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Exploratory Assessment of SUDS Feasibility in Nhieu Loc-Thi Nghe Basin, Ho Chi Minh City, Vietnam

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Authors' contributions

This work was carried out in collaboration between all authors. Author HHL designed the study, performed the PCSWMM modeling and stakeholder interviews, and wrote the first draft of the manuscript. Authors MSB and KNI provided technical advice on the modeling and survey analysis and edited versions of the manuscript. Authors PMD and SW managed the literature search. All authors read and approved the final manuscript.

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ABSTRACT

Aims: In recent decades, Ho Chi Minh City, Vietnam, frequently has been affected by local floods and inundation from heavy rainfall. Conventional flood mitigation measures such as building flood gates and upgrading sewerage systems have been implemented but problems persist. The objective of this research is to assess another approach for flood control measures, namely Sustainable Urban Drainage Systems (SUDS), with application to the Nhieu Loc - Thi Nghe Basin, located in the central part of Ho Chi Minh City.

Methodology: A combination of the Stormwater Management Model (PCSWMM) and interviews with 140 households was used to assess the efficacy and acceptability of four of the most popular SUDS: Rainwater harvesting, green roofs, urban green space and pervious pavement. Thirteen SUDS and urban build-out scenarios were simulated under 6 design storm conditions.

Results: PCSWMM results showed that inundation from intense rainfall could be reduced with proper land-use control, specifically by maintaining imperviousness at 65% or less of the surface

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area. With respect to SUDS performance, green roofs were best at reducing peak runoff (22% reduction), followed by pervious pavement, urban green space, and rainwater harvesting systems. Regarding environmental improvements, as represented by reduction in total suspended solids load, urban green space was best with 20% of the solids load removed compared to the base case scenario, followed by green roofs, pervious pavement, and rainwater harvesting. The household interviews revealed the majority of people preferred pervious pavement to the other SUDS options and the least preferred option was green roof technology.

Conclusion: Considering the combination of water quantity and water quality controls, it seems that green roof technology was the best performer for this area of Ho Chi Minh City, followed by urban green space, pervious pavement and rainwater harvesting. However, green roof technology also was the least favored option for the public and stakeholder acceptance will impact SUDS implementation.

Keywords: Urban flooding; Sustainable Urban Drainage Systems (SUDS); Storm Water Management Model (PCSWMM); rainwater harvesting; green roofs; urban green space; pervious pavement.

1. INTRODUCTION

Frequent and localized flooding in Ho Chi Minh City (HCMC) not only causes serious economic losses but also degrades the quality of life and this is particularly true for those living in the Nhieu Loc-Thi Nghe (NL-TN) Basin of the central part of the city. Rainfall events of greater than 90 mm depth, which alone could cause local inundation in some places, have occurred more frequently. This phenomenon, together with other adverse effects such as increased downstream water level due to sea level rise, has resulted in a regularly overloaded drainage system, despite hard engineering improvements that have been implemented over the past decade [1,2].

Sustainable Urban Drainage Systems (SUDS) technologies consider environmental, social and economic pillars in the design process. SUDS should integrate stakeholders in the decision making and ultimately, could achieve multiple benefits along with flood and inundation mitigation. There are several SUDS technologies available. Within the scope of this study, four of the most popular SUDS technologies were considered:

(i) Rainwater harvesting – which can be a supplement for water supply sources; reduce extra direct discharge to the drainage system and prevent urban flooding [3-5];
(ii) Green roofs – have numerous benefits [6], including: Reduction of runoff peaks and volumes, resulting in lower urban flood risks [7-10]; the insulation of heat transfer, resulting in lower cost for air conditioning, and reduction of the heat island effect [11,5,12]; reduction in air pollution [13]; provision of wildlife habitat for birds and general enhancement of environment for the area [14-16,5];
(iii) Urban green space provides improved resiliency in runoff management and multiple other ecosystem services [17-20];
(iv) Pervious pavement - a technology that both enhances infiltration and improves surface runoff quality [21-23]. There is some concern about clogging of pervious pavement, with observed clogging rates being highly variable, but Drake and Bradford [24] have reported on new generation maintenance methods to regenerate permeability.

SWMM (Storm Water Management Model) is a comprehensive computer model for analysis of quality and quantity problems associated with urban runoff [25]. Both single event and continuous simulations can be performed on catchments having storm sewers, combined sewers, or natural drainage, for prediction of flows, stages and pollutant concentrations. The model offers several choices for simple rainfall-runoff estimates and includes kinematic and dynamic wave routing options to generate flow hydrographs. Another welcome feature of SWMM version 5 is the explicit representation of Low Impact Development (LID) technologies (an alternative name for SUDS in North America). One objective of this study was to use a personal computer version of SWMM (i.e. PCSWMM) in assessing SUDS technologies to enhance flood mitigation measures already implemented in the

NL-TN Basin. A second objective of this study was to solicit stakeholder opinion about the relative desirability of the different SUDS options. This represents one of the first efforts in Vietnam to model the relative benefits of SUDS in urban areas, and more importantly it's the first instance we are aware of that integrates engineering practice with social science considerations to improve drainage and the local environment.

2. METHODOLOGY

2.1 Nhieu Loc-Thi Nghe Canal and Basin

The NL-TN Basin (Fig. 1) is located in the central part of HCMC and occupies an area of approximately 33 km^2, stretching across 7 city districts (1, 3, 10, Phu Nhuan, Tan Binh, Go Vap and Binh Thanh). The population of the Basin is about 1.2 million people (20% of the total HCMC population), representing a population density of 290 people per hectare. Land use is mixed, with 49.3% being residential and the remaining representing commercial, public and industrial uses. Elevation within the Basin is variable, with the north and northwest sections being up to 8 m above sea level, while the southern part of the Basin averages only 1.3 m above sea level.

Le [4] described the historical development of the NL-TN Canal and Basin, as it progressed from a rural, northern boundary area of HCMC in the 1700's to an area of extensive informal housing in the 1960's. By the 1960's HCMC had grown further north, so the NL-TN area was now part of the central city and the river, which formerly had provided fishing and water for domestic use, was now called "Kinh Nuoc Den", or "Black Water Canal" due to extensive degradation from wastewater discharge. Le [4] also provided a firsthand account of frequent flooding in the basin. Wust et al. [26] reported that since 1995, the city had conducted a program of cleaning up the NL-TN Canal, relocating informal settlements, and improving drainage. Ho [27] noted that since 1998 more than $1 billion USD had been spent on urban flood control projects for all of HCMC while Duc and Truong [28] discussed the comprehensive project to build a new drainage system for the NL-TN Canal which had a budget of $200 million USD over the 2001-2007 period and included funding of $166 million USD from the World Bank. Despite improved drainage conditions, Lempert et al. [29] recently concluded the new infrastructure in the NL-TN Basin would reduce risk compared to current levels if three-hour rainfall event intensities increase by no more than approximately 6% and if the Saigon River rises less than 45 cm. However, it seems possible that both of these thresholds may be exceeded by mid-century, in which case flooding risk increases above current levels even with this infrastructure in place. For example, based on projections of linear trends over the past 20 years, Ho [27] concluded sea level increase averaged 1.5 cm per year for the Ho Chi Minh City region. Ho [27] also reported an increase in the annual maximum 180 minute rainfall for the city of about 0.8 mm/year between 1952 and 2002.

2.2 Model Development

The drainage system of the NL–TN Basin was simulated using PCSWMM which was adapted from an earlier SWMM model developed by Camp, Dresser and MacKee [30], but updated to more accurately represent surface slope using DEMs in Arc GIS; represent current land use characteristics and percent imperviousness; and consider new bathymetric data for the NL-TN Canal. In total, 228 sub-catchments, 333 conduits and 228 junctions were included in the model (Fig. 2).

2.2.1 Boundary conditions and model calibration conditions

Fig. 1 shows the locations of the Tan Son Hoa meteorological station and Phu An hydrological station from which the model boundary conditions were collected. Boundary conditions for this study were defined by considering the typical tidal curve obtained from the Phu An Station, located at the downstream end of the Basin. Fig. 3 shows a typical tidal curve (1.48 m peak) from the Phu An Station.

Because sewer flow is not routinely monitored in Vietnam, an alternative approach was used to calibrate the model. A 90 mm design storm was used as input (Fig. 4) and model results for the water level along the NL-TN Canal under a similar rainfall event were compared to observed levels.

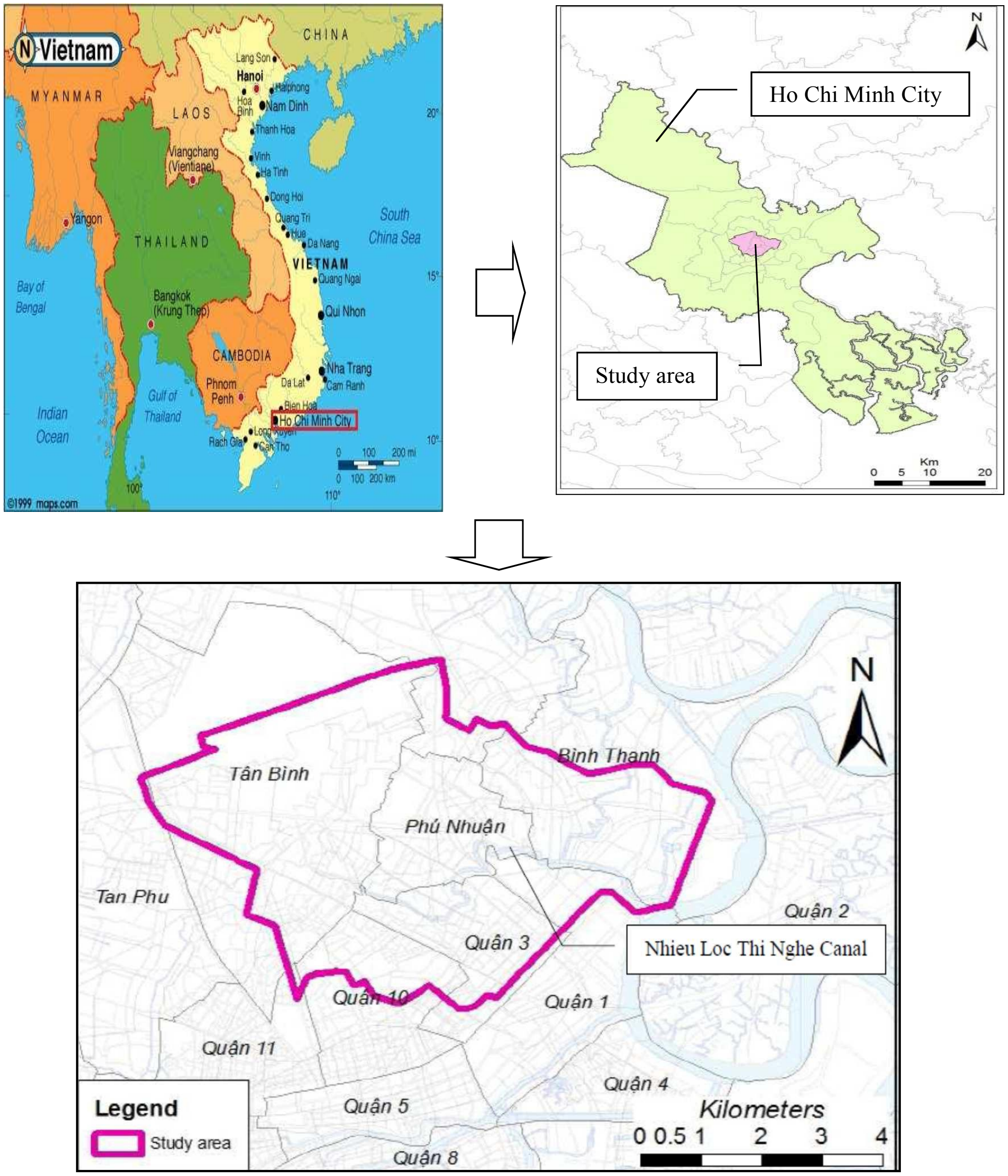

Fig. 1. Study area with details of Nhieu Loc Thi Nghe Basin

Goodness of fit between the model simulation and the observed data were assessed based on:

Efficiency Index (EI)

$$EI = \frac{\sum_{1}^{n} (X_i - \bar{X})^2 - \sum_{1}^{n} (X_i - Y_i)^2}{\sum_{1}^{n} (X_i - \bar{X})^2} \qquad (1)$$

Root mean square error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{1}^{n} (X_i - Y_i)^2}{n}} \qquad (2)$$

Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{1}{n}\sum_{1}^{n}\left|\frac{X_i - Y_i}{X_i}\right| \times 100 \qquad (3)$$

Correlation Coefficient (R)

$$R = \frac{\operatorname{cov} XY}{s_x s_y} \qquad (4)$$

Where:

X_i = Observed (measured) data at time i
Y_I = Computed (predicted) data at time i
n = Number of data points
$\overline{X}$ = Mean value of observed data $\overline{X} = \frac{1}{n}\sum_{1}^{n} X_i$
$\overline{Y}$ = Mean value of computed data $\overline{Y} = \frac{1}{n}\sum_{1}^{n} Y_i$

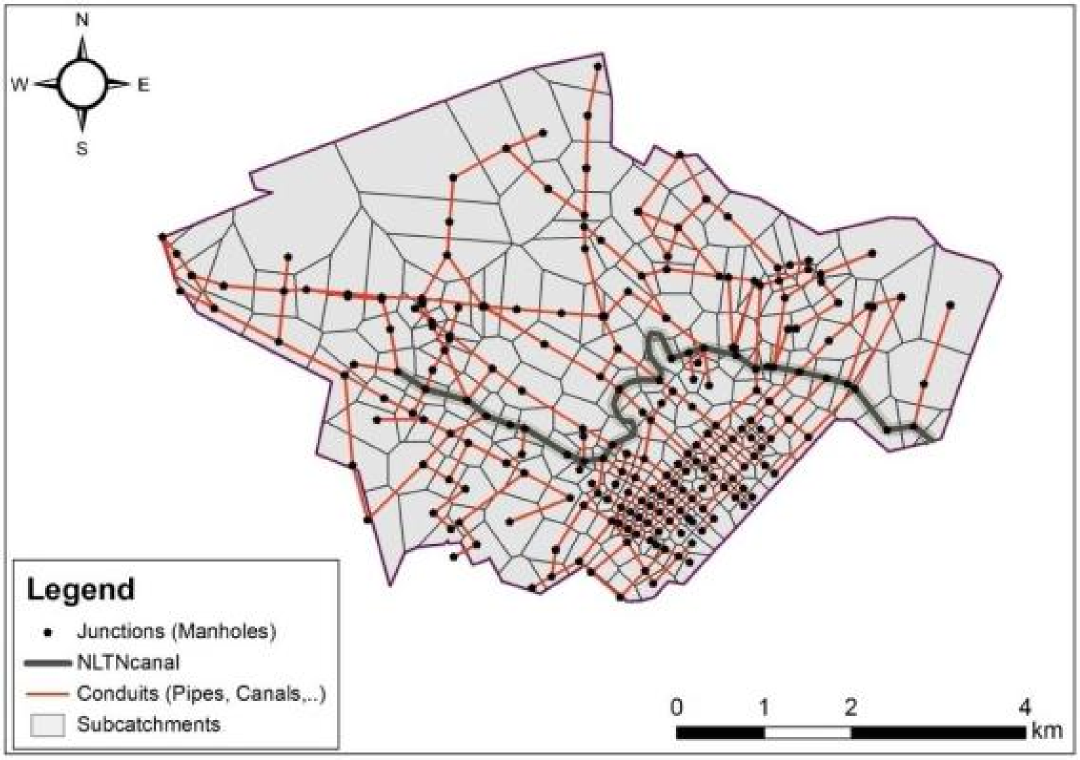

Fig. 2. PCSWMM representation of sub-catchments and sewer network

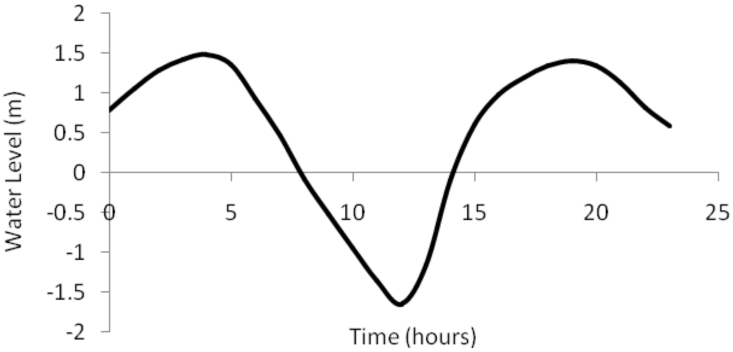

Fig. 3. Typical tidal curve at Phu An Station

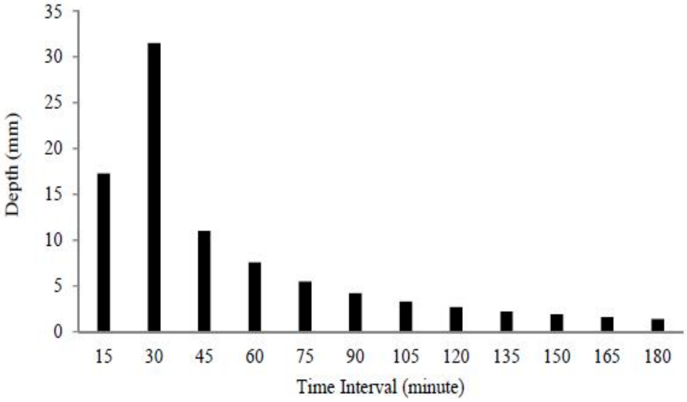

Fig. 4. Design Storm (90 mm), used to drive PCSWMM

The model was validated by comparing the flood hazard map generated by the model and the flooded streets reported by the Urban Drainage Company (UDC) and Flood Control Center (FCC) for a 100 mm storm event. UDC and FCC are two agencies assigned by the People's Committee of HCMC to be in charge of flood and inundation management for the city.

2.3 SUDS Efficiency Evaluation

The efficacy of SUDS was evaluated based on two main criteria, flood attenuation capacity and pollutant removal rates. The flood attenuation capacity is calculated as follows:

$$F = (1 - \frac{Q_*}{Q_o}) \quad (\%) \tag{5}$$

Where:

F is the flood attenuation capacity
Q_* is the peak flow after SUDS application (m^3/s)
Q_o is the peak flow before SUDS application (m^3/s)

The pollutant removal rate is calculated as follows:

$$TE = (1 - \frac{M_*}{M_o}) \quad (\%) \tag{6}$$

Where:

TE is the trap efficiency
M_* is the total pollutant mass after SUDS application (kg)
M_o is the total pollutant mass before SUDS application (kg)

The total pollutant mass is the TSS introduced through a storm event with a given concentration. This concentration is assumed to be constant through the time of simulation. This concentration used is a mean value from rainwater quality survey. This approach was used to provide a planning level estimate of the removal capacity of SUDS with respect to pollutants. A more comprehensive study is needed to better estimate this benefit of SUDS.

2.4 Citizen Surveys

An innovative aspect of this research was that, to our knowledge, citizen stakeholders in HCMC were asked for the first time about their views on localized flooding. A total of 140 households were interviewed in the watershed and these were categorized according to low, medium, and high income based on size and construction material of the house and the number of motorbikes and cars owned. The locations for the interviews were chosen based on the annual inundation reports from the FCC. During the interviews, the households were introduced to the different SUDS options and asked about their preferences with respect to rainwater harvesting, green roofs, urban green space, and pervious pavement.

3. RESULTS AND DISCUSSION

3.1 PCSWMM Calibration

PCSWMM was calibrated by comparing the water level simulation along the NL-TN Canal at a 1.48 m peak tide and under the 90 mm, 2 year design rainfall. Results are shown in Figs. 5a and 5b.

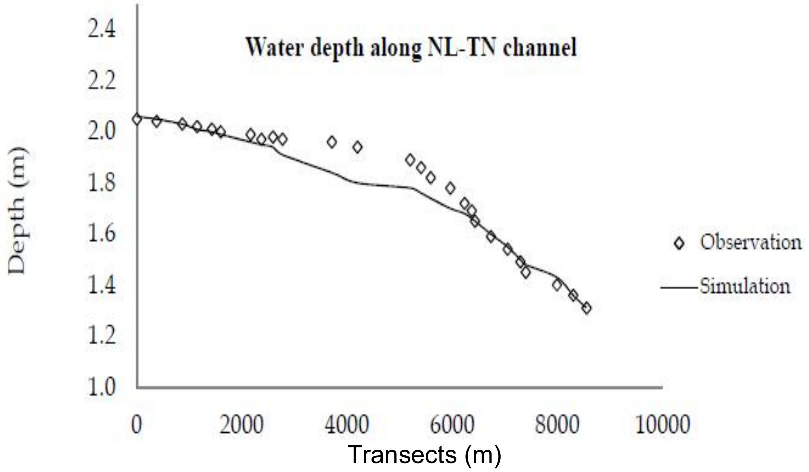

Fig. 5a. Comparison between simulated and observed water depths along the main canal

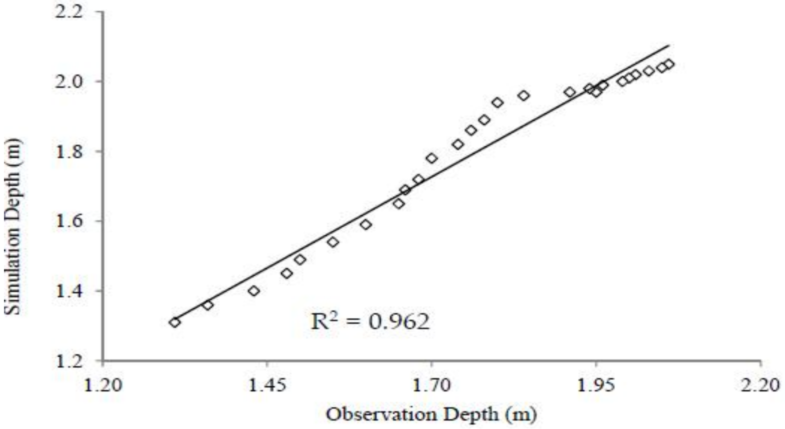

Fig. 5b. Simulation vs observation scatter plot

Additionally, the Efficiency Index, RMSE and MAPE were calculated and are displayed in Table 1. These calibration results suggest that the model is capable of reproducing local hydrology and that the model can be used with some confidence.

Table 1. PCSWMM calibration results

Indicator	Values
Efficiency index (EI)	0.93
Root mean square error (RMSE)	0.02
Mean absolute percentage error (MAPE)	1.5 %
Correlation coefficient r	0.962

3.2 PCSWMM Validation

The validation was done using two approaches. The first approach compared the locations of flooded manholes using the 1D PCSWMM simulation option with flooded streets from observation made by the UDC and FCC (Fig. 6a)

From Fig. 6a, it appears that the 1D model can be used to identify the flood locations, although some areas, such as the south central part of the Basin, were less accurately represented. The evaluation of flood extent regarding depth and affected area also was handled with the application of the 2D routing option in PCSWMM. The results are shown in Fig. 6b.

Fig. 6a and 6b show reasonable consistency between inundated streets observed by the flood control agencies of HCMC and flood hazard maps generated by the model. Additionally, Table 2 summarizes the comparison of flood depth between simulation results and observed data.

Recognizing the uncertainty associated with the limited observed data for this study, it can be concluded that the model was adequately calibrated and validated and can be used for inundation analysis of the NL-TN Basin.

3.3 Simulations

3.3.1 Design storms and urbanization scenarios

A set of simulation scenarios with different impervious percent values and surface roughness coefficients, covering the entire study area, were developed to explore impacts of urban development. This is to evaluate the effects of integrated measures. Each scenario either varied percent imperviousness or a combination of imperviousness and Manning's n. The increased roughness might result, for example, by promoting green space within the urban area. Details of each hypothesized scenario are listed in Table 3.

3.3.2 Summary of simulation results

Scenario 1 was used as the basis of comparison scenario against which all other scenarios were assessed. Results for the different development scenarios, using different storm depths and return periods are summarized in Fig. 7.

Table 2. Flood Depth Validation Results

Locations (Street names)	**Maximum flood depth (m)**	
	Simulation	**Observation**
Truong Cong Dinh	0.28	0.35
Pham Van Hai	0.28	0.35
Dong Den	0.36	0.3
Nguyen Thai Son	0.25	0.25
Truong Chinh	0.32	0.3
Dinh Tien Hoang	0.3	0.3
Phan Dinh Giot	0.23	0.2
Tran Khanh Du	0.35	0.3
Hoang Van Thu	0.28	0.3
Dinh Tien Hoang	0.27	0.3
Tran Khanh Du	0.23	0.25
Phan Dinh Phung	0.37	0.4
Xo Viet Nghe Tinh	0.3	0.25
Van Kiep	0.27	0.3
D2	0.28	0.2

Fig. 7 shows that Scenarios 2A and 3B1 generally exhibited increased surface flooding compared to current conditions. Both scenarios represented an imperviousness of 85%. The scenarios with 65% imperviousness, however, exhibited a decrease in flooded area compared to current conditions, for the whole range of design storms. This result shows that future development should try to maintain per cent imperviousness at 65% or less, assuming no other interventions (e.g. SUDS) are considered.

Table 3. Urbanization scenarios

Scenario	**Sub-scenarios**	**Impervious percentage**	**Roughness coefficient**
1 – Business as Usual		65 %	0.1
2	2 – A	85 %	
	2 – B	45 %	0.1
3 – A	3 – A – 1		0.2
	3 – A – 2	65 %	0.3
	3 – A – 3		0.4
3 – B	3 – B – 1		0.2
	3 – B – 2	85 %	0.3
	3 – B – 4		0.4
3 – C	3 – C – 1		0.2
	3 – C – 2	45 %	0.3
	3 – C – 3		0.4

3.4 SUDS Efficiency Evaluation

3.4.1 Representative sub-catchment characteristics

Simulation of the SUDS technologies was done using the LID editor in PCSWMM that explicitly represents the structure and hydrology of these technologies [31,25]. For each of the Rain Harvesting, Green Roof, Rain Garden, and Pervious Pavement, information required for input to the model included surface storage depth, roughness and slope, vegetation coverage, thickness and hydraulic conductivity of the underlying substrates and underdrain characteristics. Details about these elements are discussed in US-EPA [25,32]. The efficacy of SUDS was evaluated based on two main criteria; flood attenuation capacity and pollutant removal rates. The NL-TN Basin has in total more than 200 sub-catchments, as discussed above. Within the scope of this study, three representative sub-catchments were chosen to simulate the effect of SUDS. The selected sub-catchments are typical in land use patterns, area and were not located close to the watercourse (to avoid the confounding factor of flooding due to tides). Specific information regarding area, land use, SUDS configurations and impervious percent of these representative sub-catchments are shown in Table 4.

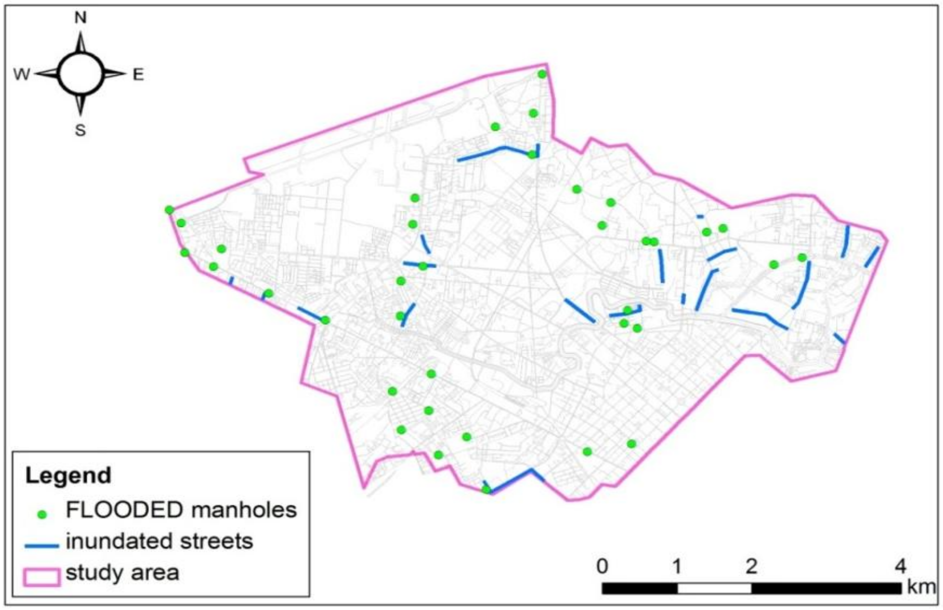

Fig. 6a. PCSWMM validation map (1D)

In Fig. 6a, the FLOODED manholes are the model simulation and the inundated streets are from the observation

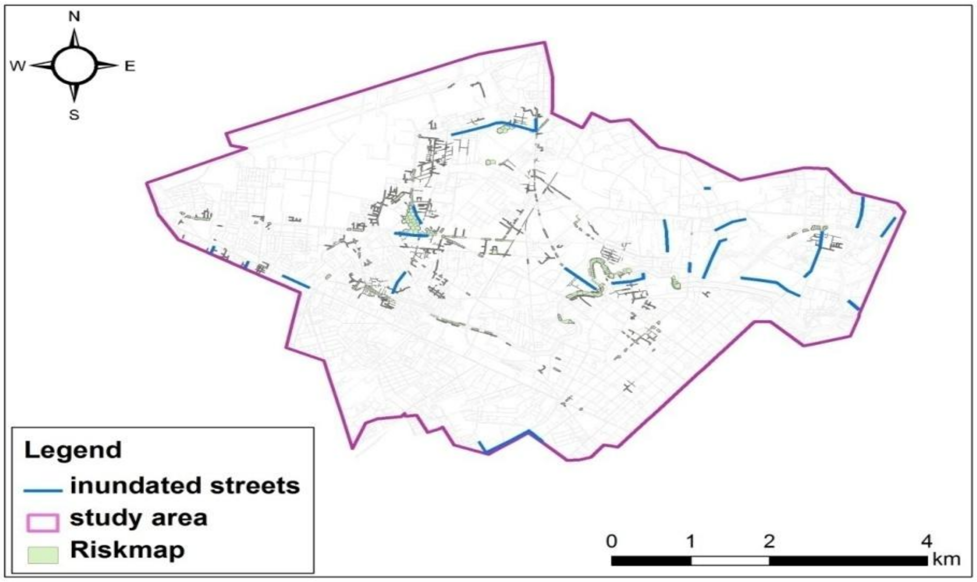

Fig. 6b. PCSWMM validation map (2D)

In Fig. 6a, the riskmap are the flooded areas from the model simulation and the inundated streets are illustrated from real- observation

3.4.2 SUDS evaluation

The SUDS technologies were applied to the selected sub-catchments as noted in Table 4 and the results for the simulations are displayed in Table 5. The rainfall chosen for SUDS evaluation was the 5 year return storm with 103 mm of depth.

3.4.3 Stakeholder survey results

Combining results for all socio-economic groups, the SUDS technology preferences were (based on the mean of a 1-5 Likert-type scale): Pervious pavement (score of 3.4); green space (score of 3.3); rainwater harvesting (score of 3); and green roofs (score of 2.4), Interestingly, however, the lowest socio-economic group favored rainwater harvesting (with a mean score of 3.4) above all other technologies.

3.5 Discussion

Although green roof technology had a strong hydrologic and water quality performance, it was least favored, in general, by the citizens surveyed. This type of technology appears to be too strange to be accepted by the majority of people. When asked, people showed substantial doubt about the applicability of vegetation coverage on their roofs. In contrast, green roofs are a common practice in Singapore Irvine et al [33] and it would be interesting to explore whether the Singaporean experience could be transferred to HCMC through exchange and training programs. Rain barrels will be filled quickly with large storms, hence could only offer limited improvement. Although a commonly promoted technology in North America, Chaosakul et al. [34] also concluded rain barrels would have a relatively small impact on runoff for a peri-urban area of Bangkok, Thailand. The lowest socio-economic group for a couple of reasons may prefer rain barrels. First, they may preferentially see rainwater harvesting as an inexpensive water source; and second many in this category may have recently migrated from the countryside where rainwater harvesting traditionally is practiced. The other two methods, urban green space and pervious pavement require specific available space for application, thereby resulting in a variable performance. More specifically, Sub catchment 1 has available areas with suitable conditions to apply urban green space and pervious pavement. These two technologies also were most favored by the surveyed citizens when results were pooled for socio-economic class. Satiennam [35] investigated the limitations of SUDS implementation arising from local attitudes in the flood prone area of Bangkok's Latkrabang District, such as inadequate plot size, inadequate budget for implementation, no homeowner's time for maintenance and lack of SUDS gardening skills. It was concluded that SUDS could not be achieved if its concepts were not compatible with local conditions, and could also be constrained by the poor enforcement of flood legislation. It should be emphasized that SUDS technologies are not a one size fits all solution. In fact, by design, SUDS implementation will be spatially distributed and must consider the existing urban landscape, *as well as the public acceptance of particular technologies*.

Table 4. SUDS application in representative sub-catchments

Parameters	Sub-catchment		
	1	2	3
Characteristics			
Area (ha)	102	13	32
Residential area (%)	46	54.	65
Roads (%)	14	30	27
Parks, paddies, (%)	40	16	8
Population (capita)	13630	2030	5510
Households	2726	406	1102
Impervious %	65	65	65
Rain water harvesting system			
Number of replicate units	2726	406	1102
Green roofs			
Number of replicate units	2726	406	1102
Area of each unit (m^2)	60	60	60
Urban green space			
Number of replicate units	4000	200	300
Area of each Unit (m^2)	100	100	100
Pervious pavement			
Number of replicate units	1400	400	900
Area of each unit (m^2)	100	100	100

Table 5. SUDS evaluation

Parameters	Sub-catchment			Mean
	1	2	3	
Current situation				
Peak Runoff (m^3/s)	29.11	4.17	10.45	14.58
TSS (kg)	573	71	177	273.67
Rain water harvesting system				
Peak Runoff (m^3/s)	27.26	3.91	9.8	13.66
F (%)	6.36	6.21	6.23	6.27
TSS (kg)	557	68	171	265.33
TE (%)	3.06	2.81	3.38	3.06
Green roofs				
Peak Runoff (m^3/s)	24.29	3.18	7.74	11.74
F^* (%)	16.54	23.7	25.94	22.06
TSS (kg)	478	57	141	225
TE^{**} (%)	16.58	19.72	20.9	19.07
Urban green space				
Peak Runoff (m^3/s)	14.8	3.26	9.09	11.59
F (%)	21.32	3.7	9.76	14.86
TSS (kg)	355	60	167	192.33
TE (%)	38.91	15.49	5.65	20.02
Pervious pavement				
Peak Runoff (m^3/s)	26.81	2.62	9.79	13.07
F (%)	7.89	37.15	6.57	17.13
TSS (kg)	552	38.3	167	244
TE (%)	3.66	46.06	5.65	16.20

*F – flood attenuation capacity as defined by eq. (5); **TE - trap efficiency as defined by eq. (6)

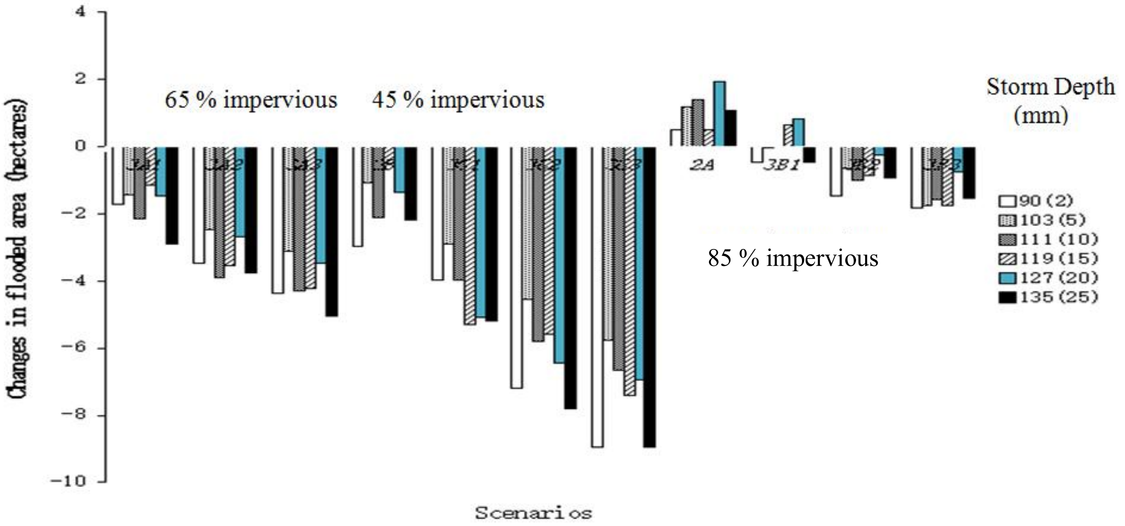

Fig. 7. Flooded Area Improvements

In Fig. 7, the number in parentheses after the storm depth refers to the return period in years of the respective storm event

4. CONCLUSION

Reducing the impervious percentage could contribute to alleviating the flood situation of the NL–TN Basin. Future development should try to maintain per cent imperviousness at 65% or less, assuming no other interventions (e.g. SUDS) are considered. The surface roughness improvements would work better for urban areas with moderate to low impervious surface. These improvements could be achieved by applying appropriate surface materials or promoting green space in the cities. If surface roughness (Manning's n) increased from 0.1 to 0.4, the number of flooded locations would decrease by 10% and 15% with 65% impervious and 45% impervious, respectively. Increasing surface roughness, however, might not be easy to achieve in practice and therefore SUDS should be considered instead.

With respect to SUDS evaluation, green roof technology was the best performer followed by urban green space, pervious pavement and rainwater harvesting when flood attenuation capacity was considered as the assessment criteria. The ranking for pollutant removal capacity was quite similar, although urban green space rated higher in trap efficiency than green roofs in this assessment category.

Despite an increasing body of research related to SUDS technologies, Marsalek and Schreier [36] noted that implementation at the municipal level has been limited. Most of the research that has been done for SUDS technologies focuses on temperate climates [31,37], although Silveira [38] and Goldenfum et al. [39] review the challenges to implementing sustainable urban drainage, particularly in developing countries having a tropical climate. There is some concern that SUDS technology will be less effective for larger storm events (or greater rainfall as experienced in tropical climates), however, the experience in Singapore [33] seems to counter this concern and similarly, an unpublished report by Drexel University for a test area in Cambria Heights, New York City, showed that SUDS performed exceedingly well in controlling runoff from Super Storm Sandy and Hurricane Irene.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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