13B.2 INCREASING TREND OF EXTREME RAIN EVENTS OVER BANGKOK METROPOLITAN AREA

Sangchan Limjirakan*, Atsamon Limsakul**, Thavivongse Sriburi*

*Environmental Research Institute, Chulalongkorn University, Bangkok, Thailand
**Environmental Research and Training Center, Pathumthani, Thailand

Abstract

Warming of the climate system is now unequivocal. Thailand is already experienced on its adverse impacts. The biggest threats are arguably the increasingly frequent and more intense extreme climate events such as tropical cyclones, floods, droughts and heavy rainfall events. The urban areas especially heavily populated mega-cities located on or near the coastal and river flood plains are highly vulnerable to such extreme events. To better understand changes in extreme rainfall characteristics and associated consequences in Bangkok Metropolis, which is situated on the mouth of the Chao Praya River, high-quality daily rainfall data during 1965-2006 were analyzed. A set of core extreme indices recommended by the WMO-CCL/CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) were calculated by measuring different aspects of extreme events such as wetness and dryness conditions, frequency and intensity rainfall events. The results reveal that Bangkok Metropolis has experienced notable changes in extreme rainfall events. Total annual rainfall increased significantly by about 6.2 % (relative to the 1965-2006 mean) per decade, whereas the annual number of rainy days decreased slightly by about 1% per decade. Consequently, intensity of rainfall measured by the simple daily intensity index (SDII) showed significant increasing trend over the 1965-2006 periods. It is also observed that more intense rainfall occurred during May to October when the south-east monsoon, originally from the Indian Ocean, prevails over central Thailand. Other rainfall indices such as heavy rainfall days (R10), very wet days (R95) and maximum 1-day rainfall total (R1d) showed discernable and coherent changes towards wetter condition and increases in magnitude and frequency of more intense rainfall events. These findings can be concluded that the risk of severe and flash floods and associated disasters in Bangkok Metropolitan area will increase and affect on millions of people, socio-economic and biophysical environment as well. Therefore, detailed study on vulnerability and risk assessment is urgently needed to provide valuable insight of adaptation strategy, disaster preparedness and management plan for Bangkok Metropolis, and to move forward as climate resilient sustainable development in a mega-city.

Keywords: Extreme rainfall events, Bangkok Metropolis, Thailand

1. Introduction

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has unequivocally affirmed that climate change is both real and man-made. Observational evidence clearly shows increases in global temperature, widespread snow and ice melting and changes in wind patterns, precipitation and some aspects of extremes (IPCC, 2007). Many parts of the world, especially those in Asia, are already experiencing its adverse impacts, and projections from IPCC suggest that such impacts will become even more intense in the future (IPCC, 2007). The biggest threats are arguably the increasingly frequent and more intense extreme climate events such as tropical cyclones, floods, droughts and heavy rainfall events.

The most adverse impacts of climate change are likely to be in urban areas with heavy concentrations of population and social-economic activities in fragile and vulnerable regions such as deltas and coastal zones. This is especially true for the East Asia Region (EAR), where is the epicenter of the current urbanization surge and home of more than 30 mega cities with population of more than 5 millions (World Bank, 2008). At present, 8 out of the 10 most populous cities in the world are located on the EAR coast, which 130 millions live in coastal low-lying cities (World Bank, 2008; Demographia, 2008). In the EAR, the urban population between 2000 and 2030 is projected to nearly double from 665 millions to 1.2 billion people (Demographia, 2008). Climate change has posed serious threats to social and economic figures of the EAR cities which account for high percentages of economic activities.

The concentration of people in cities increases their opportunities as well as increases their vulnerabilities to natural hazards and climate change impacts. There are evidences indicating that most of the coastal mega cities in the EAR are high risks of seismic and climatic natural disasters (IPCC, 2007; Nicholls et al., 2007; World Bank, 2007). Since the beginning of the 20th century, they have experienced more than 500 floods affecting over 800 million people (CRED, 2008). Moreover, the 2004 Indian Ocean Tsunami and the 2008 Cyclone Nagis hit Myanmar that caused tremendous economic damages and large losses of life are the recent example of havoc on high-density population in the coastal low-lying zones (Department of Marine and Coastal Resources, 2005; United Nations, 2008). Climate change impacts and consequences can therefore wipe out development gains and significantly reduce the standard of living as well as compound environmental degradation. Hence, climate change represents a critical challenge for the region, especially coastal and low-lying cities where people, resources and infrastructure are concentrated. This vulnerability and risk to climate change can be also exacerbated by other already existing stresses

**Corresponding author* : Sangchan Limjirakan, Environmental Research Institute, Chulalongkorn University, Pathumwan, Bangkok 10330 Thailand; E-mail: lsangcha@chula.ac.th

such as poverty, food security and environmental degradation.

Bangkok, the capital and also the largest city of Thailand, is one of the rapidly urbanized mega cities in the Southeast Asia. It is the world's 22nd largest city with current population approximately 8 million (Demographia, 2008). Bangkok has been the political, social and economic centers of not only Thailand but for much of the EAR, making it as the regional hub of a global city network. In 2005, it produced a GDP of about USD 220 billion, which accounts for more than 40 percent of the country's GDP (UN-HABITAT, 2006; BMA, 2008). Its GDP per capita is well over USD 20,000, one of the highest in the Southeast Asia (Wikipedia, 2008). Bangkok is situated on a very low-lying flat plain of the Chao Phraya River Delta, where the ground-surface elevation is about 0-1.5 meters above the mean sea level (Tang et al., 1992; Hung et al., 2008). The city is affected by flood in a regular basis. Urbanization is rapidly expanding on both sides of the river flood plain. Due to its geographic location at low-lying alluvial deposit in combination with rapid urbanization, land subsidence and increasingly degraded environments, Bangkok is recognized as a particularly vulnerable city from a wide variety of climate-related disasters and other threats. Through this study, trends in daily rainfall extreme in Bangkok have been analyzed, to evaluate whether the frequency and/or severity of rainfall extremes in the densely populated, low-lying mega city have changed in the recent decades. This knowledge will provide insight into the direction and significance of rainfall extreme changes that are particularly essential for building sustainable, resilient coastal cities and effective disaster risk and coastal management.

2. Data and analysis methods

Historical records of daily total rainfall amounts spanning the period 1965-2006 from 3 major stations located in different parts of the Bangkok Metropolis were utilized (Figure 1). The data used here were obtained from the archives of the Meteorological Department of the Royal Thai Government. Station records were selected on the basis of record length and data completeness. Each of the selected station records is at least 99% complete. Three stations studied are located in the north, center and south of the Bangkok Metropolis, respectively. Prior to calculating rainfall extreme indicators, all records were subjected to visual examination of any obvious outliers and potential discontinuities, followed by a multi-stage suite of objective quality control and homogeneity tests. Recently developed objective approaches including spatial and temporal outliers, interpolation and data homogeneity were applied to evaluate the quality of this data set (Feng, et al., 2004; Auger, et al., 2005; Wang, et al., 2007). Our thorough examination reviewed that daily total rainfall data in the Bangkok Metropolis during 1965-2006 were relatively good, which no significant inhomogenous time series were detected.

Five of the 11 core rainfall-related indices recommended by the WMO-CCL/CLIVAR/ETCCDMI were used to assess the changes in extremes for Bangkok Metropolitan area (Alexander et al., 2006). The indices were chosen primarily for assessment of many aspects of a changing climate which include changes in intensity, frequency and duration of rainfall events. They represent events that occur several times per year giving them more robust statistical properties than measures of extremes which are far enough into the tails of the distribution so as not to be observed during some years. Of the five extreme rainfall indices, four of them relate to 'wetness' [heavy rainfall days (R10), maximum 1-day rainfall total (R1d), simple daily intensity index (SDII) and very wet days (R95)] while one of them relates to 'dryness' [consecutive dry days (CDD)]. R10 is an indicator of the frequency of significant rainfall days for a given year, whereas R95 and R1d represent the magnitude of the more intense rainfall events. In contrast, the SDII is a measure of the average rainfall amount that falls on a wet day in a given year. The CDD index is a measure of the length of the driest part of the year that may serve as a valuable drought indicator.

Two methods were employed to analyze each of extreme indicator time series. One examines trends in each individual station data, and the other compares empirical probability distribution functions (PDF) for two different time periods. The trend estimator used is the ordinary least square (OLS) method, which is the most widely used and accepted non-parametric trend estimator in the literature (Griffiths and Bradley, 2007). Trend magnitudes are expressed as percentage change relative to the 1965-2006 means and statistical significance is assessed following the non-parametric Kendall's Tau test (Alexander et al., 2006). This method is resistant to outliers in the time series and robust to non-normal data distribution. For the PDF calculation, it was done by fitting the data before and after 1990 intervals with gamma distribution function. To assess whether the probabilities for two periods for each extreme indicator were significantly different, a two tail Kolmogorov-Smirnov test was employed. This test has a null hypothesis that two PDFs for two time periods are identical (Griffiths and Bradley, 2007).

3. Results and discussions

In general, Bangkok receives a relatively high average annual rainfall of about 1400 mm and is influenced primarily by the seasonal monsoon. The south-west monsoon, in which heavy rainfalls occur, begins from mid May and lasts until mid October. The north-east monsoon, which is comparatively dry and cool, occurs from mid October to mid February. Two monsoons are closely associated with atmospheric pressure conditions over the whole of Asia. The boundary zone between these two monsoonal flows called the Equatorial Through Zone (ETZ) passes back and forth over the central part of Thailand several times during the lulls and surges of the monsoons. Other studies also indicated that strengthening and weakening of the seasonal monsoon over Thailand link to the phase reversals of the El Niño-Southern Oscillation (ENSO) and interact, to some extent, with the Indian Ocean Dipole (IOD) (Singhratina et al., 2005; Juneng and Tangang, 2005; Goswami et al., 2006; Meyer et al., 2007).

Based on our analysis, there is evidence of statistically significant rising trends in total annual rainfall amounts in the Bangkok Metropolis during

1965-2006 (Figure 2). All stations examined here showed on average 6.2% per decade increase relative to the 1965-2006 mean. Further examination by analyzing separately the dry half-year period (Nov. – Apr.) and the wet half-year period (May-Oct.) revealed that only total rainfall amounts during the wet half-year period showed similar significant upward trends with comparative magnitudes (6.5 % per decade). This finding indicates that the Bangkok Metropolis has experienced increased annual rainfall amounts, resulting primarily from exceptionally enhanced rainfall amounts during the south-west monsoon. However, no significant changes were detected for the number of annual rainy days (defined as days with at least 1 mm of rain) during the same period (Figure 3). Trends in the number of rainy days both annual and seasonal time scales exhibited mixed patterns of change, which their magnitude varied from -2.5 to 5.4 % per decade.

Another noteworthy feature is a significant increase in the SDII, defined as total annual rainfall per the number of wet days in the year, in the Bangkok Metropolis during 1965-2006 periods (Figure 4). All stations showed significant increasing trends in the SDII at the 95% confidence level, which their magnitudes were in a range of 3.2 - 4.7 % per decade. It should be noted that there are consistent increases in the SDII in the Bangkok Metropolis and along the coast of the Gulf of Thailand (Limsakul et al., 2008). By comparison with trends in total annual rainfall amounts and the number of rainy days, it is found that the increase in the SDII over the Bangkok Metropolis reflects an increase in rainfall amounts rather than the number of rainy days. Similar to changes in annual rainfall amounts, the significant increase in the SDII occurred only during the south-west monsoon (May-Oct.) with rates of increase ranging from 4.8 to 5.3% per decade. Consequently, a significant change during this period is mainly attributable to annual increase in the SDII.

Trends in heavy rainfall (R95) in the Bangkok Metropolis showed similar patterns as total annual rainfall amounts and the SDII. There were significant rising trends (at 0.05 significance level) in R95 at all stations, at rates of changes in a range of 12.8 – 17.9 % per decade (Figure 5). This result is consistent with the recent study of Goswami et al. (2006), illustrating significant rising trends in the frequency and the magnitude of extreme rain events over central India during the monsoon seasons between 1951 and 2000. They further pointed out that the increasing trend in extreme rain events is related to a trend in large-scale moisture availability, which in turn is due to gradual warming of sea surface temperature. The rising trend in R95 was associated with a significant increase in the frequency of heavy rainfall days, R10 (Figure 6). For all stations in the Bangkok Metropolis, R10 index showed statistically significant upward trends, which increased in range of 3.8 – 6.8 % per decade. Similarly, another wetness indicator, R1d, exhibited a coherent change with R95 and R10. All stations revealed a tendency toward increased R1d, but only two stations have statistically significant increases at the 95% confidence level (Figure 7). For CDD, a dryness indictor, there is a mixture of stations exhibiting increasing and decreasing trends. However, no significant changes in CDD were found in the Bangkok Metropolis between 1965 and 2006 (Fig. 8).

Table 1 shows trends estimated for each of extreme rainfall indices by simply averaging from all three stations. There are 5 out of 7 extreme rainfall indices exhibiting significant increases, of which the SDII represents the largest increase. It is obvious from these results that, during 1965-2006, 5 extreme rainfall indices pointed up coherent and notable changes toward wetter conditions and increases in magnitude and frequency of more intense rainfall events in the Bangkok Metropolis.

Figure 9 shows the PDFs of seven annual rainfall extreme indicators computed for 1965-1989 and 1990-2006 intervals using data from all three stations. From this analysis, there is an evidence of a marked increase in total annual rainfall amounts, accompanied by pronounced increases in SDII, R95, R10 and R1d indices in 1990-2006 periods comparing to 1965-1989 periods. The PDFs of these indices in 1990-2006 intervals are significantly different from the previous interval. This is consistent to the results in Table 1, indicating a shift in the distribution to wetter conditions associated with notable increases in both severity and frequency of heavy rainfall events in the Bangkok Metropolis in the recent decades.

4. Conclusions

Based on this study, there is clear evidence that different aspects of extreme rainfall in the Bangkok Metropolis presented notable changes during 1965-2006. Significant change emerged from this study was marked by a pronounced increase in total rainfall amount especially during the wet season, when the south-east monsoon originally from the Indian Ocean prevails over central Thailand. In association with the change in mean state of rainfall amounts, there were coherent changes towards increases in both frequency and intensity of heavy rainfall events, as indicated by significant increases in R95, R10 and R1d. Another noteworthy feature is that the Bangkok Metropolis has experienced more intense daily rainfall, which showed the largest increase as compared to other extreme rainfall indices. These findings suggest that the risk of severe and flash floods and associated disasters in Bangkok Metropolitan area will increase and affect on millions of people, socio-economic and bio-physical environment. Impacts and consequences of such extreme rainfall events can substantially wipe out development gain and significantly reduce the standard of living as well as compound environmental degradation. Therefore, detailed study on vulnerability and risk assessment is urgently needed to provide valuable insight of adaptation strategy, disaster preparedness and management plan for Bangkok Metropolis, and to move forward as climate resilient sustainable development in a mega-city as well.

5. Acknowledgments

We would like to thank the Meteorological Department of the Royal Thai Government for kindly providing valuable daily rainfall data. This study is financially supported by Thailand Research Fund.

6. References

Alexander, L.V. et al., 2006: Global observed changes in daily climate extreme of temperature and precipitation. Journal of Geophysical Research, 111, DO5109, doi:10.1029/2005JD006290.

Auger, I. et al., 2005: A new instrumental precipitation dataset for the Greater Alpine Region for the period 1800-2002. International Journal of Climatology, 25, 139-166.

Bangkok Metropolitan Administration (BMA), 2008: http://www.bma.go.th.

Center for Research on the Epidemiology of Disasters (CRED), 2008: EM-DAT: Emergency event database. www.emdat.be.

Demographia, World Urban Areas, 2008: 2025 & 2030 population projection, Belleville, Illinois.

Department of Marine and Coastal Resources, 2005: Rapid assessment of the tsunami impact on marine resources in the Andaman Sea, Thailand. www.pbmc.go.th. 84 pp.

Feng, S., Q. Hu and W. Qian, 2004: Quality control of daily metrological data in China, 1951-2000: A new dataset. International Journal of Climatology, 24, 853-870.

Goswami, B.N., V. Venugopal, D. Sengupta, S. Madhusoodanan and P.X. Xavier, 2006: Increasing trend of extreme rain events over India in a warming environment. Science, 314, 1442-1445.

Griffiths, M.L. and R.S. Bradley, 2007: Variation of twentieth-century temperature and precipitation extreme indicators in the Northeast United States. Journal of Climate, 20, 5401-5417.

Hung, N.Q., M.S. Babel, S. Weesakul and N.K. Tripathi, 2008: An artificial neural network model for rainfall forecasting in Bangkok, Thailand. Hydrology and Earth System Science Discussions, 5, 183-218.

IPCC. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK and USA, 976 pp.

Juneng, L. and F.T. Tangang, 2005: Evolution of ENSO-related rainfall anomalies in Southeast Asia region and its relationship with atmosphere-ocean variations. Climate Dynamic, 25, 337-350.

Limsakul, A., S. Limjirakan and S. Thavivongse, 2009: Assessment of extreme weather events along the coastal areas of Thailand. The 89th AMS Conference Meeting, Arizona, USA. 11-15 Jan., 2009.

Meyers, G., P. McIntosh, L. Pigot, and M. Pook, 2007: The years of El Niño, La Niña, and interactions with the Tropical Indian Ocean. Journal of Climate, 20, 2872-2880.

Nicholls, R.J. et al., 2008: Ranking port cities with high exposure and vulnerability to climate extremes – exposure estimate. OECD Environment Working Papers, No. 1, OCED Publishing.

Singhratina, N., B. Rajagopalan, K.K. Kumar and M. Clark, 2005: Interannual and interdecadal variability of Thailand summer monsoon season. Journal of Climate, 18, 1697-1708.

Tang, J.C.S. and S. Vongvisessomjai, 1992: Estimation of flood damage cost for Bangkok. Water Resource Management, 6, 47-56.

UN-HABITAT, 2006: State of the world's cities 2006/7. Nairobi, Kenya, 136 pp.

United Nations, 2008: Myanmar Tropical Cyclone Nagis: Flash Appeal. New York, USA.

Wang, X.L., Q.H. Wen and Y. Wu, 2007: Penalized maximal *t* test for detecting undocumented mean change in climate data series. Journal of Applied Meteorological Climatology, 46, 916-931.

Wikipedia, 2008: Bangkok. http://en.wikipedia.org /wiki/Bangkok.

World Bank, 2007: East Asia Environmental Monitor : Adapting to Climate Change. Washington, USA.

World Bank, 2008: Climate resilient cities. Washington, USA, 150 pp.

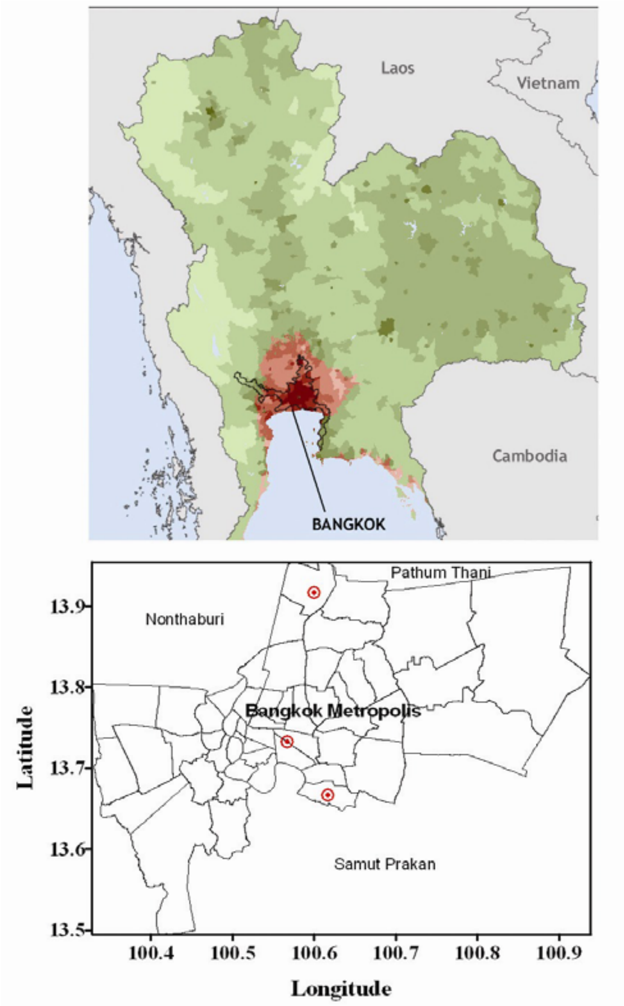

Figure 1. Locations of high-quality meteorological stations used in the rainfall extreme analysis.

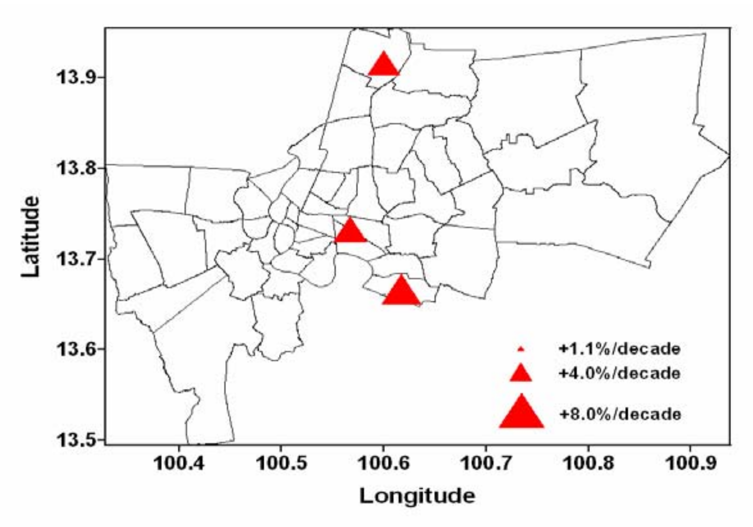

Figure 2. Trends in total annual rainfall amounts expressed as percents relative to the 1965-2006 mean. Filled triangles correspond to trends significant at the 5% level.

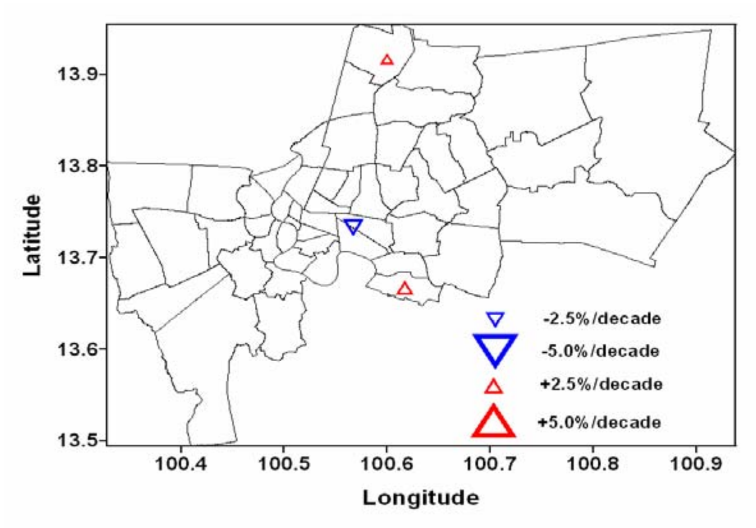

Figure 3. As Figure 2 but for total annual wet days (rainfall greater than 1 mm).

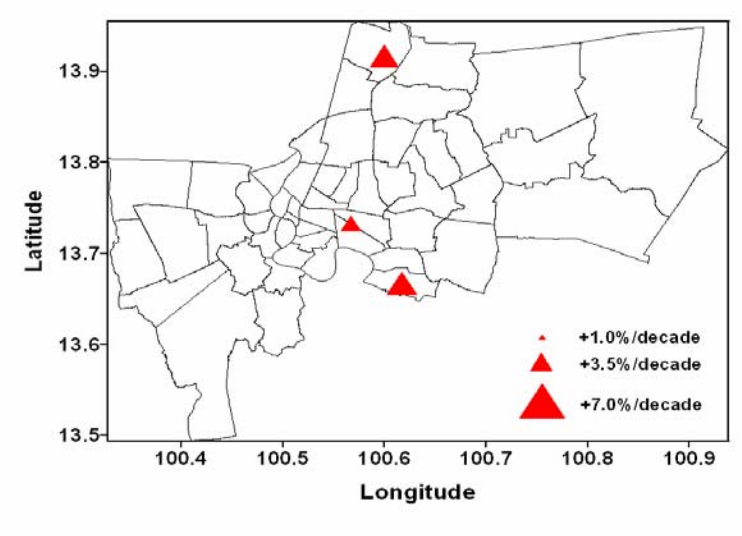

Figure 4. As Figure 2 but for simple daily intensity index (SDII).

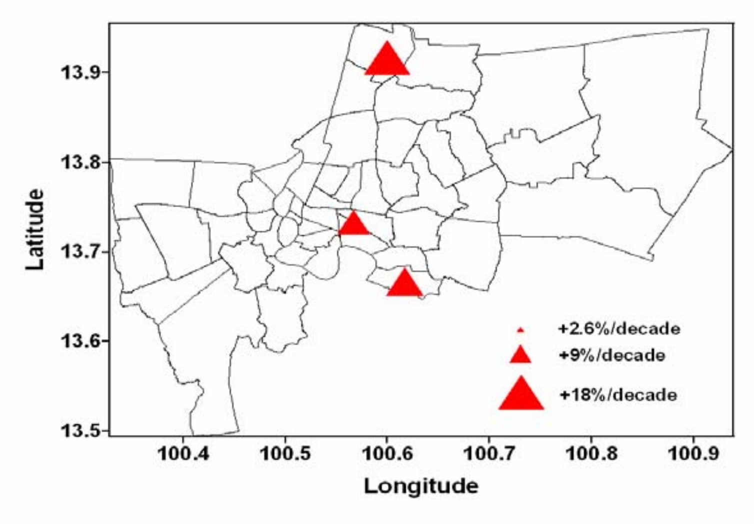

Figure 5. As Figure 2 but for R95.

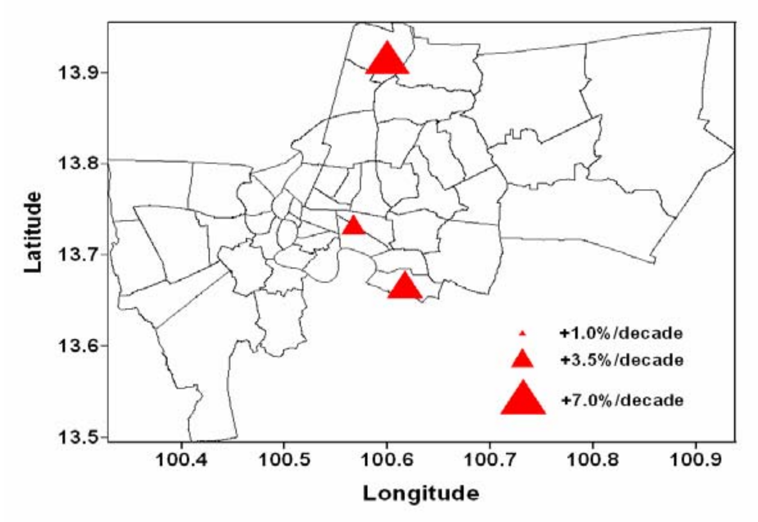

Figure 6. As Figure 2 but for R10.

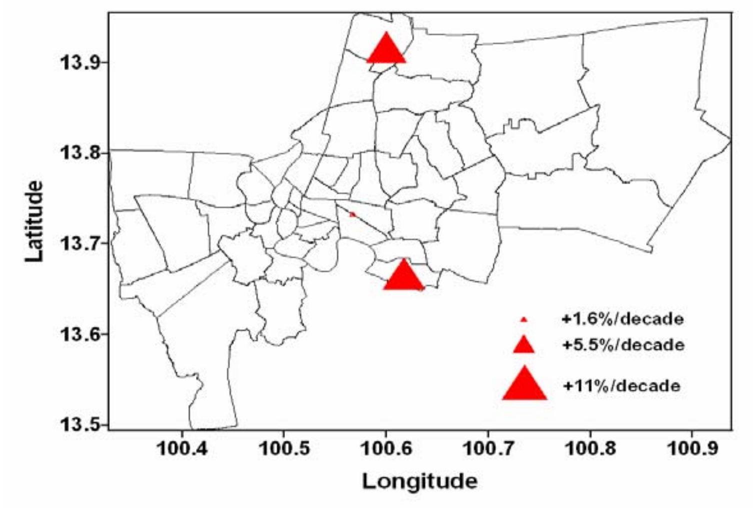

Figure 7. As Figure 2 but for R1d.

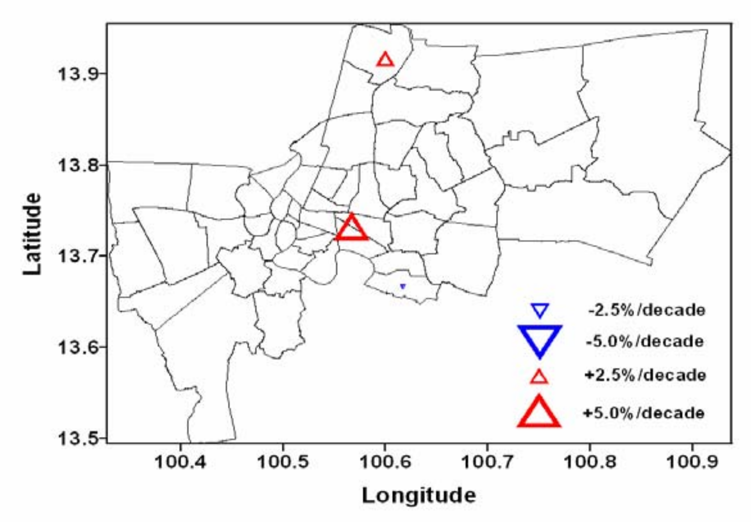

Figure 8. As Figure 2 but for CDD.

Table 1. Trends in averaged rainfall extreme indices expressed as percentage changes relative to the 1965-2006 means.

Extreme indices	Trends (%/decade)
Total rainfall amounts	5.9∗
Number of rain days	0.4
SDII	42.0∗
R10	4.7∗
R95	14.9∗
R1d	6.4∗
CDD	3.1

∗ significant trends exceed the 95% confidence level in the Kendall-Tau test.

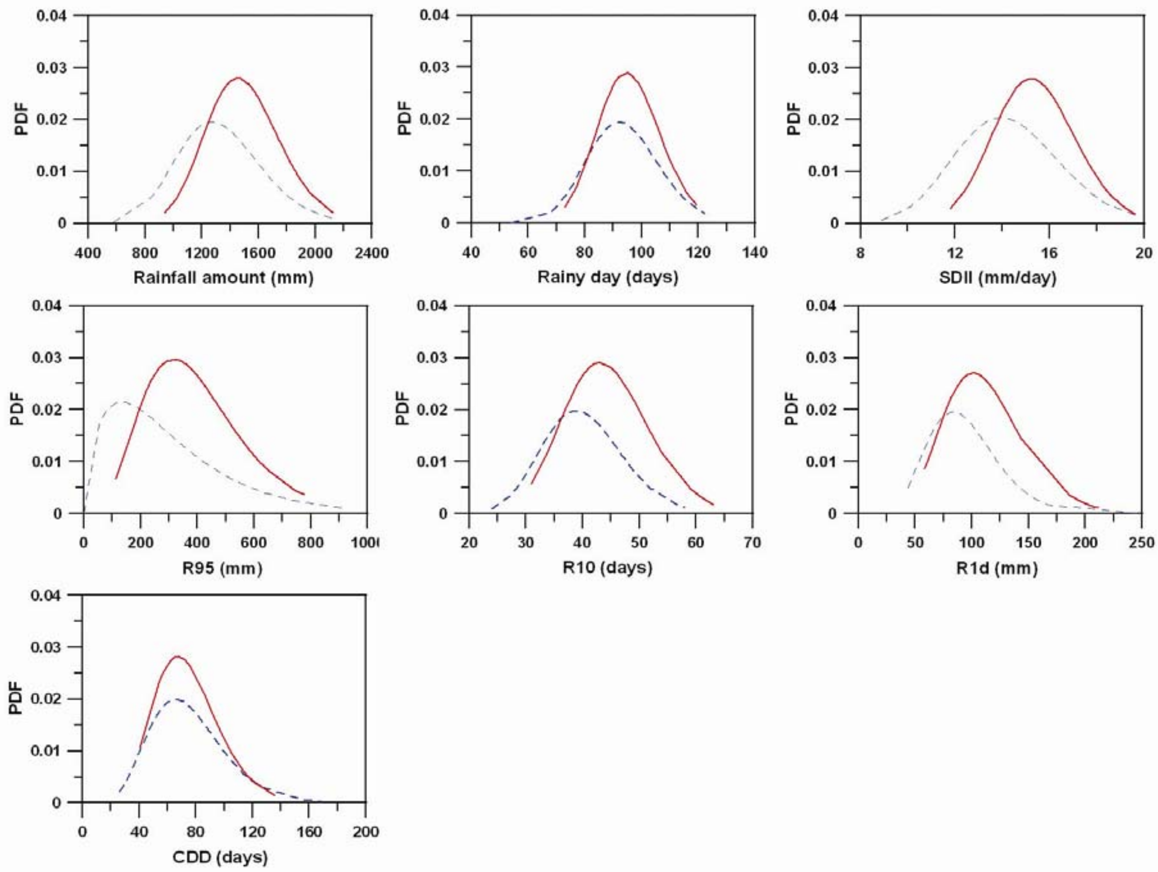

Figure 9. Annual probability distribution functions of rainfall extreme indices, estimated by gamma distribution. Blue dash lines/red solid lines are the data before and after 1990, respectively. Two-tailed Kolmogorov-Smirnov test was used to assess different significance for the data of two periods. Rainfall amounts, SDII, R95, R10 and R1d are significantly different at 95% confidence level.