STUDY OF ADAPTATION MEASURES TO CLIMATE CHANGE ON URBAN AREA IN BANGKOK, THAILAND

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ABSTRACT

In urban areas especially Bangkok, Thailand at risk from sea-level rise and heat waves, storms, and floods whose frequency and/or intensity climate change is likely to increase. This article aims to study the adaptation measures to climate change for reducing the impact of floods from heavy rainfall cause in urban areas. Through an in-depth case study of the impact of the flood (depth, area, duration) under the current drainage system and the designed drainage system in the future including under the adaptation measures to reduce the impact of flood such as sponge city, retention pond within urban areas by using iRIC (Nays2D Flood) model. It is used to simulate a flood event that occurred at this site and adapted to simulate under heavy rainfall caused by climate change. The procedure is commencing by studying the existing drainage system. The calibration, and validation of the parameter which effects on simulation model such as, a runoff coefficient, a coefficient of Manning's n. From the results, we are realized the existing drainage system could not achieve the design rainfall. Case of the present, flooding in the study areas, depth of flood 15-20 centimeters, and duration about 1-3 hours. Under projected climate change scenarios, the results of flood depths, duration and areas are increased from the present condition more than 1.0 - 3.0 times in the study area. From the adaptation measure cases, it will also reduce the impact of flooding from climate change conditions about 1.0 – 2.0 times in the study areas.

Keywords: adaptation measures, climate change, urban flood, iRIC Software, Thailand

1. INTRODUCTION

Floods occur on a more frequent base than ever before. Due to climate change, weather patterns change and rain intensity increases. Climate change also influences rainfall events. This causes increasing rainfall to flood more often. The increasing amount of rain is problematic especially in urban areas, in which the drainage system can often not handle this large amount in a short time.

Bangkok area is urbanization near coast and land below mean sea level, so a little rain may cause severe problems for certain city areas. When floods occur from heavy rain due to storms, it has a disturbance due to the impacts caused in people's every life and economic activities. The economic damage is high, but the number of casualties is usually very low because of the nature of the flood. The water slowly rises, when the city is on flat terrain the flow speed is low and rise is relatively slow.

With the current rate of climate change, these extreme situations will occur more often in the future. The increasing rain intensity will cause city drainage system will not be able to handle a large amount of water. This will lead to more floods. This threat will become major in the future but one thing that does not change is the location of these urban areas in these dangerous areas. It is estimated that the population is still growing rapidly in urban areas, which will cause an increasing number of people will be at risk in the future.

Several measures are crucial to the urban zones, especially related to water management, which is vulnerable to flood occurrence.

2. METHODOLOGY AND DATA PREPARATION

For the simulations, we prepared the data for 2 scales consist of small scale is the AREA13 (Whattana and Klong Toei districts) has an extension about 22 km^2 and large scale is the BMA area (the whole of Bangkok and Metropolitans) has an extension about 1,600 km^2. The methodology for both study areas as shown in Figure 1. The study area and the data for the simulations as shown in Figure 2.

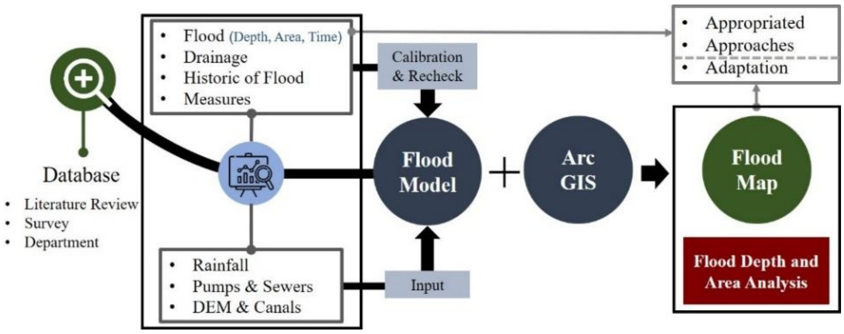


Figure 1. Methodology

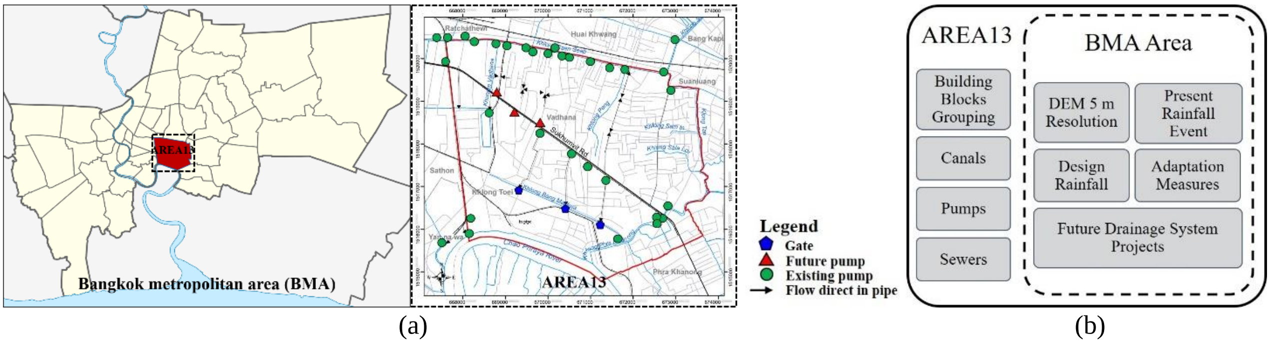


Figure 2. The scope of the data and study areas (a) the study areas (b) the data for the study areas

2.1 Digital Elevation Model (DEM)

The Nays2D Flood is a 2-dimensional, flood flow simulation modeling for simulating. Both study areas (AREA13 and BMA area), we implemented the Digital Elevation Model (DEM) form the Land Development Department (LDD) 5 meters resolution. We converted the DEM data to point and calculated coordinates X,Y by Arc GIS and then we prepared the DEM to .tpo file for the Nays2D Flood model. For the AREA13, we edit the elevation in the canals (Klong Sansab, Klong Tan, Klong Toei) and the Chao Praya River

2.2 Building blocks grouping

For the AREA13, we made building block grouping by Arc GIS. This data is a shapefile, so it can use to the i-RIC (Nays2D Flood) model. From building blocks data with aerial photo scale 1:4,000 from the Department of City Planning Bangkok Metropolitan Administration (CPD).

2.3 Rainfall data

The rainfall data from automatic rain gauge stations (15 minutes interval) from the Department of Drainage and Sewerage (DDS) with the maximum rainfall in the study area. For the model calibration, we used rainfall data recorded on 16th May 2017 at D29 station, with a maximum rainfall of 25.5 mm and the total rainfall of 93 mm (Figure 3 a). The model validation, we used rainfall data recorded on 14th October 2017 at E40 station, with a maximum rainfall of 32 mm and the total rainfall of 162 mm (Figure 3 b). In the analysis under the present rainfall event, we used rainfall data on 16th May 2017 from the model calibration for both scales of the study areas.

And the heavy rainfall event due to climate change. We use the design rainfall from the Gumbel Distribution Method and calculating all IDF curves. We estimate and forecast the rainfall resulting from the series of annual maximum rainfall at 15, 30 min 1, 2, 3, 6, 12 and 24 hr, and use the data from rainfall durations about 60 stations. Design storm depths associated with a duration of 15 minutes for 16 years (2000 – 2015) and the return period calculations for historic observations at stations. Narktap S. and Piamsa-nga N., (2018) (Figure 3 c).

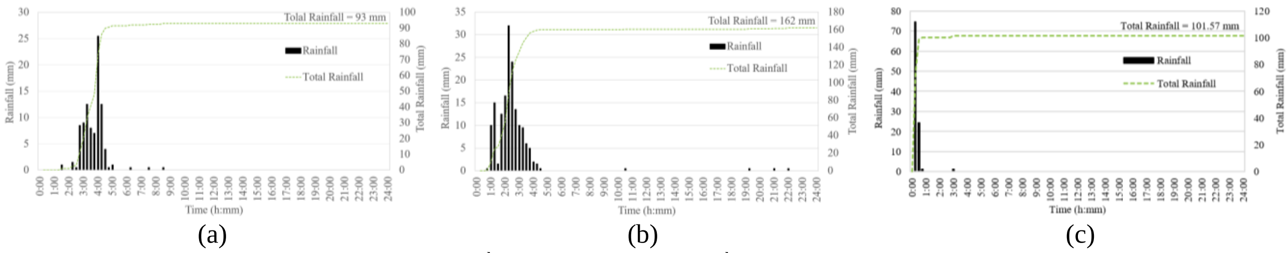
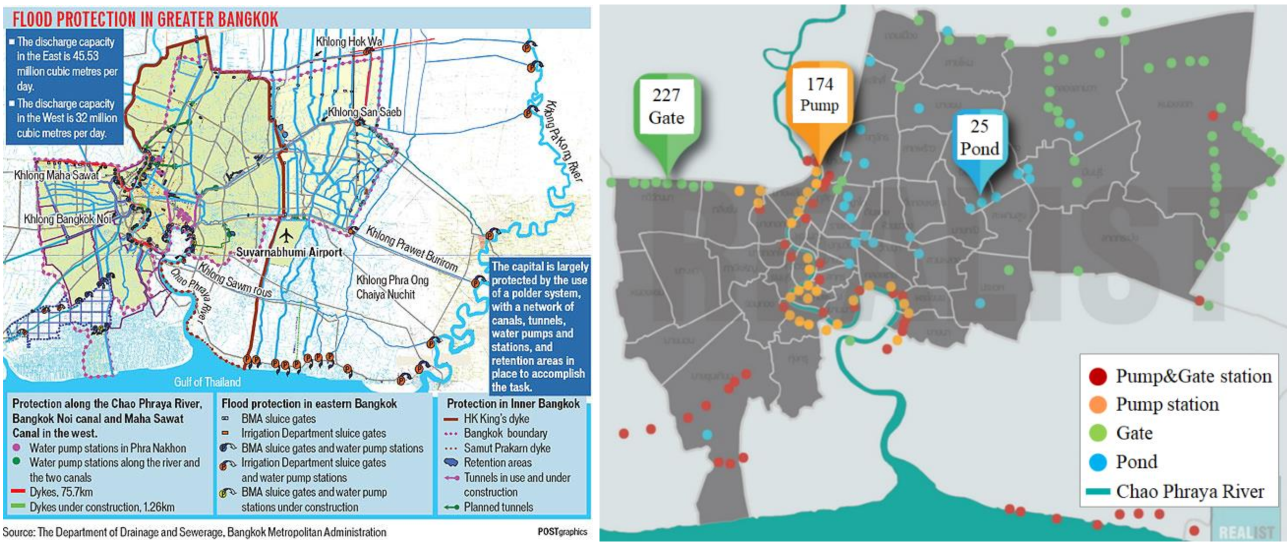


Figure 3. The rainfall for simulation (a) on 16th May 2017, (b) on 14th October 2017, and (c) the design rainfall from return period 5 years heavy rain 3 hr.

2.4 The drainage system

For the AREA13, we study intensively for calibration and validation. In the simulation under the present scenario in the AREA13, we added the existing pumps, sewers, and tunnels from the Department of Drainage and Sewerage (DDS). Under the future scenario, we used the future projects of the drainage system from DDS. These projects have 25 ponds, 174 pumps, and 227 gates in the whole BMA area. Which is the AREA13 include 2 ponds and 7 pumps (Figure 5).



(a) (b)

Figure 5. The flood protects and drainage system in the study areas (a) the existing (b) the future project (Department of Drainage and Sewerage).

2.5 Adaptation measures

The adaptation measures for reducing the impact of flood from heavy rainfall due to climate change we apply the “Sponge Cities” concept indicates that a city could be functioned as a sponge that has great resilience to environmental changes and natural disasters.

“Sponge Cities” indicates a particular type of city that does not act like and impermeable system not allowing any water to filter through the ground, but more like a sponge, actually absorbs the rain water, which is then naturally filtered by the soil and allowed to reach into the urban aquifers. This allows for the extraction of water from the ground urban or peri-urban wells. This water can be easily treated and used for the city water supply.

The optimal goals of the Sponge city are that the storm water generated from rainfall events could be absorbed, stored, infiltrated and cleaned with the natural and/or manmade facilities and the rainfall and storm water could be transformed into water resources that could be utilized during the drought MHURD (2014). Infiltration from sponge city increase about 60-70%, flood area reduce about 1-2 %, and flood depth reduce about 9-14% or 1-2 times Xiaoning Li, Junqi Li, Xing Fang, Yongwei Gong, and Wenliang Wang (2016)

3. MODEL SETUP AND SIMULATION

3.1 Model setup

The Nays2DFlood, which is one of the models enclosed in the iRIC system, is a flood flow solver developed by Shimizu et al. (2018). Tools for creating these systems are supplied in iRIC webpage (http://i-ric.org/en/) (Wongsa, 2013; Wongsa 2015; Nelson et al., 2016). This model can be used in a general, non-orthogonal coordinate system with an adaptable grid. For the procedure for operating the Nays2D Flood solver with the iRIC (Figure 6). The data preparation can be created from survey data such as rainfall data and DEM data. Then, set the calculation condition by input the data and setting the parameter such as rainfall, discharge, boundary condition, roughness. After that, you can run the Nays2D Flood for your case studies. Post-processor is for visualization and analysis of calculation results. Visualization of calculation results can be used for purposes such as graphic and animation of flood depth and flood area, and graphs.

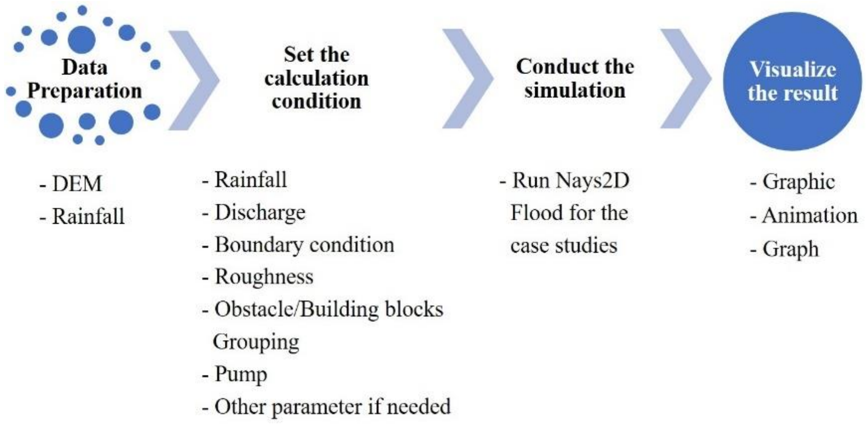


Figure 6. Procedure for operating the Nays2D Flood solver with the iRIC.

3.2 Simulation scenario and case study

For the simulation, we simulate 4 case studies under 3 scenarios. The details are shown below and Figure 7

3.2.1 Present scenario

In the present scenario, we used the present rainfall event for simulation. For calibration, we used the rainfall event on 16th May 2017. *The* validation, we used the rainfall event on 14th October 2017. Model calibration and sensitivity analysis are undertaken for the 16th May 2017 event to obtain the optimal set of parameter values for the study area.

We used the AREA13 for calibration and validation, and we perform the result to 15 m grid size. For the grid size, we considered from the wide of canals and roads/streets in the study area (5 to 15 m) Thidarat and Sanit (2019). For the flood on 16th May 2017 (calibration), the simulation of the event agrees well with the observation. The model predicted peak flood depth is about 20 cm agrees with the observed value from the flood event on this day at the 4 locations for calibration. For the flood on 14th October 2017 (validation), the simulation of the event agrees well with the observation. The model predicted peak flood depth is about 20 to 22 cm agrees with the observed value from the flood event on this day-Thidarat and Sanit (2019).

3.2.2 Future scenario

When we simulated under the present scenario finish. We used the model calibration for 2 case study simulations under the future scenario. In the first case, we used the design rainfall only. And in the second case, we used the design rainfall with the future drainage system projects.

3.2.3 Adaptation scenario

For the adaptation scenario. We used the model from caes3 to simulate under the adaptation scenario; we apply the sponge city concept to the model from simulation under future drainage system projects case.

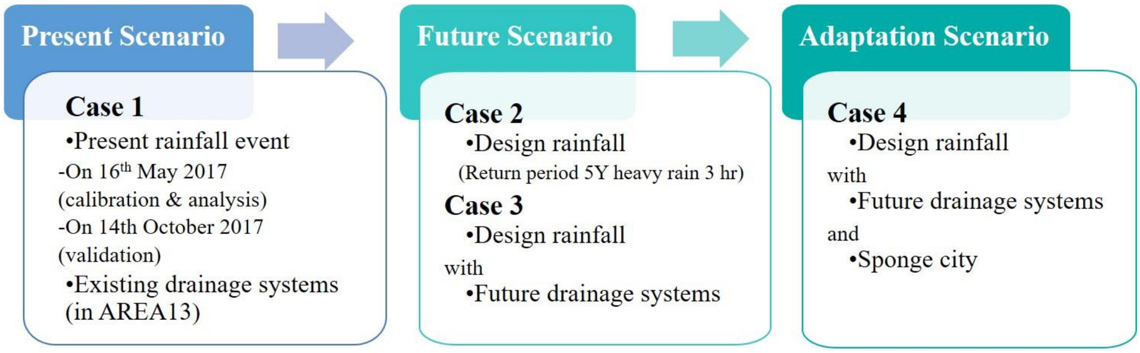


Figure 7. The simulation scenarios and case studies

4. RESULT AND DISCUSSION

We analyze the result from the present scenario with the future scenario and the future scenario with the adaptation scenario. The details are shown below.

4.1 Compare the result under present event with under climate change event

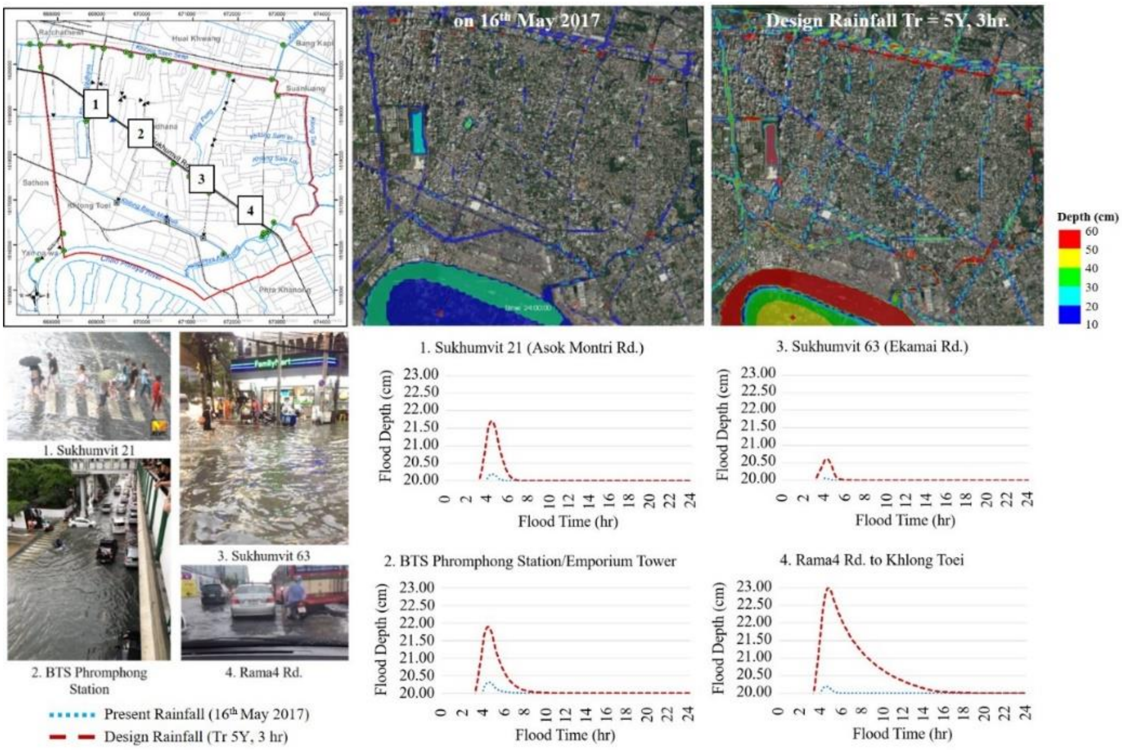


Figure 8. Compare the flood depth, duration, and area on the present event with under climate change event from design rainfall in AREA13.

Table 1. Compare the flood depth and duration of 2 cases under the present scenario with the future scenario in AREA13

CASE	PRESENT RAINFALL		DESIGN RAINFALL		DIFFERENCE	
POINT	DEPTH MAX (CM)	DURATION (HR)	DEPTH MAX (CM)	DURATION (HR)	DEPTH MAX (CM)	DURATION (HR)
1.	20.19	2.30	21.38	4.50	1.19	2.20
2.	20.31	3.00	21.56	8.00	1.25	5.00
3.	20.07	1.00	20.44	4.00	0.37	3.00
4.	20.47	3.30	22.52	15.30	2.05	12.00
AVG.	20.26	2.30	21.48	8.00	1.22	5.70

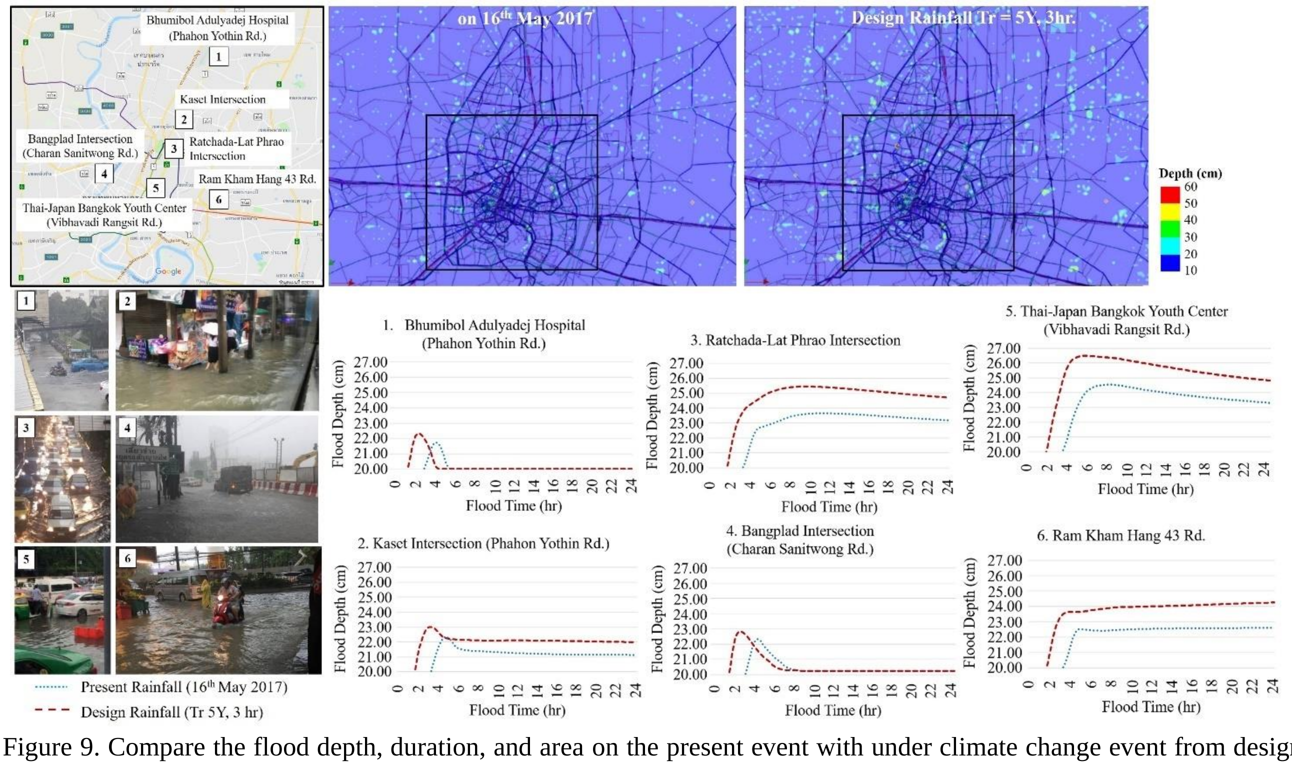


Figure 9. Compare the flood depth, duration, and area on the present event with under climate change event from design rainfall in the BMA area.

Table 2. Compare the flood depth and duration of 2 cases under the present scenario with the future scenario in BMA area

CASE	PRESENT RAINFALL		DESIGN RAINFALL		DIFFERENCE	
POINT	**DEPTH MAX (CM)**	**DURATION (HR)**	**DEPTH MAX (CM)**	**DURATION (HR)**	**DEPTH MAX (CM)**	**DURATION (HR)**
1.	21.74	3.20	22.34	3.50	0.60	0.30
2.	22.36	>24	22.98	>24	0.62	-
3.	23.66	>24	25.46	>24	1.80	-
4.	22.32	7.30	22.84	7.40	0.52	0.10
5.	24.54	>24	26.48	>24	1.94	-
6.	22.59	>24	24.26	>24	1.67	-
AVG.	22.87	17.75	24.06	17.82	1.19	0.07

Figure 8 and Figure 9 show the trends of flood depths and flood durations under climate change events from the design rainfall case compare to the present rainfall event case. For all the checkpoints, the flood depths and the flood durations from the design rainfall case more than the present rainfall event case. Table 1 compare the flood depths and flood durations in the AREA13, the flood depths are increased from 20.1 – 20.5 cm to 20.6 – 23.0 cm, the flood durations are increased from 1.00 – 3.30 hr to 3.30 – 15.30 hr, due to the insufficient drainage capacity of sewers and drainage systems. It founds that the flood depth average is increased about 1.5 cm or 1 time from the present condition, and the flood duration average is increased about 6.00 hr or 3 times from the present condition. For Table 2 compare the flood depths and flood durations in the BMA area, the flood depths are increased from 21.74 – 24.54 cm to 22.34 – 26.48 cm, the flood durations are increased from 3.20 – 24 hr up to 3.50 – 24 hr up, and it founds that the flood depth average is increased about 1.19 cm or 1 time from present condition, and the flood duration average is increased about 0.07 hr or 1 time from present condition. Due to the simulation is simulate under the real topography does not have the drainage systems, which some areas have the terrain lower than the mean sea level.

4.2 Compare the result under climate change event with future drainage system project and adaptation measure

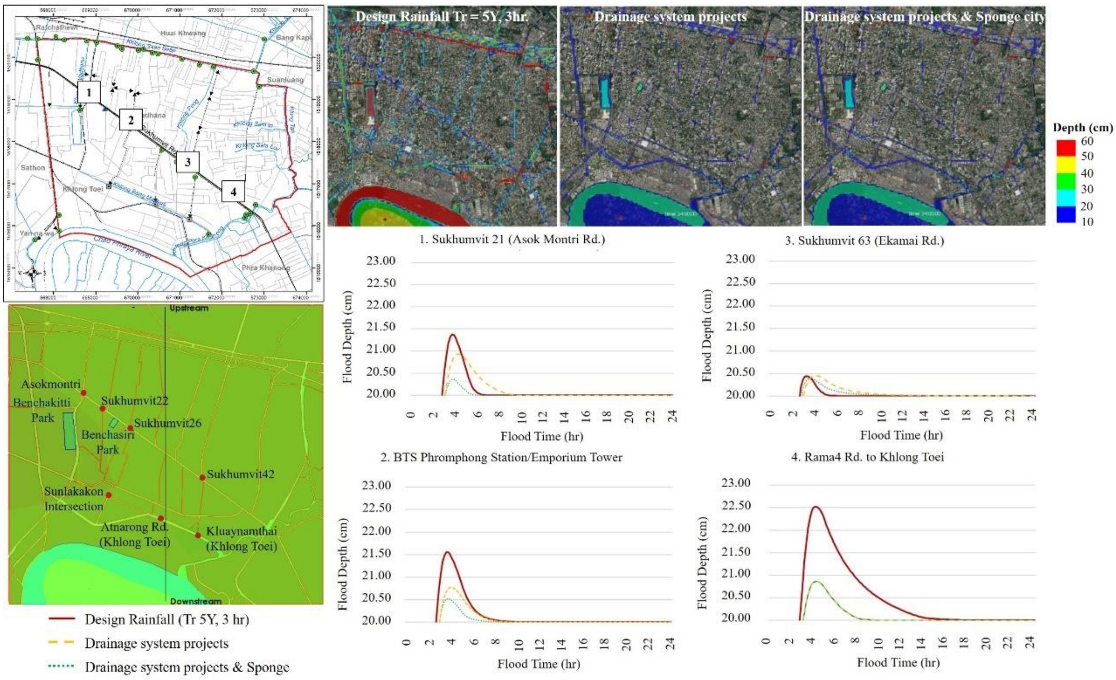


Figure 10. Compare the flood depth, duration, and area under climate change event from design rainfall with the drainage system project and drainage system project with sponge city in the AREA13.

Figure 10 shows the comparison trend of flood depth and duration between the results from the design rainfall with the results from future drainage system projects and the results from future drainage system projects with sponge city in the AREA13. The future drainage system projects for the simulation in the AREA13, we add 2 retention ponds and 7 pump stations. The results show the difference between the flood areas, flood depths, and flood durations. The flood areas between the 3 cases are minimally different.

The flood depths at the checkpoint No.1 (Sukhumvit 21), No.2 (BTS Phromphong Station/Emporium Tower), and No.4 (Rama 4 Rd. to Khlong Toei) from future drainage system projects case are reduced from the design rainfall case about 0.5-1.5 cm, and from the future drainage system projects with sponge city case are reduced from design rainfall case about 1-2 cm. For the flood durations at the checkpoint No.4 (Rama 4 Road. to Klong Toei) from future drainage system projects case and the future drainage system projects with sponge city case. In both cases, flood durations are reduced from the design rainfall case about 8 hr (Table 3).

Table 3. Compare flood depth and duration of 3 cases under the future scenario with adaptation scenario in AREA13

CASE	DESIGN RAINFALL		DRAINAGE SYSTEM PROJECT		SPONGE CITY	
LOCATION	DEPTH (CM)	DURATION (HR)	DEPTH (CM)	DURATION (HR)	DEPTH (CM)	DURATION (HR)
1.	21.38	4.50	20.93	7.20	20.36	3.50
2.	21.56	8.00	20.77	7.00	20.53	6.00
3.	20.44	4.00	20.45	14.00	20.40	12.00
4.	22.52	15.30	20.69	7.20	20.69	7.20
AVG.	21.48	8.00	20.71	9.00	20.50	7.20

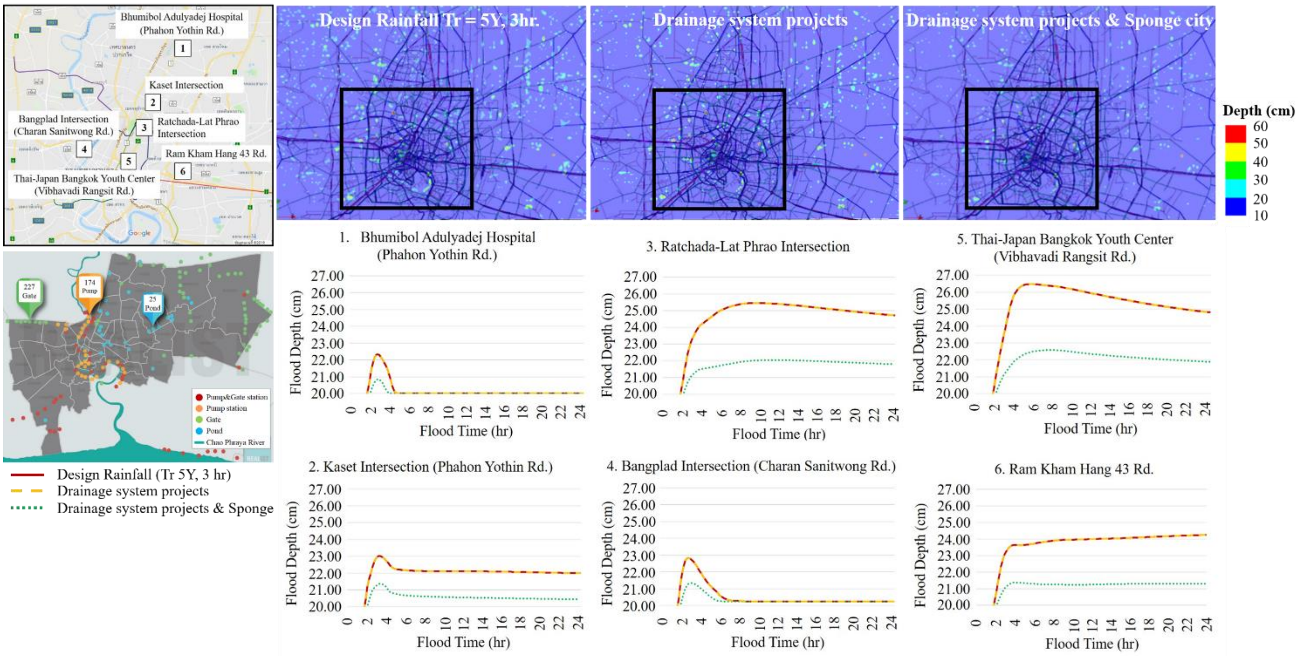


Figure 11. Compare the flood under climate change event from design rainfall with the drainage system project and drainage system project with sponge city in the BMA area.

Table 4. Compare flood depth and duration of 3 cases under the future scenario with adaptation scenario in BMA area

CASE	DESIGN RAINFALL		DRAINAGE SYSTEM PROJECT		SPONGE CITY	
LOCATION	DEPTH	DURATION	DEPTH	DURATION	DEPTH	DURATION
1.	22.34	3.20	22.34	3.20	20.85	3.00
2.	23.01	>24	23.01	>24	21.37	>24
3.	25.46	>24	25.46	>24	22.05	>24
4.	22.84	7.40	22.84	7.40	21.34	5.30
5.	26.48	>24	26.48	>24	22.58	>24
6.	24.26	>24	24.26	>24	21.30	>24
AVG.	24.07	18.00	24.07	18.00	21.58	17.40

Figure 11 compares the flood areas, flood depths, and flood durations between the case of design rainfall with the cases of the future drainage system projects and the cases of the future drainage system projects with sponge city in whole BMA area. The future drainage system projects for simulation in the MBA area, we add 25 ponds only, not include pumps and gates. In the maps, the flood areas between the 3 cases are the minimal difference. For the future drainage system projects case, the flood depths and the flood durations are not different from the design rainfall case. Because the retention pond/basin shapefiles are smaller than grid size or the location of the checkpoints do not have retention ponds/basins, so the flood depths and the flood durations at the six checkpoints are not different. For the future drainage system projects with sponge city cases, the flood depths on all the checkpoints are reduced from the design rainfall case, and the flood durations at the checkpoint No.1 (Bhumibol

Adulyadej Hospital) and No.4 (Bangplad Intersection) are reduced from the design rainfall case about 2 hr. But at the checkpoint No.2 (Kaset Intersection), No.3 (Ratchada-Lat Phrqo Intersection), No.5 (Thai-Japan Bangkok Youth Center) and No.6 (Ram Kham Hang 43 Rd.) are still flood 24 hr. Because of these locations lower more than mean sea level (Table 4).

The results above show that the model works well for the small scale in the urban area. When we add detail a lot such as pumps, sewers, tunnels, and ponds. We found the result errors from the large scale study area (whole BMA) more than the result errors from the small scale study area (AREA13). Because on the large scale study area use the large grid size more than the small scale study area and more than the pond shapes. But the model can simulate well for the setting data whole systems, it means the manning's n and rainfall etc. So, the simulations that need details a lot, especially the complex detail of water management systems in the urban area should simulation on small scale areas. The simulation for an overview of the large scale study area. If we use the size of ponds, pumps, sewers, etc. equivalent to the grid size, the result will be an error due to the data over the scale.

5. CONCLUSIONS

According to the above comparison, the result of projected climate change scenarios from design rainfall, the results of flood depths and duration are increased from the present condition more than 1.0 - 3.0 times in the study area. From the results, we are realized the existing drainage system could not achieve the design rainfall. Case of the design rainfall, average flood depth about 20-30 cm, and average duration about 8-18 hr and more than 24 hr on some area lower mean sea level. Under the future drainage system projects, the results of flood depth and duration are reduced a few from the design rainfall condition in the study area. And under adaptation measures (future drainage system projects with sponge city), the results of flood depth and duration are reduced from the design rainfall condition about 1.0-2.0 times in the study area. A concept of applying adaptation measures (Sponge City) and increasing pump capacity to improve the drainage capacity locally may be used as a tool to reduce the impact of the flood.

ACKNOWLEDGMENTS

This research was supported by "Advancing Co-design of Integrated Strategies with Adaptation to Climate Change in Thailand (ADAP-T)" supported by the Science and Technology Research Partnership for Sustainable Development (SATREPS), JST-JICA. And the Department of Drainage and Sewerage (DDS: BMA) for supporting and providing the data.

REFERENCES

Jiang, Y., Zevenbergen, C., and Fu, D. (2017). Can "Sponge Cities" Mitigate China's Increased Occurrences of Urban Flooding?. *Aquademia: Water, Environment and Technology,* 1(1):1-5. doi: 10.20897/awet.201703

Metropolitan Waterworks Authority. (2011). Potential and solution for raw water crisis: Final report, Bangkok.

Ministry of Housing and Urban Rural Development (MHURD). (2014). Announcement on Publishing Preliminary Technical Guidance for Sponge City Construction-Low Impact Development Rainwater System Construction.

Narktap, S., and Piamsa-nga N. (2018). The High-Resolution Analysis of Intensity-Duration-Frequency Curves for Bangkok Metropolitan Area. Proc. 23th Intl. *Conference on The 23th National Convention on Civil Engineering*., pp. 380– 385.

Nelson, J.M., and 16 co-authors. (2016). The international river interface cooperative: Public domain flow and morphodynamics software for education and applications, *Journal of Adv. in Water Res.,* 93: 62–74.

Shuhan, Z., Yongkun, Li., Meihong, Ma., Ting, S., and Ruining, S. (2018). Storm Water Management and Flood Control in Sponge City Construction of Beijing. A special issue of Water (ISSN 2073-4441). This special issue belongs to the section "Urban Water Management".

Thidarat, K., and Sanit, W. (2019). Impact of Heavy Rainfall Cause by Climate Change on Urban Area in Bangkok, Thailand. *Conference on THA 2019 International Conference on Water Management and Climate Change towards Asia's Water-Energy-Food Nexus and SDGs*., pp. 78– 83.

Wang, C., Hou, J., Miller, D., Brown, I.,and Jiang, Y. (2019). Flood risk management in sponge cities: The role of integrated simulation and 3D visualization. *International Journal of Disaster Risk Reduction*. 101139. 10.1016/j.ijdrr.2019.101139.

Wongsa, S. (2013). 2011 Thailand Flood, *Journal of Disaster Research,* 8(3):380-385.

Wongsa, S. (2015). Experiment and Simulation on Earthen Embankment Breach, *Journal Geoscience and Environment Protection,* 3:59-65. (http://dx.doi.org/10.4236/gep.2015.310010).

Xiaoning, Li., Junqi, Li, Xing, F., Yongwei, G., and Wenliang, W. (2016). Case Studies of Sponge City Program in China. *Conference on World Environmental and Water Resources Congress 2016.*, pp. 295– 308.

Yabe, T., Ishikawa, T., Kadota, Y., and Ikeda, F. (1990). A Multidimensional Cubic-Interpolated Pseudoparticle (CIP) Method without Time Splitting Technique for Hyperbolic Equations. *Journal of the Physical Society of Japan, 59:* 2301-2304 (1990) 10.1143/JPSJ.59.2301