Evaluation of sustainable urban storm drainage systems approach for reducing peak runoff at Sukhumvit area in Bangkok, Thailand•

Detchphol Chitwatkulsiri
Faculty of science and technology, Valaya Alongkorn Rajabhat University under the Royal Patronage
1 moo 20, Phahonyothin Road, Khlong Nueng, Khlong Luang District, Pathum Thani, 13180
Corresponding author Email: detchphol@vru.ac.th
(Received: May 19, 2019; Accepted: August 20, 2019)

ABSTRACT

Urban Flooding has long been believed to be the results of natural phenomena which could be cited as heavy rainfall, tidal surges, and land subsidence. Urban flooding becomes more frequent as the population rapidly increasing, urbanization, unplanned development, and climate change. This phenomenon are not only damages lives and environment but also impacts of economy, health, social, and transportation. In urban areas, flooding is caused by several reasons: the rise of the water level in the river through the city high tides for coastal cities, poor operation of the drainage system, and poor maintenance, etc. Flood management requires an understanding of the causes and adaptation to take appropriate improvement by implementing sustainable urban drainage systems techniques (SUDS). Thus, it will be a decreased percentage of imperviousness in an urban area. In this study, SUDS solutions, such as green roofs, rainwater harvesting, pervious pavements, urban green space, are applied at representative inundated sub-catchments. The study was conducted in the Sukhumvit area, Bangkok, Thailand. The results show green roofs are the best performer for reducing peak runoff because it is applied to all kinds of buildings, either residential, commercial. Rainwater harvesting and pervious pavements require specific available space for application making their performance very unstable. The best performing overall is green roofs, followed by rainwater harvesting, pervious pavements, and urban green.

Keyword: SUDS, Green roofs, Rainwater harvesting, Porous pavements, Urban green space.

1. Introduction

Urbanization is the process of turning greenfield sites into developments. For example, building in the countryside. Infiltration is rainfall soaking into the ground and eventually ending up in rivers over days. Once the site has been developed, and the site is now impermeable, so the rainfall becomes surface runoff quickly without soaking into the ground to get to the rivers in hours or even minutes. These make the hydrograph to peak higher and sharper (more water in less time), and flooding occurs.

Bangkok is the capital city of Thailand. Bangkok is located in the Chao Phraya River basin,

• บทความนี้ได้ถูกนำเสนอบางส่วนในการประชุมวิชาการวิศวกรรมโยธาแห่งชาติ ครั้งที่ 23

and the river split down the middle of the city. Nowadays, Bangkok has flooding regularly and more impacts to residential than the past because Bangkok has rapid urbanization, impact from change of both upstream and downstream condition from the northern to the central part of Thailand, heavy rainfall on the upstream and also inside Bangkok area, insufficient drainage capacity, tidal effect, land subsidence from groundwater consumption and climate change. These can cause urban flooding in Bangkok area. In the central part of Bangkok, Sukhumvit area is a representative of urbanization. Bangkok metropolitan administration (BMA) has a department of drainage and sewerage (DDS) working on flood problem in Bangkok. Several studies from DDS have shown that the drainage capacity of the existing system is still not perfect enough. In Sukhumvit area has a primary drainage system from surrounded canals and the secondary drainage system inside the area. Therefore, when the water level in primary drainage system around this area higher, the secondary drainage system will have a problem to drain water out [1].

The study in the Sukhumvit area by using a modeling tool and analyze the decreasing percentage of imperviousness can show the capability of infiltration effect to the urban area. These can help to reduce the impact of floods in the urban area.

2. Study area and Methodology

2.1 Study area

This research is the case of Bangkok, Thailand, where the Sukhumvit area has been chosen as a case study area due to its history of frequent pluvial floods and a wealth of information produced by Bangkok metropolitan administration (BMA). Sukumvit area which is located at the eastern suburban part of Bangkok which is one of the parts of the central business district. The geographical location of the Sukumvit, Bangkok is 13°44'18.01"N latitude and 100°33'41.31"E longitude. The catchment had an area of 21 km2 and located at the right side of Chao Phra Ya river. The elevation of the study area is around 0.4 to 1 m (MSL) [1]. The primary drainage of Bangkok consists of 10 polders as the secondary drainage system. Its characteristics are to prevent floodwater from outside by pumping stormwater out of the area to the main drainage. The city was able to avoid fluvial floods caused by Chao Phraya River overflow in 1995 and 1996 [2]. The rainfall station data used is from Bangkok metropolis rainfall station of Thai meteorological station.

Fig.1. Case of Study. Sukhumvit area. Bangkok, Thailand

Table 1 Methodological Framework

1. Data Collection	• Rainfall 20 years return period IDF curves in Bangkok, Thailand. • Account the various SUDS solutions at representative sub-catchments.
2. Modelling Approach	• Model calibration and verification • SUDS solutions are applied at representative inundated sub-catchments.
3. Evaluation	• Data analysis • Resulting

2.2 Methodology

To evaluate the sustainable urban drainage systems (SUDS) techniques approach for reducing flood inundation at the study area, the study is subdivided into three processes which are data collection, modeling approach, evaluation.

2.2.1 Data collection

Rainfall input data - Information about IDF curves in Bangkok, Thailand, was obtained from the M.Sc. research "Impact of climate change on urban flooding in the Sukhumvit area of Bangkok." This information was used for modeling different scenarios of precipitation in the study area [3].

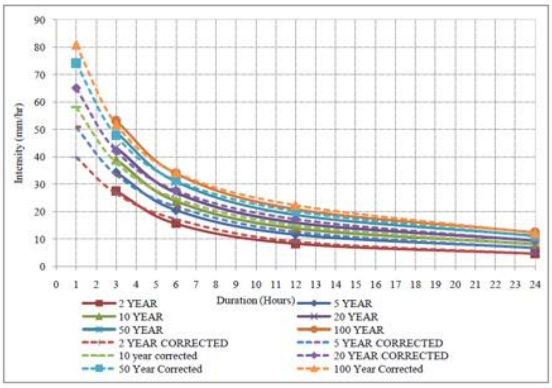

Fig.3. Corrected IDF curve for 1981-2010. Source: Shrestha (2013)

Representative inundated sub-catchments - The criteria to evaluate are the most residential Area (from land-use map) and mostly flooded area. The representative inundated and characteristics of sub-catchment are shown in Fig.4 and Table 2.

Fig.4. The locations of 3 sub-catchments in the study area.

Table 2 Characteristics of sub-catchment

Characteristics	Sub-catchment		
	1	2	3
Area (sq.km.)	0.36	0.25	0.30
Residential area (%)	64	72	44
Roads (%)	35	21	40
Other (%)	1	7	16
Green roofs implement (%)	25	35	15
Rainwater harvesting implement (%)	20	30	20
Urban green space implement (%)	10	15	10
Pervious pavements implement (%)	35	21	40

2.2.2 Modelling approach

SWMM - Stormwater management model is a comprehensive computer model for the analysis of quality and quantity problems associated with urban runoff [4]. Both single event and continuous simulation can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. The model offers several choices for simple rainfall-runoff estimates and utilizes kinematic routing to form the hydrographs. Sustainable urban drainage systems techniques such as green roofs, rainwater harvesting, pervious pavements, urban green space, are applied at representative inundated sub-catchments in SWMM. The modeling which is already calibrated and verified will use four of SUDS and evaluate their performance for reducing flood inundation at a particular area.

One of the fundamental principles for SUDS application is site-specific functionality. Therefore, the ultimate goal of this section is to identify the right tools for the job. These are some examples of SUDS.

- Porous pavements

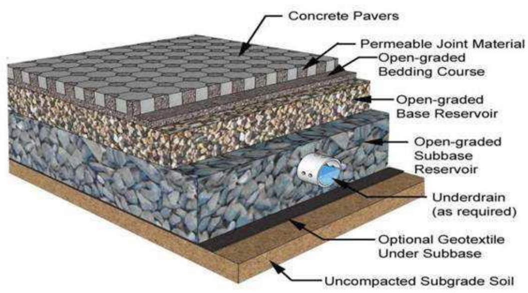

Fig.5. Porous pavements

A solution to the increase of impervious areas in urbanized areas is porous pavements. These include pavers, asphalt, concrete, or other kinds of porous materials letting water passing through. These pavements retain water in a subgrade where it can percolate into the groundwater, evaporate or drained away afterward. The general principle of porous pavements is to collect, treat, and infiltrate any surface runoff freely for groundwater recharge. Therefore, Porous has many potential benefits over traditional, impermeable pavements, including reduction of surface runoff, groundwater recharge, recycling of water, and prevention of pollution. Porous pavements have been seen as a technology for pollutant control concerning surface runoff from adjoining buildings, parking lots, driving lanes or roads where polluted water can contaminate the underlying soil. Another advantage of this SUDS techniques is that it needs no frequent maintenance.

- Rainwater Harvesting

Rainwater Harvesting (RWH) is presented as a sound strategy for SUDS. It offers several benefits such as being supplementary for water supply sources; reducing other direct discharge to the drainage system and preventing urban flooding.

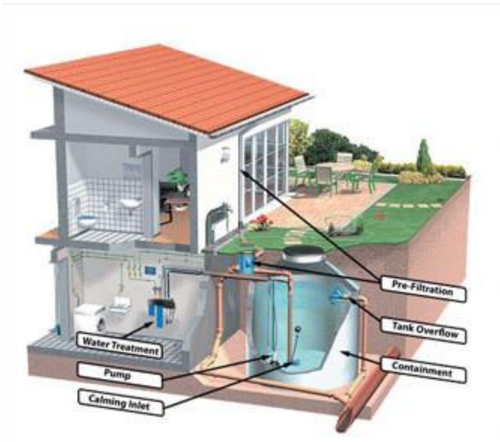

Fig.6. Rainwater harvesting

RWH can provide a supplemental water source in urbanized areas for secondary uses such as gardening, toilet flush, landscaping, etc. This amount of water can even serve as a significant water supply source in less-developed areas or places suffering from severe water scarcity. RWH has been recognized as a sound strategy to increase water supply capacity.

- Urban green space

Fig.7. Urban green space

The urban green space is an important source control strategy for sustainable stormwater management, provided that the soil is sufficiently previous and the quality of runoff does not pose any risks of contaminating groundwater identified these devices are an essential part of developing a sustainable system for urban drainage. Relatively common devices of this type are infiltration trenches and soakaways. These underground structures are filled with materials like gravels or highly porous plastic media which can act as temporary storage for collected water and at the same time infiltrate it into the surrounding soil. Soakaways may be equipped with an overflow pipe that diverts runoff to the sewer network or another SUDS device.

- Green roofs

Green roofs, due to its typical design consisting of layers of membranes and vegetation medium, are capable of capturing water falling on the rooftop area and therefore resulting in the attenuation of runoff to the pipe network. The benefits of turning the roofs green by covering them with soil, plants have numerous benefits [5].

Fig.8. Example of green roofs implemented

2.2.3 Evaluation

SUDS solutions, such as green roofs, rainwater harvesting, pervious pavements, urban green space, are applied at representative inundated sub-catchments. The evaluation will focus on peak runoff from modeling results.

3. Results

The study showed that green roofs are the best performer because it is applied to all kinds of buildings, either residential, commercial. Rainwater harvesting and pervious pavements require specific available space for application making their performance very unstable. More specifically, sub-catchment 3 is representative for an area with suitable conditions to apply rainwater harvesting and pervious pavements. The best performing of overall is green roofs followed by rainwater harvesting, pervious pavements, and urban green space. SUDS evaluation table is shown in Table 3.

Table 3 SUDS evaluation results

SUDS evaluation		Sub-catchment			Average
		1	2	3	
Normal	Peak runoff (m3/s)	25.17	9.45	7.54	14.05
Green roofs	Peak runoff reduction (m3/s)	20.10	48.25	12.86	27.07
R.W.H.	Peak runoff reduction (m3/s)	11.16	23.39	40.45	25.00
Space	Peak runoff reduction (m3/s)	3.26	12.91	2.65	6.27
Pervious	Peak runoff reduction (m3/s)	14.82	19.26	27.98	20.69

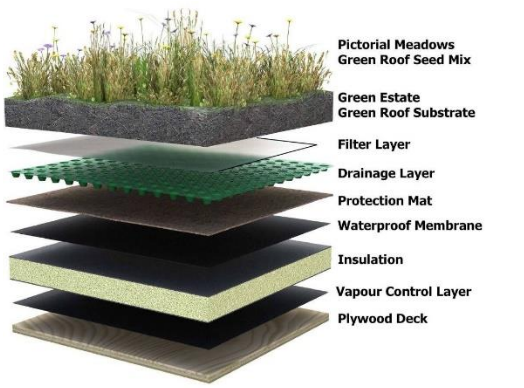

Fig.9. Example of green roofs structure

Green roofs, due to its typical design consisting of layers of membranes and vegetation medium, are capable of capturing water falling on the rooftop area and therefore resulting in the attenuation of runoff to the pipe network. The benefits of turning the roofs green by covering them with soil, plants have numerous benefits such as reducing runoff peaks and volumes, resulting in lower urban flood risks, achieving thermal benefits through the insulation of heat transfer, resulting in cost for air conditioning, heat island effect can also be reduced, reducing air pollution and providing wildlife habitat for birds, enhancing the environment for the area.

4. Conclusions

The results showed that green roofs have the most signification of reducing peak runoff at the study area. Green roofs are the best performer because it is applied to all kinds of buildings either residential, commercial. Rain barrels will be filled up quickly with massive storms, hence could not offer many improvements. The other two methods, urban green space, and pervious pavements require specific available space for application making their performance very unstable. On the other hand, represents areas with a high density of residential houses. The best player, in this case, is green roofs followed by rainwater harvesting, pervious pavements, and urban green space. Summarized percentage of peak runoff reduction is shown in Table 4 and Fig.10.

Table 4 Summarized percentage of peak runoff reduction.

Type of implements	Sub catchment 1	Sub catchment 2	Sub catchment 3	Average
Green roofs	20.10%	48.25%	12.86%	20.07%
Rainwater harvesting	11.16%	23.39%	40.45%	25.00%
Urban green space	3.26%	12.91%	2.65%	6.27%
Pervious pavement	14.82%	19.26%	27.98%	20.69%

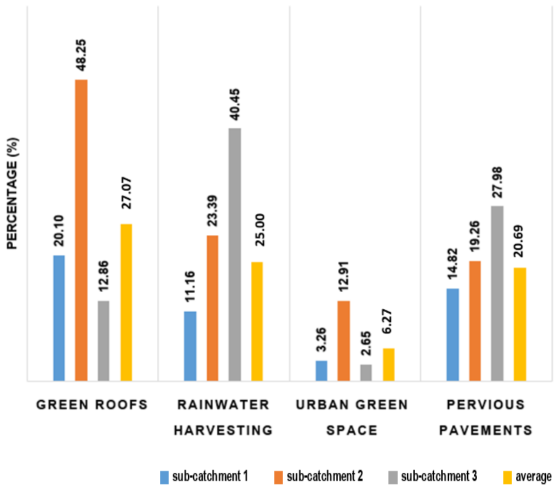

Fig.10. Peak runoff reduction capacity

5. Acknowledgments

This study was conducted as a part of APN project. Sincere thanks are extended to the advisors and faculties of AIT. Also, I would like extend my gratitude to Bangkok metropolitan administration (BMA) for providing data for the study.

6. References

[1] Bangkok.go.th, 2019. [Online]. Available: http://www.bangkok.go.th/upload/user/00000130/Logo/statistic/stat%202016%20eng%20(2).pdf. [Accessed: 27- Dec- 2018].

[2] J. Leitão, S. Boonya-aroonnet, D. Prodanović and Č. Maksimović, "The influence of digital elevation model resolution on overland flow networks for modelling urban pluvial flooding", Water Science and Technology, vol. 60, no. 12, pp. 3137-3149, 2009. Available: 10.2166/wst.2009.754.

[3] N. Thanvisitthpon, S. Shrestha and I. Pal, "Urban Flooding and Climate Change", Environment and Urbanization ASIA, vol. 9, no. 1, pp. 86-100, 2018. Available: 10.1177/0975425317748532.

[4] L. Rossman, "Modeling Low Impact Development Alternatives with SWMM", Journal of Water Management Modeling, 2010. Available: 10.14796/jwmm.r236-11.

[5] J. Czemiel Berndtsson, "Green roof performance towards management of runoff water quantity and quality: A review", Ecological Engineering, vol. 36, no. 4, pp. 351-360, 2010. Available: 10.1016/j.ecoleng.2009.12.014.