NMRF/RR/04/2024

सत्यमेव जयते

RESEARCH REPORT

Climate analysis over Nepal

Kumarjit Saha, Mohan. S. Thota and Raghavendra Ashrit

April 2024

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

Climate analysis over Nepal

Kumarjit Saha, Mohan. S. Thota and Raghavendra Ashrit

April 2024

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

Ministry of Earth Sciences
National Centre for Medium Range Weather Forecasting
Document Control Data Sheet

1	Name of the Institute	National Centre for Medium Range Weather Forecasting
2	Document Number	NMRF/RR/04/2024
3	Date of Publication	April 2024
4	Title of the document	Climate analysis over Nepal
5	Type of the document	Research Report
6	Number of pages, figures, and Tables	21 Pages, 6 Figures
7	Authors	Kumarjit Saha; Mohan. S.Thota; Raghavendra Ashrit
8	Originating Unit	National Centre for Medium Range Weather Forecasting (NCMRWF)
9	Abstract (brief)	This comprehensive study examines climate conditions and variability in Nepal from 1951 to 2020. Notably, the central region of Nepal stands out for having the highest annual precipitation, measuring approximately 2700 mm/year. In the Terai region, the annual mean maximum temperature (Tmax) ranges from 24-28°C, presenting a stark contrast to the mountainous areas where it varies between 4-8°C. Similarly, the annual mean minimum temperature (Tmin) in the Terai fluctuates from 14-18°C, while in the mountains, it registers between -6 to -10°C. The study identifies statistically significant positive trends at a 95% confidence level in precipitation during the pre-monsoon period, and negative trends during the monsoon season. Additionally, both Tmax and Tmin exhibit increasing trends over the study period.
10	References	14
11	Security classification	Unrestricted
12	Distribution	General
13	Key Words	CRU, Nepal

Table of contents

सारांश

यह अध्ययन 1951 से 2020 तक नेपाल में जलवायु स्थितियों और परिवर्तनशीलता का एक व्यापक मूल्यांकन प्रदान करता है। वार्षिक और मौसमी जलवायु विज्ञान के विश्लेषण के साथ-साथ संचित वर्षा, औसत अधिकतम तापमान (टीमैक्स) और न्यूनतम तापमान (टीमिन) के रुझान से महत्वपूर्ण पता चलता है। जाँच - परिणाम। नेपाल में औसत वार्षिक वर्षा 300-2700 मिमी/वर्ष के बीच होती है, नेपाल के मध्य भाग में लगभग 2700 मिमी/वर्ष होती है। तराई क्षेत्र में वार्षिक औसत टीएमएक्स 24-28 डिग्री सेल्सियस के बीच है, जो उच्च ऊंचाई वाले पर्वतीय क्षेत्र के 4-8 डिग्री सेल्सियस है। इसी प्रकार, तराई में वार्षिक औसत तापमान 14-18°C के बीच होता है, जबकि पहाड़ों में यह -6 से -10°C के बीच होता है। मानसून के मौसम में नेपाल के मध्य भाग में चरम वर्षा (लगभग 500 मिमी/मौसम) देखी जाती है। इसके अलावा, अध्ययन में प्री-मानसून (1.05 मिमी/वर्ष) के दौरान वर्षा में 95% सांख्यिकीय रूप से महत्वपूर्ण सकारात्मक प्रवृत्ति और मानसून के बाद (0.01°C/वर्ष) और सर्दियों (0.009°C/वर्ष) के साथ-साथ Tmin की पहचान की गई है। प्री-मॉनसून (0.01°C/वर्ष), मानसून (0.01°C/वर्ष), पोस्ट-मानसून (0.02°C/वर्ष) और सर्दी (0.02°C/वर्ष) सहित सभी मौसमों के लिए। इसके विपरीत, मानसून के मौसम के दौरान वर्षा में 95% सांख्यिकीय रूप से महत्वपूर्ण नकारात्मक प्रवृत्ति देखी जाती है (-1.05 मिमी/वर्ष)। यह शोध नेपाल में जलवायु गतिशीलता की हमारी समझ में महत्वपूर्ण योगदान देता है, जो क्षेत्र में जलवायु परिवर्तन के आकलन के लिए मूल्यवान अंतर्दृष्टि प्रदान करता है।

Abstract

This study provides a comprehensive assessment of climate conditions and variability over Nepal, spanning the years 1951 to 2020. Analysis of annual and seasonal climatology, along with trends in accumulated precipitation, mean maximum temperature (Tmax) and minimum temperature (Tmin), reveals significant findings. Mean annual precipitation over Nepal ranges from 300-2700 mm/year, peaks at around 2700 mm/year over the central part of Nepal. Annual mean Tmax in the Terai region ranges from 24-28°C, contrasting with the high-altitude mountain region's 4-8°C. Similarly, annual mean Tmin in the Terai varies from 14-18°C, while in the mountains, it ranges between -6 to -10°C. Monsoon season witnesses peak precipitation (around 500 mm/season) in the central part of Nepal, alongside Tmax and Tmin peaks in mountain and Terai regions, respectively. Furthermore, the study identifies a 95% statistically significant positive trend in precipitation during the pre-monsoon (1.05mm/year) and Tmax during post-monsoon (0.01°C/year) and winter (0.009°C/year), as well as Tmin for all seasons, including pre-monsoon (0.01°C/year), monsoon (0.01°C/year), post-monsoon (0.02°C/year) and winter (0.02°C/year). Conversely, a 95% statistically significant negative trend is observed in precipitation during the monsoon season (-1.05mm/year). This research significantly contributes to our understanding of climate dynamics in Nepal, offering valuable insights for climate change assessments in the region.

1. Introduction:

Nepal, a landlocked country in South Asia, is situated in the Himalayas between India and China. The geography is predominantly mountainous, featuring some of the world's highest peaks, including the renowned Mount Everest standing at 8,848 meters. While the northern region is characterized by challenging terrains and high altitudes, the southern part of the country consists of low-lying areas with elevations below 100 meters. The climate in Nepal exhibits significant variation based on Mean Sea Level (MSL) altitude. The lower regions of the country are predominantly characterized by a humid and warm climate, while the mountainous areas experience colder temperatures and lower humidity levels (Robinson and Henderson-Sellers, 1999).

As of 2019, Nepal is home to approximately 28 million people, with about 80% residing in rural areas. Despite its predominantly agrarian economy, with small-scale subsistence agriculture employing nearly 69% of the workforce in 2015, the contribution of agriculture to the Gross Domestic Product (GDP) was only 25% in 2019 (World bank, 2020). The impact of climate change on rice production and productivity is a critical concern, particularly with regards to rising temperatures and changing precipitation patterns. Karn (2014) described a 5.2% drop in rice yield relative to current production levels. This underscores the vulnerability of rice cultivation in the face of changing climate conditions and emphasizes the need for adaptive strategies, resilient crop varieties, and sustainable agricultural practices to mitigate the adverse impacts on food production. Efforts to address climate change impacts on agriculture are essential to ensuring food security and the livelihoods of communities dependent on rice cultivation. In Nepal, there is average rise of temperature by 0.06^{o}C per year. The rise from 1975 to 2006 is nearly at 1.8^{o}C (Malla, 2008).

This study aims to conduct a thorough analysis of climate conditions from 1951 to 2020 in Nepal, emphasizing both spatial and temporal trends and variations. This analysis will specifically focus on annual and seasonal climatic patterns, including accumulated precipitation, mean Tmax and mean Tmin. The intention is to provide valuable insights and data that enhance our understanding of climate dynamics over Nepal. This information will not only contribute to broader climate change assessments but will also aid in the development of effective mitigation strategies for the region. The primary objective is to generate new knowledge that significantly contributes to the scientific understanding of climate variability, trends, and impacts in Nepal, thereby advancing the body of research in the field of climate science.

As part of the NCMRWF BCWC project, the aim is to draft a report aimed at generating climate information system for the BCWC countries, which include Bangladesh, Bhutan, India, Myanmar, Nepal, Sri Lanka, and Thailand. The initial focus lies on conducting a preliminary assessment of Nepal's climate using CRU observation data. Subsequently, the plan involves conducting a more extensive analysis by integrating additional sources of observational data and reanalysis data and also investigating the impact of teleconnections on the climate conditions over the region.

2. Data and Methodology:

This work is carried out using $0.5^{o}x0.5^{o}$ gridded Climate Research Unit (CRU) monthly data, (https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.07), which includes a precipitation, Tmax and Tmin. The CRU data is based on a network of weather stations worldwide, providing a reliable and consistent record for climate research. The analysis in this study focuses on the monthly, seasonal, and annual variations of mean and trends of temperature and precipitation across Nepal from 1951 to 2020.

a. Mean Analysis:

This study examines spatial patterns in mean climate variables to delineate regional averages and trends. Maps were generated to depict the mean distribution of essential climate parameters, including temperature and precipitation, spanning the study period from 1951 to 2020. The spatial plots highlight areas with distinct mean values, aiding in the identification of regional climatic variations.

b. Trend Analysis:

The study utilized spatial plots to assess the temporal trends in climate variables. These plots provide a visual depiction of the direction and amplitude of changes in precipitation, Tmax and Tmin over Nepal. To quantify the rate of change for each grid cell, robust statistical techniques, including non-parametric tests, the Mann–Kendall test, and the Thiel–Sen slope test, were applied to generate trend maps. These maps serve as valuable tools in identifying regions undergoing significant positive and negative trends, thereby contributing crucial insights to climate change assessments. In addition to spatial analyses, time series trend analysis plays a crucial role in determining and quantifying the magnitude of trends in climate time series data. Notably, the World Meteorological Organization (WMO) recommends the Thiel–Sen slope method for assessing trends in environmental data time series (Rustum et al, 2017).

3. Results and discussion:

Figure 1 depicts the annual variations in accumulated precipitation (a), mean Tmax (b), and mean Tmin (c) over Nepal spanning the period from 1951 to 2020. Figure 1(a) highlights a significant contrast in maximum precipitation between the Terai region, situated near the Indian border, and the hilly regions. The Terai consistently records higher maximum precipitation compared to the hilly areas, with the central and eastern parts of Nepal experiencing the highest annual precipitation, reaching around 2700 mm/year, in comparison to other regions.

The annual mean Tmax over the Terai region ranges between 24-28°C. Notably, there is a consistent and monotonic decrease in temperature with increasing altitude, reaching as low as 4-8°C, as illustrated in Figure 1(b). This temperature gradient is indicative of a decline in temperatures as elevation increases. Similar patterns are observed in the mean Tmin, with peak values ranging from 14-18°C and minimum temperatures reaching around -6 to -10°C which is shown in Figure 1(c). This pattern signifies a clear relationship between temperature and altitude, further contributing to the understanding of Nepal's climatic variations.

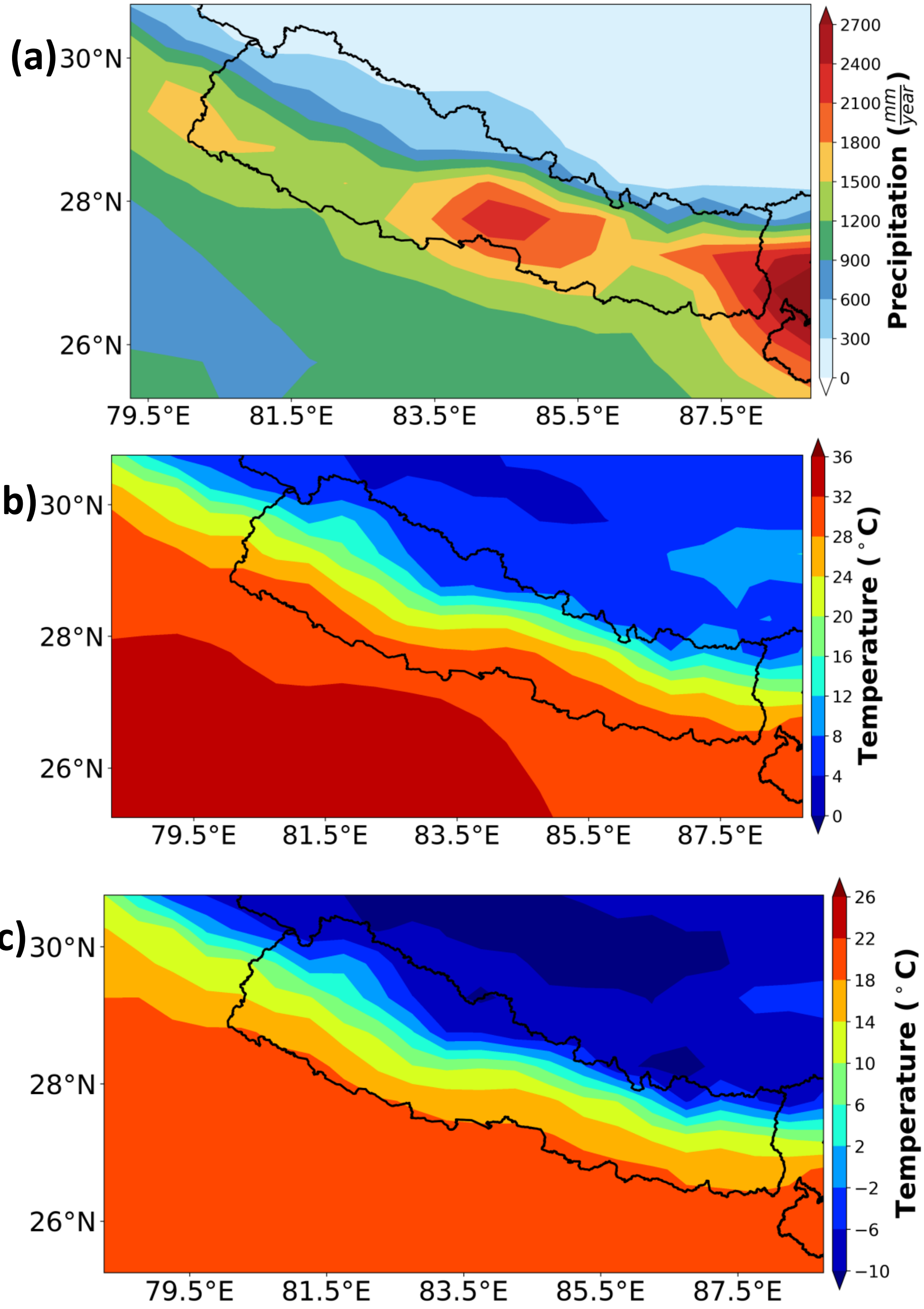

Figure 1: Annual variations in yearly accumulated precipitation (a), mean Tmax (b), and mean Tmin (c) over Nepal for the period 1951-2020.

Figure 2 illustrates the seasonal variation (winter, i.e., December, January, and February (DJF); pre-monsoon, i.e., March, April, and May (MAM); Monsoon, i.e., June, July, and August (JJA); and post-monsoon, i.e., September, October, and November (SON)) (Adhikari and Mathema, 2023) in accumulated precipitation (a-d), mean Tmax (e-h), and mean Tmin (i-l) across Nepal spanning the period from 1951 to 2020. From Figure 2(a), it is evident that the lowest precipitation occurs during the winter season, averaging around 100 mm/season, and approximately 150 mm/season during the pre-monsoon period, as depicted in Figure 2(b). On the other hand, the monsoon season receives the maximum precipitation, reaching around 500 mm/season in the central and eastern parts of Nepal, as illustrated in Figure 2(c). During the post-monsoon season, Nepal receives approximately 200 mm/season, as shown in Figure 2(d). These findings align with the results presented in Figure 1(a). Central Nepal experiences maximum precipitation because this region is influenced by its distinctive topographical features. Dhar and Nandargi (2005) attribute this high precipitation to significant orographic variations occurring over short distances, facilitating the swift ascent and condensation of moist air. The northwestern part receives a lower amount of rainfall, possibly attributed to its location in a rain shadow region, a consequence of the presence of high-altitude mountains (Dhar and Nandargi, 2002).

Figure 2 (e-h) illustrates the seasonal variation of Tmax, revealing a consistent pattern where high-altitude regions consistently demonstrate cooler temperatures compared to low-altitude areas across all seasons. The winter season records the lowest temperatures, dropping below 0°C in hilly regions and ranging between 20-24°C in the Terai region shown in Figure 2(e). On the other hand, the monsoon season witnesses the highest temperatures, peaking at approximately 12-16°C in hilly areas and 32-36°C in the Terai region, as depicted in Figure 2(g). Similar patterns are observed in the seasonal mean Tmin. In the Terai region maximum temperatures in winter 5-10°C, pre-monsoon 15-20°C, monsoon 20-25°C and again 15-20°C in post-monsoon season. The minimum temperature over the mountain regions are below -10°C in winter, 4-8°C during the pre-monsoon season, 5-10°C during the monsoon season, and 0 to -10°C during the post-monsoon season as shown in Figure 2(i-l) respectively. This pattern signifies a clear relationship between temperature and altitude.

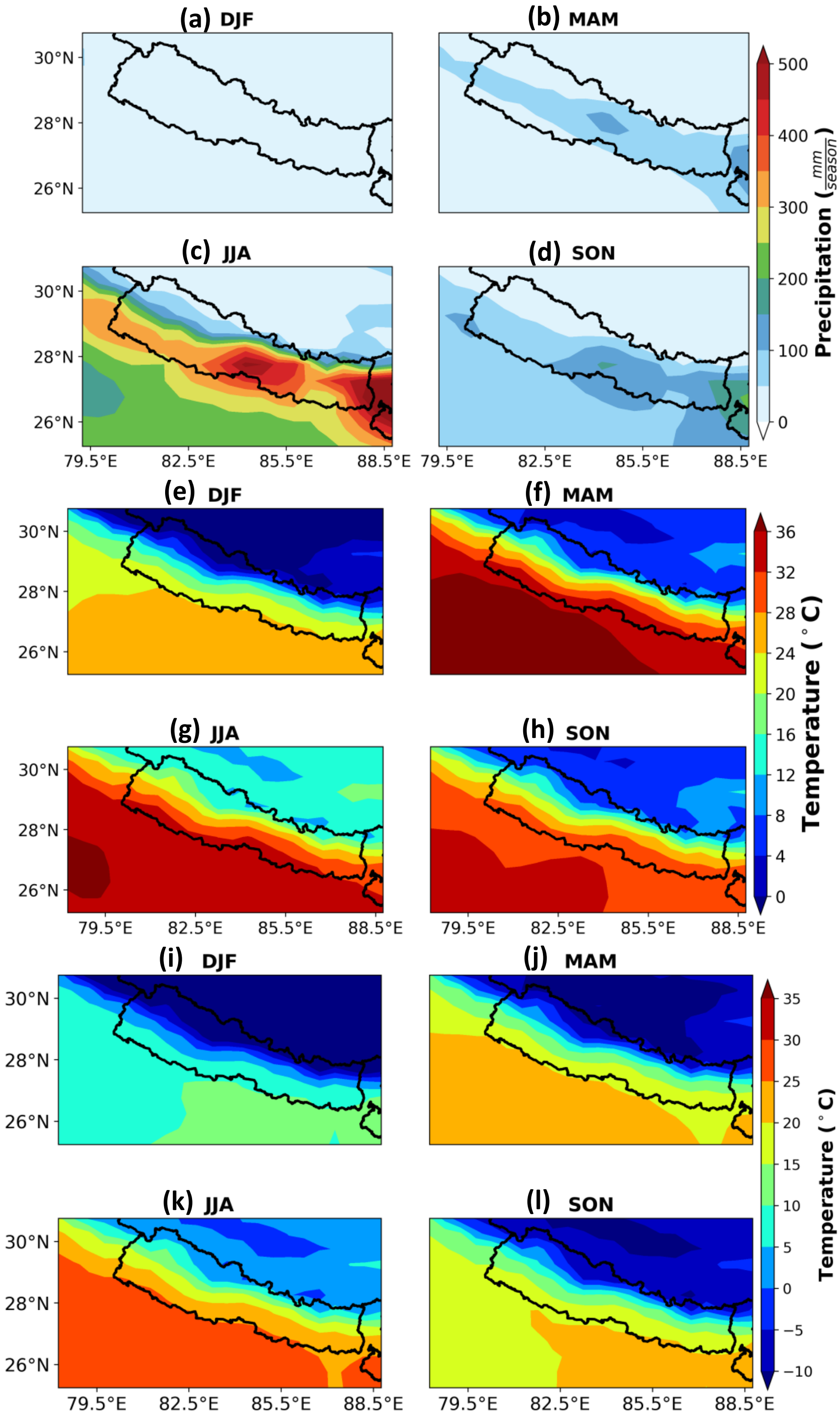

Figure 2: Seasonal variation of accumulated precipitation (a-d), mean Tmax (e-h) and mean Tmin (i-l) over Nepal for the period 1951-2020.

Figure 3 depicts the 95% statistically significant seasonal trends per decade across all seasons. In Figure 3(a), a noteworthy positive trend of 95% significance per decade in winter season precipitation is evident over the mountainous region of central Nepal. This phenomenon may be attributed to increasing temperature trends at higher altitudes, potentially influencing permafrost distribution, resulting in reduced snowfall and increased rainfall (Fort, 2014). The pre-monsoon season also exhibits a positive trend, aligning with the findings of Karki et al. (2017) and Sigdel et al. (2022), suggesting an augmentation of intense thunderstorms in the region shown in Figure 3(b). Conversely, a negative trend per decade is observed in the monsoon and post-monsoon seasons over the northwestern part of Nepal, as depicted in Figure 3(c) & 3(d) respectively. This could be attributed to the complex topography of the region, characterized by drastic elevation changes, where precipitation is locally determined. Factors such as mountain shape, relief, and land cover play a role in precipitation variations, and the deep valleys in this area establish their own wind systems, contributing to diverse precipitation patterns (You et al, 2015; Chen et al, 2018). Further research is warranted to identify key factors influencing precipitation distribution in regions with complex topography.

Figure 3(e) displays a notable positive trend in the central region of Nepal during the winter season, which corresponds with the conclusions drawn by Konchar et al. (2015). In contrast, no significant trend is observed during the pre-monsoon season, as indicated in Figure 3(f). However, both the monsoon and post-monsoon seasons show a significant positive trend across the eastern region and the entirety of Nepal, as depicted in Figure 3(g) & 3(h) respectively. Additionally, Figure 3(i-l) illustrates a significant positive trend in Tmin across Nepal for all seasons.

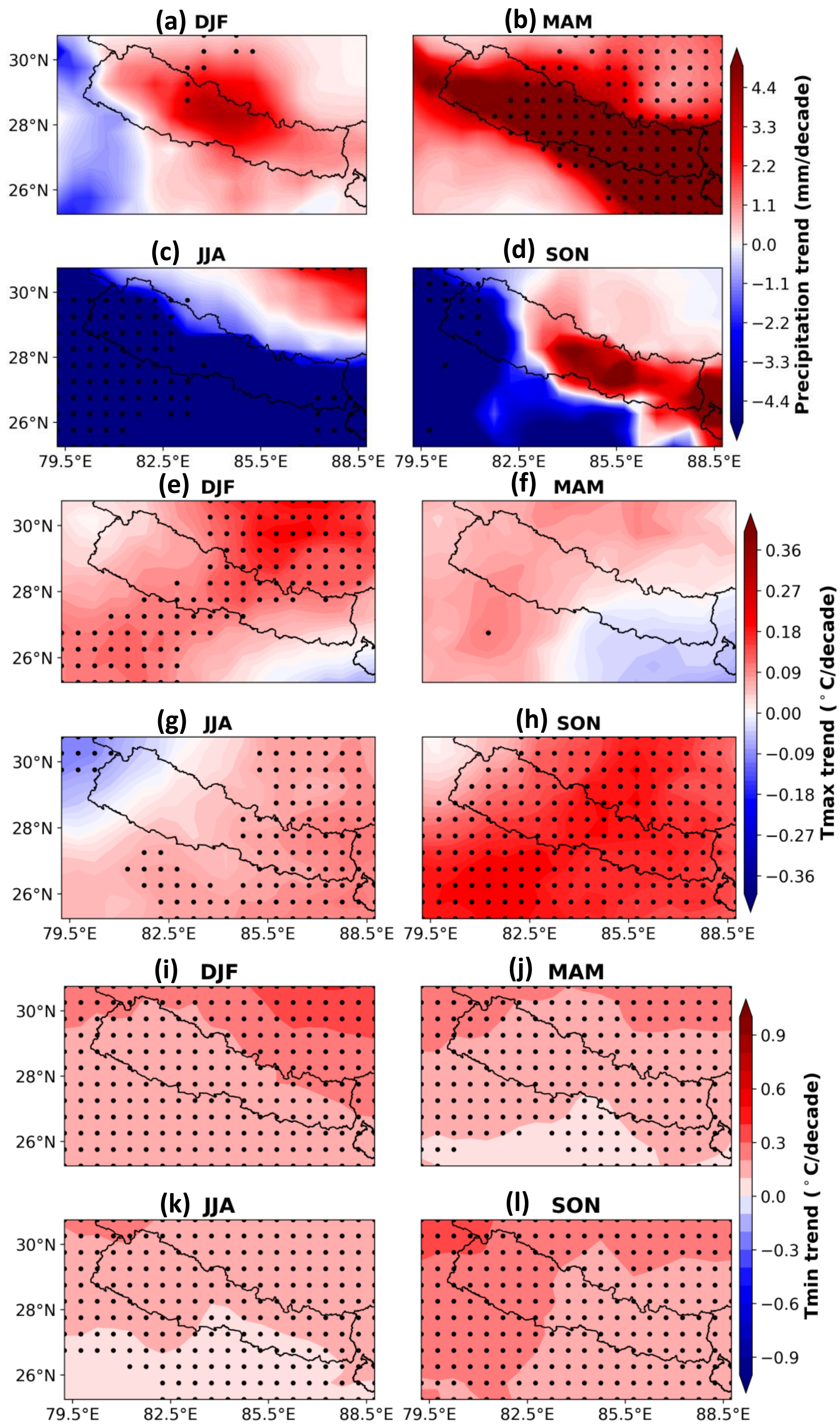

Figure 3: Spatial trends per decade for precipitation (a-d), Tmax (e-h) and Tmin (i-l) over Nepal during the period from 1951 to 2020. The black dot represents the significance at a 95% confidence level.

Figure 4 presents the monthly timeseries and trends in precipitation averaged over Nepal from 1951 to 2020. Notably, the statistical analysis reveals a 95% significant positive trend in precipitation for April, May and December, while August exhibits a negative trend. The findings suggest a consistent increase in precipitation during the pre-monsoon season from 1951 to 2020, aligning with similar conclusions reported by Karki et al. (2017) and Sigdel et al. (2022). Additionally, a decrease in precipitation during the monsoon season, as documented by You et al. (2015) and Chen et al. (2018), corresponds with the results presented in Figure 3(a-d). These collective findings contribute to a comprehensive understanding of Nepal's changing precipitation patterns over the specified period.

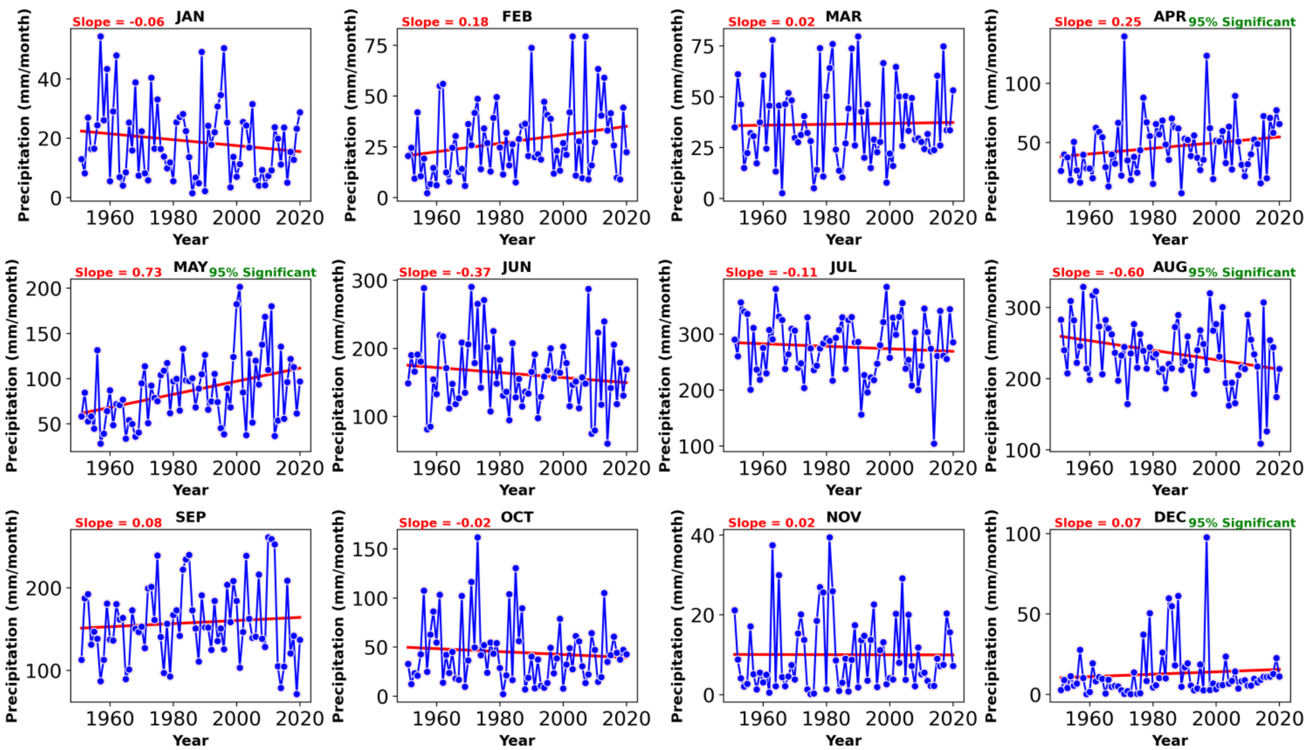

Fig: 4 Monthly variation of the trend of precipitation over Nepal for the year 1951-2020

Figure 5 illustrates the monthly time series and trends in Tmax averaged over Nepal spanning the years 1951 to 2020. Notably, the statistical analysis indicates a 95% significant positive trend in Tmax for the months of August to December, whereas no significant trend is observed for January to July. This figure highlights a monotonically increasing Tmax trend during the post-monsoon season in Nepal. A similar result was also found in Figure 3(e-h).

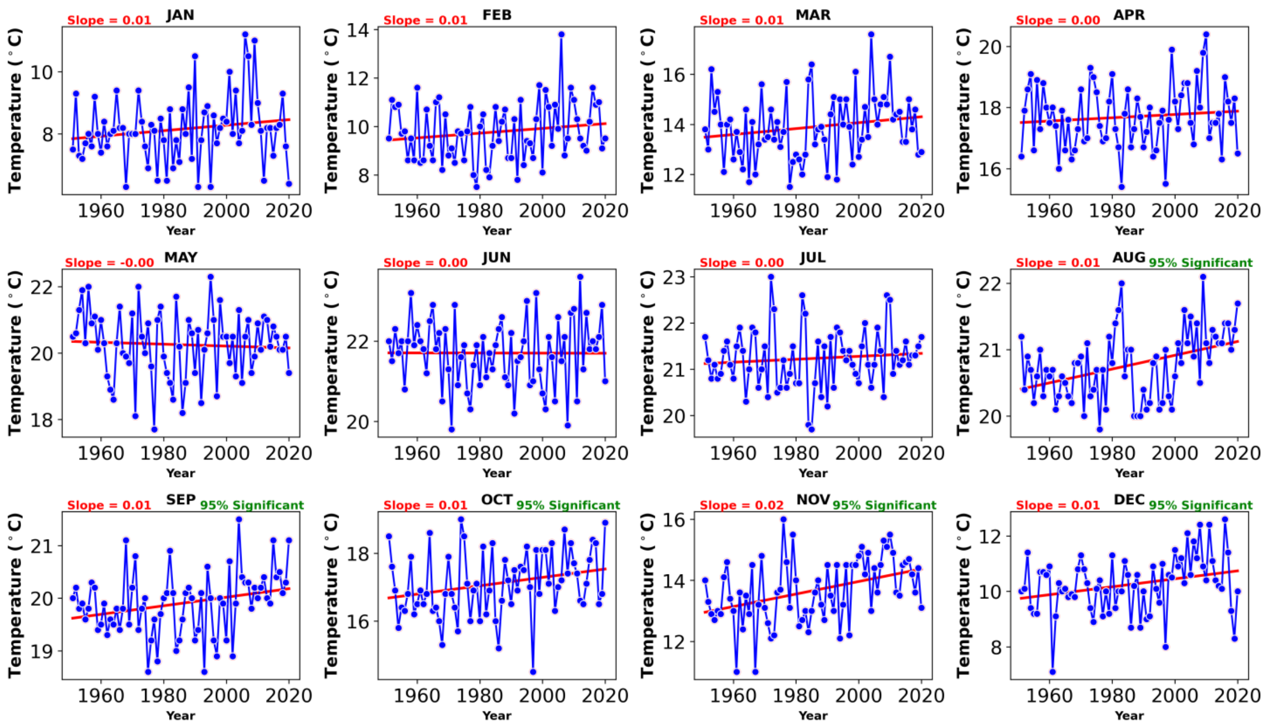

Fig: 5 Monthly variation of trend of Tmax over Nepal for the year 1951-2020

Figure 6 displays the monthly Tmin trends observed throughout Nepal from 1951 to 2020. Notably, the statistical analysis reveals a significant 95% positive trend in Tmin for all months across the years. This figure underscores a consistent and monotonically increasing Tmin trend throughout the year in Nepal. Similar results are also evident in Figure 3(i-l).

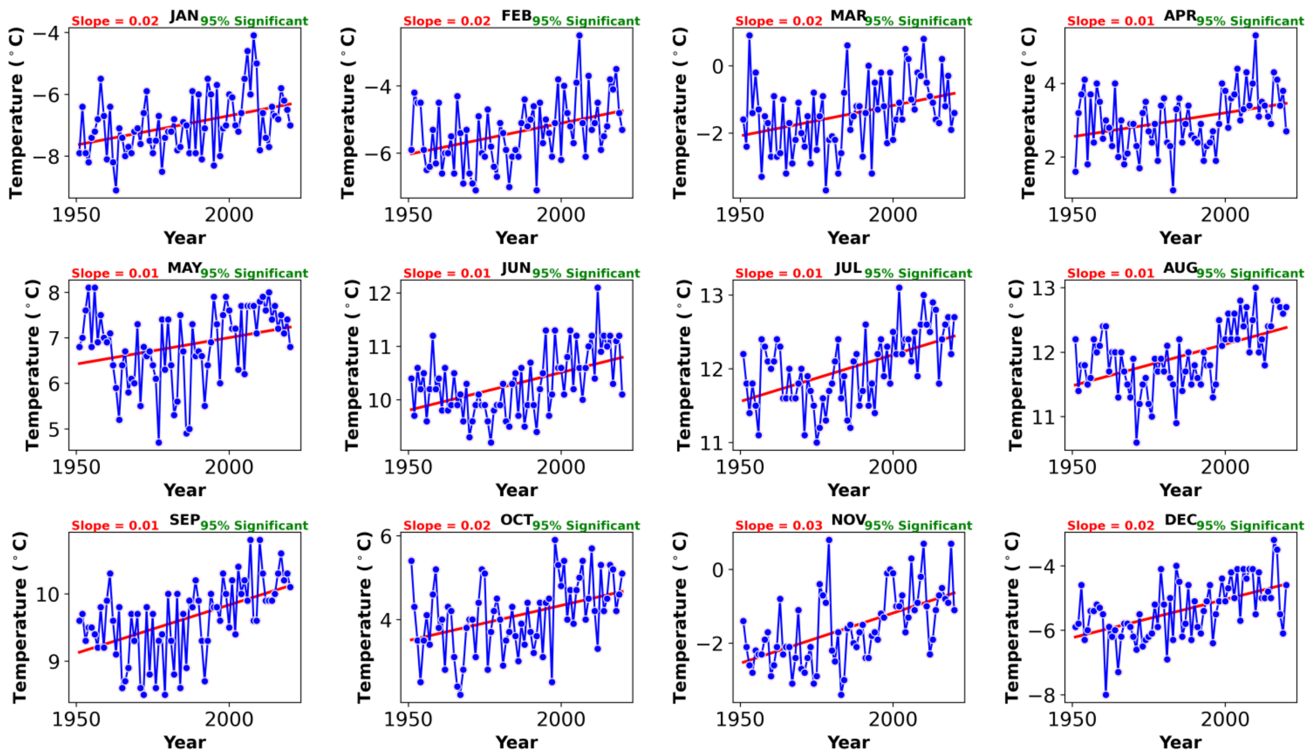

Fig: 6 Monthly variation of the trend of Tmin over Nepal for the year 1951-2020

4. Summary and conclusion:

The study concentrated on evaluating climate conditions and climate change over Nepal, examining annual and seasonal climatology, seasonal and monthly trends in accumulated precipitation, and mean Tmax and Tmin from 1951 to 2020.

1. Climatological findings indicate that the mean annual precipitation over Nepal ranges from 300-2700 mm/year. The peak amounts of around 2700 mm/year can be seen over central part of Nepal.
2. Annual mean Tmax in the low-altitude Terai region ranges between 24-28°C, while in the high-altitude mountain region, it varies between 4-8°C.
3. Annual mean Tmin in the Terai region ranges between 14-18°C, while in the high-altitude mountain region, it fluctuates between -6 to -10°C.
4. The central part of Nepal experiences maximum precipitation, reaching around 500 mm/season, during the monsoon.
5. During the monsoon season, Tmax reaches its peak, approximately 12-16°C in mountain areas and 32-36°C in the Terai region.
6. The winter season records the lowest Tmax temperatures, dropping below 0°C in mountain regions and ranging between 20-24°C in the Terai region.
7. Monsoon season witnesses the highest Tmin temperatures, peaking at approximately 4-8°C in mountain areas and 20-25°C in the Terai region.
8. Winter season records the lowest Tmin temperatures, dropping below -10°C in mountain regions and ranging between 5-10°C in the Terai region.
9. Nepal experienced a statistically significant 95% positive trend of 1.05mm/year in precipitation during the pre-monsoon and a negative trend of -1.05mm/year during the monsoon season.
10. There is also a statistically significant 95% positive trend in Tmax during post-monsoon (0.01^{o}C/year) and winter (0.009 ^{o}C/year), as well as Tmin for all seasons like MAM(0.01^{o}C/year), JJA(0.01^{o}C/year),SON(0.02^{o}C/year) and DJF(0.02 ^{o}C/year)

In conclusion, the study reveals a statistically significant increasing trend in precipitation during the pre-monsoon, Tmax in winter and post-monsoon, and Tmin for all seasons. Conversely, a significant decreasing trend in precipitation was observed during the monsoon season.

This study will be extended in future with detailed investigation of trends using IMDAA regional reanalysis data and to study the teleconnections affecting the weather and climate over Nepal.

5. Acknowledgments

The research conducted in this study leveraged the computational power of the MIHIR supercomputers at the NCMRWF. We are deeply grateful to our colleagues and fellow scientists at NCMRWF for their invaluable assistance throughout this endeavor. Furthermore, we extend our appreciation to the Head, NCMRWF for his encouragement and support. Special thanks to the anonymous reviewer whose evaluation of the report was greatly appreciated by the authors.

6. Author contribution

The study was designed collaboratively by all authors, with significant input from KS. KS performed the calculations and wrote the manuscript. All authors contributed to the modification of the manuscript.

7. References

1. Adhikari, A, P. & Mathema, A, B. 2023 Examining trends in temperature and precipitation mean/extremes over Gandaki Province, Nepal. Journal of Water and Climate Change Vol 14 No 7, 2342 doi: 10.2166/wcc.2023.066

2. Chen, R., Han, C., Liu, J., Yang, Y., Liu, Z., Wang, L. & Kang, E. 2018 Maximum precipitation altitude on the northern flank of the Qilian Mountains, northwest China. Hydrology Research 49 (5), 1696–1710. https://doi.org/10.2166/NH.2018.121.

3. Dhar ON &Nandargi S. 2002 Precipitation distribution around the Annapurna range of Nepal Himalayas—a brief appraisal. J Meteorol 27:377–382

4. Dhar, ON & Nandargi, S. 2005 Areas of heavy precipitation in the Nepalese Himalayas. Weather, Vol. 60, No. 12, RMETS, UK

5. Fort, M. 2014 Natural hazards versus climate change and their potential impacts in the dry, northern Himalayas: focus on the upper Kali Gandaki (Mustang District, Nepal). Environmental Earth Sciences 73 (2), 801–814. https://doi.org/10.1007/S12665-014-3087-Y.

6. Karki, R., Hasson, S., Schickhoff, U., Scholten, T. & Böhner, J. 2017 Rising precipitation extremes across Nepal. Climate 5 (1), 4.https://doi.org/10.3390/CLI5010004.

7. Karn, P. K. 2014 The impact of climate change on rice production in Nepal. SANDEE Working Paper No. 85-14. Kathmandu: SANDEE

8. Konchar, K. M., Staver, B., Salick, J., Chapagain, A., Joshi, L., Karki, S., Lo, S., Paudel, A., Subedi, P. & Ghimire, S. K. 2015 Adapting in the shadow of Annapurna: a climate tipping point. Journal of Ethnobiology 35 (3), 449–471. https://doi.org/10.2993/0278-0771-35.3.449.

9. Malla, G. 2008 Climate change and impact on Nepalese agriculture. Journal of Agriculture and Environment, 9(5)

10. Robinson P J and Henderson-Sellers A 1999 Contemporary characteristics; Addison Wesley, Longman, 317p.

11. Rustum, R., Adeloye, A. J. & Mwale, F. 2017 Spatial and temporal trend analysis of long term rainfall records in data-poor catchments with missing data, a case study of Lower Shire floodplain in Malawi for the period 1953–2010. Hydrology and Earth System Sciences Discussions [preprint]. https://doi.org/10.5194/HESS-2017-601.

12. Sigdel, K. P., Ghimire, N. P., Pandeya, B. & Dawadi, B. 2022 Historical and projected variations of precipitation and temperature and their extremes in relation to climatic

indices over the Gandaki River Basin, Central Himalaya. Atmosphere 13 (11), 1866. https://doi.org/ 10.3390/ATMOS13111866

13. You, Q., Min, J., Zhang, W., Pepin, N. & Kang, S. 2015 Comparison of multiple datasets with gridded precipitation observations over the Tibetan Plateau. Climate Dynamics 45 (3–4), 791–806. https://doi.org/10.1007/S00382-014-2310-6.

14. World Bank 2020 DataBank – World Development Indicators. URL: https://databank.worldbank.org/source/world-developmentindicators [accessed 19 Se

Appendix -I

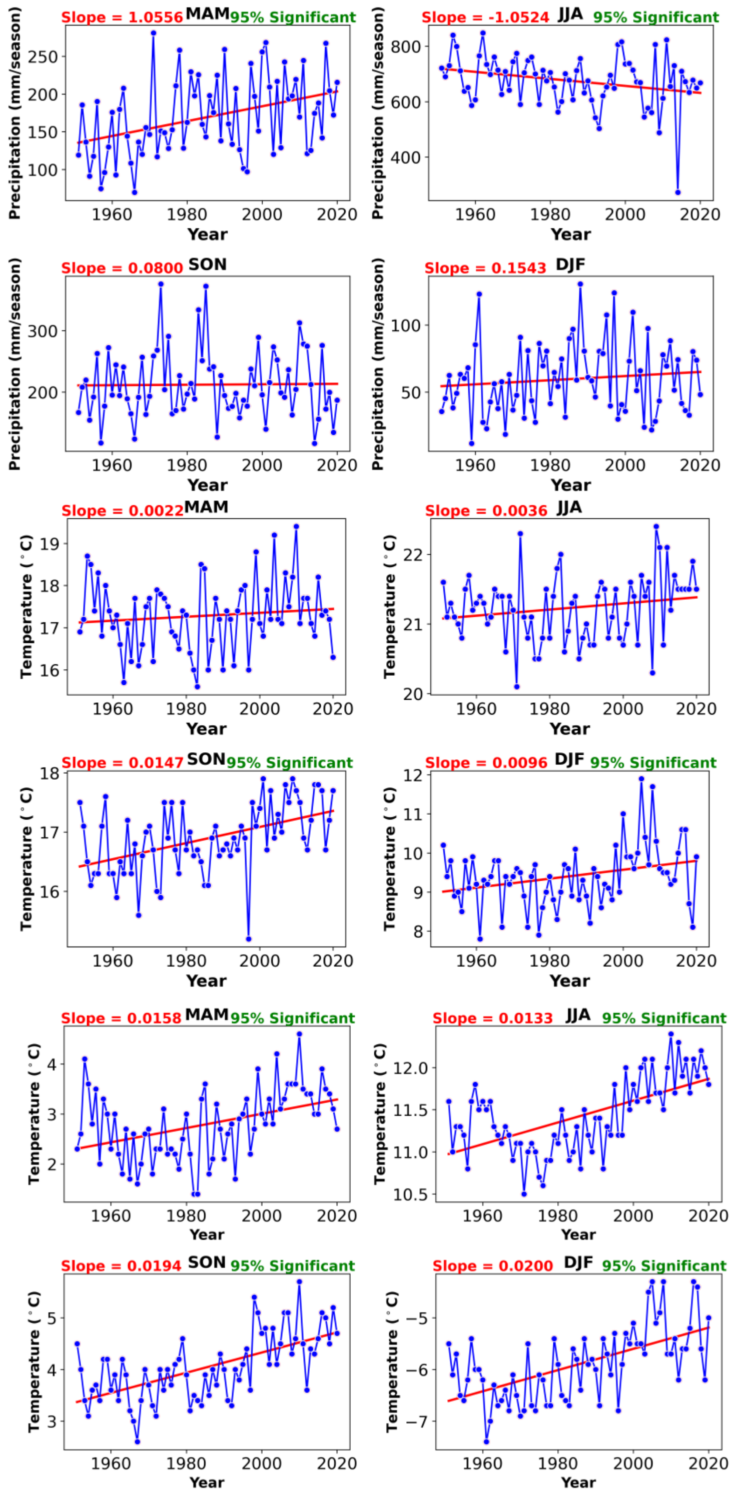

Figure: This figure displays the seasonal variation of 95% statistically significant linear trends for precipitation, Tmax and Tmin across Nepal during the period from 1951 to 2020.