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RESEARCH REPORT

Regional climate analysis over Sri Lanka

Bibhuti Sharan Keshav, Mohana S. Thota, Raghavendra Ashrit

May 2024

National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
A-50, Sector-62, NOIDA-201 309, INDIA

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10	References	10
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सारांश

यह रिपोर्ट 1951 से 2020 तक फैले सीआरयू टीएस (जलवायु अनुसंधान इकाई ग्रिडेड टाइमसीरीज) संस्करण 4.07 डेटा का उपयोग करते हुए श्रीलंका भर में मौलिक वायुमंडलीय चर, जैसे वर्षा और सतह के तापमान (टीमैक्स और टीमिन) से संबंधित जलवायु विश्लेषण का एक संक्षिप्त अवलोकन प्रस्तुत करती है। श्रीलंका का आकार छोटा होने के बावजूद वर्षा और तापमान के परिमाण में काफी स्थानिक और लौकिक भिन्नताएँ मौजूद हैं। देश में दो प्राथमिक मानसून मौसम (मई से सितंबर और दिसंबर से फरवरी) और दो अंतर-मानसून मौसम (मार्च-अप्रैल और अक्टूबर-नवंबर) का अनुभव होता है, प्रत्येक मौसम अलग-अलग वर्षा और तापमान पैटर्न में योगदान देता है। अंतर-मानसून सीज़न के दौरान, वर्षा आमतौर पर बंगाल की खाड़ी के ऊपर अभिसरण, संवहन और अवसाद से प्रेरित होती है। अत्यधिक वर्षा मुख्य रूप से निकटवर्ती समुद्री क्षेत्रों में उष्णकटिबंधीय चक्रवातों और उष्णकटिबंधीय निचले इलाकों के कारण होती है। सबसे अधिक वार्षिक औसत वर्षा श्रीलंका के दक्षिण-पश्चिम क्षेत्र में दक्षिण-पश्चिम मानसून (एसडब्ल्यूएम) सीज़न के दौरान होती है, जबकि पूर्वोत्तर क्षेत्र मुख्य रूप से पूर्वोत्तर मानसून (एनईएम) से प्रभावित होता है। श्रीलंका में किसी भी मौसम में वर्षा में कोई स्पष्ट वृद्धि या कमी का रुझान नहीं देखा गया है। मासिक वर्षा विश्लेषण से सितंबर में उल्लेखनीय वृद्धि की प्रवृत्ति और अप्रैल में उल्लेखनीय कमी की प्रवृत्ति का पता चलता है। अध्ययन अवधि के दौरान अधिकतम और न्यूनतम दोनों तापमानों में समग्र वार्मिंग प्रवृत्ति देखी गई है। दिन का तापमान अप्रैल में चरम पर होता है, जबकि रात का तापमान दिसंबर और जनवरी के दौरान अपने न्यूनतम स्तर पर पहुंच जाता है। टीमिन में वार्मिंग की प्रवृत्ति को सभी मौसमों में रात के तापमान में वृद्धि के लिए जिम्मेदार ठहराया जा सकता है।

Abstract

This report presents a concise overview of the climate analyses concerning fundamental atmospheric variables, such as rainfall and surface temperatures (Tmax and Tmin), across Sri Lanka utilizing CRU TS (Climate research unit gridded timeseries) version 4.07 data spanning from 1951 to 2020. Despite Sri Lanka's small size, there exist considerable spatial and temporal variations in the magnitudes of rainfall and temperatures. The country experiences two primary monsoon seasons (May to September and December to February) and two inter-monsoon seasons (March-April and October-November), each contributing to varying rainfall and temperature patterns. During inter-monsoon seasons, rainfall is typically induced by convergence, convection, and depressions over the Bay of Bengal. Extreme rainfalls are primarily attributed to tropical cyclones and tropical lows in the adjacent oceanic regions. The highest annual mean rainfall occurs during the Southwest Monsoon (SWM) season in the southwest region of Sri Lanka, while the northeastern region is primarily influenced by the Northeast Monsoon (NEM). No discernible increasing or decreasing trends in rainfall have been observed in any season over Sri Lanka. Monthly rainfall analysis reveals a noteworthy increasing trend in September and a significant decreasing trend in April. An overall warming trend is noted in both maximum and minimum temperatures throughout the study period. Daytime temperatures peak in April, while nighttime temperatures reach their minimum during December and January. The warming trend in Tmin may be attributed to elevated nighttime temperatures across all seasons.

1. Introduction

A complete understanding of the weather extremes over a country is important because these events affect the social and economic states of the country. Sri Lanka is one of the largest islands situated in the Indian Ocean which is located in proximity to the equator and surrounded by the Bay of Bengal (BoB) and the Indian Ocean. The country is vulnerable to extreme rainfall events and exhibits a diverse climatic profile, encompassing four climatic zones (Alahacoon and Edirisinghe (2021)) which is shown in figure 1 are described below:-

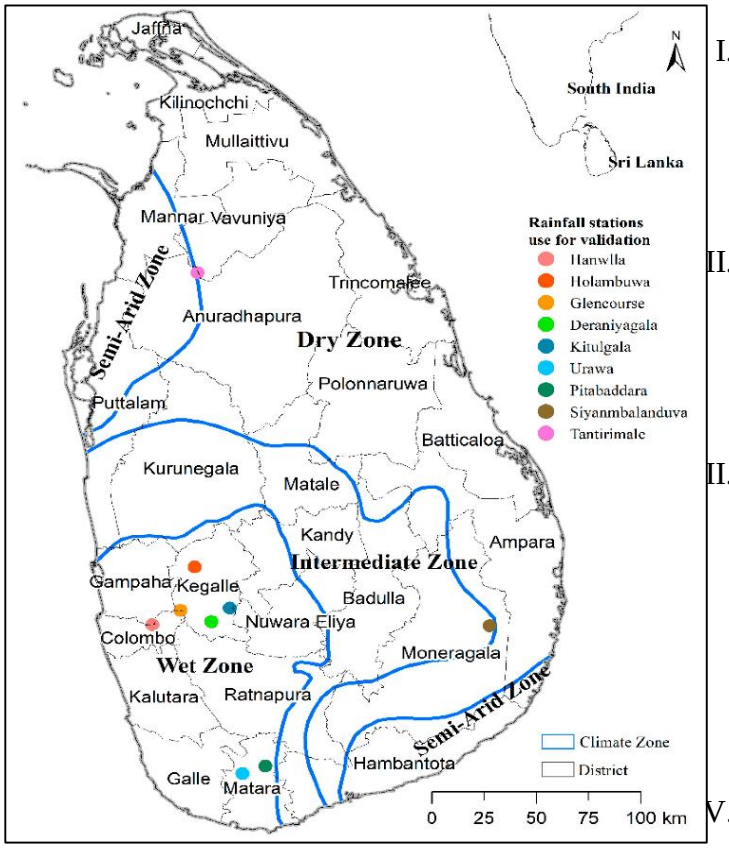

Figure 1 : Different climatic zones over Sri Lanka (from Alahacoon and Edirisinghe 2021)

I. **Wet zone**- This zone is located in the western part of the mountainous region which receives an annual rainfall of approximately 2500 mm and well known for its lush vegetation and high humidity.

II. **Intermediate zone**- This zone is bridging the realm of the wet and dry zone which experiences moderate rainfall and manifest a transitional climate, combination of both wet and dry regions.

II. **Dry zone**- This zone receives annual rainfall ranging from 1200 to 1900 mm and mainly influenced predominantly by the northeast monsoon. It strikes a balance between the lushness of the wet zone and the aridity of the semi-arid zone, offering a unique climatic character.

V. **Semi-arid zone**- This zone is extending along the northwestern and southeastern coasts of the country and receives annual rainfall between 800 to 1200 mm and characterized by drier conditions and lower vegetation cover compared to other zones.

This division of Sri Lanka into these climatic zones showcases the complex interplay of geographical features and meteorological influences, contributing to the country's ecological richness and climatic diversity. The rainfall is extremely varying spatially as discussed above and at the same time highly depends upon different seasons and months.

The country experiences two distinct monsoon seasons, spanning from May to September (SWM-South West Monsoon season) and December to February (NEM- North East Monsoon season), as well as two inter-monsoon periods in March-April (MA), known as first inter-monsoon (FIM) season and October-November (ON), known as second inter-monsoon (SIM) season, all contributing to varying precipitation levels. The rainfall patterns over Sri Lanka is highly varying seasonally as well as spatially as heavy rainfall during SWM and NEM seasons occurs in south-western and north-eastern regions of Sri Lanka respectively (Thevakaran et al 2019). Apart from these two core monsoon seasons, the country receives intense rainfall also during two inter-monsoon seasons in which precipitation is primarily influenced by the convergence, convection, and depressions occurring over the Bay of Bengal. Extreme rainfall events in Sri Lanka caused by tropical cyclones and tropical lows in the nearby oceanic regions of the country results in inundation in low lying areas. This report highlights the spatial and temporal rainfall climatology and trends over Sri Lankan region during 1951 to 2020.

Furthermore, this report touches upon surface temperatures (Tmax and Tmin), a detailed exploration of temperature variations across Sri Lanka region. Sri Lanka is undergoing a noticeable warming trend, evident in the consistent raise of both maximum (Tmax) and minimum (Tmin) temperatures across the most weather stations (Naveendrakumar et al 2018). Particularly noteworthy is the highest increase in daily Tmax, predominantly occurring in October, with a significant uptick observed in at least 75% of the stations. The wind effects during the SWM season may induce occasional decreases in Tmax, particularly in the month of May. Daily Tmin consistently exhibits an increasing trend, with the most pronounced trends emerging during the SWM season (May to September). The projected rise in nighttime temperatures contributes significantly to the overall increase in Tmin, aligning with broader global temperature trends.

BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) Centre for weather and climate (BCWC) is an important component of Ministry of Earth Sciences (MoES). The Government of India's BCWC actively collaborates with BIMSTEC nations, organizing annual workshops and training programs to build disaster management capacity and engages in weekly online discussions with scientists from member countries. Collaborative research focuses on developing and improving weather and climate prediction models and enhancing early warning capabilities. Under capacity building, efforts include training programs, workshops, fellowship initiatives, and international conferences to showcase advancements in weather and climate information for the BIMSTEC region.

The first section of this report is an introduction continued with data and methodology in the second section. Results are discussed in section 3, summary in section 4, future works in section 5 and references in section 6.

2. Data and Methodology:

Monthly precipitation, Tmax and Tmin data from CRU4.07 (Climate Research Unit version 4.07) of 0.5°×0.5° horizontal resolution from 1951 to 2020 are used in the climate analysis over Sri Lanka. The dataset is globally available covering land areas excluding Antarctica. However, for this study, data has been specifically extracted from the region of Sri Lanka, bounded by coordinates 5.5°N to 10°N latitude and 79.5°E to 82°E longitude. A complete details of CRU dataset can be found in the Harris et al (2020). The monthly, seasonal and annual timeseries data of rainfall, Tmax and Tmin over Sri Lanka are also available at CRU and using directly in the analysis. The monthly precipitation data are summed to find the seasonal and annual total precipitation for respective months and monthly temperature data are averaged to find the seasonal and annual Tmax and Tmin profiles. The group of months for different seasons are considered based on the works of literatures available at the Meteorological Department of Sri Lanka (Jayakodi 2015; Naveendrakumar et al 2018) which is described in the introduction. The mean, standard deviation (coefficient of variation for rainfall) and trends are calculated monthly, seasonally and annually to investigate the regional climate information over Sri Lanka. Slopes and trends are calculated and tested using non-parametric Mann-Kendall (MK) test and significance is tested at 95% significance level.

3. Results

(I)Precipitation

(a) Annual

The country Sri Lanka is prone to extreme rainfall events throughout the years because it receives rainfall in both the monsoon seasons SWM and NEM as well as in the two of the inter-monsoon seasons all over the climatic zones as discussed in the introduction. During inter-monsoon seasons, tropical cyclones and lows formed in the BoB brings enormous rainfall to the country. Climatology of annual accumulated precipitation, coefficient of variation (CoV) and timeseries over Sri Lanka is shown in the figure 2. Figure 2a indicates a significant amount of precipitation across various parts of the country, with a notable concentration in the southern regions. Maximum precipitation around 2600 mm per year is observed over the south-western region where

precipitation is caused due to south west monsoon and tropical lows and tropical cyclones formed in the BoB. The second maximum rainfall around 1700 mm per year is received over north-eastern region which is caused by north east monsoon. The northern part of the country receives comparatively less rainfall. Even though the size of Sri Lanka is small, the spatial differences in the magnitude of precipitation are not consistent. The high amount of precipitation over different regions of Sri Lanka is highly varying over the years as well as spatially. The amount of rainfall varies more than 1000 mm over a distance of few hundreds kilometers. Figure 2b shows that the CoV of annual precipitation over Sri Lanka in the south eastern region shows maximum variation in the precipitation of about 20% whereas western regions have comparatively less variability which goes up to 16% for some parts. The northern regions have also high variability where the annual rainfall is comparatively less. The variations in annual rainfall increase when moving from western coast to the eastern coast of Sri Lanka. Few stations in Sri Lanka show a significant decreasing trend in daily rainfall from 1961 to 2015 because of delayed south west monsoon (Naveendrakumar et al 2018). However, the timeseries of weighted mean annual precipitation over Sri Lanka doesn't show a significant decreasing trend when tested with the Mann-Kendall (MK) test at 95% significance level which is shown in the figure 2c.

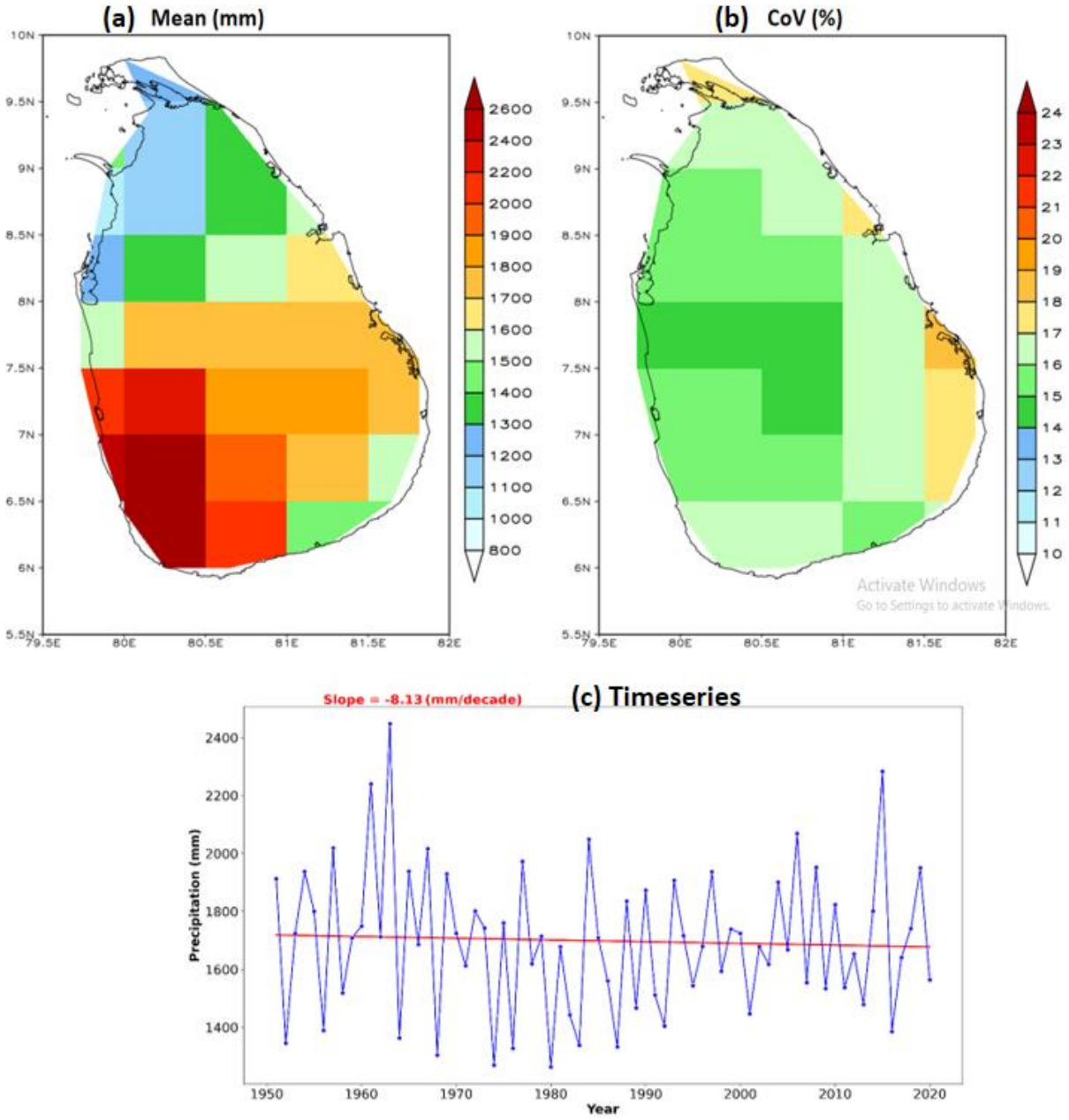

Figure 2 Climatology of annual accumulated precipitation, coefficient of variation and timeseries with trend line over Sri Lanka from 1951 to 2020 (Unit- mm)

(b) Seasonal

There is considerable variation in the total annual precipitation in Sri Lanka, which is attributed to four distinct seasons, each contributing significant amounts of rainfall throughout the year. All four seasons are taken into account in this study to analyze the seasonal variations in

rainfall. Rainfall from different months are summed for respective seasons to find the seasonal rainfall over different seasons and the spatial distribution of annual mean rainfall during these four seasons is given in figure 3. The highest amount of rainfall during the south west monsoon season over the south western regions (fig 3b) which falls under wet zone and least amount of rainfall during the first inter-monsoon season are received (fig 3a) over the country which is in accordance with some of the previous studies. During the second inter-monsoon season, high amount of rainfall is received throughout the country because of tropical cyclones and tropical lows formed in the BoB in the post-monsoon season. Dry zone receives good amount of rainfall during the NEM season. Residuals of the SWM over BoB is the primary reason behind the formation of these low pressure areas during the post monsoon seasons which bring enormous rainfall during SIM season. The coefficient of variation in the seasonal rainfall is given in Figure 4 which shows that annual variation in seasonal rainfall is maximum during the first inter-monsoon season over the northern parts of Sri Lanka (fig 4a). Minimum variation is observed during the second inter-monsoon season which is shown in figure 4c. The variations in rainfall is less over the regions where the mean annual rainfall is greater and vice versa for instance southern regions show lesser variations in annual mean rainfall than northern regions of the country.

The spatial distribution of trends of seasonal rainfall for different seasons is given in figure 5. No coherent increasing or decreasing trends are seen in the rainfall during the period of consideration. Trends are highly varying during the seasons. The figure 5 shows that negative trends over entire country during FIM (fig 5a) and NEM seasons (fig 5b) with minimum over eastern part of country whereas positive trends during SWM (fig 5c) and SIM seasons (fig 5d), but do not find any region with significant trend when tested with the MK test at 95% significance level. The time series of seasonal rainfall over Sri Lanka is given in the figure 6 which shows increasing trend during SWM (fig 6b) and SIM (fig 6c) seasons and decreasing trend during NEM (fig 6d) and FIM (fig 6a) seasons however these trends do not show significance with MK test at 95% confidence level.

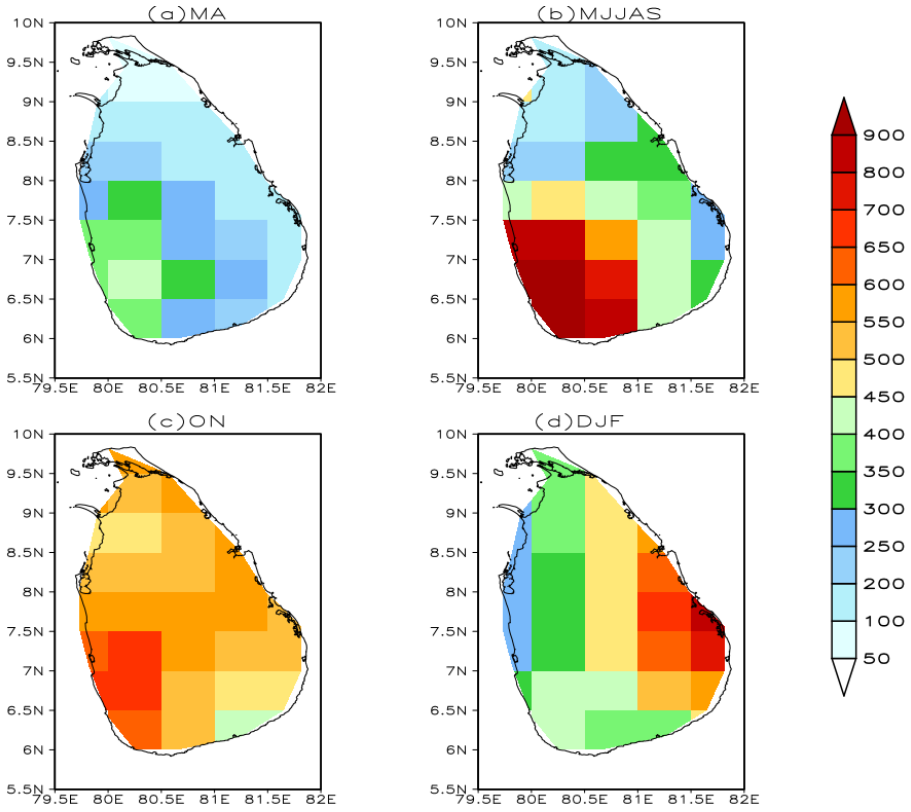

Figure 3 Climatology of seasonal precipitation from 1951 to 2020. (Unit- mm)

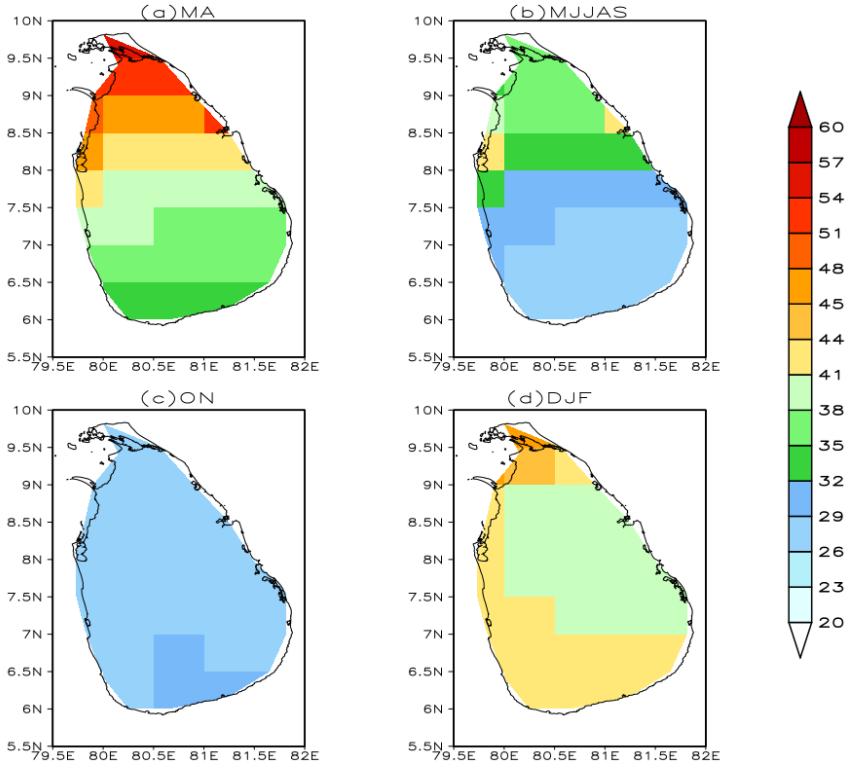

Figure 4 Seasonal coefficient of variation in percentage of seasonal precipitation.

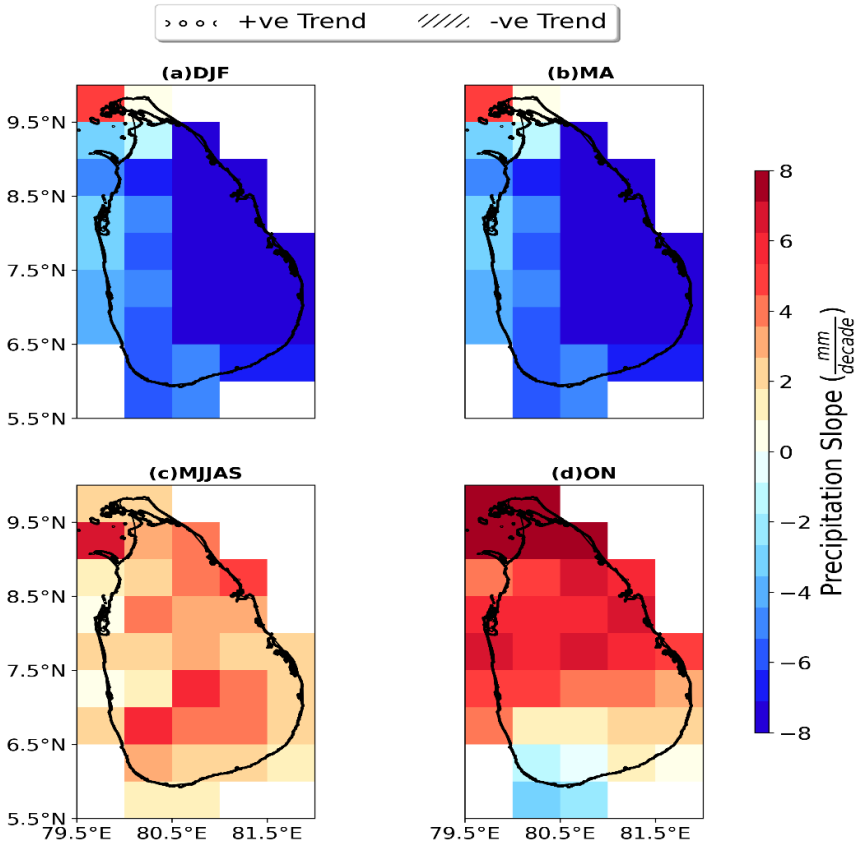

Figure 5 seasonal trend of annual precipitation from 1951 to 2020.

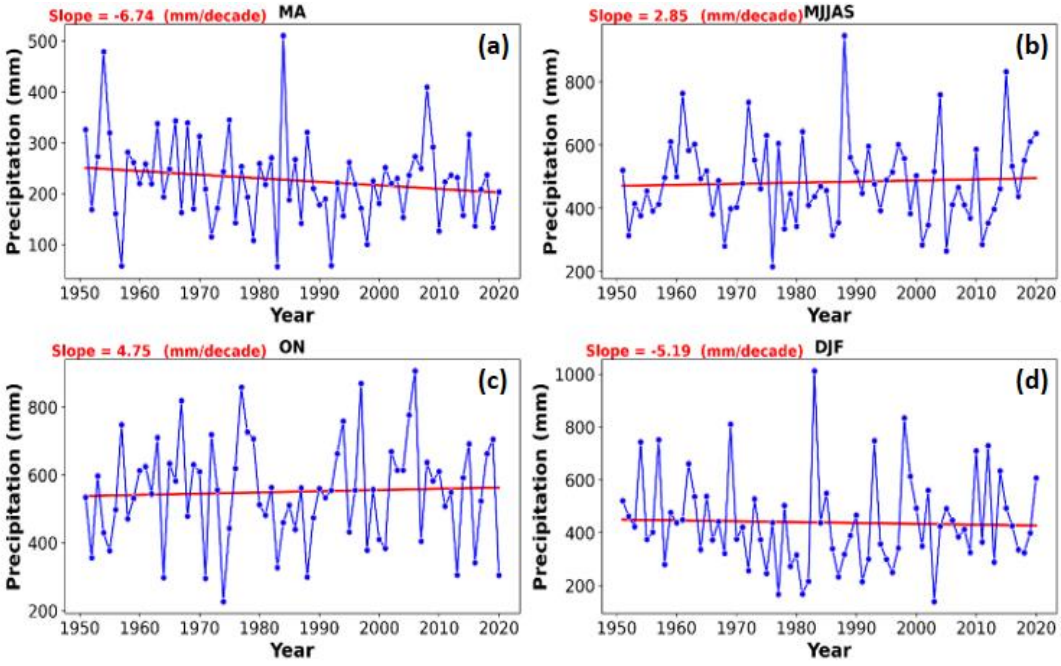

Figure 6 Timeseries of annual precipitation for different seasons.

(c) Monthly

The annual mean and coefficient of variations of precipitation for different months are given in figures 7 and 8 respectively. Figure 7 shows that annual mean of monthly precipitation is highest during the month of November where climatological mean precipitation is around 300 mm over the whole country. During the month of December and January, more rainfall is observed over the eastern part of the country when the north east monsoon is active over this region. From April to October, more rainfall is received over south-western part of the country when the south east monsoon is active and in the post monsoon season, tropical lows and cyclones in BoB bring extreme rainfall over these regions. Least variations around 40% in monthly rainfall is observed during October and November which can be seen in figure 8. Figures 8a and 8c show that some regions in the northern part of the country have highest variations in rainfall up to 100% during January to March months. When moving from north to south, the variations in the rainfall decrease and comparatively less over the regions where climatological mean rainfall is generally higher.

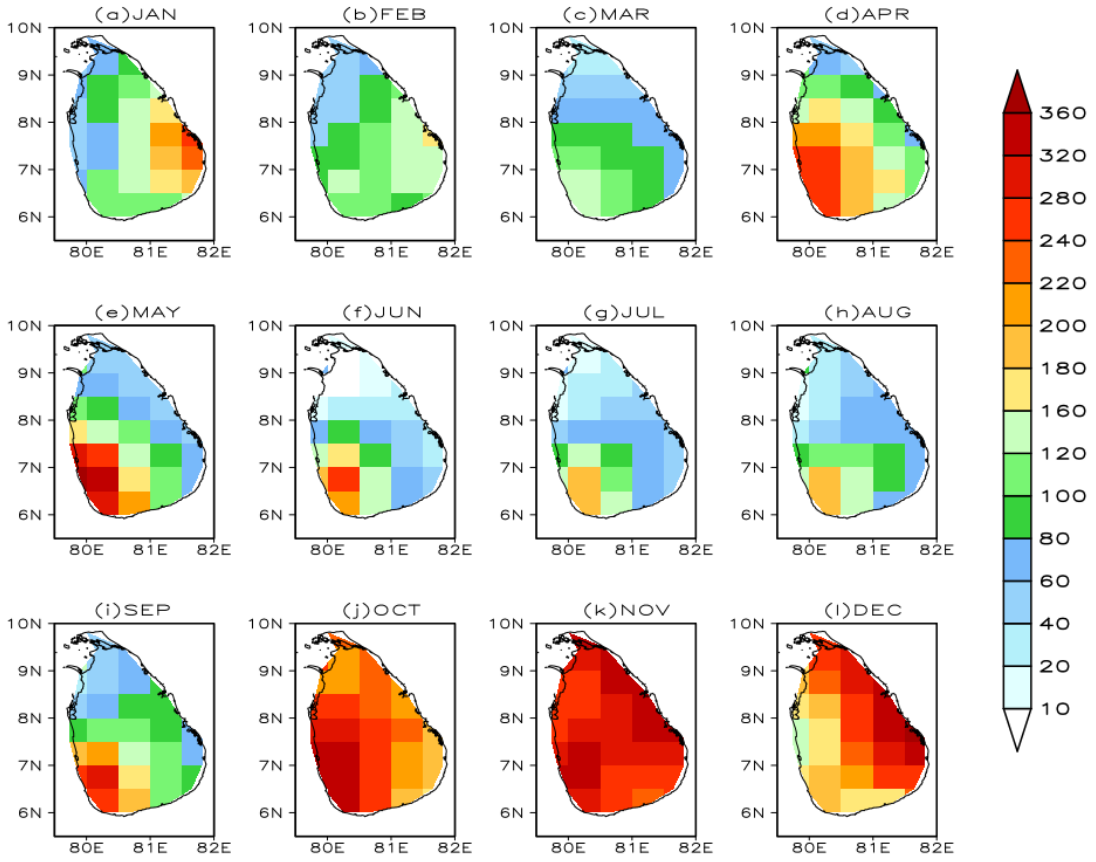

Figure 7 Spatial maps of monthly precipitation climatology from 1951 to 2020 in mm.

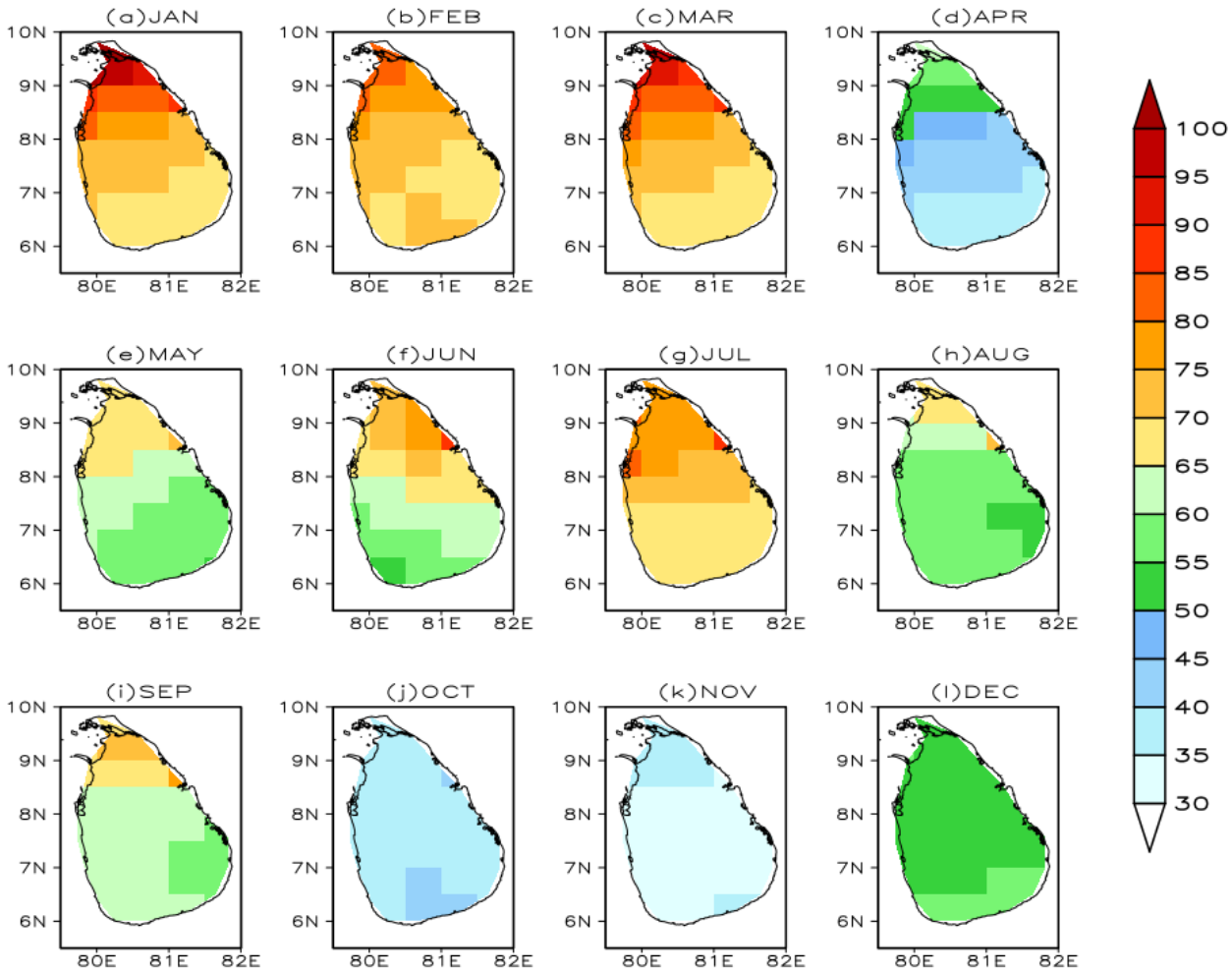

Figure 8 CoV in percentage of annual mean precipitation for different months from 1951 to 2020

The spatial distribution of trends of monthly precipitation and timeseries are given in figures 9 and 10 respectively. The monthly spatial trends given in the figure 9 shows negative during January to July and October and positive during August-September, November and December. Some regions in the central part of Sri Lanka show significant negative trends during April. South central and eastern regions show significant positive trends during September. These results are reflected in the monthly timeseries given in the figure 10 where significant negative and positive trends are observed during April and September respectively at 95% significance level.

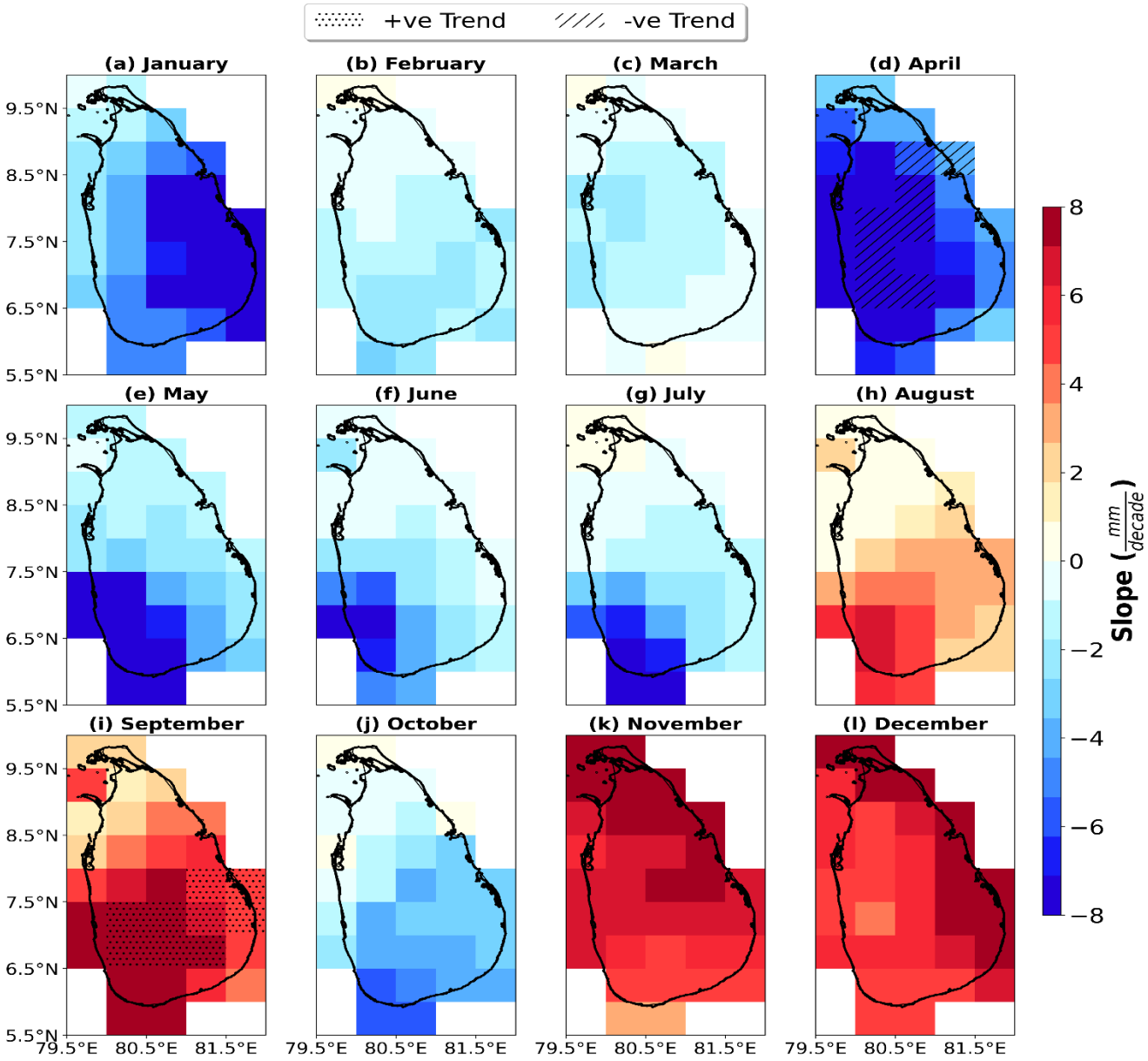

Figure 9 Trends of monthly precipitation from 1951 to 2020. The regions with significant trends are highlighted with dots (positive) and hatching lines (negative) at 95% significance level of MK test.

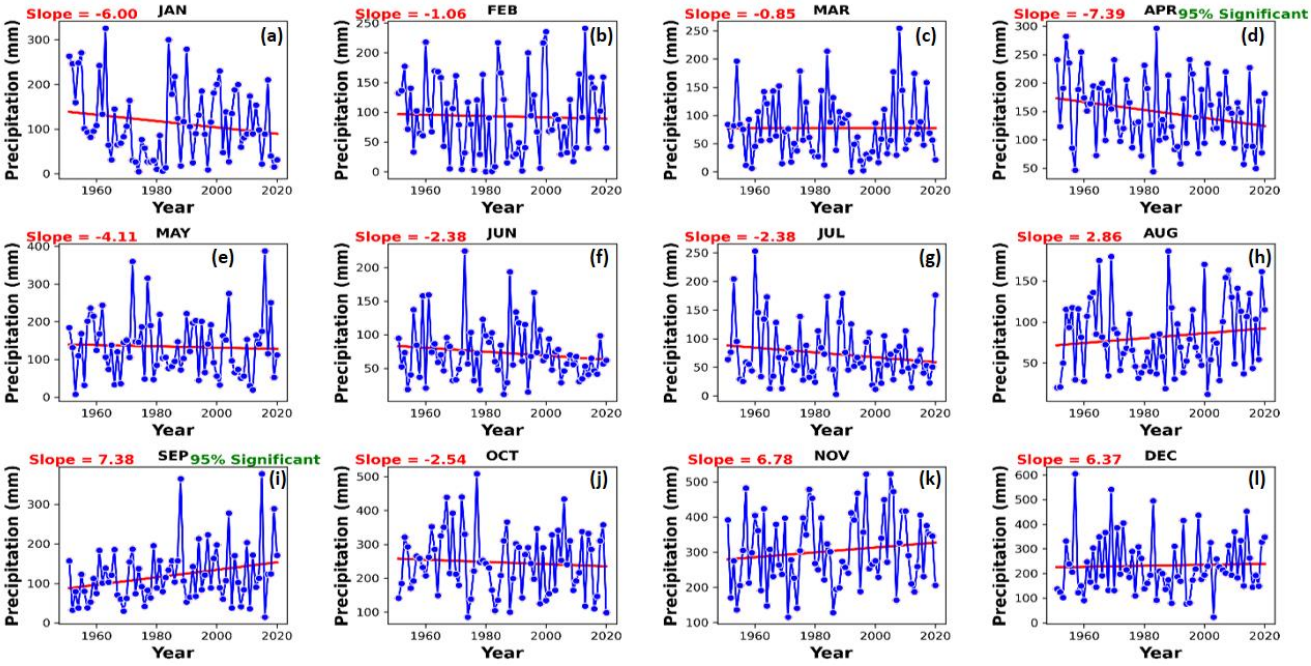

Figure 10 Timeseries of monthly precipitation along with trend line from 1951 to 2020

(II) Maximum Temperature (Tmax)

This section elaborates on spatial and temporal variations of maximum temperature over Sri Lanka from 1951 to 2020. The section is further classified into annual, seasonal and monthly analyses to explain the spatial distribution of mean and trends of maximum temperature for different season and month separately.

(a) Annual

The annual climatology, standard deviation (SD) and timeseries along with trend line of maximum temperature is shown in figure 11. The figure shows that northern regions have higher temperatures of about 30^{o}C to 32^{o}C than southern part of the country where the temperature regime is between 26^{o}Cand 30^{o}C. Some part of the southern central regions has the lowest maximum temperature of about 26^{o}C. The spatial variation of about 6^{o}C is observed over the country. In addition to the spatial variation, the maximum temperature has temporal variation as well which is also shown in figure 11b. The northern part has more variability than the southern part but variation is less and the SD goes up to 0.5 ^{o}C. There is a shallow gradient in the SD of maximum temperature when moving from north to south in Sri Lanka. Maximum temperature over Sri Lanka has significant increasing trend when tested with Mann-Kendall test at 95% significance level from

1951 to 2020 which is clearly shown in the figure 11c. The annual mean maximum temperature raised more than 1^{o}C in the mentioned time frame. These warming trends of Tmax is found in most of the temperature related investigations in Sri Lanka (Zubair et al 2005; Chandrapala 1996; De Costa 2010).

(b) Seasonal

The annual mean of maximum temperatures is further classified into different seasons to see the spatial distribution of seasonal mean temperature over different regions of the country which is shown in the figure 12. Figure 12 shows that in the FIM season, Tmax is about 35^{o}C in the western region, 28^{o}C in south central region and in the rest of the country Tmax varies from 28^{o}C to 30^{o}C. During SWM season Tmax is increased up to 35^{o}C over north eastern part where annual mean rainfall is less and Tmax is reduced up to 27^{o}C over south western region where annual mean rainfall is maximum for this season. Similarly, during SIM season the south region where annual mean rainfall is higher having lesser Tmax over that region and the rest of the country has comparatively higher temperature. During NEM season when the climatological rainfall is more show lesser Tmax over eastern region and higher Tmax over some parts of western regions of Sri Lanka.

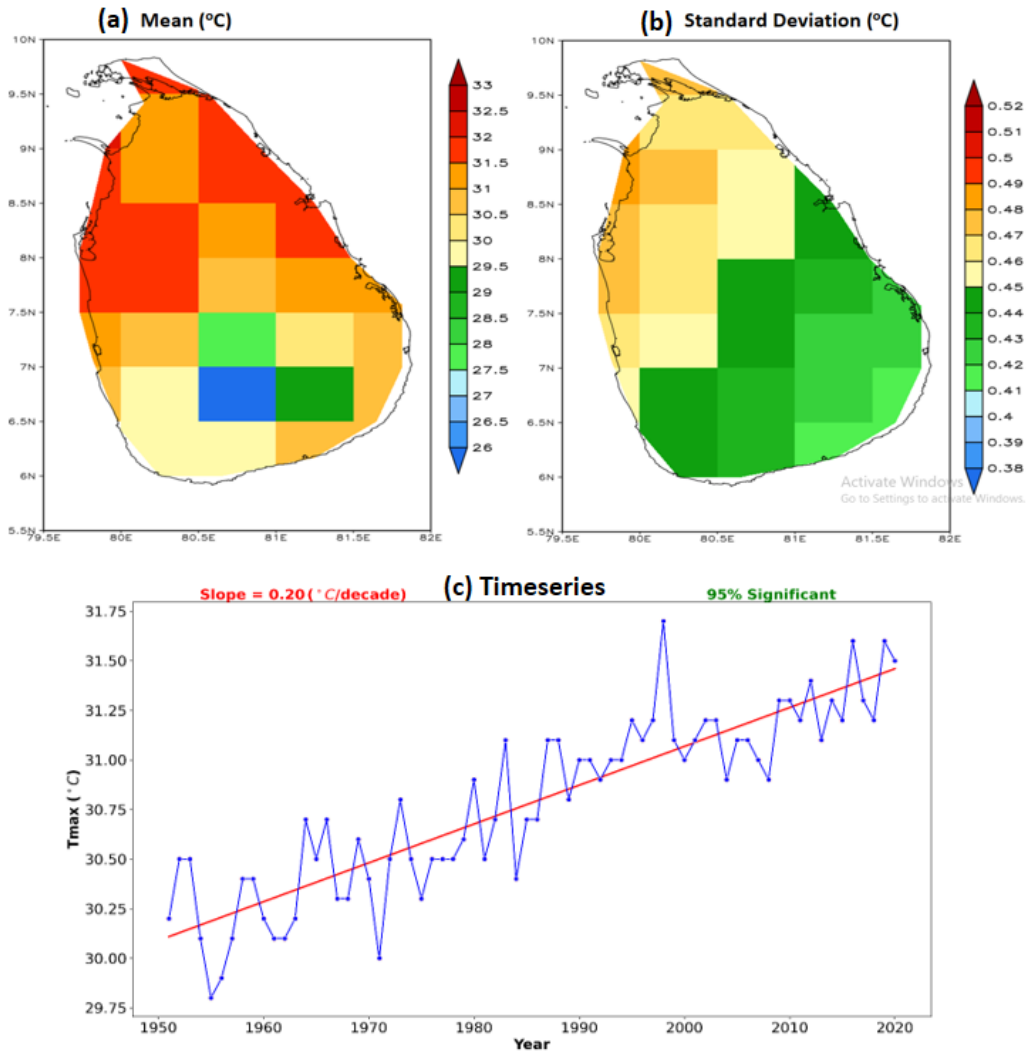

Figure 11 Annual climatology, standard deviation and timeseries along with trend line of Tmax (maximum temperature) over Sri Lanka from 1951 to 2020

The SD of maximum temperature is varying from 0.4 ^{o}C to 0.6 ^{o}C over the country for different seasons which is shown in the figure 13. From the figure it is observed that within a season, northern regions have higher variations from the mean than the southern regions. FIM season shows highest SD of about 0.62 ^{o}C over north eastern region whereas south eastern regions have the least variations during SWM and SIM seasons. The spatial variation of seasonal mean SD of Tmax is lowest at about 0.42^{o}C during the NEM season. The latitudinal variation in the SD of Tmax is more than the longitudinal variation i.e. moving from west to east. It is also observed that the coastal regions show more extremes i.e. variations in Tmax than the central regions. The reasons could be because of coastal areas are more vulnerable to the ocean impacts during extreme weather events like depressions formed over BoB.

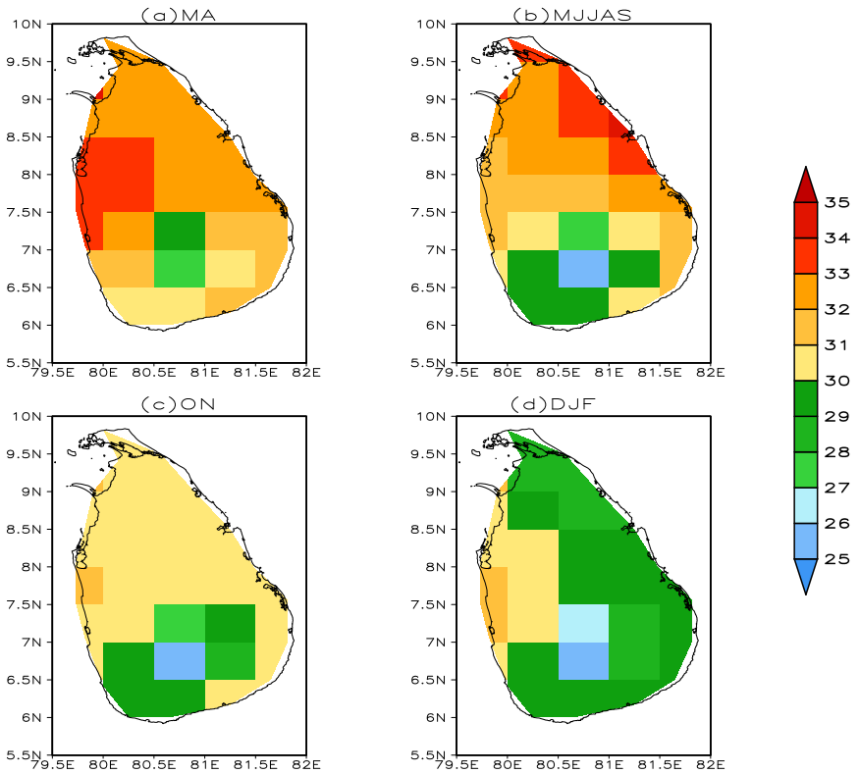

Figure 12 Annual mean of seasonal mean Tmax from 1951 to 2020 (*In ^{o}C)*

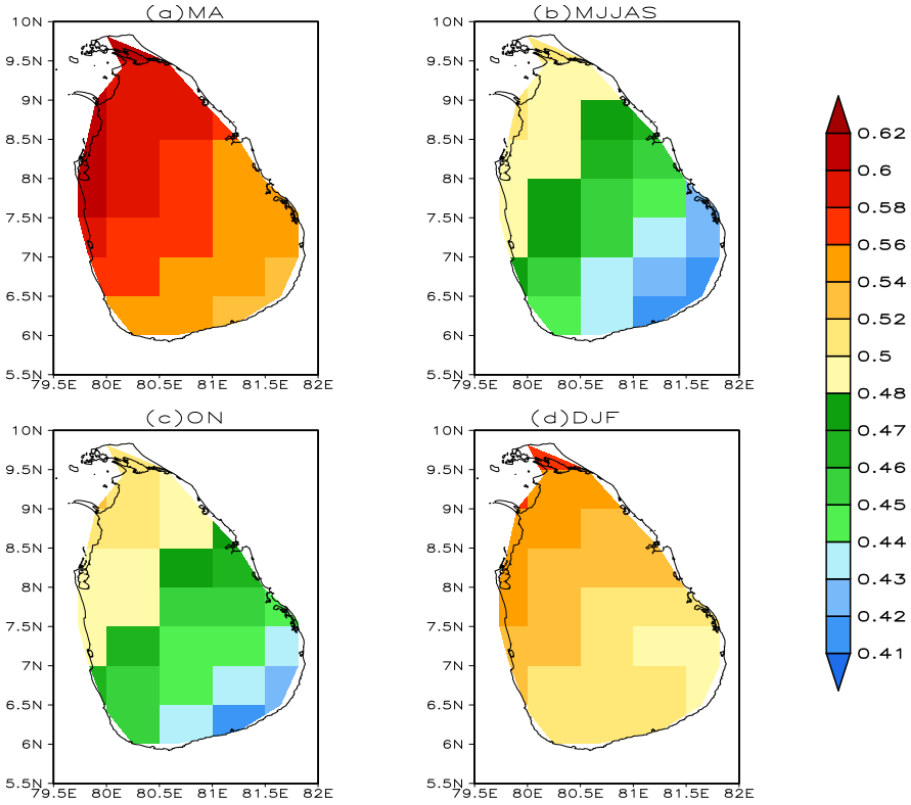

Figure 13 Annual SD of seasonal mean Tmax from 1951 to 2020 (In ^{o}C)

The timeseries of Tmax for different seasons is given in the figure 14. The spatial distribution of slopes obtained from MK test shows significant trends throughout the country in all four seasons with maximum slope of 0.3^{o}C per decade during NEM and FIM seasons (figure not shown). Some of the studies based on Sri Lankan temperature showed that most of the regions of the country have significant increasing trends in all the seasons (Naveendrakumar et al 2018). Figure 14 shows that the trend line of Tmax has significant increasing trend in all the seasons at 95% confidence level. The increasing slope of Tmax is maximum about 0.2 ^{o}C per decade during the FIM and NEM seasons and minimum of 0.18 ^{o}C per decade during the FIM season.

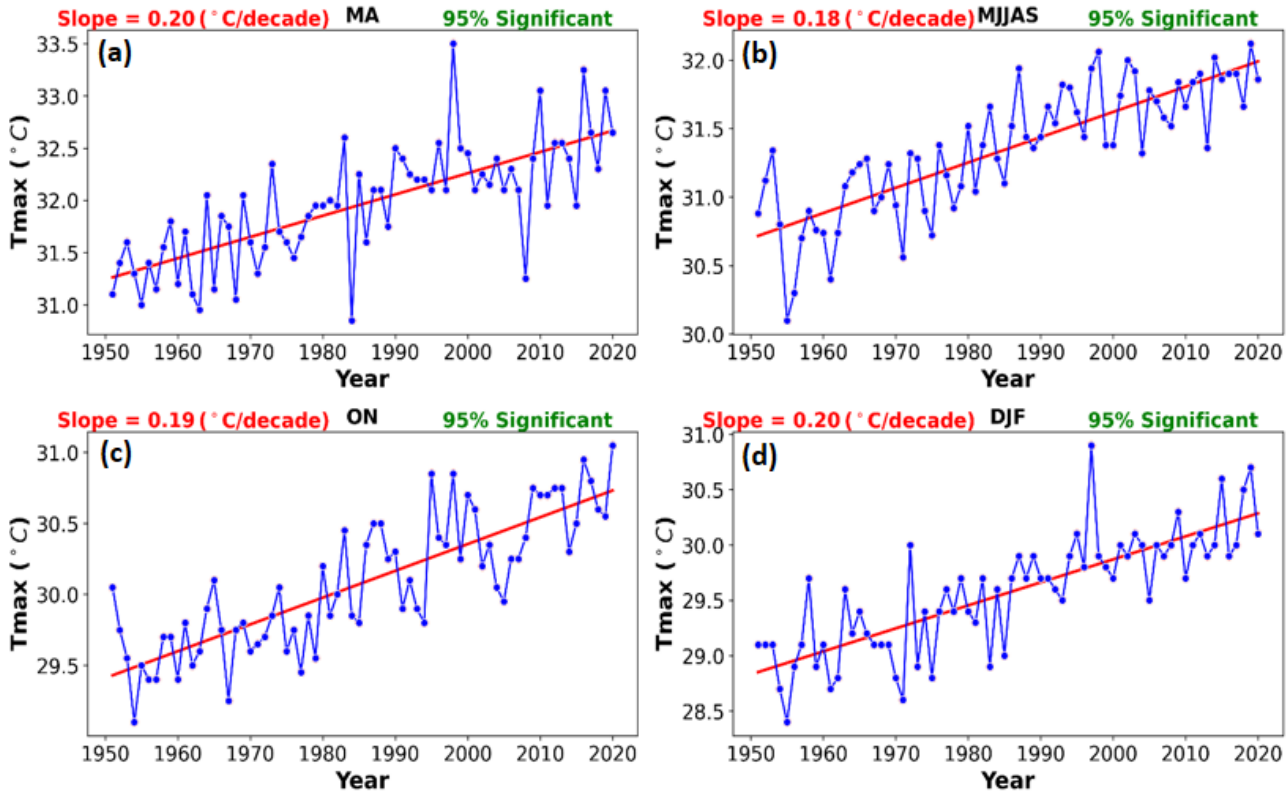

Figure 14 Timeseries (blue) and trend line (red) of seasonal Tmax from 1951 to 2020

(c) Monthly Tmax

The seasonal variations do not give a clear picture of Tmax, therefore it is further classified into different months to analyze the annual mean monthly Tmax over different regions of Sri Lanka which is given in figure 15. Tmax varies from 32^{o}C to 35^{o}C over northern part of the country during April to September. A small region within the south central region has least Tmax around 22^{o}C to 26^{o}C during every month. The eastern region has Tmax around 35^{o}C during March. Tmax gradient across the latitudes is higher than the

gradient of Tmax across the longitudes. The standard deviation of Tmax from the mean during each month is shown in figure 16. The figure shows that a maximum SD of about 0.7 ^{o}C is observed over north eastern regions in February to June. Whereas during the months of August to December the variations in the Tmax from the mean is less around 0.52^{o}C however these values are very low. Latitudinal variation in Tmax is very high during the January.

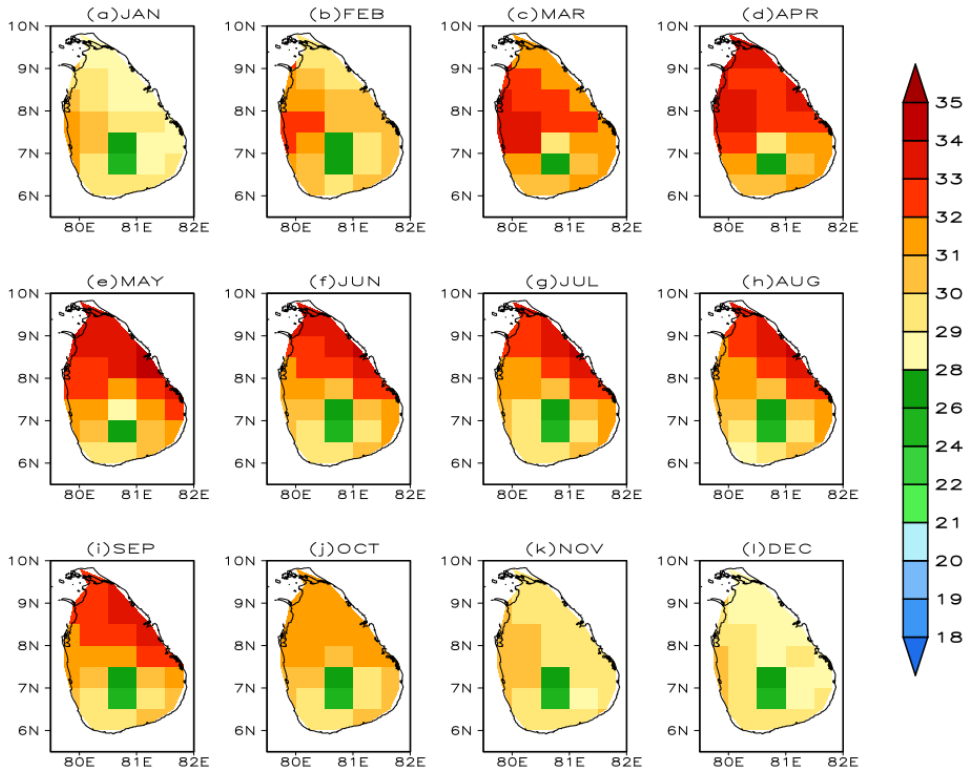

Figure 15 Spatial pattern of annual climatology of Tmax from 1951 to 2020

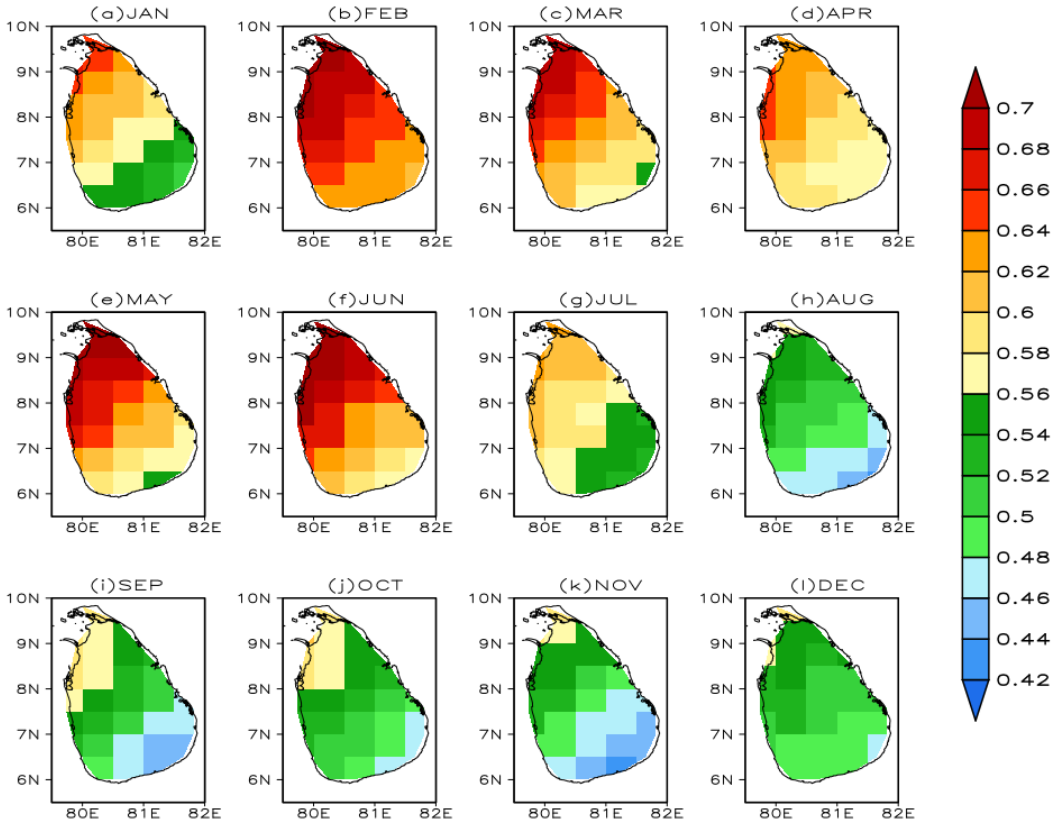

Figure 16 Standard deviation of annual Tmax from 1951 to 2020

The spatial distribution of slope shows positive values across Sri Lanka with significant increasing trends at 95% significance level in each of the month (figure not shown). The increasing slope of Tmax is higher about 0.3ºC per decade during January to April and July. Slopes during May-June and August to December are comparatively low about 0.1ºC to 0.2ºC per decade. During the months of SWM season, although there is a significant increasing trend but the low slopes might be due to monsoonal winds over Sri Lanka. There are not much spatial variations in the increasing slopes observed within a month. In all the months except April more than 50% of the stations in Sri Lanka experienced significant increasing trends in Tmax (Naveendrakumar et al 2018) which is reflected in the current study also. The timeseries of monthly Tmax over Sri Lanka is shown in figure 17, which explains that in each of the months, Tmax has a significant positive trend throughout with a maximum slope 0.24 ºC per decade and a minimum slope 0.15 ºC per decade during the months of February and September respectively.

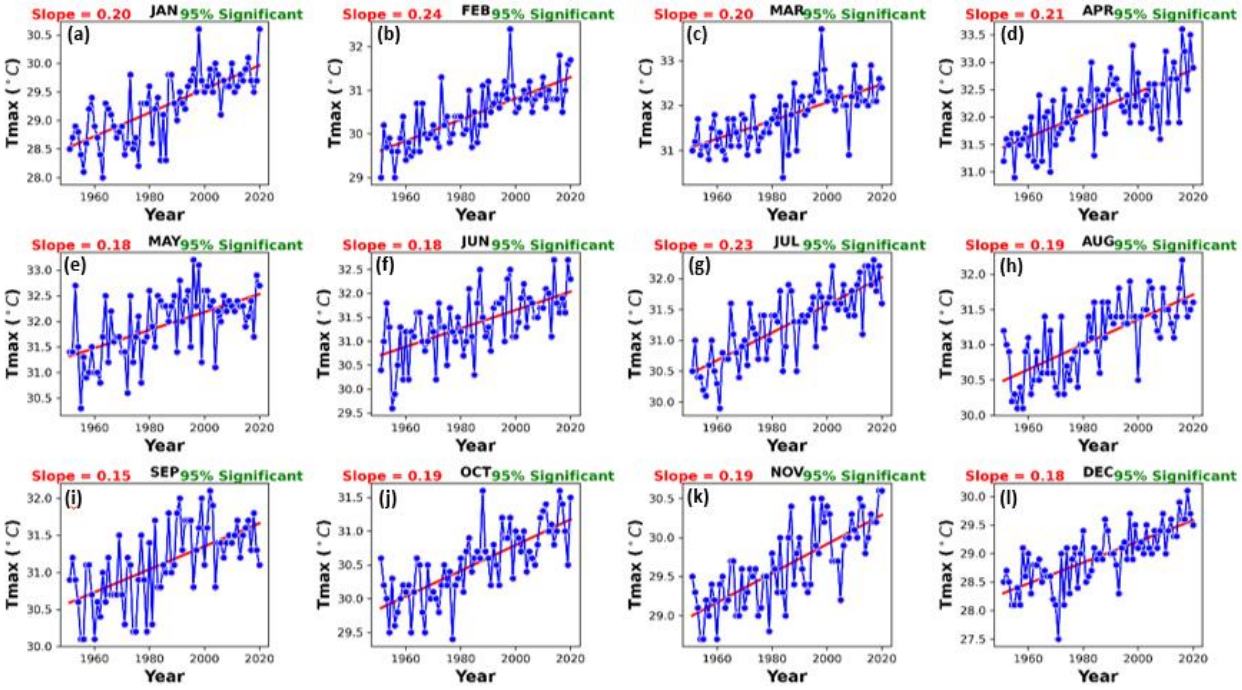

Figure 17 Timeseries of monthly Tmax (blue) along with linear trend line (red) from 1951 to 2020 (Unit of slope- oC per decade)

(III) Minimum temperature (Tmin)

This section elaborates about spatial and temporal variations of minimum temperature over Sri Lanka. The analysis is based on the classification of Tmin into annual, seasonal and monthly data to explain the spatial distribution of Tmin for different seasons and months separately.

(a) Annual

The climatological mean, standard deviation and timeseries of annual mean minimum temperature (Tmin) over Sri Lanka is shown in the figure 18 which shows that Tmin is high, about 25^{o}C over the northern region of Sri Lanka and less, about 19 ^{o}C over some parts of the south central region. South eastern and western coastal regions have Tmin around 23^{o}C to 24.5^{o}C where annual mean rainfall is generally higher. The north-south gradient of Tmin is more as the difference of Tmin in the top north and bottom south is around 3^{o}C but there is no much variation in spatial distribution of Tmin across the longitudes. However, the annual mean Tmin is not constant for each year, therefore SD of annual mean Tmin is calculated to find the temporal variation which is given in the figure 18b. The variation from the mean is very small and it is up to 0.4^{o}C which is present over most of the regions of Sri Lanka. The spatial distribution of the variations in Tmin shows slight variations throughout the country. Figure 18c also shows that the

timeseries of Tmin over Sri Lanka has a significant increasing trend with a gradient of 0.17ºC per decade at 95% significance level.

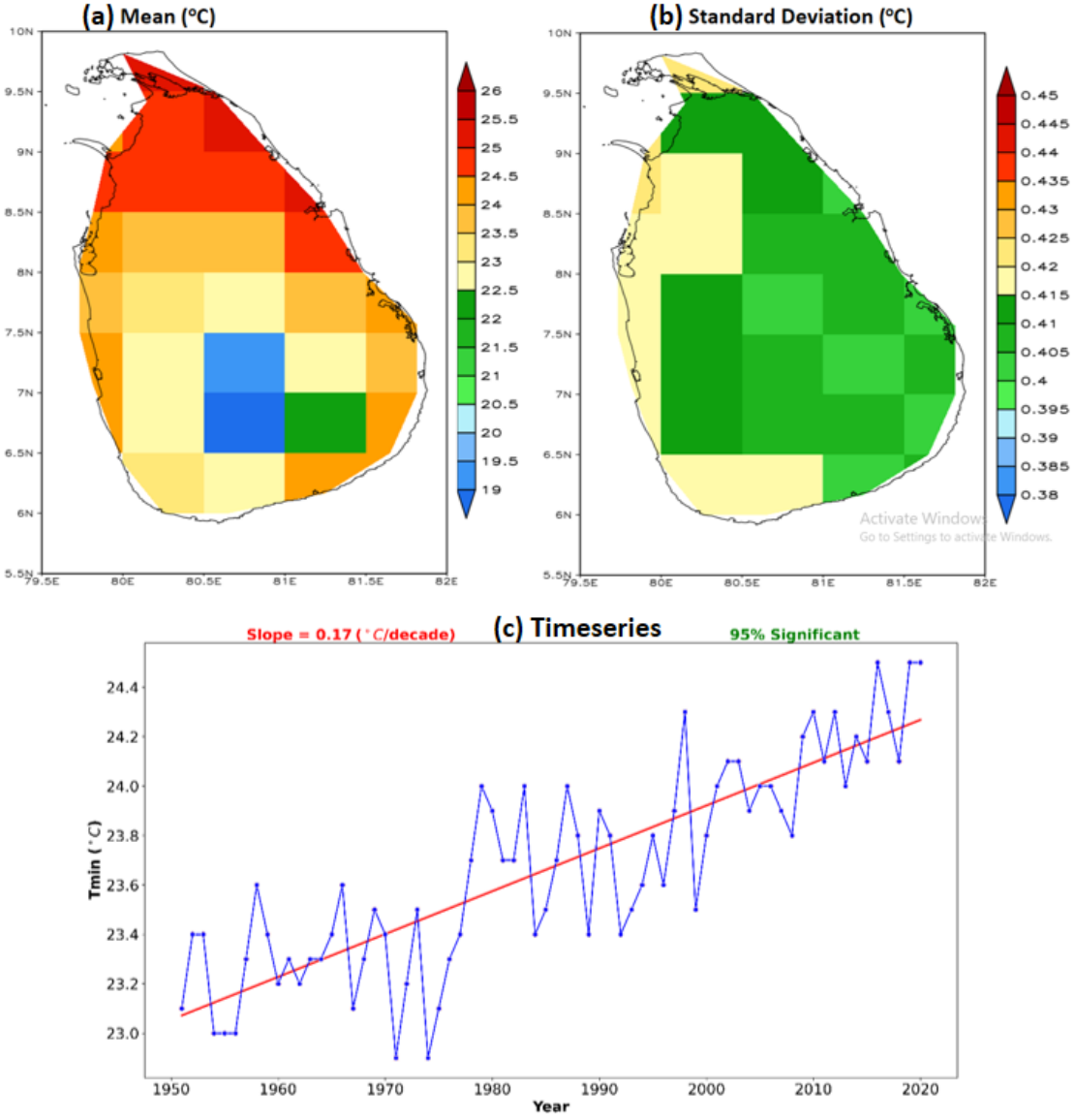

Figure 18 Climatology, standard deviation and timeseries along with trend line of annual Tmin over Sri Lanka from 1951 to 2022.

(b) Seasonal

The climatology, SD and trends of minimum temperatures (Tmin) are further classified into different seasons to see the spatial distribution of mean and trends of Tmin over different regions of the country for different seasons which are shown in the figures 19, 20 and 21. The range of Tmin is varying from 16 ºC to 26 ºC over the seasons which are visible in figure 19. During the FIM season Tmin is maximum about 26 ºC in the north eastern region, and minimum over a few places

of south central region, about 19 ^{o}C and this continues further in the SWM season. But during SWM season, the spatial extent of higher Tmin has increased and the spread moves further southwards. In the SIM season the Tmin has reduced over northern Sri Lanka but there is not much changes are observed over southern Sri Lankan regions. During NEM season the changes in Tmin over different parts of the country are less. Large variations in the spatial distribution of Tmin are observed across the seasons. Figure 20 shows spatial distribution of SD of seasonal Tmin for different seasons and it is observed that within a season, northern regions have higher variations from the mean than the southern regions. FIM season shows highest SD of about 0.64 ^{o}C over north eastern region whereas south eastern regions have least variations during SIM season. Spatial variation of seasonal mean SD of Tmin is lowest about 0.36 ^{o}C to 0.4 ^{o}C during the SWM season. The latitudinal variation in the SD of Tmin is more than the longitudinal variation i.e. moving from west to east the variation from the mean is less.

The spatial distribution of trends shows that the Tmin has significant increasing trend throughout the country during all the seasons (figure not shown). These results agree well with some of the previous studies of Tmin over Sri Lanka which showed that warming trend of Tmin across the country for most of the regions (Naveendrakumar et al 2018). The positive slope during SWM season is about 0.1 ^{o}C per decade which is comparatively lesser than other three seasons FIM, SIM and NEM seasons with positive slope value of 0.2 ^{o}C per decade. These results are reflected in figure 21 which shows that the timeseries of Tmin over Sri Lanka has significant positive increasing trend in all the seasons with maximum value 0.2^{o} C per decade in FIM season and minimum value of 0.15 ^{o}C per decade during SWM season. All positive trends of Tmin are significant when tested with MK test at 95% significance level. This warming trend of Tmin might be caused by warming nighttime temperature in most of the regions which is consistent with the global trends (Davy et al 2017).

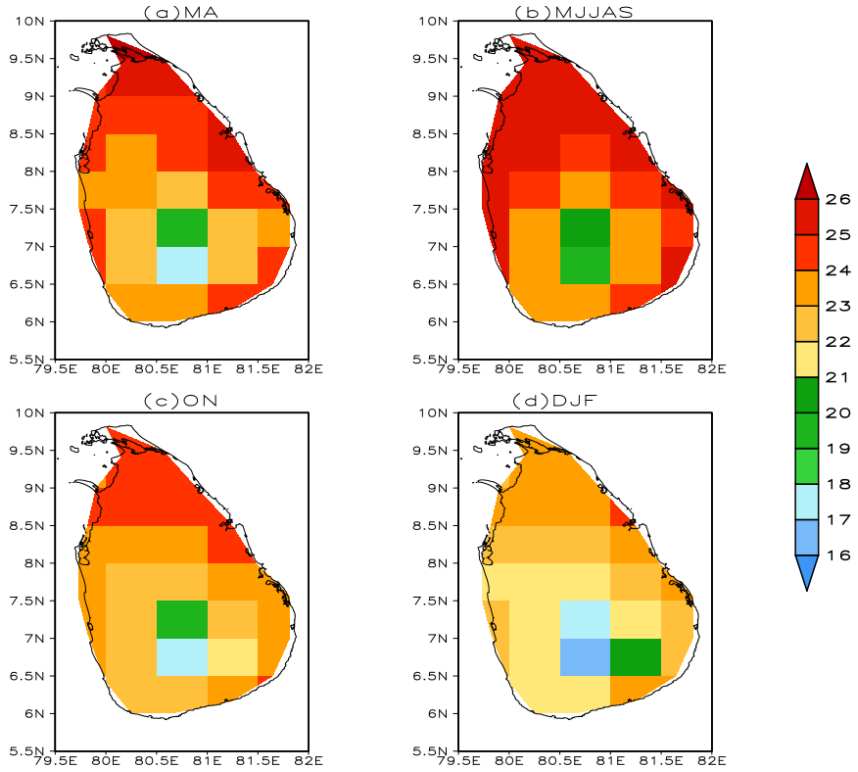

Figure 19 Annual climatology of seasonal Tmin from 1951 to 2020. (Unit- ^{o}C)

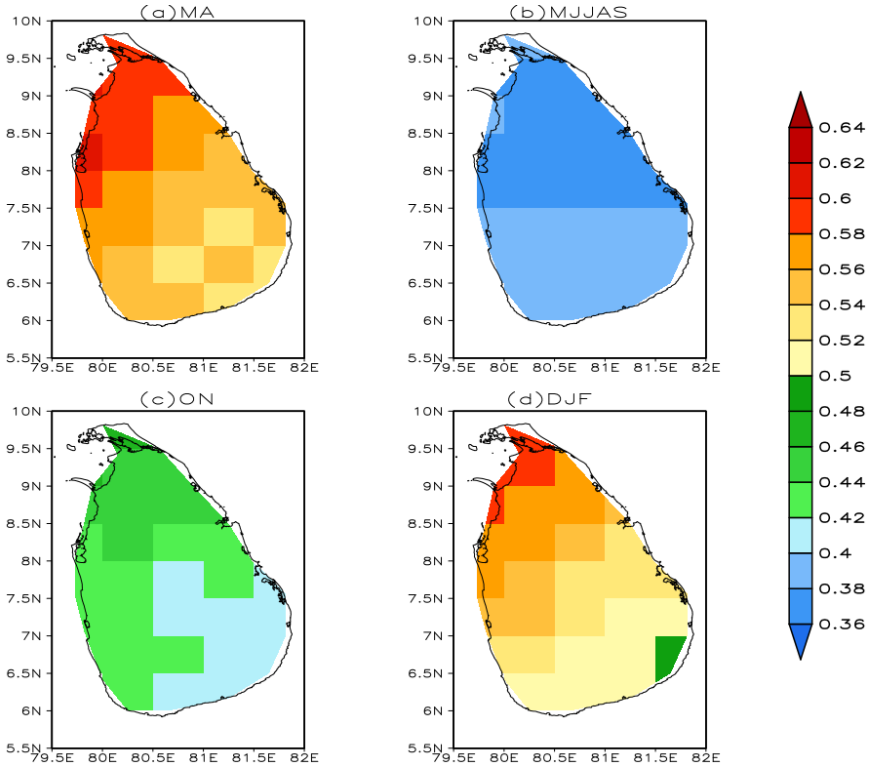

Figure 20 Annual SD of seasonal Tmin from 1951 to 2020 (Unit- ^{o}C)

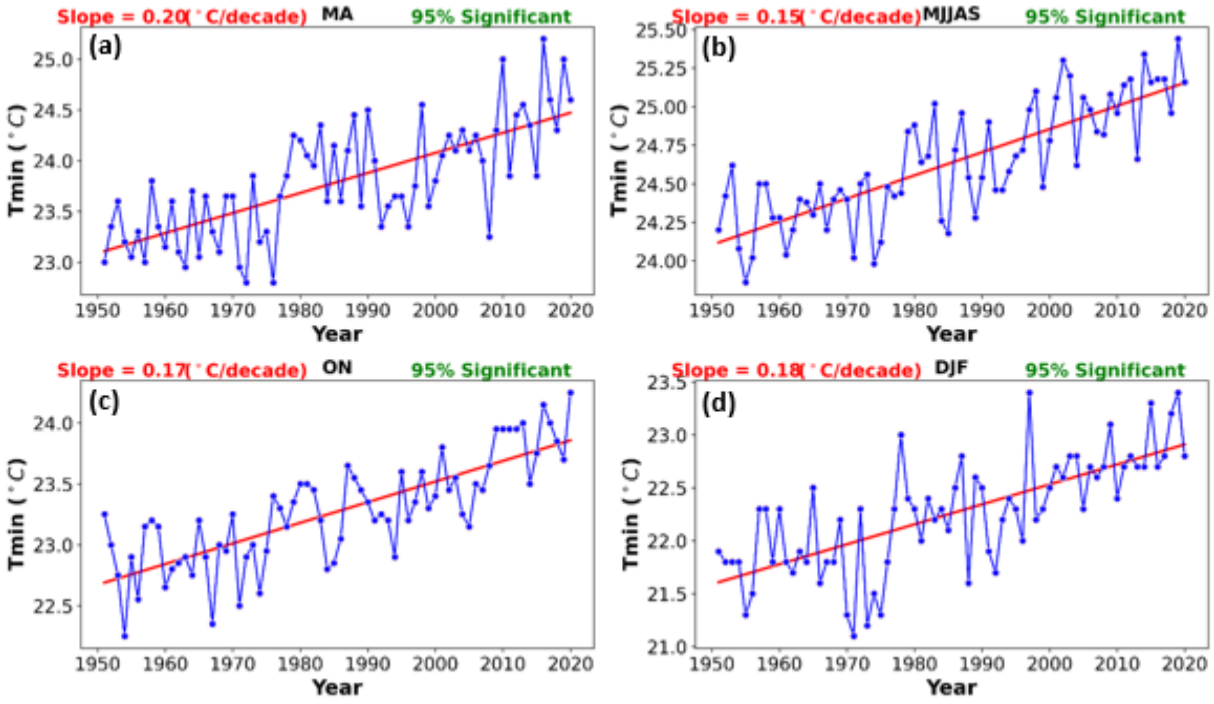

Figure 21 Timeseries of seasonal mean Tmin over Sri Lanka (blue) along with trend line (red) from 1951 to 2020.

(c) Monthly

The climatology of monthly Tmin for each month is given in the figure 22 which shows that during the months of April to September Tmin is around 25ºC to 26ºC over northern regions of Sri Lanka. Southern central region has least Tmin during all the months with minimum during January. Spatial distribution of Tmin shows that it is increasing from March to June and further starts decreasing till the month of December. Northern Sri Lanka has normally higher Tmin than southern region which receives high amount of rainfall during most of the months in a year. The SD of monthly Tmin is maximum during the month of February and March over northern regions which can be seen in the figure 23. Variations in the Tmin from the mean is minimum during the months of August and September over most parts of the country. The spatial distribution of deviations in the Tmin shows large variations during the months of January to March and December of about 0.66 ºC. The spatial structure of long term trend of monthly Tmin over Sri Lanka shows that significant positive trends throughout the country at 95% significance level (figure not shown). However the warming trends of Tmin are higher around 0.3 ºC per decade during the months of February and March and the slopes are comparatively less during other months and minimum during

September around 0.1ºC per decade. These results are also reflected in the figure 24 which shows that timeseries of monthly Tmin over Sri Lanka along with linear trend line for each of the month. Tmin has maximum increasing trend of 0.21ºC per decade during March and minimum 0.13 ºC per decade during the month of September. Overall all the months show significant increasing trends of Tmin at 95% significance level. The minimum temperature has raised from 21ºC to 23ºC in the years starting from 1951 to 2020.

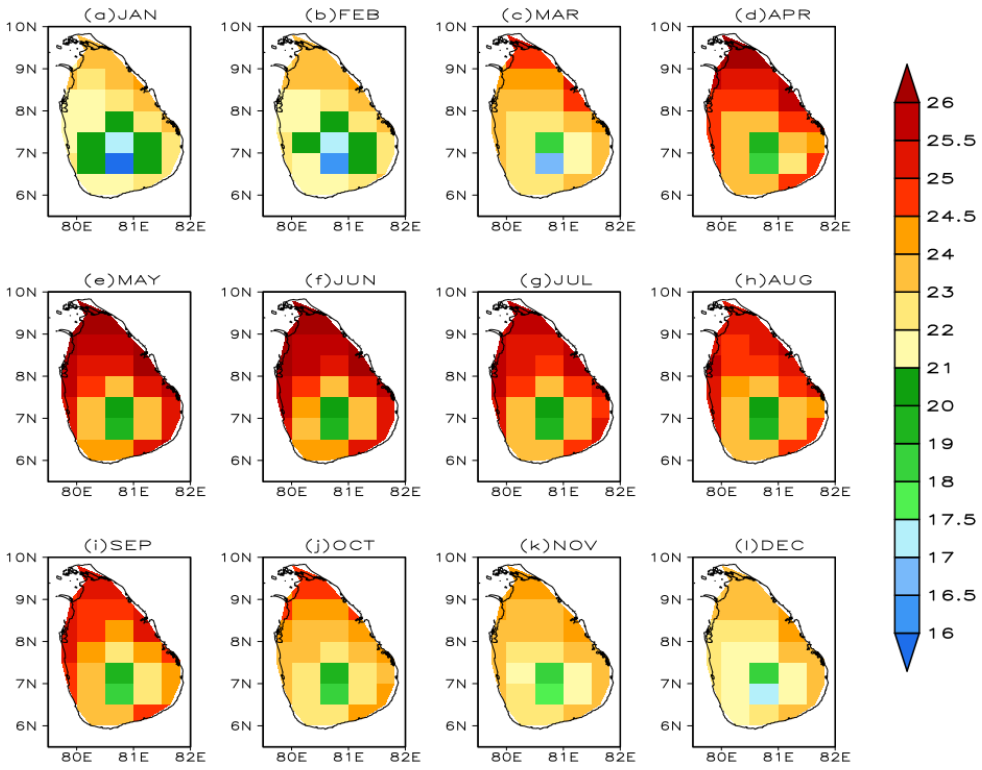

Figure 22 Climatology of monthly Tmin from 1951 to 2020 (Unit- ºC)

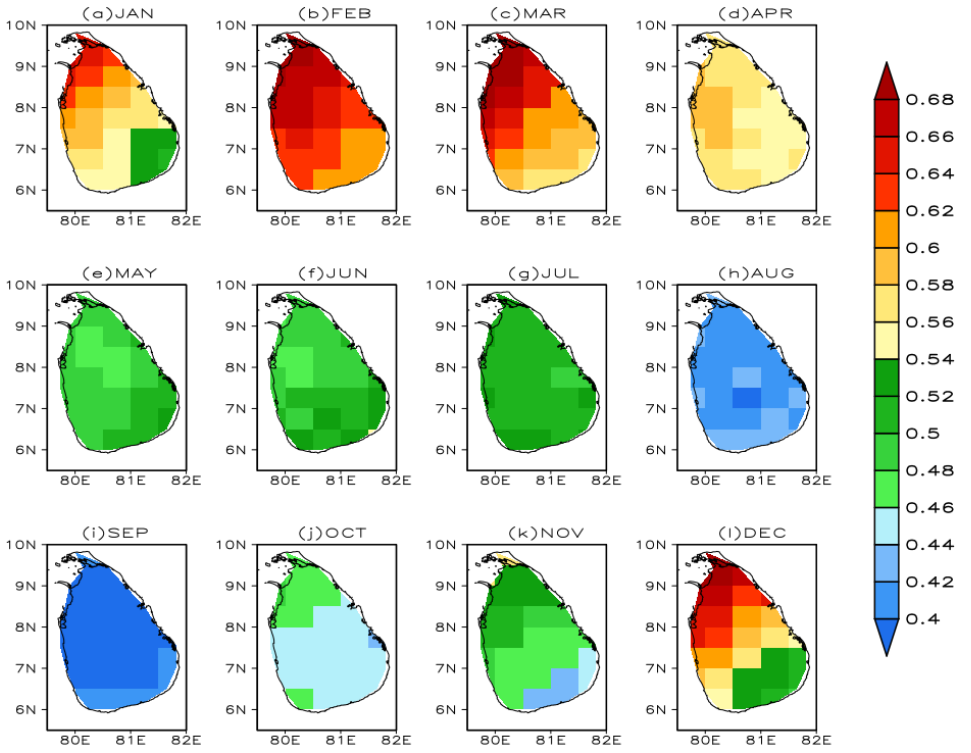

Figure 23 SD of annual mean of Tmin for each month from 1951 to 2020 (Unit- ^{o}C)

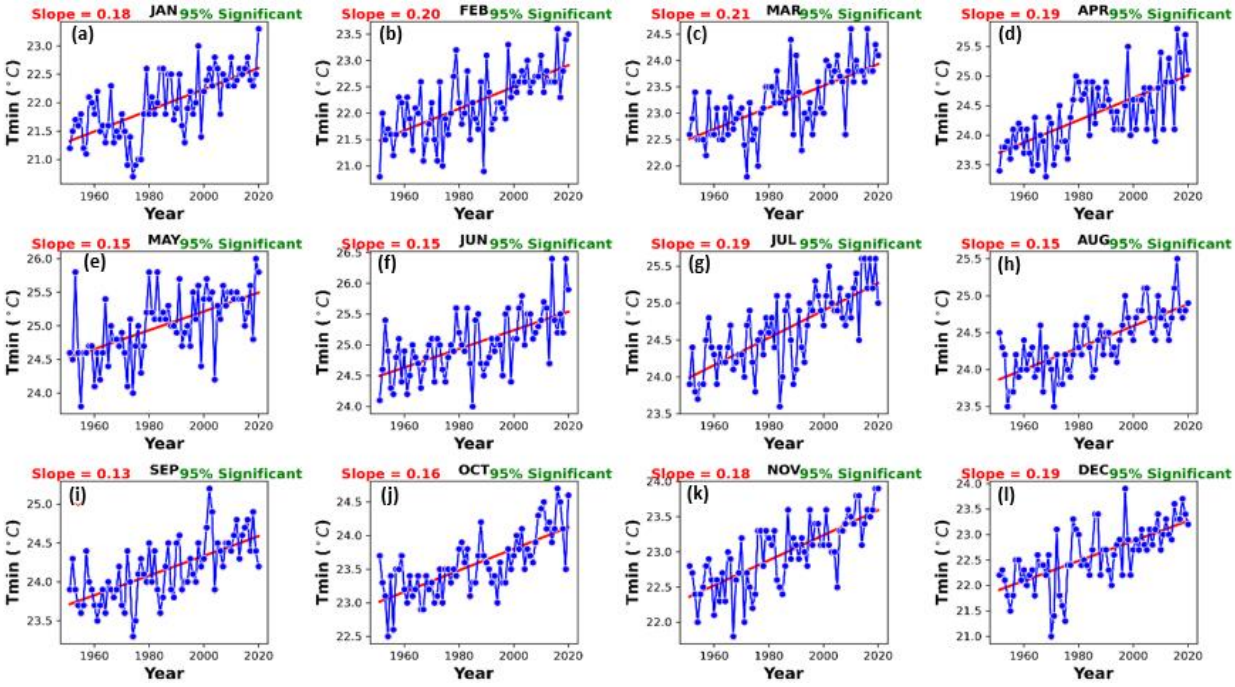

Figure 24 Timeseries of monthly Tmin along with trend line (red) from 1951 to 2020

4. Summary

The objective of this report is to delineate the climatic characteristics of fundamental atmospheric variables Precipitation, maximum temperature (Tmax) and minimum temperature (Tmin) across Sri Lanka using CRU TS v4.07 data spanning from 1951 to 2020. Monthly precipitation exhibits notable seasonal and spatial disparities prominently influenced by both the season and geographical location. For instance, the southwest region experiences substantial rainfall during the Southwest Monsoon (SWM) season whereas the eastern region encounters heightened rainfall during the Northeast Monsoon (NEM) season. Analysis reveals that there is no significant trend observed in rainfall except April and September at 95% significance level by using the Mann-Kendall test. Conversely, both Tmax and Tmin exhibit notable warming trends across all seasons manifested consistently throughout the months, albeit with slight variations in the positive slope values. Notably, no cooling trend is observed in either Tmax or Tmin across any month or season underscoring the prevailing warming tendency.

5. Future scopes

Influence of convectively coupled equatorial waves specifically the boreal summer intra-seasonal oscillations (BSISO) and Madden-Julian oscillation (MJO) on Sri Lanka's climate dynamics will be investigated. Tropical regions such as Sri Lanka are particularly susceptible to the effects of these phenomena. Additionally, the teleconnections of major oceanic phenomena such as the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) will be examined within this region. These oceanic phenomena play significant roles in modulating the climate patterns over Sri Lanka. Furthermore, the study will incorporate analyses using alternative datasets including the Indian Monsoon Data Assimilation and Analysis (IMDAA), NCMRWF Global Forecast System (NGFS), and Integrated Multi-Satellite Retrievals for Global Precipitation Measurement (IMERG).

6. Acknowledgements

This report constitutes a pivotal component of an exhaustive investigation into the meteorological and climatic conditions of the BIMSTEC nations. The research undertaken in this study leveraged the computational prowess of the MIHIR supercomputers at the NCMRWF. We extend profound gratitude to our colleagues at NCMRWF for their indispensable assistance. Moreover, we sincerely thank the Head of NCMRWF for their consistent encouragement and unwavering support. Additionally, we express our gratitude to the anonymous reviewer whose valuable insights significantly enriched the refinement of this report.

7. Author contribution

The study was collaboratively designed by all authors, who collectively contributed to refining the manuscript. Dr. Bibhuti Sharan Keshav conducted the technical work outlined in the study and generated the initial draft of the report. Dr. Mohan S. Thota and Dr. Raghavendra Ashrit provided guidance in preparing the final version of the report.

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