Review on Green Infrastructure Approach in Urban Flood Management and Its Possible Application in Binh Duong Province

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Abstract. The Green Infrastructure (GI) is a concept that incorporates vegetation, natural processes, and land-use into the built environment and it has been regarded as an effective intervention for storm-water runoff minimization in urban flood management. In the context of increasing flood in many cities of Vietnam, the paper has carried out an overall review on GI, its advantages and constraints in urban flood management, and then tried to identify the possibilities for applying in Binh Duong's urban areas.

The literature review shows that GI can offer a multifunctional approach such as reducing storm-water runoff, improving water quality, mitigating the impacts of climate change, and maintaining healthy and sustainable communities. However, the practical utilization of GI in urban flood management is still overwhelmed by the traditional grey infrastructure such as roads, drainage pipe networks, and sewerage treatment or water treatment systems, etc. which generally offer low sustainability as shown in the literature. The main reasons are the uncertainties of GI hydrological performance, service delivery and lack of appropriated decision-making supports for its multiple-benefit assessment. From that, certain possibilities for applying GI in Binh Duong province are proposed through the review of the current situation on policy, authorities and communities awareness and the natural conditional of Binh Duong. There is also a need for further studies on the technical deployment of the GI solutions through experiments as well as the methods and tools for its performance assessment in comparison with the traditional grey solutions.

Keywords: Green infrastructure; urban flood management; runoff-water; sustainable development; Binh Duong.

1 Introduction

Urban flooding is known as the overwhelm of drainage systems because of the capacity of the system is much lower than the peak discharge of surface flow, especially during heavy rain. It causes a serious challenge to cities' development and the living of urban inhabitants, particularly residents of rapidly expanding towns and cities in developing countries (Stevens et al., 2012, Eldho et al., 2018). Although this type of flood happens more frequently and becomes more localized, its characteristics have not been well understood. In fact, the flood flows in the urban environment have just been recently focused despite many centuries of flood events (Crowe et al., 2019; C.Luu et al., 2019).

Binh Duong province is located in the Southeast of Vietnam which counts for top 3rd urbanization speed of the country, the urban flooding problem in its town is not an exception. As a result, the urban flooding has been raised significantly, especially in the lower topography areas and adjacent zones with a high population such as Thu Dau Mot city, Thuan An and Di An town. Although many traditional drainage projects have been deploying last years, the frequency and consequence of urban floods seem not to be relieved.

The green infrastructure concept views natural areas as another form of infrastructure needed for both ecological health and quality of life that people have come to expect. The benefits of green infrastructure have been reported in numerous publications including deliver a wide range of ecosystem services and protect biodiversity (European Commission, 2013); improve water quality and manage water quantity by restoring the hydrologic function of the urban landscape (Lovell et al., 2013; Robert, 2018). Therefore, this paper aims to review and systemize the properties of the green infrastructure which could be utilized for urban flooding management and then propose certain possibilities for application in Binh Duong province as a sustainable solution.

The paper mostly uses a secondary documentary research method in which different literature documents are reviewed, summarized, and synthesized based on the authors' knowledge. On-site observation and photo-taking are also employed to get a deeper understanding on the context of Binh Duong province and its towns, especially the urban flooding problem. Within the scope of this paper, the proposals for green infrastructure development in Binh Duong will be proposed for provincial level, flooding areas at city level, as well as project-scale possibilities of application.

2 Green Infrastructure in Urban Flooding Management

The traditional drainage systems (called “grey infrastructure”) are recently proved to exacerbate pollutant inputs and hydrologic disturbance, resulting in localized floods, degradation of ecosystem structure and function because they route the runoff directly to streams and rivers (Vojinovic, 2015). Therefore, the requirement for a solution of post-development stormwater discharge peaks not to exceed pre-development peaks is extremely urgent (Gupta, 2016). Recently, the sustainable stormwater management system which utilized green infrastructure concept is formulated on the design for the characteristics of predevelopment flow regimes in addition to reducing pollutants and their loadings have been widely studied (Hamel and Fletcher, 2013). Some sustainable concepts are in many different countries such as water sensitive urban design (WSUD) in Australia, the “Sponge City” initiative in China, sustainable urban drainage systems (SuDS) in the UK and low impact development (LID) in the USA. Dhakal and Chevalier (2017) referred to such approaches alternatively as green infrastructure (GI). These green approaches have been proved that could offer more sustainable management solution for the cities runoff flow (Allen, 2013; Alves et al., 2018).

Besides, green stormwater management projects can have multiple uses. Not only do they act as stormwater storage areas, water conveyance areas, and runoff filters, but they also provide a number of co-benefits. These co-benefits are included environmental and socio-economic aspects such as reduction of energy and water consumption, biodiversity enhancement and health benefits, among many others (Roy et al., 2008; Ciria, 2013; Arup, 2014; Vojinovic, 2015; Feng et al., 2016; Jegatheesan, 2019). Although the economic benefits are still debated as part of the policy discourse, there is growing evidence in economic and ecosystem valuation studies with consensus that investments in green infrastructure provide a good return on investments and multiple, far-reaching benefits such as health and climate change benefits (Winz et al., 2014; E. C. O’Donnell el at., 2017; Robert, 2018; Carolyn, 2019). The following Table 1 gives a summary of the co-benefits of green infrastructure.

There is a range of sustainable and green flexible drainage techniques that alter the focus of drainage design, practice, construction, and maintenance to

facilitate a higher consideration for society in general and the receiving environment. (CIRIA, 2016). The designs for these concepts include pond, infiltrate, and harvest water at the source, encouraging evaporation, evapotranspiration, groundwater recharge and re-use of stormwater. Table 2 provides an overview of the most popular green infrastructure components applied for sustainable drainage systems.

Table 1. The co-benefits of green infrastructure.

Environmental benefit	Economic benefits	Social benefits
Improved visual amenity	Increased property prices	Encouraging physical activity
Enhance urban microclimate	Increased land values	Improving childhood development
Improve air quality	Faster property sales	Improved mental health
Reduced flood risk	Encouraging inward investment	Faster hospital recovery rates
Better water quality	Reducing energy costs via microclimate regulation	Improved workplace productivity
Improved biodiversity	Improved chances of gaining planning permission	Increasing social cohesion
Reduces ambient noise	Improved tourism and recreation facilities	Reduction in crime
Reducing atmospheric CO_2	Lower healthcare costs	

(Source: Crowe L. and Rotherham I.D., 2019).

Table 2. The common green infrastructure types applied for urban flooding mitigation purpose.

Green infrastructure type	Description	Flood risk reduction (*)
Pervious surfaces	Surface that allows inflow of rainwater into the underlying construction or soil	M
Green roofs	Vegetated roofs that reduce the volume and rate of runoff and remove pollution	M
Filter drains	Linear drains consisting of trenches filled, permeable material	H
Filter strips	Vegetated areas of sloping ground designed to drain water	H
Swales	Shallow vegetated channels that conduct and retain water	M
Basins, pond, and wetland	Areas that may be utilized for surface runoff storage	H
Infiltration devices	Sub-surface structures to promote the infiltration of surface water to the ground. They can be trenches, basin or soakaways.	H
Bio-retention	Vegetated areas designed to collect and treat water before discharge via a piped system or infiltration to the ground.	H

Note: (*) H – High; M – Medium (scores towards contributing to ecosystem service function reducing flood risk according to the NWRM benefit tables, available at: nwrm.eu/catalogue-nwrm/benefit-tables). (Source: CIRIA SuDS Manual, 2015; Ferreira et al.,2017)

3 Green Infrastructure in Practice

3.1 Successful green infrastructure projects

There is a trend in many cities around the world where green infrastructures have been developed alongside measures to improve their flooding management and climate resilience (Arup, 2014). For example, the Spangen district at Rotterdam, Netherlands has almost no open water and a high proportion of paved surfaces within a dense urban environment. In order to build resilience to climate change, a series of attractive well-vegetated water squares have been proposed in the district. The central area of each square has been lowered and paved to act as a buffer for rainwater, allowing runoff to occasionally fill the central area to reduce the impact of rainfall and storm events on the city infrastructure. A parking garage beneath Museumplein Square was created with 10,000 cubic meters of underground storage. This initiative alone provides 12% of the water storage capacity required for the city center (Pötz and Bleuzé, 2012).

Another example for successful green infrastructure application in urban flooding management is Chulalongkorn University Centenary Park in Thailand which covers an area of 44,415 square meters city land and an estimated worth of $700 million USD in 2017. In addition to reducing the urban heat island for such a crowded area of Bangkok, this park plays an important function for the flood-prone area as it collects and cleans water. Essentially, this flood-proof park can hold nearly one million gallons of water during severe floods (WLA, 2019). According to Le, To Quyen et al. (2019), “flood-resilient urban parks” are the projects which could provide a range of environmental, social, cultural, education and economic functions while integrating flood adaptation infrastructural strategies. The researchers mentioned the sixteen successful projects located in coastal cities and urban areas that regularly experience flash floods, heavy rain, tidal floods and storm surges and that have a rich flood control experience in Asian, European and North American countries.

In Vietnam, the World Bank Group intends to finance the assignment that aims to provide capacity building support and technical assistance to seven participating cities in the Mekong Delta under World Bank Scaling up Urban Upgrading Project to incorporate green infrastructure principles to urban

planning and infrastructure design (World Bank, 2018). Besides, Can Tho province is planning to build its first green infrastructure park which will cover over 0.5ha of land in An Khanh ward of Ninh Kieu district (VNA, 2019).

3.2 Factors that influence green infrastructure project implementation

Although recently the science and engineering related to green infrastructure have evolved significantly, the application of green infrastructure is still facing many challenges. Practically, the commons factors that influence the implementation of green infrastructure include education, provision of ecosystem services, financial incentives, coordination among actors, laws and policies, and planning recommendations. Meanwhile, related researches on the application of green infrastructure into stormwater management and flooding mitigation projects identified the implementation challenges such as uncertainties in performance and cost (Roy et al., 2008); lacking of institutional capacity, legislative mandates and funding (Roy et al., 2008; Carolyn, 2019); dominance of technical engineering knowledge (Carolyn, 2019); lacking of the cross-collaborative authority agreements (Arup, 2014); resistance to change in the public, private and community sectors (Roy et al., 2008; Winz et al., 2014); absence of the effective conceptual models to guide the implementation (Le, To Quyen et al., 2019), and so on. In addition, Winz et al. (2014) have also highlighted the significant overall effect of the interaction between the barriers.

In summary, the important factors that influence the adoption of green infrastructure for flooding management could be grouped into the following four majors groups: (1) Economic and financial factors; (2) Regulation, policies and institutional factors; (3) Technological and physical factors; and (4) Awareness and education. Table 3 illustrates those common groups.

Table 3. Group of factor(s) as barriers to the implementation of green infrastructure (GI) in urban flooding management.

Group(s)	Type
(1) Economic and financial factors	High land values and high transaction cost
	Difficulty in quantifying the co-benefits which GI brings
	Long-time horizons perceived higher risk
	Initial high costs, undefined financial Responsibilities
	Low priority for GI projects compared to other infrastructure projects

	Lack of financial resources
(2) Regulation, policies and institutional factors	Insufficient policy coherence
	Complications associated with property rights
	Lack of a clear regulatory framework
	Lock-in of traditional practices and lack of resources
	Lack of integration of green infrastructure in local rules and regulations
	Lack of long-term planning
(3) Technological and physical factors	Unfamiliarity with GI, little trust in the science and technology behind it
	Limited or no maintenance experience of GI
	Lack of understanding of how GI is relevant to local stormwater issues
	Lack of physical space for GI projects
(4) Awareness and education	Insufficient and inaccessible information about green infrastructure and its benefits for political leaders, administrators, agency staff, developers, builders, landscapers, and others, including the public
	Resistance by developers to integrate and use green infrastructure
	Shortage of trained Professionals

(Source: US. EPA, 2016; Robert, 2018).

4 Flooding in Binh Duong Province and Green Infrastructure

4.1 Rapid urbanization and flooding problem in Binh Duong

Binh Duong province is located in the Southeast region of Vietnam, immediately to the north of Ho Chi Minh City. It is crossed by Saigon, Dong Nai and Be rivers. Across the province, there are different topographic regions including low mountainous terrain with slight undulation, flat plains, and alluvial valley. The location map of Binh Duong province is illustrated in Figure 1.

Fig. 1. Location of Binh Duong province (Source: https://en.wikipedia.org)

According to Binh Duong's Department of Construction, the rapid urbanization leads to a considered reduction of natural permeability areas that make both quantity and velocity of surface flows become significantly higher than usual during heavy rainfall and lead the capacity of the existing drainage systems to overload. The failure of the drainage systems leading to local inundation of low-lying areas during heavy rain or high tide is the main causes of urban flooding in the province. Besides, low maintenance services and low awareness in environmental protection for the drainage systems also cause for blocking the pipelines, culvert systems make the system capacity reduction, especially in the crowded areas such as Thu Dau Mot City, Thuan An town, Di An Town. Furthermore, the allocated funds for drainage systems investment are not appropriated with the urbanization speed, the funding resources are unstable and usually much lower than the setting up of new urban areas and development projects.

In addition, the drainage in most of the new roads or traffic built-up is usually designed for draining water from the road surface only, while the surface water from the surrounding areas is underestimated. Therefore, during heavy rainfall, these drainage systems have also overwhelmed by the runoff from surrounding areas which cannot be drained in time leading to floods. (Phuong Le, 2016). The Fig.2 below shows the current flooding situation in Binh Duong urban areas.

(a) 0.5 – 0.8m depth flood in An Phu ward, Thuan An town
(Source: Hung Phuoc (2018), www.bao-binhduong.vn)

(b) Nguyen Van Tiet Str. in Thuan An town, flooded in every heavy rain
(Source: Cao Cuong (2016), www.bao-xaydung.com.vn)

(c) Flood in Thu Dau Mot Central Market by heavy rain and high tide event
(Source: Duong Chi Tuong (2018), www.vietnamplus.vn)

(d) The fulfill drainage canal at central Thu Dau Mot City (8 hours after heavy rain)
(Source: Taken by author, 2019)

Fig. 2. Flooding situation in Binh Duong urban areas

4.2 Opportunities for green infrastructure solution in urban flooding mitigation in Binh Duong province

As determined by Binh Duong province in its development mission, the Party, government, and people in the province are on the way to make Binh Duong a green - clean - beautiful city worth living in. In the context of rapid urbanization where land funds for urban infrastructure development of Binh Duong are more in need, factories and processing establishments located in the residential areas in the province are directed to move to industrial zones. According to Binh Duong's Department of Construction, 30 parks and flower gardens covering a total area of 18,000 square meters have been built in Thu Dau Mot City during 2015-2017 period by the decision of local authorities in order to utilize more areas for new parks and public gardens to improve the quality of life of the local communities.

Besides, many projects on enhancing drainage system capacity in the province have been developing such as Chom Sao – Suoi Don new drainage system in Thuan An town, Bung Biep – Suoi Cat new drainage system for Thu Dau Mot

city and Thuan An town catchment (Fig.3 and Fig.4), KT3 drainage channel project and numbers of dredging and clearing flows for canals. These are the results of positive changes in the awareness, responsibility, and actions on environmental protection of the political system, the business community, and the residents.

Therefore, the green infrastructure should be one of the best alternatives for Binh Duong province in future urban flooding management. Along with the province's development mission, the green solutions will be strongly supported by the authorities and the decision-makers of Binh Duong province if the cost and benefits of the projects are clearly defined.

Fig. 3. New projects for urban flooding management in Binh Duong Province. (Source: https://www.google.com/maps, 2019)

(a) An under-construction part of Bung Bip – Suoi Cat Drainage Project. (Taken by author, 2019)

(b) A completed part of Chom Sao – Suoi Don Project (Source: Phuong Le, 2017)

Fig. 4. Picture of the under-construction urban flooding management projects in Binh Duong Province

4.3 What should be the solutions for Binh Duong

Although the application of green solutions for urban flooding management is known as one of the best alternatives at the present and Binh Duong province has a number of advantages for applying these solutions, their practical implementation in the other cities in the world has shown that the slow uptake of green infrastructure solutions into the urban flooding control is due to a number of constraints and barriers compared with other technical solutions. (Schanze, J., 2017; Meyer C., 2018). Therefore, it is important for Binh Duong authorities to pay an appropriated consideration and provide research funding for the green infrastructure application. This section will introduce the very first steps for green infrastructure deployment in Binh Duong in terms of urban flooding management purpose.

Urban Green Infrastructure Plan for the provincial level

Development of an Urban Green Infrastructure Plan for the provincial scale should be the first step for the implementation of green infrastructure in urban flooding management. This plan will act as a strategic approach for addressing the broad range of challenges in Binh Duong urban areas in addition to the flooding problem such as conserving biodiversity, adapting to climate change, supporting the green economy, and improving social cohesion (Hansen et al., 2017). Besides, an effective plan should be a basis for dealing with different factors and barriers that influence the adoption of green infrastructure for flooding management as summarized in Table 3 above.

In terms of flooding management, the plan should clearly define the current problems related to the existing stormwater systems which are risks to residential health and socio-economic activities of the province. The Urban Green Infrastructure Plan of Binh Duong Province, therefore, should be based on four principles as follows:

- Green and grey integration: combining green and grey infrastructures;
- Connectivity: creating green space networks;
- Multifunctionality: delivering and enhancing multiple functions and services;
- Social inclusion: collaborative and participatory planning.

Sustainable Urban Stormwater Management Plan for the sensitive areas

In Binh Duong city, the high-density population areas such as Thu Dau Mot city, Thuan An, Di An, and Ben Cat towns are strongly affected by the urban flooding problem. These towns, therefore, should develop their own Sustainable Urban Stormwater Management Plan with the goal of incorporating existing community objectives such as runoff volume reduction, increasing infiltration and rainwater harvesting, flooding reduction, and social amenities for health or wellbeing of the community (EPA, 2016). This plan should be an important component of the provincial Urban Green Infrastructure Plan. Effective local planning should be clearly assessed in accordance with their current status including:

- Illustrate the existing stormwater systems and consider how current system performance may be impacted by changes in the local climate;
- Propose the sensitive areas and environmental justice concerns;
- Evaluate the implementation of the approach for communities with green infrastructure requirements in their permits or an enforcement order.

Opportunities for green and grey integrating at project scale

Until 2017, thirty new green parks and flower gardens with the area of 100 – 300 square meters per each have been renovated or newly built in Thu Dau Mot City. The number of these parks are reported to be sixty-six until the end of 2019 that increases the city's total green area up to more than 50,000 square meters. This is the result of Thu Dau Mot city's green space enhancement project (Tri Dung, 2018). Besides, there is a newly developed green park with total area of 75 hectares located in Binh Duong New City, which is just about ten kilometers from the central area of Thu Dau Mot City (Fig.5).

In practice, these parks only provide the single function as public and green space for recreation. While, by conducting green and grey infrastructure integration, they can be modified to "flood-resilient urban parks" which both function as water infrastructure and public space (Le, To Quyen et al., 2019). A successful green and grey integration can make the parks more functioned such as catching, collecting water, and storing water before it flows to stormwater runoff. Besides, the stored water from the parks can also be filtered and

purified by native vegetation, then used for irrigation and other purposes. As a result, the discharged water quality could also be improved.

Fig. 5. The 75 hectares park located in Binh Duong New City (Source: Ba Son – Xuan An, tuoi-tre.vn, 2018)

Besides, there are numbers of residential or industrial investment projects which are located in the city where land is very limited and thus, the utilized land for green space of each project site is extremely low. Especially, as many projects are located in the central areas where the land value is extremely high such as Thu Dau Mot City, Di An town and Thuan An town, the use and design of land for only green space could lead to low effective land-use. Therefore, integrating green and grey infrastructure concept could be the optimal solution for these cases. The integration could be conducted at the small-scale projects such as renovating the concreted surface with permeable materials, installing the stormwater planters along the road to absorb stormwater and prevent sewer backups and overflows water enhance the absorbance, renovating the grassland of the public buildings into bio-swale, rain garden, etc. The Fig.6 below illustrates the common integrating of green infrastructure into the urban's drainage system.

An effective integration could help the projects to increase the benefits of green space and permeable area as well as improve the infiltration capacity or water retention of the design. The project's green and grey integrating plan could also be a useful quantitative document to illustrate the actual co-benefits of the project design as an advantage for the decision-makers to consider in the project appraisal process.

(a) Alley renovated with permeable paving located in Chicago, Illinois (Source: US EPA - Document No. EPA-833-F-08-009)

(b) Stormwater planters designed to absorb stormwater and prevent sewer backups and overflows (Source: obp.org; pinterest.com)

(c) Glencoe Elementary School Rain Garden in Portland, USA (Source: Portlandonline.com)

(d) A parking lot with permeable concrete floor and bio-swale for stormwater collection (Source: flickr.com)

Fig. 6. The illustration of green infrastructure integrating with the urban drainage system.

5 Conclusions

By reviewing the previous researches and studies, the paper has summarized the four groups of factors or barriers to the implementation of green infrastructure in urban flooding management. These should be considered during the green project deployment that Binh Duong province can apply for the start-up of green infrastructure concept in urban flooding mitigation. Based on Binh Duong's advantages for the application of green infrastructure, the proposed solutions the province are selected and summarized by reference from the guidelines and publication of European Union (EU) project entitled "GREEN SURGE" and the publication of United States Environmental Pro-

tection Agency (US EPA) on green infrastructure application and implementation. In more specific, an Urban Green Infrastructure Plan for the province and Sustainable Urban Stormwater Management Plan for the sensitive areas should be developed as a robust base green infrastructure application in Binh Duong in terms of urban flooding risk mitigation and climate change adaptation. Besides, development of a guideline on planning and implementation for integrating of green and grey infrastructure at project scale could be the optimal and urgent action for the case of Thu Dau Mot City, which can also be used for other cities of the province. The pilot-scale studies should be conducted as the lesson learnt for the guideline application.

The proposed solutions in this study are a very first step for green infrastructure application in Binh Duong by raising awareness of the local authorities on the approach. It is necessary to have further detailed researches on the green infrastructure application in different aspects, such as an up-to-date risk assessment research on urban flooding in Binh Duong's flooding hot-pot, research on most appropriated green infrastructure types for each urban area of the province based hydrological characteristics, study to define the suitable locations for green infrastructure and the priorities of each location across Binh Duong province, and so on. Besides, the knowledge and perception of the authorities and local communities on green infrastructure for stormwater management are also important to be studied. The more specific green infrastructure projects then may be proposed for actual implementation.

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