Feasibility of low impact development measures to mitigate inundation in tidal – impacted urban area: A case in Ho Chi Minh City, Vietnam

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Abstract. Recently, urban inundation is becoming more severe in Ho Chi Minh City. Many structural measures have been proposed, but low impact development (LID) measures have not been sufficiently considered. This study quantitatively investigated the possibility of LID measures in District 12, Ho Chi Minh City using modelling approach. Based on the collected secondary data on land use, sewer network, and terrain elevation, a semi-two-dimensional storm water management model (PCSWMM-2D) was constructed and calibrated against heavy rainfall and high tidal event on 26 September 2016. Errors between measured and simulated inundated depths at several positions was smaller than 5%; thus, the calibrated model was at reliable accuracy to predict design scenarios. Using 10-year return period scenarios of tidal levels at Sai Gon River and rainfall at Tan Son Hoa gauging station, the model was used to analyse several designed LID measures including green roof, pervious pavement, and storage or flood retention lake/pond. The simulated results indicated that if green roof and pervious pavement are separately applied, the average magnitude of inundation depth can be reduced by 11.4% and 14.0%, respectively. Meanwhile, when a well-designed storage system including a gated-flood retention lake in combination with suitable conduits and a pumping station is constructed, the flooding situation is completely controlled. In conclusion, it is suggested that to manage urban inundation in terms of sustainable development for Ho Chi Minh City, a well-designed storage system is needed prior to the urbanizing area. In addition, those LID measures should be widely applied as long-term strategy for flooding management in Ho Chi Minh City.

1. Introduction

Ho Chi Minh City (HCMC) is the biggest city of Vietnam located in lower Dong Nai river basin with the total area of 2.061 km². The city is characterized as a lowland area with dense river network. There are two big rivers (namely, Dong Nai river and Sai Gon river) together with many tributaries flowing throw the city (Figure 1); which is estimated to have 975 km length used for navigation. This area is a relatively flat and low-lying terrain. The regions with the elevation (AMSL) less than +0.5 m and less than +1.0 m are 18.67% and 53.54%, respectively of the total area and are mostly located along the rivers or canals in the city. Additionally, the city also is influenced by the semi-diurnal tide of the East Sea. Recently, under the context of climate change and sea level raising, frequency of high tidal water levels is recently increasing; therefore, the drainage situation of the city becomes more difficult leading to more tidal flooding in the city [1]. For example, as the result of high tidal phenomena
occurred on 30 September 2019 with the peak of water level rising up to + 1.77 m at Phu An gauging station in Sai Gon river, a large area in the south of the city is highly inundated and prolonged.

Moreover, HCMC is in the tropical monsoon region with a high average annual rainfall ranging from 1,200 mm to 1,900 mm. Nevertheless, ninety percent of this annual value mainly occurs during the rainy season (from May to November). On the other hand, intensity and frequency of heavy rainfall events caused city flooding tend to increase in recent years [2]. Consequently, urban flooding usually happens more frequently and widespread during the rainy season. The flooding situation becomes more severe when heavy rains and high tides simultaneously occur. For instance, a heavy storm on November 25, 2018 from 07:00 to 15:00 produced 401 mm rainfall measured at Tan Son Hoa gauging station. The peak tidal level measured at Phu An gauging station at 18:30 on the same day was + 1.29 m, 9 cm higher than flooding alarm level 1 of the city. This resulted to 102 roads in the city being inundated with depths varying from 10 cm to 70 cm [3].

Presently, the flooding situation in the city is still very serious despite many projects implemented under the urban drainage master plan Decision 752 QĐ/TTg [4] signed by the Prime Minister on June 19, 2001; and many previous studies related to urban flood management in HCMC prioritizing conventional hydraulic structures. However, there are few studies considering Low Impact Development (LID) approach. Some of the studies on applying LID measures in HCMC modeled using Storm Water Management Model developed by United States Environmental Protection Agency (EPA-SWMM) are those of Ho et al. [5] and Quan et al. [6]. Ho et al., assessed four Sustainable Urban Drainage Systems (SUDS) namely rainwater harvesting, green roofs, urban green space, and pervious pavement, with application to the Nhieu Loc - Thi Nghe Basin, located in the central part of HCMC. Quan et al. used Tuflow and SWMM models for simulating surface and drainage water system in assessing the effectiveness of green infrastructure development in urban flood reduction. The models were developed at a specific study area namely Tham Luong - Ben Cat Catchment in HCMC. For a more comprehensive discussion on the use SWMM to model the long-term performance of specific types of LID alternatives, which could be referred to the work of Rossman [7].

In line with sustainable flood management for HCMC, the objective of this study is to investigate the feasibility of implementing LID measures, modeled using the Personal Computer Storm Water Management Model (PCSWMM) through a case study in the District 12. The study area is in the north of the city (Figure 1), which is selected due to its high urbanization rate. No studies on application of LID measures for inundation reduction have been conducted in this area yet.

Figure 1. Study area: District 12, Ho Chi Minh City.
2. Methodology and data collection
In this study, the numerical model (PCSWMM model), is used as a supporting tool. PCSWMM is a commercial software conducted by Canadian Computational Hydraulics International. Its fundamental concepts are the same with EPA-SWMM model [8]. In application of the model, two important steps have been carried out, including: (i) calibrating PCSWMM model; and (ii) evaluating the LID measures using the calibrated model. The general research framework is presenting in the figure 2.

![Research Framework](image)

**Figure 2.** The research framework using PCSWMM model for the case study.

To calibrate PCSWMM model, a huge of data set was officially collected from governmental agencies and academic institutes of Ho Chi Minh City. For example, the map of existing urban drainage system of the city was collected from Department of Construction. The land use and soil map were provided by Department of Natural Resources and Environment. The data on digital elevation map (DEM), climatic and hydrology was transferred from Ho Chi Minh City Institute for Meteorology, Hydrology and Climate Change. The historic flooding water depths in the city were collected from Operations Center of the City Flood Control Program of Ho Chi Minh City, and so forth.

The drainage system of the case study was modelled by some components such as sub-catchment, node (or junction), and culvert (or conduit). Each component had many parameters that were determined directly or indirectly. After standardizing the data, inputting data and calibrating the model have been processed. Following paragraphs is briefly describing how to input some important parameters.

For sub-catchments, the inputted data include percentage of impervious area, slope, maximum and minimum infiltration rates. Percentage of impervious area were taken as 75% to 85% for densely...
populated areas; and 35% for sub-basins with low levels of urbanization, mostly in the eastern region. The slope of the sub-catchment was based on DEM elevation of District 12 varying from 0.1 to 0.5. The infiltration equation used was Horton’s formula with parameters determined for loamy soil (according to soil data), including maximum water infiltration rate and minimum infiltration rate on saturated soil taken as 76.2 mm/h and 7 mm/h, respectively. In addition, decay constant is inputted as 4 L/h; and soil time from saturation to completely dry was 5 days.

For the collection nodes, beside of geometric data, the inflow parameter is defined as amount of wastewater that the nodes are received. This amount of wastewater was calculated basing on domestic water consumption within the sub-basin, according to Decree No. 80/2014/ND-CP signed by the Prime Minister on 6 August 2014 [9], and other national regulations related to water use.

For the conduits, the Manning roughness coefficient, $n$ was selected as 0.013. Moreover, the slope of the conduit was taken as $1/D$ in which $D$ is diameter of the conduit in cm, following QCVN 07-2:2016/BXD [10]. Other parameters included in the model were based on existing data on drainage system and topographic map.

Moreover, referenced to the previous studies ([5] and [6]) and our experience in flood management for the city, three potential LID measures were considered in the case study, including: (i) green roof, (ii) pervious pavement, and (iii) storage system (flood retention lake/pond and pumping station). Furthermore, evaluating the feasibility of the measures was based on reduction of flooding depth simulated by the calibrated model.

3. Results and Discussion

3.1. Performance of calibrated model

As the result of calibration, the final PCSWMM model for the study area consisted of 168 sub-catchments, 267 nodes (junctions) and 319 culverts (conduits) as showing in the figure 3. Moreover, the data of hydrological boundary conditions were rainfall intensity and water levels on rivers and canals at the outlets of existing sewer systems (or outfalls) were inputted in the model. A real storm event, with estimated return period of 10 years which occurred on 26 September 2016, was selected for calibration. The design rain pattern was determined using the IDF curve provided by the Ho Chi Minh City Institute for Meteorology, Hydrology and Climate Change. The water levels at the outfalls located in Vam Thuat river and Sai Gon river were extracted from a Mike 11 model constructed for lower Dong Nai river system from a different project by the author [11]. Those inputted parameters are shown in the figure 4.

![Figure 3. Model setup in PCSWMM software.](image-url)
To calibrate the model, data of inundated depth measured at four locations after the rain on 26 September 2016 was used. The results showed that the error between simulated and measured depths are less than 10% as illustrated in the figure 5, which is indicated that the calibrated model is good reliability for predicting designed scenarios. The calibrated model then was applied for three different scenarios employing LID measures namely green roof, permeable pavement, and retention lake with pumping station to assess their potential in inundation reduction.

3.2. Evaluation of LID measures in inundation reduction

3.2.1. Green roof
Some areas in the western part of the district that have been highly urbanized was assigned an impermeability of 63% (including residential areas, industrial parks, services, etc.) in the basic model (without LID measures applied). Potentially, to reduce inundation, these areas should be converted into green roof, especially for the region along Nguyen Van Qua Street (green circle in the figure 6). Based on technical design of the green roof planted by dense vetiver grass (Figure 6a), parameters of the roof were inputted for the model in 3 categories such as surface, soil, and drainage mat. The simulated results show that, if the green roof measure is adapted for all the buildings having good

![Figure 4](image-url)  
**Figure 4.** Rainfall data and two tidal curves of Vam Thuat river and Sai Gon river.

![Figure 5](image-url)  
**Figure 5.** Calculated and measured inundation depths at different locations in District 12.
structure (e.g.: high residential and commercial buildings, industrial buildings and so on) in this sub-catchment, the flooding level can be reduced by as much as 17% for the scenario with rain and high tide with probability of occurring P = 10% (Figure 7).

Figure 6. The regions where (a) green roof and (b) permeable pavement were investigated in the PCSWMM model.

Figure 7. Flood depth simulation results with and without using LID measures: (a) green roof, (b) permeable pavement, and (c) retention lakes and pumping station. Values represent percent reduction in depth of flooding.

3.2.2. Permeable pavement
The geological condition of District 12 is old alluvial soil mixed with sandy loam soil in the western part which has high level of urbanization, and clay mixed with impurities in the eastern part with the dense canal system. Therefore, increasing surface permeability appropriate for each sub-region has
potential in reducing floods. Permeable pavement is applied for Song Hanh street (blue circle in figure 6). The permeable pavement was designed for this area showing in the figure 6b, which are several permeable layers in vertical direction, including block paver, porous concrete (or asphalt mix), and gravel with drainage pipe system. Based on the designed pavement, numerical data is standardized for the model. The modelling results show that permeable pavement can reduce the amount of flooding in the surrounding area by as much as over 40% (Figure 7b).

3.2.3. Retention lake and pumping station

The areas along Phan Van Hon and Nguyen Anh Thu Street have enormous spaces to build a flood retention lake, the red circle in the figure 8a. To control the flooding along those streets, a system was designed, which consists of a retention lake with a volume of 40,000 m$^3$ together with gated-pump station as illustrated in the figure 8b. The pump with the head above the head of junction was chosen. The pump will be operated when drainage capacity of sewer system is over as the result of very heavy rainfall or tidal water level higher than probability design. Based on modelling results, this measure shows significant reduction in inundated depth (Figure 7c), which is various from 96% to 100%. Comparing to the other proposed measures, this one is the best measure to reduce urban flooding in the district 12.

![Figure 8](image)

Figure 8. (a) Location of the lake and pumping station in the map of District 12, (b) system design.

4. CONCLUSION

With aid of PCSWMM model, feasibility of potential LID measures; which were green roof, permeable pavement and a retention lake together with pumping station, are investigated through a case study in the District 12, Ho Chi Minh City. The simulated results of inundation depth reduction show that a well-designed storage system including a gated-flood retention lake in combination with suitable conduits and a pumping station is the best measure. Therefore, this measure is suggested as priority to build at urbanizing area of the city because its land occupation. In addition, designed green roof, and pervious pavement are not much effective in flooding reduction, estimated as 11.4% and 14.0% of inundated depth, respectively. However, application of these two measures also is encouraged as long-term strategy for flooding management in the city because of some benefits such as improving the city landscape by green space, discharging underground water, and so on.

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