Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 142 (2016) 229 – 235
Procedia Engineering
www.elsevier.com/locate/procedia

Sustainable Development of Civil, Urban and Transportation Engineering Conference

Analysis of Changes in Precipitation and Extremes Events in Ho Chi Minh City, Vietnam

Dao Nguyen Khoi[a,b,*], Hoang Thi Trang[a]

[a]*Faculty of Environment, University of Science, Vietnam National University Ho Chi Minh City 700000, Vietnam*
[b]*Center of Water Management and Climate Change, Vietnam National University Ho Chi Minh City 700000, Vietnam*

Abstract

Precipitation is one of the most important climate variables which can impact the urban water and urban flooding. Thus, knowledge of precipitation and precipitation extremes is important to manage urban water and to design urban drainage infrastructure to reduce the urban flooding. This paper presented trends in precipitation and precipitation extremes in Ho Chi Minh City for the 1980-2013 period based on the precipitation data obtained from nine rain gauges. Non-parametric test, i.e. Mann-Kendall test, was used for trend analysis, and the precipitation extremes indices were used to calculate the extreme events. The results indicated that the precipitation has increasing trend in the northwest part of the city and decreasing trend in the southeast part of the city in the 1980-2013 period. In addition, the precipitation and precipitation extremes had generally increasing trends. The results obtained in this study can be used for urban water management and sustainable urban drainage system in Ho Chi Minh City.

Peer-review under responsibility of the organizing committee of CUTE 2016

Keywords: Ho Chi Minh City; precipitation; climate extreme indices; Mann-Kendall test

1. Introduction

Climate change is identified as one of greatest challenges which mega-urban regions in coastal areas in Southeast Asia are facing. As a result of climate change, the frequency and intensity of extreme weather events, such as heavy rainfalls, droughts, floods, and tropical typhoons occurred frequently in recent years. Precipitation is one of the most

* Corresponding author. Tel:
E-mail address: dnkhoi86@gmail.com

Peer-review under responsibility of the organizing committee of CUTE 2016
doi:10.1016/j.proeng.2016.02.036

important climate variables which can impact the urban water and urban flooding. Thus, knowledge of precipitation and precipitation extremes is important to manage urban water and to design urban drainage infrastructure to reduce the urban flooding [2,3].

In recent years, many researcher have analyzed the precipitation trends. For example, Gocic and Trajkovic [3] trends at most of the stations in the study area; Keggenhoff et al. [4] analyzed the precipitation extremes over Georgia in the 1971-2010 period and detected the increasing trend of precipitation and precipitation extremes during that period; da Silva investigated the rainfall trend in the Cobres River Basin in Portugal over the 1960-2000 period and they indicated that there are signs of significant decreasing trend of rainfall in the basin. In general, non-parametric test (i.e., Mann-Kendall test and Sen’s slope) and climate extremes indices were used to identify the changes of precipitation and precipitation extremes in those studies.

Ho Chi Minh City (HCMC) is the biggest of Vietnam with rapid urbanization and economic growth. It is facing to changing climate. HCMC is ranked among the top 10 cities in the world most likely to be severely affected by climate change [1] Major impacts of climate change are floods and droughts as a consequence of water scarcity in the dry season [8]. In addition, heavy rainfall and flooding can also contaminate surface water and affect environmental health in urban area. Thus, the understanding of changes in precipitation extremes will also be useful for HCMC in managing water urban and preventing urban flooding. However, a comprehensive analysis of trends and variability in precipitation extremes in Ho Chi Minh City is still lacking. The objective of this study was to investigate the changes in precipitation extremes over the 1980-2013 period in Ho Chi Minh City, Vietnam by using the non-parametric test and climate extremes indices.

2. Study area

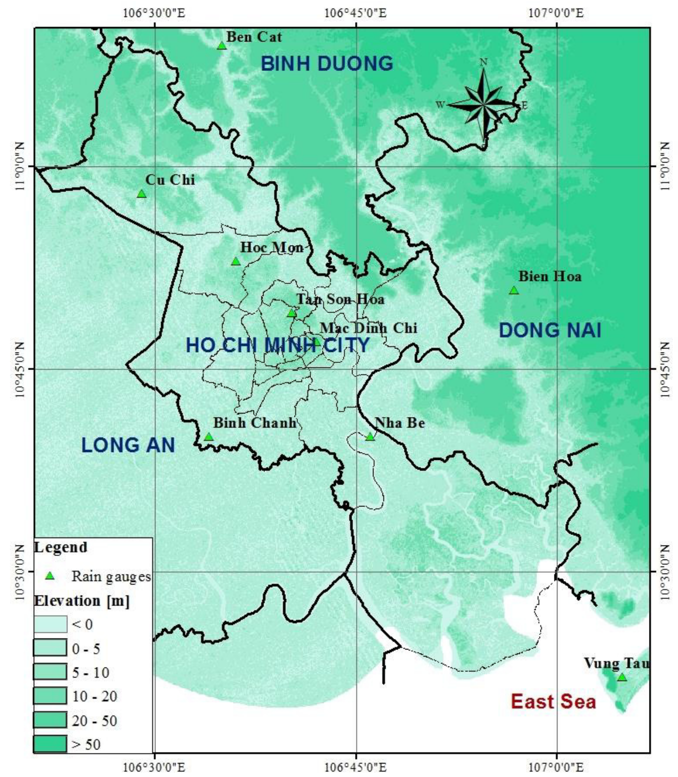

Fig. 1. Map of Ho Chi Minh City

Ho Chi Minh City (HCMC) is located in the south of Vietnam, and is the biggest city in Vietnam. Its latitude and longitude are approximately 10°10' to 10°40'N and 106°20' to 106°50'E (Figure 1). HCMC is situated on the downstream of the Dong Nai River Basin and the distance of the city center to the East Sea is about 50 km. The city has an area of about 2095 km^2 and a population of nearly 8 million inhabitants in 2014. HCMC consists of 24 districts, including 19 urban districts and 5 suburban districts. These suburban districts are accounting for 79% of the total area of the city and 16% of the total urban population. HCMC is the biggest economic center in Vietnam and a transport hub of the southern region. Despite accounting for only 0.6% of country's total area and 8.8% of the country's total population, HCMC contributed about 24% of Vietnam's GDP and 30% of the national state budget in the 2011-2014 period. This area is located in tropical area and has two distinct seasons: the rainy season and the dry season. The average annual rainfall quite high, about 1800 mm. The rainy season lasts from May to October and account for 80-85% of the total annual precipitation. In addition, HCMC is vulnerable to flooding due to land subsidence, urbanization, heavy rainfall, flow from the upstream, and sea level rise [9].

3. Methodology

3.1. Man-Kendall test

The Mann-Kendall test [6,9] is a non-parametric test for identifying trends in meteorological time series. The Mann-Kendall test statistic is calculated as follows:

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \quad (1)$$

where

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \quad (2)$$

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1 & x_j - x_i > 0 \\ 0 & x_j - x_i = 0 \\ -1 & x_j - x_i < 0 \end{cases} \quad (3)$$

$$Var(S) = \frac{\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5) \right]}{18} \quad (4)$$

where n is the length of the dataset, x_i and x_j are the sequential data values, m is the number of tied groups (a tied group is a set of sample data with the same value), and t is the number of data points in the mth group. The null hypothesis H_0 (there is no trend) is accepted if $-Z_{1-\alpha/2} \leq Z_c \leq Z_{1-\alpha/2}$, α is the significant level. When $|Z_c| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exits in the time series. A positive value of Z_c indicates an increasing trend, and a negative value indicates a decreasing trend.

In the Mann-Kendall test, the Kendall slope is another very useful index that estimates the magnitude of the monotonic trend and is given by

$$\beta = Median\left(\frac{x_j - x_i}{j - i} \right), \forall i < j \quad (5)$$

where $1 < i < j < n$. The estimator β is calculated as the median of all slopes between data pairs for the entire dataset.

3.2. Serial autocorrelation test

To remove serial correlation from the series, we conducted pre-whitening the series before applying the Mann-Kendall test. In summary, the series are examined using the following procedures: (1) Computing the lag-1 serial correlation coefficient (designed by r_1); (2) If the calculated r_1 is not significant at the 5% level, the Mann-Kendall test is applied to the original time series; and (3) If the r_1 is significant, the 'pre-whitened' time series should be obtained prior to application of the Mann-Kendall test as ($x_2 - r_1x_1$, $x_3 - r_1x_2$, …, $x_n - r_1x_{n-1}$). The details and formulas for the serial autocorrelation test can be found in Gocic and Trajkovic (2013).

3.3. Climate extremes indices

Table 1. An example of a table.

ID	Index name	Definitions	Unit	Recommended by
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm	ETCCDMI
R50mm	Number of heavy precipitation days	Annual count of days when precipitation ≥ 50 mm	days	VNHMS
R95p	Very wet days	Annual total PRCP when precipitation > 95th percentile	mm	ETCCDMI
CDD	Consecutive dry days	Maximum number of consecutive days with precipitation < 1mm	days	ETCCDMI
CWD	Consecutive wet days	Maximum number of consecutive days with precipitation ≥ 1mm	days	ETCCDMI

To identify extreme events, the join WMO Commission for Climatology (CCI)/World Climate Research Programme (WRCP) Climate Variability and Predictability (CLIVAR) project's Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) defined 27 core extreme climate indices based on daily temperature and precipitation. Table 1 presents five precipitation-based indices used in this study. We selected these indices to consider frequency, intensity, and duration properties of precipitation extremes. Specifically, we used R50mm to measure the frequency of heavy precipitation. The 50 mm/day is the threshold used to issue severe weather alerts by the National Hydro-Meteorological Service of Vietnam (VNHMS) (Ngo-Duc et al., 2014). The RX1day and R95p were used to analyze the change of extreme precipitation intensity. For the precipitation duration, we considered the duration of consecutive dry days (CDD) and wet days (CWD). In this study, a wet day is defined as a day with precipitation accumulation greater than or equal to 1.0 mm, whereas a dry day represents a day with precipitation less than 1.0 mm. All selected indices were calculated annually using the software RClimDex 1.1.

3.4. Data

Series of precipitation data were collected from nine rain gauges inside and around Ho Chi Minh City (Figure 1) for the 1980-2013 period and were obtained from Hydro-Meteorological Data Center of Vietnam. These rain gauges were selected based on three criteria: (1) the dataset should have good quality; (2) the dataset should be reliable; and (3) the dataset should have adequate record length.

4. Results and discussion

4.1. Summary of statistical parameters

Statistical parameters of annual precipitation time series at nine rain gauges during the 1980-2013 period are summaries in Table 2. The mean annual precipitation is ranged from 1438 mm in the Vung Tau station to 1940 mm in the Tan Son Hoa station. Figure 2 presents the spatial distribution of annual precipitation in Ho Chi Minh for the 1980-2013 period. In general, the annual precipitation decreases from northeast to southwest. The highest coefficient of variation (CV) of the precipitation was observed at the Hoc Mon station at the rate of 24%, while the lowest CV of 13% was found at the Tan Son Hoa station.

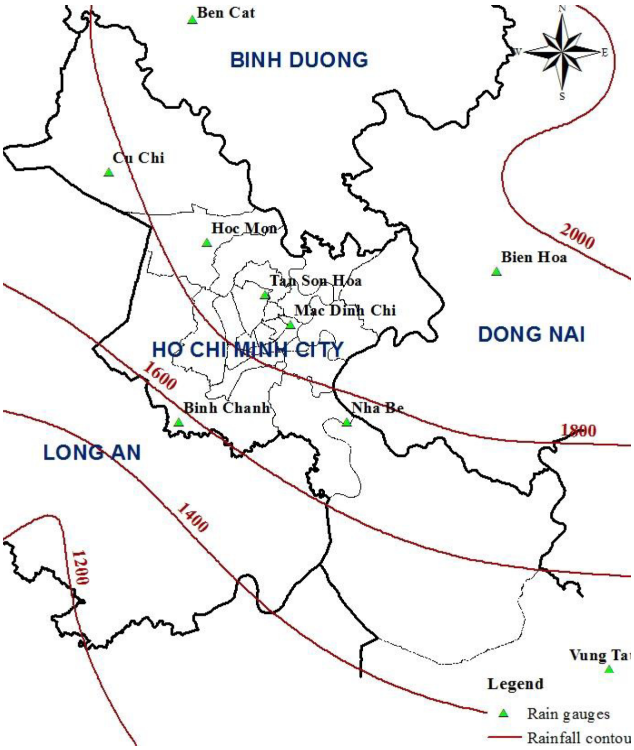

Fig. 2. Spatial distribution of annual rainfall in Ho Chi Minh City

Table 2. Statistical parameters of annual precipitation time series during the 1980-2013 period.

Station	Min (mm)	Max (mm)	Mean (mm)	STD (mm)	CV	Skewness	Kurtosis
Ben Cat	1030	2211	1675	275.3	0.16	-0.20	-0.42
Bien Hoa	1230	2679	1837	342.1	0.19	0.86	0.44
Binh Chanh	1072	2385	1603	286.3	0.18	0.99	1.31
Cu Chi	922	2357	1672	313.7	0.19	-0.16	0.43
Hoc Mon	948	2269	1497	363.7	0.24	0.47	-0.42
Mac Dinh Chi	1242	2431	1829	281.2	0.15	0.25	0.07
Nha Be	1102	2406	1701	354.6	0.21	0.30	-0.69
Tan Son Hoa	1321	2663	1904	242.2	0.13	1.02	2.88
Vung Tau	874	1970	1438	230.4	0.16	-0.50	0.79

CV: Coefficient of variation; STD: Standard deviation

4.2. Analysis of precipitation

The serial correlation coefficient can improve the verification of the independence of precipitation time series [3]. Autocorrelation plot for the precipitation at the nine rain gauges is presented in Figure 3. As shown, the precipitation had positive serial correlations. The strongest and the weakest serial correlations were found at the

Bien Hoa and Ben Cat stations, respectively. In this study, there is no correlation between two consecutive series when the value of the serial correlation coefficient should fall between -0.367 to 0.306. The result shows that the precipitation time series at the Bien Hoa, Hoc Mon, and Vung Tau stations have significant serial correlation. Thus, the data at these stations were removed serial correlation before applying the Mann-Kendall test.

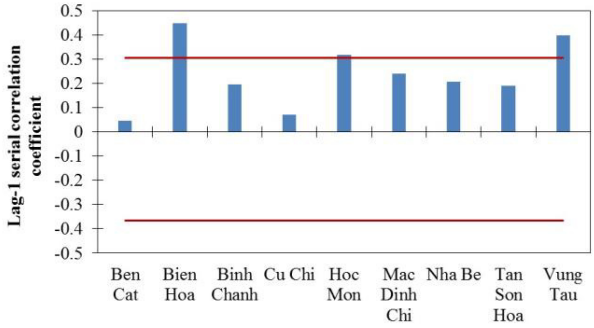

Fig. 3. Lag-1 serial correlation coefficient for the precipitation at the rain gauges

Table 3. Results of the Mann-Kendall test for annual precipitation over the 1980-2013 period

	Ben Cat	Bien Hoa	Binh Chanh	Cu Chi	Hoc Mon	Mac Dinh Chi	Nha Be	Tan Son Hoa	Vung Tau
Zc	0.129	0.241	0.299	0.062	0.274	-0.083	-0.048	0.098	-0.340
β	6.556	10.383	10.617	3.333	18.774	-5.427	-5.057	1.793	-9.24
p		*	*		*				*

** Statistically significant trends at the 5% significant level*

The results of the Mann-Kendall test for the annual precipitation series over the 1980-2013 period are presented in Table 3. Acording to these results, the significant increasing trends in annual precipitation series were detected at the Bien Hoa station with a slope of 10.383 mm/year, the Binh Chanh station with a slope of 10.617 mm/year, and the Hoc Mon station with a slope of 18.774 mm/year; and the sigificant decreasing trend was dectected at the Vung Tau station with a slope of 9.24 mm/year. The other stations had no significant trends. In general, the annual precipitation has increasing trend in the northwest part of the city and decreasing trend in the southeast part. Over the whole of Ho Chi Minh City, dominant trends for annual rainfall are increasing, but evidently statistically insignificant.

Table 4. Trends in precipitation extremes for the 1980-2013 period

Station	Frequency	Intensity		Duration	
	R50mm	*RX1day*	*R95p*	*CDD*	*CWD*
Ben Cat	0.035	-0.669	0.607	-1.042	-0.044
Bien Hoa	0.059	0.243	4.498	-1.094	-0.019
Binh Chanh	0.084	0.315	6.477	-1.346	0.113
Cu Chi	0.005	0.285	0.851	-1.919	0.089
Hoc Mon	0.100	0.900	6.82	-1.939	-0.048
Mac Dinh Chi	0.03	-0.493	1.928	-1.218	0.016
Nha Be	0.013	0.779	4.61	-1.477	-0.024
Tan Son Hoa	0.056	-0.155	3.101	-0.979	-0.035
Vung Tau	-0.042	-0.967	-5.014	-1.733	0.039

Note: (-) is decreasing trend, statistically significant trends are set grey color at the 5% significance level

4.3. Analysis of precipitation extremes

Considering the precipitation extremes (Table 4), the maximum number of consecutive dry days (CDD) shows a decreasing trend at all stations, with significance declines in the Bien Hoa, Cu Chi, Hoc Mon, and Vung Tau stations. This means decreasing trends in the dry season length. Besides that, variable trends in consecutive wet days (CWD) were found. Specially, there are four stations (the Binh Chanh, Cu Chi, and Mac Dinh Chi, and Vung Tau stations) shown increasing trends, and five stations (the Ben Cat, Bien Hoa, Hoc Mon, Nha Be, and Tan Son Hoa stations) shown decreasing trends. Regarding the R50mm index, the number of heavy precipitation above 50 mm was detected to increase at most stations, except for the Vung Tau station. Heavy rain is one of main causes of urban flooding in Ho Chi Minh City. Regarding other indices (RX1day and R95p), the increase of very wet days (R95p) is continuous in 8 stations analyzed and the maximum 1-day precipitation (RX1day) indicated an insignificant variable trend.

5. Conclusion

The main objective of this work was to study the trends in precipitation and precipitation extremes in Ho Chi Minh City for the 1980-2013 period. In order to do this, the precipitation data from nine rain gauges located inside and around the study area were analyzed using the Mann-Kendall test and five precipitation extremes indices. The major findings can be summary as follows: (1) the annual rainfall in HCMC has generally insignificant increasing trend. In case of spatial distribution, the precipitation has increasing trend in the northwest part of the city and decreasing trend in the southeast part of the city; (2) The precipitation extremes had the increasing trends in the 1980-2013 period. Increases in heavy rainfall and flooding can cause environmental pollution and health in HCMC. The need for adaptaion is emphasized in the study area.

Acknowledgements

This research is funded by Vietnam National University Ho Chi Minh City (VNU-HCM) under grant number A2013-48-01.

References

[1] Asian Development Bank. Ho Chi Minh City Adaptation to climate change – Summary report, 2010.
[2] K. Arnbjerg-Nielsen, P. Willems, J. Olsson, S. Beecham, A. Pathirana, I. Bulow Gregersen, H. Madsen, V.-T.-V. Nguyen. Impacts of climate change on rainfall extremes and urban drainage systems: a review. Water Science & Technology 68 (2013) 16-28.
[3] M. Gocic, S. Trajkovic. Analysis of precipitation and drought data in Serbia over the period 1980-2010. Journal of Hydrology 494 (2013) 32-42.
[4] I. Keggenhoff, M. Elizbarashvili, A. Amiri-Farahani, L. King. Trends in daily temperature and precipitation extremes over Georgia, 1971-2010. Weather and Climate Extremes 4 (2014) 75-85.
[5] M.G. Kendall. Rank correlation Measures. Charles Griffin, London, 1975.
[6] H.B. Mann. Non-parametric tests against trend. Econometrica 13 (1945) 245-259.
[7] T. Ngo-Duc, C. Kieu, M. Thatcher, D. Nguyen-Le, T. Phan-Van. Climate projections for Vietnam based on regional climate models. Climate Research 60 (2014) 199-213.
[8] L.V.T. Noi, V. Nitivattananon. Assessment of vulnerabilities to climate change for urban water and wastewater infrastructure management – case study in Dong Nai river basin, Vietnam. Environmental Development (2015). DOI: 10.1016/j.envdev.2015.06.014.
[9] C.J. Van Leeuwen, N.P. Dan, C. Dieperink, The challenges of water governance in Ho Chi Minh City. Integrated Environmental Assessment and Management (2015). DOI: 10.1002/ieam.1664.