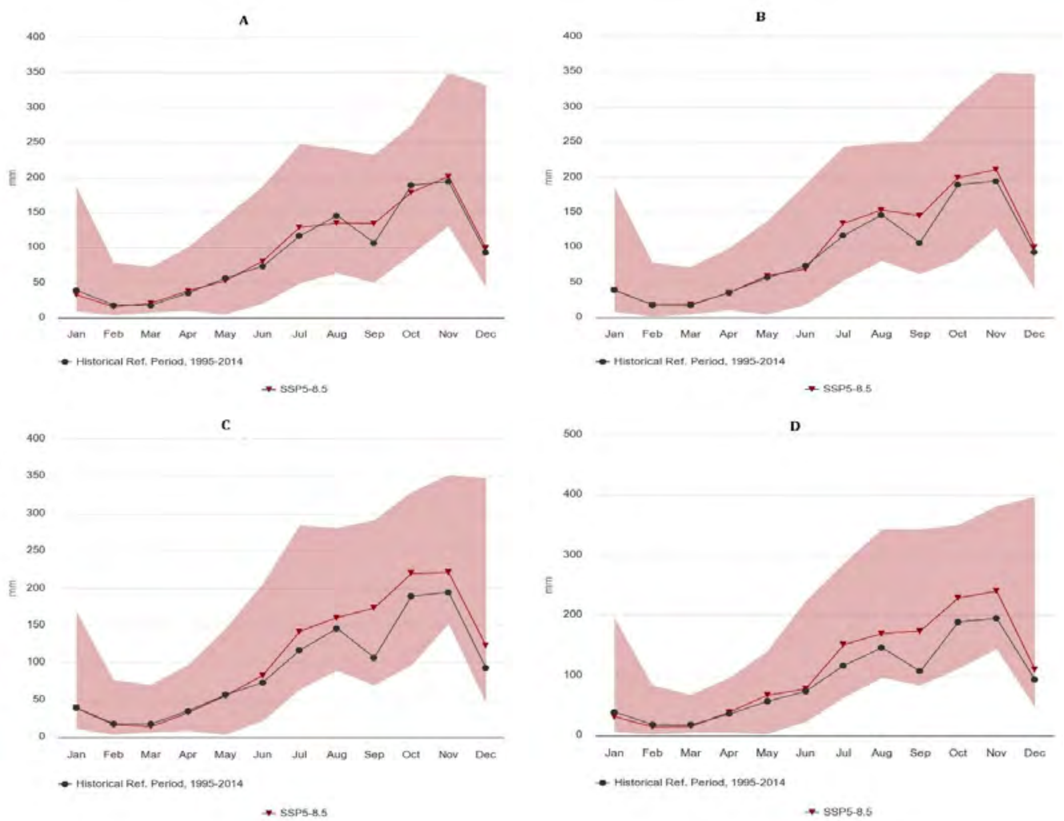

Fig. 19. Multi-model ensemble projected monthly rainfall total for the different climatic periods of the Northern Province of Sri Lanka under SSP8.5 (A-2020 to 2039, B-2040 to 2059, C-2060 to 2079, D- 2080 to 2090). There are variations in the monthly pattern of rainfall in different climatic periods under SSP5-8.5.

BCC_CSM1_1_M model projected the highest average value of 55.51mm, while FIO_ESM projected the lowest average value of -3.19mm. The NORESM1_M model projected an increase of 42.62mm, the CSIRO_MK3_6_0 model projected 41.34mm, and MIROC5 projected 36.01mm as the month-based average for the period of 2020 to 2100.

The models also projected variations in monthly rainfall patterns for the period of 2020 to 2100 under the SSP 8.5 scenario. The projections for January varied significantly between models, with the NORESM1_M model projecting the highest value of 95.36mm and the GFDL_ESM2G model projecting the lowest value of -43.08mm. For February, the GISS_E2_R model showed the highest value of 33.66mm, while the CCSM4 model showed the lowest value of -41.92mm. In March, the GISS_E2_R model predicted the highest rainfall increase (9.74mm), while the GFDL_ESM2G model predicted the greatest rainfall decrease (-42.05mm). The NORESM1_M model predicted the highest rainfall increase (17.95 mm) for April, while the BCC_CSM1_1_M model projected the lowest value (-60.54mm) of rainfall in April. For May, there is a great variation in the projected rainfall by the models, with the NORESM1_M model projected with the highest rainfall value of 24.73mm and the GFDL_ESM2G model showing the lowest value of -57.22mm. In June, there is a vast variation in the models, with the BCC_CSM1_1 model predicting the highest rainfall (132.07mm) and the FIO_ESM model predicting the lowest rainfall (76.91mm). In July, the BCC_CSM1_1_M model predicted the highest value of 61.61mm, while the FIO_ESM model projects the lowest rainfall value of -49.2mm. The projections for August vary between the models, with the BCC_CSM1_1_M having the highest value of 195.29mm, and MIROC_ESM having the lowest value of -37.93mm. The CCSM4 model projected the highest rainfall increase (115.14mm), while the GISS_E2_R model projected the lowest rainfall (-43.12mm) for September. For October, all models showed an increasing rainfall pattern, with the BCC_CSM1_1_M model projecting the highest value of 246.12mm and the GISS_E2_R model projecting the lowest value of 7.94mm. In November, the CSIRO_MK3_6_0 model predicted the highest value of 196.81mm, while the BCC_CSM1_1 model projected the lowest value of -95.79mm under the SSP 8.5 in the period of 2020 to 2100. Lastly, the CSIRO_MK3_6_0 model projected the highest value of 147.24mm, while the CESM1_CAM5 model projected the lowest value of -48.3mm under SSP 8.5 scenarios for December (Fig. 21).

The study has also identified the variations in projected rainfall under SSP 8.5 scenarios in the study area during different climatic periods. Fig. 4.63 illustrates the projected rainfall variations across these periods. The upcoming climatic period (2020 to 2050) presents varying climate change projections for the

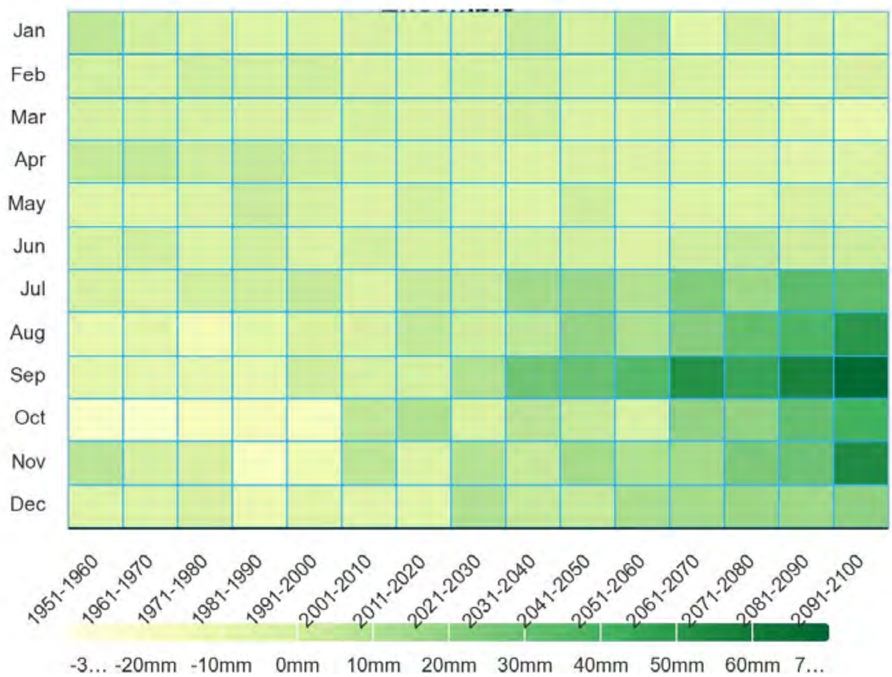

Fig. 20. Projected multi-model ensemble decadal monthly rainfall changes in the Northern Province of Sri Lanka from 2020 to 2100 under SSP4.5

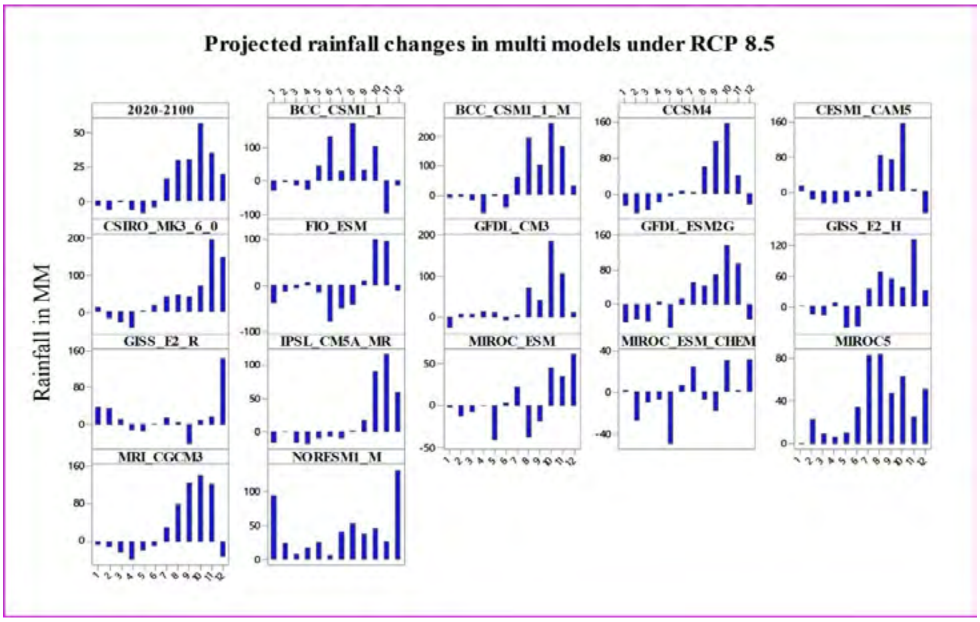

Fig. 21. Various models projected rainfall of the Northern region of Sri Lanka for the period from 2020 to 2100 under the SSP 8.5 scenario

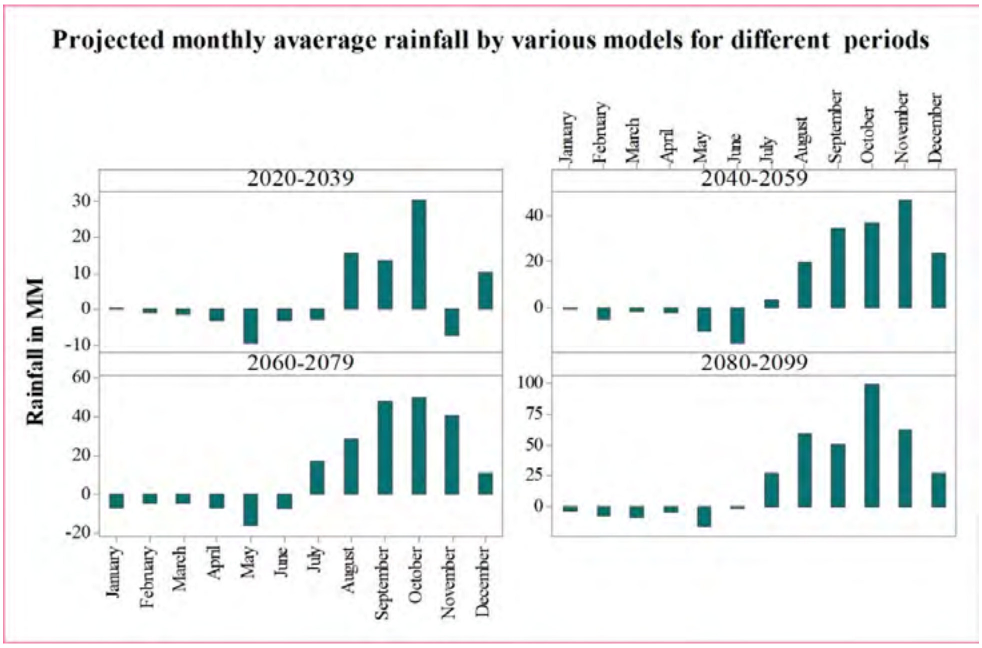

Fig. 22. Ensemble projected rainfall for a different climatic period of the Northern region of Sri Lanka under the SSP 8.5 scenario

Northern region of Sri Lanka, contingent on the SSP scenarios. This marks the initial analysis of the future climate change projections for the region under SSP 4.5 and SSP 8.5.

Discussion

Upon analysis of future climate change, every model has indicated varying temperature and rainfall values in the study area. Therefore, future climate change projections vary among each model and scenario. Regrettably, there is currently no existing research on the future climate change projection in the Northern region of Sri Lanka. Hence, the present study is the first piece of literature regarding the analysis of future patterns of climate change in the area. While most studies on climate change in Sri Lanka have been based on earlier scenarios such as A1, A2, B1 & B2, there have been very few studies done with new scenarios such as SSP 4.5 and SSP 8.5. (Thennakone, 2018) Despite some similarities with the results of earlier studies, the current study explores new scenarios, resulting in different seasonal and monthly basis values.

Concerning temperature analysis, all models in this study show identical results to previous studies related to climate change in Sri Lanka. However, seasonal and monthly basis values display differences. For instance, De Costa, (2012)indicated that temperatures would increase by 0.6°C in the future, varying for each climatic period. Furthermore, other studies have shown different values for temperature projections, with some presenting high increases and others low increases, depending on the season and month (Basnayake et al., 2021; Shanthi De Silva, 2016).

Regarding rainfall projections as future climate change, there are no similarities between this study and other studies. Every study displays different rainfall changes annually, seasonally, and monthly. Additionally, ensemble values also vary, and few studies indicate an increased value, while others show low values in rainfall changes. The impact of climate change on surface water is adverse. The high evaporation rates have greatly decreased the water levels and availability, and high runoff rates have likewise affected water levels, water availability, flood vulnerability, and drought in the study area. Unfortunately, research about climate change's impact on surface water resources in Sri Lanka has shown similar results (Withanachchi et al., 2014; Rajendram, Gunewardena & Rajendram, 2017). Studies such as Bonjean Stanton et al., (2016), Alahacoon & Edirisinghe, (2021), and Weerasinghe et al., (2018) reveal that the authors' water sources' evaporation rates directly affect water resources when studying future climate change. Based on the analysis of future rainfall and temperature, an interesting fact is that the study area projects an increase in both temperature and precipitation under the SSP 4.5 and 8.5 scenarios.

The analysis of climate change is indicative of significant outcomes in this study. Notably, several crucial alterations have been identified in the area under survey, consistent with other studies that revealed comparable trends in different parts of the world(De Silva & Hornberger, 2019; Shanthi de Silva, 2014; Basnayake et al., 2021; Naveendrakumar et al., 2018). According to the report of national agencies assessing climate change, the temperature increase of 0.81 °C from 1901 to 2019 is considered a baseline and acceptable definition of changes in Sri Lanka's climate (Eriyagama, N., Smakhtin, V., Chandrapala, L. and Fernando, 2010). Furthermore, the current research found that the temperature change in the Northern region of Sri Lanka corresponds to the national average of 0.84 °C, with similar seasonal temperature fluctuations observed in other areas. The study further identified a temperature increase of 0.96 °C in the SWMS, likewise observed in other studies (Chandrasekara et al., 2013; Weerasinghe et al., 2018;ADB, 2022; Kaklauskas et al., 2018; G. De Silva & SB, 2015). Nevertheless, there are considerable variations in monthly temperature changes observed in our study compared to others. Specifically, reports from June to September, differ from other studies that indicate different values of temperature changes. Although previous studies indicated substantive temperature increments in the country's monthly mean, daily maximum and minimum vary. Altogether, there are distinctive differences recorded in the daily mean and overall annual changes in temperature experienced in various parts of Sri Lanka (Somasundaram et al., 2020; Naveendrakumar et al., 2018; Piratheeparajah, 2010; ADB, 2022; Hettiarachchi, 2015).

The current study has divulged a transformation in the seasonal rainfall trend that signifies a shift in the pattern. The NEMS' power is dwindling, and SWMS' contribution to the total rainfall in the study area is on the increase. The majority of climate change studies conducted in Sri Lanka reflect significant changes in the amount of seasonal rainfall. According to the country's observed climate change, certain parts of Sri Lanka have experienced a increase in seasonal rainfall, whereas others have undergone a decrease in rainfall. In particular, some studies conducted by (Eriyagama, Smakhtin, Chandrapala, and Fernando, (2010), Praveen et al., (2020), Guruge, (2017) Makubura et al., (2022), Alahacoon & Edirisinghe, (2021)report a decline in rainfall during SWMS. However, the present study demonstrates growth in rainfall patterns during the SWMS. Furthermore, numerous other studies have prompted the possibility of an alteration in the spatial distribution of rainfall, although a discernible pattern has not yet emerged (Weerasinghe et al., 2018; Makubura et al., 2022; G. De Silva & SB, 2015; Hettiarachchi, 2015; Alahacoon & Edirisinghe, 2021a). Nevertheless, many researchers agree that the variability of rainfall has increased over time, particularly during the Yala season

Currently, there exist certain studies that suggest that the evaporation rate within the study area has increased due to the rising temperature. If the temperature continues to increase in the future, it will lead to a further augmentation of the evaporation pattern. At present, several areas within the study area, including Manthai West, Nanaddan, Musali, Manthai East, Thunukkai, Cheddikula, Velanai, Kyts, Delft, Karainagar, and selected areas within the Karaichchi Divisional Secretariat Division are afflicted with a severe water scarcity problem during the South West Monsoon Season because of temperature spikes, which are associated with a higher rate of evaporation. If temperatures climb higher in the future, it will exacerbate the water scarcity and drought problem during this season. The model projections suggest that during the SWMS months, the temperature will continue to increase; thus, it will have a serious effect on water resources and people, further compounding their struggles to obtain water for household and consumption purposes. Additionally, during the months from mid-November to mid-December, some of the low-lying areas in the study area tend to face floods during the North-East Monsoon season. If the rainfall during the November-December months increases, it would negatively impact the people living in these low-lying areas of the study area.

Conclusions

The predicted temperature and rainfall patterns in the Northern Province of Sri Lanka reveal a significant upward trend across various SSPs and climatic periods. The multimodal ensemble predicts varying degrees of temperature and rainfall increases in the study area, with different models projecting different values between 2020 and 2100. The study finds that, under SSP 4.5, temperatures are expected to increase by 1.13°C and rainfall by 106.9mm; while under SSP 8.5, temperatures will increase by 1.81°C and rainfall by 159.46mm. Given that temperature is a primary weather element that affects other weather conditions, these changes are expected to have far-reaching impacts on the physical, economic, and social structures of the study area, potentially leading to extreme weather events that disrupt day-to-day life. With human survival dependent on these two weather parameters, studying their future patterns is crucial in promoting sustainable development in the Northern Province of Sri Lanka.

As the region is identified as particularly vulnerable to the effects of climate change, it is incumbent upon us to take immediate action to mitigate these impacts. This requires prioritizing the development of sustainable strategies to reduce our carbon footprint and enhance our resilience to a changing climate. To this end, we must take a comprehensive and proactive approach that recognizes the unique environmental and socio-economic factors of the region. Key among these must be the implementation of sustainable and low-emission agricultural practices, the development of infrastructure to manage water resources and protect coastal ecosystems, and effective and transparent governance of natural resources. We must also promote public awareness and engage communities to confront the realities of climate change. Only by taking collective action can we hope to safeguard the region's environment, protect vulnerable communities, and ensure a sustainable future for generations to come.

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