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Application of SWMM to Explore Possible Climate Change Impact on Urban Stormwater Drainage

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Abstract: *In urban areas, there is concern that storm water runoff and flooding may be intensified because of the effect of climate change on precipitation amounts, intensities, and frequencies. The objective of this study is to use the Storm Water Management Model (SWMM) to assess the existing drainage's capacity, to quantify the impact of climate change on existing drainage system and to propose a structural measure for reducing the flood impact. The SWMM was set up to simulate the single event that generated into hyetograph with 6mn time step by Soil Conservation Service (SCS) curve type II in year 1990 (current extreme rainfall over 20 years), 2014, 2055, 2 year and 5 year design strom located in Chamkamorn district, the highly urbanized area in Phnom Penh. The results indicate that more surface flooding will be expected in the future. The number of critical nodes in the system and the number of pipes performing over their capacity also will increase due to the greater expected rainfall. The highest flood is in 1-day maximum rainfall for a 20-year centered on 2055 using an Representative Concentration Pathway (RCP 8.5) with maximum flooding volume 153212m^3 and duration of flood is 2h 27mn. In 5 different scenarios, increasing percentage of highest inflow was occurred in junction14 (J14) comparing to its flow capacity. The result indicated that the highest increasing is on the projected 1 day of maximum rainfall for a 20-year period centered on 2055 using an RCP 8.5 was increased 949%. Based on Japan International Cooperation Agency (JICA) report aimed to reduce flooding within 2hours so the diameter has been enlarged for year 2055 for conduit C16 from 1.5m to 1.8m that can reduce from 2h 27mn to 1h 10mn.*

Keywords: Hyetograph; Rainfall; Stormwater runoff; Flooding

1. INTRODUCTION

Phnom Penh is located in alluvial floodplains on the right bank at the junction of Tonle Sap River, Bassac River and the Mekong River. The capital city is surrounded by the natural levee and ring dike and its suburbs form low wetlands, while some places are flooded in the rainy season [1]. Urban drainage facilities in the Phnom Penh with functions of draining storm water and domestic wastewater have been gradually upgraded in line with the development of the city, but all of the drainage facilities have been constructed since the beginning of the 1900's so that those are not functioning well due to old age, as well as poor maintenance after the 1970's [2]. Consequently, it causes frequent flooding during the rainy season. Additionally, the city developed with little planning or control, resulting in flooding problems, squatter problems along drainage ways, increasing wetland in-fill, and poor urban infrastructure [3]. Therefore, the city suffers from habitual inundation and poor environmental conditions caused by stagnant wastewater in lowland areas. These are serious constraints to the residents' living environment as well as social and economic development, not only in Phnom Penh City but also the whole country in general because similar conditions occur in other urban areas of Cambodia [2]. Emerging infrastructure is needed to respond with changing conditions in the future in such climate change which results in changing in the parameter of climate such as rainfall, temperature, wind speed, and humidity, etc. Specifically, rainfall and temperature are the input parameters to the surface hydrology as well as surface runoff, and thus their changes will directly cause the change to the flooding characteristics under climate change. For example, the Intergovernmental Panel on Climate Change (IPCC) states that an increase in temperature of between 1˚C and

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3.5˚C due to an increase in greenhouse gases would occur by the end of this century. Further, the effects of climate change on hydrology and the potential intensification of the hydrological cycle have also to be considered in order to prevent future problems in the urban drainage system (Rodr et al., 2013). In the analysis of the influence of climate change on urban drainage systems, the challenges lie in of the choice of climate change projection to be used and the parameters to be used to measure the impacts. Global Climate Models (GCMs) are the best available tools for simulating future climates based on various greenhouse gas and aerosol emission scenarios. GCMs depict the climate using a three dimensional grid over the globe, typically having an horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans [5]. Global models are intended for use with large spatial scales and are too coarse to determine local scale climate variations in precipitation. Downscaling climate data generates locally relevant climate data from GCMs although inherent errors may be carried over from GCMs to local data. The Conformal Cubic Atmospheric Model (CCAM) is a regional climate model that was run specifically for South East Asia and it is used in this study [6]. Urban drainage system and hydraulic process impacted by extreme rainfall event using climate projection from GCMs [7,8]. The geographical distribution of urban flooding is expected to increase in the future, as will both the flooding frequency and duration. Objective of this study is to use Storm Water Management Model (SWMM) to assess the existing drainage's capacity, quantify the impact of climate change on existing drainage system, and to propose a structural measure for reducing the flood impact.

2. METHODOLOGY

2.1 Study area

The study area is situated in Khan Chamkar Mon which is located on the southernmost in central of Phnom Penh Chamkar Mon District. It is considered as high density area located at the city's core which has total area approximately 11.1 Km2 with the population about 182,004 people and population density of

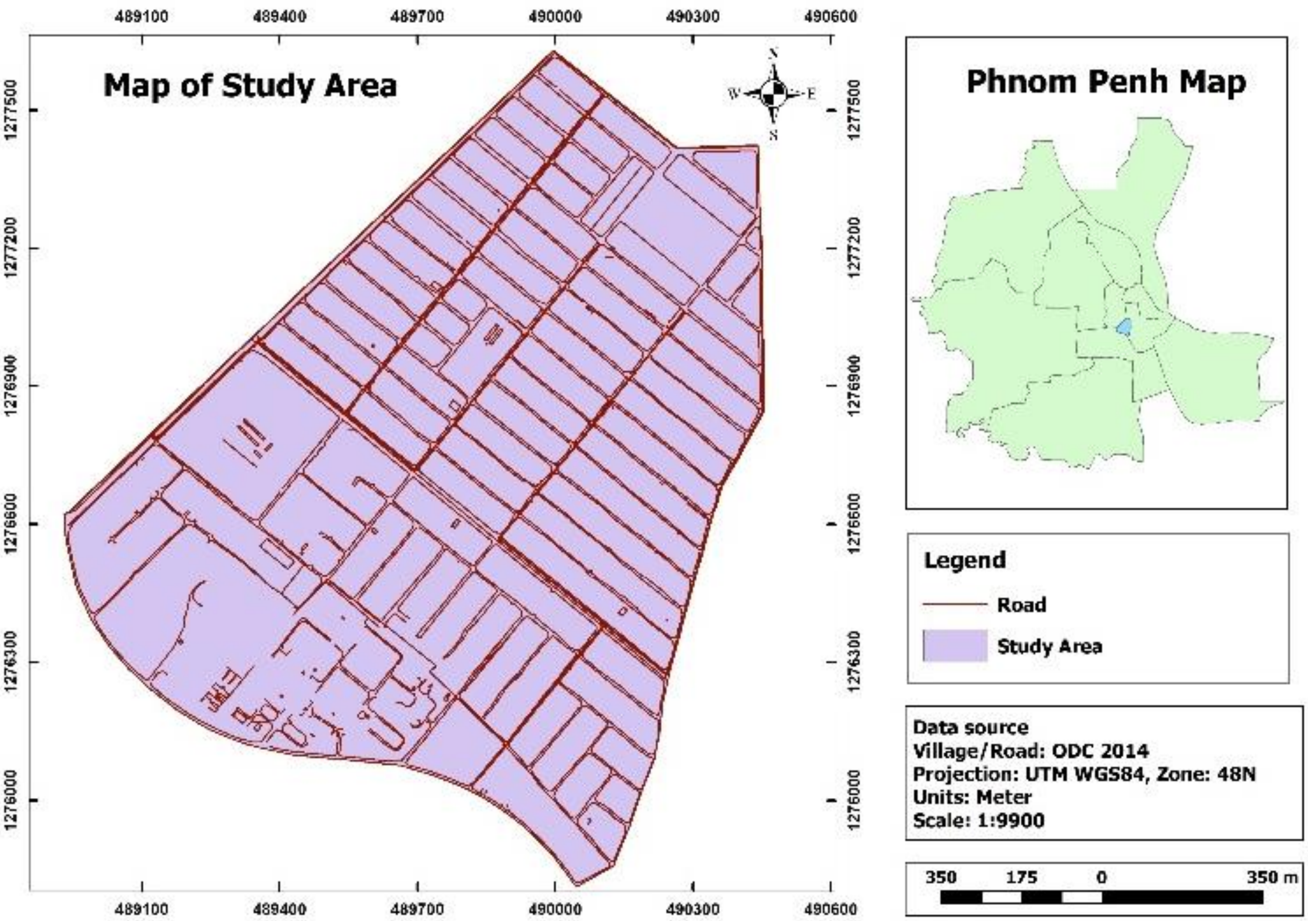


Fig. 1. Location map of study area

164 persons/ha [9]. Chamkar Morn district is subdivided into 12 Sangkats. In this study, we have chosen three Sangkats for our study such as Sangkat Toul Svay Prey 1,2 and Sankat Tomnub Tek that have approximate total area of 160ha as shown in Fig.1.

2.2 Data collection

Boundary of the catchment was taken from the website of Open Development Cambodia. The catchment was delineated to sub-catchment base on ALOPASAR satellite imagery, base map in Qgis and flow direction was taken from sewer system maps from [10]. Additionally, JICA have provided detail about sewer information such as invert elevation, pipe geometry, and flow length. The rainfall data were taken from the rain gauge installed at Institute of Technology of Cambodia (ITC) from 2011 to 2017 (Fig. 2), JICA previous design JICA [10] (Fig. 3) and the Detailed Design Report Urban Drainage in Sihanoukville Town [11] for climate change (Table 1).

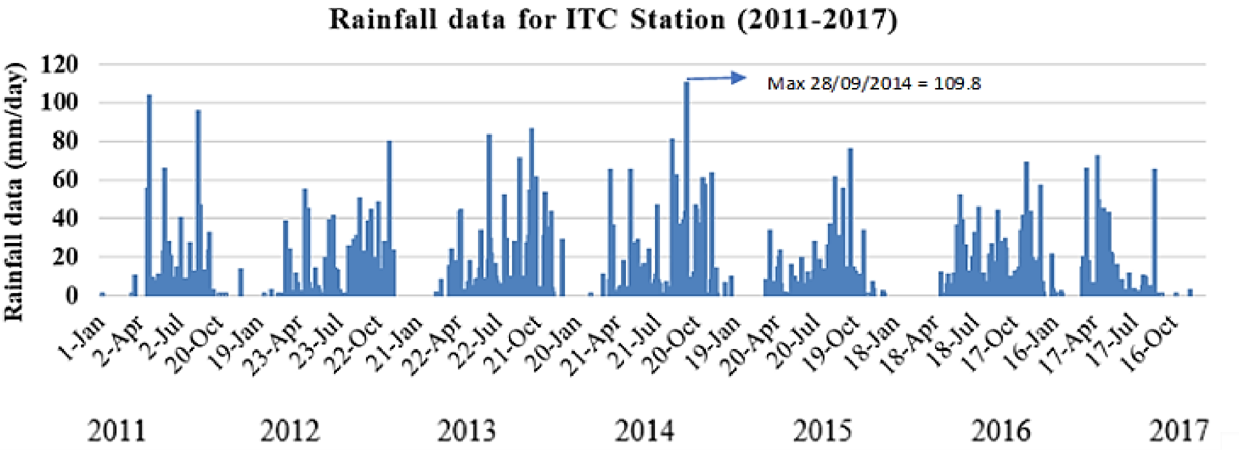
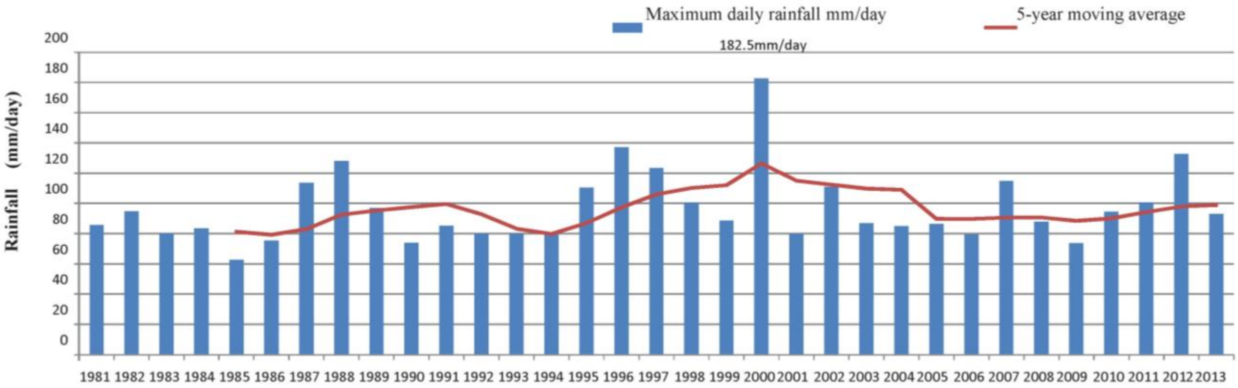


Fig. 2. Daily rainfall data from ITC station 2011 to 2017



Source: MoWRAM (Ministry of Water Resources and Meteorology)

Fig. 3. Maximum daily rainfall (1981 to 2013)

Table 1 Detail of data collection

No.	Data	Period	Source
1	Rainfall	2011-2017	ITC
		1981-2013	Pochentong
2	Pipe Diameter	2015	JICA
3	Invert Elevation	2015	JICA
4	Length of Conduit	2015	JICA
5	Flow Direction	2015	JICA
6	Location of Manhole	2015	JICA

As part of an earlier modelling effort, the drainage system in the catchment area was divided into a network consisting of 16 subcatchments, 16 junctions and 16 conduits. The total length of the conduits was 3,768 m. There are 2 gravity type outfalls. The system discharges to the MeanChey creek labeled O2 at the upstream of the canal that located near Steung Menachey Bridge and O1 at the downstream of the canal that situated near the Russian hospital.

The Green–Ampt infiltration model and kinematic flow routing were used for this simulation. Manning's roughness coefficient for impervious areas was selected as 0.011, and for pervious areas was selected as 0.15 (Fig. 4). Percentage of impervious area is 60% to 90% and average surface slope is 3% [12].

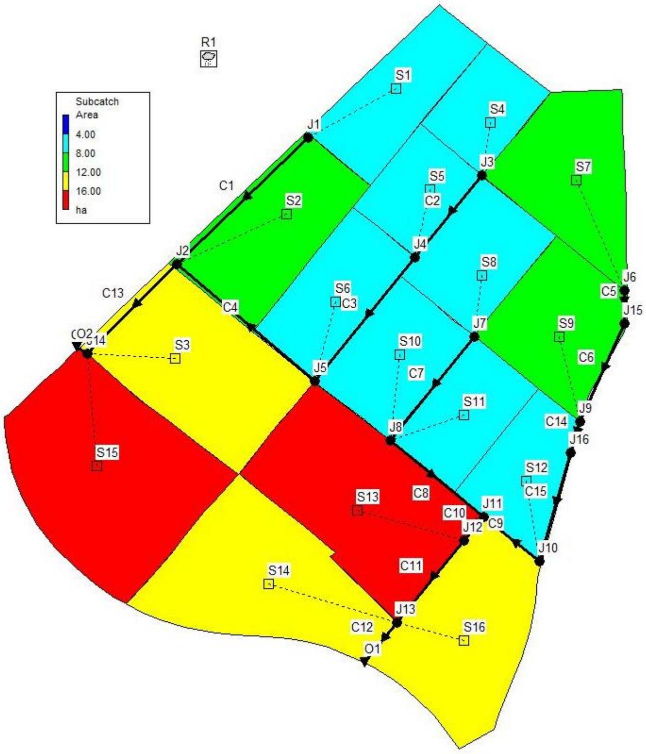


Fig. 4. Subacatchment delineation in SWMM

2.3 Climate model data and future scenario

CMIP5 models were used in this study for future climate change projections for the wider Southeast Asian region, including Cambodia. They were also used as boundary conditions or initial input to drive six high-resolution simulations over the Indochina Peninsula using the Conformal Cubic Atmospheric Model (CCAM), developed in Australia at CSIRO's Marine and Atmospheric Research division (CMAR), for projections of changes in mean and extreme climate indices for Cambodia.The 21st century simulations were driven by Representative Concentration Pathways, which describes a wide range of potential future with different values of the main drivers of climate change: greenhouse gas and air pollutant emissions and land use, in terms of their radiative forcing. Radiative forcing of 3.0 (low), 4.5, 6.0 and 8.5 (high) Watts/m^2 were estimated by the end of the 21st century. Base on the study of ADB [5], there are six GCMs such as CNRM-CM5, CCSM4, NorESM1-M, ACCESS1.0, MPI-ESM-LR, and GFDL-CM3 were selected for downscaling experiments using CCAM. In order to assess climate change impacts for Cambodia, new high-resolution projections of future climate have been produced. In this project, the CMIP5 GCM sea surface temperatures (after bias correction) and sea ice distributions were used to drive the Conformal Cubic Atmospheric Model (CCAM) at 50 km global horizontal resolution using a future scenario or RCP 8.5. For a scenario, values for equivalent CO2 and ozone were input, as well as the aerosol emissions. No atmospheric data was used from the GCMs. These CCAM 50 km simulations were then further downscaled to 10 km resolution over the Indochina Peninsula.

2.3 Design precipitation hyetograph by SCS menthod

SCS adopted a method similar to DDF to develop dimensionless rainfall temporal pattern called type curve for four different regions in the US. SCS type curve is in the form of percentage mass (cumulative) curves based on 24-hr rainfall of the desired frequency. If a single precipitation depth of desired frequency is known, the SCS type curve is rescaled (multiplied by the known number) to get the time distribution. For durations less than 24 hr, the steepest part of the type curve for required duration is used.The SWMM was set up to simulate the single event that is generated by hyetograph with 6mn time step in SCS curve type II wihin 6h storm duration [2] (Fig. 5).

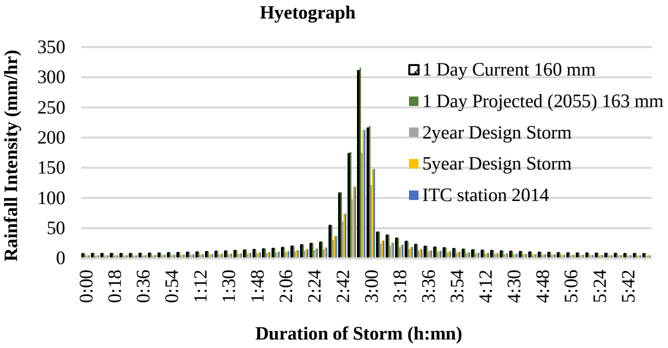


Fig. 5. Hyetograph of rainfall data

3. RESULTS AND DISCUSSION

3.1 Runoff

After model simulation in 5 scenarios, results indicated that the peak runoff were generated the greatest runoff in subcatchment S15, and the scenario projected 1-day of maximum rainfall for a 20-year period centered on 2055 using an RCP of 8.5 generated the highest discharge 15.18m^3/s because of their large area and the greater width than other subcatchment. Otherwise, the lowest peak runoff were generated in subcatchment S5, and the scenario rainfall at return period 2 years generated the lowest discharge 2.33m^3/s due to small area and width as shown in the Fig. 6.

3.2 Maximum inflow analysis

Considering precipitation different scenarios, the result show that the highest maximum inflow occurred at the nodes near the outfall because all subcatchment runoff were aggregated to this point. In 5 different scenarios, the highest maximum inflow was in junction J14 in the projected 1-day of maximum rainfall for a 20-year period centered on 2055 using an RCP 8.5 with maximum inflow 27.128 m3/s and the lowest of the maximum inflow is rainfall at return period 2 years with maximum inflow 14.413 m^3/s (Fig. 7).

3.3 Scenario analysis of existing drainage

Fig. 8 shows the increasing percentage of the highest inflow comparing to the drainage capacity with maximum flow of $2.586m^3/s$. The maximum highest inflow occurred in junction J14, So in all scenarios the smallest increasing as percentage is

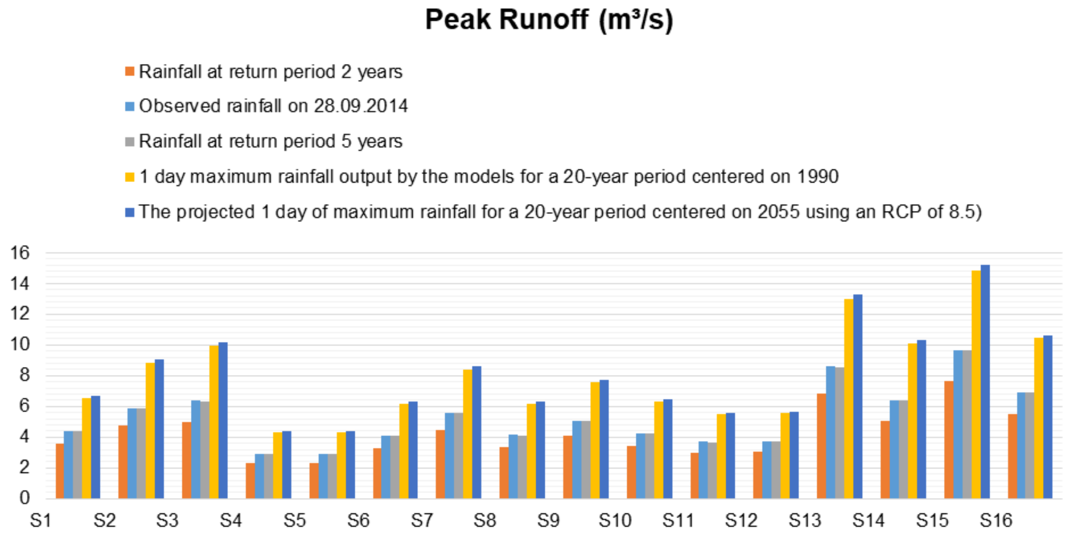


Fig.6. Peak runoff from the 16 subcatchments

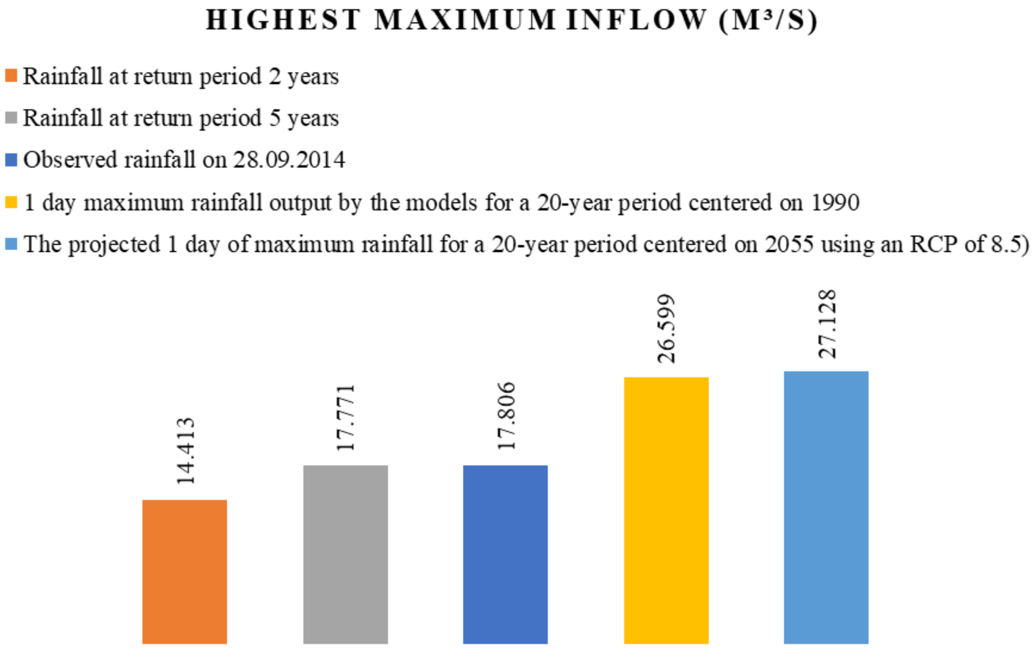


Fig.7. Highest maximum inflow of 5 different scenarios

in scenarios rainfall at return period 2 years that increased 457% and the highest is in the projected 1-day of maximum rainfall for a 20-year period centered on 2055 using an RCP of 8.5 that increased 949%.

Fig. 8 indicates that more surface flooding will be expected in the future. The number of critical nodes in the system and the number of pipes performing over their capacity will also increase due to the greater expected rainfall.

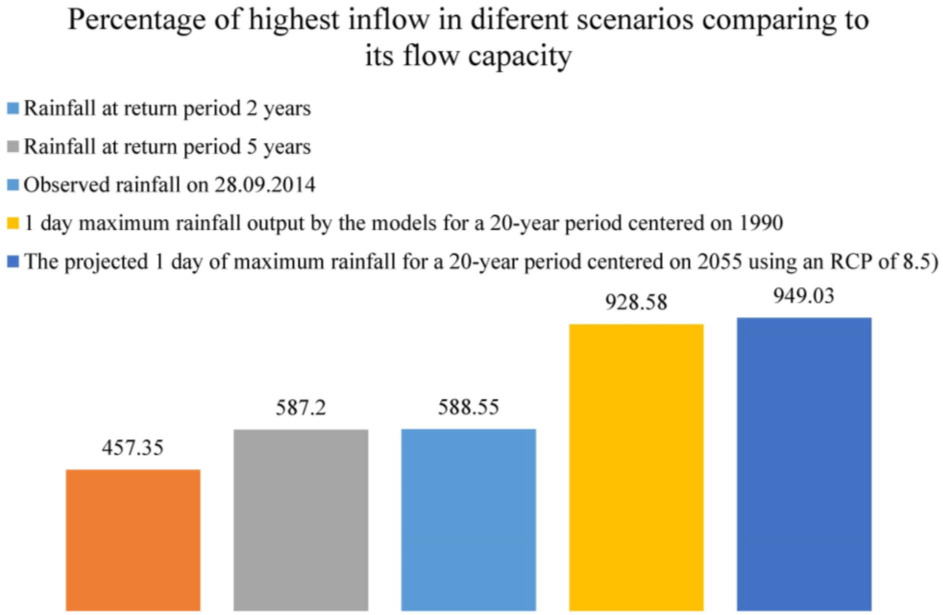


Fig.8. Percentage of highest inflow in junction J14 in different scenarios comparing to its flow capacity

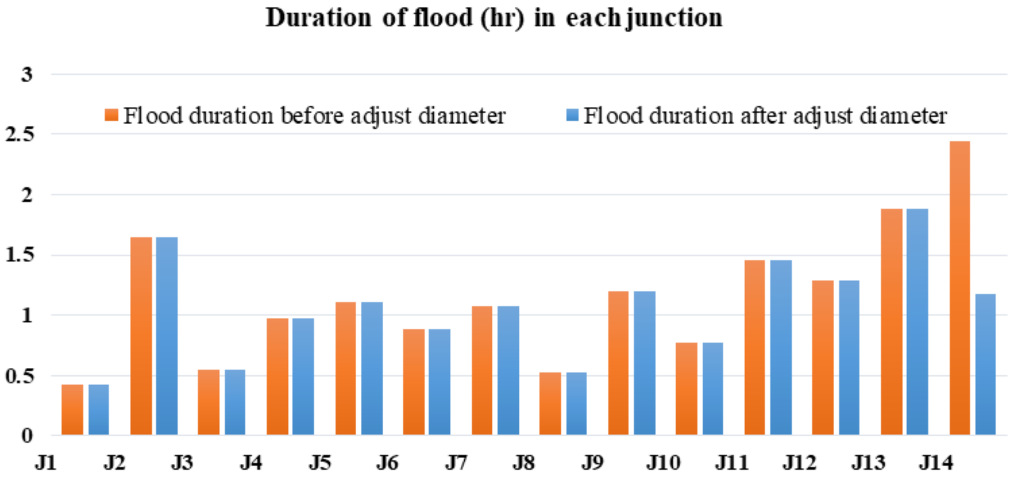


Fig.9. Duration of flood after enlarge of conduit C16

3.4 Improvement of drainage network based on the JICA report after the improvement of drainage pipe, pumping station and underground reservoir. In order to achieve this condition, larger size of objective facilities is needed. However, there are many negative aspects to enlarge drainage facilities to achieve "no inundation", such as limited construction space for new facilities, excessive costs, lengthy construction period, and relocation of obstructive existing underground facilities. Therefore, it is practical to set the tolerant flood depth to lower than 20 cm and flood duration to less than 2 hours under the condition of 2-year return period" which is same condition with it is desirable to achieve "Inundation duration and Inundation depth becomes zero, i.e. there is no longer inundation occurred" drainage improvement in Phase II and Phase III. It is decided to follow the same target as previous Project from the following points of view. But in this study, the SWMM model is 1D model, so it can not define the depth of the flood in the study area. Tt is merely able to define flood in each node and duration of flood. The rainfall at return period of 2 years, 5 years in this study is achievable due to flood duration is within 2 hours. However, for the data simulate in CCAM model, it is over in junction J14 for 1-day maximum rainfall output by the model for a 20-year period centered on 1990, and for the projected 1-day of maximum rainfall for a 20-year periods centered on 2055 using an RCP of 8.5 with 2h 23mn and 2h 27mn, respectively. So for the reduction of flood impact, it is recommended to enlarge the capacity of its system. In its system, J14 carries flow via C16 with size of diameter of 1.5m and flow capacity of 2.586 m^3/s. After the diameter C16 has been enlarged from diameter 1.5m to 1.8m, the duration of flood has been reduced from 2h 27mn to 1h 11mn as seen in Fig. 9.

4. CONCLUSIONS

In conclusion, the drainage system in the catchment area located in Sangkat Toul Svay Prey 1 & 2 and Tomnob Teuk within an area of 160 ha was simulated using the Strom Water Management Model (SWMM) as single event type. Rainfall data from ITC in 2014, the previous design storm from JICA , and the Climate Change Scenario were generated into hyetograph with 6mn time step, and all drainage data obtained from JICA were used as input to SWMM. The result indicated that the study area is expected to be impacted by climate change resulting from the increase of precipitation. Based on model results, the number of flooded volumes and the duration of flood increased. The increase in rainfall intensity and total depth appeared to have bigger impact on flooding characteristics. The simulation results show that greater surface flooding can be expected under the various climate change scenarios. The highest flood is in 1-day maximum rainfall for a 20-year centered on 2055 using an RCP 8.5 with maximum flooding volume of 153212m^3 and flooding duration of 2h 27mn. In all scenarios, increasing percentage of highest inflow was occurred in junction J14 comparing to its flow capacity. And the highest is in scenarios projected 1 day of maximum rainfall for a 20-year period centered on 2055 using an RCP of 8.5 that increased 949%. Base on JICA report, it aimed to reduce flooding within 2 hours so the diameter has been enlarged. There are two scenarios that duration of flood over 2 hours are the 1-day maximum rainfall output by the model for a 20-year period centered on 1990 and the projected 1-day of maximum rainfall for a 20-year period centered on 2055 using an RCP 8.5 which were flooded in junction J14. In its system, junction J14 carries flow via conduit C16 with diameter of 1.5m and flow capacity of 2.586 m^3/s. After the diameter of conduit C16 was enlarged from diameter 1.5m to 1.8m, the duration of flood has reduced from 2h 27mn to 1h 11mn. The peak runoff generated the greatest runoff in subcatchment S15 in the scenario the projected 1 day of maximum rainfall for a 20-year period centered on 2055 using an RCP of 8.5 that generated the highest discharge, 9.67m^3/s. Otherwise, the lowest peak runoff generated by subcatchment S5 in scenario 2 year design storm which generated the discharge 2.34m^3/s. The recommendation from this study is that the calibration and verification of the model using field measurements is necessary, e.g. Water elevation in the manhole should be recorded with the rainfall events, Manning's roughness coefficient either for the conduit or land surface should be investigated since it is one of the relative sensitivities of SWMM input parameters.

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REFERENCES

[1] JICA (2016). The Study on Drainage and Sewerage Improvement Project Metropolitan Area.

[2] JICA (2017). Preparatory Survey Report on the Project for Flood Protection and Drainage Improvement in Phnom Penh (Phase IV)

[3] Sothea, K., Sovann, P., Irvine, K., Duval, K. (2012). Phnom Penh Sewer Modelling and Contaminant Load Estimates. Coast. Environ. Focus Asian Reg. 238-249.

[4] Rodr, R., Navarro, X., Casas, M.C., Ribalaygua, J., Russo, B., Pouget, L., Reda, A. (2013). Influence of climate change on IDF curves for the metropolitan area of Barcelona (Spain).

[5] ADB (2014). Supplementary Appendix M - CAM GMS BCC-PPCR Climate Change Impact Modeling and Vulnerability Assessments for Koh Kong and Mondulkiri Provinces in Cambodia Part 1 : Climate Change Impact Modelling Part 2 : Climate Change Vulnerability Assessment.

[6] ADB (2017). Road Network Improvement Project., Climate Risk Assessment and Management.

[7] Davies, A., Hernebring, C., Svensson, G., Gustafsson, L.-G. (2008). The Impacts of Climate Change and Urbanisation on Drainage in Helsingborg, Sweden: Suburban Stormwater. J. Hydrol. 350, 114–125.

[8] Berggren, K., Olofsson, M., Viklander, M., Svensson, G., Perttu, A.-M.. (2012). Hydraulic Impacts on Urban Drainage Systems due to Changes in Rainfall Caused by Climatic Change. J. Hydrol. Eng. 17, 92–98.

[9] NIS (2008). The Statistical Yearbook of Cambodia.

[10] JICA (2011). The Project for Flood Protection and Drainage Improvement in the Phnom Penh Capital City (Phase III) in the Kingdom of Cambodia, Preparatory Survey Report.

[11] MPWT (2018). Ministry of Public Works and Transport

Second Greater Mekong Subregion (GMS) Corridor Towns Development Project, Project Management and Implementation Support, Detailed Design and Construction Supervision Urban Drainage in Sihanouke Ville.

[12] Gironás, J., Roesner, L. A., Davis, J., & Rossman, L. A. (2009). Storm water management model applications manual. National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency, Cincinnati, OH 45268.