Spatiotemporal Variability of Seasonal Precipitation in Central Dry Zone, Myanmar

Yin Yin Htwe[1], Thet Zin Htoo[1,2]
[1]Department of Civil Engineering, Mandalay Technological University, Mandalay, 05072, Myanmar;
[2]Department of Civil Engineering, Pandit Deendayal Energy University, Gandhinagar, 382426, Gujarat, India.
yinyinhtwe.civil@gmail.com, info.thetzinhtoo@gmail.com

Abstract – *This study investigates seasonal precipitation trends across ten townships in the Central Dry Zone (CDZ) of Myanmar using the non-parametric Mann-Kendall (MK) test and Sen's slope estimator. A 31-year record of historical precipitation data (1992–2022) was utilized to assess seasonal variations. The objective was to examine the spatiotemporal variability of rainfall and its implications for water resource management and agricultural planning in this climatically vulnerable region. The results revealed significant seasonal and spatial variability in precipitation trends. During the summer season, most stations exhibited either a slight positive trend or no statistically significant change, indicating relatively stable conditions. In contrast, the rainy season showed a general increasing trend across most townships, with the most pronounced increases observed in Naung-U, Yemathin, and Magway. Conversely, Shwebo and Monywa experienced decreasing trends, suggesting localized declines in monsoonal rainfall. No significant trends were detected during the winter season across all stations. Finally, QGIS software was used to develop seasonal trend maps of precipitation, providing a visual representation of the spatial distribution of trends. These findings underscore the complex nature of precipitation dynamics in the CDZ and highlight the need for localized climate adaptation strategies to enhance sustainable agriculture and water resource management in the face of ongoing climate change.*

Keywords: *Central dry zone, Precipitation, Non-parametric approach, Seasonal Variability, QGIS software*

INTRODUCTION

Climate change occurs when changes in Earth's climate system result in new weather patterns that last for at least a few decades, and may be for millions of years. Climate change is likely to affect hydrological cycle through precipitation, evapotranspiration and soil moisture etc. Global climate change has been an increasing challenge to agricultural ecosystems, which will significantly affect the reference evapotranspiration. All climatic parameters as well as precipitation and evapotranspiration are influenced by climate change. Changes in the world's climate have significant effect on water resources which affect the livelihood of people especially in arid and semi-arid regions [1],[2]. Precipitation is a key component of the global water cycle. Precipitation is also one of the most important climatic variables that has a direct and indirect impact of agricultural production and ecosystem health. Changes in rainfall intensity, quantity, and spatiotemporal patterns often lead to extreme events such as droughts and floods. These changes may require adjustments to current strategies of planning and management of water resources. Analysis of the spatial distribution and temporal trends of precipitation is crucial for water resource management, agricultural productivity and climate change mitigation [1],[2],[3].

Myanmar is one of the country's most vulnerable to the impacts of climate change, with its agriculture-based economy and communities highly sensitive to fluctuations in weather and water availability [4], [5]. In recent years, the monsoon weather pattern, Myanmar's primary source of rainfall has become increasingly unpredictable in terms of onset, duration, and intensity, leading to both droughts and floods across different regions [1], [7]. Analyzing and understanding the spatiotemporal characteristics of precipitation in Myanmar is essential for addressing water-related challenges such as water scarcity, declining agricultural productivity, and increasing competition over water resources [8]. Moreover, human activities such as deforestation, land-use change, and the expansion of irrigated agriculture further disrupt the natural water cycle, amplifying the impacts of climate variability and hydrological extremes [9].

The Central Dry Zone (CDZ) of Myanmar is increasingly affected by climate variability, with precipitation patterns becoming more erratic and unpredictable. Given that agriculture and water supply in the CDZ are heavily reliant on seasonal rainfall, changes in precipitation directly influence crop yields, water availability, and rural livelihoods. Despite the critical role of precipitation, there is a lack of detailed studies on the spatial and temporal variability of rainfall in the region. Without reliable information and analysis, local authorities and farmers are unable to effectively plan for climate-resilient agricultural practices and water resource management. This gap presents a significant challenge to achieving sustainable development and food security in one of Myanmar's most vulnerable regions. Therefore, this study was undertaken to analyze long-term precipitation trends in the CDZ, providing essential data and insights needed to support informed decision-making and promote sustainable development in one of Myanmar's most climate-sensitive regions.

OBJECTIVES

The objectives of this study are:

1. To analyze long-term precipitation trends in the Central Dry Zone of Myanmar using non-parametric statistical methods.
2. To develop seasonal precipitation trend maps to visualize changes across the Central Dry Zone.

STUDY AREA

The boundary of the central dry zone region of Myanmar is generally defined between the North latitudes 19° 20′ to 22° 50′ and East longitudes 93°40′ to 96° 30′. The study area encompasses three major regions in Myanmar: Mandalay Region, Sagaing Region, and Magway Region which located within the Central Dry Zone (CDZ), a region characterized by low rainfall, high temperatures, and significant vulnerability to climate variability. The locations of the study area are illustrated in Figure 1.

Collection of Meteorological Data

In this study, precipitation of 31 years record (1992-2002) are collected from the Department of Meteorology and Hydrology, Upper Myanmar. To analyze the seasonal variability of precipitation across this climate-sensitive area, ten meteorological stations have been selected based on their geographic distribution, data availability, and representation of key environmental conditions. These include five stations in Mandalay Region (Yamethin, Kyaukse, NaungU, Meilhtila, Myingyan), three in Sagaing Region (Monywa, Shwebo, Sagaing), and three in Magway Region (Magway, Minbu). The selected stations are presented in Figure 2.

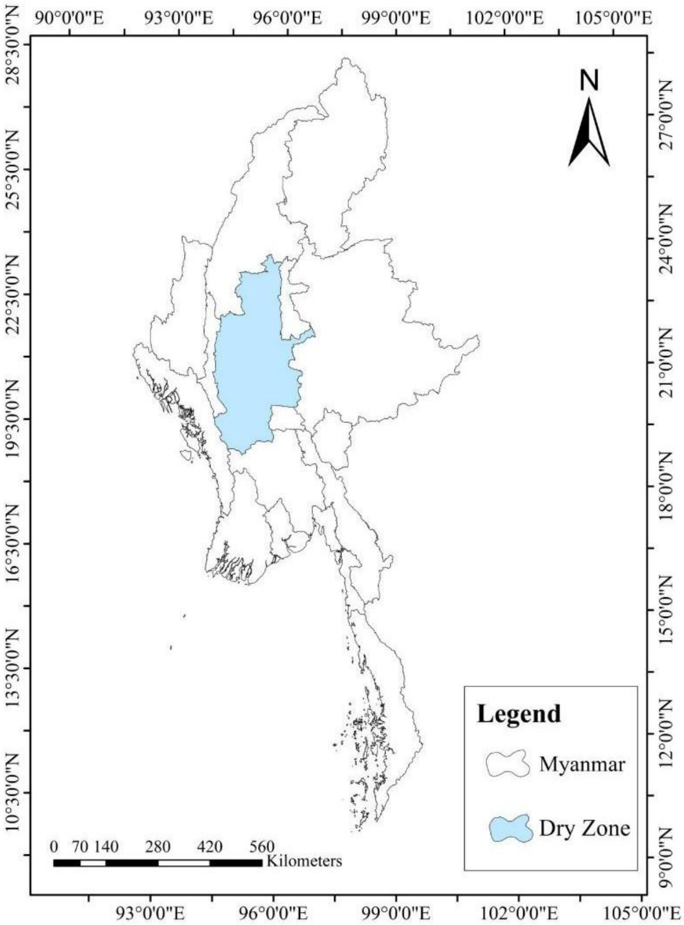


Figure 1. Locations of the study area

METHODOLODY

Trend detection of precipitation was conducted using two widely applied non-parametric statistical methods: the Mann-Kendall (MK) test and Sen's slope estimator. The MK test was used to assess trends in the data, while Sen's slope estimator quantified the rate of change over time. Both methods were applied to monthly precipitation data to capture seasonal variations and evaluate the statistical significance of detected trends.[5][6]

A. Mann-Kendall test

The Mann-Kendall test is a non-parametric test used for identifying trends in time series data. This test is carried out on monthly precipitation.

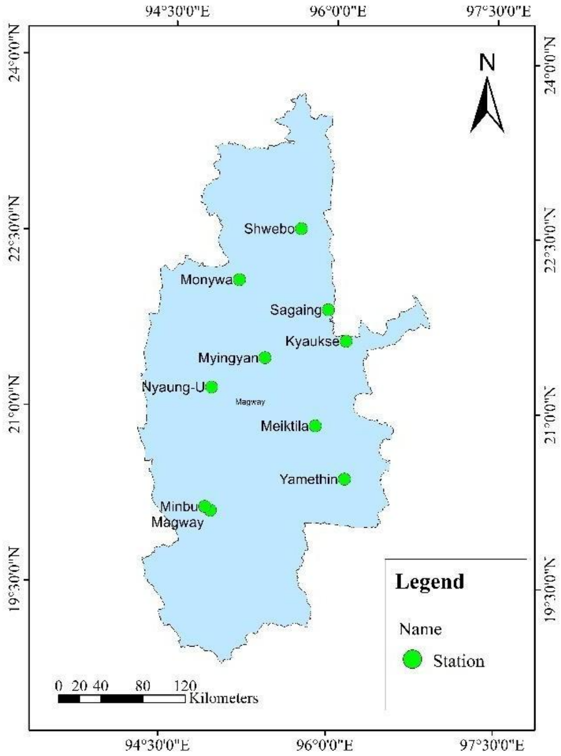


Figure 2. Locations of the selected stations in central dry zone

Kendall's statistic S is obtained using the following equations;

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad (1)$$

$$\operatorname{sgn} = \begin{cases} +1, \text{if } (x_j - x_k) > 0 \\ 0, \text{if } (x_j - x_k) = 0 \\ -1, \text{if } (x_j - x_k) < 0 \end{cases} \quad (2)$$

where,

S = Mann-Kendall's statistic,
x_j, x_k = data values at time j and k (j>k).

$$V = \frac{n(n-1)(2n+5) - \sum_{j=1}^{g} t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

where,

V = variance of S,
n = number of periods,
t_i =number of ties in group i.

$$Z_s = \begin{cases} \frac{(S-1)}{V^{0.5}} \text{ for } \rightarrow S > 0 \\ 0, \text{ for } \rightarrow S = 0 \\ \frac{(S+1)}{V^{0.5}}, \text{ for } \rightarrow S < 0 \end{cases} \quad (4)$$

where,

Z_s = Normal Standard Deviate

B. Sen-Slope Estimator Test

Sen's estimator of slope, which is a non - parametric method, was used to develop linear models in this study. This test is also done based on monthly precipitation. This method offers many advantages that have made it useful in analyzing atmospheric chemistry data. Missing values are allowed and the data need not conform to any particular distribution.

If a linear trend is present, the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen. The test procedure is given below in detail. The slope estimates of N pairs of data are first computed by

$$Q_i = \left(\frac{x_j - x_k}{j-k}\right) \quad (i=1,\ldots\ldots, N) \quad (5)$$

where,

Q_i = slope estimates of the pairs of data
x_j ,x_k = data values at times j and k (j > k)

The median of these N values of Q_i is Sen's estimator of slope. If there is only one datum in each time period, then N = n (n–1)/2 where n is the number of time periods. If N is odd, then Sen's estimator is computed by

$$Q_{median} = Q_{(N+1)/2} \quad (6)$$

If N is even, then Sen's estimator becomes

$$Q_{median} = \frac{\left[Q_{N/2}\right] + \left[Q_{(N+2)/2}\right]}{2} \quad (7)$$

The detected value of Q_{median} is tested by a two-sided test at the 100(1 –α) % confidence interval and true slope may be obtained by the non-parametric test.

RESULTS AND DISCUSSION

Seasonal precipitation trends across ten townships in the Central Dry Zone (CDZ) of Myanmar were analyzed using 31 years of monthly precipitation data (1992–2022). The non-parametric Mann-Kendall (MK) test was applied to detect the presence and direction of trends, while Sen's slope estimator was used to quantify the rate of change. Trend analysis was conducted on a seasonal basis; summer, rainy, and winter to capture variations in rainfall patterns across different times of the year.

A. Mann-Kendall trend test for seasonal analysis

The rank-based nonparametric Mann-Kendall method was applied to the long-term data to detect statistically significant trends for 90%, 95% and 99% confidence level. In this test, the null hypothesis (H_0) was that there has been no trend in precipitation over time; the alternate hypothesis (H_1) was that there has been a trend (increasing or decreasing) over time. If $\|$ > $Z_{1-\alpha/2}$, (H_0) is rejected and a statistically significant trend exists in the hydrologic time series. The critical value of $Z_{1-\alpha/2}$ for 90%,95% and 99% confidence level are ± 1.64, ± 1.96 and ±2.54 respectively. Z statistics is calculated using described equations and the results of the test for summer, rainy and winter season are presented in Table I, II and III respectively. And QGIS software are used to develop map for seasonal variability with 90%, 95% and 99% confidence level are shown in Figure 3, Figure 4 and Figure 5 respectively.

Table I. Mann-Kendall trend test for summer season

No	station	Z Statistics	level of confidence		
			90%	95%	99%
1	Shwebo	z = 0.7112	No Trend	No Trend	No Trend
2	Monwya	z = 0.9899	No Trend	No Trend	No Trend
3	Sagaing	z = 0.4544	No Trend	No Trend	No Trend
4	Myingyan	z = 0.2150	No Trend	No Trend	No Trend
5	Yemathin	z = 0.3439	No Trend	No Trend	No Trend
6	Kyaukse	z = 1.5148	No Trend	No Trend	No Trend
7	Magway	z = 0.4293	No Trend	No Trend	No Trend
8	Meikhtila	z = 0.7664	No Trend	No Trend	No Trend
9	NaungU	z = 0.1914	No Trend	No Trend	No Trend
10	Minbu	z = 0.424	No Trend	No Trend	No Trend

According to the Mann-Kendall (MK) test for the summer season, the analysis indicates no statistically significant trends in precipitation at any of the selected confidence levels (90%, 95%, and 99%) across all townships, suggesting a relatively stable precipitation pattern during this season. In contrast, the winter season reveals notable spatial variations. Both Yamethin and Nyaung-U townships exhibit increasing trends in precipitation at the 90% confidence level, while Nyaung-U also demonstrates a statistically significant increasing trend at the 95% confidence level. These results highlight localized shifts in winter precipitation, particularly in Nyaung-U, which may have implications for agricultural planning and water resource management. The remaining townships show no significant trend in winter precipitation at any of the evaluated confidence levels, indicating stability in those areas. Moreover, when examining monthly precipitation trends during the winter season, only Yamethin township shows a statistically significant upward trend at the 90% confidence level. All other townships show no significant trends at any of the selected confidence levels, further emphasizing the localized nature of observed changes.

Table II. Mann-Kendall trend test for rainy season

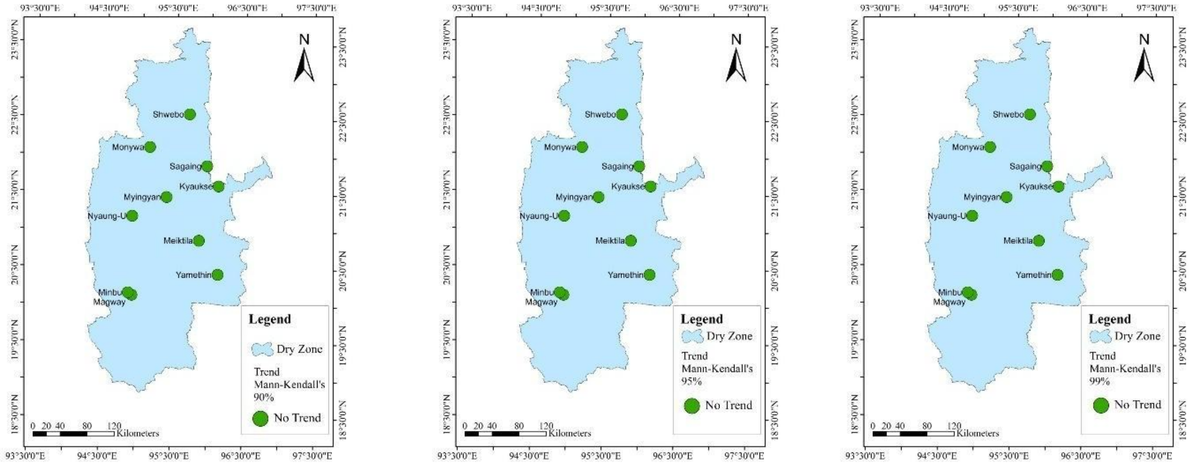
No	station	Z Statistics	level of confidence		
			90%	95%	99%
1	Shwebo	z = -0.7603	No Trend	No Trend	No Trend
2	Monwya	z = -0.8143	No Trend	No Trend	No Trend
3	Sagaing	z = -0.0734	No Trend	No Trend	No Trend
4	Myingyan	z = 1.5595	No Trend	No Trend	No Trend
5	Yemathin	z = 1.8251	Increasing	No Trend	No Trend
6	Kyaukse	z = 1.1296	No Trend	No Trend	No Trend
7	Magway	z = 1.4904	No Trend	No Trend	No Trend
8	Meikhtila	z = 0.9028	No Trend	No Trend	No Trend
9	NaungU	z = 2.2744	Increasing	Increasing	No Trend
10	Minbu	z = 1.3155	No Trend	No Trend	No Trend

Table III. Mann-Kendall trend test for winter season

No	station	Z Statistics	level of confidence		
			90%	95%	99%
1	Shwebo	z = 0.1883	No Trend	No Trend	No Trend
2	Monwya	z = -0.2514	No Trend	No Trend	No Trend
3	Sagaing	z = -0.0743	No Trend	No Trend	No Trend
4	Myingyan	z = 0.7384	No Trend	No Trend	No Trend
5	Yemathin	z = 1.9164	Increasing	No Trend	No Trend
6	Kyaukse	z = 1.528	No Trend	No Trend	No Trend
7	Magway	z = -0.8150	No Trend	No Trend	No Trend
8	Meikhtila	z = 0.5835	No Trend	No Trend	No Trend
9	NaungU	z = 0.1454	No Trend	No Trend	No Trend
10	Minbu	z = 0.1693	No Trend	No Trend	No Trend

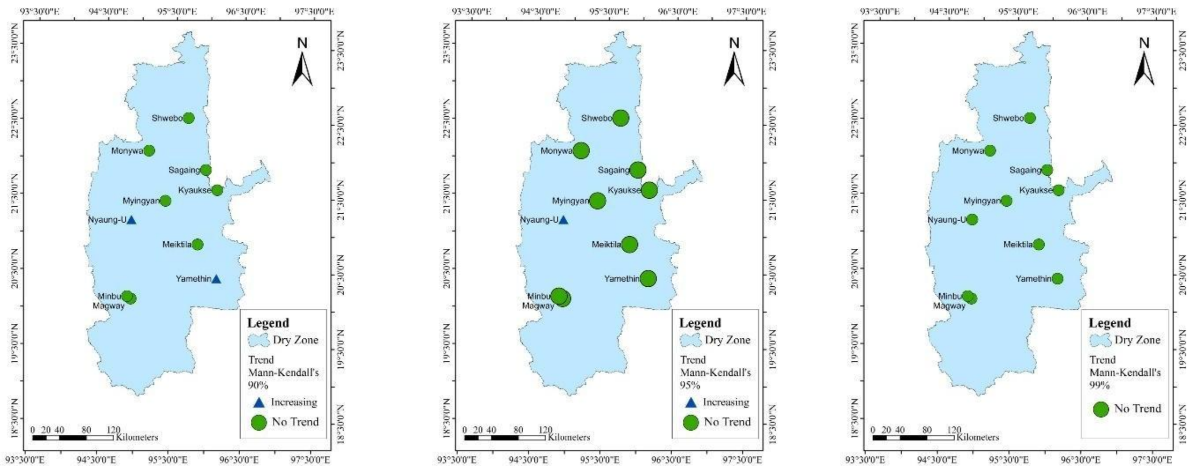
B. Sen's Slope estimator test for seasonal analysis

The seasonal precipitation trends across ten meteorological stations in the Central Dry Zone were assessed using Sen's slope estimator, which indicates both the direction and magnitude of change in precipitation over time. Sen's Slope test results for monthly precipitation in seasonal analysis at selected stations were presented in Table IV. Map of variability for monthly precipitation are developed using QGIS sosftware and demostrated in Figure 6, Figure 7 and Figure 8.



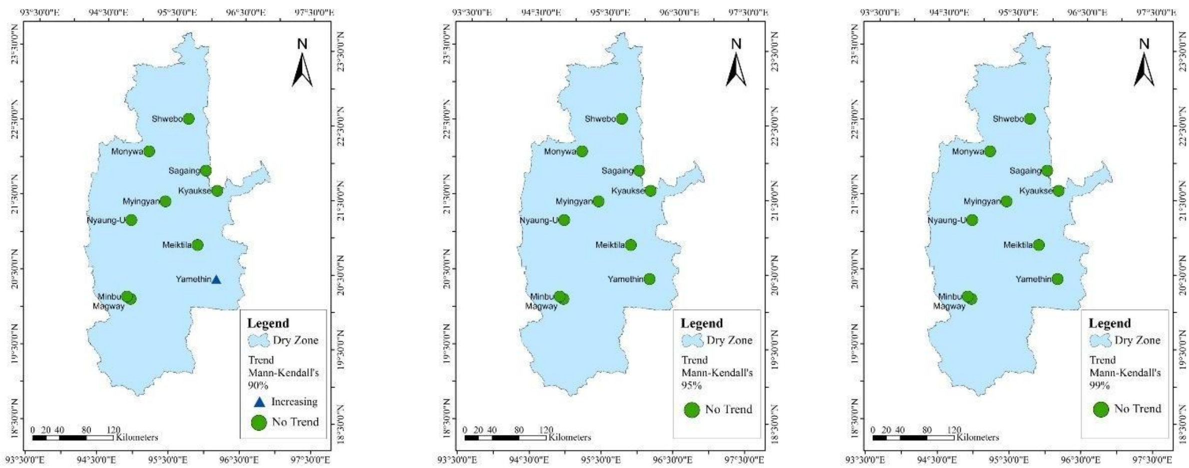
(a) 90 % confidence level (b) 95 % confidence level (c)99 % confidence level

Figure 3. Location of site with trend at 90%, 95% and 99% confidence level for monthly precipitation (summer season)



(a) 90 % confidence level (b) 95 % confidence level (c) 99 % confidence level

Figure 4. Location of site with trend at 90%, 95% and 99% confidence level for monthly precipitation (rainy season)



(a) 90 % confidence level (b) 95 % confidence level (c)99 % confidence level

Figure 5. Location of site with trend at 90%, 95% and 99% confidence level for monthly precipitation (winter season)

Table IV. Sen's Slope estimator test for seasonal analysis

No	Station	Sen's slope (Q_{median})					
		Summer		Rainy		Winter	
1	Shwebo	0.0118	Positive	-0.1745	Negative	0	No Trend
2	Monwya	0.0833	Positive	-0.1785	Negative	0	No Trend
3	Sagaing	0.0108	Positive	-0.0124	Negative	0	No Trend
4	Myingyan	0	No Trend	0.2500	Positive	0	No Trend
5	Yemathin	0	No Trend	0.2964	Positive	0	No Trend
6	Kyaukse	0.1382	Positive	0.1585	Positive	0	No Trend
7	Magway	0	No Trend	0.2849	Positive	0	No Trend
8	Meikhtila	0.0203	Positive	0.1937	Positive	0	No Trend
9	NaungU	0	No Trend	0.3872	Positive	0	No Trend
10	Minbu	0	No Trend	0.2068	Positive	0	No Trend

In the summer season, most stations showed either a positive trend or no significant trend. Positive trends were observed in Shwebo (0.0118), Monywa (0.0833), Sagaing (0.0108), Kyaukse (0.1382), and Meikhtila (0.0203), suggesting a gradual increase in precipitation. These increases, although modest in magnitude, may reflect localized variability in summer rainfall. On the other hand, Myingyan, Yemathin, Magway, Naung-U, and Minbu showed no significant trend, indicating stable summer precipitation over the analysis period.During the rainy season, most stations exhibited a positive trend, indicating an increasing pattern in rainfall. The highest positive Sen's slope was recorded at Naung-U (0.3872), followed by Yemathin (0.2964), Magway (0.2849), Myingyan (0.25), and Minbu (0.2068). Other stations such as Meikhtila (0.1937), Kyaukse (0.1585), and Monywa (–0.1785) also showed notable trends.

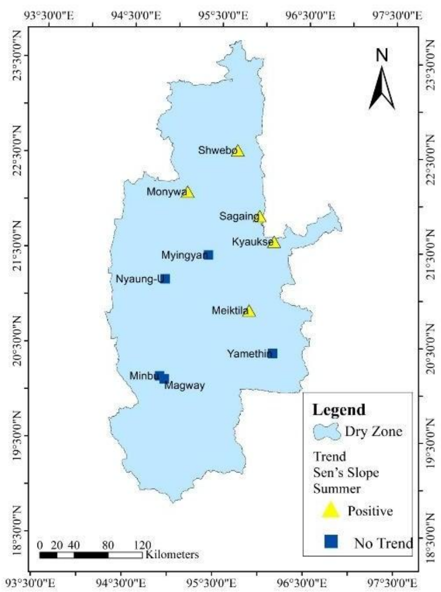


Figure 6. Sen's Slope trend map of stations with increasing trends and no trend in precipitation during the summer season.

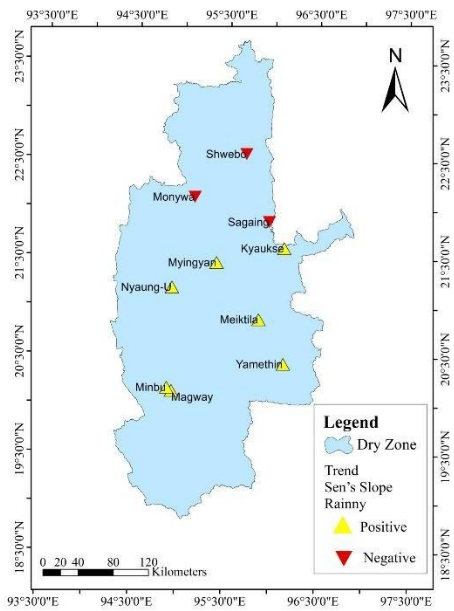


Figure 7. Sen's Slope trend map of stations with increasing trends and decreasing trend in precipitation during the rainy season

However, Monywa and Shwebo demonstrated negative slopes (–0.1785 and –0.1745 respectively), suggesting a decreasing rainfall trend in the rainy season for these locations. These results indicate that while most areas are experiencing increased monsoonal rainfall, a few stations may be facing reduced rainfall, which could impact water availability and crop productivity.The winter season shows no significant trend across all ten stations, with all Sen's slope values being zero. This consistent result suggests that winter precipitation patterns have remained stable over the analysis period in the Central Dry Zone. The lack of trend may reflect the generally low and variable nature of winter rainfall in this region, which typically contributes the least to the annual precipitation total.

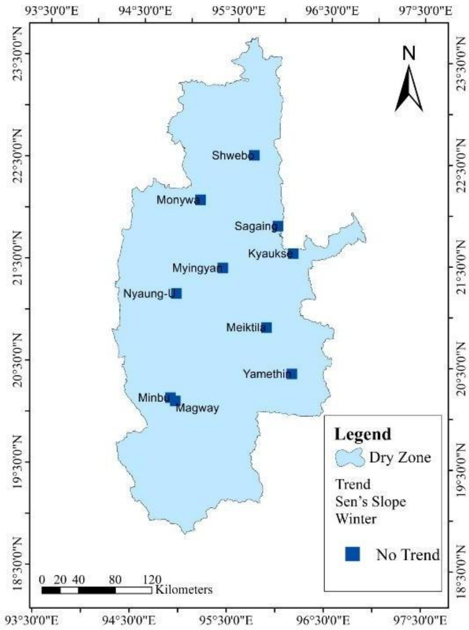


Figure 8. Sen's Slope trend map of stations with no trend in precipitation during winter season.

CONCLUTION

This study analyzed seasonal precipitation trends across ten townships in the Central Dry Zone of Myanmar using the Mann-Kendall (MK) test and Sen's slope estimator. The results revealed distinct spatial and seasonal variations in rainfall patterns. During the summer season, most stations exhibited either a slight positive trend or no significant trend, indicating relatively stable rainfall conditions. In contrast, the rainy season showed a general increasing trend in precipitation across the majority of townships, with the highest rates observed in Naung-U, Yemathin, and Magway. However, Shwebo and Monywa presented decreasing trends, suggesting localized declines in monsoonal rainfall. The winter season displayed no significant trend at any station, reflecting a consistent but low level of rainfall during this period. These findings highlight the complexity of precipitation dynamics within the Central Dry Zone and underscore the need for localized climate adaptation strategies. Understanding these seasonal and spatial variations is essential for effective planning in agriculture, water resource management, and climate resilience. Continued monitoring and targeted interventions will be critical to address the challenges posed by both increasing and decreasing rainfall trends in different parts of the region.

REFERENCES

[1] IPCC. (2021). Climate Change 2021: *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press. https://doi.org/10.1017/9781009157896

[2] FAO. (2016). *Climate change and food security: risks and responses*. Food and Agriculture Organization of the United Nations.

[3] WMO. (2012). *International Glossary of Hydrology* (3rd ed.). World Meteorological Organization.

[4] UNDP (2012), *Climate Change Vulnerability in Myanmar*, United Nations Development Programme.

[5] MOECAF (2012), *Myanmar's National Adaptation Programme of Action (NAPA) to Climate Change*, Ministry of Environmental Conservation and Forestry, Myanmar.

[6] FAO (2017), *Myanmar Climate-Smart Agriculture Strategy*, Food and Agriculture Organization of the United Nations. [Online]. Available: http://www.fao.org/3/i8465en/I8465EN.pdf

[7] ADB (2019), *Myanmar: Climate Change and Water Resources*, Asian Development Bank. [Online]. Available: https://www.adb.org

[8] Hussain F, Nabi G, Waseem Boota M. (2015). *Rainfall Trend Analysis by Using the Mann-Kendall Test & Sen'S Slope Estimates: A Case Study of District Chakwal Rain Gauge, Barani Area,* Northern Punjab Province, Pakistan. Sci Int (Lahore);27(4):3159–65.

[9] Mann, H. B., & Kendall, M. G. (1945). *Non-parametric tests against trend*. Econometrica, 13(3), 245–259. https://doi.org/10.2307/1907187

[10] Sen, P. K. (1968). *Estimates of the regression coefficient based on Kendall's tau.* Journal of the American Statistical Association, 63(324), 1379–1389

[11] Yue, S., Pilon, P., Phinney, B., & Cavadias, G. (2002). *The influence of autocorrelation on the ability to detect trend in hydrological series*. Hydrological Processes, 16(9), 1807–1829. https://doi.org/10.1002/hyp.1095

[12] Yue, S., & Wang, C. Y. (2004). *The Mann–Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series*. Water Resources Management, 18(3), 201–218.

[13] Helsel, D. R., & Hirsch, R. M. (2002). *Statistical Methods in Water Resources (Vol. 323). U.S. Geological Survey, Techniques of Water-Resources Investigations.*

[14] Muia VK, Opere AO, Ndunda E, Amwata DA (2024). *Rainfall and temperature trend analysis using Mann–Kendall and Sen's slope estimator test in Makueni County, Kenya*. J Mater Environ Sci;15(3):349–67.

[15] Sun N, Wigmosta MS, Wada Y, Bierkens MFP, Shehabi A (2023). *An investigation of the changing patterns of rainfall in the Indravathi Subbasin utilizing the Mann-Kendall and Sen's slope methods*. IOP Conf Ser Earth Environ Sci; 1173:012036

[16] Mulugeta S, Fedler C, Ayana M (2019). *Analysis of long-term trends of annual and seasonal rainfall in the Awash River Basin, Ethiopia*. Water (Switz);11(7):1498.

[17] Wilks, D. S. (2011), *Statistical Methods in the Atmospheric Sciences* (3rd ed.), A comprehensive textbook covering statistical tools used in climate science, including non-parametric tests like Mann-Kendall and methods for detecting trends and variability.

[18] Helsel, D. R., & Hirsch, R. M. (2002), *Statistical Methods in Water Resources*, U.S. Geological Survey, Focused on hydrological data analysis with detailed guidance on non-parametric methods like Mann-Kendall and Sen's slope.

[19] WMO (World Meteorological Organization). (2008), *Guide to Climatological Practices* (WMO-No. 100), Offers procedures and standards for analyzing climatological data, including trend analysis and rainfall variability.

[20] Maidment, D. R. (Ed.). (1993), Handbook of Hydrology, McGraw-Hill, *An authoritative reference covering*

hydrologic processes, data management, and analysis techniques. Ideal for advanced water resource studies.

[21] Burn, D. H., & Elnur, M. A. H. (2002), *Detection of hydrologic trends and variab*ility. Journal of Hydrology, 255(1–4), 107–122.

[22] Yue, S., & Wang, C. Y. (2004). *The Mann–Kendall test modified by effective sample size to detect trend in serially correlated hydrological series*. Water Resources Management, 18(3), 201–218.

[23] Kumar, V., Jain, S. K., & Singh, Y. (2010). *Analysis of long-term rainfall trends in India*. Hydrological Sciences Journal, 55(4), 484–496.

[24] Agbo EP, Nkajoe U, Edet CO. (2023) *Comparison of Mann–Kendall and Şen's innovative trend method for climatic parameters over Nigeria's climatic zones*. Clim Dyn; 60:3385–401.

[25] Ussalu JLM, Bassrei A (2023). *Long memory and trend in time series of precipitation in Mozambique*. Theor Appl Climatol;154(1–2):643–59.

[26] Sumila TCA, Ferraz SET, Durigon A (2023) . Evaluating possible changes in air temperature and precipitation patterns in Mozambique by comparing present and future RegCM4 simulation. Meteorology;2(1):15–36.