IMPACT OF CLIMATE CHANGE ON INTENSITY-DURATION-FREQUENCY CURVES IN HO CHI MINH CITY

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Abstract: *Viet Nam is considered as one of the countries most affected by climate change. The magnitude and frequency of extreme events (such as high-intensity rainfall, flooding, severe droughts) are expected to increase in future due to climate change. The evaluation of the possible climate change influence on extreme precipitation is very interesting in megacities city due to the usual and characteristic high intensities of its rainfall pattern. This study aims at developing Intensity-Duration-Frequency (IDF) curves for Ho Chi Minh City, Viet Nam for the present as well as future climatic scenarios. The rainfall projections for future periods based on ensemble regional climate modeling approach are used to calculate IDF curves and their plausible changes in the middle of the 21st century (2050s), and at the end of 21st century (2090s). The results suggest that intensities of extreme rainfall events versus various durations with different return periods are all likely to increase over time in comparison with baseline period (1986-2005): [11, 60]% in 2050s, and [15, 69]% in 2090s under most likely case; and [38, 141]% in 2050s, and [28, 105]% in 2090s under high impact case. Such a consistent increase in the exceedance values of rainfall intensity of extreme events, implying that intense rainfall events are likely to occur more frequently in the future under climate change. The results presented in this paper are important for the design and construction of different hydrological structures in water management in Ho Chi Minh City.*

Keywords: *IDF curve projection, climate change, Ho Chi Minh City.*

1. Introduction

The effects of climate change on hydrology and the potential intensification of the hydrological cycle have to be considered in order to prevent future problems in the urban drainage systems. The intensity-duration-frequency (IDF) curves, a very important tool used in the design and construction of different hydrological structures in water management, could be altered by a presumed increase of intense rainfall caused by climate change. Therefore, there are many research studies in rainfall IDF for specific regions or provinces not only in developed countries but also in many developing countries. De Paola et al. (2014) estimated the rainfall IDF for three cities, including Addis Ababa (Ethiopia), Dar Es Salaam (Tanzania) and Douala (Cameroon), using rainfall observations and rainfall estimates derived from the CMCC model. The temporal disaggregation method was used to obtain the rainfall amounts over smaller time scale. The evaluation of rainfall IDF was conducted, and then the projection of rainfall IDF was estimated to verify the change of extreme values under climate change. Akpan and Okoro (2013) developed two sets of rainfall IDF models for Calabar City (Nigeria), and estimated the relationship between rainfall intensity and duration for specific frequencies and associated rainfall intensity and frequency for specific durations, using a rainfall dataset from 2000 to 2009. These models are used to predict the possibility of a certain amount of rainfall that may be used in planning and designing the infrastructure in Nigeria. Logah et al. (2013) analyzed rainfall data of four stations in Greater Accra Region to develop the rainfall intensity - duration - frequency curves by fitting the rainfall intensity to Gumbel distribution for

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various durations. Le et al. (2006) used four empirical functions including the Talbot, Bernard, Kimijima and Sherman equations to construct rainfall IDFs for several stations in Viet Nam. Their study compared the results among these four methods and then chose the appropriate equation for Viet Nam. In addition, this study also proposed a method to generalize the IDF curve for ungauged rainfall locations over Viet Nam. Nguyen et al. (2007) constructed rainfall IDFs using temporally and spatially downscaled rainfall data under the A2 scenario. The SDSM method combined with bias correction is employed to obtain adjusted daily rainfall estimates at several rain gauge stations in Quebec. After that, the scaling General Extreme Value (GEV) distribution produces sub-daily rainfall from daily data. The impact of climate change on rainfall IDF over Barcelona (Spain) is considered by Rodríguez et al. (2013). This change is analyzed from the output of five Global Circulation Models (GCM) under three scenarios including A1B, A2 and B2.

Ho Chi Minh City (HCMC) is located in the delta area of the Saigon and Dong Nai rivers. It is Viet Nam's largest city and an important economic, trade, cultural and research centre, both within the country, and in South-East Asia. Like most cities situated in deltas, HCMC faces serious challenges due to climatic change. HCMC is ranked among the top 10 cities in the world most likely to be severely affected by climate change [2]. 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, IDF curves for future have been developed much for Ho Chi Minh City. The objective of this study was to assess climate change impact on rainfall IDF curves at Ho Chi Minh City. The firstly, present IDF is analysed based on observed data. Follow that, the rainfall projections for future periods based on ensemble regional climate models approach are used to develop projected intensity-duration-frequency curves and their plausible changes in the middle of 21st century (2050s), and at the end of 21st century (2090s).

2. Methodology and data

2.1. Data

2.1.1. Observation data

In this study, daily rainfall observations from the Tan Son Hoa station covering the period of 1986-2005 were collected for bias correction of the Regional Climate Model (RCM) output. In addition, rainfall data of several short duration extreme events were collected for this station. The dataset consists of rainfall in several durations including 15 min, 30 min, 45 min, 1 hr, 1.5 hr, 2 hr, 3 hr, 6 hr and 12 hr. Both daily and shorter-duration rainfall datasets are provided by Viet Nam Institute of Meteorology, Hydrology and Climate Change.

2.1.2. Simulation data

To constructs rainfall IDF curves for baseline and future periods, daily rainfall datasets from four RCMs (including (i) PRECIS from Hadley - UK, (ii) CCAM from CSIRO, (iii) RegCM from ICTP, Italy and (iv) clWRF from the USA) are obtained. Each RCM has been used to calculate different climate projections based on the results from GCMs of IPCC. In total, there are 24 projections from the 4 models with 2 Representative Concentration Paths (RCP). Information about these models is described in Table 1. It is noted that, the bias of RCM simulations is corrected by using quantile mapping technique before used. The detailed steps for doing bias correction are provided in the work of MONRE (2016).

2.2. Methodology

2.2.1. Temporal downscaling

High-temporal-resolution (e.g., 15 min, 30 min, and 1-h) data are needed to create the IDF curves. Since the simulation data are only available at daily interval, it is necessary to temporally downscale the daily maximum rainfall intensity to hourly or sub-hourly rainfall

Table 1. Information on RCMs

No.	RCM	Organization	Driving GCMs	Resolution, Domain	Vertical level
1	clWRF	NCAR, NCEP, FSL, AFWA,...	1. NorESM1-M	30 km, 3,5÷27°N and 97,5÷116°E	27
2	PRECIS	Hadley, UK	1. CNRM-CM5 2. GFDL-CM3 3. HadGEM2-ES	25 km, 6,5÷25°N and 99,5÷115°E	19
3	CCAM	CSIRO, Australia	1. ACCESS1-0 2. CCSM4 3. CNRM-CM5 4. GFDL-CM3 5. MPI-ESM-LR 6. NorESM1-M	10 km, 5÷30°N and 98÷115°E	27
4	RegCM	NCAR, USA	1. ACCESS1-0 2. NorESM1-M	20 km, 6,5÷30°N and 99,5÷119,5°E	18

intensities for different return periods. For the purpose of constructing rainfall IDF curves for the future period, scaling theory was applied to produce short-duration rainfall intensity from daily rainfall data. The scaling property is proven by many studies and is applied to rainfall intensity by Menabde (1999), Le et al. (2007), and Mishra et al. (2011).

Based on empirical evidence, it is assumed and verified that random variable Id and ID as annual maximum rainfall intensities over time duration d and D respectively can have the following scaling property (Menabde et al., 1999):

$$I_d = \left(\frac{d}{D}\right)^{-\eta} I_D \qquad (1)$$

In equation 1, the equality refers to the identical probability distribution for both variables and η represents the scaling exponent. The relationship between the moments of order *q* can be obtained by raising both sides of the equation to power *q* and taking the expected values of both sides (equation 2).

$$E\left[I_d^q\right] = \left(\frac{d}{D}\right)^{-\eta(q)} E\left[I_D^q\right] \qquad (2)$$

Estimation of scaling exponent η is illustrated in Figure 1 which includes (i) log-log graph of moments $E[I^q_d]$ versus durations of different order q; and (ii) linear graph of slopes *(of moments versus duration lines)* and moment order q. If the resulting graph is a straight line i.e., value of η (slope) remain same for different values of q, it is of simple scaling otherwise it is of multi-scaling.

2.2.2. Rainfall IDF curves construction

The rainfall IDF curve is constructed by using short-duration rainfall observations from the Tan Son Hoa station. The Gumbel distribution is chosen for conducting frequency analysis. The cumulative distribution function can be expressed as below:

$$F_d(i) = \exp\left(-\exp\left(-\frac{i-\mu_d}{\sigma_d}\right)\right) \qquad (3)$$

where *i* is rainfall intensity, μ_d and σ_d are the location and scale parameters respectively, and F_d *(i)* is the non-exceedance probability of intensity i in duration *d*.

To obtain the rainfall intensity ***i*** from a given probability or return period, we find the inverse of function (3) by taking the natural logarithm of the left side twice. After doing this step, function (4) is derived:

$$i = \mu_d - \sigma_d * \left(\ln\left(-\ln\left(1-\frac{1}{T}\right)\right)\right) \qquad (4)$$

where ***T*** is the return period. The relationship between the return period *T* and the non-exceedance probability F_d is shown in function (5):

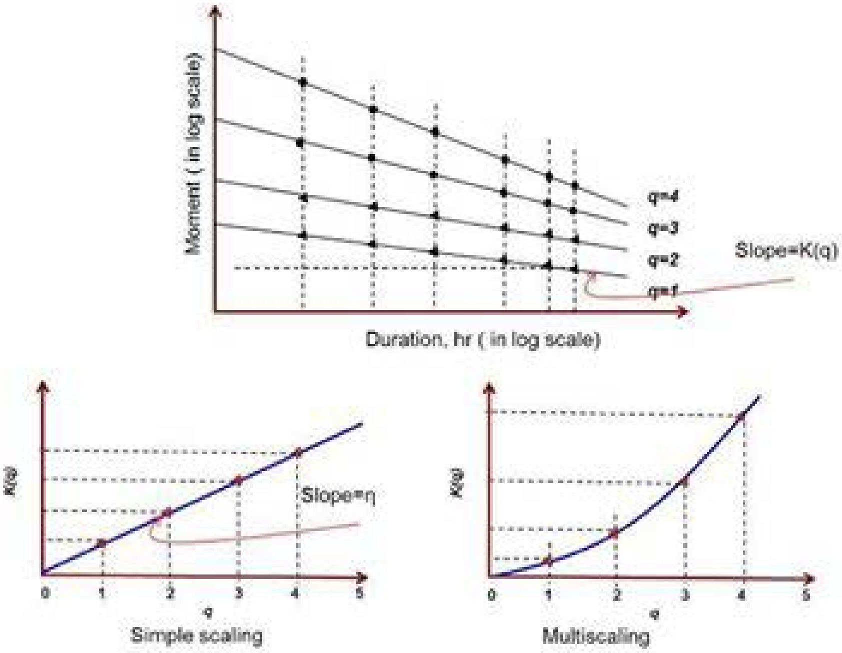

Figure 1. Simple scaling and mutil-scaling (Le Minh Nhat, 2008)

$$T = \frac{1}{1-F_d} \tag{5}$$

2.2.3. Ensemble percentiles

In climate change scenario, the state of climate in the future is addressed base on greenhouse gas (GHG) Concentration scenarios. Different GHG input for climate model generates different climate change scenario. In addition, there are many uncertainty sources inside the model as well as from the outside. It is indicated that the uncertainty in climate change scenario is very clear for any region in the world. Therefore, it is indispensable to consider several situations and state of climate in the future with different RCMs and under some GHG Concentration scenarios. To synthesize the ensemble simulations, this paper is following the approach used in the UK Climate Projections report (Murphy et al., 2009). To allow for more freedom in exploring the uncertainties associated with the simulations, this paper select two typical percentiles (50^{th}, and 75^{th}) to summarize the possible outcomes of future projections:

The most likely case: This case is obtained by calculating the 50^{th} percentile of all IDF projection members. The 50^{th} percentile is used here to represent the central value of the distribution, indicating that half of the members are less than or equal to it.

High impact case: This case is the 75^{th} percentile of all IDF projection members. The 75^{th} percentile is to indicate very likely to be less than or very unlikely to be greater than.

3. Results and Discussion

3.1. Observed IDF curves

Average intensities of rainfall in duration from 15 minutes to 1 days for several return periods from 2 years to 100 years at Tan Son Hoa station are shown in Table 2 and Figure 2 performs the graph of IDF relationship at Tan Son Hoa station.

For 100-year return period, this is a very rare occurrence, average rainfall intensity in 15 minutes is 222 mm/hour. If this intensity remains for 15 consecutive minutes, the total accumulated rainfall at Tan Son Hoa station will be around 55.5 mm. In 46 years of observation data used in this study (not shown in the paper), this event has never happened. In 1-hour duration, average rainfall intensity is 129.9 mm/hour. The intensity which is equal or greater than that value has occurred for one time in 2016. Average daily intensity is 7.3 mm/hour corresponding to 175.2 mm total rainfall in a day. The one-day maximum rainfall in the period from 1971-2016 is 171 mm, which occurred on 26/09/2016.

For 50-year return period, average rainfall intensity in 15 minutes is 206.8 mm/hour. This rain event also has not happened in the period from 1971-2016. With the duration of 1 hour and 24 hours, average rainfall intensity is 120.2 mm/hour and 6.7 mm/hour, respectively. These two rain events have only occurred once, in 2016 with 1-hour duration and 1994 with 1-day duration.

For 25-year return period, the average rain intensity in 15 consecutive minutes is 191.5 mm/hour. In 46 years of observation data, there was one time that heavy rain with the intensity is greater than 191.5 mm/hour occurred, in 2000. With the duration of 60 minutes, average rain intensity is 110.4 mm/hour, this rain event happened two times, in 1981 and 2016. With the duration of 24 hours, average rain intensity is 6.2 mm/hour, the corresponding total precipitation accumulated in 24 consecutive hours is 148.8 mm. This event also occurred in 1994 and 2016.

For 2-year return period: Correspond to rain duration in 15 minutes, average rainfall intensity is 130 mm/hour. In 46 years of observed data, the rain event with intensity higher or equal to 130 mm/hour has happened 25 times. Average rainfall intensity in 60 minutes is 70.9 mm/hour, occurred 26 times in 46 years of observed data. With the duration of 24 hours, average rainfall intensity is 4 mm/hour, corresponding to the total rainfall accumulated in 24 consecutive hours of 96 mm. This event has happened 24 times in the period from 1971-2016.

Table 2. Average rainfall intensity (mm/hour) in several durations and return periods at Tan Son Hoa station from short duration observation data (1971-2016)

	15'	30'	45'	60'	90'	2h	3h	6h	12h	24h
2 years	130.0	100.7	85.2	70.9	51.5	40.0	28.3	14.2	7.1	4.0
5 years	154.6	121.8	102.4	86.7	64.3	50.2	35.7	17.9	8.9	4.9
10 years	170.9	135.7	113.8	97.1	72.7	56.9	40.6	20.3	10.2	5.4
25 years	191.5	153.2	128.2	110.4	83.4	65.4	46.8	23.4	11.7	6.2
50 years	206.8	166.3	138.9	120.2	91.3	71.7	51.4	25.7	12.8	6.7
100 years	222.0	179.2	149.5	129.9	99.2	78.0	55.9	28.0	14.0	7.3

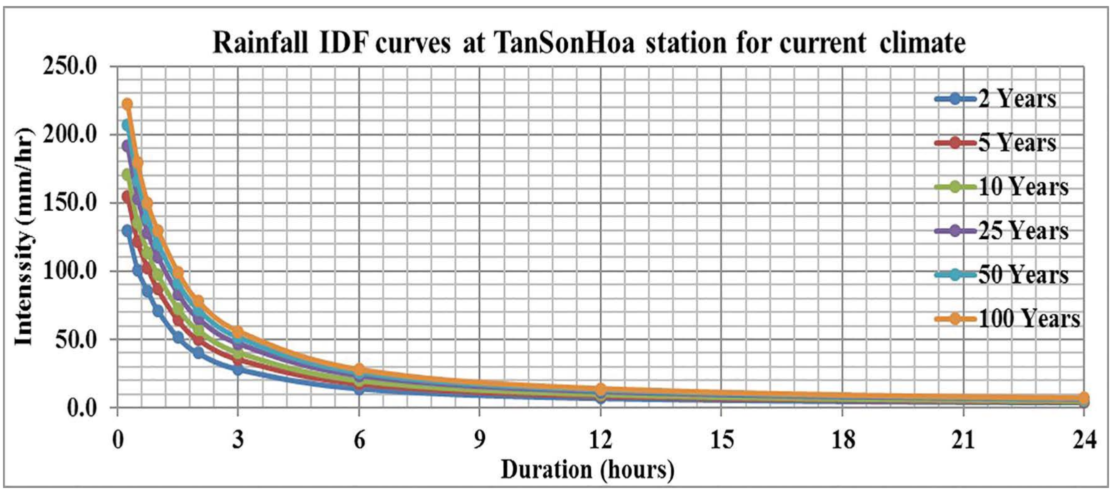

Figure 2. Rainfall IDF curves at Tan Son Hoa station from short duration observation data (1971 - 2016)

3.2. Projected IDF curves

3.2.1. The most likely case (percentile 50%)

The change of rainfall intensity in several durations and return periods for future periods relative to the baseline period is shown in Table 3 and Table 4. The changes are presented as relative percentages, and positive values indicate percentage increases relative to the baseline projections, whereas negative ones indicate percentage decreases. The result shows that the regional modeling ensemble is likely to project an overall increasing pattern in the intensities of all extreme rainfall events. The projected changes in rainfall intensities for all durations also show an apparent increasing trend with time. The change for 2050s are mostly in the range of 11% and 60%, the changes for 2090s are mainly ranging from 15% to 69%. The changes depend on various durations return periods.

In the middle of the century (2046-2065): For the 100-year return period, rainfall intensity in 15-minutes duration tends to increase by 38.8% that corresponds to the intensity of 326.8 mm/hour. In 60-minute duration, the intensity is 194.6 mm/hour and its upturn is 56.4%. The increase in 24-hour duration is 40.1%. 24-hour duration average intensity in the middle of the 21st century is 10.2 mm/hour; For 50-year return period, average rainfall intensity in the duration of 15 minutes, 60 minutes and 24 hours will increase by 35.7%, 52.7% and 37.7% respectively. With the duration of 24 hours, the average rainfall intensity is 9.3 mm/hour; For 25-years return period, average rainfall intensity at Tan Son Hoa station in 15 minutes will be 264.4 mm/hour (by 32%). With the duration of 60 minutes and 24 hour, average rainfall intensity will increase by 48.5% and 38.2% respectively; For the 2-year return period, the increment of rainfall intensity in 15-minutes, 1-hour and 24-hours duration is respectively 11%, 21.8% and 29.9%.

In the end of the century (2080-2099): For the 100-year return period, average rainfall intensity in durations of 15 minutes and 60 minutes will increase by 54.6% and 63.9%, while in duration of 24 hours will increase by 69%; For the 50-year return period, average rainfall intensity in 15 minutes will increase by 49.5%. With 60 minutes duration, average rainfall intensity will increase by 58.7%, and with 24-hour duration, average rainfall intensity will increase by 66%; For the 25-year return period, average rainfall intensity in 15 minutes and 60 minutes will increase by 43.6% and 52.1%. In 24 hour duration, it will also increase by 64.1%; For the 2-year return period, the average rainfall intensity in 15-minutes, 1-hour and 24-hours duration is respectively 15.4%, 30.5% and 47.2%.

Table 3. Change in rainfall intensity (%) in several durations and return periods at Tan Son Hoa station in the middle of 21st century in the most likely case

	15'	30'	45'	60'	90'	2h	3h	6h	12h	24h
2 years	11.0	12.3	15.2	21.8	23.9	25.2	26.2	28.7	29.4	29.9
5 years	21.2	22.0	27.2	34.4	36.6	37.0	36.9	45.0	38.0	36.7
10 years	26.4	27.1	33.6	41.5	43.5	43.4	42.5	48.7	39.9	36.2
25 years	32.0	32.2	40.4	48.5	50.4	49.8	48.7	54.4	42.5	38.2
50 years	35.7	35.4	44.5	52.7	54.4	53.7	52.3	57.5	44.1	37.7
100 years	38.8	38.1	48.1	56.4	58.0	57.7	55.8	60.6	45.5	40.1

Table 4. Change in rainfall intensity (%) in several durations and return periods at Tan Son Hoa station at the end of 21st century in the most likely case

	15'	30'	45'	60'	90'	2h	3h	6h	12h	24h
2 years	15.4	19.2	23.5	30.5	31.0	30.7	29.6	43.6	43.6	47.2
5 years	26.1	28.2	32.0	37.9	38.1	37.6	35.5	50.0	49.1	57.1
10 years	33.7	32.3	36.0	41.5	41.5	40.0	37.8	52.4	53.1	58.2
25 years	43.6	41.0	46.2	52.1	50.3	48.0	43.5	54.4	55.2	64.1
50 years	49.5	46.0	52.7	58.3	57.0	54.2	49.4	55.8	57.2	66.0
100 years	54.6	50.1	57.7	63.9	62.0	59.6	53.8	56.8	57.8	69.0

3.2.2. The higher impact case (percentile 75%)

The change of rainfall intensity in several durations and return periods for future periods relative to the baseline period in case of higher impact is shown in Table 5 and Table 6. The result shows that rainfall intensity may increase substantially in all durations and return periods by both two future periods. Similar to the most likely case, the projected changes in rainfall intensities for all durations also show an apparent increasing trend with time. The change for 2050s are mostly in the range of 38% and 141%, the changes for 2090s are mainly ranging from 28% to 105%. The changes depend on various durations return periods.

In the middle of the century (2046-2065): With 100-year return period, average rainfall intensity in the duration of 15 minutes will increase by 141.6% with the value of rainfall intensity of 568.8 mm/hour. Average rainfall intensity in 60 minutes and 24 hours durationswill be 282.5 mm/hour (by 127%) and 13.5 mm/hour (by 85.9%) ; With 50-year return period, average rainfall intensity of 15 minutes and 60 minutes durations will increase by 137.3%, 121.8% respectively. With the duration of 24 hours, average rainfall intensity will increase by 79%; With 25-year return period, projected rainfall intensity in the duration of 15-minutes increase by 131.3%. In 60-minutes duration, rainfall intensity is expected to increase 115.5%. 74.2% is the expected increase in rainfall intensity in 24-hours duration; With 2-year return period, rainfall intensity is expected to increase by 90.2%, 73.3% and 38.5% in 15-minutes, 60-minutes and 24-hours duration, respectively.

In the end of the century (2080-2099): For 100-year return period, average rainfall intensity in 15 minutes duration with the value of 397.6 mm/hour will be an upward trend by 68.9%. In 60 minutes and 24 hours durations, it will increase by 87.7% and 84.9%; For the 50-year return period, average rainfall intensity in 15 consecutive minutes will be 361.4 mm/hour, increasing by 65.9%. With 60 minutes and 24 hours durations, it will increase by83.4% and 82.3% respectively; For 25-year return period, average rainfall intensity in 15 minutes, 60 minutes and 24 hours durations will increase by 62.6%, 79.0% and 81.9%, respectively; For the 2-year return period, average rainfall intensity in 15 minutes will increase by 31.7%, reaching 170.2 mm/hour. With 60 minutes and 24-hours duration, the increase in rainfall intensity will be 34.4% and 68.2%, respectively.

4. Conclusions

In this study, the rainfall projections for future periods based on ensemble regional models approach are used to develop projected intensity-duration-frequency curves and their plausible changes in the middle of the 21st century (2050s), and at the end of 21st century (2090s) for the Ho Chi Minh City, Viet Nam. To cope with the uncertainty of climate change projection, the ensemble of the final result was divided into two following cases: i) the most likely case (percentile 50%) and high impact case (percentile 75%).

Based on the results of this study, it can be concluded that the intensities of extreme

Table 5. Change in rainfall intensity (%) in several durations and return periods at Tan Son Hoa station in the middle of 21st century in high impact case

	15'	30'	45'	60'	90'	2h	3h	6h	12h	24h
2 years	90.2	75.5	70.2	73.3	66.3	61.2	54.0	40.4	41.8	38.5
5 years	112.0	94.0	91.5	95.3	87.6	80.9	71.1	47.7	52.7	53.6
10 years	121.9	102.7	102.3	105.7	97.4	90.7	79.5	55.8	62.4	60.9
25 years	131.3	111.3	112.5	115.5	107.1	99.7	87.2	63.8	71.9	74.2
50 years	137.3	116.0	118.6	121.8	113.3	104.9	92.1	68.9	77.5	79.0
100 years	141.6	119.8	123.0	127.0	117.7	109.4	96.8	72.8	81.6	85.9

Table 6. Change in rainfall intensity (%) in several durations and return periods at Tan Son Hoa station at the end of 21st century in high impact case

	15'	30'	45'	60'	90'	2h	3h	6h	12h	24h
2 years	31.7	27.9	28.0	34.4	36.7	38.8	40.6	71.5	71.1	68.2
5 years	48.9	45.1	51.5	59.5	61.8	62.8	61.7	91.3	81.1	78.1
10 years	55.8	53.0	61.0	70.1	72.0	72.1	71.5	96.4	85.5	77.4
25 years	62.6	59.4	69.4	79.0	80.6	81.1	79.1	101.3	86.8	81.9
50 years	65.9	63.3	73.9	83.4	85.9	85.1	83.8	103.9	89.0	82.3
100 years	68.9	65.9	77.9	87.7	89.8	89.2	86.3	105.7	88.4	84.9

rainfall events versus various durations with different return periods are all likely to increase over time in comparison with baseline period (1986-2005): [11, 60]% in 2050s, and [15, 69]% in 2090s under most likely case; and [38, 141]% in 2050s, and [28, 105]% in 2090s under high impact case. Such a consistent increase in the exceedance values of rainfall intensity of extreme events, implying that intense rainfall events are likely to occur more frequently in the future under climate change. Results of this study are of significant practical importance for design, operation and maintenance of storm water management infrastructures under the changing climate in Ho Chi Minh City.

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