EVALUATING THE IMPACTS OF CLIMATE CHANGE ON THE SPATIO-TEMPORAL VARIABILITY OF EXTREME PRECIPITATION IN HO CHI MINH CITY (VIETNAM)

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ABSTRACT

This study aims to assess the impact of climate change on the variability and stability of extreme precipitation in HCMC by analyzing the trend of rainfall in the current period (1980 – 2017). The research method focused on the calculation of extreme indices as RX1day, RX5day, R95p, R99p, CDD, and CWD, which based on daily precipitation data of 11 meteorological gauge stations in the research area and adjacent areas, thereby identifying the spatial and temporal variability and stability of precipitation trend by the Mann-Kendall test and Spatial Distribution Mapping method. The results indicate that there is a variation in the intensity, duration, and frequency of extreme precipitation in HCMC with the intensity of extreme precipitation has tended to reduce in most regions, while the frequency and duration have shown the rising trends in the southern areas and some parts of the central area in Ho Chi Minh City during the period 1980 – 2017.

1. INTRODUCTION

Precipitation has increasingly recognized as either a fundamental element of the hydrological cycle or a critical meteorological variable for investigating the behavior of climate in a specific area, due to its significantly direct and indirect effect on natural ecosystems (Guan et al., 2014) and human society (Barrett & Santos, 2014; Mei et al., 2018). Therefore, a comprehensive analysis of change in precipitation tendency plays an instrument in diagnosing the current state or predicting the future scenarios of climate extremes across the research area. (Chen, Chen, & Yang, 2015; Y. Wang et al., 2016). Moreover, Ho Chi Minh City (HCMC) – a coastal city in the southern part of Vietnam, besides the rapid economic growth, has been encountering many challenges such as population explosion, reducing of green space due to urban development and building construction, high and increasing infrastructure provision as well as transportation pressure.

Additionally, HCMC has been ranked in the top 20 port cities that been considered to be vulnerable and severely affected by climate change with the estimated cost for mitigation and adaptation is expected to be the highest in the East Asia region. (ADB, 2010; World Bank, 2010). However, there has long been a knowledge-based gap between the current regional behavior of climate-related extremes and urban development strategies. Due to the insufficient number of research in the specific context of HCMC and existing previous studies generally focused on analyzing the change of average climate conditions not on the frequency and tendency of extreme events, which are the main culprit of severe impacts on the socioeconomic activities of residents.

Consequently, in this study, the characteristics of extreme precipitation events were analyzed by using eight representative extreme indices, which calculated through the observation daily rainfall data provided by selected meteorological stations in HCMC during the period 1980 – 2017. The results are expected to contribute informative assessment of the extreme precipitation events' behavior on spatiotemporal scales in HCMC during the current period for city governors in planning urban development strategies with integrated climate change mitigation and adaptation frameworks.

2. STUDY AREA AND DATA

Ho Chi Minh City is the biggest city in the south of Vietnam with the geographical coordinates of HCMC range from $10^o10'$ to $10^o40'$ north latitude and $106^o20'$ to $106^o50'$ east longitude (Ho Chi Minh City Statistical Office, 2016). The total area of HCMC is $2095.39 km^2$, including 19 urban districts and 5 rural districts, and the average population is 8.4 million people in 2016 with the highest population density in Vietnam as 4,029 people per km^2. For climatology, HCMC has a tropical monsoon climate with distinct dry and wet season fluctuations in precipitation. The wet season lasts six months from May to October with the amounts of rainfall varies between 1760 and 2307 mm, meanwhile, the dry season usually lasts from November to April with low rainfall, high evaporation, and the average annual temperature variations around 27^o– 28^oC (Ho Chi Minh City Statistical Office, 2016).

In this study, observed daily precipitation data recorded from 11 meteorological stations in Ho Chi Minh City and the neighboring areas during the period 1980 – 2017 were provided by the Hydro-Meteorological Data Center of Vietnam.

3. METHODOLOGY

3.1 Precipitation extreme indices

To provide useful information for climate change detection and attribution, together with the climatic characteristics of HCMC, 8 appropriate extreme precipitation indexes within 27 core extreme indices, which recommended by the World Meteorology Organization, were selected in this study (Table 1) to consider major attributes of an extreme event, such as duration or intensity.

Table 1. List of precipitation extremes used in this study

Indices	Name	Definitions	Unit
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation amount	Monthly maximum 5-day precipitation	mm
R95p	Very wet days	Annual total PRCP when precipitation > 95^{th} percentile	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days	mm/day
R20mm	Number of heavy precipitation days	Annual count of days when precipitation ≥ 20 mm	days

R25mm	Number of very heavy precipitation days	Annual count of days when precipitation ≥ 25 mm	days
CDD	Consecutive dry days	Maximum number of consecutive days with precipitation < 1mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with precipitation ≥ 1mm	days

3.2 Trend analysis

3.1.1 *Mann-Kendall test*

To access the significant monotonic trends in precipitation data series, a well-known and efficient technique which recommended by the WMO is the Mann-Kendall test (Kendall, 1955; Mann, 1945). The Mann-Kendall test is a non-parametric hypothesis test for identifying the statistically significant trends in hydro-meteorological time series data. Additionally, the Sen's slope estimator was applied to estimate the magnitude of trends (Sen, 1968).

3.1.2 *Trend strengths, stability, and magnitude*

In this study, the strength of statistically significant trends is classified by the p-value (i.e., the significance level of a trend test), with the corresponding categories as follows: very strong trends: $p \leq 0.05$; strong trends: $0.05 < p \leq 0.1$; weak trends: $0.1 < p \leq 0.2$; insignificant trends: $p > 0.2$. Then, the stability of trends was calculated as the percentage of the number of 25-year moving periods with statistically significant trends at the significance level of 0.2 with respect to the total number of 25-year moving periods. The suggested classification of trend stability is as follows: unstable trends: $0\% \leq S \leq 15\%$; poor trend stability: $15\% \leq S \leq 25\%$; stable trends: $25\% \leq S \leq 50\%$; strongly stable trends: $50\% \leq S \leq 75\%$; and very strongly stable trends: $S \geq 75\%$. Then, the Sen's slope estimator method was applied to calculate the trend magnitudes of each 25-year moving periods at every station for every extreme precipitation indices and the averaged quantities were computed at each station and each respective extreme indices during the study period 1980 – 2017 (Lupikasza, 2010; Wu et al., 2014).

4. RESULTS AND DISCUSSION

4.1. Temporal distribution of spatially averaged extreme indices

The arithmetic areal values of each index were calculated by averaging the respective annual extreme values computed at all 11 selected stations (Fig. 1). The dominant type of statistical strengths, stability, and averaged magnitude of the general trends for respective extreme indices were calculated and presented in Table 2. Based on the results, there was no significant trend for most of the indices except for the SDII and CDD index. In particular, the RX1day, R20mm, R25mm, CWD, and R95p showed an increasing trend, while the RX5day exhibited a decreasing trend; however, all of these trends were insignificant and unstable. Among indices, the SDII index showed a very strongly significant and stable downward trend, with the decreasing magnitude as 0.111 unit per year. Besides, the CDD also presented a weak decreasing trend but strongly stable with the magnitude of 1.22 unit per year.

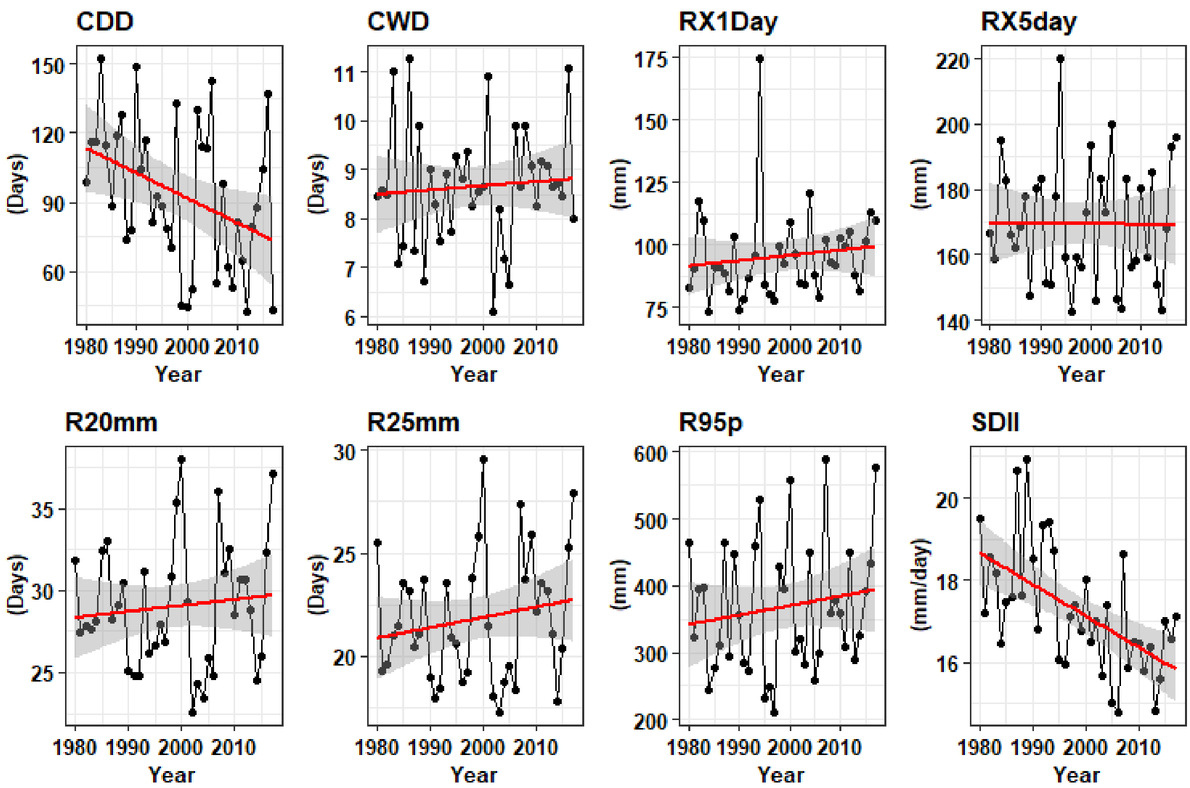


Figure 1. Temporal variations of the spatially averaged extreme precipitation indices in the period 1980 – 2017. The blue solid line indicates the arithmetic average values of the 11 stations. The red dash line indicates the average level and the blue dotted line shows the trends.

Table 2. Trend strengths, stabilities, and magnitudes of the spatially averaged values of the extreme precipitation indices during the period 1980 – 2017

Trend	***RX1Day***	***RX5Day***	***SDII***	***R20mm***	***R25mm***	***CDD***	***CWD***	***R95p***
Strengths	IU	ID	VSD	IU	IU	WD	IU	IU
Stability	UT	UT	VSSD	UT	UT	SSD	UT	UT
Magnitude	0.343	-0.052	-0.111	0.016	0.024	-1.220	0.009	1.143

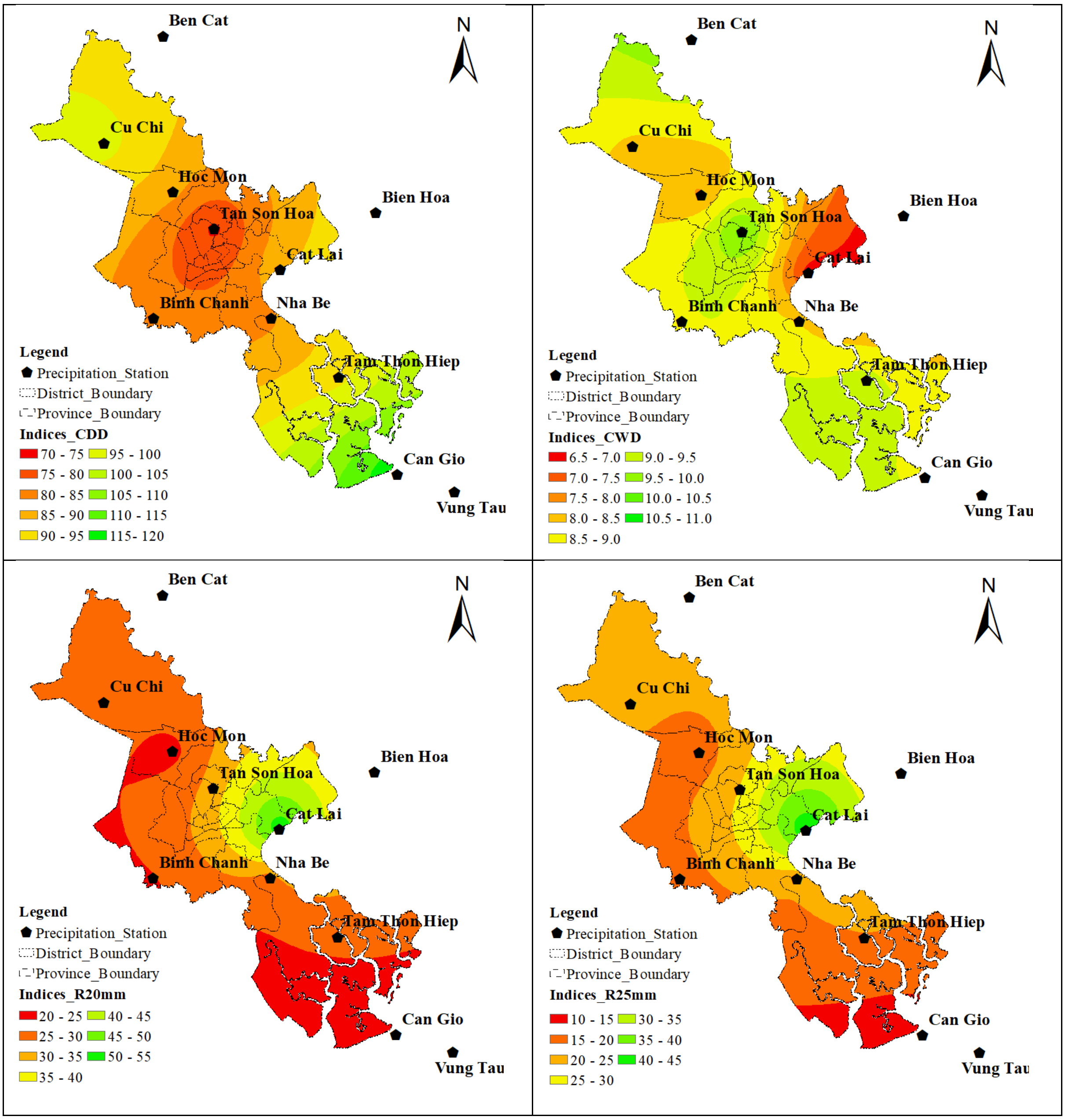
IU: Insignificant upwards; ID: Insignificant downwards; VSDT: Very strongly downwards; WD: weak downwards; UT: Unstable trends; VSSD: Very strongly stable downwards, SSD: Strongly stable downwards.

4.2 Spatial distribution of temporally averaged extreme indices

The spatial distribution of the average mean of inter-annual values calculated for each extreme precipitation indices and each station during the period 1980 – 2017 were demonstrated in Fig. 2.

In term of the CDD, the variant range of averaged consecutive dry days in the period 1980 – 2017 were between 82.0 and 120.3 days, with the highest value at Can Gio station and the lowest value at Tan Son Hoa station. On the contrary, the number of CWD showed an increasing trend in most of the central region (except for Cat Lai station), and tended to decrease in the northwestern and southeastern part of the city with values ranged from 6.6 to

10.2 days. For the R20mm and R25mm indices, there were no remarkable differences between the spatial distributions of two indices over the research period. The number of R20mm were varied between 22.3 and 53.5 days, while the R25mm fluctuated at shorter day intervals from 11.9 to 44.2 days. Regarding RX1day and RX5day, the mean values of RX1day ranged between 69.7 and 114.2 mm, whereas values of RX5day were varied at higher intervals of 138.5 – 232.0 mm. Turning to R95pTOT, the mean values ranged from 288.7 mm (Can Gio) to 464.2 mm (Tan Son Hoa), in which the central part of the city indicated high values (between 350 and 475 mm) while the northwestern and southeastern regions depicted lower range as less than 375mm. Lastly, the mean values of SDII in most regions of the city were varying at intervals 14 – 18 mm/day and exhibited the west-to-east increasing gradient of rainfall intensity.



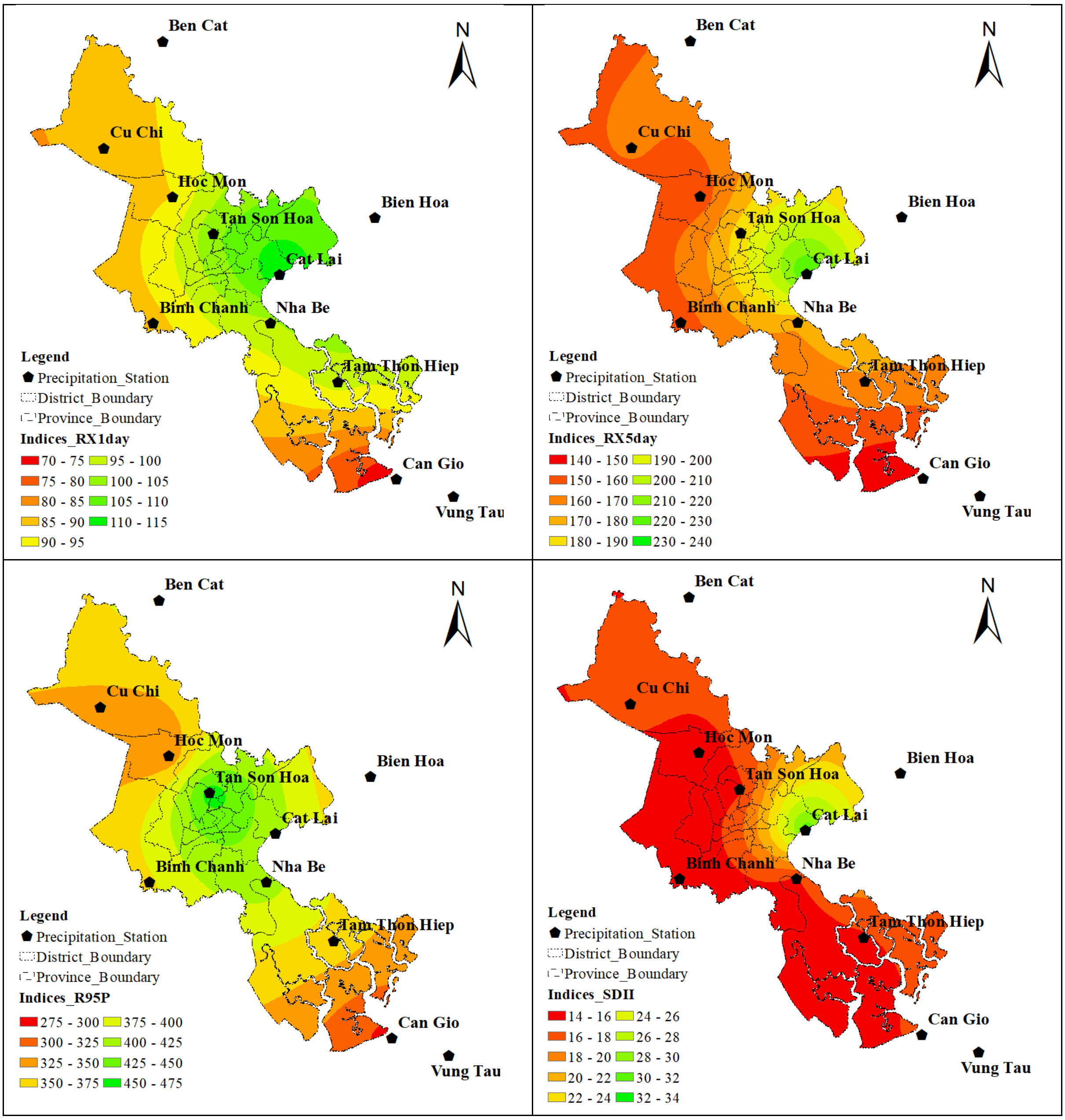


Figure 2. Spatial distribution of temporally averaged extreme precipitation indices calculated for each station during the period 1980 – 2017 in HCMC.

5. CONCLUSION

In this study, we investigated the temporal and spatial variability of precipitation and extreme precipitation in Ho Chi Minh City during the period 1980 – 2017. The summary of prominent findings in this study are highlighted that the average extreme indices for the period 1980 – 2017 presented the insignificant trends in most indices, except for SDII and CDD observing strongly and stable downwards. In term of spatial analysis, the temporally averaged extreme indices showed high values in the central regions and low values distributed in the northern and southern sides, together with the increasing trends from west to east.

Finally, the results in this study are expected to contribute to the analysis and assessment of the temporal and spatial variability of precipitation and extreme precipitation in the current period 1980 – 2017. The spatial distribution maps established in this study describe a comprehensive picture of mean and extreme rainfall in Ho Chi Minh City. It also provides a scientific reference for the policymakers and city planners to develop, design, and propose the urban strategic development planning with integrated mitigation and adaptation in the context of climate change.

6. ACKNOWLEDGEMENTS

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