Changes in Temperature and Precipitation and their Extreme Indices over Dry Zone Area in Central Myanmar

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***Abstract*- Dry zone is situated in central part of Myanmar in Magway, Mandalay, and lower Sagaing regions and covers 10 percent of country. This area falls under arid to semi-arid zone with low rainfall, intense heat and degraded soil conditions. The dry zone is one of the most vulnerable areas to the climate change impacts as compared to other parts of the country which affecting on ecosystem services and communities living in this region. The main objective of this study is to improve our**

understanding of the long term variations and extreme changes in temperature and precipitation in dry zone region. Such information is necessary for quantifying the impacts of climate change. Temperature and precipitation data over 41-year period (1975-2015) from five selected meteorological stations (Mandalay, Monywa, Meikthila, Minbu, Pyinmana) as proxies to their changes in this region were analyzed. The results indicated the increase in maximum temperature by 0.25℃~0.35℃/decade and minimum temperature by 0.04℃~0.27℃/decade. During 1975 and 2015, most of the temperature extremes showed significant warming trends. Trends in annual total precipitation and number of heavy precipitation days indicate the slightly increase with 2~28 mm/decade and 0.25~0.97 mm/decade, respectively. Therefore, it is evident that significant changes in climate patterns and extreme climate parameters have occurred in this area. This information could be applied for evaluating the impacts of climate variable on local community, ecosystems and biodiversity.

***Keywords* – Climate extremes, Dry zone, Precipitation, Temperature, Myanmar**

I. INTRODUCTION

Extreme weather and climate events have a negative impact on ecosystems, economies, and communities in a variety of ways [1]. Due to increasing trends of several climate extreme events such as cyclones, intense rainfall, floods, droughts, and landslides, the agricultural production, water resources and environment are under threats [2]. Many parts of the world have been experienced the climate extremes during the last century [3]. In recent years developing countries including Myanmar are more vulnerable than developed countries in terms of climate risk index due to exceptional catastrophes and low-income. According to the Global Climate Risk Index (2016), Myanmar is the second highest vulnerability country in terms of climate extreme events and socio-economic losses during the past 20 years [4]. Several researches have been conducted in understanding of the trends in climate extremes on global and regional scale (e.g., [5]-[10]). However, long term climate data for the Southeast Asia and Asia-Pacific region is limited, especially at the country level [11]. Manton *et al.* [8] selected 6 synoptic stations in Myanmar and reported the overall warming trend in the region with increased in hot days and warm nights as well as a decrease in cold days and cold nights. In addition, the frequency of precipitation has declined with statistical insignificance.

The aim of this study is to evaluate trends and extreme indices over 41 years of daily temperature and precipitation in a dry zone region in Myanmar and in order to improve our understanding of the long term variations and extreme changes in this area. The results would benefit for both future evaluation of the impacts of climate changes as well as for finding out the appropriate measures for adaptation.

II. MATERIAL AND METHODS

A. Study Area

Dry zone is located in central part of Myanmar in Magway, Mandalay, and lower Sagaing regions. The area covers about 10 percent of country with a population of about 12 million. Livelihoods in this area mainly depend on the south-west monsoon. Average annual rainfall in dry zone is the lowest (500-1000 mm/year) and the variation of seasonal temperature is highest ranging from a minimum of 10-15°C to a maximum of 40-43°C within the country. Thus, this region is characterized by low rainfall, intense heat, degraded soil conditions, and lack of significant surface water availability which affect the ecosystem services of the local communities [13]. Moreover severe drought has been experienced in 2005 and drought has become more frequent in this region [13]. Considering the data availability, this study focused on five major cities of central dry zone, namely, Mandalay, Minbu, Meikthila, Monywa, and Pyinmana, as shown in Fig. 1.

B. Data Collection

Long term time series data of daily maximum temperature (°C), minimum temperature (°C), and daily precipitation (mm) of five stations were collected from the Department of Meteorology and Hydrology (DMH), Nay Pyi Taw, Myanmar for the period of 1975 to 2015 as shown in Table I. However, Minbu station has data gap between 1975 to 1980 periods and is assigned as no data.

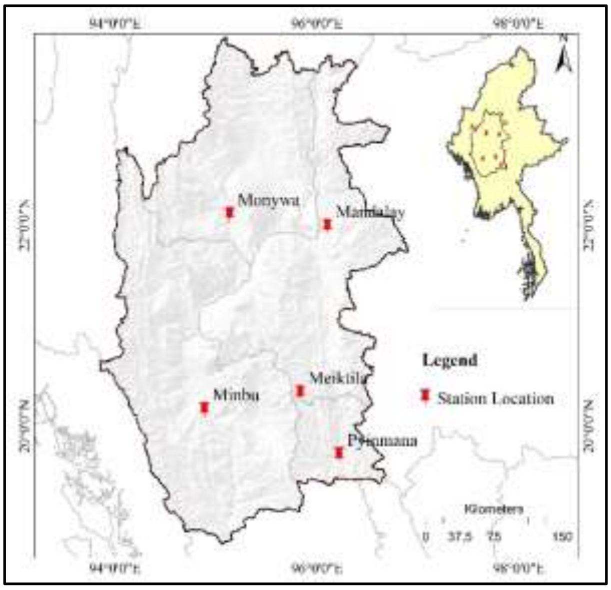

Fig. 1. Location map of the study areas located in Myanmar's central dry zone

C. Data Quality and Homogeneity Checks

The data quality control and homogeneity are necessary for statistical analysis as climatic trends are very sensitive to errant values and outliers from a numerous sources [14, 15]. Prior to analysis of climate data, it is important to remove the data errors and outliers in standard methodological manner [14]. In this study, the basic quality control and temporal outliers check were carried out for all data sets using [14, 15]. During the basic quality control checking, the following errors such as missing value, negative precipitation value (human typing error), daily maximum temperature is less than or equal daily minimum temperature, and daily maximum or minimum temperature is greater than 70°C were detected [16]. All errors from basic quality control were assigned as no data. The temporal outliers check for a specific station is based on the premise that an individual monthly value should be statistically "similar" to the values of the same month from the other years. Outliers were identified by utilizing the sample distribution for each month of individual station. Extreme values are flagged out based on limited determination from a multiple of the interquartile range calculated for each station and each month using Eq (1). This procedure is common in exploratory data analysis procedures. An outlier is flagged using the formula [15];

$$Xij - q50j > f*IRj \qquad \text{Eq (1)}$$

where,

Xij is the observed values on *i* date in *j* month.

q50j is the median (or the 50th percentile) in *j* month.

f is the multiplication factor (f = 5).

IRj is interquartile range (75th percentile minus 25th percentile) in *j* month.

After data have been passed the quality control, the temporal homogeneity test was carried out using RHtestsV4 software developed by Climate Research Division of Atmospheric Science and Technology Branch of Canada [17]. This method detects and adjusts for the multiple change points based on the penalized maximal *t test* and penalized maximal *F test* which are embedded in a recursive testing algorithm.

TABLE I

DETAIL INFORMATION FOR METEOROLOGICAL STATION

Station Name	Station Code (WMO Standard)	Latitude (DD)	Longitude (DD)	Elevation (m)	Data Availability
Mandalay	48042	21.98	96.10	78	1975-2015
Meikthila	48053	20.33	95.83	214	1975-2015
Minbu	48064	20.17	94.88	51	1975-2015
Monywa	48037	22.10	95.13	81	1975-2015
Pyinmana	48074	19.72	96.22	95	1975-2015

D. Calculating Extreme Indices

Expert Team on Climate Change Detection, Monitoring, and Indices (ETCCDMI) has defined a core set of 27 extreme indices for temperature and precipitation with user friendly R-based software, RClimDex. All of the extreme indices (seven for temperature and nine for precipitation, Table II) are computed from the daily observation of temperature and precipitation using RClimDex software [18]. These indices are recommended by the Climate Variability and Predictability (CLIVAR) as well as adopted by the IPCC AR4.

TABLE II

LIST OF TEMPERATURE AND PRECIPITATION INDICES IN THIS STUDY

ID	Indicator	Definitions	Units
Tmaxmean	Mean max temp	Annual mean maximum temperature	°C
Tminmean	Mean min temp	Annual mean minimum temperature	°C
SU33/32	Summer days	Annual count when TX(daily maximum)>33/32 °C	Days
TN10p	Cool nights	Percentage of days when TN<10th percentile	Days
TX10p	Cool days	Percentage of days when TX<10th percentile	Days
TN90p	Warm nights	Percentage of days when TN>90th percentile	Days
TX90p	Warm days	Percentage of days when TX>90th percentile	Days
R10	Heavy precipitation days	Annual count of days when PRCP>=10mm	Days
R20	Very heavy precipitation days	Annual count of days when PRCP>=20 mm	Days
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
R95p	Very wet days	Annual total PRCP when RR>95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	mm
CDD	Consecutive dry days	Maximum number of consecutives days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutives days with RR>=1mm	Days

E. Anomaly and Trend Identification

To evaluate the variation of climate pattern, anomalies based on the difference between mean temperature in each year and the long-term average for the period 1975-2015 are calculated. The observed mean annual maximum temperatures (Tmaxmean) or annual minimum temperature (Tminmean) were then plotted in time series.

The statistical significance of the trends was calculated using ordinary least square method. The Thiel-Sen nonparametric method is used to estimate the slope of linear trends [19]. This method is frequently applied in previous climatological studies (e.g. [20, 21]) and which outperforms the least squares regression in computing the magnitude of linear trends when the sample size is large [22]. The 95% significant levels were used to consider a trend to be statistically significant. The slope estimates of *N* pairs of data are first computed by;

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{For } i = 1,\ldots,N \qquad \text{Eq(2)}$$

Where,

x_j and x_k are data values at times j and k (j>k), respectively. The median of these N values of Q_i is the Sen's estimator of slope.

III. RESULTS AND DISCUSSION

A. *Anomaly and Trend Analysis*

1) Mean Maximum Temperature: The overall trend of mean maximum temperature anomalies at four stations in Mandalay, Meikthila, Monywa, and Pyinmana are increased throughout the latter half of observed periods in all stations except Minbu.The anomalies in Minbu were varied, moving between positive and negative ones. Most of the station reaches the highest anomalies about +1.5°C versus the normal value. The mean maximum temperature in dry zone area started to increase since 1977. The continuous positive anomalies started from 1993 ranging from a minimum of +0.01°C (2001) to a maximum of +1.12°C (2010). The significant positive anomalies can be observed in 2009, 1998, 2005, 2014, 2012, and 1979 (descending order of anomalies value) (Fig. 2) and almost the years corresponds with the declining phase of strong El Niño events [23]. During the 20th century, temperatures have continued to increase from 2003 to 2015 except in 2007 and 2011, which experienced the La Niña events [23].

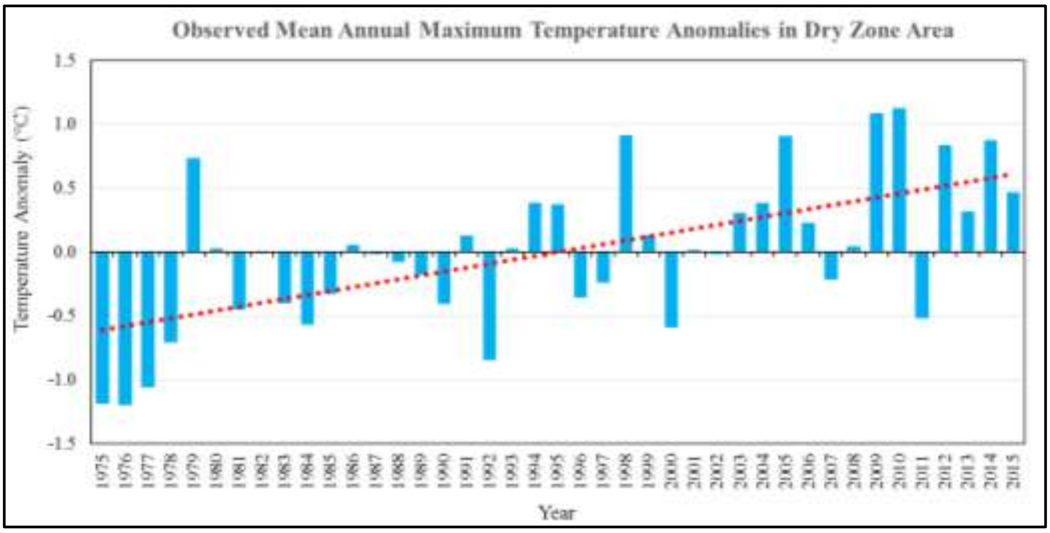

Fig. 2. Observed mean annual maximum temperature anomalies in dry zone area.

2) Mean Minimum Temperature: The mean minimum temperature anomalies for all stations demonstrated an overall increasing trend with values becoming positive after 1990s. However, the nature of the anomaly are not consistent among stations, both positive and negative anomalies were found. On average, dry zone area shows the continuous positive anomalies from 2001 to 2014 with the range +0.01°C (2001) to +1.01°C (2005). Generally, it can be expected that warm periods started after 2000 (Fig. 3). During the warm periods, the significant positive anomalies were detected in 2005 and 2010 which coincided with El Niño events.

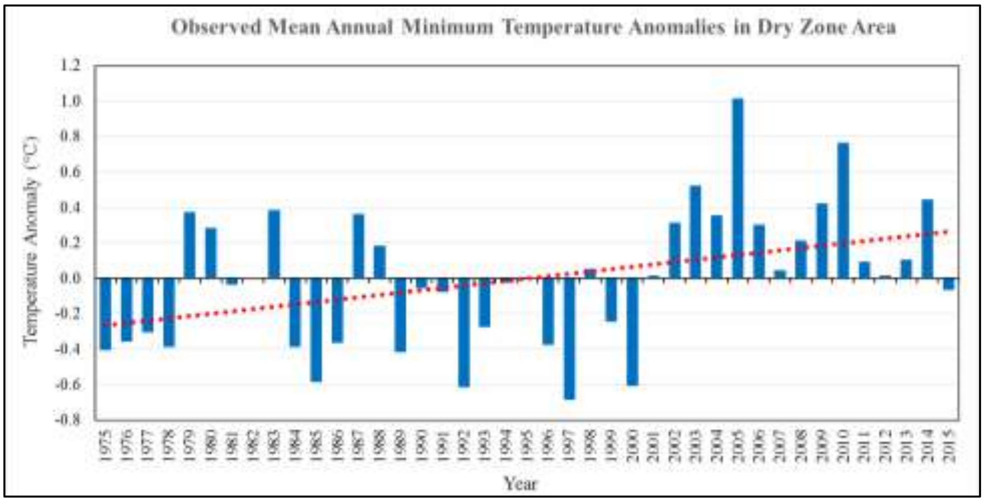

Fig. 3. Observed mean annual minimum temperature anomalies in dry zone area.

3) Annual Total Precipitation: The trends of annual total precipitation illustrates the increasing trend but not significant for all stations. The highest precipitation were found in El Niño year 2006 and 2010 and La Niña year 2011. It could be explained by the fact that precipitation pattern in dry zone area cannot directly interpreted based on the links with El Niño and La Niña during the study period 1975-2015 (Fig. 4). More detailed investigations are needed to explain the precipitation trends.

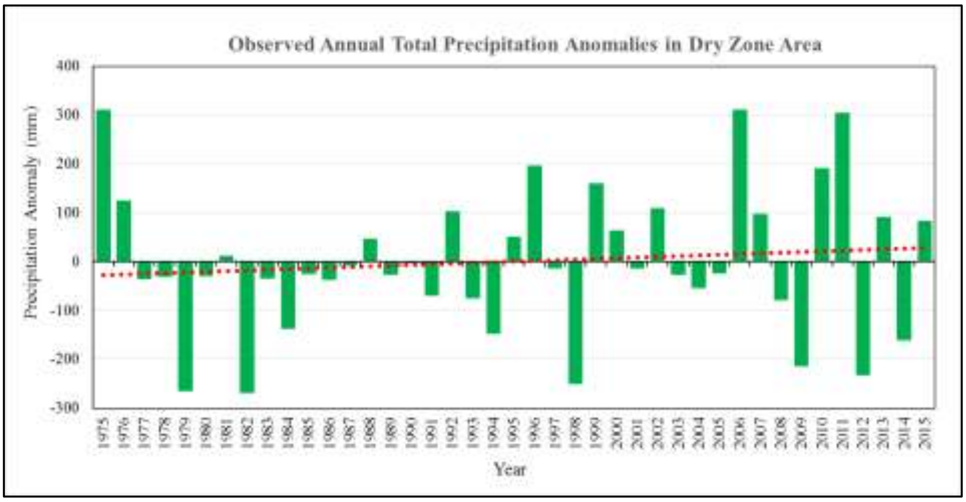

Fig. 4. Observed annual total precipitation anomalies in dry zone area.

B. Extreme Indices

1) Maximum and Minimum Temperature: There are significant increases in average maximum temperature (Tmaxmean), average minimum temperature (Tminmean), summer days (SU33/32), warm days (TX90P), and warm nights (TN90P) in all selected stations. Cold days (TX10P) are significantly decreasing in three (Mandalay, Monywa, Pyinmana) of five stations. Fig. 5 shows the trends in frequency of mean maximum temperature, Fig. 6 shows the trends in the frequency of days with maximum temperature above 33/32°C (summer days) and Fig. 7 shows the trends in frequency of days with maximum temperature above the 90th percentile (warm days). In each figure, an increase is represented by (+) sign and decrease is (-) sign, a significant increase with (▲) symbol and significant decreases with (▼) symbol, respectively.

Table III shows in details about the calculated values used to determine the direction and significance of the trends in extreme temperature for each of the five stations in dry zone area. The stations which showed a statistically significant trend at the 95% significance level are highlighted grey.

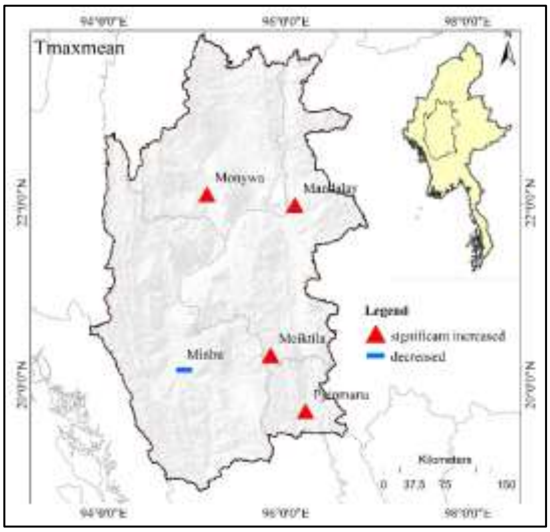

Fig. 5. Trends in mean maximum temperature in dry zone area for the period 1975-2015.

In dry zone area, four of five stations showed statistically significant increase in maximum temperature, summer days, and warm nights while increase in minimum temperature and warm days.

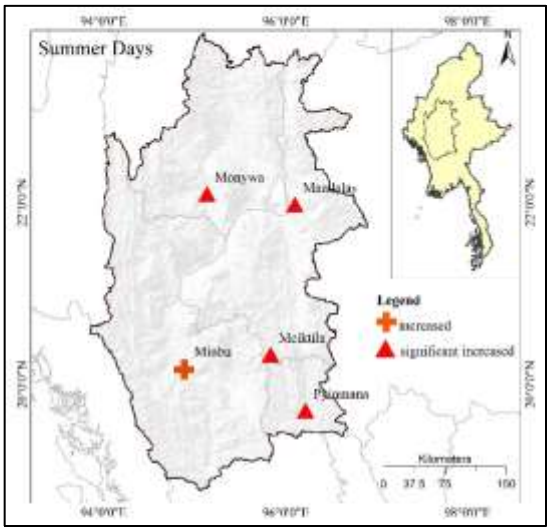

Fig. 6. Trends in frequency of days with maximum temperature above 33/32°C in dry zone area for the period 1975-2015.

The only one station, Minbu shows decreasing trend in maximum temperature with 0.02°C/decade. It could be considered as the effect from data missing during 1975 to 1980.

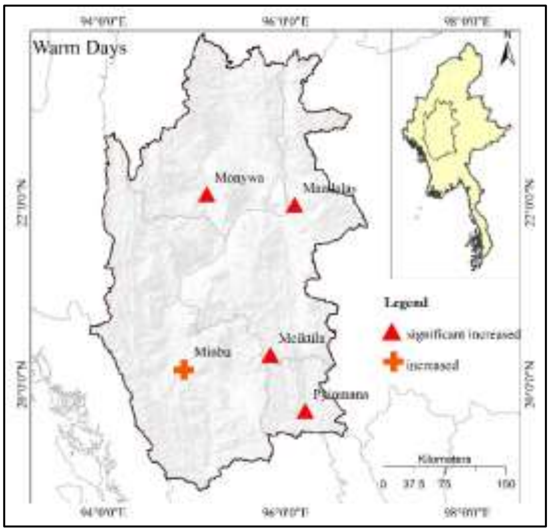

Fig. 7. Trends in frequency of days with maximum temperature above the 90th percentile (warm days) in dry zone area for the period 1975-2015.

2) Annual Total Precipitation: All the stations in dry zone area shows the increasing trends in the number of heavy precipitation days (annual count of days when precipitation >= 10 mm), number of very heavy precipitation days (annual count of days when precipitation >= 20 mm), and annual total precipitation (Fig. 8).

The results from monthly maximum 1 day precipitation amount (RX1day) and monthly maximum consecutive 5 day precipitation amount (RX5day), very wet days (RX95P), and extremely wet days (RX99P) indicate the increasing trends of these indices in Mandalay, Meikthila, and Monywa while decreasing in Minbu and Pyinmana. Both consecutive dry days (CDD) and consecutive wet days (CWD) were increased in Mandalay and Minbu whereas decreased in Meikthila and Pyinmana.

Table IV shows in details calculated values used to determine the direction and significance of the trends in extreme precipitation for each of five stations in dry zone area. The stations which showed a statistically significant trend at the 95% significance level are highlighted in grey.

TABLE III
TRENDS IN EXTREME TEMPERATURE FOR THE PERIOD 1975-2015

Station	Temperature Indicies						
	Tmaxmean (˚C/decade)	Tminmean (˚C/decade)	SU33/SU32 (Days/decade)	TX10P (Days/decade)	TN10P (Days/decade)	TX90P (Days/decade)	TN90P (Days/decade)
Mandalay	0.35	0.27	12.04	-2.11	-2.76	3.34	2.13
Monywa	0.48	0.12	14.26	-2.53	-0.09	4.51	1.07
Meikthila	0.25	0.13	13.26	-0.72	-1.23	2.99	2.25
Minbu	-0.02	0.14	0.30	0.98	0.88	0.91	3.52
Pyinmana	0.30	0.04	19.15	-1.12	0.17	3.85	0.58

Note: Tmaxmean = mean maximum temperature, Tminmean = mean minimum temperature,
SU33/SU22 = annual number of days when daily maximum temperature >33℃ or 32℃,
TX10P = Number of cool days, TN10P = Numer of cool nights, TX90P = Number of warm days,
TN90P = Number of warm nights, (-) is decreasing trend,
Stastically significance trend are set grey color at the 95% significance level

TABLE IV
TRENDS IN EXTREME PRECIPITATION FOR THE PERIOD 1975-2015

Station	Precipitation Indicies							
	PRCPTOT (mm/decade)	R10mm (Days/decade)	R15mm (Days/decade)	RX1day (mm/decade)	RX5day (mm/decade)	R95P (mm/decade)	R99P (mm/decade)	CDD (Days/decade)	CWD (Days/decade)
Mandalay	28.20	0.40	0.71	8.99	15.49	28.30	26.94	1.84	0.46
Monywa	17.50	0.25	0.66	1.28	2.95	9.15	5.55	-3.41	0.34
Meikthila	28.88	0.97	0.32	2.09	10.71	11.56	1.95	-2.98	-0.09
Minbu	11.53	0.81	0.18	-0.78	-3.43	-2.19	-20.74	0.65	0.24
Pyinmana	2.48	0.37	0.58	-6.06	-3.83	-6.84	-9.02	-3.02	-1.00

Note: PRCPTOT = annual total precipitation, R10mm = annual number of days when precipitation >= 10 mm,
R20mm = annual number of days when precipitation >= 15 mm, RX1day = maximum 1 day precipitation amount,
RX5day = maximum consecutive 5 day precipitation amount, R95P = very wet days precipitation amount,
R99P = extreme wet days precipitation amount, CDD = consecutive dry days, CWD = consecutive wet days,
(-) is decreasing trend
Stastically significance trend are set grey color at the 95% significance level

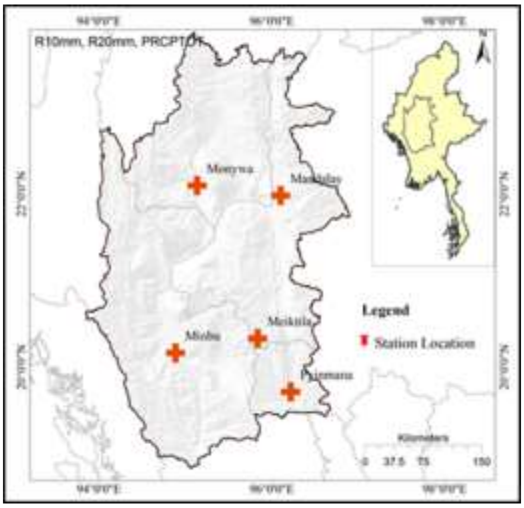

Fig. 8. Trends in number of heavy precipitation days, very heavy precipitation days and annual total precipitation in dry zone area for the period 1975-2015.

IV. CONCLUSIONS

This study has presented continuous positive anomalies in both mean maximum and minimum temperature between the years 1975 to 2015. The increase of maximum temperature, minimum temperature, summer days, and warm days were between 0.25~0.35°C/decade, 0.04~0.27 °C/decade, 12~19 days/decade, and 1~5 days/decade, respectively. Both decreasing and increasing trends in number of cool days and cool nights were observed.

On the other hand, trends in annual total precipitation and number of heavy precipitation days indicate a slightly increase in the range of 2~29 mm/decade and 0.25~0.97 mm/decade, respectively. Most of the stations describe decreasing trends in extreme wet days and consecutive dry days.

This study provides the evidence on the pattern of climate change in the dry region as well as the possible impacts on various aspects of which the impacts on forest ecosystems in Myanmar are under investigation by the authors.

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REFERENCES

[1] IPCC, *Climate Change 2007*. *The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovern-Rmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 2007.

[2] J. Alcamo, N. Dronin, M. Endejan, G. Golubev, and A. Kirilenko, "A new assessment of climate change impacts on food production shortfalls and water availability in Russia," *Global Environmental Change*, vol. 17, no. 3-4, pp. 429-444, 2007.

[3] TR. Karl, N. Nicholls, and A. Ghazi, " CLIVAR/ GCOS/WMO workshop on indices and indicators for climate extremes." *Climatic Change*, 42: 3-7, 1999.

[4] K. Sönke, D. Eckstein, L. Dorsch, and L. Fischer, *Global climate risk index 2016: Who suffers most from Extreme weather events? Weather-related loss events in 2014 and 1995 to 2014*. 2015.

[5] D. R. Easterling, B. Horton, Ph. D. Jones et al., "Maximum and minimum temperature trends for the Globe," *Science*, vol. 277, no. July, pp. 364-367, 1997.

[6] X. Zhang, L. a. Vincent, W. D. Hogg et al., "Temperature and precipitation trends in Canada during the 20th century," *Atmosphere-Ocean*, vol. 38, no.3, pp. 395-429, 2000.

[7] D. R. Easterling, G. a Meehl, C. Parmesan et al., "Climate extremes: observation, modeling, and impacts," *Science*, vol. 289, no. 5487, pp. 2068-2974, 2000.

[8] M. J. Manton, P. M. Della-marta, M. R. Haylock et al., "Trends in extreme daily rainfall and temperature in southeast Asia and the south Pacific: 1961-1998," *International Journal of Climatology*, vol. 21, no. 3, pp. 269-284, 2001.

[9] P. Frich, L. V. Alexander, P. Della-Marta et al., "Observed coherent changes in climatic extremes during the second half of the twentieth century," *Climate Research*, vol. 19, no.3, pp. 193-212, 2002.

[10] L.V. Alexander, X. Zhang, T. C. Peterson et al., "Global observed changes in daily climate extremes of temperature and precipitation," *Journal of Geophysical Research Atmospheres*, vol. 111, no. 5, pp. 1-22, 2006.

[11] T. a. Cinco, R. G. de Guzman, F. D. Hilario et al., "Long-term trends and extremes in observed daily precipitation and near surface air temperature in the Philippines for the period 1951-2010," *Atmospheric Research*, vol. 145-146, pp. 12-26, 2014.

[12] G. M. Griffiths, L. E. Chambers, M. R. Haylock et al., "Change in mean temperature as a predictor of extreme temperature change in the Asia-Pacific region," *International Journal of Climatology*, vol. 25, no. 10, pp. 1301-1330, 2005.

[13] NECC. (2012) Myanmar's National Adaptation Programme of Action (NAPA) to Climate Change. [Online]. Available: http://unfccc.int/resource/docs/napa/mmr01.pdf.

[14] T. R. Karl, J. D. Tarpley, R. G. Quayle, H. F. Diaz et al., "The recent climate record: What it can and cannot tell us," *Reviews of Geophysics*, vol. 27. no.3, p. 405, 1989.

[15] J. K. Eischeid, C. B. Baker, T. R. Karl et.al, "The quality control of long term climatological data using objective data analysis," *Journal of Applied Meteorology*, vol. 34. pp. 2787-2795, 1995.

[16] T.C. Peterson, "Introduction to Quality control of daily climate data," National Climatic Data Center Asheville, North Carolina, USA, no. March, pp. 1-19, 2013.

[17] X. L. Wang, Y. Feng, "RHtestsV4 User Manual", Climate Research Division, Atmospheric Science and Technology Directorate, Science and Technology Branch, Enviornment Canada, no. July, pp. 1-29, 2013. [Online]. Available: http://etccdi.pacificclimate.org/software.shtml.

[18] X.Zhang, F. Yang, "RClimDex(1.0)User Manual," *Climate Research Branch Environment Canada,* Downsvies, Ontario, Canada, no. September 10, pp.22, 2004.

[19] P. K. Sen, "Estimates of the regression coefficient based on Kendall's tau," *Journal of American Statistical Association*, vol. 63, no. 324, pp. 1379-1389, 1968.

[20] K. E. Kunkel, K. Andsager, D. R. Easterling, "Long-term trends in extreme precipitation events over the conterminous United States and Canada," *International Journal of Climatology*, vol. 12, no. 8, pp. 2515-2527, 1999.

[21] X. Zhang, W. D. Hogg, E. Mekis, "Spatial and temporal characteristics of heavy precipitation events over canada," *International Journal of Climatology*, vol. 14, no. 9, pp. 1923-1936, 2001.

[22] X. Zhang, F. W. Zwiers, G. Li, "Monte Carlo experiments on the detection of trends in extreme values," *International Journal of Climatology*, vol. 17, no. 10, pp. 1945-1952, 2004.

[23] (2016) The NOAA website. [Online]. Available: http://www.el-nino.com/