DEVELOPING FLOOD RESILIENT TRANSPORT SYSTEMS IN COASTAL CITIES:

A CASE STUDY OF HO CHI MINH CITY, VIETNAM

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RESEARCH ABSTRACT

Flooding has emerged as an increasing problem in many cities across the world. Investigations of recent flood incidents have proved that climate volatility is likely to exceed present day conditions, meaning that existing protection systems are not likely to be suitable for dealing with extreme events. The problem is particularly acute in Southeast Asia. Here, flood vulnerability is often exacerbated by inappropriate planning for urban expansion, associated with transportation development. This has so far proved to be a significant challenge for governments seeking long-term strategies related to urban resilience.

Ho Chi Minh City (HCMC), an emerging-coastal in Vietnam, is facing frequent flood events as a result of rapid development. This research uses HCMC as a case study to show how resilience theory, along with key experiences from other coastal cities such as New Orleans, Manila and Bangkok, can be used to explore:

i) The evidence of increasing flood vulnerability in HCMC as the consequence of rapid urbanisation in new development districts situated on flood plains.

ii) The challenges and opportunities for emerging coastal cities to integrate flood resilience into urban planning in order to reduce flood vulnerability.

iii) The application of resilience theory to transportation to conceptualise a model of a Flood Resilient Transport System (FRTS) applicable to HCMC.

iv) A number of potential adjustments to the current plans for transportation development, also referred to as the transport component in the general plan for HCMC.

Overall, the implications of this research, including the combined method approach to flood simulation and GIS analysis, have the potential for application not only in HCMC, but also referenced in other emerging coastal cities, especially in Southeast Asia, to mitigate flood impacts.

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PUBLICATIONS ARISING FROM THIS THESIS

International publications:

1. Duy P. N., Chapman L., Tight M., Thuong L. V., and Linh P. N. (2017a). **Increasing Vulnerability to Floods in New Development Areas: Evidence from Ho Chi Minh City.** International Journal of Climate Change Strategies and Management, Vol. 10 (1), pp.197-212. Emerald. DOI: 10.1108/IJCCSM-12-2016-0169
2. Duy P. N., Chapman L., Tight M., Thuong L. V., and Linh P. N. (2017b). **Urban Resilience to Floods in Coastal Cities: Challenges and Opportunities for Ho Chi Minh City and other Emerging Cities in Southeast Asia.** Journal of Urban Planning and Development, Vol. 44 (01), ASCE. DOI: 10.1061/%28ASCE%29UP.1943-5444.0000419
3. Duy P. N., Chapman L., Tight M. (2019). **Resilient Transport System to Reduce Urban Vulnerability to Floods: A Case Study of Ho Chi Minh City, Vietnam.** Travel Behavior and Society, Vol 15 (2019), pp. 28 – 43. Elsevier. DOI: 10.1016/j.tbs.2018.11.001

Given the nature of the research, significant additional contributions have also been made at a national level in Vietnam:

4. Duy P. N. (2013). **The integrated underground works planning method in the urban master plan to reduce damage by climate change** (in Vietnamese)**.** Construction planning (of Vietnam), Vol. 63-2013 (pp. 67 – 69). Vietnam Institute for Urban and Rural Planning (VIUP) - Ministry of Construction.
5. Duy P. N. (2015). **Urban resilience: from devastations to lessons for urban spatial planning and management to mitigate flood impacts in HCMC** (in Vietnamese). Urban planning, Vol. 22-2015. Urban planning (of Vietnam). The association of urban development planning – Vietnam.
6. Duy P. N. and Tri L. D. (2015). **Management of urban spatial development in response to climate change by applying GIS in Ho Chi Minh City**. Conference proceedings of Management of Planning and Architecture for Ho Chi Minh City, 2015, pp. 335 – 344.

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ADB	Asia Development Bank
ASL	Above Sea Level
CRED	Centre for Research on the Epidemiology of Disasters
DEM	Digital Elevation Model
DFT	Department for Transport (of the UK)
DSM	Digital Surface Model
DTM	Digital Terrain Model
FRTS	Flood Resilient Transport System
GIS	Geographic Information System
GSOV	General Statistic Office of Vietnam
HCMC	Ho Chi Minh City
HMGA	Hydrological Modelling and GIS Analysis
IPCC	International Panel on Climate Change
LECZ	Low-Elevation Coastal Zone
MNRE	Ministry of Natural Resources and Environment (of Vietnam)
RHCM	Region of Ho Chi Minh City
SAC	Southeast Asia Countries
SCFC	Steering Centre of the Urban Flood Control Programme (in Ho Chi Minh City)
SLR	Sea Level Rise
SRHC	Southern Regional Hydro Meteorological Centre
UFR	Urban Resilience to Flood
UN	United Nations
WB	World Bank

Chapter 1

INTRODUCTION

Urban floods have emerged as an increasing climate hazard in many countries, particularly prevalent in Southeast Asia, in which many cities are faced with a worsening flood situation but still have opportunities for improvement in flood resilience. This can be seen acutely in Ho Chi Minh City (HCMC), an emerging coastal city in Vietnam, a Southeast Asian Country (SAC), which has experienced significant increases in the concentration of both people and assets located in new developments on land historically susceptible to flooding. Unless an appropriate planning for flood management can be found, the city is now at risk of extreme flooding incidents in the future due in part to both climate change and uncontrolled urbanisation. Urban flood resilience is of increasing importance for cities, in which transport systems play an important role in maintaining urban activities during adversity. Thus this chapter introduces the general rationale for the development of a Flood Resilience Transport System (FRTS) in HCMC.

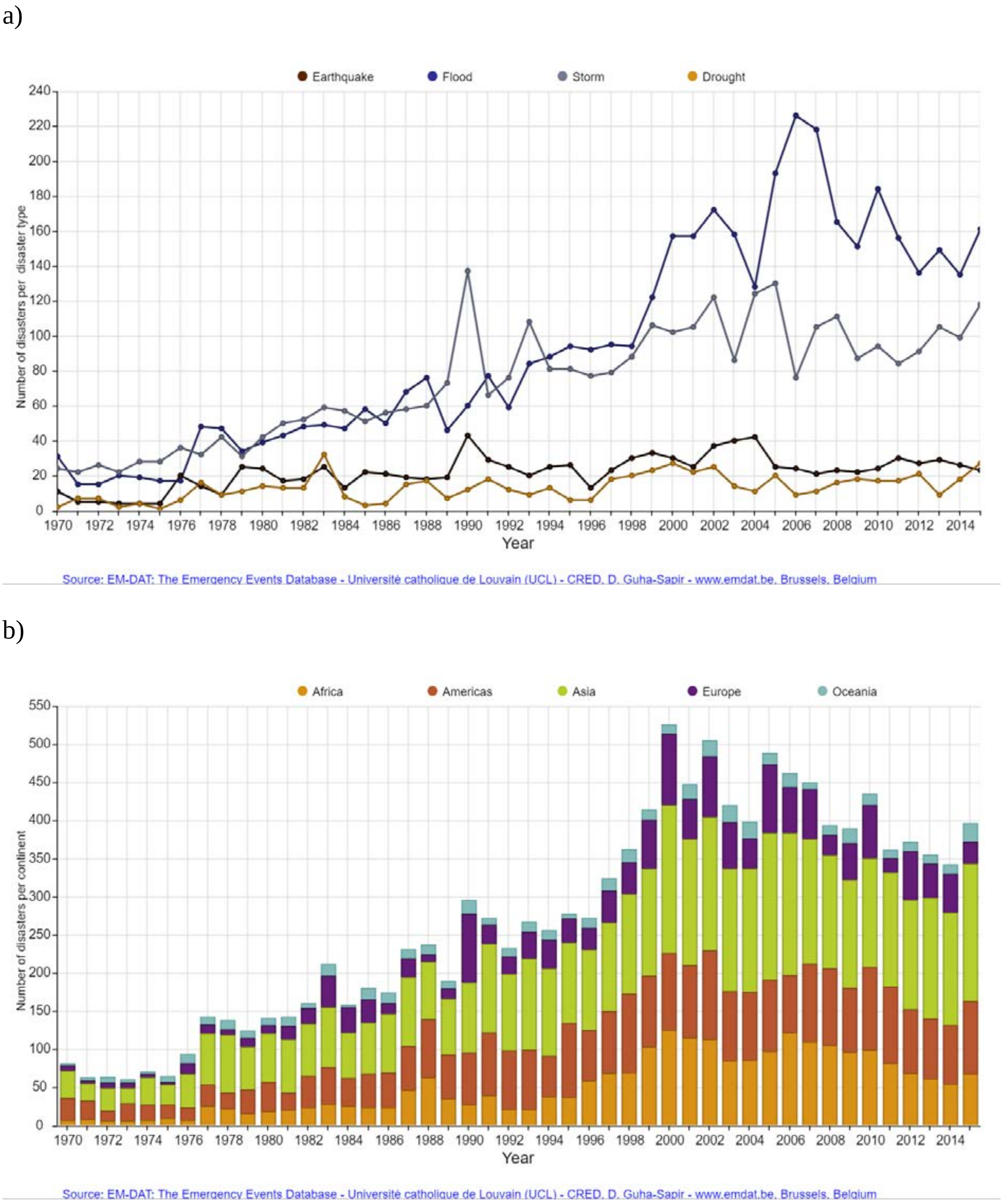
1.1. The rationale for flooding

1.1.1. The rise in flood hazards

Flood incidents result in a disproportionate amount of losses and damages across the world. In a global review of significant events from 1980 to 2009, Doocy et al. (2013) attribute flooding to have been the direct cause of 539,811 deaths, whilst affecting a further 2.8 billion people. They have been reported to be the most prevalent natural disaster, defined as “a situation or event that overwhelms local capacity, necessitating a request at the national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering” (Guha-Sapir, 2016, p. 13). Indeed, flood events have occurred frequently in the period since 2000, in comparison with other types of disasters

(*Figure 1.1a*). The annual economic losses from floods are predicted to increase from US$ 6 billion in 2005 to US$ 52 billion by 2050 (Nicholls, 2011), with the growing threat of climate change as a key factor in these predictions (i.e. Sea Level Rise (SLR), intensification of tropical cyclones with heavy rains or storm surges: Nicholls et al., 2014). “Against the backdrop of demographic growth, urbanization trends and climate change, the causes of floods are shifting and their impacts are accelerating” (Lamond et al., 2012, p. 16). Given the nature of the changes, these impacts will be realised most acutely in coastal cities (Gornitz, 1990; Nicholls, 2011), with numerous recent residences affected e.g. Hurricane Harvey impacting Houston, Texas, and Irma, which affected several coastal areas along the coast of the American continent in 2017.

The term ‘coastal city’ is used to define an urban area where settlement has occurred on the low elevation coastal zone (LECZ). The LECZ normally refers to land that is less than 10 metres above sea level (Vafeidis et al., 2011; IPPC, 2014). According to the Population Division of the UN (1993, cited in Nicholls, 1995), there has been a remarkable increase in the number of coastal mega-cities which have the potential to be impacted by a rise in sea-levels, from 13 in 1990 to 20 in 2010. This feeds into a general trend of global cities becoming more vulnerable to disasters, including extreme floods, due to spatial development in relation to sprawling sub-urbanisation into areas prone to environmental hazards (National Research Council, 2006), creating spatial redistribution of the population into vulnerable areas (Chang et al., 2012). In comparison with other parts of the world, floods appear to be occurring with a disproportionately increasing frequency across Asia (*Figure 1.1b*), with Dutta (2011) amongst the first to highlight the problem, after reviewing natural disasters over a 27 year period. Indeed, the scale of the issue on the continent can be vast; for example, it was reported that “deadly South Asia floods affect 16m people”, impacting on several countries such as Nepal, Bangladesh and India in 2017 (BBC, 2017). Additionally, research by Hanson et al. (2011) shows that the majority of the top 20 cities with a population exposed to climate change impacts are located in Asia (*Figure 1.2*).



Source: EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium

Source: EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium

Figure 1. 1 Flood occurrence and distribution:

a) The increasing occurrence of flood related natural disasters in comparison to others (e.g. earthquake, storm, and drought) particularly since the 2000s;

b) Flood distribution across the different continents showing a significant increase in Asia

1.1.2. Increasing flood vulnerability in emerging coastal cities

Flooding, which has become a threat to urban transportation, is classified into different common types, such as fluvial (river) flooding, caused by the water levels of rivers overflowing embankments; and pluvial flooding (or surface water), caused by an excess of down-pour water on “hard dry ground or paved areas” (DfT, 2014, p. 27). Alongside this, flood vulnerability is a term which can be used to describe the human impact of flood hazards and can thus be considered as the potential extent of flood effect, either now or in the future. As such, coastal cities are being increasingly considered to be more vulnerable to flooding, due to a combination of climate change and rapid urbanisation.

As the world’s growing population is particularly concentrated in urban areas, emerging coastal cities have inherently become more vulnerable. Low-lying land in coastal areas only accounts for two percent of the world’s land, but now houses 13% of the global urban population (McGranahan et al., 2007). Along with the general trend of 75% of the global population expected to be living in urban areas by 2050 (UN Habitat, 2005), the pressure of rapid development in coastal zones is resulting in larger (or new) settlements facing flood hazards. Hoozemans et al. (1993) estimated that around 46 million people could be at risk of storm surges every year. Furthermore, economic drivers which encourage counter-intuitive behaviours (e.g. a desire to live close to water increasing property prices) has meant rapid urbanisation is resulting in a concentration of people and assets in areas prone to floods - particularly in built-up areas along major bodies of water (Zevenbergen et al., 2008). Indeed, uncontrolled urbanisation is now common on low lying wetlands, forests, floodplains and mangroves adjacent to urban areas (and often located in coastal areas) which for centuries have provided a natural defence to flooding (UN, 2013). For example, in a study of 76 developing countries, Dasgupta et al. (2012) highlight the gradual loss of coastal wetlands through human actions resulting from urban expansion.

This development trend is particularly acute in the emerging coastal cities of developing countries in Southeast Asia. Low income countries are considered particularly vulnerable, because they have limited finances to aid preparation for such adversities (UN, 2013). “Urban flooding poses a serious challenge to development and the lives of people, particularly the residents of the rapidly expanding towns and cities in developing countries” (Lamond et al., 2012, p. 17). In a synthesis report entitled *Climate Risks and Adaptation in Asian Coastal Megacities*, the World Bank (2010) noted Bangkok, Manila and HCMC as the three vulnerable ‘hotspots’ facing climate change in the region. Manila and Bangkok have already experienced significant flood incidents (e.g. in 2009 and 2011 respectively). In comparison, flood events in HCMC have to date been on a small scale, but this provides an opportunity for mitigation actions in the city before an extreme event occurs. This city is considered one of the three coastal cities in this region vulnerable to climate change effects, such as rising sea levels (WB, 2010; ADB, 2010), and also one of top 20 cities having population exposed to the impacts. The concern is that HCMC could experience an extreme flood like that seen in Bangkok 2011, as it lacks appropriate long-term plans for urban development (Phi, 2013).

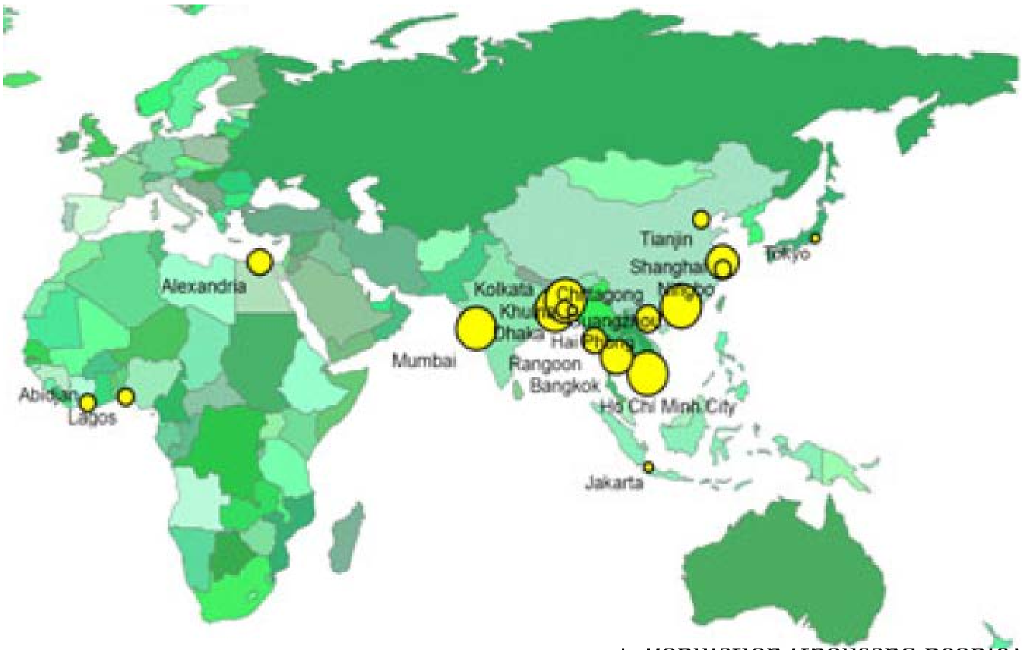


Figure 1. 2 Top 20 cities (yellow circle) with a population exposed to climate change impacts by 2070. Adapted from Hanson et al. (2011)

1.1.3. Flood resilience: an appropriate strategy for transport development shifting from existing resistance as cities becoming vulnerable to flooding

In many cities across the world, conventional flood defences have been built to resist floods, such as dams, levees or embankments. During the urban development process, these hard-engineered structures have been built alongside the expansion of urban territory to protect urban activities, and they have proven their effectiveness in reinforcing natural riverbanks against tidal flooding. However, these only protect cities from certain flood levels due to the limitation of capacity design based on the accumulated historical data, which are not always representative of future events (Liao, 2012; Zevenbergen et al., 2008). For example, the Kuala Lumpur Smart Tunnel had been built in 2007 as the giant road-tunnel to deal with flooding in the inner city. Despite the proven effectiveness for some years after the completion, its sufficiency became doubted when this city experienced an extreme flood in 2011 due to unpredicted flood factors such as rainfall levels overwhelming the design capacity and the effects of uncontrolled urbanisation in different parts of the city (Zabidi and De-Freitas, 2013; Varadharajan and Bailey, 2013). Additionally, the dependence on these engineering systems is now under increasing scrutiny as cities confront the climatic uncertainties related to flood factors such as SLR and heavy rains. Ultimately, such defence structures cannot realistically be built to resist all future threats, as the existing design codes for systems are based upon current and historic events (Zevenbergen and Gersonius, 2007). This has become critical to emerging coastal cities, especially in Southeast Asia, where uncontrolled urban growth on vulnerable areas is occurring faster than flood protection systems, which can be constructed even at locations where flood defences are feasible. To this end, there is a need to look at alternative approaches to complement or to deal with the vulnerabilities.

Given the increasing challenge of designing effective resilient systems in the light of climate change, urban resilience has become a prominent concept in many growing cities (Stern, 2006; IPPC 2014). If the increase in vulnerability is a result of the ultimate processes of urban growth, resilience could be a more sustainable strategy to reduce flood vulnerability (Balica et al., 2012; Berkes, 2007; Tuner et al., 2003). It is defined as “the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change” (IPCC, 2007, p.86). Referred a social-ecological system, adaptive capacity is considered as the ability of systematic actors to influence or manage resilience (Walker and Meyers, 2004; Berkes et al., 2007). Developed into a different interdisciplinary fields, the interpretations of resilience theory were commonly focused on two aspects (the engineering and the ecological: Holling, 1996; Liao, 2012). Related to urban planning, it has widely evolved through perspective thinking and understanding (Walker et al., 2004; Berkes, 2007; Wang, 2015) as a conceptual framework for planning in practice (Zevenbergen et al., 2008; Liao, 2012; Dezousa and Flanery, 2013), and in particular in urban physical infrastructures including the transportation system (Tierney and Bruneau, 2007; Rogers et al, 2012; Xenidis and Tamvakis, 2012).

As a vital urban component, transportation is a key driver of productivity, economic growth and living (Ratcliffe, 1981), hence potential flood disruptions to networks are a major concern. The transport system is an element of urban infrastructure which is important for daily life, enabling the movement of people, goods and services for social activities and community development at all levels (Desousa and Franery, 2013; Xenidis and Tamvakis, 2012; Wang, 2015), and also plays a crucial role in the urban resilience to extreme flood incidents seen in some coastal cities (Cigler, 2007; WB, 2012). Whilst it is proving increasingly difficult to engineer infrastructures to defend against flooding, the scale of urban and economic development has been shown to have direct links with the increasing transport routes vulnerable to flooding when cities extend their built-up areas particularly on low-lying lands potentially affected by hydro-meteorological changes such as high tides (e.g. in HCMC). Indeed, urban transport systems are considered susceptible to tidal effects, extreme rainfalls, so adaptive capacity needs to be improved in order to ensure efficient continued use during flood events (Hooper and Chapman, 2012). This is essential whether dealing with a serious flood (i.e. for aid and evacuation) or just small scale daily disruption to avoid effects spreading to different sectors (Prager et al., 2011).

As such, with an approach focusing on flood resilience as an indicator of vulnerability (Balica et al, 2012; Berkes, 2007; Turner et al., 2003), this thesis sets out an argument that to improve the flood resilience of urban transportation, rather than simply making continual investment in flood defences. The development of resilient urban transport systems with an emphasis on robustness and redundancy (two of four properties of a resilient physical infrastructure system: Bruneau et al., 2003; Tierney and Bruneau, 2007), can be more effective in mitigating losses and damages to urban systems. Such an approach offers more travel choices through alternative routes in coordination with appropriate transport modes and means. For implementation, Dezousa and Flanery (2013) suggest that urban resilience can be built up through a conceptual framework of the planning, design and management of urban components, including transportation, but that it needs further development in certain cases. As a theoretical development to distinguish between engineering resilience and ecological resilience (Holling, 1996), the engineering flood resilience targets a stable state of the system, such as urban transport system, referring to potential developments of enhanced structures to deal with moderate floods (e.g. alternative roads to ensure the network continuation), while the ecological tends to ensure the survival of the system, referring to transport accessibility particularly in emergency (e.g. high elevated roads for evacuation). Though the ecological approach is advocated by many studies for long term urban development, the engineering approach is still necessary for transport development, which is developed in line with the demand for urban physical infrastructure development. Hence, while these two aspects are normally distinguished for understanding in general theory; they are usefully coordinated together in practice.

However, resilient interpretations are still in their infancy (Carpenter and Brock, 2008; Folke, 2006), and this theory needs more contextual applications in corresponding to different conditions of particular cities. There is a need to develop this theory into specific areas, such as urban planning considering the role of professionals e.g. planners or architects, but the challenge is how to translate resilience objectives into actual urban contexts (Coaffee and Lee, 2016). These refer to the need of practical development of resilience theory into different sectors with more demonstration of potential application to particular cities through their planning framework. To address flooding, a city needs a resilience-based hazard management system (Folke et al., 2002; Anderies et al., 2006; Zevenbergen et al., 2008), with an interaction between different scales (catchment, city and building: Zevenbergen et al., 2008), of which the city level is considered the most important scale of concern by urban planners because a disruption at this level might have important effects on not only the city but also the sustainable development of a nation. However, the role of physical transport systems has been addressed inadequately as the vital physical connection between different levels of the practically planning for flood resilience development. Liao (2012) proposes a transfer from existing resistant systems to resilient systems, advocating “floodable areas” within a city in relation to the benefit of balancing flood thresholds, but this concept needs further development to identify particular values for such thresholds, which should be linked to flood vulnerability level by an assessment. Additionally, accepting such floodable areas can create interruptions to transport systems, especially some critical routes which might constrain urban activities. Therefore developing the flood resilience of the transport system is essential if a city expects to shift from resistance to resilience. It is postulated that a revision of plans for transport development with the integration of flood resilience, can be seen as a promising strategy to mitigate flood impacts, but few studies focus on this.

In summary, increasing flood vulnerability has resulted in the need for flood resilience improvement instead of the resistant strategy, especially in emerging coastal cities in Southeast Asia. Despite a large amount of research in resilience, there is still the need for more detailed work to promote and embed the role of resilient transportation in urban resilience to flooding, with a shift from existing resistant systems. A model for developing flood resilience of urban transport systems can be developed using advances in existing literature and knowledge, with a particular reference to better integrating urban spatial dimensions such as elevation. Thus, this research has developed resilience theory in planning for urban transport systems to reduce flood vulnerability, and also makes a contribution to the field of urban resilience to flooding with a case study of HCMC in Vietnam. Potential application of such a conceptual model into a city is useful to support the value of resilience theory in practice.

1.2. Study area

1.2.1. Urban development: economic prosperity and transport development

HCMC is located in the South of Vietnam (50 km inland from the sea; *Figure 1.3*), with a territory of 2095 km^2 and a registered population of 8.2 million (GSO, 2015), although the actual figure is closer to 10 million and is predicted to grow to 12 million by 2025 (WB, 2010). With a growth rate of around 9.6% / year between 2010 and 2016, it is the largest coastal city in Vietnam and is responsible for more than 20% of national GPD (Investment and Trade Promotion Centre of HCMC, 2015). It is second only to Delhi in the top 30 Asian cities with respect to gross domestic growth forecasts up to 2021 (Oxford Economics, 2016).

The economic contribution of the larger HCMC region (Binh Duong, Binh Phuoc, Tay Ninh, Long An, Dong Nai, Ba Ria-Vung Tau and Tien Giang) is a key driver for immigration to the area. To cope with the high demand for accommodation, new development districts have rapidly appeared in what has become known as the urban spatial plan for development for 2020 to 2025 (decree 03/CP/1997 from the central government). Subsequently, urbanisation has expanded rapidly from the older central areas found on relatively high land (now known as the core-part of zone 1), to emerging suburbs (e.g. in zones 2 and 3) (see *Figure 1.4*). However, these new urban areas are mostly clustered on the flood prone eastern side of the Saigon River, which has significantly increased the number of people and assets exposed to extreme floods (ADB, 2010). Several transport investments have been undertaken to link the current centre with the new development areas particularly to the East, as the key direction for urban development; but these new transport developments are still mainly developed on the ground with a strategy for horizontal extension. Threatened by flooding, the investment process has been constrained in relation to the high cost of construction as a result of inadequate planning for a continuation of the ground-based network on low-lying lands vulnerable to flooding.

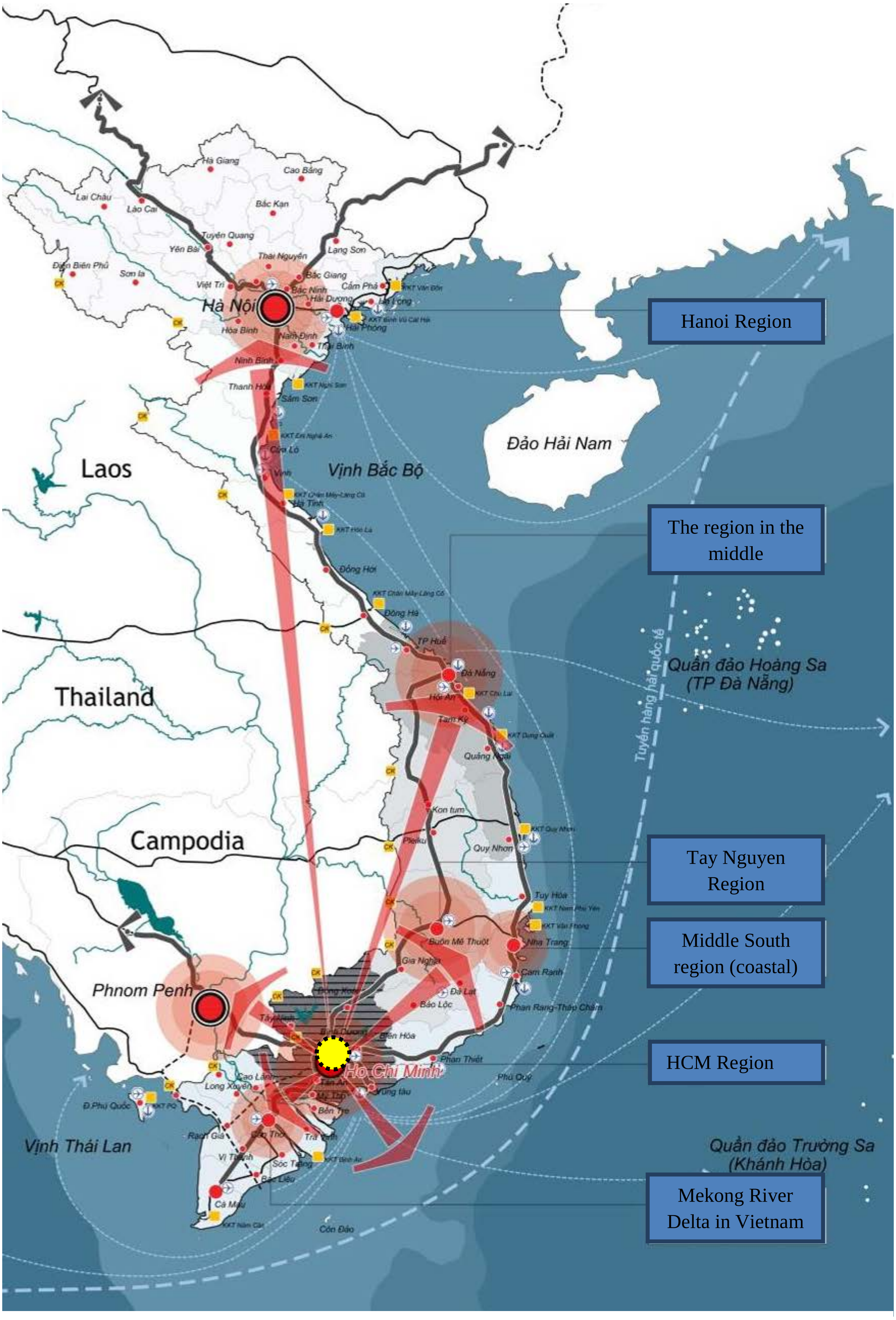
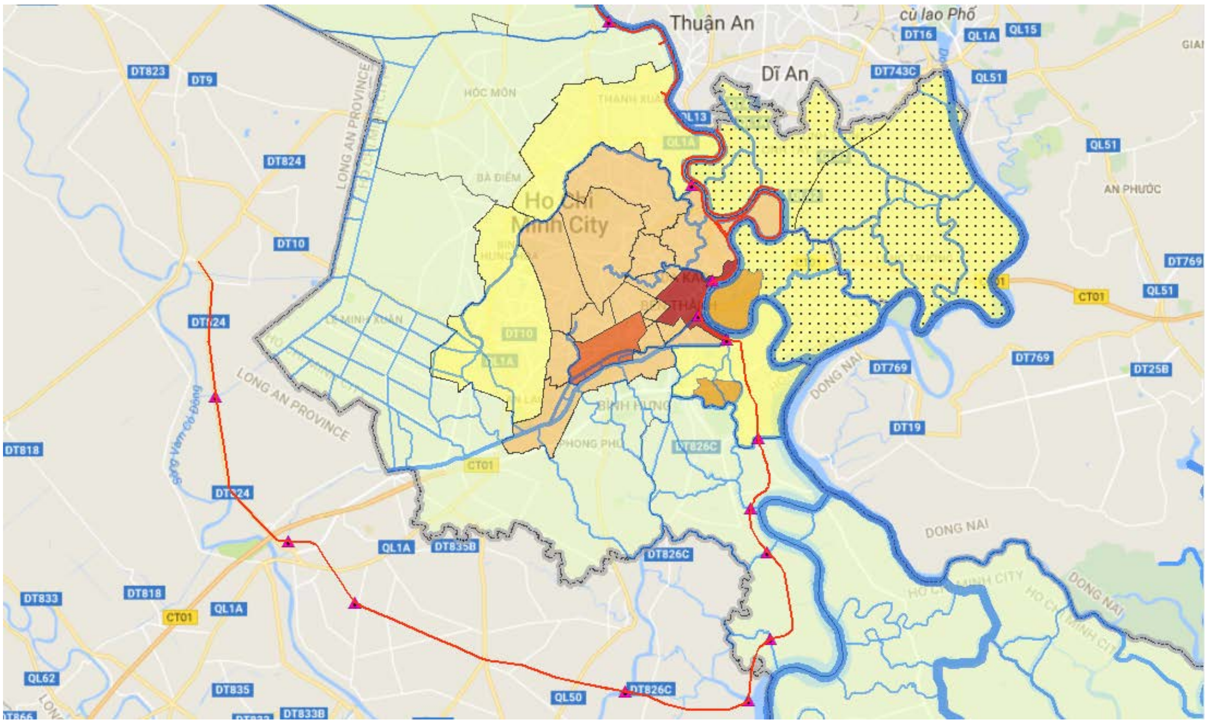


Figure 1. 3 Location of HCMC in Ho Chi Minh Region (HCMR), and in Vietnam

Adapted from SISP (2018)



🟧 Zone 1 (central districts); 🟨 Zone 2 (new development districts); 🟩 Zone 3 (rural districts)

🟥 Old town/ City centre; 🟧 New city centre (Thu Thiem); ▨ 3 districts: 2,9,Thu Duc

△ Slucies — Embankment in plans: 752, 1547

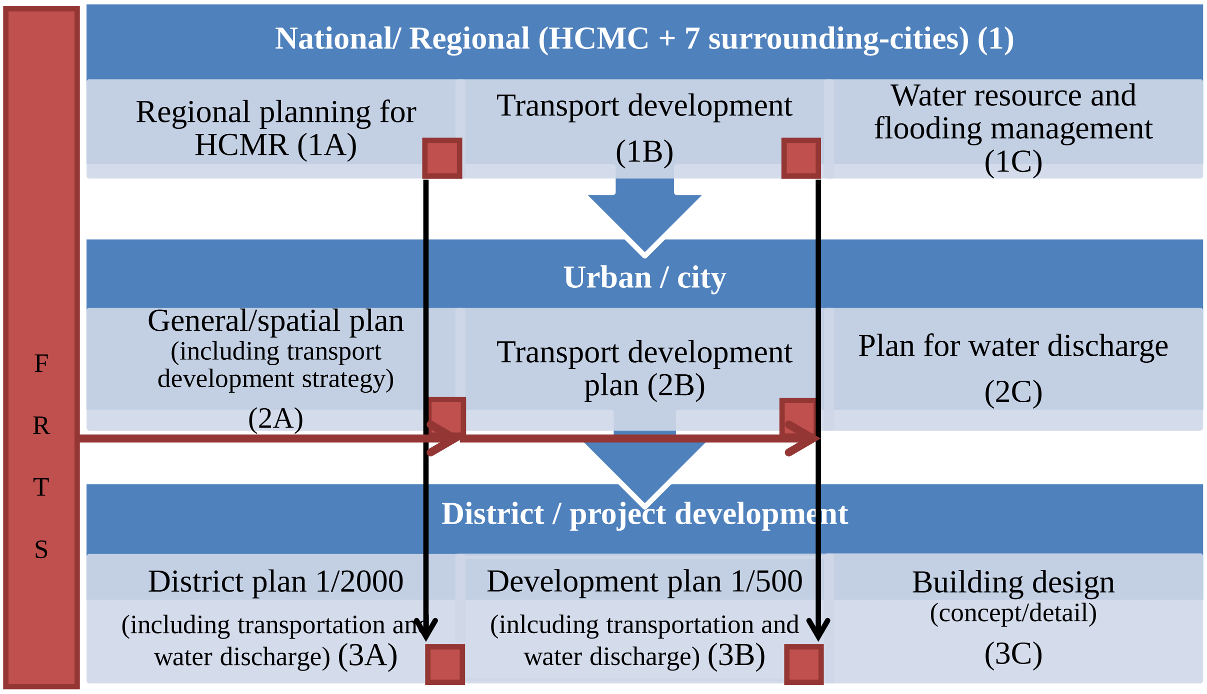
Figure 1. 4 Urban area division in different zones

Situated on a low lying coastal plain, about 40 - 45% of territory of HCMC is under +1.0m (above sea level, hereafter referred to as ASL) (Thinh et al., 2009; ADB, 2010; Storch and Downes, 2011), with almost all low-elevated areas located in the east and the south of the city. These areas were the wetlands containing a sprawling network of channels are a typical characteristic in relation to urban hydro-meteorology in several cities in Mekong Delta in Vietnam. The annual high water level of the Saigon River, the main water body going through the urban area, has risen significantly; for example, from + 1.32 m ASL in 1997 (the period of the preparation of several urban development plans) to + 1.71 m ALS in 2017 (TEDI-South, 2013; SRHC, 2017). This has become a challenge to urban planning for development particularly of transport system in dealing with flood impact, as this city has seen a vast number of housing projects being built on such vulnerable areas, to which transport accessibility have been frequently affected. Flood impacts to the transport system not only create a constrain on urban commuting, referred to as daily activities, but also blame an indication to increasing flood vulnerability in this city, which needs more effective urban planning for long-term development.

1.2.2. The plans for transport development in relation to flooding

In planning for transport development, building codes have also been modified to create higher resistance to flooding, such as the higher elevations required for road developments, especially in new urban areas located on low-lying lands (e.g. from + 1.5 to +2.0m ASL). Such a solution would reduce flooding on some local road segments in the short-term, but create other detrimental impacts on the living environment, in terms of accessibility to housing along new road developments, as well as moving inundations to other places; after all, the water has to go somewhere. For example, Nguyen Van Huong road (in Thao Dien, district 2) was developed to solve flooding about eight years ago, but it has been re-flooded since the rapid development of Thu Thiem in recent years; consequently, an on-going redevelopment has forced all houses along this road to continuously lift their ground again as inconvenience to the living environment from flood resistance solutions. This also raises questions to the local government seeking more sustainable planning for long-term development in response to increasing flood factors.

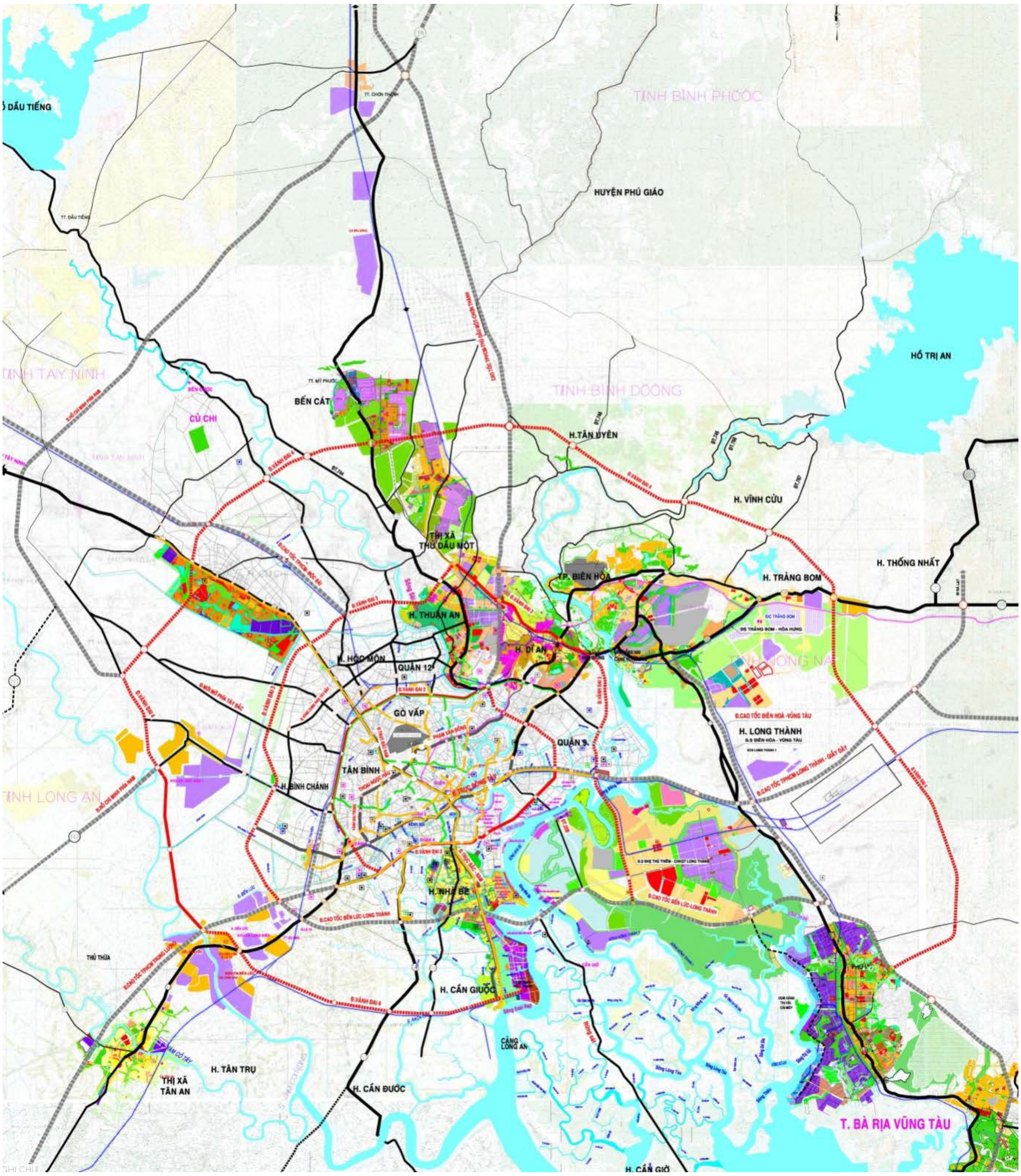
In line with the planning framework in Vietnam (*Figure 1.5*), several plans for the urban development of HCMC were completed during the period 2008 – 2010 (with some updates to 2013). Following the spatial plans according to a decision numbered 24/QĐ-TTg by the then Prime Minister, a plan for transport development was approved in 2013 (see *Figure 1.6*: TEDI-South, 2013). Regarding to continual changes, the general plan for urban development including transportation has been accepted for a revision which has to be completed by 2020. Corresponding to the revision of this general plan, the plan for transport development is also expected to be changed in the near future. This provides a golden opportunity to better incorporate previously absent flood resilience concepts into the transport system, and is thus a driver for this research, which is expected to propose potential adjustments integrated into this revision process, initially in the general plan (2A, figure 1.5) and subsequently transport development plan (2B in figure 1.5).



🟥 Transport plan (a part of the infrastructure element) in the general or district plan

→ Interaction between different planning levels; → Potential integration of FRTS

Figure 1. 5 Integration of FRTS into transport plans in the planning framework in Vietnam



🟧 Inner urban land;

🟨 Residential land;

🟫 Residence development

⬜ Land for army;

🟩 Green land;

🟩 Wetland;

🟪 Industrial land;

━ Ring road (existing);

╍ Ring road (planned);

┅ Highway (planned);

━ National road;

─ Provincial road;

━ Urban artery;

╍ High-elevated road

─ Other main road

━ Existed rail

━ Planned rail

━ Monorail (planned)

🟪 Existed sea-port

🟦 Planned sea-port

Figure 1. 6 Integrated map of transport plan for developments in HCMC by 2020. Adapted from TEDI-South (2013)

1.2.3. Increasing flood impacts and the inefficiency of resistant solutions

Flooding was previously never considered to be a problem in HCMC, and indeed the city rarely experienced floods until the 1960s (Hong, 2011), but since its rapid expansion, more than 50% of the urban area of HCMC is now affected by regular floods (ADB, 2010). The impacts on the urban transportation have become more disruptive, as the scale of the city now means that it is more dependent on the reliability of the transport system than ever before. From 2003 to 2009, 680 road sections had been affected by floods (Phi, 2013), and flood data from the Steering Centre of The Urban Flood Control Program of HCMC - SCFC (2010 – 2016) show that the number of inundations nearly doubled, about 1250 during the next seven years (2010 – 2016). Shortly, flooding has become problematic particularly to roads on the ground (some examples shown in *Figure 1.7*), and any flood disruption to the urban transport system can cause significant losses to economic development of this city.

To date, resistant solutions to flooding have been the chosen approach to the flood problem in HCMC but they show ineffectiveness in long-term development. The original master plans for flood management were approved in 2001 and 2008 (following decisions 752 and 1547 respectively), and led to a number of widespread investments being implemented, such as river embankment and sluices, which currently protect the central area and a part of zone 2 on the western side of Saigon River (referred to *Figure 1.4*). These defensive structures have cost over USD 1.2 billion during the first stage, and expect a further cost of about USD 4.3 billion to be invested for the second stage (Nguyen, 2015). However, the flood problem has never been resolved. Along with the worsening flood situation, the effectiveness of these structures is highly questionable (Nguyen, 2015). During 2015/2016 the city experienced at least two large-scale floods (i.e. the events of 15th September 2015 and 26th September 2016 - *Appendix A.2.2*), with the number of road locations with significant inundations recorded as 66 and 50 respectively. These events demonstrate the inefficiency of existing investments, and also referred to the inadequacy of the current plans development.

a)

b)

c)

d)

e)

Figure 1. 7 Flood impacts on transportation and some examples of developments in response:
a) Power of flood water dangerous to travellers on Nguyen Van Huong road, district 2;
b) Flood making traffic jam on Huynh Tan Phat Street, district 7;
c) Increase in elevation of road developments on the ground level, Luong Dinh Cua Street, Thu Thiem, district 2;
d) An example of constraints on the entrance to private houses
e) An example of high-elevated road development for traffic congestion without consideration of flood resilience function. Photo taken from Kieu-Tien (2018).

1.2.4. Research into flood vulnerability in HCMC

In order to better understand flooding in HCMC, several projects have performed flood simulations. For example, using mean sea level data, Thinh et al. (2009) investigated tidal effects related to a flood event in 2008 and identified nine vulnerable districts which suffered floods over 10 times, five of which were directly adjacent to water bodies. Using satellite data overlaid with the land-use plan, Storch and Downes (2011) highlighted the increasing spread of built-up areas vulnerable to flooding. They showed that in the worst-case scenario of a +2.5m ASL flooding level, affected built-up areas would rise from 45% (230 km^2) in 2010 to

59% (450 km^2) by 2025, being most noticeable in the South and the East. In a detailed investigation of district 8, close to Tau Hu channel, a river branch of the Saigon River, Dang and Kumar (2017) concluded that this area, and also referred to urban areas adjacent to water bodies, is mainly affected by tidal floods combined with heavy rains. However, the most comprehensive work to date was compiled by ADB (2010, p. 4), which highlighted that 71% of the existing areas of HCMC would be at risk of combined floods by 2050 (without additional flood protection systems). Interestingly, the ADB's maps (2010, maps 5, 6 pp. 15 - 16) show "current and planned road infrastructure affected by projected extreme floods by 2050", but the actual elevation of the existing transportation network is not mentioned and remains a key research gap. This can be referred to as potential differentiation between the "flooded" or "vulnerable to flood" situations and it is accepted that a more detailed analysis in this regard is necessary (ADB, 2010); a gap that this thesis aims to address.

Overall, the generalised conclusions of recent research are that the city is confronting higher flooding risks related to both urbanisation and climate changes (ADB, 2010; Storch and Downes 2011; Ministry of Natural Resources and Environment of Vietnam – "MNER", 2012; Phi, 2013). Some deficiencies in planning can be accommodated by the inclusion of elevation data on designs for transportation, although this source is normally limited to project- based data in the city.

1.3. Research aims

Faced with a current flood problem and the increasing vulnerability in the future, the transport system of HCMC needs more appropriate plans for long-term development, particularly helping the city to deal with extreme events. This establishes the rationale for this study, which aims to build on the previous studies highlighted to not only produce an analysis of flood risk in the city but to develop a conceptual model of a Flood Resilient Transport System

(FRTS), built-up from the development of resilience theory in transportation. Given the rapid changes to flood risk in HCMC, there is a pressing need to conduct a more detailed flood vulnerability assessment, which will become the base for an application test case of HCMC; in order to demonstrate the applicability of the model through the current planning framework of the city. This aim will be realised in line with the following objectives:

i. *Highlight the evidence and key factors underpinning the increasing flood vulnerability in HCMC in light of the rapid urbanisation in new development areas prone to flooding;*
ii. *Identify lessons learned (and best practice in urban planning), and in particular the role of transportation to improve flood resilience, in coastal cities that have previously suffered flood devastation;*
iii. *Develop a conceptual model of a Flood Resilient Transport System (FRTS) for potential application in HCMC to reduce the vulnerability; and*
iv. *Propose potential adjustments (roadmap and blue-prints) for revisions in planning for transport development in accordance to the urban planning framework in Vietnam.*

1.4. Thesis structure

In line with the research aims, the thesis consists of eight chapters and two appendices. The three middle chapters (4 – 6) are now published as three papers (attached in appendix B). Appendix A presents anecdotal evidences of worsening floods observed from the fieldtrips.

Chapter 1 has introduced the global context of flood hazards to coastal cities, especially in developing countries in Southeast Asia. A brief summary of contemporary approaches to flood vulnerability in relation to the emerging resilience theory is also introduced. The main case study city, HCMC, is also outlined and highlights how its new economic prosperity has become a driver for revising urban plans under urban planning framework in Vietnam.

Finally, this chapter also introduces the current flood situation and the inadequacy of on-going plans for transport development as the rational for the aims of this research.

Chapter 2 reviews the background theories of flood vulnerability and resilience, particularly with respect to transportation. Using an approach to investigate increasing flood vulnerability using three indicators in an urban context, the role of resilience is discussed to address the need of planning for transport development using the properties of a city level resilient system. Flood thresholds related to urban floodable areas is also developed in theory in order to look for potential coordination to classification of the elevations of the transport network, as a basis for vulnerability assessment. These have become the fundamental principles to conceptualise a model of flood resilient transport system.

Chapter 3 presents the research design and methods. Based upon the research aims and informed by the literature reviews, this research uses different methods, combining hydrological modeling and GIS analysis. This requires a combined methods approach and the context for this is set via introducing the concept of flood vulnerability assessment for resilience development in this chapter. The methodological review is also integrated in this chapter.

Chapter 4. Using the case of HCMC, this chapter addresses the potential of increasing flood vulnerability, especially in new development districts where the rapid development of accommodation on floodplains is proving problematic. The inaccessibility of the main transport routes between the old city centre and three of these new emerging-districts (on the eastern side of the Saigon River) is analysed as an increasing disincentive to urban resilience. This chapter also introduces a vision for urban compactness development which is relevant to the role of resilient transport in connections between different urban high-density areas and perhaps appropriate for minimising new residential developments on floodplains.

Chapter 5 compares three flooding incidents in New Orleans - USA, Manila – Philippines and Bangkok – Thailand, to synthesise generic lessons of urban resilience to flooding with the essence of transport accessibility when dealing with flood catastrophes and the implications for HCMC. The chapter also highlights why HCMC and other emerging-coastal cities in Southeast Asia still have opportunities for city-wide resilient improvement, particularly with respect to potential revision of transport plans for development.

Chapter 6 presents a conceptual model to develop the flood resilience of urban transport systems, regarding to the fundamental principles highlighted in the literature review (chapter 2), the evidence for increasing flood vulnerability and particular local issues in HCMC (chapter 4) and the lessons learned from other cities of the need to improve flood resilience through the transport system (chapter 5), and also the current conditions of transport development in HCMC. For application, this chapter also shows a process of flood vulnerability assessment to identify urban areas and transportation sections vulnerable to flooding. Through two scenarios, the simulation tests for potential application and benefit of FRTS are also presented in this chapter.

Chapter 7 presents the implications for inadequacy of current plans for transport development, in relevance to the actual causes and factors to flooding in HCMC. For potential adjustments to the current plans for transport development, roadmap and blue-prints are proposed for potential application of the FRTS model in HCMC.

Chapter 8 concludes the main findings and contributions for HCMC, and also informed to other coastal cities in Southeast Asian Countries (SAC). It also mentions the critiques, as well as suggestions for further work required.

Appendix A: Collection of supplementary anecdotal evidence during the field campaigns.

Appendix B: Papers arising from this thesis.

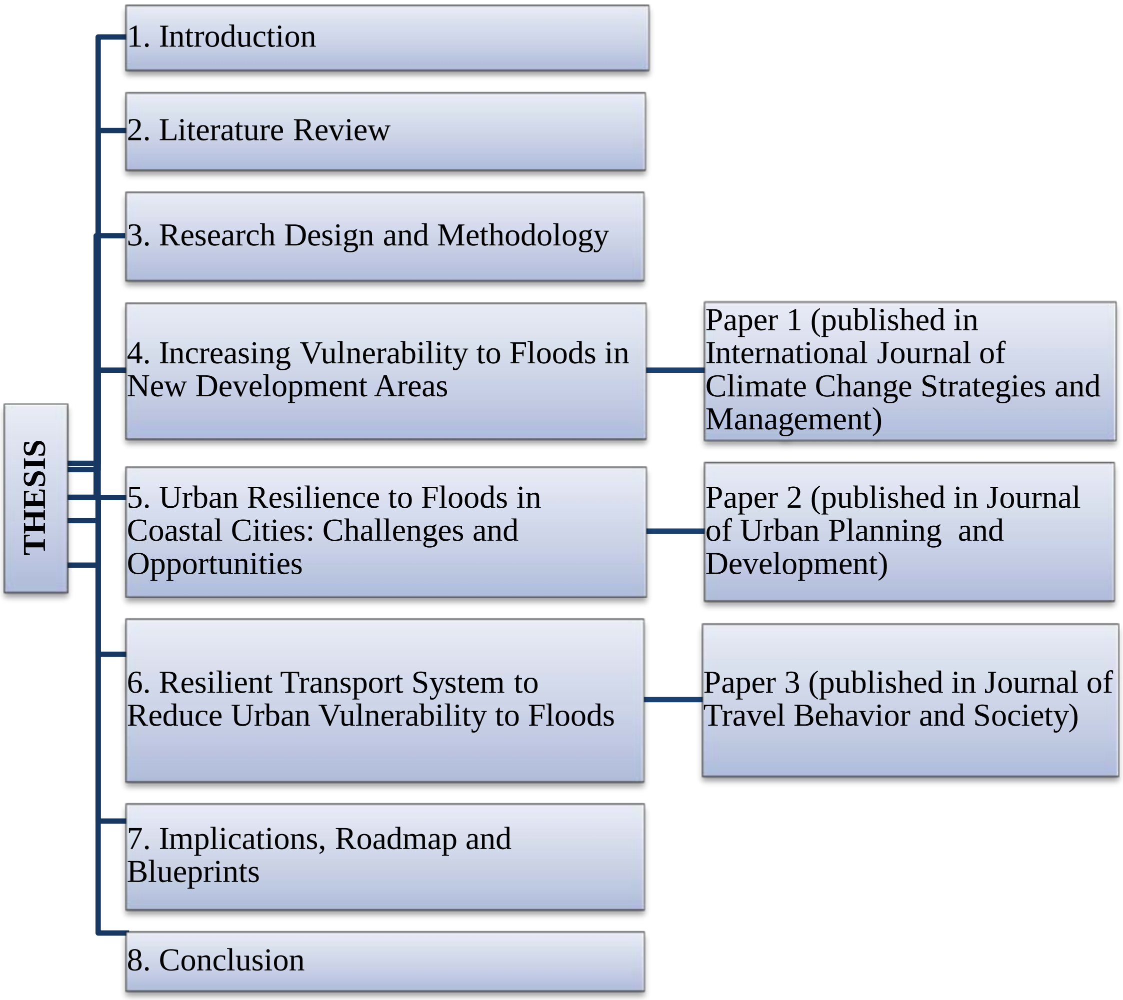


Figure 1. 8 Thesis structure

Chapter 2

LITERATURE REVIEW

As rapid and uncontrolled development has resulted in increasing flood vulnerability in several emerging coastal cities, resilience has emerged as a conceptual theory to help such cities deal with adverse events. This chapter reviews the contemporary literature on flood vulnerability in relation to resilience to flooding. As part of a vision for transport planning, this will lead to opportunities for theoretical flood resilience development, relying on the properties of a resilient system with a focus on application at a city level within a planning framework. These then become the fundamental principles for a conceptual FRTS model, outlined at the end of this chapter.

2.1. Urban growth: urbanisation and transport development in relation to flooding

2.1.1. Trends in developing countries in Southeast Asia

Driven by economic growth, cities all over the world are continuing to expand. In 2010, 167 cities had over 750,000 inhabitants, a 10-20 fold increase in population since 1960 (UN, 2014). As a result, over 50% of the world's population now lives in urban areas (UN, 2014). This has triggered a process of rapid urbanisation, but has also exacerbated environmental risks related to climate change, such as rising sea levels. Such a rapid urbanisation trend can be observed particularly in major cities, which attract workers from surrounding areas, with an increasing demand for accommodation as a result of urban agglomeration. Camagni et al. (1998) stated that cities contain the main sources for new technology, economic development and new environmental initiatives, which are drivers for the growth of urban populations and urbanisation. An illustration of this trend is that urbanisation dramatically increased from 39% in 1890 to 53% in 1940 in many American cities. This trend reached 75% 50 years later (Glaeser, 1998), with no evidence of a decline in larger cities (Glaeser, 1998; Eaton and

Eckstein, 1995; Dobkins and Ioannides, 1996). The concentration of people in the 10 largest cities has fallen slightly since 1970 (from 23% to 21%), but has continued to increase in metropolitan areas (from 41% to 48.1%) (Glaeser, 1998).

Urban growth can be traced back to the 19th century, when economic drivers provided an impulse for territorial expansion as a direct impact of industrialisation (Hall and Jones, 2011). This trend has continued to the present day. Often adjacent to main water bodies (which also serve as a major transport mode), old towns were normally founded on land which provided suitable conditions for urban settlement, such as sources of pure water, high elevations against flooding risk, and easy connections to new urban areas. These lands would be planned for development but would be limited to certain population levels and territorial areas, while the surrounding areas were normally left unused, due to their disadvantages in relevance to low terrain subject to flood risk. As rising urban populations produce higher demand for accommodation, the availability and lower cost of such lands can be seen as a dominant driver for property development. Particular in many cities situated on coastal zones or river basins, these areas, which are low-elevated wetlands, have the function of balancing the hydrological cycle for water discharge (through riverine networks) and absorption (in water space, soil). Thus urbanisation in these areas can therefore lead to a decline in permeable surfaces (green land or water areas) and water storage capacity, resulting in a higher risk of flooding. Cigler (2007) stated that a growing imbalance between the natural and human environment has led to a higher risk of urban flooding.

In line with global trends, the emerging coastal cities of developing countries have also experienced much more rapid urbanisation tendencies. In an investigation of global urban expansion in 90 cities worldwide, Angel et al. (2005) projected that built-up areas would expand from 200,000 km^2 in 2010 to 600,000 km^2 by 2030, with a doubling of the population in developing countries. However, these cities are more vulnerable to the impacts of climate change, as they do not have enough financial power to prepare for urban adversity, nor experience of urban planning and management to control (WB, 2010). As a result, these cities are predicted to continuously see populations and assets being concentrated in vulnerable areas. Indeed, the results from the research of Hanson et al. (2011) show a large number of coastal cities in developing countries in Asia with highly exposed populations and assets at risk from climate change impacts. As introduced in Chapter 1, this is acute in the Southeast Asia region, as many main metropolitan cities such as Bangkok and Manila have experienced severe flood incidents, whilst HCMC is predicted to be more vulnerable to flooding in the future (WB, 2010; ADB, 2010; Storch and Downes, 2012; Phi, 2013).

2.1.2. Transport development and flooding

Associated with the urbanisation process, the appearance of new suburbs has become a significant driver for transport development, with an expansion of the network from the old centres to surrounding areas. Dominating the 20th century, the growing trend of urbanisation will also importantly affect the remainder of the 21st century, particularly in developing countries. This not only reflects the trend of increasing concentration of people and assets over specific areas, but also refers to mobility problems linked to urban activities particularly in major cities where residents have different demands, lifestyles and levels of consumption (Rodrigue et al., 2016). Wang (2015) states that the change in land use, in terms of demand and planning of places for people to work and live, has an inextricable link with the transport system, as a direct result of various decisions by inhabitants and policymakers. “Transportation is the spatial linking of a derived demand” (Rodrigue et al., 2016, p. 1), and its network is normally upgraded in relation to expansion of physical infrastructure in practice (ibid). Indeed, the growth of populations in cheaper, peripheral lands has led to a higher demand for transport accessibility, quantified by the length and number of vehicle trips especially in developing countries (WB, 1996). Such a rising demand is overwhelming the existing capacity of transport systems, as these countries have experienced a dramatic increase in private vehicles for a shorter period than in developed countries (WB, 1996); and "demand for public transportation (both motorized and non-motorised) has also grown much more rapidly than the population and has far outstripped the growth in revenues available for the transportation infrastructure" (Armstrong-Wright, cited in WB, 1996 p. 75). Meanwhile, spatial allocation for urban roads in these countries is much lower than that in western cities during the motorisation phase (WB, 1996). Thus key infrastructure investments, mainly in transport structures such as highways, elevated roads, bridges and metro lines, have been recently used by local governments to ensure the connections between existing city centres and new development areas as emerging-cities continue the expansion of urban territory. Land-routes can be extended to meet the requirements of the growth of built-up areas providing connections to existing urban areas, such as city centres (Rodrigue et al., 2016). In fact, faced with the challenge of financial investments, the effectiveness of planning for transport investments in these cities is really concerned, not only to meet the increasing demand of transport capacity, e.g. reduce congestion, but also to help deal with other environmental effects, such as flooding. Potential integration between these objectives can be seen as an opportunity to improve resilience with appropriate transport plans following spatial planning for urban development.

In addition to the problem of flooding, it appears that transport development also challenges the planning and management process in terms of its interaction with existing riverine systems especially in coastal cities. Along with historic development, waterways have been an important transport mode in many cities situated on river basins since the early stage of establishment, thus potential intersections between the transport network and urban watercourses is inevitable. The expansion of built-up areas normally leads to horizontal development of transport network, such as number of routes or width of road developments, but the efficiency in transport development in the long-term is considerable when the city not only deals with the pressure of increasing demand but also the environmental hazards such as flooding. Hart (1993) argued that research needs to emphasise the spatial effectiveness of existing roads rather than unique investments in creating new roads or expanding road-widths. In reference to the typical characteristics of cities located in coastal zones or river basins, horizontal extension of the transport network can lead to the presence of diversified river networks. Hydrology is one of the “three basic constraints of terrestrial space” (Rodrigue et al., 2016, p. 12). In practice, an extension of transport networks can lead to more transport routes along or needing to cross main water bodies. Under a changing climate, it is common for river levels to be gradually rising as a result of hydro-meteorological changes (e.g. higher tides), making tidal floods an increasing hazard for transport systems, particularly on critical routes, which are responsible for transferring intensive urban activity transport flows, but are vulnerable to flooding because of their geographical location close to flood sources such as water bodies.

In brief, urban growth associated with the expansion of built-up areas has generated demand for the development of transport systems. Along with this, networks will be expanded in terms of spatial scale, particularly from the old urban areas to new development areas. Although such a process can create the risk of flooding due to increasing geographical intersections between new transport structures and riverine networks, it can be seen as a tremendous opportunity for a revision of more effective plans to reduce flood vulnerability. A balance between horizontal and vertical development of urban transport systems can help cities dealing with flood hazards from riverine network, and improve investment efficiency during implementation. Along with this, the continuity through alternative links and nodes within a network is really important when planning for transport development. This is acutely in emerging coastal cities in Southeast Asia if they can maintain economic prosperity as a driving factor for new investments in urban infrastructure.

2.2. Flood vulnerability

2.2.1. Definition, indications and relation with resilience to flooding

“Risks from climate change impacts arise from the interaction between hazard (triggered by an event or trend related to climate change), vulnerability (susceptibility to harm) and exposure (people, assets or ecosystems at risk)” (IPCC 2014, p. 36). Climate change has created more risks to residences, people and their belongings, while activities distributed in urban areas are susceptible to potential effects, referred as the degree of vulnerability in relation to exposure.

Vulnerability is defined as a harm extension, which can be assessed and predicted by indicators of exposure, susceptibility and resilience (Turner et al., 2003; Berkes, 2007; Balica and Wright, 2009; Hufschmidt, 2011; Scheuer et al., 2010; Willroth et al., 2010; Fuchs et al., 2011). Focusing on large urban areas located within deltas, Van-Beek (2006) suggests a systematic approach to coastal flood vulnerability assessment with regard to different components identified by natural systems, socio-economy and administration and institutions (e.g. the authority for planning and implementation). This implies that to assess flood vulnerability needs, an understanding of a wide-range of issues is required such as:

- River networks as a part of the hydro-ecology system related to water levels, especially high tides as a flood factor;
- Presence of citizens and their daily activities (e.g. urban commuting potentially exposed to flooding); and
- Authority for planning and implementation in relevance to the urban plans for deployment in practice.

Along this, Balica et al. (2012) developed an index to assess flood vulnerability consisting of three indicators, which are readily extendable to transport systems, particularly in transportation as follows:

FVI (Flood Vulnerability Index) = E (exposure) x S (Susceptibility) / R (Resilience)

- *Exposure*: more generally for urban spaces, exposure refers to any increase in the number of people and assets located in areas prone to flooding. This can be extended to transport networks, as an increasing number of links, measured by length or percentage, are predicted to be affected by flooding.

- *Susceptibility*: this considers the factors influencing the degree of flood impact arising from changes in urban hydrometeorology, which can have the potential to exacerbate the impacts.

- *Resilience*, defined as the ability to self-reorganise the network, such as through existence of alternative routes for daily travelling, and emergency routes for evacuation to maintain certain levels of transportation in adaptation to different flood levels, in order to mitigate impacts.

Based on these indicators, each transport link can be initially assessed as being vulnerable to flooding if it is located (or planned) across a flood plain (*Figure 2.1a*). In order to accomplish this, flood risk maps are required for the city under study. These can be generated from hydrological modelling, and as such there exists an opportunity to further refine the process by providing probabilistic information pertaining to flood depths (*Figure 2.1b*). Flood vulnerability can then be analysed by focusing on the key nodes and links exposed to flood factors, such as river water levels simulated from a hydrological model.

The process then becomes increasingly sophisticated by adding detailed elevations and attribute data (i.e. localised flood defences) to the model. Although this data is not always readily available corresponding to the resolution of existing digital elevation models, combined data from observations or manual collection can be useful for potential application. If achieved, this approach permits an investigation into existing resistance, as well as the implications of various planned developments on both transport and buildings. Resilience of the wider network can then be explored. For example, by integrating data from experimental studies, safety literature, expert opinion, and anecdotal video observations, Pregnolato et al. (2017) identified a 30cm deep flood as being passable for cars travelling on flooded roads.

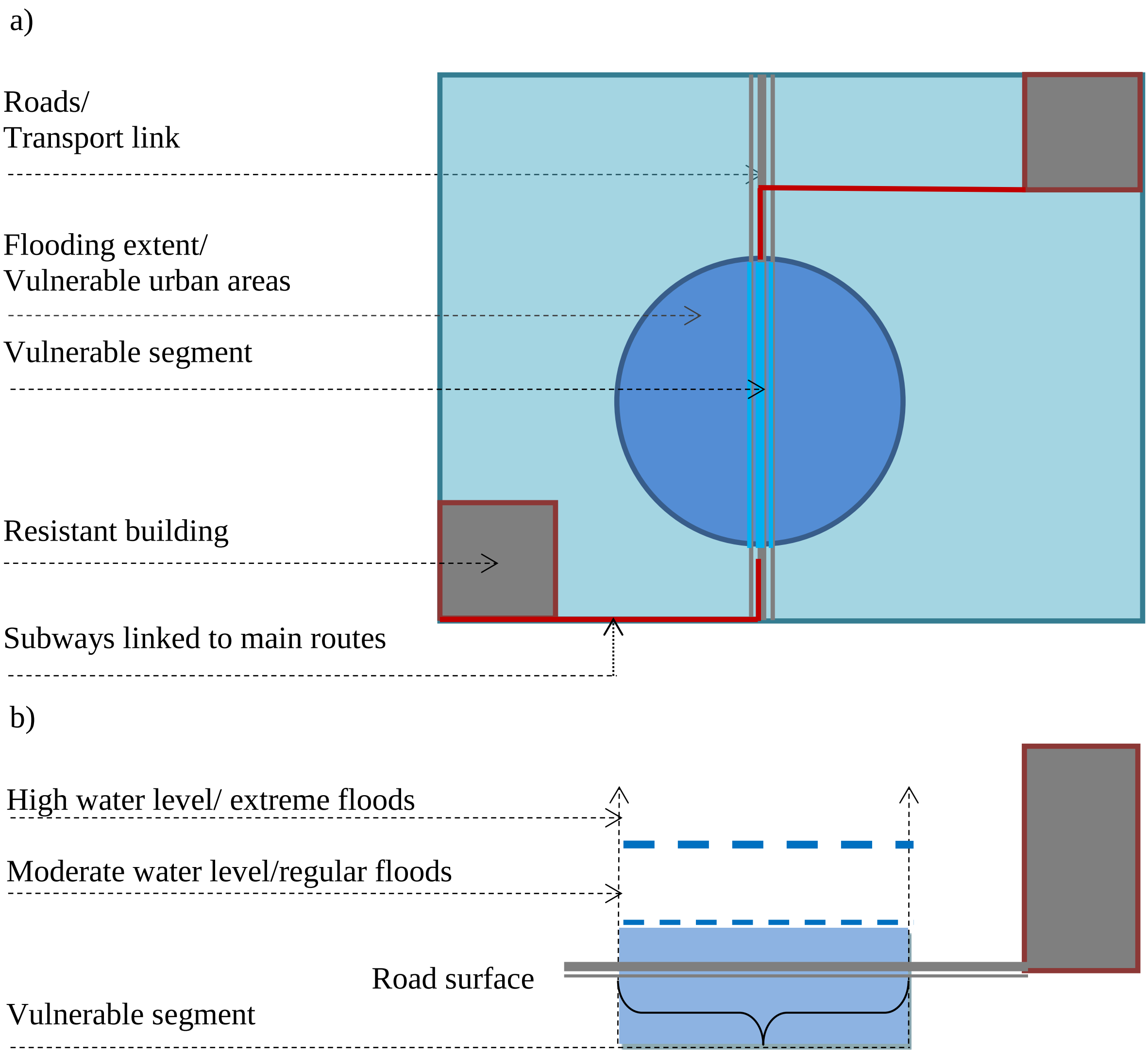


Figure 2. 1 Clarification of flood vulnerability assessment in transportation

a) Flood vulnerability: urban areas/transport segment

b) Difference between “affected” and “vulnerable” level

From the definition of flood vulnerability, it can be clarified that the level of ‘vulnerability to flooding’ can be differentiated from the ‘inundated level’ in terms of probability of occurrence, influenced by water level and time scale. An inundation (e.g. on a road) refers to an urban area (or a transport segment) which has usually already been immersed by flood water, while flooding of a vulnerable area (or transport route) can be predicted if flooding factors continue to aggravate the magnitude of the flood (e.g. higher tides or heavier rainfall). Such clarification not only helps analysis on flood situation, but also will be useful in the projection of flood impacts when considering changes to the urban environment to improve resilience. An illustration of this differentiation is a road segment which has been redeveloped with a higher elevation design against an accumulated flooding level, but which can be still assessed as being vulnerable to further floods if tides continue to rise to higher levels, potentially exceeding the new elevation design. However, focusing on current inundated levels tends to result in the enhancing of short-term resistant solutions, which can be viewed as a short term vision for the broader system.

In relation to flood impacts on transportation, a vulnerable segment can result in ‘inaccessibility’ of travel over a longer route or larger network, as it can be linked to others, such as paths or entrances to resistant buildings in term of commuting. Floods still affect the activities of people living in these buildings even though their elevation (e.g. the ground floor) may be higher than the flood level. Hence, higher elevation against current flood levels only deals with flooding to certain local segments but higher elevation adapting to vulnerable levels can help dealing with potential flood disruptions to the whole system. This requires an assessment of flood vulnerability by simulating potential extreme floods in the future.

2.2.2. Increasing flood exposure: uncontrolled urbanisation and concentration of people and assets on floodplains

The ongoing rapid expansion of urban areas in coastal areas presents a real challenge. Unless there is adequate planning and management of such expansion, it will lead to more residences being at risk of flood. Indeed, New Orleans and Manila have experienced high losses and damage, and serve as warnings of illegal settlements and uncontrolled urban development on low-lying land vulnerable to flooding *(see Chapter 4)*. Despite the fact that new urban areas have been designed for higher resistance, flooding factors have become more volatile. It is argued that the impacts of climate change are crucial in relation to urban flooding, but inadequate spatial planning of urban development on floodplains obviously means more people and assets are exposed to flooding. This can be explained by the fact that the objective of economic growth can put pressure on local government, which then ignores the necessary assessment of flood vulnerability when planning and approving new developments on floodplains. Uncontrolled spatial expansion can result in rapid urbanisation processes, which not only increase urban exposure to shocks and stresses but can also create more burdens for the distribution and maintenance of the infrastructure (Coaffee and Lee, 2016).

2.2.3. Susceptibility to flooding: uncertain changes in urban hydro-meteorology

Uncertainty of climate change versus limitations of flood protection systems

Flood magnitude is affected by factors related to changes in urban hydro-meteorology, such as river level and local rainfall. Sea Level Rise (SLR) and intensification of tropical cyclones followed by heavy rains or storm surges are attributed to climate change (Nicholls et al., 2014), and accelerate the increasing frequency of tidal flooding (Fenster and Dolan, 1996). Globally, the sea level rose annually by 3.3mm/year on average from 1993 to 2009 (Beckley et al., 2010), and it is predicted to rise by about 74 cm by the end of the 21st century (IPPC, 2014). Such changes will have long term effects on urban areas; the Royal Society (2014) states that extreme weather has severely and frequently affected cities worldwide since the beginning of this century, and that this is predicted to continue in the future. Concern for susceptibility, based on a combination of heavy rains and tidal floods, has become a significant issue for cities, especially those in coastal zones, because of their characteristic location in river basins containing a sprawling tributary, and close to main estuaries. For example, the flood incidents in Manila in 2009 and Thailand in 2011 were combined consequences of water accumulated by a series of heavy rains and high river tides (WB, 2012).

To deal with the increasing flood risks, many coastal cities have upgraded their flood defences (i.e. resistant systems), such as dams, river banks or drainage development. However, such systems still have a limited design capacity and can be overwhelmed by the uncertainty of climatic factors (Liao, 2012). Although, hurricanes in the tropical North Atlantic can be predicted, but it is hard to know where exactly a hurricane such as Mitch or Katrina will strike, as the knowledge and ability to forecast such events is incomplete (Balica et al., 2012). The greater the dependency on resistant systems, the greater the susceptibility to flooding that cities face, in particular when there is a combination of unpredicted events.

Critical transport routes

Climate change has had more impact on transport systems in relation to the uncertain changes in hydro-meteorological factors. Conditions of extreme weather or phenomena of natural environmental changes can result in inaccessibility to parts of the road network, daily incidents, or even a collapse of major transport structures such as bridges (Berdica, 2002). Any obstruction to main roads or transport nodes can have a widespread impact on the whole urban network; this will be more significant if such floods happen during a sensitive period (for example, peak-time travel). The consequences for the whole transport network mean that urban activities can be disrupted, with various subsequent impacts on the economy interlinked with urban development.

Particularly in extreme floods, certain essential routes, which should be familiar with most people for daily activities, need to be secured for evacuation to safer places (i.e. shelters). Emergency routes need to be clarified, such as in urban road networks, in spite of the existence of hazard maps determined by different methods and tools (Lumbroso et al., 2011; Yu et al., 2017). This will be useful in planning routes for evacuation, and in allocating necessary resources (McCarthy et al., 2017). In relation to this, municipal buildings such as council offices, universities (or other educational campuses) and hospitals can be seen as the most common places for the citizens to seek refuge in many cities. The locations of these kinds of urban areas should be planned as evacuation routes, especially those of hospitals because of the healthcare services they provide. For example, in Florida, USA, the main shelters have been planned on the sites of hospitals (Kar and Hodgson, 2008). Of relevance to the location characteristics, emerging coastal cities are considered to be more susceptible to river flooding because of the presence of dense river networks connected to the sea. During the development process, urban expansion commonly creates an increase in the transport routes which interact with the water bodies within the urban area. This creates a higher risk of flood effects on urban transportation, especially during sensitive periods, such as peak work travel times. Thus an assessment of flood vulnerability in transport networks should focus on intensive routes which have a geographical correlation with water bodies, for example along or across main river branches.

In summary, *a transport network vulnerable to flooding can be assessed by identifying vulnerable urban areas potential affected by a flood extent, including which transport routes cross the area or are planned to do so*. The exposure indicator is likely to be more relevant to potential effects on particular routes in term of location, while susceptibility is relevant an exacerbation due to potential changes in flood factors influenced by urban hydro-meteorology. In practice, if these two indicators are hard to reduce, the third indicator, the resilience, should be considered for mitigating potential loses and damages.

2.2.4. Relationship between flood vulnerability and flood resilience

Although rapid urbanisation in vulnerable areas can be partly minimised by spatial planning and management, the increasing population in new development areas can be seen as an inevitable trend due to the ultimate target of economic development. Additionally, climate change has become more uncertain, and is likely to exceed the ability of conventional forecasting systems. Hence an enhancement of flood resilience also potentially leads to a reduction in flood vulnerability.

From the previous review of the common trends in urban expansion and increased climate change uncertainties, it can be seen that urban vulnerability should be alleviated by an improvement in the flood resilience, which can be integrated in urban plans for development, in parallel with effective management of new residences in vulnerable areas, especially in emerging coastal cities. However, urban resilience is only observed and 'tested' through particular events (Desouza and Flanery, 2013). The case studies reviewed chapter 4 demonstrate that some emerging coastal cities can cope with frequent small scale events, but that their resilience is only verified when facing extreme incidents. This is linked to anticipation of a worst-case scenario, as the vulnerability of particular environments affects investigations into both current situations and predictions of the future. Such typical events bring risks to those cities with vulnerable elements exposed to related effects, and subsequent losses and damage to their socio-economic development. This underlines the necessity to assess vulnerable components and to understand how they are interlinked with others

(Desouza and Flanery, 2013). This requires an integrated framework approach to potential disruptions so that planners can adjust existing plans, or devise additional plans for action in case of emergency. In terms of urban spatial planning and management, an early assessment of urban flood vulnerability of urban areas and transport segments gives the opportunity to predict potential impacts, not only in these areas, but also in the surrounding urban areas. Extreme events should therefore be simulated in comparison with regular events in order to refer to potential revisions of planning for future development, such as master development plans for urban spaces and transportation. In brief, *Figure 2.2* shows the relation between the three indicators of flood vulnerability, and also implies that the degree of flood vulnerability can be reduced by:

- The probability of a reduction in exposure and susceptibility to flooding; otherwise
- Potential improvement in resilience to flooding.

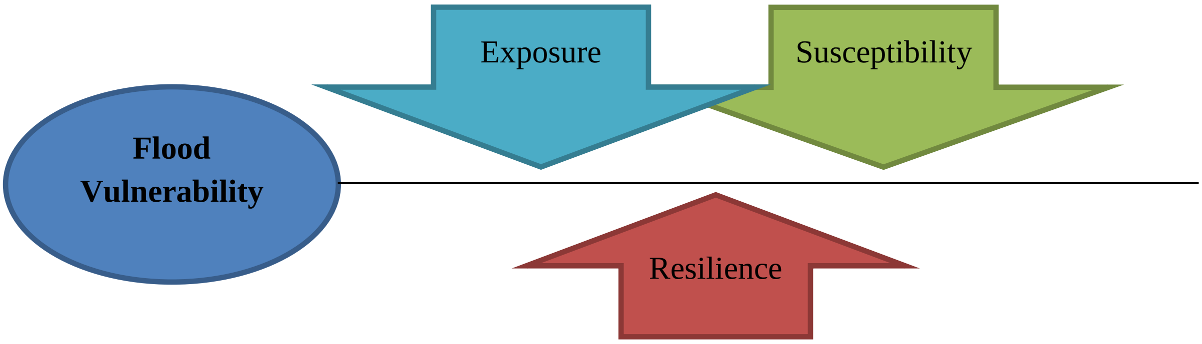


Figure 2. 2 Relation between flood vulnerability and flood resilience: as the increase in potential "objects" exposed to flooding – exposure (e.g. people and assets, or roads and users) and the degree of flood factors rise – susceptibility (e.g. higher tides, more heavy rains), resilience becomes more crucial to mitigate flood effects, regarding to reduce flood vulnerability.

2.3. Flood resilience

Vulnerable cities need to be planned to have more resilience to particular events, such as large scale floods combined with other factors. Planning for evacuation and emergency management can lessen vulnerability (Campanella, 2006). This poses urgent questions to many governments in relation to practical design, stress management and emergency planning (Valdes and Purcell, 2013; Coaffee and Lee, 2016). Cities need to be prepared for worst-case situations; this refers to the threshold of stress that an urban system could withstand, adaptation to unpredicted changes, or to the reorganisation of their structure for survival.

2.3.1. An integrated approach

Since the early concept of ecological resilience of Holling (1973), scholars have attempted to develop approaches to deal with potential environmental disasters in cities. Indeed, this theory has been advocated after the realisation of increasing environmental losses and damages at the beginning of this century (Coaffee and Lee, 2016). As a development in community resilience to natural hazards, it is described as "the ability to survive and cope with a disaster with a minimum impacts and damage" (Berke and Campanella, 2006; Cutter et al., 2003; cited in Burton, 2015, p. 68). However, "community and social resilience is harder to determine, as it is more difficult to understand fully the impact on individuals and social groups of shocks that may come from either external or internal forces" (Rogers et al., 2012, p. 79). Furthermore, this has become much more difficult to evaluate in some mega-cities in developing countries, in which fully systematic datasets of all social development have not been built and are not accessible for research. For example, HCMC has officially registered about 7.2 million residences in 2015 but the actual number is expected to be about 10 million people due to a large number of immigrating labourers particularly located in new development districts. At the time of this research, the urban population distribution is still managed on a paper based system meanwhile a new programme for national population statistic has recently started by the central government. Thus, an access to data of people currently living at particular residential areas vulnerable to flooding is currently very hard to achieve. This acts as a considerable constraint to research and as such social resilience is beyond this research.

Therefore, for the remainder of this work, resilience theories can be interpreted as being engineering- or ecology-based (Holling, 1996; Liao, 2012). The first strand focuses on an ability to stabilise a state of a system near to an equiblirium point, while the second "emphasises conditions far from any equilibrium steady state" (Holling, 1996, p. 33; Holling 1973, O' Neill et al., 1986; Pimm, 1984; Tilman and Downing, 1994). These are often considered as two contrasting aspects and can be conceptualised under efficiency and existence, or "between constancy and change, or between predictability and unpredictability" (Holling, 1996, p. 33; Holling, 1973). Whilst the engineering emphasis is on the ability to 'bounce-back' to normal status (Wang and Blackmore, 2009); the ecological focus is on the capacity for survival (Walker et al., 2004). This has raised critical thinking around whether a system, such as urban transport, can be planned for resilient development considering both strategies, when dealing with natural disasters including extreme floods.

Liao (2012) proposed that 'urban resilience to floods' is the capability of a city to tolerate flooding and to reorganise itself in order to minimise potential fatalities and injuries, while maintaining its socioeconomic identity. This concept advocates 'floodability' and reorganisation in urban systems, and a reduction in the value of thresholds in order to increase the rate of tolerable socioeconomic fluctuation. However, it is argued that an acceptance of occasional floods within a city will in itself constrain urban development. For example, whilst properties can be designed to withstand the worst effects of flooding, the impacts of regular floods on daily commuting remain hugely disruptive to urban activities and economies (e.g. work, education, commerce and healthcare). Liao's research does not clarify how a city organises its floodable areas in terms of spatial dimensions in planning, which should demonstrate particular benefits in practice.

To this end, there remain several unanswered questions; for example, what flooding thresholds (in relation to particular flood levels) could be planned and assigned to urban areas and transport structures, or how a resilient model can be integrated into a framework for the planning and management system of a city. It is also argued that the gap between theoretical models and their practical applications is due to a lack of testing to demonstrate their feasibility. The greater the number of applications of a model into particular cases (e.g. cities, towns), the greater their value in practice. This has challenged urban researchers, who need to establish ways to apply their conceptual models to practical plans for specific cities. ‘Enhanced built-in resilience’ is needed in different urban fields, particularly in planning, management and design for cities (White and Howe, 2002; Godschalk, 2003). In practice, wider approaches to the urban context can be used to explain the rising number of resilient models for cities to mitigate hazards, including urban flooding, although some contemporary models of resilience still need more reality in the unevenness of space (Coaffee and Lee, 2016). Thus further research of resilience into the urban context is still necessary to propose more spatial-temporal models associated with tailor-made solutions to urban flooding, in which the resilience of transport is expected to complement urban flood resilience.

2.3.2. Properties of resilient systems

In the face of potential shock and stress, a resilient city can be seen as a complex adaptive system including sub-urban systems, of which their resilience can contribution to the resilience of a whole system for long-term development. Considered as a physical system, the resilience of urban infrastructure, including transportation, is constituted by the following four properties (Tierney and Bruneau, 2007, p. 15; Bruneau et al., 2003; Bruneau and Reinhorn, 2006; Liao, 2012):

i) Robustness: physical strength to withstand a disturbance;

ii) Redundancy: substitution of system components;

iii) Resourcefulness: identifying problems and mobilising resources;

iv) Rapidity: capacity for timely restoration.

With respect to urban development, rapid urbanisation has necessitated a major construction of urban infrastructure (e.g. roads, railways, embankments etc.,), which are normally planned and designed to cope with predicted demand with capacity. With respect to the stability feature of engineering resilience outlined in the previous section, new investments in infrastructure buildings are required to ensure a persistent state as the main function for urban activities. Thus robustness is considered as the key property, allowing a move from resistance to (engineering) resilience, whilst redundancy can be seen as an equally important to offer different options for critical elements, as a target to adjust system scale in order to ensure the 'survival' of the whole system regarding the objective of an ecologically resilient system. For example, in transportation Berdica (2002) believes that the preparedness of various options for transport routes/means between departures and destinations can mitigate the serious impacts on some parts of the system in the case of disturbance.

As secondary factors, resourcefulness and rapidity can be gradually evolved in the longer term, depending on the development conditions of each city. It is difficult to evaluate the sufficiency of urban resources and restoration capacity of a city if it has never experienced a shock. The true resilience of any city can only be observed and recognised through particular events (Desouza and Flanery, 2013). Otherwise, it could be tested by simulating worse-case scenarios for potential preparation (Coffee and Lee, 2016). For instance, urban areas vulnerable to flooding should retain a higher number of transport modes and means ready to deal with different flood scenarios, but this requires high (even abundant) budgets for investment and maintenance; e.g., a number of spare public transport vehicles and parking facilities for private vehicles. Such costs can be minimised by an effective forecasting ability, employing early warning systems in relation to different modelled scenarios. However, each simulation model also contains uncertainties due to the potential assumptions and data limitations, which are notable barriers. Therefore, it can be envisaged that robustness and redundancy should be prioritised for immediate development planning, whilst resourcefulness and rapidity should be included in longer-term plans following economic development prospects particularly in developing countries.

2.4. Flood resilience development for urban transport systems

2.4.1. Definition, and perspectives of development

Vision of transport development

Urban transport systems can comprise internal components, such as transport structures (roads, pedestrian crossings, corridors and terminal stations), vehicles and equipment, and external components (government, customers etc.) (Desousa and Franery, 2013); and they consist of several different modes, such as road, rail, sea and air. The transport network "is an indispensable component of the economy and plays a major role in spatial relations between locations", linking people's activities between different regions of the world (Rodrigue et al., 2006, p. 3). Evidence of how it acts as a key driver of economic growth can be traced back to the 19th century, in places which had seen little or no such development previously (Hart, 1993).

Development of a transport system is relevant to the shares of different transport modes, which can be changed in regard to practical demands. Roads are normally the dominant mode of individual mobility, while rail can satisfy the demand for high capacity travel (Xenidis and Tamvakis, 2012). Indeed, motorisation constituted the largest proportion of urban commuting in the EU due to their convenience; as a result, road and rail were the two types of transport which have rapidly increased in recent decades (ECMT, 1995). For urban commuting, social activities still mainly depend on urban road systems, which serve not only people’s daily mobility needs and the transport of goods, but also act as a lifeline system to rescue people when a city is faced with disruptions or needs repair or recovery (Mattsson and Jenelius, 2015). For longer distances, maritime transport is more effective in cost, while air has become a more competitive mode, with the fastest innovation (Xenidis and Tamvakis, 2012). In contrast to waterways, road continues to be the most popular mode, while rail is predicted to increasingly gain a share of urban trips. This has become a common trend during the development process in response to fundamental changes in social functions in many cities around the world (Mattsson and Jenelius, 2015).

Cities are still developing; they are not only an agglomeration of people and firms, but also a hub of transport networks for various human activities. There is no evidence of any potential reduction in urban commuting, despite future improvement in information technology (Glaeser, 1998). Particularly in developing countries, the demand for urban transport has been rising due to:

i) The increase in population (the larger number of transport trips);
ii) The expansion of built-up areas (longer journeys);
iii) Higher incomes (greater propensity for travel);
iv) Rising activities of commerce and industry

(Wright, 1991).

As cities continuously expand, changes in the level and distribution of urban populations in terms of spatial and geographic dimensions will inevitably lead to an increase in the complexity of transport systems, such as the generation of highly intensive routes between old centres and new residential areas. In terms of spatial structure, urban territorial expansion subsequently requires the enlargement of the transport network, and accelerates new investments in transport structures, such as new main roads, bridges or tunnels; in turn, new road development can trigger the development of housing and associated commercial activities. For example, main roads from the old town can be extended with potential connections to new suburbs in surrounding areas, so the resistant approach is often used for new developments in order to ensure the interconnection between the old and the new (e.g. elevation of road surfaces to accumulated flood levels). Reviewing the historical evolution of transportation, Rodrigue et al. (2006, p. 16) states that such a process is complex and is "related to the spatial evolution of economic systems", but many contemporary networks are either unchanged or only slightly modified, even after a long period of urban development, sometimes more than a hundred years. For example, the highway network in France has been established from the pattern of national roads, which were built in the early 20th century, but originated from roads built by the Romans (Rodrigue, 2006). "The development of a location reflects the cumulative relationships between transport infrastructure, economic activities and the built-environment" (Rodrigue, 2006, p. 11).

Flood impacts to transportation

As a result of the impacts of climate change, the transport systems of many cities have suffered many unpredicted effects. Extreme weather has affected transport modes, particularly road and rail, which can be susceptible to flooding (West and Gawith, 2005; Hooper and Chapman, in Ryley and Chapman, 2012). For instance, floods caused by heavy rain can result in physical damage and operational obstructions to certain segments, or to a whole network of roads or railways (Hooper and Chapman, 2012). The impacts can increase the direct costs of repair and maintenance, or lead to indirect economic losses due to closures of important transport links. For example, flooding resulting in road closures costs at least £100,000 per hour due to delays at peak times in London (Arkell and Darch, in Ryley and Chapman, 2012), an example being the floods of July 2007 (Standley et al., 2009). Related to SLR, flooding is more challenging to urban infrastructures in coastal areas compared to those inland (Walsh et al., 2007).

Flooding, which can be seen a kind of “external threat” related to “natural phenomena including various degrees of adverse weather and natural disasters”, can cause disruption to urban infrastructures, including the transport system (Mattsson and Jenelius, 2015, p.18). Any disruption to urban transportation may not only potentially damage physical structures, but will also result in widespread disruption to urban operations. Based on the two dimensions of frequency and degree of damage, Wang (2015, p. 184) classifies disruptions to urban transport systems into three categories: “disasters, day-to-day variations and ongoing long-term changes”. Normal incidents can occur more regularly (Campanella et al., 2006). For example, three hours of heavy rain in August 2008 overwhelmed the capacity of the urban drainage system (assembled under the road network) of Mexico City, with the resultant flood causing “a chaos of collisions” (Lankao, 2010). Despite their rarity, it can take a long time for urban areas to recover from the effects of disasters (Wang, 2015). They can even create lasting memories in people over many generations. Similar to the event 11/9, the US still has memories of Hurricane Katrina, a painful event associated with the failure of the central government to provide appropriate planning and a sufficient response to the disaster. It took hundreds of millions of US dollars to attempt to reconstruct New Orleans, but the former citizens would not return due to the fear of potential reoccurrence (Campanella et al., 2006).

Hence, it can be stated that urban transportation has become more susceptible to floods related to climatic uncertainties, although Divall (2012) argues that "the threat of climate change does not mean that we must trade or travel less". This implies that the intensity and complexity of urban transportation are expected to continue to grow, despite the increasing threats from environmental changes. This requires governments, particularly of cities in developing countries, to pay more attention to planning urban transport systems which are more resilient to adversity, and resilient development is required to coordinate with the existing resistant systems to maintain the operation of a whole system.

2.4.2. Developing flood resilience in transport planning

As previously mentioned, it is well established that the resilience of the transport system represents a key component of the overall resilience of the urban system, particularly as cities are becoming vulnerable to flooding. The transport system is a sub-system of physical and critical urban infrastructure systems and needs to be considered in resilience improvement, thus consisted by four properties (Tierney and Bruneau, 2007). "A certain minimum operational level must be ensured in any case of sudden disturbances that have various and adverse impacts to the systems; moreover, a quicker recovery of the system is imperative to avoid long-term effects" (Xenidis and Tamvakis, p. 3449). This highlights the need for early stage planning in the transport sector to develop resilience to precarious conditions, during which cities are still able to maintain certain levels of urban commuting.

In the UK, the resilience in transportation is defined by DFT (2014, p. 8) as "the ability of the transport network to withstand the impacts of extreme weather, to operate in the face of such weather and to recover promptly from its effects", in order to ensure:

- Continued transportation of people and goods;
- Quick restoration of services and routes to normality;
- Sufficient and thorough communication to transport users.

These three objectives of a resilient transport system are suggested in the context of UK conditions with a transport system and infrastructure developed over a long period of time. They can be targeted differently under a developing countries context which have more recently planned for their infrastructure developments as a driver for economic development. During a flood event, resilient transportation would be expected to minimise potential widespread disruptions from some critical routes to the whole network as the capability to maintain its vital connection between different areas. Thus, the continuation of its function therefore should be a priority while the time for restoration and communication can be considered as the less important features which could be developed in longer term as cities can obtain stronger finance to achieve.

Flood resilience development relying on key properties

With respect to the properties of a resilient system addressed in the previous sections, whilst robustness allows an urban transport system to develop its resilience, initially based upon engineering, in coordination with its existing resistant structures; the redundancy can align to the objective of an ecological system. As mentioned in section 2.2.1 (Figure 2.1), a new road development with significantly higher elevation for the whole structure (e.g. high-elevated road about 4 – 6 m from current ground and leaving open space underneath) compared to an at-grade route can offer another choice for travelling avoiding inundation. This implies that an appropriate engineering solution to such critical routes remaining available in flood conditions. Indeed, Xenidis and Tamvakis (2012) state the need for engineering resilience to help a transport system regain balance and return to normalcy, with a focus on the system’s robustness depending on its capacity to adjust functions when it is affected.

Additionally, redundancy is considered as an objective to develop a resilient transport system. It can be measured by the extent of routes and modes potentially being substituted as elements which have lost their function (Tierney and Bruneau, 2008). It not only increases the diversity of options to stabilise travelling activities (the engineering), but also ensures survival of essential routes for emergency (e.g. high elevated roads for evacuation or waterways for rescues), in regarding to the ecological in long-term. Wang (2015) considered transport system as an ecological system with the ability of self-adaptive organising. “Resilience reflects the degree to which a complex adaptive system is capable of self-organization (versus lack of organization or organization forced by external factors) and the degree to which the system can build capacity for learning and adaptation” (Adger et al., 2005, p. 1036).

In planning for urban transport development, the four properties of a flood resilient system can be detailed below.

- *Robustness* refers to the physical strength of the transport system. With the shift from resistance to resilience, the elevation of transport structures can be increased in response to particular flood thresholds, which can be linked to vulnerable flood levels or different scenarios. In this case, engineering solutions can be deployed, with a focus on stable structures against existing flood levels, with buffers, such as:
    - An elevated transport surface against accumulated flooding levels, with proposed ‘empty spaces’ under these structures for floodable areas, instead of ‘solid spaces’, in order to retain open spaces for water storage and absorption, as part of the infiltration process.
    - Co-ordination between any increase in the elevation of main roads, and corresponding decrease in the elevation of the remaining roads less important (e.g. residential roads). This can ensure the connection between urban roads (at different levels) and civil buildings and can also achieve a cost reduction in backfill if increasing the whole network and linked buildings.

- *Redundancy* refers to the ‘back-up’ capacity of the transport system. It should ensure the continuation of urban travel during disruptions, and can be targeted by a self-flexible organisational structure constituted by links and nodes, through plans for substitution to vulnerable or disrupted segments, such as:
    - Surrogate routes avoiding regular floods, also emergency routes for evacuation;
    - Alternative modes can be transferred to at transport nodes, which should have appropriate conditions for potential switches between the different modes; for example, from roads (private-motorbike) to waterways (public-water bus).

- *Resourcefulness* is the ability to identify problems in priority to mobilise appropriate resources for potential replacements. A target to increase transport spare-capacity needs to be planned, such as number of vehicles or buffer spaces for any sudden increase in demand and occupation (both people and vehicles). For example, a number of buses and bikes can be preferably allocated at critical nodes (i.e. stations) near to vulnerable areas in order to prepare for transport transfers. This also consolidates redundancy although it requires the financial strength for high level investments; and this can lead to an abundance of transport resources if there is a lack of an effective plan.

- *Rapidity* refers to the capacity to decide appropriate priority for actions to achieve goals in a timely fashion in order to constrain losses, recover functionality and avoid future disruption. This can be achieved by the operational plans for different flood scenarios, is related to the capacity of real-time tracking of the ongoing progress of flooding situations, and to the forecasting of potential widespread effects on other vulnerable places. This can be achieved by using of a smart network, including tracking devices set up at critical routes/places, Internet of Things sensors, and a controlling system. Software (e.g. mobile apps) can maintain communication between commuters and operators (e.g. centres for forecasting and resolution).

Planning framework with the integration of a resilient transport system

In terms of flood management, Zevenbergen (2008) emphasises the spatio-temporal relationship evident in the varying scales of catchments, cities and buildings. “Urban flood risks should be proactively managed through resilience, taking advantage of interventions at different spatial levels” (Zevenbergen et al., 2008, p. 87). At each scale, flood vulnerability can be measured and reduced using indicators of exposure and sensitivity, with resilience development at each level enhancing the resilience at others (Zevenbergen et al., 2008). However, this approach does not consider the role of physical transportation as a mechanism for the objectives of an increase in routing options. This can be seen as a gap for further research, as transport, such as road networks, is a vital component in the interlinking of these scales. For example, urban road networks can be organised to offer different routes for commuters from their home to their working place or to temporary refuge locations in cases of emergency. To consolidate, the structure of the transport system can be broken down corresponding to these spatial levels, so that it can also be applied to existing plans for urban development with an emphasis on city level where potential integration can be targeted (e.g. spatial development strategy, land-use, transportation and flood management). Therefore, the concept of Zevenbergen et al. (2008) can be extended to transport resilience planning as follows:

- *Building level:* improved design for ‘inner-transport’ such as ‘flooding exits’, which could be combined with ‘fire exits’ to safe places which should be able to link to emergency routes at the urban level;
- *Urban/city level:* classification of road groups based on flood thresholds, with reference to elevation, in particular the use of ‘hardened and elevated’ emergency routes linking transport nodes (major or minor);
- *Regional level:* enhanced connectivity between different urban refuges, which should be interlinked by emergency routes.

Of the three levels identified, the middle scale (urban/city) is key, and allows for the most intensive application of measures, as well as encouraging the general shift from engineering to ecological resilience. On this scale, Desouza and Franery (2013) conceptualise a framework consisting of three sets of interventions to build urban resilience through a process of planning, design and management, but such a framework means that failure at a certain level can create widespread effects which propagate and cascade to other levels. This requires a connection between the master plan for spatial development (i.e. the general plan in HCMC) and a transport plan, both of which should be synchronised within a comprehensive planning framework.

Based on the concept of ecological resilience in a planning framework, Liao (2012) suggests a shifting process from resistance to “urban resilience to floods”, with regard to the capability of a city to tolerate flooding and reorganise itself in order to minimise potential fatalities and injuries, while maintaining its socioeconomic identity. This concept actively advocates ‘floodable areas’ in planning and considers a balance of flood thresholds which would be tolerable (Liao, 2012). However an identification of appropriate values being assigned to such thresholds has not been addressed, meanwhile an acceptance of flood prone areas in a city needs a consideration of potential effects on transportation, such as the potential flood disruptions to urban commuting crossing such “flood-able areas”. This has encouraged the search for further development concepts for the urban transport systems when cities are expected to “contain” some inundated areas within their territory.

As a development of a pertinent concept by Liao (2012), a comparison and contrast between a resistant or resilient city, a reduction in flood thresholds can downgrade requirements for construction in practice. This can be applied in planning for urban development in adaptation to flooding, regarding to more efficient investments in urban infrastructure including transport facility. For example, a continuation of increasing the elevation of existing urban physical infrastructures, such as crest of embankments or road surfaces which is nearly breached by rising river-water levels, is still considered unsustainable in long-term as flood factors have become more uncertain in line with climate change and rapid urbanisation. Alongside this, the important issue is to identify threshold values, based on which potential transfers can be triggered to mitigate unexpected effects to daily activities and, ultimately, urban development. In other words, values of flood threshold should be specified in practical planning, and perhaps a link to flood vulnerability degree assessment is an appropriate implementation. Linked to this, McDonald and Walker (2007) highlight that a resilient system, being complex, should have the capacity of adaptability in order to manage the current status away from the threshold and transfer it to another kind of system. Until a tipping point is reached, a transport network will self-organise under different thresholds of flooding (*Figure 2.3a*).

Although resilient strategy is emerging, almost all cities at risk to flooding have been built using resistance systems (e.g. riverbanks, levees), which mainly protected old town areas in former times. It is argued that replacements for such systems are less feasible in practice due to the potentially high cost of systematic change. Additionally, citizens tend to believe in ‘visible systems’ which display their physical strength and which can be presented on particular sites (e.g. higher crest elevation of riverbanks against current flood levels). Therefore, coordination between existing resistance systems and new resilience systems are more convincing, from the planning to the implementation stages. Thus, the concept of Liao (2012) can be seen as a promising strategy for the revision of spatial plans for cities to become resilient to flooding through a framework, but resistance and resilience should work together through a shifting process. They need to be allocated a spatial presence for co-existence in a city. For long-term strategies, resilience development should be applied in a cycle including three circular stages:

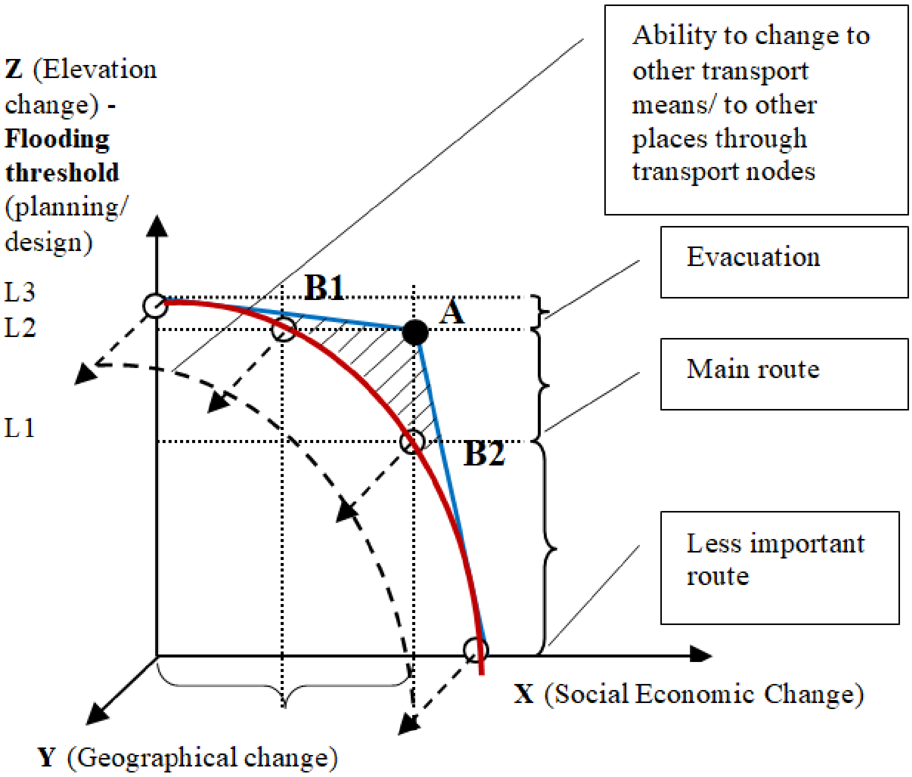
Resistance - Engineering Resilience - Ecological Resilience (see *Figure 2.3b*)

This shifting process can be applied in cities which need to identify which urban areas actually need to be planned for resistance, resilience or cooperation. The benefits of this process are predicted to:

- Balance flood thresholds in order to lower the resistance rate, and create an initial step for a shift to resilience;
- Develop resilient capacity without the destruction of existing resistant systems, with consideration of effective investments.

In short, a system-based approach has contributed to a more sophisticated understanding of flood resilience through the interpretation of resistance and engineering/ecological resilience, followed by different frameworks such as spatial-temporal interactions on different scales (Zevenbergen et al., 2008); increased tolerable socioeconomic fluctuation (Liao, 2012); and planning, design and management of the process for transport systems or cities (Xenidis and Tamvakis, 2012; Desouza and Flanery, 2013). Cities are generally not keen to abandon existing flood defences in order to create a resilient system; sustainable development is needed, with fewer effects or disruption from flooding. To satisfy this need, resistance and resilience (including engineering/ecological) can and should co-exist in the same urban system. Within this debate, transportation has developed its role in the connections between sub-systems (e.g. electricity, communication), or in the breakdown of spatial levels (national/regional, city, community/residence). Its resilience can be planned over long-term development, with an appropriate framework of planning and management.

a)



<u>Notes:</u> *One fixed threshold A can be transferred to the thresholds B1 and B2 to lower investment levels and influences on existing buildings; referring to social economic change (e.g. living environment)*

b)

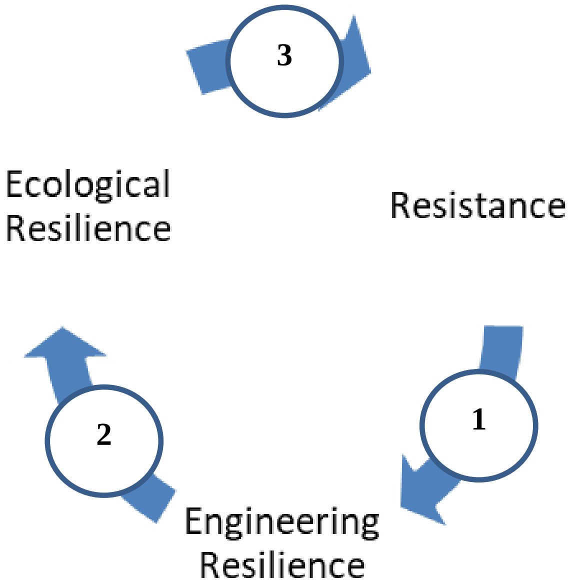


Figure 2. 3 Shift from resistance to resilience (engineering and ecological):

a) Shift from resistance to resilience. Adapted from Liao (2012);

b) Flood resilience transfer cycle applicable in transport system

As a theoretical development by this research in planning for flood resilience, an increasing elevation of the transport surface can add to the robustness while cooperation between such increase and potential change in location of transport structures can offer higher levels of redundancy. This has become the fundamental argument that the flood resilience of the transport system can be still developed based on engineering solutions such as increasing elevation, and by planning for spatial transfer of transport flows in adaptation to flood uncertainties as part of the long-term strategy for the ecological system. The engineering and the ecological are differentiated in theory, but can complement each other within a transport system during development. These theoretical strands can be incorporated in a model of planning for development.

With an inter-links to the previous sections (3.2 and 3.3), increasing elevation of transport routes overpassing potential inundations can be seen as a strategy for engineering resilience development based on the robustness of physical infrastructure. A lower-level road surface for the majority of roads (with solid underneath) is a resistant solution to slight (and perhaps regular) floods, and leaving underneath spaces for floodable areas is targeted at more resilient development in dealing with extreme floods. In planning, a classification and cooperation between these transport routes can be seen as an appropriate strategy for shifting from resistance to engineering resilience. The floodable areas can be designed for natural water absorption such as “bare-earth surface”, referred to as the wetlands, for a further step towards ecological resilience. On the other hand, an improvement of alternative routes substituting for vulnerable segments is referred to as redundancy. This property can help a resilient transport system deal with the uncertainty of flooding (e.g. changeable inundations) in coordination with robustness dealing with changeable flood levels. Besides, as mentioned in section 3.1.2, a transfer is also possible between different transport modes (e.g. road to waterways) and can be seen as a means to target the “survival objective” of an ecological system. Overall, the spatial transfer of transport flows on physical structures can contribute to engineering resilience as the key stage emphasised by this research, while the possibility of using different transport modes can help these systems survive greater adversity, .

2.4.3. Compact spaces coordinated with a resilient transport system: a vision for urban development in adaptation to flooding

As urban development is inevitable in many countries, increasing compactness in terms of spatial planning and management is also potentially the answer for a city to minimise its urban areas vulnerable to flooding, as long as the reliability of transport between these areas is consistently ensured. The notion of a compact city, which adheres to the desirability of sustainable development advocated by the European Community since the 1990s (Commission of the European Community, 1990), continues to be supported by scholars who place emphasis energy efficiency with promotion of the “intensification of the use of space in the city” (Elkin et al., 1991, p.16); the viability of amenities and facilities for social sustainability (Haughton and Hunter, 1994); and the ability to “offer the maximum scope for effective traffic reduction” (McLaren, 1992; p. 281). In several such cities in OECD countries, their potential success has been demonstrated in meeting urban needs and reducing environmental impacts (Matsumoto, 2012).

To a wider extent, the focus can be on reducing urban areas prone to floods, with land-use efficiency achieved by utilising ‘advanced’ lands, referred to as higher land with the advantages of interlinked transport routes, for spatial development in a vertical dimension, rather than centripetal urbanisation, leading to widespread construction on floodplains. Centralised, compact spaces could be deployed from the building scale to urban scale in order to reduce land occupation for urban development. Subsequently, urban public space should employ ‘absorbable surfaces’ such as green areas; there is also a need for maximised functions within buildings in terms of architectural design, e.g. optimised height, interconnected corridors and storage spaces for water, whilst transportation structures are not only links between civil buildings and urban spaces, but also an incentive for improving adaptation to flooding.

Despite its advantages, compactness theory has been debated in relation to different contexts (e.g. Europe, the UK, US and Australia); the quality of the living environment; and transport development. In terms of urban density, the relation between transport development and urban compactness has become a hot topic, with divergent opinions on density and travel (Breheny, 2001; Banister, 2005). In the UK, larger metropolitan areas have shorter transport travelling distances and energy consumption (Department of Environment, Transport and the Regions, 1997; Banister, 2007), but this is hard to clarify in the US context (Gordon and Richardson, 1997). Although urban compactness shows varying empirical evidence of saving transport energy consumed in centralised areas (Banister, 2007), decentralisation has still remained the trend in urban development (Breheny and Rookwood, 1993). On the other hand, Thomas and Cousins (1996) advocate that urban centralisation, referred to as compactness, is an appropriate choice for cities targeting sustainable development.

On balance, a stance based on compromise reconciles sustainability with controlled development (Jenks et al., 1996). In the 21st century, cities are notional urban forms; this means that they are not completely compact or dispersed (Banister, 2007). For example, urban decentralised areas can contain several compact settlements interlinked by public transport (Houghton and Hunter, 1994); with appropriate walking and cycling modes to encourage social interaction between different residential areas (Elkin et al., 1991), as well as health benefits and lower levels of congestion (Tight et al., 2012; Tight, 2016). Additionally, these routes can become emergency evacuation routes if incorporated into defence schemes. Hence, new developments with compact spaces on advantageous land (e.g. high elevation, at a distance from flooding risk) can be less exposed to floods and are a promising solution to enhancing urban resilience.

In practice, compact developments can go hand in hand with resilient transportation. There is much evidence to support the benefits of spatial compactness to improve transportation efficiency with regard to the control of emissions in cities (McLaren, 1992; Bozeat et al., 1992, Rickaby et al., 1992; Matsumoto, 2012). Indeed, in recent testing of a compact city index in 41 Japanese cities, Lee et al. (2015) state that the transportation network can complement the improvement of urban compactness for sustainable development. However, the costs of compact development can be high, whereas the development of surrounding areas, such as wetlands, is normally low cost, and offers affordable housing for migrants on low incomes. In addition, land directly adjacent to bodies of water is attractive to those on high incomes and offers significant profit potential for developers. These two factors result in high demand for such locations, the development of which needs to be constricted by governmental authorities. The higher costs associated with compact development can to some extent be offset by the need to invest less in flood protection systems, the savings from which can be further realised in cases of severe floods which breach defences (i.e. the significant costs and losses experienced in New Orleans and Manila). As the aim is for urban areas vulnerable to flooding to be reduced, spatial compactness is expected to be delivered for the demand of urban development. Thus a resilient transport system is essential to interlink these separate areas, and to maintain connected urban activities. This also requires an assessment of which areas are not vulnerable to flooding to plan for potential compact developments in the long term.

2.4.4. Geographic network in transportation

Assessing the flood vulnerability of specific urban areas or transport networks is essential when referring to the planning for resilient development. “Planning for resilience to the impacts of stressors within cities to network disruption requires an evaluation of the vulnerable network components of cities, an understanding of how these components facilitate certain interactions, and the capacity to design various components and their interactions with the ultimate goal of achieving resilience” (Desouza and Franery, 2013, p.90). In respect of an adaptive strategy, Koetse and Rietveld (2009) suggest identification of the most vulnerable locations and routes considered for accessibility to essential facilities such as hospitals. Along these, ‘flooded road hotspots’ can be used to manifest the wider impact of floods on emergency responses (Yu et al., 2017, p. 420). To succeed, the use of detailed hydrological models for flood simulation provides an important contribution to mitigating future flood losses and damages, informing a GIS analysis to map inundations and to consider their impacts (Wang et al, 2010).

To analyse transport systems in urban geography, networks are commonly used to present an analogy for transport structure and commuting flows (Rodrigue, 2006). The term ‘network’ refers to a framework of routes, one of which is defined as a link between different locations, identified as nodes, in a spatial system (Rodrigue, 2006). A link between two nodes can be a part of a larger network including tangible routes such as roads and rail, or less tangible routes such as air and sea lines (Rodrigue, 2006). Despite being specifically catagorised in the spatial dimension, urban transport networks also belong to wider networks, mainly including non-spatial elements such as social interactions, corporate organisations, and biological systems (Rodrigue, 2006). Such an approach allows identification not only of particular segments directly affected by particular factors such as flooding, but also of further indirect effects on linking segments or whole routes belonging to the network.

For the planning of transport development, the network of a city can be designed to meet the demand for urban commuting related to the spatial structure characteristics (e.g. zone division versus population distribution), and daily activities (e.g. work, education or recreation). In terms of location, the variety of structural types depends on the interactions between key components such as nodes, links, flows, hubs or corridors constituting the network (Rodrigue and Ducruet, 2017). According to Blum and Dudley (2001), the three territorial structures can be simplified into three types, namely the centralised structure (one core centre and multi-directions of transport accessible routes); the decentralised structure (multi-centres offering different accessibility); and the distributed structure (a balance of accessibility allocated to various centres). These types have been divided into two categories *(see Figure 2.4a)*:

- A centripetal structure, showing a radial pattern with strong centrality allocated at certain major nodes, referring to important transport hubs intersected by several routes.
- A centrifugal structure, showing a likely 'grid pattern' with unspecific centrality, which is likely to be equally distributed between all nodes.

When observing urban networks, the second category can be identified through a square-grid line pattern of urban road networks, whilst the first can be easily realised by a large volume of transport converging on intersections such as roundabouts. In fact, that type of transport hub, i.e. a highly centripetal structure, has recently emerged in many cities, but the form has shown a significant disadvantage related to high vulnerability and potential disruptions due to the limitation of alternative routes (Rodrigue and Ducruet, 2017). For instance, an obstruction to a road section can easily lead to inaccessibility to other linked segments due to the lack of necessary substitution, even disruption to the whole urban network (see illustration in *Figure 2.4b*). This also implies potential isolation to particular nodes, with reference to urban areas.

The disadvantage of centripetal networks is more of an acute problem in many emerging cities in developing countries. It can be expanded from a unique core centre (old towns) to the new surrounding suburbs, but the development plans maybe fail to ensure the reliability of some intensive routes vulnerable to unexpected effects such as flooding. With a link to the section 2.1, a large number of intersections between road networks and river networks can be seen as weak points in emerging coastal cities, many of which have a network constituted by one level on the ground. Thus the effects of flooding of some main routes or nodes can be transferred to others. A transport network is still considered less resilient if it can be disrupted on some critical routes or hubs (Rodrigue and Ducruet, 2017), subsequently resulting in effects on the whole network. "A resilient network remains connected after facing disruptions such as severed nodes or links" (Rodrigue and Ducruet, 2017). Along this, *network redundancy refers to various links ensuring continuous and consistent accessibility in response to different flood magnitudes and can primarily contribute in planning for resilience development in transportation.* This needs an analysis of the vulnerability of the network. This requires an understanding of the characteristics of the integrated network, or at least the main modes such as roads, with reference to the type of structure, the orientation of structural development, and the potential interactions with flood factors (e.g. riverine networks) during the historical process of spatial development.

Hence, a comparison between the outputs of different studies is an appropriate mechanism to control the uncertainties in research, and to realise a general pattern. The most important consideration is that the results of the simulation process can become a reference for subsequent analysis, from which flood mitigation should be based on different scenarios instead of fixed solutions. Urban planners can thus anticipate what type of, and in what way, disruptions will materialise in particular urban areas or transport segments. The aim of such anticipation is not only to revise existing plans, but also to replicate this combined method for potential updating of more accurate inputs to produce further flooding scenarios. This is an appropriate way to deal with uncertainty in respect of resilient strategy. The following chapter will present evidence for increasing flood vulnerability in HCMC in line with the current situation, and the existing master plan for development.

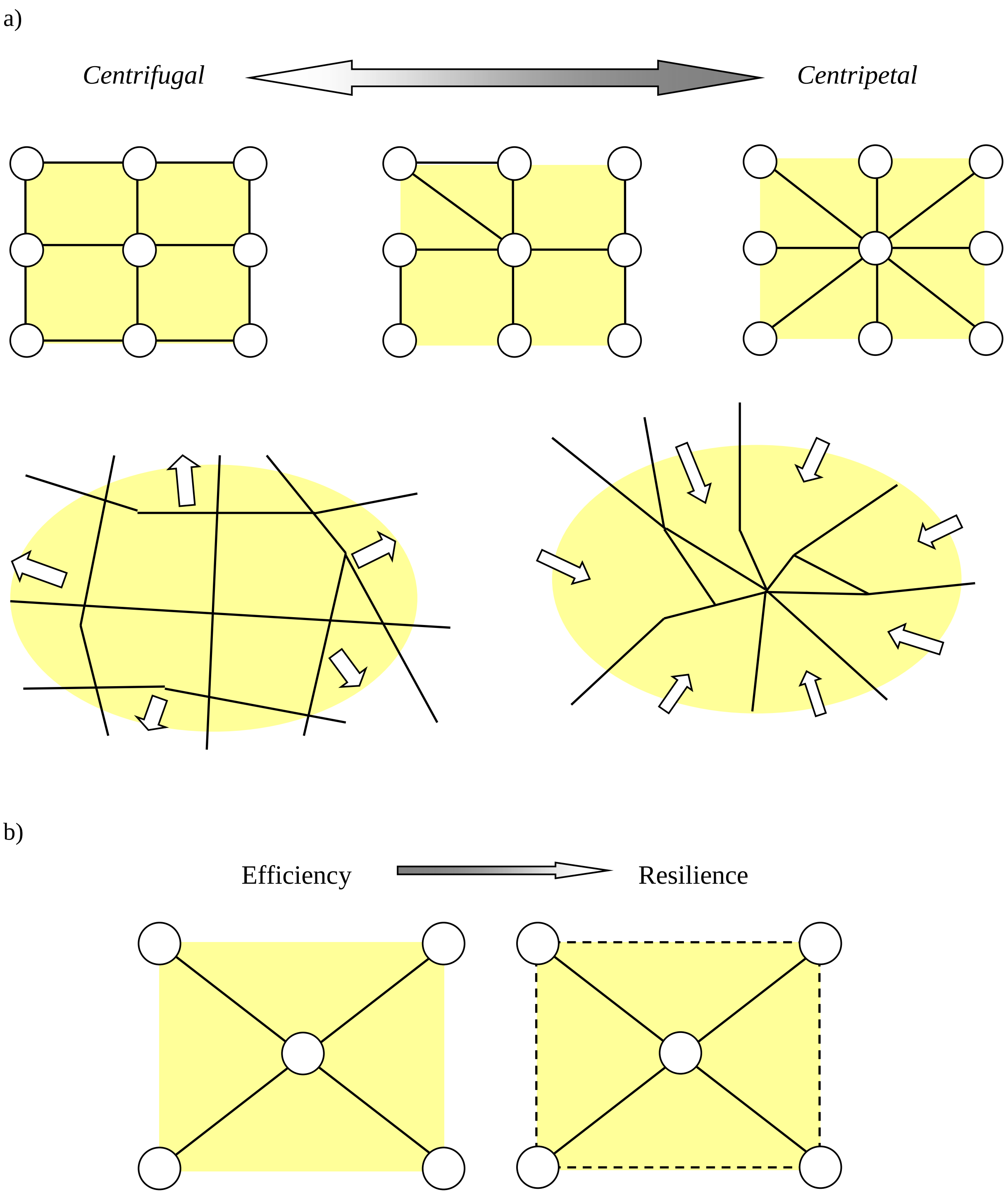


Figure 2. 4 Different types of urban network structures (adapted from Rodrigue and Ducruet, 2017):

a) Categories/ types of transport network development: from a simple centrifugal structure in theory, to complex centripetal structures in practice

b) Structural difference between efficient and resilient networks

2.5. Summary

2.5.1. A vision for transport development constrained by flooding, in line with rapid urbanization driven by ultimate economic growth in emerging coastal cities

Along with historical urban expansion driven by economic growth, transport systems have developed in terms of spatial and geographical dimensions, such as larger horizontal networks, and also more geographic links to new suburbs surrounding their old centre in order to meet the higher transportation demand. A characteristic of coastal cities which often have many river channels in the vicinity as well as low-elevation of the areas surrounding such water bodies raises the potential threat to the transport network. Moderate floods can break the continuity and cohesion, and affect the transport connections between different urban areas, while extreme floods can cause constraints on evacuation, consequently leading to high losses and damages to isolated areas. Case studies from other cities are therefore necessary to draw useful lessons related to uncontrolled settlement on low-lying lands vulnerable to flooding, and potential losses and damages due to inaccessibility of transport in emergency. Therefore, the development of transport systems in emerging coastal cities are required not only to meet the increasing demand of urban commuting, but also to deal with potential flood effects. Closely linked with the urbanisation process and the expansion of urban areas facing flood hazards, a balance between horizontal and vertical development of the physical transport system is necessary, referred to efficiency in long-term development particularly in developing countries.

2.5.2. The relationship between flood vulnerability and flood resilience

With reference to flooding, vulnerability and resilience are claimed to be closely related, understanding the relationship between these two aspects is useful to alleviate flood impacts. Thus development of flood resilience of is much more important, particularly for the transport systems of emerging-coastal cities, which have become vulnerable to flooding due to the exacerbating flood factors related to climate changes (e.g. higher tides, increased intensity of rainfall), and rapid urbanisation on low-elevated land close to water bodies. Particularly in emerging-coastal cities in developing countries, increasing the elevation of the whole network is infeasible for practical implementation. Thus the elevation classification in planning for network expansion is essential to consolidate their robustness and the redundancy of transport systems regarding to flood resilient development. This has led to the need of assessing flood vulnerability, with a focus on the main mode (e.g. road network) especially some critical routes bearing intensive flows, between the old centres and new development areas. Alongside this, vulnerable routes need to be identified by a comparison of simulations of flood surfaces and the transport network. This requires a combination of methods to include hydrological-modelling and spatial analysis based on GIS.

2.5.3. Developing flood resilience in transport planning

Although resilience has emerged as a promising and iterative approach, and has also evolved with a wide range of interpretations, the application of existing models needs to be developed through a framework for spatial planning, and development of a particular case study referring to a city facing flood problems. In fact, few studies have proposed a model for developing the flood resilience of transport systems with a comprehensive process from the concept, application and testing to implications, roadmap and blueprints for implementation in practice. The literature review has identified this knowledge gap in flood resilience as well as highlighted the fundamental principles in planning for transport development under the context of emerging-coastal cities vulnerable to flooding. Therefore the model of FRTS is proposed to be the key element to be investigated by this research along with the main aims mentioned in the introduction, with a focus on how to make urban transport systems more resilient if these cities have opportunity for revising urban plans for transport development.

Through an urban planning framework, the flood resilience of transport system can be planned for development based on four properties: *robustness, redundancy, rapidity and resourcefulness*. With respect to emerging-coastal cities in Southeast Asia, this research emphasises the first two of these properties due to main target of coordination between new resilient developments, and existing physical transport infrastructure resistant to flooding, as the contemporary opportunities for revising plans under the pressure of rapid urban development driven by economic prosperity. Linked to the interpretation of resilient properties (sections 3.3.2 and 3.4.2), an improvement in robustness and redundancy can help maintain a stable transport system, referred to as the efficiency function of an engineering resilience system and the key objective of the FRTS, meanwhile an ecological development could be achieved along with the resilience cycle in the longer term. Thus, the FRTS model of can be developed in planning with the following fundamental principles:

- *Horizontal development, referred to spatial distribution broken down to three levels, with the focus on city level, subsequently divided into different zones;*
- *Vertical development, referred to elevation classification corresponding to flood thresholds, which can have a link to the value of vulnerable assessment.*
- *For such spatial organisational structure, critical nodes need to be identified and suitably engineered to support the possibility of transport transfers.*

For application in HCMC, vulnerability assessment is crucial to identify which urban areas, followed by transport sections, are vulnerable to floods at present and in the future. This can be achieved by the combined method as mentioned, with reference to hydro-meteorological changes, and existing plans for transport development. Besides, the applicable feasibility of this model also needs a consideration of current flood impacts and conditions of transport development in different cities through on the ground study. The next chapter will explain the methods needed for this research.

Chapter 3

RESEARCH DESIGN AND METHODOLOGY

In order to achieve the aims, the research uses a combination of different methods informed by the outcomes from the previous chapter to provide an approach to developing resilience of the transport system with a conceptual model for cities vulnerable to flooding. The design for this research is particularly applied to the case of HCMC, but also is expected to be useful in reference for urban planners conducting urban planning projects in other coastal cities having the characteristics of transport development similar to HCMC, especially in SAC.

3.1. Research design

Each city is unique. Methodologies need to evolve to work at the local level, but remain generic to ensure applicability elsewhere. Based on common approaches encountered in the literature review, this research is designed as follows:

- Understand the local flooding issues in HCMC, providing evidence of increasing flood vulnerability to ground conceptual solutions in the real world;

- Look at other cities around the world to review lessons related to flood resilience to a level far worse than that currently experienced by HCMC, to illicit common issues and best practice with the focus on the role of transportation;

- Model the future flooding situation by using Hydrological Modelling and GIS in HCMC to inform a conceptual model of flood resilient transport systems (FRTS) with potential application in planning;

- Based on the principles of FRTS, propose adjustment to the transport plans in HCMC through the outcomes of implications, roadmaps (for implementation) and blueprint.

More generally, the approach commences with fieldtrips to HCMC to investigate flood impacts particularly affecting urban commuting with some anecdotal evidences from observations. For the flood factors related to flood vulnerability due to urbanisation, the secondary data of property developments were also collected for GIS analyses on spatial distribution as the anticipation for increasing residences exposed to flood risk especially in new development districts.

It is proposed that a number of flood cases studies, which are devised, highlight the lessons regarding to high losses and damages due to uncontrolled urbanisation on vulnerable areas, and the importance of transport systems in flood resilience. As per the literature, the theoretical development of flood resilience allows the identification of some fundamental principles for proposing a conceptual model for a flood resilient transport system with an application in HCMC. Testing of such conceptual models requires hydrological-modeling and GIS analysis for flood vulnerability assessment, which has become the base for solutions in practical planning (e.g. flood vulnerability levels linked to thresholds for resilience). The final outcome of this process will be the base of proposed adjustments to the current plans for transport developments in HCMC. The author has already been registered in a research team by the Department for Architecture and Planning, with the brief to make recommendations for potential changes in transport planning in relation to the flood problem and in line with climate change. Furthermore, with the support of the University of Architecture of HCMC, the use of combined method between Hydrological Modeling and GIS Analysis (HMGA) will be introduced for students in urban planning field.

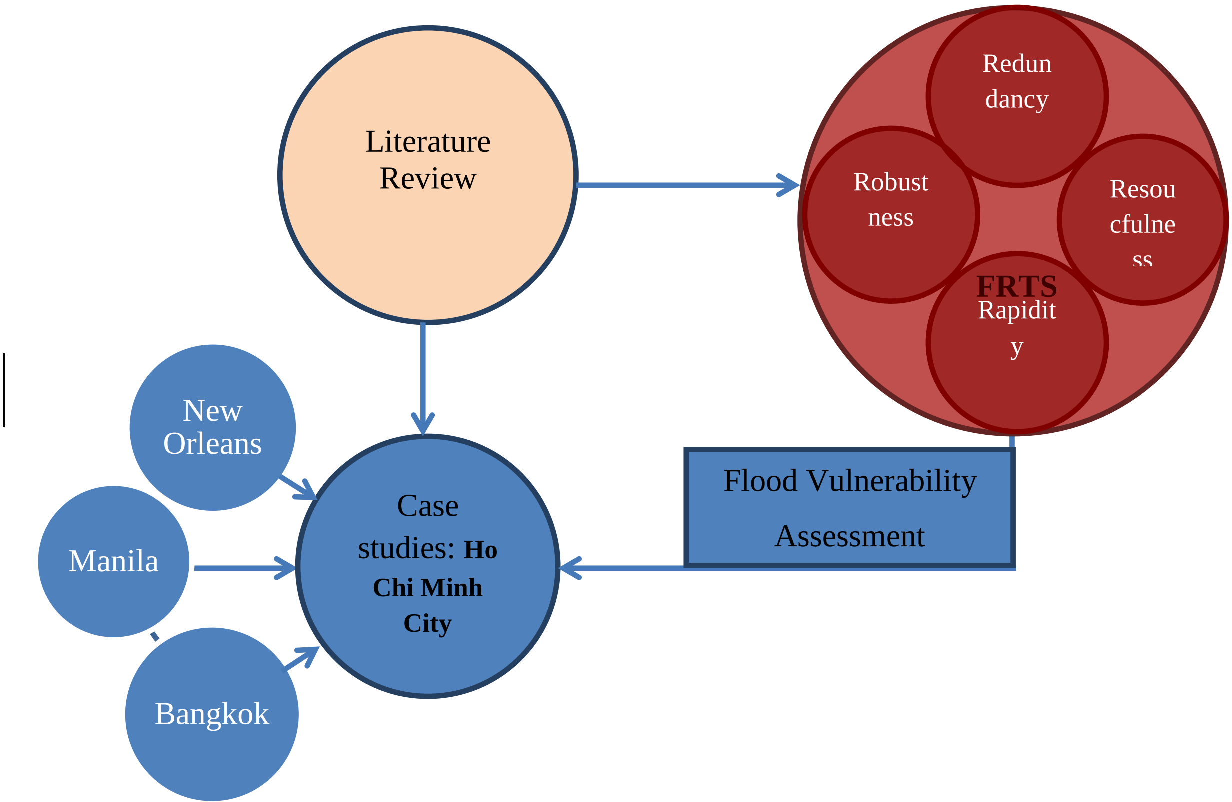


Figure 3. 1 Research design

3.2. Methods used in this research

3.2.1. Fieldtrip

Two fieldtrips were conducted in 2015 and 2016 to provide the initial anecdotal evidence of the worsening floods affecting transportation in HCMC. The onsite observations were used to capture the actual impacts to transportation and transport facilities, in reference to flood factors such as high tides and heavy rains. In particular, two large-scale events were analysed to demonstrate potential flood disruptions to some critical transport routes, with widespread effects to the whole network. Besides, the observations and measurement of some flood facilities along transport structures, as well as on-going transport developments in line with resistance implementation, are also necessary to recognise the inadequacy of current plans for transport development to deal with flooding.

Wherever possible, site approaches were deployed in order to collect information attached with related photos. This approach was used by Pregnolato et al. (2017) for the case of Yorkshire and provides useful anecdotal evidence of different flood impacts to transport vehicles. As discussed about potential investigation to flood effect in the previous chapter (section 2.2.1), flood depths in particular places were identified after measurement by tools or by estimation based on nearby indicators such as motor-bike wheels or sign posts. Additionally, secondary inundation data were also used to illustrate some critical routes vulnerable to flooding and as supporting evidence for certain deficiencies in planning and implementation of transport development. Tools and computer applications are used including:

- Tape measure and laser distance measurer (for flood depth and change in tides);
- Camera (for photos) and laptop (outline travel routes, mark locations of inundations);
- Google online form (Google docs/ sheets), Arc-GIS.

3.2.2. Case studies

Next, to put the current flood situation in HCMC in context, three extreme flood case studies in three coastal cities are made to investigate the lessons of flood resilience related to the role of transport systems in contribution to urban resilience to flooding. In parallel the increasingly uncertain threats by climatic changes exceeding resistant systems, uncontrolled urban developments on low-lying lands adjacent to water bodies and the lack of transport availability during extreme floods has resulted in high-losses and damages as proved in the cases of New Orleans 2005 (Petterson et al., 2005; Cigler, 2007; Campanella, 2008), Manila 2009 (Sato and Nakasu, 2011) and Bangkok 2011 (WB, 2011). These lessons have implied the importance of preparedness, referred to as long-term planning for urban development, in which physical infrastructure including the transport system are a vital element. By comparing these cases, the research highlights the implications for HCMC, as well as other emerging coastal cities in SAC, which have opportunities for revising their urban plans including transport development, which need to be integrated flood resilience objectives.

3.2.3. Hydrological modelling

Next, there is a need to understand how flood vulnerability will change in HCMC to understand if the city could be prone to more extreme flooding in time. Hydrological modelling, as the base for flood vulnerability, is commonly used to create flood surfaces in simulations. Simulations based on such models can help predict flood events and to understand hydrological processes (Bates et al., 1999). Depending on different case studies, the process of simulation can be carried out in several ways, depending on the availability of data (e.g. water level, discharge water volume or rainwater) and site conditions, which decide appropriate techniques and accuracy parameters for the process (e.g. resolution - cell size). In practice, a one-dimensional model (hereafter called “1D”) is commonly applied for large scale areas, such as a mega-city located on a large river basin, influenced by complex meteorological factors related to a wide range of data availability.

Several 1D-models have been used for such an approach in the literature (for examples, ANSWERS (Beasley et al., 1980), IHDM (Calver and Wood, 1984), VSAS (Barnier, 1985), SHE (Bathurst, 1986), DBSIM (Garrote and Bras, 1995), reviewed in Bates et al. (1999). As a development, two-dimensional modelling can be used for smaller catchment areas but it requires more in-depth investigation accompanied by much more complex data sets which are difficultly obtained in cities in developing countries. Though there are certain “constraints on the ability of the model to simulate fluvial processes”, the 1D is still appropriate for large-scale sites indeed (Bates et al., 1999, Triet et al, 2008). In particular, the main objective of a hydrological modelling process is to identify the values of water levels in terms of temporal and spatial dimensions (location and elevation) based on time series. These are normally processed by computer software if the 1D model relies on the St. Venant equation. The process requires fundamental inputs such as river networks, cross-sections at certain places, boundary inputs and parameter sets. As a result, the outputs of this hydrological modelling process are the elevation of several ‘water points’ situated on the river network. For the application in the case of HCMC, the use of hydrological modeling by this research allows to calculate elevation values of different water points for flood simulation.

Following a review of available models, the research uses a hydrological model by Triet et al. (2008). This model comprises three important components: i) the river network associated with cross-sections; ii) boundary inputs; and iii) processing parameters, and is built on the basis of a 1D model, and run by Mike Zero which requires a comprehensive dataset including:

- A digitised network of water bodies, including 372 river branches in the HCMC region influenced by the main rivers, Saigon and Dong Nai, and 2296 sections of water bodies;
- Data inputs for 101 boundaries, including 97 inflows and four water levels, with the ‘open, distributed source, point source’ categories, as defined by the software. Among these are the three main sources which primarily influence the hydraulic results: Vam Kenh - Vung Tau (estuary), Dau Tieng (upstream reservoir), and Tri An (upstream reservoir);
- Other processing parameters (e.g. bed resistance).

As a development and application by this research, the model by Triet al al. (2008) is used to simulate the extent of flooding in HCMC in 2015 (for calibration and validation), and by 2020 (for vulnerability assessment). Inputs include sea level, river discharge and rainfall, whereas outputs from the model were validated by the 2015 water level observed at Phu An, a station on the Saigon River.

3.2.4. Spatial Analysis based on GIS (hereafter called GIS analysis).

GIS analysis is frequently used in assessing degrees of flood vulnerability for different objectives. It can be used to map inundations and consider their contributing impacts on mitigating future flood losses and damage (Wang et al., 2010; Kermanshah and Derrible, 2017). GIS computational software, e.g. ArcGIS/ ArcMAP by ERSI, which has a built-in mathematical model for spatially processing, referred to the plugins in the ArcTool Box. Besides a raster interpolation from basic points attributed to elevation values exported from the hydrological models, this GIS application also offer several tools to aid the objectives of spatial analysis, such as extraction, intersection, classification and referencing. In performance, the flood extent is commonly the intersection between a Water Surface (WS) and a Digital Elevation Model (DEM). The WS can be interpolated from the outputs of the hydrological model, while a Digital Terrain Model (DTM) can be established by different methods. Normally, it is created from several elevation points, which can be digitised after conducting a land survey or by using satellite imagery. For fairly flat areas, elevation points can be extracted from land survey maps, with a resolution (of DTM) matching the resolution of the WS. As the result of intersection between the WS and DEM, inundation map can be overlaid by the urban plans, e.g. an integrated transport map, for subsequent analysis in line with the objectives of the particular research.

With respect to transportation, two distinct traditions of vulnerability analysis are commonly conducted, i.e. the topological, based on graph theories, and the system, based on the demand and supply side (Mattsson and Jenelius, 2015). The first requires ‘definitional network data’, which enables detailed analysis, while the second needs extensive data about demand, supply and available models to simulate consequences (Mattsson and Jenelius, 2015). Depending on the scale of different cities and data availability, particular research can use appropriate method. For flood vulnerable assessment in practice, the first is suitable for large-scale/ mega cities due to the less requirement of data, which are normally complex and hard to collect all.

For example, in New York and Chicago, Kermanshah and Derrible (2017) developed a GIS analysis-based method to assess the “robustness of road systems by means of network topological indicators” by simulating extreme floods. They investigated the changes in the number of trips completed before and after the events by measuring the proportional losses of infrastructure segments (e.g. the total length of roads or intersections affected), and determined the roads exposed to flooding (Mattsson and Jenelius, 2015). In Hyuga, Japan, to find appropriate routes for evacuation, Wijatmiko and Murakami (2008) used GIS analysis on road networks to identify the viability of service areas and route risk levels in city planning for natural disasters such as tsunamis.

In this research, GIS analysis is used for two purposes: anticipating the potential increase of people and assets in new urban areas vulnerable to flooding (in chapter 4), and flood vulnerability assessment for the conceptual model of FRTS and its application in HCMC (in chapter 6, 7). In chapter 4, the secondary data of 270 property development projects from 2010 to 2015 were also collected for spatial analysis (GIS) for evidence of increasing flood vulnerability. Using the map of property projects by Department of Construction (2010), overlaying their locations on the flood hazard map by ADB (2010) allows anticipating the trend of increasing people and assets exposed to flood risk. This also shows the possible transport inaccessibility to these new residences, as the evidence for increasing exposure to flooding and the need to understand the role of transport connections for emergency use. In chapter 6, as continuing analysis after the hydrological modelling, the values of about 1000 points (on the river network) translated from the hydrological model were used to interpolate the water surface in ArcMAP (a GIS software). This surface was then incorporated into a DEM (Digital Elevation Model) interpolated from 28,675 elevated points, to produce a ‘floodable surface’. Overlaid with the maps of the urban area and transport, this allowed the identification of urban areas and transport segments vulnerable to flooding as the reference for existing development and transportation plans in HCMC, thus permitting development of the FRTS. Besides, the GIS analysis also allows applying the outcomes of the FRTS to create the blue-prints in chapter 7, referred to the proposed maps for adjustments to the transport plans.

In summary, the four research aims have shaped the methodology and thus the thesis structure including the corresponding chapters. The following chapters each focus on delivering a different component of this methodology. Most importantly, a combination between hydrological modeling and GIS analysis can be highly useful for planners to anticipate several degrees of flood impacts particularly on transportation, in terms of urban areas leading to transport routes vulnerable to flooding. By linking the results of flood vulnerability assessment linked to flood thresholds, they can propose different conceptual models for spatial planning, and seek appropriate application in different cases, such as the FRTS for HCMC. Coordinating with transport maps, urban researchers or planners can propose a conceptual model associated with potential adjustments to the existing plans in order to improve the robustness and redundancy regarding resilient development. Both hydrological modeling and GIS analysis have commonly been used in urban studies, and the combination as the base for a process from conceptual model to application can be seen an exploration by this research in transport planning for particular emerging-coastal cities in Southeast Asia. Although this combined method can contain uncertainties, related to data availability as a typical characteristic of flood simulation methods, it is still an appropriate choice. This can be improved by more data availability in the future, as a pathway for a resilient system to learn and improve future adaptability and response.

Table 1 Review of research using flood simulation by coordination between hydrological modeling and GIS analysis

Research	**Location/ spatial scale**	**Resolution**
Combined fluvial and pluvial urban flood hazard analysis: concept development and application to Can Tho City, Mekong Delta, Vietnam (Apel et al., 2016)	**Can Tho City, Southern Vietnam** (Mekong Delta area)	DTM: 15m resolution
A scenario-based approach to assess Ho Chi Minh City's urban development strategies against the impact of climate change (Storch and Downes, 2012)	**Ho Chi Minh City** Land-use map 2010 (1:25,000)	DTM: 20m resolution
Use of GIS to map impacts on agriculture from extreme floods in Vietnam (Chau et al., 2013)	**Vietnam,** Quang Nam, LANDSAT-agriculture (central Vietnam)	DTM: 30m resolution
Detection of temporal changes in the extent of annual flooding within the Cambodian and Vietnamese Mekong Deltas from MODIS time-series imagery (Sakamoto et al., 2007)	**Vietnam** MOD09 8-day composite time-series data (time period: 2000–2005)	DTM: 500 m
Regional flood dynamics in a bifurcating mega delta simulated in a global river model CaMa-Flood (Yamazaki et al., 2009)	**Southeast Asia** Mekong Delta area	DTM: 30m resolution, grids: 1km^2
Flood hazard in Europe in an ensemble of regional climate scenarios (Dankers et al., 2009)	**Europe,** similar to the HIRHAM	DTM: 12 km
Derivation of global flood hazard maps of fluvial floods through a physical model cascade (Pappenberger et al., 2012)	Rivers worldwide	DTM: 1km

Chapter 4

INCREASING VULNERABILITY TO FLOODS IN NEW DEVELOPMENT AREAS: EVIDENCE FROM HO CHI MINH CITY

4.1. Introduction

In HCMC, flooding is fast becoming a major barrier to urban development while the current flood management has proved to be ineffective in following a resistance strategy. There is growing concern that a continuation of rapid urban expansion on floodplains and increasing impacts from climate change not only exacerbate the problem in this city, but also will lead to many more new residences on vulnerable areas, which can be isolated by extreme floods due to the lack of transport accessibility. In response to the first research aim, this chapter claims evidences and factors to the increasing flood vulnerability with a link to property developments. This has generated the need to integrate flood resilience into urban planning with the importance of transportation in order to reduce vulnerability, and also informs on potential alignment with the theory of urban compactness in vision.

4.2. Urban expansion and rapid urbanisation on flood plains

The growth of HCMC can be attributed to its location as a port city on a river basin (of Saigon River and Dongnai River). As the core-city of a large metropolitan area, it is attracting a large number of workers as the driving factor for economic growth. The population of HCMC increased from 3.5 million in 1976 to 8.2 million in 2015 (GSOV, 2015), but the actual number of people (including unregistered migrants) is now estimated to be nearly 10 million (ADB, 2010). With a current territory of 2095 km^2, the city consists of three zones:

- Zone 1: 13 central districts, including the ‘old-town’ (partly located in districts 1 and 5)
- Zone 2: six new development districts surrounding the existing central area
- Zone 3: five suburban districts, formally rural land

During the historical development process, the territory of HCMC has largely expanded *(Figure 4.1)*. In the 17th century, the original town covered about 5 km^{2,} with a population of around 200,000 people; it was built on high land (+4 - +8m, ASL) in the current district 1 area. In the 19th century, Saigon, the old name of HCMC, was established as the most modern city in Southeast Asia in the light of a development plan to expand the city to 25 km^2, with a view to accommodating about 500,000 people. The built-up area was limited to the western side of the Saigon River by the end of the 20th century. At the beginning of the 21st century, widespread urban enlargement of HCMC occurred dramatically, from the old centre (presently district 1 and 3) to the surrounding areas, especially to the southern and eastern sides of the Saigon River. For example, the built-up area increased by 13% from 1998 to 2006 (Van et al., 2011); this is also evident from the high rate of construction across the emerging districts in Zone 2 (e.g. in districts 2, 6, 7, 8, 12 and Binh Tan: Viet, 2008).

From the 2000s, the city has experienced significant economic growth, associated with a rapid urbanisation process. Since the establishment of six new development districts, it has seen the appearance of a large number new specialised urban area, the location of industry, accommodation and education, particularly on the eastern side of the Saigon River. According to the general plan for urban development, about 80% of the industrial parks will be located in these districts (TEDI-South, 2013). As a result, there has been a trend for dwellers moving from the old centre (in zone 1) to the new suburbs (in zone 2), (Storch and Downes, 2011; GSOV, 2015). For instance, the six new development districts (2, 7, 9, 12, Thu Duc and Binh Tan) have experienced the highest rate of population growth since 2011, which is predicted to continue grow up (GSOV, 2015; TEDI-South, 2013). However, flood vulnerability related to such changes in population distribution have not adequately considered in planning, as several new residences are located on low-lying lands close to water bodies which are considered to be flooding sources. For example, district 2, with the new city centre – Thu Thiem (in Zone

2), was assessed to have been more impacted by floods because the rapid urbanisation has resulted in high density residences on floodable areas (Tu, 2010). Another illustration of this is the rapid development of Phu My Hung (in district 7) and Thu Thiem (in district 2), which are the two key projects of a more extensive process involving a vast number of property developments *(see some examples in Figure 4.2)*. Subsequently, several key transport projects have been also built. However, these projects not only trigger the further expansion of built-up areas, accompanied by a higher concentration of people and assets, but also affect indigenous hydrological systems in these wetlands, including green areas and water bodies.

Overall, the footprint of the city has rapidly changed since the 1990s, with rapid urbanisation, particularly on low-elevated wetlands in the east and the south. This has blamed a concern that such uncontrolled urbanisation is a dominant factor in increasing the flood exposure of the city, in terms of people and assets accommodated on new urban areas (Hong, 2011; Storch and Downes, 2011; Phi, 2013). Referring back to the literature review, the susceptibility and resilience of new expanded urban areas should be also considered. This has become a challenge for flood management, resulting from the dynamic social changes, in combination with the uncertainty of climate change.

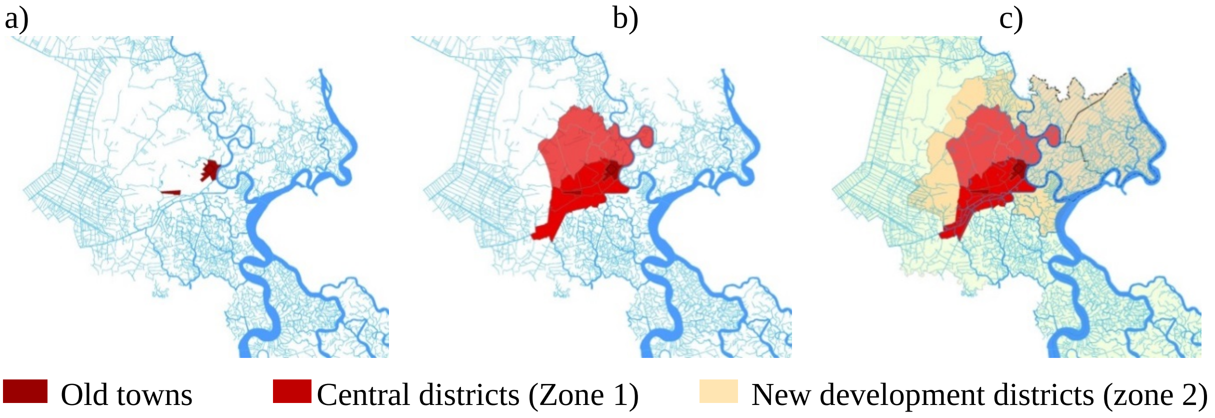


Figure 4. 1 Historical expansion of the urban area of HCMC (initially towards to the North direction but change to the East):

a) 17th – 18th century;

b) 19th–20th century;

c) Beginning of 21st century.

a)

Photo taken from Waibel (2016)

b)

Photo taken from Waibel (2016)

Figure 4. 2 Some examples of property projects in line with urban expanision:

a) Vincom residence in Binh Thanh district (Western side of Saigon River), on low-lying land adjacent to water bodies; and

b) Duc Khai residence in district 2 (Eastern side of Saigon River), on low-lying land which used to be the wetlands.

4.3. Current flood management: resistance and ineffectiveness

Since the decision by the central government in 2001, master plan 752 for water discharge up to 2020 identified six zones, consisting of the current inner city (about 140 km^2) and the surrounding areas (about 510 km^2), from which water would be discharged through dedicated channels. Subsequently, a supplementary plan with expanded areas for management (decision 1547), was actioned in 2008 to optimise the water storage capacity of the current water bodies of HCMC, and to control flash floods from the upper regions and upstream water from the main rivers (*see a brief illustration in Figure 4.3).*

According to this plan, the water level of +1.32 m ASL (in 1997) at the mouth of the Saigon River was chosen for the subsequent designs. Most fundamentally, these plans focus on the utilisation of existing water bodies, and the flooding control system mainly consists of sluices and embankments, which in light of the safety range for current thresholds risk to be exceeded. An illustration of this is the proposed elevation of the river bank system (about +2.5m, according to plan 1547 mentioned in section 3.2). When completed, this will be only approximately 80 cm above the recent maximum tides of +1.68m (ASL) recorded in 2013 and 2014, and + 1.71m (ASL) in 2017. SLR in Vietnam is projected to increase by 75-100 cm by 2100 (ADB, 2010; MNRE, 2012), with the increasing water levels in the rivers in HCMC actually higher (Phi, 2013). Extreme weather, such as heavy rains, has been challenging the existing capacity of the urban infrastructure. 2016 experienced unprecedented rainfall over 200mm in 2 hours, while the current drainage system was designed for rainfall of under 100 mm (SCFC, 2016).

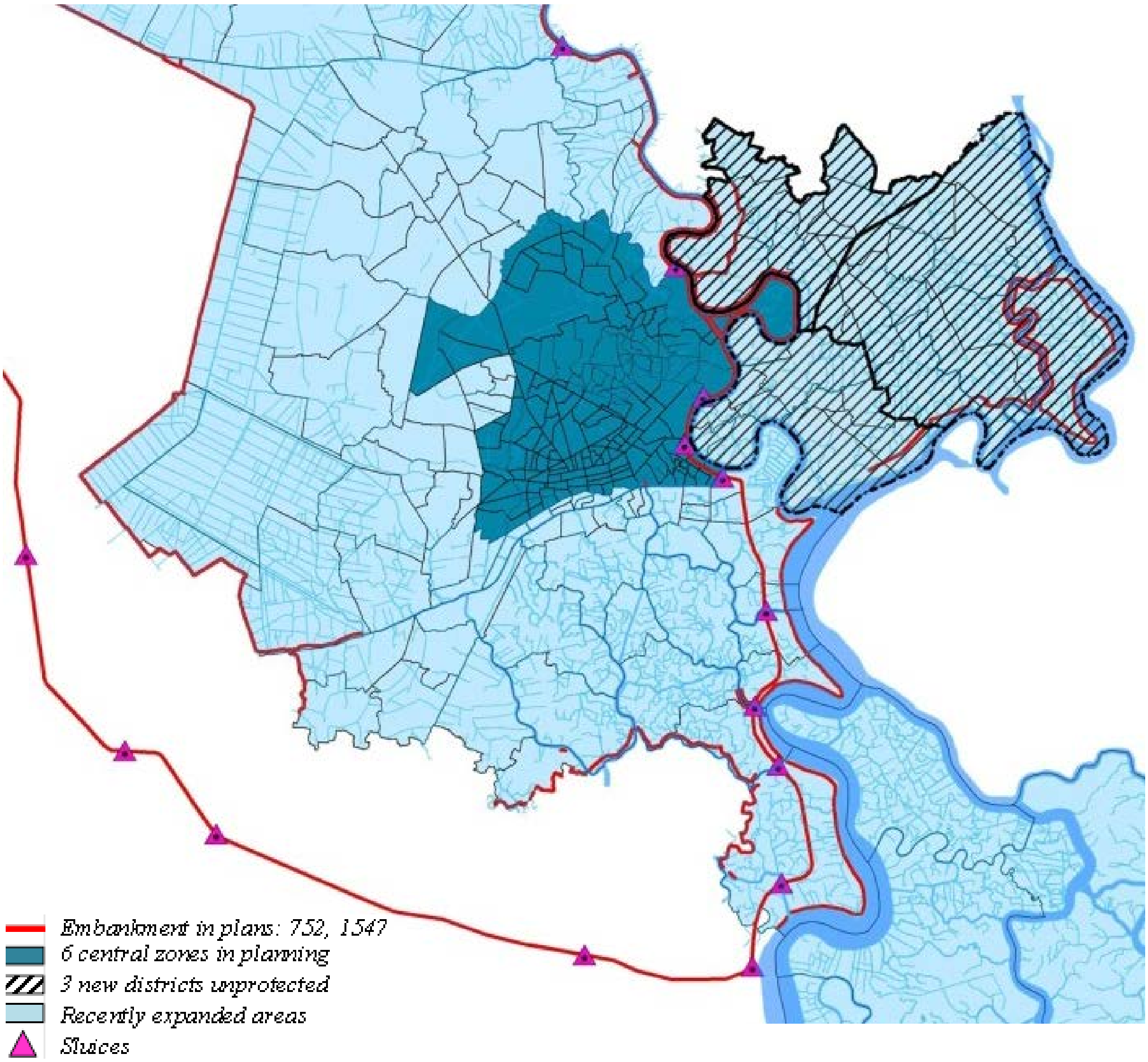


Figure 4. 3 Flooding management in the zones

Urgent action is now required, so the city has been accelerating existing projects, such as dredging channels, improving drainage systems, building an embankment along the left hand side of the Saigon River, construction of sluices, and creating reservoirs. However, there have been several debates on the effectiveness of these projects, as well as doubts over the feasibility of new proposals for further constructions with the high cost of construction addressed by Nguyen (2015), in chapter 1. It is argued that the current proposals are just short-term solutions based on engineering structures, while the city has not resolved its poor spatial planning (Phuc, in Nguyen, 2015). Long-term flood management ultimately needs to control the rapid urbanisation process, especially in new development areas (Storch, 2008; Storch and Schmidt, 2009; Storch and Downes, 2011; Hong, 2011; Phi, 2013). From another viewpoint, the implementation of these projects can accelerate a continuation of high density residences settled on such vulnerable areas, which will highly depend on these protection structures. A breach of these structures may cause tremendous losses and damages.

4.4. Flood vulnerability in new development areas

Using a Geographical Information System (GIS) approach, the locations of 270 property developments, which were marked by the Department of Construction of HCMC – DOC (2010), would be overlaid on flood maps by ADB (2010). The statistical population growth from GSOV (2015) and the flood records from SCFC (2015) were also used as supporting evidences. Then, linked to the literature on flood vulnerability assessment discussed in chapter 2, three indicators were evaluated: Exposure, Susceptibility and Resilience. Exposure is the core factor, but susceptibility and resilience can significantly increase or decrease the degree of vulnerability. There is a need to drill down an application of vulnerability assessment with the following indicators:

- *Exposure* refers to the increase in property investment projects in the light of the increase in population and assets (e.g. houses) in flood-prone areas.
- *Susceptibility* is indicated by factors influencing the degree of flooding, such as higher tidal levels and time for potential combined effects
- *Resilience* can be evaluated through the accessibility to important transport routes (e.g. emergency routes) when the city faces an extreme flood.

4.4.1. Exposure

Alongside the urban expansion, in contrast to Zone 1 (13 central districts), the population growth rate in Zone 2 (six new development districts) has been extremely high, particularly from 2003 onwards *(Figure 4.4a)*. In this zone, the land area for housing projects was 725 ha in the period from 2010 to 2015, and this is predicted to have increased to 3670 ha by 2030 *(Figure 4.4b, yellow column)*. The subsequent GIS-analysis (overlaying land occupied by these projects with flood extent calculated by ADB (2010)) indicates that the majority of new residential developments are located in vulnerable areas; and this trend will continue until 2023, and 2050 according to the extreme flooding scenario *(Figure 4.5).* Such developments are now starting to include more peripheral areas, but these are of low elevation, and particularly prone to fluvial flooding. Indeed, the SCFC flood records over six years (2010 – 2015) also support the fact that there was a rising number and length of inundations, especially in Zone 2. This implies a trend of an increasing number of people whose assets will be exposed to flooding in the future.

4.4.2. Susceptibility

HCMC is primarily affected by fluvial flooding upstream from the Saigon River and its branches, especially in the monsoon season. Yearly highest water level in year, referred to as highest tide in year, have been recognised recently, e.g. +1.55 - + 1.59m (ASL) in 2010 - 2011, +1.68m (ASL) in 2013 and 2014, and + 1.71m (ASL) in 2017. The statistics of flooding events by month (SCFC, 2010 – 2015, 2017) show that the highest level and frequency of floods is normally from September to November every year. Related to the characteristics of hydro-meteorology of HCMC (please referred to more details in chapter 6, section 6.1.2), this can be explained by the high possibility of occurrence for high tides and high rainfalls. Furthermore, the impacts are more disruptive if floods happen at peak times (6-8 am and 4-6 pm), when urban activities are at their daily peak in terms of physical transportation (mainly on the roads). For example, the extreme flood on 15th September 2015 occurred after heavy and long rainfall, coinciding with overflowing tidal water of around 4-6 pm, resulting in a large-scale effect on urban transportation. In brief, high tides can be seen as the *background* (gradually happening), whilst heavy rains are the *exacerbating factor* (uncertainly happening) in the combination of flood impacts on new urban areas located on low-lying land close to water bodies, especially from September to November.

4.4.3. Resilience

With respect to reducing flood vulnerability, urban resilience can help the city to return to a normal situation after flooding effects as long as the important transport routes are maintained. The GIS-analysis conducted for this study recognises the possibility that a large-scale flood can affect several critical roads, and divide the city into two parts (the western and the eastern sides of the Saigon River). This would lead to the isolation of three development districts (2, 9 and Thu Duc) on the eastern side of Saigon River because of the potential inaccessibility to them, and to the city centre or higher, and safer places (e.g. higher land in the Northwest). For example, the severe flood of 15th September 2015 created “transport chaos” in HCMC, many main roads were obstructed for up to four hours as vehicle flows slowed down, before blockages formed at some important segments and nodes, such as Nguyen Huu Canh, Dien Bien Phu and the Hang Xanh roundabout (Tran et al., 2015). As a result, many people were trapped in these immersed places, and could not return to their homes such in the three districts. Tran et al. (2015) reported that a lady had to “push” her broken motorbike (by water) about one kilometre and still had to return home because of a large number trapped vehicles. This provides an example of how the resilience of the city is compromised by floods affecting the transportation network, especially the main roads.

In general, flooding vulnerability in this city is generated by the increase in the number of people and assets exposed to flooding, especially in the new development districts (zone 2), while the high susceptibility is probably caused by a combination of heavy rains and tidal floods, which can affect urban areas adjacent to the main water bodies. Thus this chapter stresses the areas of recent property development in districts 2, 9, and Thu Duc, which are concluded to be the districts most vulnerable to an extreme flooding, due to inaccessibility to the city centre or safer places.

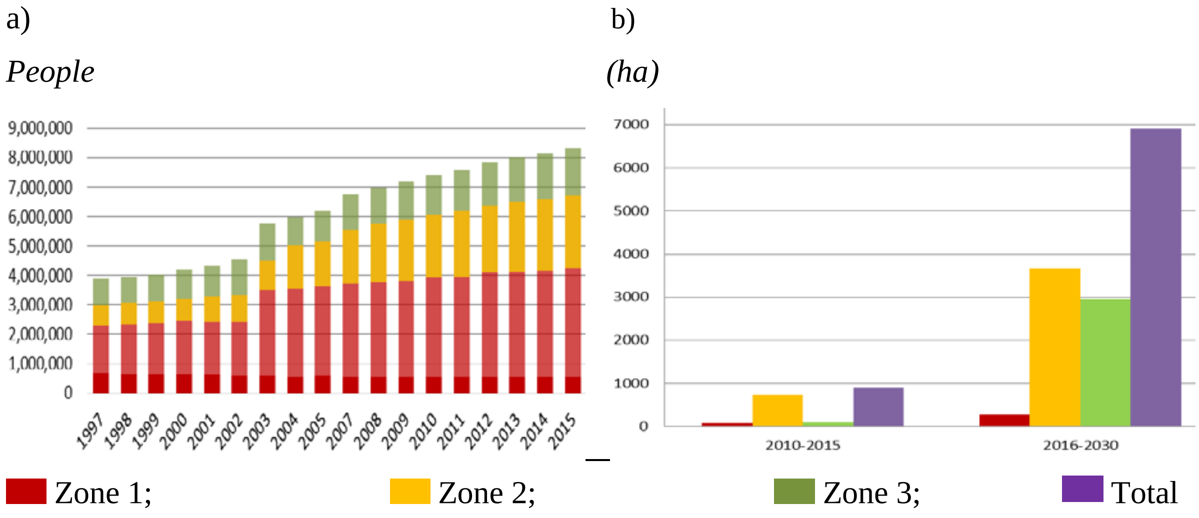


Figure 4. 4 Changes in property developments related to population distribution, with the significant increase in new development districts (zone 2):

a) Population distribution (source: GSOV, 2015);

b) Land for housing development 2010–2023

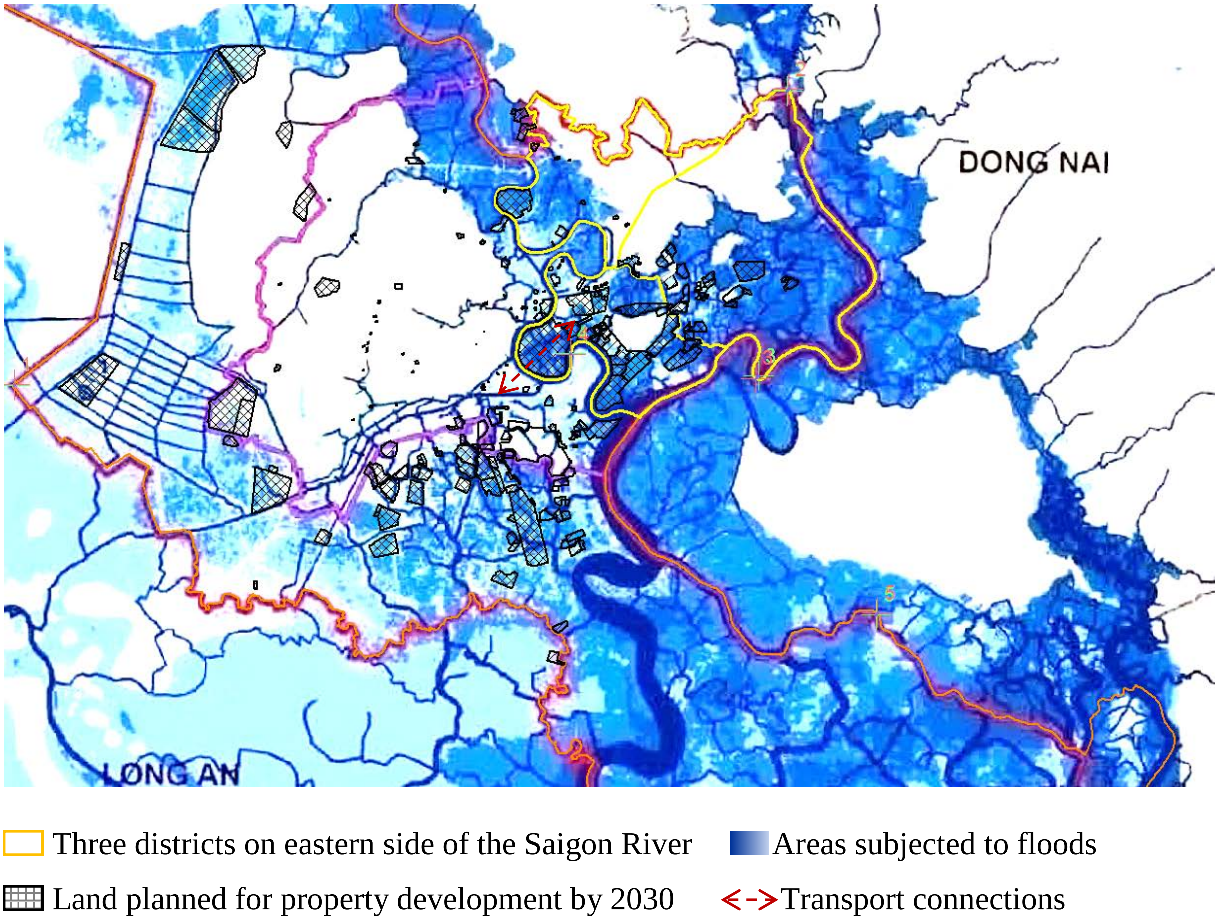


Figure 4. 5 Distribution of property developments exposed to floods by 2050.

The flood hazard map adapted from ADB (2010).

4.5. Vision for urban compactness and resilient transport system

Regarding rapid urbanisation and climate change, HCMC has continually been improving its flooding management, but the continuing mismatch between current planning, implementation and the volatility of climatic and social factors remains considerable. Several flood defence projects, mainly deployed in the central areas, are still in progress, but the built-up area has rapidly extended beyond the zones identified for protection. Furthermore, there are concerns that the design and construction of city-scale protection systems have become obsolete because of the rapid changes in precipitation and river levels (Phi, 2013). Aforementioned in the previous section, the facts imply that the current flood management plans are lagging behind the changes in both climatic and human factors. As the implementation of the current plans and worsening flood situation (Phi, 2013; SRFC, 2015), it is impractical to deliver a large budget to new defences which mainly protect the central areas, but the majority of citizens have been accommodated in the new development areas. In the future, the threshold of flood defences, representing the safety range, will be exceeded by climate changes, with the city seeing more new residences on flood plains unless there are appropriate adjustments to spatial development. Fundamentally, this chapter criticises the uncontrolled and subjective plans for urbanisation, dependent on hard engineered protection systems. When coupled with climate changes, this approach will lead to the increasing flood vulnerability and will be in urgent need of a long-term and comprehensive strategy, from theory to practice.

Like many cities around the world, the original urban areas of HCMC, referred to the old towns, have been built on higher elevation lands (e.g. districts 1, 3 5: Thinh et al., 2009). This has traditionally made them resistant to floods, but vulnerability increases as more and more peripheral land is built on in line with the urban expansion from the core centre particularly to the East and the South (Storch and Downes, 2011; Phi, 2013). The speed of development following the expansion of built-up area is crucial here. To meet the increase in demand of accommodation, urbanisation fundamentally follows the free market of property development, whereas flood management policy can be slow, and often a long time is needed to establish a protection system from planning to implementation. For example, the master plan for water discharge by 2020 in HCMC, including flood management, was approved in 2008 with the focus on inner city for protection about 650 km^2, in order to become the base for following construction projects (SRFC, 2010). However, the outer centre (at the time for that plan), referred to new development districts, have rapidly urbanised with a large number of housing projects as mentioned in the previous section. For example, the construction rate was remarkably high during the period 1989 – 2002 particularly in new development districts such as districts 2, 7, 9, 12, Binh Tan (Viet, 2008). This trend challenges the sufficiency of the existing plan and its performance in terms of design capacity and high cost required for investments leading to potential delay.

Indeed, the fieldtrips to HCMC also show evidence that riverbank had only been completed on the Western side of Saigon River after eight years, while the opposite site, which has seen rapid developments, a temporary embankment has just been built by local residents but was nearly overtopped by the recent high tides. Continuation of such resistant solutions unable ensure a protection for this city from flooding. Hence, this highlights the need for appropriate planning to minimise new urban areas vulnerable to flooding, and simultaneously spatial compactness in dealing with increasing urban concentration on limited high land. Respected to the sustainable development for the case of HCMC, spatial compact development should be made in the centre (old-town areas) to allow high density development in particular areas protected by current flood defences, whereas the new development areas should be designed to leave more open spaces for water absorption *(Figure 4.6).* The correlation between the reduction in the area of water surface or permeable surface, and the increase in built-up area is considered as one of the important factors to worsening flooding in HCMC (Phi, 2013). As a consequence reduced vulnerable urban areas, by increasing urban compactness will lead to increased importance of transport connections between potentially more separate and compact urban areas.

Along with this, *horizontal transportation* is expected not only to ensure the continuous links between different concentrated areas, but also to shorten local travelling distances on the plains. This will encourage transport means more adaptive to flooding, such as walking and cycling, referred to as a contribution to more resilience to extreme events, because of their flexibility and independence compared to motorised vehicles. With a vision to reduce number of motorised vehicles, these two types of transport modes are desirable in terms of not only potential reduction in noise, air pollution, greenhouse gases emissions, but also improvement in safety, fitness and sociality (Tight et al., 2011). Thus potential integration between these objectives with flood resilience can be seen as a strategy for more sustainable development in cities facing increasing urban concentration. Alongside this, *vertical transportation,* referred to elevated development such as different road layers (for urban level) or “flood exit” integrated with fire exit paths (in building level), will be an appropriate solution to flood emergencies. Once the continuity of urban commuting distances between different urban areas is focused and ensured, this will be more possible for emergency evacuation (to safer places) through a resilient transport network, including emergency routes, which should be elevated from the ground and in coordination with transferable means and services.

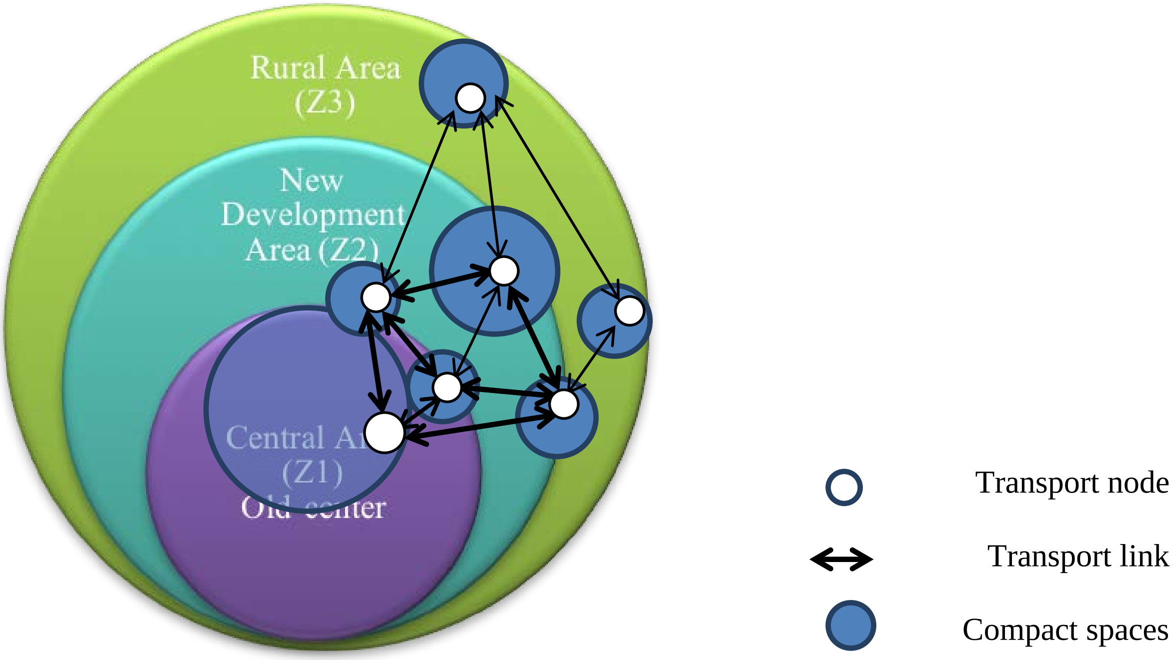


Figure 4. 6 Resilience and compactness in urban planning with role of the transport network

4.6. Summary

As the development of HCMC is threatened by worsening floods, this chapter has briefed on the urban expansion related to uncontrolled urbanisation particularly in new urban areas as the result of inappropriate planning and management. Based on the flood vulnerability indication, and the use of GIS analysis on property developments overlaid on flood hazard maps, the chapter has demonstrated that the increasing flood vulnerability of this city is mainly due to the rising new residences exposed to flood risk, especially in the new development districts whilst the climate change obviously acts as a contributing factor to fluvial flooding. The three new emerging districts in the East of the city (2, 9 and Thu Duc) will be the most vulnerable ones to extreme floods in the near future with the note on potentially inaccessibility of transport connections between these districts and the city centre (two urban sides of the Saigon River).

Referring to the role of urban planning for resilient development to reduce flood vulnerability, the city needs to focus on these vulnerable districts with regard to providing more open areas being floodable (e.g. green or water area), whilst more compact spaces in the centres (of city or districts) can reduce the pressure of enlarging built-up area on these lands. Furthermore, this has a link to resilient development of the transport system in order to ensure accessibility between these compact areas, potentially being more separated in the vision. Faced with an increasing threat of flooding, HCMC needs to learn from cities that have experienced more extreme incidents than that already experienced. In particular, lessons related to uncontrolled settlement on low-lying lands and the importance of transport system in urban resilience to flooding are essential, which will be presented in the following chapter.

Chapter 5

URBAN RESILIENCE TO FLOODS: CHALLENGES AND OPPORTUNITIES

5.1.Introduction

Flooding is a hazard not only in HCMC, but also in many other coastal cities, despite the presence of flood protection systems. Recent losses and damage due to flooding have indicated that the increasing volatility of natural disasters and flood events are now exceeding present day design considerations, and the accessibility of transportation during adversity is really important. Thus the aim of this chapter is to investigate flood incidents in three coastal cities to determine what lessons can be learned for potential improvements in flood resilience related transport development along with urban planning and management. Central to this chapter is the increasingly important role of transportation in improving urban resilience to extreme flood events, with an emphasis on increases in coverage of high-elevated roads, and greater reliance on waterways. It primarily uses a case study approach to document the impacts of key flood events in Southeast Asia (e.g. Manila and Bangkok). However, for contrast, the high profile impacts of Hurricanes Katrina and Rita in New Orleans are also documented.

5.2. Flood resilience: a trigger following the failure of resistant systems and increasing urban vulnerability

Floods in urban areas continue to make headline news throughout the world, with the increasing frequency and severity of events often attributed to climate change (Zevenbergen et al., 2008). The standard response to flooding is the development of flood defence systems. These can take on many forms - coastal dikes, river embankments, dams and levee systems - but they typically have design constraints (e.g. being built to withstand a once in a 100-year flood). There is a need to balance probability with cost benefits, but in a changing climate the likelihood of disasters continues to increase, which has meant that in recent years flood protection systems have not always proven successful in dealing with the disastrous effects of large scale flooding. This is demonstrated by many recent examples of ‘protected’ cities worldwide, which have subsequently suffered substantial losses to floods: in America (New Orleans, 2005); Europe (Lancaster, United Kingdom, 2015); China (Guangzhou-Guangdong, 2007), Australia (Brisbane, 2011), as well as a number of cities in South East Asia (Manila, the Philippines, 2009; Bangkok, Thailand, 2011 and Ho Chi Minh City (HCMC), Vietnam, 2015).

The flooding problem can be particularly acute in cities situated in coastal zones, where pressure to increase development is also increasing, resulting in larger (or new) settlements facing flooding hazards (McGranahan et al., 2007). Of the 20 largest cities in the world, 13 are located on the coast (WB, 2010), with more than 20% of the world’s population now living in the coastal zone (Du-Gommes et al. 1997; Brooks et al. 2006). Whilst tidal flooding and storm surges have always been a hazard in the LECZ, vulnerability increases in a changing climate due to the rise in sea levels (Neumann et al., 2015), which is now estimated to be 74cm by the end of the 21st century (IPPC, 2014). Located on low-lying lands (e.g. estuaries at the mouths of major rivers), these cities face with high risks to combined floods. An illustration of this is the location of Manila city on the western shore of Manila bay, and through which the Pasig and San Juan rivers traverse. This means the threat of flooding in this zone can also be fluvial or pluvial, or often a combination of both.

5.3. Challenges: inevitable rapid urbanisation and climate change

As cities worldwide become increasingly urbanised, in line with the growth of the global population, urban expansion results in a concentration of citizens and assets outside of the former centres. This process is producing a concentration of people and assets in areas prone to floods, particularly in built-up areas along major bodies of water, in many cities which have followed an inappropriate plan with weak management of built-up areas (Zevenbergen, 2008). Indeed, Angel et al. (2005) examined the processes of global urban expansion and concluded that populations had not in fact been distributed according to the plans approved in almost all of the 90 cities surveyed, while Gentlemen (2007) relied on the estimation of the UN that only 5% of new developments had been implemented exactly in accordance with existing plans.

Due to the rapid development experienced over the last few decades in Southeast Asia, a large concentration of increasingly vulnerable coastal cities has emerged in this region. Here, countries are targeting the economic growth associated with urbanisation, but this now means that urban expansion has spread to areas at risk of flooding. This is compromising the adaptive capacity of the broader city to cope with natural risks, which is essential for the long-term planning of urban development (UN, 2013) but is frequently overlooked by local government. Since 2008, the average growth rate in this region has been around 6%, compared with the world average of around 2.4% (UN, 2015; UN, 2016). Linked to this is the second highest projected urbanisation rate in the world from 1990 to 2020 (UN, cited in Economic and Social Commission for Asia and Pacific, 2013). In short, economic growth has entailed a tendency for rapid and uncontrolled urbanisation on new development lands which may face higher flood risks while flood protection system can be overwhelmed by increasingly uncertain floods. This can be seen as a common tendency, particularly in coastal cities in this region. The following section presents some lessons about high losses and damage.

5.4. Case studies: lessons from flood devastations

The volatility of urban areas to natural disasters has become increasingly evident, and the losses and damage suffered by humans are nearly always catastrophic. A combination, or series, of different events has caused floods resulting from typhoons, storms and heavy rains in several cities such as New Orleans, Manila and Bangkok since the beginning of this century to be more serious.

5.4.1. Katrina and Rita in New Orleans - USA 2005.

The devastation caused by Hurricane Katrina in August 2005 was one of the biggest natural disasters in American history, and resulted in significant impacts on the Gulf Coast area of the country, including the city of New Orleans. Although the unpredicted storm surge which caused the failure of flood protection systems was the main reason for the scale of the impacts, and resulted in the city being disrupted at all levels - households, extended families, neighbourhoods and communities (Petterson et al., 2006),the flooding effects were actually made worse by catastrophic human failure in relation to the insufficiency of spatial planning and management, and community power in dealing with natural disasters (Cigler, 2007).

First, the failure of weather forecasts is not only an insufficient basis for planning and designing a protection system in the early stages, but also influences the awareness of citizens when preparing for unexpected disorders. The scale of the storm surge which overran flood defences had not been well predicted, and the design of the flood protection was mostly inadequate for such an event (Petterson et al., 2006). Indeed, the levee system in fact maintained the water within the city at depths of up to 3m, while many citizens had remained in the city due to their confidence in the flood protection system (Petterson et al., 2006). Fortunately, small boats have been used to rescue about 4000 people (Cigler, 2007).

Second, the accessibility of transportation is vital in dealing with emergency circumstances, but it had been a matter of inadequate concern. Once the scale of the disaster became apparent, the lack of available roads not only prevented people from escaping from the flooded areas, but also hampered the evacuees' return to the city after the flood (Cigler, 2007). This is believed to have been one of the main reasons for the large number of deaths in New Orleans (Cigler, 2007).

Third, the high risk of flooding originated from insufficient consideration of the limitations of the region for urban spatial expansion, with many areas of the city being developed on average about two metres below sea level (Cigler, 2007). The early settlements had been limited to high land in their initial development, but were expanded to low-lying land located in the Mississippi River basin, especially after the significant urbanisation in the early 20th century (Olshansky and Johnson, 2010; Coaffee and Lee, 2016). Such development ensured that the city was totally reliant on flood defences, the insufficient maintenance of which meant that the levee system was nearly one metre lower at the time of Katrina than when it was originally constructed (Petterson et al., 2006). Driven by the popularity of living at a waterside location, wetland development was also common, but reducing the area's natural resilience to disaster (Cigler, 2007).

Finally, the role of communities is also important in rebuilding both the built and social environment. Urban resilience will be viable if the former residents do return and contribute to the rebuilding process of the city (Campanella, 2006). For example, a small number of the Vietnamese community who had lived in the Lower Ninth Ward remained in the city, and proactively reconstructed their accommodation and social fabric on the post-disaster sites (Campanella, 2006). Such triggers can be seen as the core element, from which further processes can be pursued. It is generally stated that human beings will have their own adaptation to harsh situations; in contrast, thorough protection will dampen individuals' ability against unpredicted attacks. Indeed, substantial flooding defences were built after the great flood of 1927, followed by long-term maintenance, but Katrina-Rita still caused considerable losses and damage to New Orleans because of the higher number of people living in vulnerable areas (Olshansky and Johnson, 2010).

5.4.2. Ketsana (Ondoy) in Metro Manila – Philippines, 2009.

This flood was mostly caused by heavy rains accompanying a tropical storm in the Metro Manila region, causing large parts of the region to be inundated in September 2009. Manila City, the main city of the region, is located on coastal lowlands adjacent to Manila bay, and usually experiences fluvial flooding from the Pasig and San Juan rivers. Whilst inadequate flood management was clearly a contributing factor, settlement on low-lying flood plains reduced the natural capacity of the system (Sato and Nakasu, 2011). Following the extreme flood, the particular characteristics of the city and its citizens did mitigate flooding impacts, despite the failure of the government to manage urbanisation and flooding. The flood taught some valuable lessons.

First, the city had constructed a flood management system consisting of a dense network of floodways and reservoirs. This system had been designed to permit a maximum discharge into the Marikina River of 2,600 – 2,900 m^3/s, but its real capacity was only 1,500 m^3/sec – 1,800 m^3/s when dealing with Ketsana (Sato and Nakasu, 2011). In practice, some floodways were blocked by rubbish from inhabitants, especially illegal residences along these watercourses (Sato and Nakasu, 2011). Second, reviewing its historic development, the city has significantly expanded its urban area over recent decades, but such expansion has been inappropriately planned and managed. This has created new ‘artificial flood-prone basins’ which influence the flooding patterns. The process of urban encroachment onto the low-lying plain of Laguna lake since the 1960s is evidence for this (Sato and Nakasu, 2011). In contrast, the severity of the impacts was alleviated by the experience of the citizens and the plans prepared by the government, such as a network of shelters supplied with food and drink.

5.4.3. Flooding in Bangkok - Thailand 2011.

This flooding was the consequence of a series of natural events originating in mid-2011 and lasting for around five months. It followed a series of prolonged heavy monsoon rains and storms, which produced consistently high precipitation downstream from the north, to the lower plains of the Chao Phraya River Basin, where it was frequently met with high tides. The peak impact was realised in Bangkok City in November 2011, when nearly the whole city was immersed. Although water levels were lower than in other historic events in 1942, 1983 and 1995 (WB, 2012), the duration of the flooding made it a more significant incident. The larger scale impact of the flood was the result of unpredicted weather and an inadequate forecast system, together with other factors related to urban planning and management. First, forecast failure led to the inadequate operation of water storage for agricultural purposes, but it had to be urgently discharged to the lower deltas, including the metropolitan area of Bangkok, because of the overload (WB, 2012). Second, the design of the urban flooding system had relied on prior accumulated information and knowledge, but this was not integrated into a combined effect. Consequently, 10 of the 12 levees were breached by the flood, although Thailand had made long-term investment in flooding protection. Finally, the sinking of land in highly concentrated areas of urban construction on low-lying land was another cause of the higher flood impacts. The decline in urban ground, which can be seen as the physical foundation for urban life and any flooding protection system, should be integrated into flood management plans and urban spatial development.

Shortly, the Thai flood of 2011 can be seen as the combination of heavy rains, tropical storms, monsoon and high tides. Although the evacuation of inhabitants helped to mitigate the impact, the long duration of the event caused a chaotic situation across the country and had an effect on the economic and political situation, despite the water level not actually being the highest on record. This not only demonstrated the uncertainty of flood factors as the challenge to forecasting systems, but also revealed need of “visible roads” for evacuation.

Overall, the three case studies analysed in this chapter are all very different in terms of the number of people affected and economic losses, yet there are also many similarities between them, and opportunities to learn from the events. Whilst the cause of flooding is ultimately a combination of different factors, the geographical location of each city in the LECZ (and associated inadequate planning decisions), along with human failures, have significantly increased the impact of the events. The lessons for urban resilience to flooding are:

- Flooding defences, referred to as resistant systems, on which cities are increasingly dependent during development, are gradually becoming insufficient to deal with uncertain flood factors. On the negative side, dependency on these systems leads to inadequate consideration of settlement along water bodies, especially in new development areas. This has not only resulted in an increase in residences vulnerable to floods, but has unexpected effects on natural alleviation systems in terms of natural water discharge.

- A resilient infrastructure, particularly with regard to the role of the transportation system, is essential to ensure continuity of urban functions, or ultimately to aid evacuation (e.g. transport and shelter networks); along with this, elevated roads in case of emergency are crucial for evacuation, while individual boats on waterways, which could be less important to daily commuting, are an outstanding transport mode to rescue people.

- Forecasting capacity related to climate change significantly aids important decisions by government, and potential preparation by communities to natural incidents. Linked to this, communication during such extreme cases is vital to ensure appropriate actions by both communities and governmental bodies.

As the evidences supporting the literature review in chapter 2, the aftermath of such events also implies that the resilient capacity of cities is only exposed when facing disruption. This requires an assessment of flood vulnerability in a worst-scale scenario, rather than being a 'late realisation'.

5.5. Opportunities: potential integration into urban planning

5.5.1. Flood resilient development with the role of transportation

Whilst the expansion of cities is inevitable, the consideration of natural hazards such as flooding, especially in a changing climate, cannot be ignored. Cities need effective planning for resilience development through their urban plans to avoid the 'quick and easy win' associated with building on vulnerable areas such as lowlands adjacent to rivers and coasts (even if these areas command the highest real estate values through their desirability). For the physical infrastructure, the role of efficient transportation for flood resilience has also been emphasised. In vulnerable locations, transport links need to be consolidated in terms of capacity and number of alternatives in order to ensure connectivity to other urban areas. Additionally, the importance of emergency routes in the case of extreme floods is explicit, and the number of fatalities in New Orleans would have been significantly reduced if key elevated, or 'hardened', roads had been available. Such roads should be linked to other elements of the critical infrastructure of the city (i.e. medical facilities) and higher topographical land in the city should be reserved for such purposes. This are in line with recent thinking from the UN (2013, p. vii), which states that *"A new wave of urbanization is unfolding in hazard-exposed countries and with it new opportunities for resilient investment emerge"*.

Besides, the case studies also demonstrate the importance of communication between community and government when dealing with disaster. Thus early warning systems accompanied by action plans for certain scenarios are essential. This provides the tools to enable individual adaptation, based on the notion that community resilience can be consolidated by learning experiences and the ability to solve problems (Berkes, 2007). Fundamentally, early preparation is always more effective (Godschalk, 2003), but this requires a change towards transparency of information about flooding risks to avoid over-confidence in hard-engineered solutions. People need sufficient information to make an informed choice with respect to risk, adaptation and resilient capacity in their living environment.

5.5.2. The need of integration into urban planning

As the case studies reviewed, coastal cities are increasingly reliant on flood protection systems. Whilst these are designed to cope with extreme events (e.g. once in a 100 year floods), it is becoming clear that in a changing climate these may not be adequate, and traditional principles may no longer be appropriate (Rogers et al., 2012). Estimates of current flood protection are normally based on knowledge accumulated from historic weather records, but climatic features are now more volatile (Zevenbergen et al., 2008). It appears that the limited capacity of flood protection systems in face of the volatility of a changing climate is becoming a serious threat. Furthermore, the presence of such protection systems can lead to complacency, and actually encourage further vulnerable development by attracting people and assets to vulnerable areas (Hallegate et al., 2013). It is obviously impractical to continue to build ever-higher flood defences, and there is a need to consider alternative means to improve urban resilience to flooding. As such, control of the urbanisation process is crucial to ensure ongoing resilience. The case studies highlight that inappropriate (and sometimes illegal) urban expansion onto wetlands and floodplains is frequently common practice, exposing more citizens to flood risk.

Shortly, coastal cities need to be flood-resilient developments integrated into urban plans in particular areas (such as urban spaces or transportation), rather than unique investments using conventional flood protection systems. It is accepted that this creates more pressure on authorities to ensure that the process is under control and is following the approved master plan containing detailed strategies for flood risk management with reference to land use. Ultimately, the government must control urban changes in different sectors such as water resources, land use and construction, housing and human settlement, transportation and mobility, economy and trading, as well as policy and governmental perspectives.

5.6. Opportunities for HCMC and other emerging coastal cities in Southeast Asia

As shown in the previous chapter, HCMC has seen increasing vulnerability to floods in recent years due to the effects of rapid urbanisation and climate change. While its population and territory have increased four-fold with the increasing number of housing developments located on low-lying lands in the south and east, the uncertain changes in urban hydro-meteorology have become significant. Thus, the city needs to avoid the pitfalls experienced in the flood incidents reviewed; with respect to resilience development, the contribution of a resilient transport system including emergency routes for evacuation is crucial when the city is facing extreme floods. Specifically, the road network should focus on accessibility on some critical routes in response to different flood levels. Integration of urban compact development in terms of the higher altitude ‘old town’ and hardened transport routes appears to be a sensible future option. For example, new housing developments could follow a strategy of spatial compactness, and should be located on higher land, with sufficient distance from water bodies. These objectives can be achieved in HCMC by a plan for resilient development integrated into the general plan, and one for transport development aligned with the planning framework.

The lessons learnt from the flooding incidents are also opportunities for other coastal cities in this region, which are defined as on-going, rapidly developing, urban agglomerations in emerging economies in SE Asia (UN, 2016, table 1; Pena et al., 2014). These cities alone are expected to expand the number of their built-up areas into flood-prone zones from 30% to 70%, with the cost of damage ranging from 2% to 6% of regional Gross Domestic Product (WB, 2010). They can improve resilient capacity based upon their significant economic growth, which can drive the integration of flood resilience objectives into potential revises of urban plans particularly in transportation. Along with these plans, investments in key infrastructure projects can be seen a fascinating chance for resilient development.

5.7. Summary

Exemplified through the case studies in this chapter, a primary cause for these coastal cities becoming increasingly vulnerable to flooding is inappropriate spatial planning for urban expansion on lands vulnerable to flooding, such as the wetlands low-elevated and highly influenced by river network. This has increased flood risks to such new urban areas between which transport connections are concerned. Indeed, the chapter focuses on the lessons about the high losses and damages to uncontrolled settlements on low-lying lands vulnerable to flooding in relation to the inaccessibility of transport during extreme events. This has become an implication for emerging-coastal cities to integrate flood resilience into their plans for development. First, regarding urban concentration, urban spatial compactness should be encouraged to minimise residential development on areas prone to floods, and also to leave open spaces for water absorption. Second, referred to transport connections, the continuation of transport network need to be ensured especially some critical routes, with the highlight on the advances of elevated roads available for evacuation or navigable waterways for boats for potential rescues in emergency. Finally, these cities should improve their ability in the integrated forecasting of flood factors related to extreme weather and hydrological changes, and more effective communication between communities and local governments.

As HCMC has been experiencing the evidence of increasing flood vulnerability demonstrated in the previous chapter, the lessons in this chapter are believed to be useful for the city and are also the opportunities for resilience development through the revision of plans for urban development including the transport system, with a stress on the links between the city centre and new development areas particularly located on low-lying land on the Eastern side of Saigon River. This has become an important reference when conceptualising a model with an application in this city in the next chapter.

Chapter 6

A RESILIENT TRANSPORT SYSTEM TO REDUCE FLOOD VULNERABILITY

As highlighted in the previous chapters, the role of transportation is becoming ever more important as cities are increasingly vulnerable to flooding. The flood impacts on transportation can pose significant, lasting disruption to almost all urban activities, while the inaccessibility of main routes results in losses and damage to urban development and human beings. Thus the development of a resilient urban transport system is essential in order to ensure transport connections between different urban areas when flooding occurs. This can be translated into the objective of improving the capacity of ‘self-adaptive organising’ transport flows between different spatial levels in adapting to different flood levels, which can be predicted by vulnerability assessment. Based on the foundational principles built from the literature review in chapter 2, and the current conditions of transport development of HCMC, this chapter proposes a conceptual model of FRTS. For application in HCMC, this chapter also assesses the flood vulnerability of the transport system in HCMC by using a combined method of Hydrological Modelling and GIS analysis. This is also applied to help the development of transport system shift from resistance to flood resilience strategies through a planning framework. Although HCMC is the case study for this work, its problems are symptomatic of many other rapidly developing cities in Southeast Asia, and so the concepts can be readily applied elsewhere.

6.1. Transport development and flood impacts

6.1.1. Transport development

In HCMC, the process of urban expansion mentioned in chapter 4 has necessitated the expansion of the transport network, which has evolved significantly from the original grid network found in the old town located on high ground (+4m - +8m, ASL) to surrounding suburbs, with a notice on low-lying lands (under + 1.5m ASL) especially in the East. Along this direction, the growing urban functional areas (e.g. industrial parks, educational campus: TEDI-South, 2011) and the trend for people to move (Storch and Downes, 2011; GSOV, 2015) from the city centre (zone 1) to new development districts (zone 2), has generated intensive transport flows allocated to some critical routes between these two zones (e.g. about 11.000 motorbike travelling on one direction at peak hours: Mai, 2017 cited in Huy, 2017), such as the East-West (national road 1 - Vo Van Kiet – Mai Chi Tho, see *Figure 6.1*). These routes play a vital role in assuring the reliability of urban daily commuting; for example, workers travelling between districts 2, 9 (in zone 2) and the city centre (districts 1 and 3, zone 1). However, transport development is still considered to be based on an insufficient proportion of land dedicated to transport construction in the new urban areas compared with the central areas, and this has become a driver for potential plans and investments (TEDI-South, 2013).

a)

b)

c)

Figure 6. 1 Examples of transport development in following to urban development

a) A part of the East-West artery (red line), traversing the city centre (district 1)

b) A part of the first metro line in construction (red line). Photo taken from Hung (2017)

c) Ground-based road development (red line) in Sala Residence in Thu Thiem, district 2. Photo taken from Waibel (2016).

The general plan, which was approved in 2010, shows a strategy connecting the existing central areas and sub-centres via four transportation directions (*Figure 6.2*). In the 2000s, several plans for urban development, including transportation, were drawn up by the central government and city council. Some of these key plans included:

(1) ***First direction (to the East)***, from the city centre to the East, with connections to districts 2, 9, and Thu Duc (on the eastern side of the Saigon River). This is currently considered to be the most important direction, given the large scale urban developments in this area, such as Thu Thiem (a new city centre for international trading and commerce), Quang Trung Industrial Park, and a new campus of the National University in HCMC. As a result, some main roads have been widened and extended from the centre along this direction, such as Nguyen Huu Canh, the Ha Noi-highway (national road 51), and Mai Chi Tho, with many key transport projects focused on new crossings over the Saigon River, e.g. Saigon 2 bridge, Thu Thiem tunnel, Thu Thiem bridges 1 and 2, Phu-My Bridge, as well as further projects in progress such as Thu Thiem Bridge 3 and the first city metro line.

(2) ***Second direction (to the South)****, traversing district 4*, along Nguyen Huu Tho Street, and connecting to district 7, Nha Be and Can Gio. This direction is attractive for new residential property investments due to the pleasant living environment, with the proximity of water bodies. Phu My Hung residence is a cornerstone project which has triggered investment in several transport structures, such as the Nguyen Van Linh Boulevard. However, the land in this area used to be wetland and is low elevated; it also contains a large number of watercourses.

(3) ***Third direction (to the North)***, *traversing Tan Binh district,* following Cong Hoa street - national road 22, connecting to district 12, Cu Chi and Hoc Mon. This direction is more elevated, and part of the planning strategy of the local government is to create new development areas for both accommodation and industry. This direction carries a busy transport flow of workers travelling from Tan Binh, Binh Tan and Tan Phu to the central districts for their jobs.

(4) ***Fourth direction (to the West)***, interlinking district 5, district 10 and Binh Chanh, and connecting with the national road towards other provinces in the Mekong delta area of Vietnam. This can be viewed as an emerging direction, with the main link from the city centre to satellite cities in the HCMC region, such as Tan An. A key feature of the area is several affordable accommodation projects, which are intended to meet the rising demand for accommodation by low income people who have migrated to HCMC.

In association with the urban spatial structure, the four directions constitute the main transport flows distributed on certain arteries along these city corridors, primarily between zones 1 and 2. Since the early stage, urban development was mostly along the third and fourth directions, away from the Saigon River. In recent decades, the first direction has been more attractive and empowered, as new sub-centres and urban functional areas have been planned and invested in in the three new development districts on the eastern side of Saigon River. Following with the general plan, the transport plan relies on a centripetal structure consisting of transport links and nodes (major and minor) and sub-networks (TEDI-South, 2013), with the on-going implementation of different transport modes, as summarised below.

(1) ***Road network.*** Mainly ground-based, HCMC has a complex road network with a total length of approximately 3265 km, including national roads, regional roads, ring roads and

elevated roads and district roads (TEDI-South, 2013). 90% of the transport intersections are on the same level on the ground, and the land area for transport structures continues to be low (4.7%) (TEDI-South, 2013). Two national and international coach stations are located in the west and the east of the city; the second is planned for movement (from Binh Thanh district to district 9, on the eastern sides of the Saigon River). Private vehicles are the most popular transport means, while public transport is still inadequately developed. As a challenge to urban development, traffic congestion is the most significant barrier to urban growth, while flooding constrains daily commuting.

To solve the current congestion situation, bus services have been given a more important role in urban transportation, in coordination with other solutions, such as a project for a public electric bike service, which has been trialled in district 1 since 2017 (about 1000 electric bikes allocated on the pavements of the main streets: An and Hoa, 2017). For construction investments, several overpasses (about 4-5m above the current ground level) have been recently built at some critical nodes, e.g. Hang Xanh, Lang Cha Ca, Thu Duc and Nguyen Huu Canh; while five high-elevation roads with a length of approximately 70 km are planned.

To deal with flooding, the road network is currently increasing resistance to the phenomenon of higher tides, by increasing the required elevation of road developments (e.g. from +1.5m ASL to at least + 2.0m ASL). However, this solution has proved detrimental to the current urban infrastructure and general living environment because of the elevation gap between the new road surfaces and the existing roads and buildings. Associated with the low-elevated land in new urban areas, the large number of ground-based roads can be seen as a barrier to the feasibility of such a solution because of the high cost and unexpected influences on the whole urban network (see more examples in *Appendix A and Figure 1.7 in chapter 1*)

(2) ***Railways.*** According TEDI-South (2013), the city currently has 13.5km of national lines (within the urban territory). Eight city lines (172.6 km) and eight national lines (697 km) interconnected via seven depots are proposed in the development plan (TEDI-South, 2013). The current unique national rail line has been built on the ground, whilst the national railway station is still located in the central area. National and urban rail lines have been planned and invested in, with two new urban rail lines crossing the Saigon River. One of these, the first metro line (from the city centre to district 9), is being constructed with potential operation in 2020 for a connection between the Ben Thanh Market (the city centre in district 1, zone 1) and Suoi Tien Park (in district 9, zone 2). This line includes an underground segment (in zone 1) and a remaining highly elevated segment (approximately 10m from the ground) in zone 2 (some illustrations can be seen in *Appendix A).* Although the development is targeted at reducing pressure on the road network, the connections between this mode and the others are considered to be a weakness of the scheme. For example, commuters can now use the metro service between Thu Duc and the centre, but the bus services are now insufficient for their travel to places of work or their homes. Moreover, a flood risk to this mode has not been considered thoroughly.

(3) ***Waterways.*** Navigable waterways still cross the city (with a total length of about 1200 km, including 848 km length of rivers), with their routes are mainly influenced by the Saigon and Dong Nai Rivers, and connecting to an additional network of channels and canals, such as Nhieu Loc-Thi Nghe, Ben Nghe-Tau Hu, and Kenh Doi-Te. Watercourses, which used to be the main transport mode, are now nearly exclusively maintained for water discharge and general aesthetics, although some main courses have been restored for public transport (water buses). Beside the main role of water discharge, some of them have been used for water buses, with the first services along the Saigon

River (about 10.8 km) in operation since 2017. In this vision, water transport is still envisaged to contribute in public transport; however, its links with other modes of transport face the same difficulties as the rail network. The waterways have not been interlinked to become a contiguous network (TEDI-South, 2013). In fact, the waterways used to be popular in the city in the last century, and the mode can be seen as one adaptive to flooding, but it has not been considered for potential involvement in flood resilience.

(4) ***Air travel.*** The existing airport (Tan Son Nhat) in the North is now operating above its designed capacity and is surrounded by built-up areas, which are challenges to this mode of transport. Development to improve its capacity, with a land area of about 850ha, has been approved, but such an expansion is still a temporary solution to the steeply rising demand, given the prospective growth of this city as an international transportation hub. Due to its inner city location, this transport mode is absolutely dependant on accessible links to the urban road network; as a consequence, the congestion on some main roads, such as Nam Ky Khoi Nghia and Hoang Van Thu, usually influences accessibility to the airport. Hence, a proposal for a new airport (about 5,000 ha in Long Thanh, 40 km from the centre to the East), which is one of the key infrastructure developing projects in HCMC, has been approved, with the objective of operation by 2025 (Nguyen, 2018). This project is predicted to not only concentrate on the importance of the first transport direction (previously mentioned), but to also foster a more rapid process of expanding built-up areas in the three new development districts on the east side of the Saigon River (districts 2, 9, and Thu Duc).

The transportation system of HCMC has been planned and developed based on a centripetal structure, see *Figures 5.2* (Tedi-South, 2013). According to this, developments have been implemented through key projects, which are driving subsequent development (e.g. smaller roads, housing etc.) in order to meet the increasing demand and to target a more balanced share between different transport modes. However, it is still heavily reliant on the ground level road network, which is faced congestion and flooding. These are the two major problematic issues which need to be resolved by the local government of this city through urban redevelopment programmes (Khoa, 2016). It has been revealed that the inadequate current plans for the implementation of transport developments are subject to flood vulnerability.

First, such rapid urban developments have accelerated the network expansion prevalent in new urban areas, which are not only low-elevated but also wetlands containing a sprawling network of river tributaries. Such expansion creates more critical routes interacting with the existing water bodies (along or intersecting with them). According the transport plan (Tedi-South, 2013) there will be five transport structures crossing the Saigon River providing connections between the current centre to district 2, but there had been a unique Saigon Bridge before this plan. Additionally, the ground-based nature of this network has become a constraint in dealing with flooding in relation to flood risks and levels of investment in the whole network. For example, the development of the new Thu Thiem centre (in district 2) has resulted in the development of some main roads, such as Tran Nao and Mai Chi Tho, with higher elevation resistance to accumulated flood levels, but this also causes difficulties in accessing existing buildings and smaller roads. Local rising elevations, particularly of ground-based roads situated on low-lying land, can result in unsynchronised development in terms of elevation, while a change in the elevation of the whole urban area of the city is perceived to be unfeasible in the context of an emerging city in a developing country such as HCMC. This not only entails high cost, but also consequently influences the urban infrastructure and any construction linked to accessibility (e.g. houses, drainage systems).

Second, the current plan for transport development fails to addresses a prolonged strategy of elevation development in terms of spatial cohesion, nor the potential flood impact on the system. It only mentions the basic requirements for road development in response to the current tidal effects, without considering possible scenarios. Although it has been updated for higher elevation in response to higher tides in recent years (e.g. from + 1.5m ASL to + 2.0m ASL: Tedi-South, 2013), potential obsolescence in terms of the rising flood factors means it is argued that such continuation of the resistance strategy is not sufficient to meet the uncertain changes in hydro-meteorological factors (e.g. from + 1.68m ASL in 2013, 2014 to + 1.71m ASL in 2017: SRHC, 2010 – 2015, 2017). On the other hand, a centripetal transport structure (mentioned in chapter 2) may be deficient in the continuously linking transport nodes when enlarging their scale, especially as it contains a diversified riverine network. This can lead to potential isolation of several important urban function areas in the case of large-scale floods, with the implication of the undermining of flood resilience, as mentioned in chapters 4 and 5.

Overall, these weak points imply the need for more adequate planning of resilience development in terms of*: i) ground-based network lacking of comprehensive classification of road levels for development, with an inherited transfer from current resistance constructions; and ii) flexible organised structures with better (contiguous) links for transport accessibility in adaptation to different scenarios*. These objectives are closely linked to the two main properties of a resilient transport system: robustness and redundancy, as mentioned in chapter 2. With a link to chapter 4, the rapid urbanisation in the three new development districts (2, 9 and Thu Duc) have blamed the concern for flooding risks on some critical routes along direction 1 to these areas. Flood obstructions to these easily spread the effects out to the urban system. On the positive side, HCMC has a large sprawling network of roads and waterways, which have demonstrated the role in flood resilience from the lessons in chapter 5. Along with the objectives of investments in transport to resolve traffic congestion, these two transport modes could play a vital role in the resilience development of the transport system.

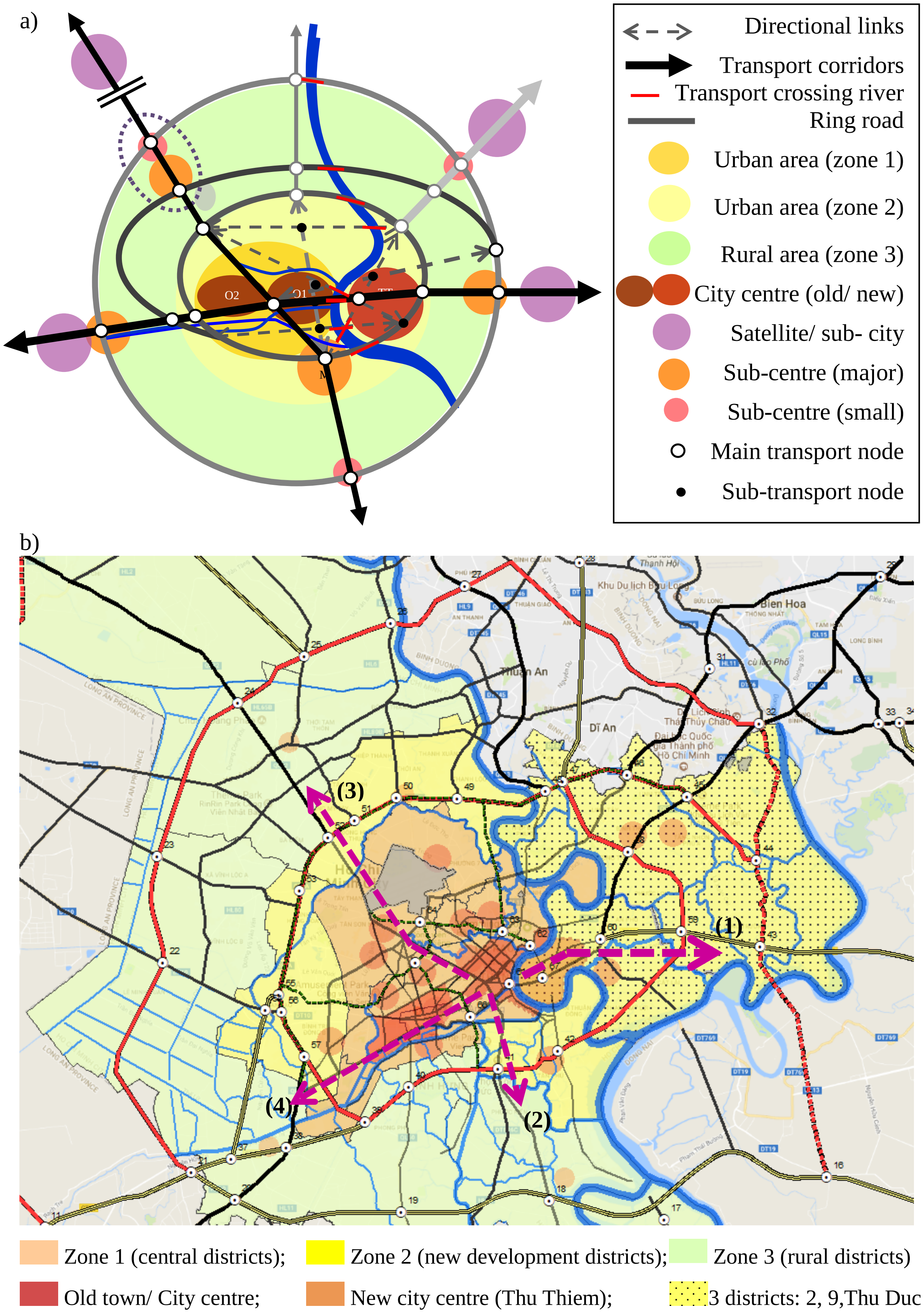


Figure 6. 2 Structure and four directions of transport development:

a) Transport and urban development structure. Adapted from TEDI-South (2013)

b) Transport corridors and main routes. Source: TEDI-South, 2013.

6.1.2. Flood factors related to changes in urban hydro-meteorology

Influenced by tropical weather, monsoon rains typically occur from June to November, with especially heavy rains (50 - 100mm) from August to October. The city has experienced an increase in the frequency of high rainfall since the 1990s (Phi, 2013). Furthermore, extreme weather is also apparent, with torrential rains becoming more frequent; for example, slightly over 200mm rainfall in just two hours on September 26th, 2016 (SRHC, 2016; SCFC, 2016). The total amount of rainfall is tending to decrease, but it is more unevenly distributed over different urban areas, represented by the locations of different stations *(Figure 6.3a)*.

Regarding tidal effects, the Saigon River is the main water body connecting the city to the sea, which means that the associated network of rivers and channels across HCMC experiences semi-diurnal tides. Observation data from the Southern Regional Hydro-meteorology Centre - SRHC (1981-2015) show that the highest tides occur annually during the period September to December. It typically takes about 4-5 hours to raise the river level by around 2m (50cm/h on average). Compared to the water level at Vung Tau (the sea mouth), the increasing level of the highest tides has been most notably seen at Phu An, a station on the Saigon River; for example, +1.42m in 2005, +1.55m in 2010, +1.68m in 2013 and 2014, and even + 1.71m in 2017 (SRHC, 2010 – 2015, 2017) *(Figure 6.3b)*. These levels are put into direct context given the fact that more than half of the city is under + 1.5m ASL (Thinh et al., 2009; ADB, 2010; Storch and Downes, 2011), hence a rise to such level is sufficient to cause overflows over many roads close to water bodies.

In short, the transport system of HCMC has become more susceptible to combined floods, especially in the period from September to November. The increasing water levels of the riverine network can be seen as key gradual factors for fluvial floods, whilst heavy rain is the exacerbating and uncertain factor. Therefore, a hydrological model for flood simulation for the city should rely on the water level primarily influenced by tidal effects to ensure consistency in the construction of extreme scenarios concerning flood vulnerability.

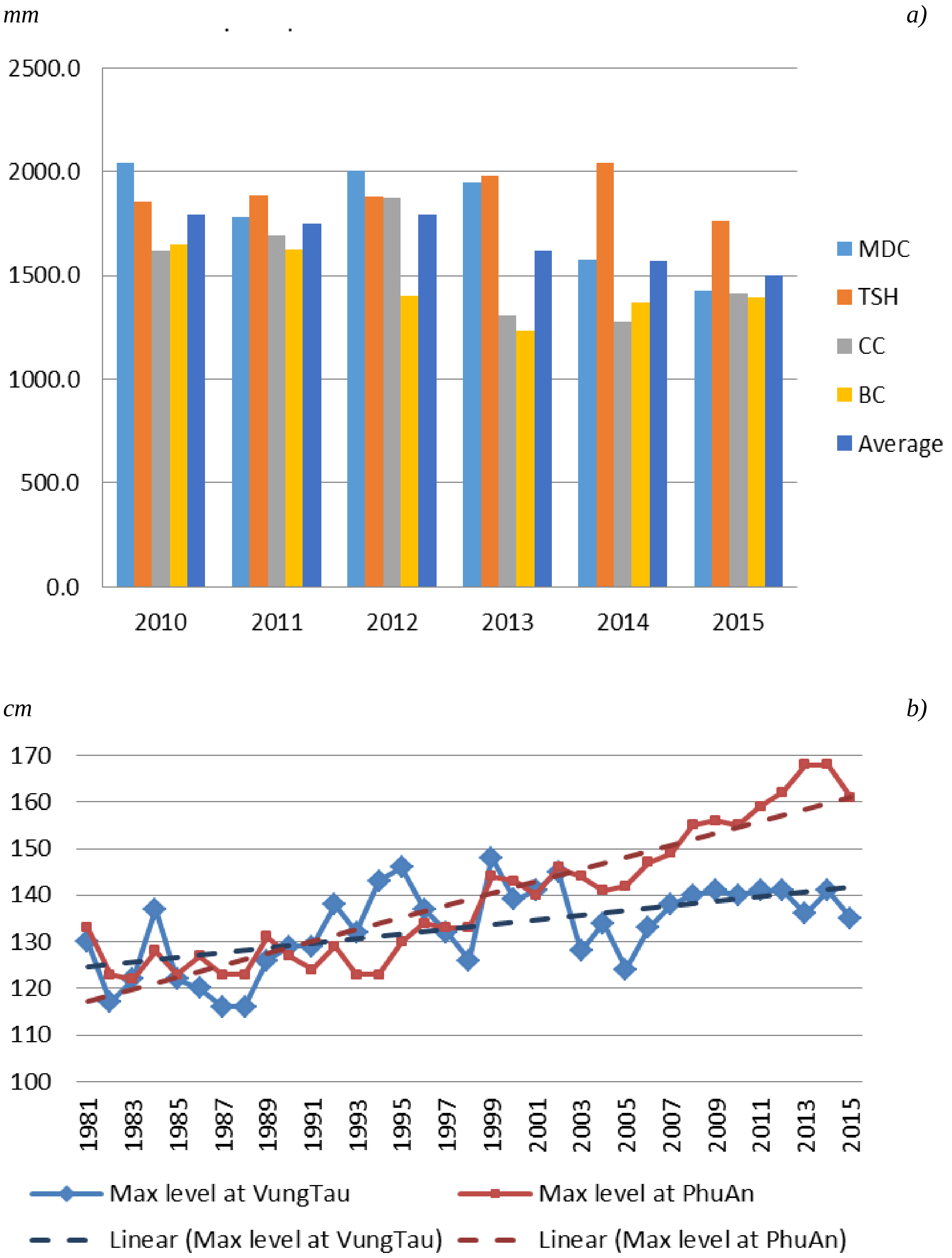


Figure 6. 3 Changes in hydro-meteorological factors

a) Annual precipitation at four meteorological stations in HCMC. Source: SRHC (2010–2015

b) Annual maximum water levels observed at Vung Tau and Phu An. SRHC (2010 – 2015)

6.2. Flood simulation and analysis

In line with the objective of contributing to the revision of the general plan and transport plan to be completed by 2020, this research will create a flood simulation for 2015 (for calibration and validation, see *Figure 6.5*), and for 2020 (for flood vulnerability assessment). The flood extent, referred to as urban areas vulnerable to flooding, will be compared to the scenarios of extreme flood effects by 2025 and 2050 projected by Storch and Downes (2011) and ADB (2010) respectively. The flood surface will then be intersected with the integrated transport map (in ArcGIS/ ArcMap) to assess the subsequent flood vulnerability of the transportation network.

Hydrological modelling in MIKE Zero, computer software with a built-in hydraulic 1D classic module, was employed to simulate the water surface (WS) in 2015 and 2020. The outputs were transferred to ArcMAP for interpolation (about 1000 points on the river network, 15m grid cell). For coordination, a DEM (Digital Elevation Model) was interpolated from the elevation points (about 28,600 points, 15m grid cell), surveyed on the existing surface of built-up areas such as pavements, in the same period as the hydrological model and the transport plan (*Figure 6.4*). The intersection between the WS and the DEM results in the flood surface, which is referred to as the flood depth (in metres) and classified into five levels. For 2020, this flood surface was then overlaid onto an urban zone map and a map of the integrated transport network (the road network filtered to main roads by TEDI-South, 2013). Urban areas and transport segments vulnerable to flooding were identified.

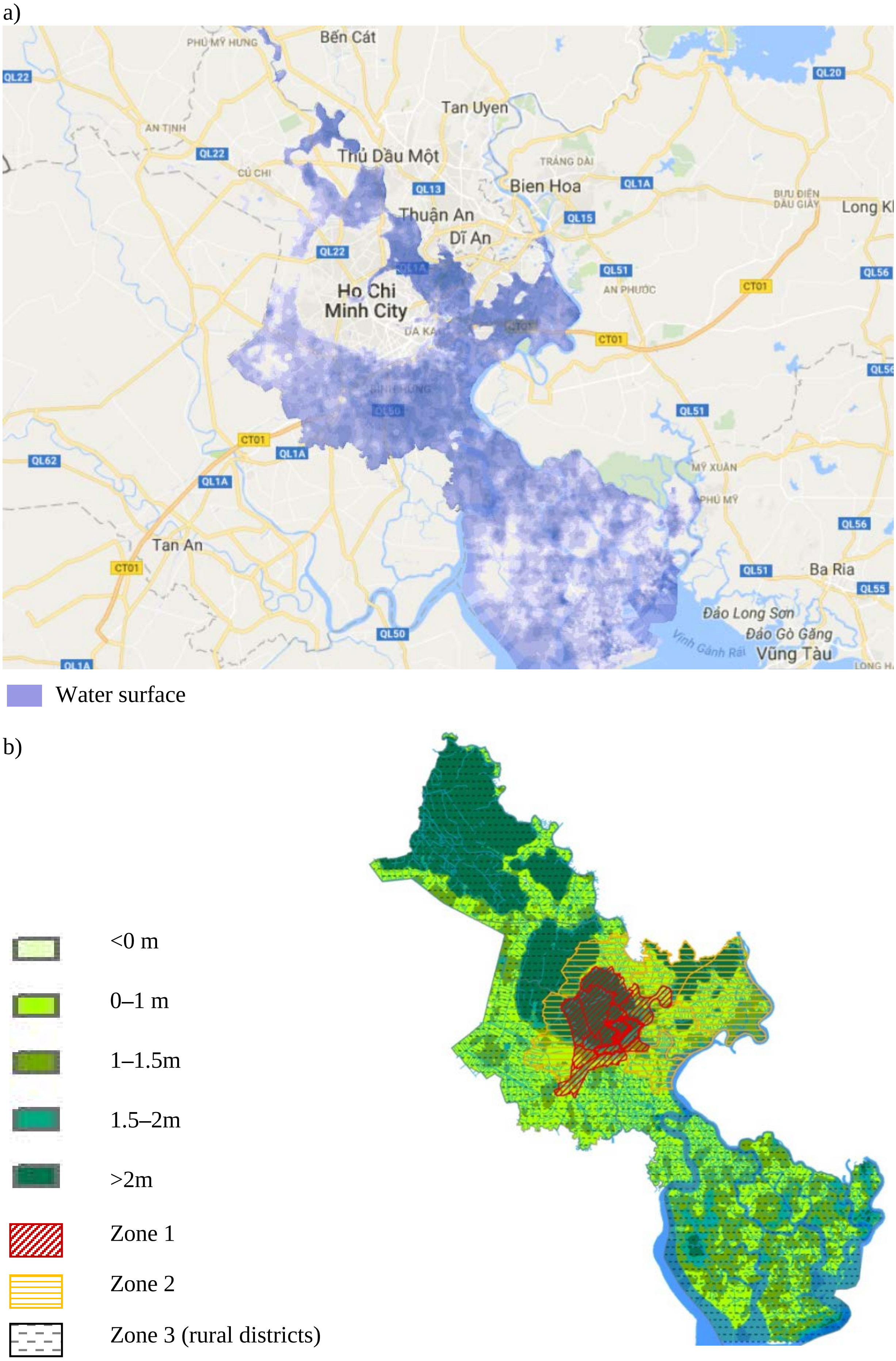


Figure 6. 4 Water surface (a), and digital elevation model (b) for HCMC:

6.2.1. Hydrological modelling

Using actual data from 2015 and projections for 2020, the model was used to simulate water levels in HCMC for the two time horizons. In the case for 2015, the results were validated against observed levels at Phu An, a hydro-meteorological station located at the middle of the Saigon River. Trends, maximum values and average growth rate were then stored for a subsequent simulation of a worst-case scenario in 2020 (Table 2).

Table 2 Data input for the simulation

Year	**Inputs for main boundaries**			
	Water level	**Water discharge**	**Point sources**	**Precipitation**
2015 (real data)	Observed level at Vam Kenh – Vung Tau	Actual discharge from reservoirs: Dau Tieng, Tri An	Residences and industries (estimated increase of around 30%-40% since 2008	Observed at four stations (MĐC, TSH, CC and BC)
2020 (projection)	Projected rise of 3.8 mm/year by 2020 (approx. 130 mm after 34 years).	Highest value (2010 – 2015) - $TriAn_{max}$:1500 m^3/s; - $DauTieng_{max}$: 250 m^3/s	Maintenance of the same trend 2008 – 2015	Highest rainfall for 40 years on 26th September 2016 204 mm/2 hours

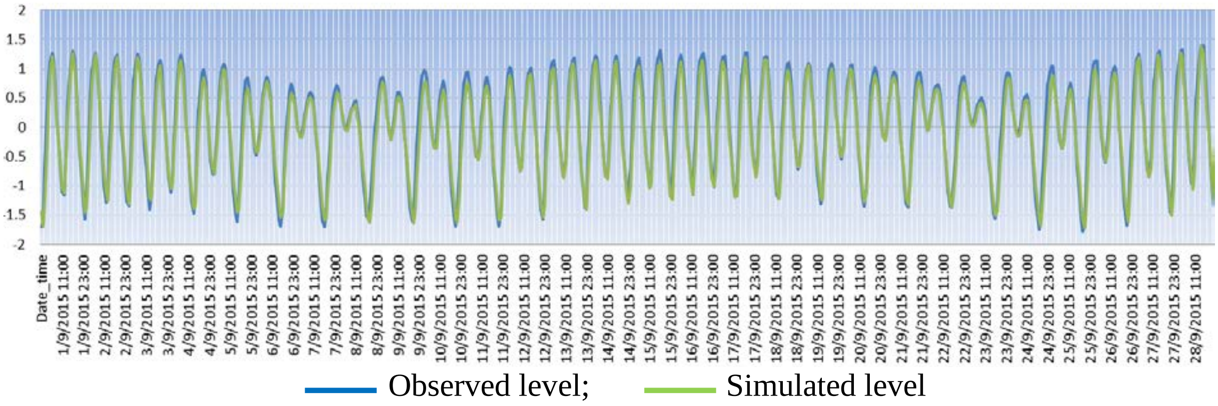


Figure 6. 5 Water level validation: between simulated and observed values in 2015

6.2.2. GIS analysis

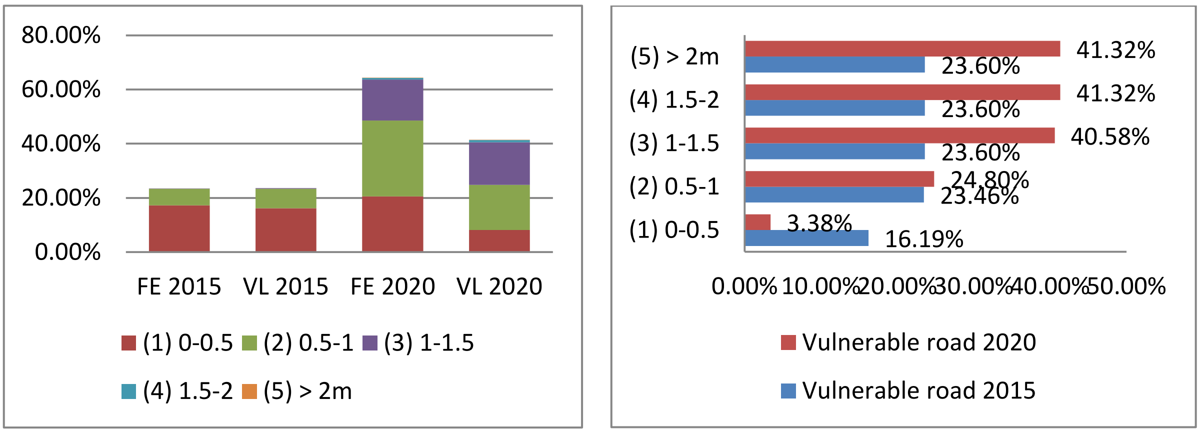
As previously mentioned, a flood surface was created to identify flood extent (FE) and vulnerable road length (VL). The overlaid maps for the two time horizons (2015 and 2020) are shown in *Figure 6.7a, b*. Generally, the city is expected to increase the FE and the VL from 23% and 24% in 2015, to 64% and 41% in 2020 respectively, with the highest depth of about 2.0m (*Table 3*). Both FE and VL tend to increase up to level 3, then remain stable till level 5 *(Figure 6.6)*. Almost all the FE is predicted to be mainly distributed in the East and the South of the city, referring to the new development districts located on low-lying land.

Table 3 Urban areas and road segments vulnerable to flooding

Flood Level	**Flood vulnerability 2015**				**Flood vulnerability 2020**			
	Flood extent 2015 (FE)		**Vulnerable roads 2015** (VR)		**Flood extent 2020** (EF)		**Vulnerable roads 2020** (VR)	
(1) 0-0.5	360.91	17.23%	594.23	16.19%	431.70	20.61%	298.74	8.14%
(2) 0.5-1	128.54	6.14%	266.83	7.27%	585.00	27.92%	611.27	16.66%
(3) 1-1.5	1.73	0.08%	5.10	0.14%	318.08	15.18%	579.14	15.78%
(4) 1.5-2	0.00	0.00%	0.00	0.00%	12.31	0.59%	27.15	0.74%
(5) > 2m	0.00	0.00%	0.00	0.00%	0.04	0.00%	0.24	0.01%
Total	491.18	23.45%	866.16	23.60%	1347.13	64.30%	1516.54	41.32%

Notes: - The urban area is defined as the administrative area of HCMC (2095 km^2*);*

- Urban roads are filtered (without small roads and alleys) and limited to the administrative area.



a) b)

Notes: - "FE": flood extent; "VR": vulnerable roads

Figure 6. 6 Charts for illustration of flood simulation results showing the changes in percentage of flood extent and vulnerable roads from 2015 to 2020:

a) Vertical column chart with the highlight on change in individual portion

b) Horizontal column chart with the highlight on different flood degrees

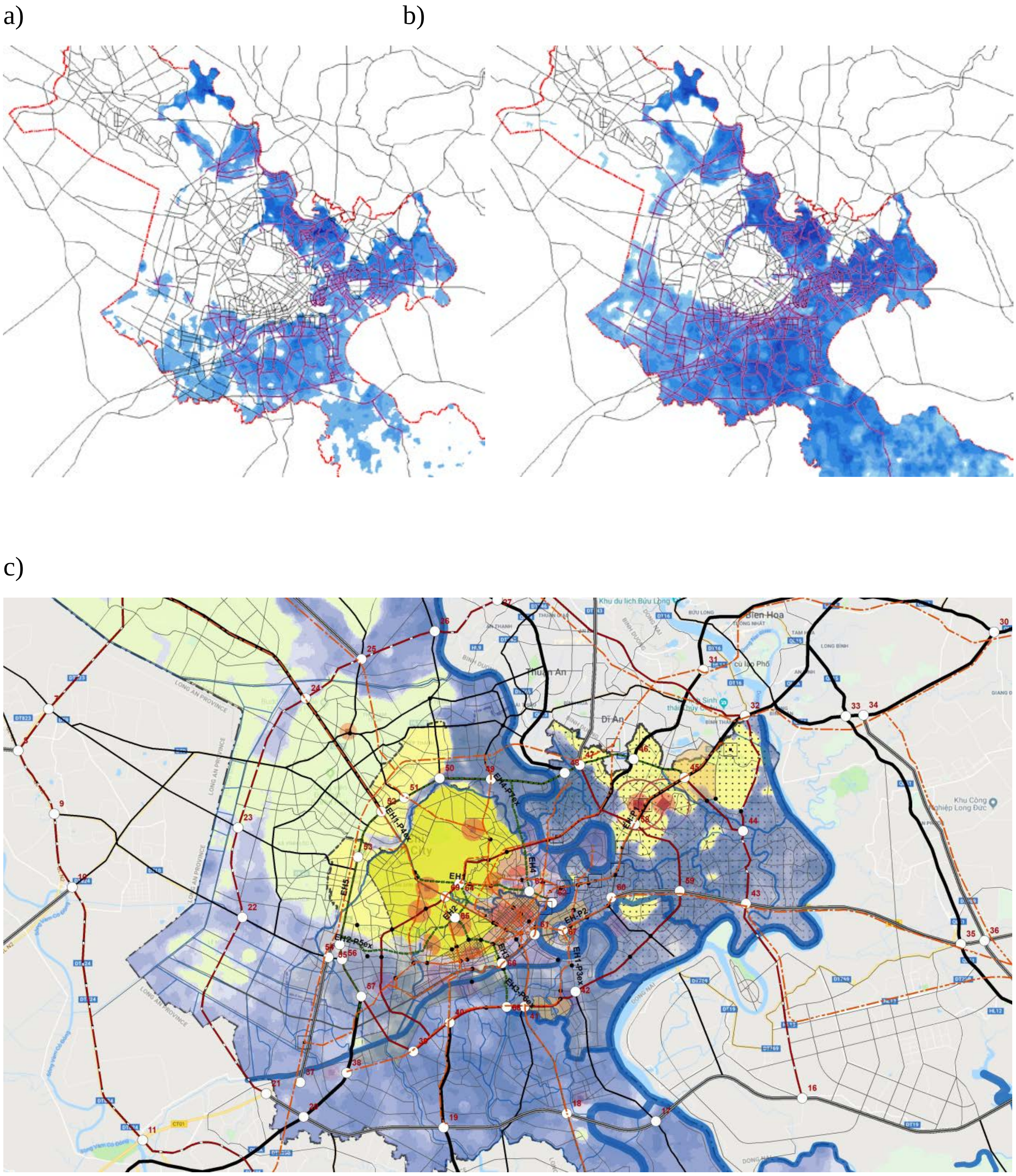
For urban areas, *Figure 6.7* indicates that the flood extent is mostly distributed in the new development districts surrounding the central districts. High flood depth areas are especially situated in some districts in the East and the South (e.g. districts 2, 7, 9 and Thu Duc). With respect to transportation, the network is currently vulnerable to level 1 floods (under 0.5m), but will be more vulnerable to level 2 and 3 floods after 5 years. In correlation to the flood extent, the proportion of VL is predicted to decrease by 8% at level 1 (under 0.5m), but to significantly rise by about 9% and 15% at levels 2 and 3 respectively. The total length of VL is predicted to nearly double from 2015 to 2020. Through the initial results above, the flood vulnerability of the transport system of HCMC can be further evaluated in terms of city scale (spatial dimensions):

- *Horizontally:* characterised by a centripetal structure, the transport network has some key routes extending from the city centre to surrounding areas, particularly the wetlands low-elevated in the East and South. This expands the network scale, referring to the increase in number of transport links, a large number of which are located on areas vulnerable to flooding. This refers to the increasing vulnerability as the exacerbation of flood factors (e.g. higher tides), as the network has insufficient links which ensure connectivity between new development areas vulnerable to flooding (e.g. Thu Thiem) and the city centre, or safer places. Figure 6.6a shows the correlation between flood extent and vulnerable roads, referring to the relation between the increase in urban areas vulnerable to flooding and the increase in flood vulnerability of the transport network including main routes. With a link to chapter 4 (section 4.3.3) and the anecdotal evidence mentioned in Appendix A, vulnerable routes along the first direction to the East and Southeast, to which disruption by extreme floods can result in isolation of the three districts on the eastern side of the Saigon River, are an implication of weak resilience.

- *Vertically:* the continuation of the ground-based development without layering has led to increased intersections between transport network (mainly road network) and riverine network, which is considered as the source of fluvial floods. As a result, the network has more transport routes, crossing flood plains, in accordance to the increase in length of roads vulnerable to different flood levels shown in Table 3 (e.g. 266 km in 2015 to 611 km in 2020 for flood level 2). Particularly, the ease of exacerbating disruptions triggered by some critical routes or nodes is obvious as the effects on these routes can lead to widespread disruption of the whole network. In relation to elevation development, the current plan fails to create systematic entropy, which is not only useful for alternative routes to avoid flooded places, but is also essential to prepare some emergency routes for evacuation in the case of extreme events. This was witnessed first-hand on the 15th September 2015, when immersed segments of main roads such as Nguyen Huu Canh and the Hanoi Highway created traffic congestion across the whole network (e.g. 15 km of congested roads from the Hang Xanh roundabout to the Rach Chiec bridge).

Overall, the transport system of HCMC is assessed to be more vulnerable to flood levels 2 and 3 by 2020, compared to the situation in 2015. It may face extreme flooding (e.g. level 4) as a result of:

- The increasing number of transport structures exposed to flooding in regard to location, particularly critical routes to the East and the South;
- The higher susceptibility to uncertain changes in urban hydro-meteorology in regard to elevation, particularly a combined effect between heavy rain and high tide; and
- The lack of resilience objectives integrated in the plan for development.



🟦 Vulnerable areas (flood extent)

🟧 Zone 1 (central districts) 🟨 Zone 2 (new development districts) 🟩 Zone 3 (rural districts)

▦ Old town/ City centre 🟧 District centre ▨ 3 districts: 2,9,Thu Duc

— National road — Provincial road — Main city road

- - Elevated road (already planned) -·- City rail — Ring road

○ Major node ● Minor node

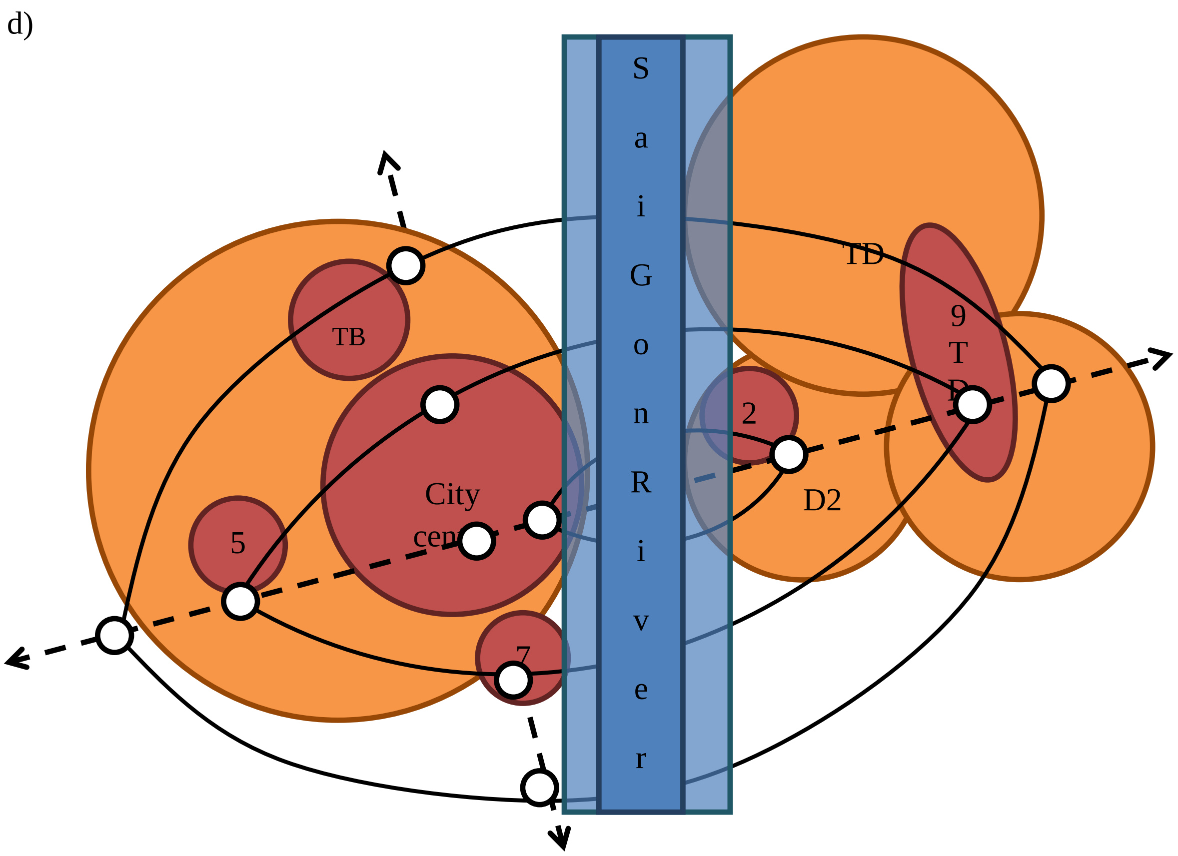


Figure 6. 7 Map of urban areas and transport segments vulnerable to floods, and potential flood disruptions to main transport flows

a) Urban areas and transport sections vulnerable to flooding in 2015

b) Urban areas and transport sections vulnerable to flooding in 2020

c) Critical routes including segments vulnerable to flooding in 2020

d) Potential flood obstructions to the main routes between two sides of the Saigon River

6.2.3. Consensus on increasing flood vulnerability and its potential effects

The results (in the previous sections) show a consistency in the increasing trend of urban areas vulnerable to flooding in HCMC, when compared with the results from previous research; for example, 59% of built-up areas flooded by 2025 (Storch and Downes, 2011), and 71% of urban areas affected by an extreme combined flood scenario by 2050 (ADB, 2010) (see *Table 4*). In transportation, this research affirms that the transport system of HCMC has been increasingly exposed to combined flooding, with the most stress on the links between the two sides of the Saigon River, referring to the transport connections between the city centre (zone

1) and the three new development districts (2, 9 and Thu Duc) as a part of zone 2. Given the importance of the reliability of the whole network, these links have also become more susceptible to changes in urban hydro-meteorology, with high tides now a key factor in extreme flooding. The actual flood effects observed on the fieldtrips, and also reported by SCFC (2015), are also supporting evidence for this trend.

Table 4 Flood simulation results compared with other studies

	Extreme flooding impacts	**Notes**
ADB (2010)	71% (by 2050)	Urban areas
Storch & Downes (2011)	59% (by 2025)	Built-up areas
This research	64% (by 2020)	Urban areas

As a consequence, extreme floods could cause obstructions to several critical routes, with cascading effects to the whole network and ultimately act as a barrier to urban development. With the rapidly increasing population and urbanisation, potential disruptions to transportation, particularly the connections between the city centre and new development districts, may have significant impacts on the socio-economic development of the city.

For example, with reference to the large-scale events in 2015 and 2016 (*Appendix A*), flood inundations to the connections between the two sides of the Saigon River (direction 1) can affect the intensive transport flows on four critical routes including:

- Phạm Van Dong – Binh Loi Bridge – Pham Van Dong;
- Hanoi Highway – Saigon Bridge – Nguyen Huu Canh;
- Mai Chi Tho – Thu Thiem Tunnel/ Thu Thiem Bridge – Vo Van Kiet; or
- Vo Chi Cong – Phu My Bridge – Huynh Tan Phat

This can result in,

- Residents in districts 2, 9 and Thu Duc not being able travel to their work places (e.g. offices, shops etc.) in the central areas (e.g. districts 1 and 3); and in turn,
- Residents in the city centre not being able to return home or travel for their business in the new city centre (Thu Thiem, district 2), or other functional areas (e.g. industry, education and recreation in district 9, Thu Duc).

As the leading contributor to the national economy, the income of HCMC was VND 347,882 billion in 2017 (about USD 16.5 billion) (Mr. Nguyen Thanh Phong – the city mayor, cited in Phuong, 2018); and it is predicted to continuously grow to around VND 376.780 billion in 2018 (about USD 18 billion) (Hoang, 2018). As few studies have proposed an appropriate method of exact measurement of economic losses from flooding, this would be used to equate to potential economic losses from a one day flood. Thus, a fundamental rethink of transport system planning is needed. The following section will present FRTS as an appropriate development approach for the transport system of the city.

6.3. Flood resilient transport system (RTS)

Extreme flooding events around the world (e.g. New Orleans, Manila and Bangkok, see Chapter 4) underline the importance of the resilience of urban transport systems to mitigate losses and damages, as cities become increasingly vulnerable to flooding. For HCMC, the results from chapter 4 and the vulnerability assessment in this chapter are used as the basis for a conceptual model of a Resilient Transport System (RTS). Alongside this, the transport connections between the city centre and the three most vulnerable districts (2, 9 and Thu Duc) are focussed on to demonstrate the application of FRTS, which is then tested by optional routes provided in moderate floods, and special routes for evacuation in extreme floods.

6.3.1. Conceptual model

In respect of the resilience literature reviewed in chapter 2, four properties of a resilient transport system need to be developed through a spatial planning framework. To achieve this, with a focus on robustness and redundancy in the context of emerging coastal cities in Southeast Asia, a balance in flood thresholds and alternative links between important nodes are stressed to ensure the transferable possibility of transport flows in urban spaces in terms of plain (horizontal: X, Y) and elevation (vertical: Z). Thus this research proposes a conceptual model based on the fundamental principles, summarised in chapter 2, as follows:

- *Horizontal development (Figure 6.8a),* referred to as a planarised network (X, Y), which can be broken down into different hierarchical levels (i.e. three levels: national and regional; city and district; and residence or community); this research emphasises the city - district level for connections between different urban areas, in which important nodes need surplus and contiguous links to the others. This increases alternative choices for safe travel to avoid inundated places in order to maintain organisational and flexible connectivity of the whole network in response to the geographical uncertainty of flooding. Critical links vulnerable to flooding should be prepared for potential substitutions. Linked to the literature review in chapter 2, the more vulnerable a particular urban area is assessed to be, the greater the number of various links that should be increased in such area.

- *Vertical development (Figure 6.8b)* refers to the elevation (Z) of the network, which can be classified according to the vulnerable levels being assessed. As the pathway for shifting from resistance to resilience referred to the literature reviewed in chapter 2 (section 2.4.2), a symmetrical threshold can be assigned with different elevation rates, depending on the current conditions of the physical infrastructure, characteristics and changing trends in flooding factors. Transferring to higher levels (elevation), the number of routes will be reduced, but the network will still ensure certain critical routes passing over inundations with respect to the organised structure of the network. This not only maintains transport reliability between different urban areas, but also ensures accessibility between transport developments and interlinked buildings without the requirement of a change in the elevation of the ground floor, with reference to effective investments for the whole system.

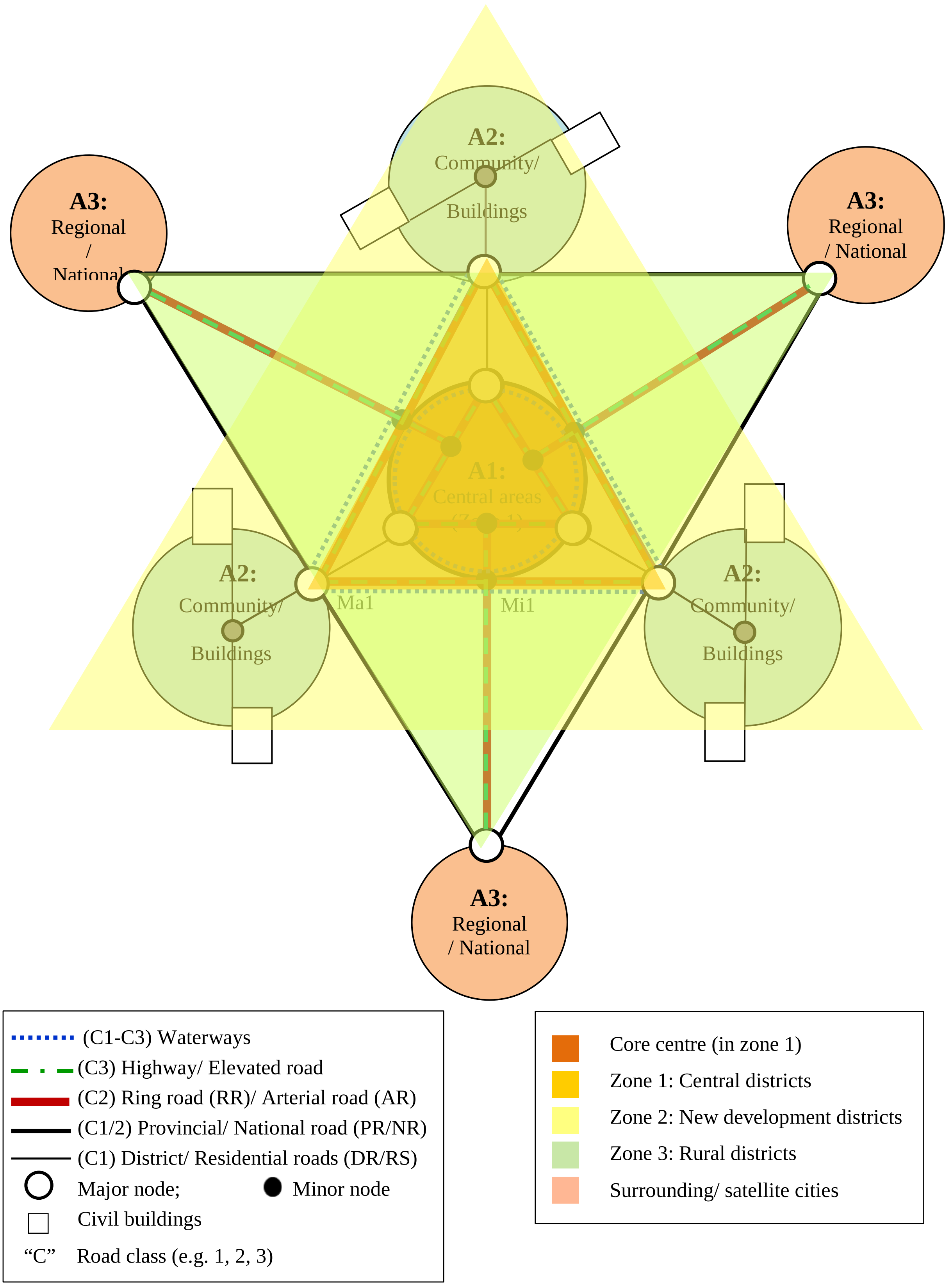
In coordination, *'transfer nodes', at which travellers can change transport mode (e.g. from road to rail), mean (e.g. motorbike to bike) or service (private to public),* should be classified (e.g. major, minor). They should be situated at appropriate geographic locations, where different transport modes can be easily interconnected and interchanged (e.g. road and rail, or road and water). Additionally, transport investments in facilities (e.g. stations, stops etc.) should be planned for their proximity to these nodes. Besides, they could be potentially integrated with the function of temporary refuges in times of extreme flooding. In terms of construction, instead of 'solid spaces' in conventional designs, this research proposes 'empty spaces' under the transport structures, which can be used to contribute to urban resilience solutions, such as expanding open and green areas for water absorption and storage, and also reducing unnecessary costs for backfill materials in the construction.

In brief, the "self-adaptive organisation" of FRTS refers to the spatial transferability of transport flows through alternative links and nodes and between different modes, means or services. This can be seen as a key indication of a resilient transport system, as it shows the capacity for self-adaptive organisation in transportation (reduced to a smaller scale in response to flood levels, and then reverted to normal and full operation when floods subside; see Table 5). This conceptual model is mainly based on a development of engineering *resilience, shifting from resistance, and towards improved ecological resilience in the long-term. The spatial transfer of transport flows through elevated roads, and improved nodes is regarded as the engineering while the coordination with different transport modes offers an opportunity for an ecologically focused objective in the long term, following this research.* Waterways can be seen as the most 'survivable' transport mode with regard to resilience to flooding, not only for travelling in normal conditions but also for rescue in adversity. Referring back to the objective of a resilient transport system in general, the focus on robustness and redundancy the priority to the continuation of travelling, and the time for recovery and maintenance of communication can be referred to the rapidity and resourcefulness as the further development in the future.

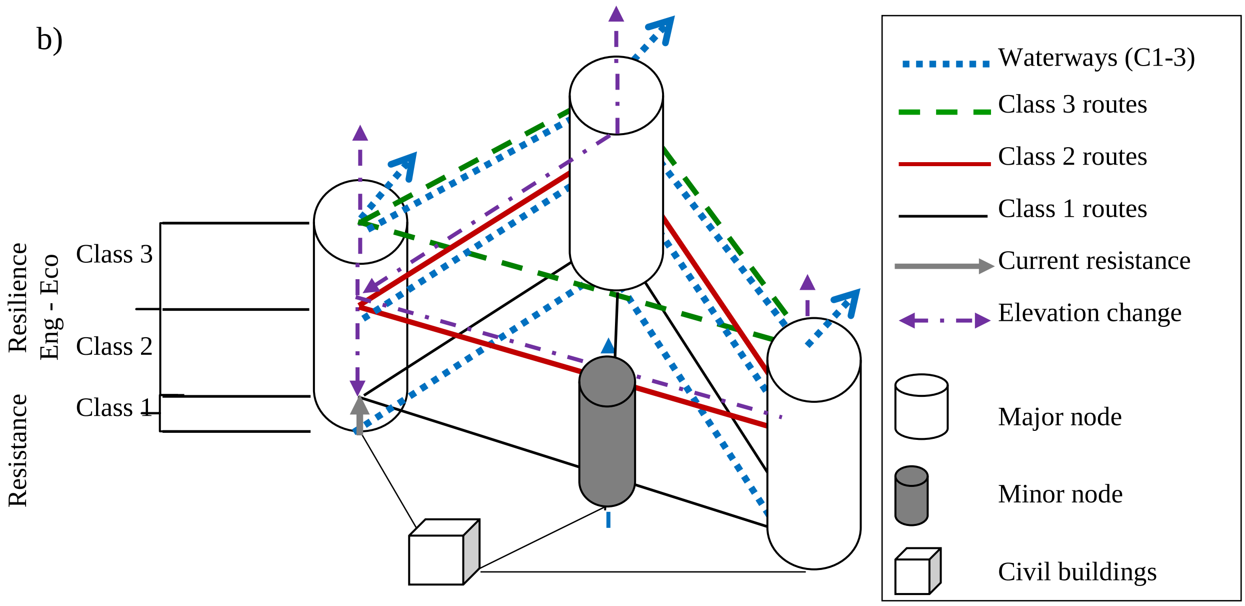
Table 5 Transport self-organising adaptation to flood levels

	Transport Mode	**Transport Mean/ Service**	**Correlation to urban areas**
Class 1	Full	Full	Full
Class 2 (flood levels 2,3)	- Limited to critical routes available (roads/rail lines); - Role of waterways encouraged	- Preferred in public - Constraints on motor vehicles	- Towards less vulnerable areas (compact development/ protected areas)
Class 3 (flood levels 4,5)	- Limited to emergency routes (elevated road/ rail line) - Intensified role of waterways - Prepared air/water-rescues	- Preferred in public - Strictly allowed (walking, bikes)	- Towards safe places/ refuges (e.g. hospitals, buildings, and airports)

a)

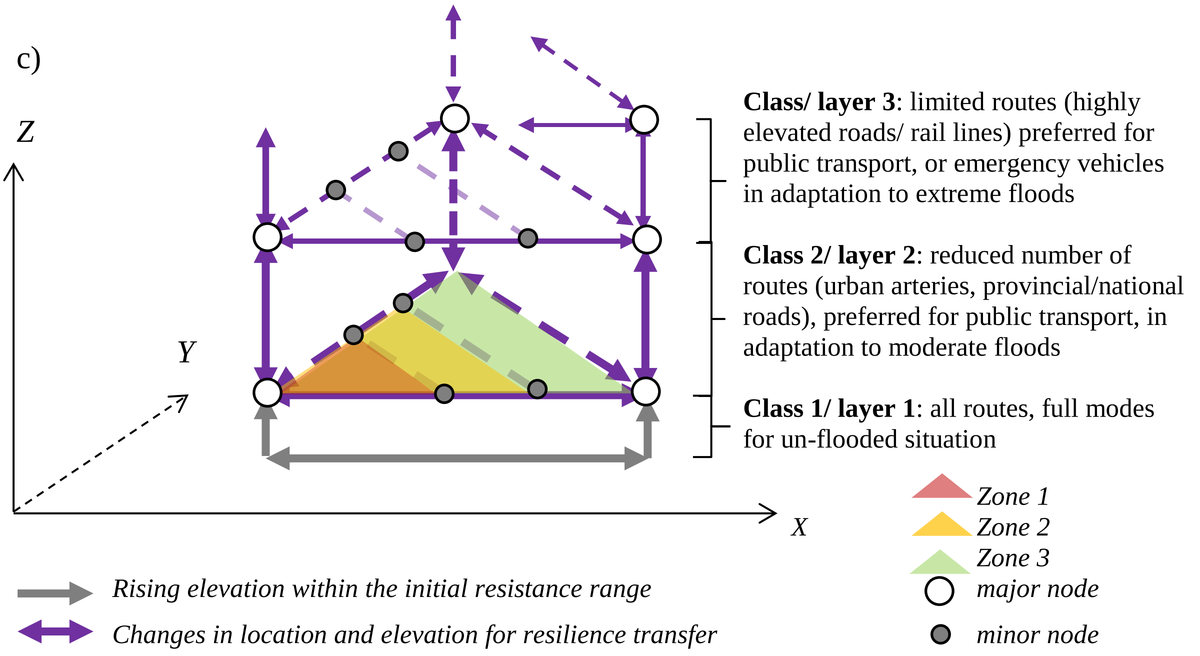


Note: for spatial transfer between different areas, for example from A2 to A1, travellers can obtain an interchange at the nodes Ma1 and Mi1, such as from residential road (C1) to ring road (C2) or from private (motorbikes/ car) to public (metro or bus, or BRT - Bus Rapid Transit)



Notes: transport routes classified in different classes (elevation) can be linked together at the nodes, in coordination with transport modes, means and services allocated around these node in order to offer options for travellers' movement between different elevations (e.g. from class 1 to class 2, 3).

Note:	*Class 1: ER-elevated road;*	*HW-highway;*	*WW-waterway*
	Class 2: RR-ring road;	*NR-national road; PR-provincial road;*	*WW- waterway*
	Class 3: NR-residential road	*DR-district road;*	*WW-waterway*



Class/ layer 3: limited routes (highly elevated roads/ rail lines) preferred for public transport, or emergency vehicles in adaptation to extreme floods

Class 2/ layer 2: reduced number of routes (urban arteries, provincial/national roads), preferred for public transport, in adaptation to moderate floods

Class 1/ layer 1: all routes, full modes for un-flooded situation

Rising elevation within the initial resistance range

Changes in location and elevation for resilience transfer

Note: spatial transfers of FRTS to be integrated with urban zone division in order to ensure movement between:

- *Different locations at same level, or different levels at one horizontal location;*
- *Different location at different levels.*

Figure 6. 8 Diagrams illustrating conceptual model of FRTS (integrated structure)

a) Horizontal development;

b) Vertical development;

c) Spatial transfers (a, horizontal and b, vertical).

6.3.2. Application

Taking into account current planning and development characteristics, the results of the simulated vulnerability assessment are used to highlight the key problems facing flood resilient development of the transport system in HCMC. It has been planned and developed according to the 2010 plan, but lacks elevation classification in the transport network, with reference to spatial planning in line with resistance strategy. The precarious situation and the vulnerability assessment in the previous sections have proved the inadequacy of the plan. Instead, FRTS offers a far more sustainable structure for spatial planning for transport development at city level. Its fundamental principles can be applied by classifying the different roads with respect to the flood vulnerability levels and the current developmental conditions, as follows.

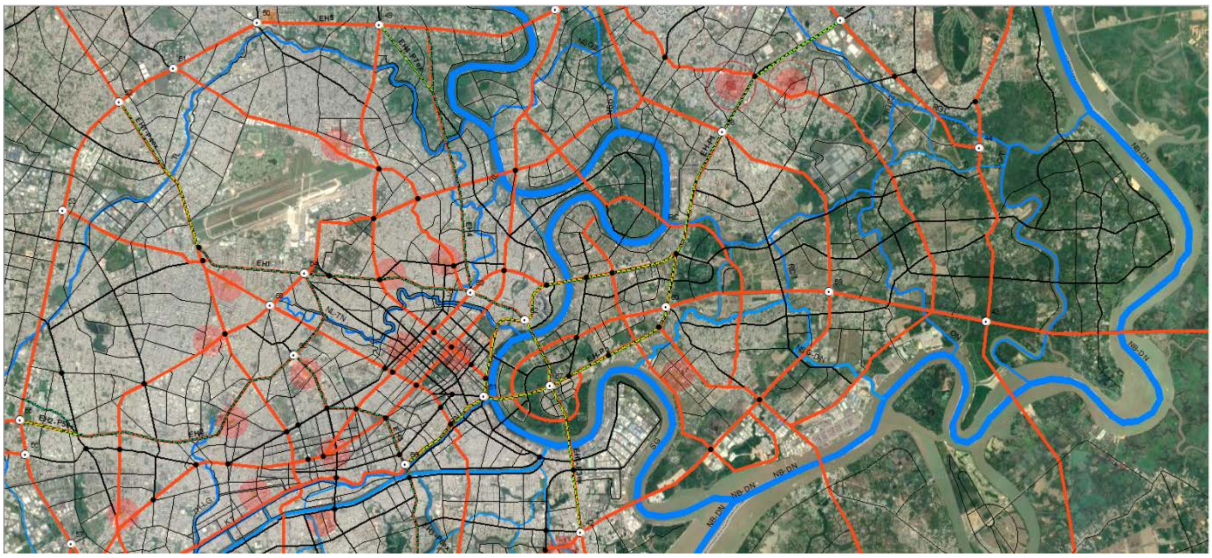
- ***Class 1/ layer 1*** (under + 2.5m ASL, corresponding to flood vulnerability level 1). A consideration here is that the most common vehicles (motorbikes, cars) can naturally cope with this situation, as the heights of the engine and air intake are normally at about 0.3 m; while the common road developments are being raised by about 0.5 – 1.0m (including the minimum buffer required by current building code: 0.3 – 0.5 m above the highest tide in local), as observed on the fieldtrips. With the existing resistant system, the current plans and on-going developments of this city can deal sufficiently with this level.

- ***Class 2/ layer 2*** (+ 4.0 –> + 6.0m ASL, corresponding to flood vulnerability levels 2 and 3). This magnitude relates to some recent large-scale floods. As an initial move from resistance to resilience (engineering), increasing elevation (e.g. 2.5m from the current ground level, with a preference for empty space under the constructions) is required for critical roads, while the remaining can be left at the current low level in order to maintain easy accessibility to existing buildings. Applying the principle of FRTS, roads need to be prioritised for such a ‘surface uplift’ in significance with empty space underneath, particularly the urban arteries identified by the vulnerability assessment in section 5.2.2. Public transport is the preferred service for this level to maximise transport capacity, as the number of routes could be reduced, while the waterways will again have more opportunities to contribute to the whole network.

- ***Class 3/ layer 3*** (> + 6.0m ASL, corresponding to flood vulnerability levels 2, 3, 4, 5). Floods of this magnitude can be considered extreme, such as those seen in New Orleans in 2005, Manila in 2009 and Bangkok in 2011. As a continued move towards ecological resilience to such ‘disaster level’, elevated roads (hardened links) and waterways (softer links) can work together, as the emergency routes, to help people escape from inundated places, or to provide rescue transportation to safer places (e.g. the nearest hospital on higher land), while the hardened nodes can be also used for temporary refuges. Once the emergency subsides, these routes will gradually be reopened to general use, reinstating urban connectivity above current levels.

As an integration of FRTS principles into a smaller scale, such as urban and architectural design, regarding spatial compactness development mentioned in chapter 2 (section 2.4.3*)* and chapter 4 (section 4.5), for examples, elevated walkways and cycle routes between key buildings should be incorporated. Moreover, open spaces alongside transport structures (green and blue solutions), could also be used to improve the urban capacity of water absorption and storage. Besides, the contribution of early warning systems could be involved by updating real-time information systems/mobile apps (e.g. integrated with Google maps) to keep citizens informed about localised conditions and travel options, indicating the transport modes or means available for transfer on particular routes/ nodes.

Overall, the application of such an FRTS model could help the transport system of HCMC become more resilient to flooding, as the robustness and redundancy of the system are expected to be developed by: i) more available routes being substituted to vulnerable road segments in the case of regular /moderate floods; ii) emergency routes being prepared for evacuation in the case of extreme floods. As the initial improvement of these two properties, the rapidity and resourcefulness of the transport system could be improved along with long-term investments in terms of transport facilities allocated at concentrated areas close to major nodes, and forecasting capacity with early warning systems supported by the Internet of Things.



Note: Current roads assigned in different classes should be controlled in terms of their elevation development as mentioned, and their connectivity needs to be developed at different nodes. This has subsequently required the elevation management of urban developments referred to surrounding areas.

Figure 6. 9 An illustration of three road levels classified with respect to the FRTS (the map zoomed in the middle part of HCMC).

6.3.3. Testing

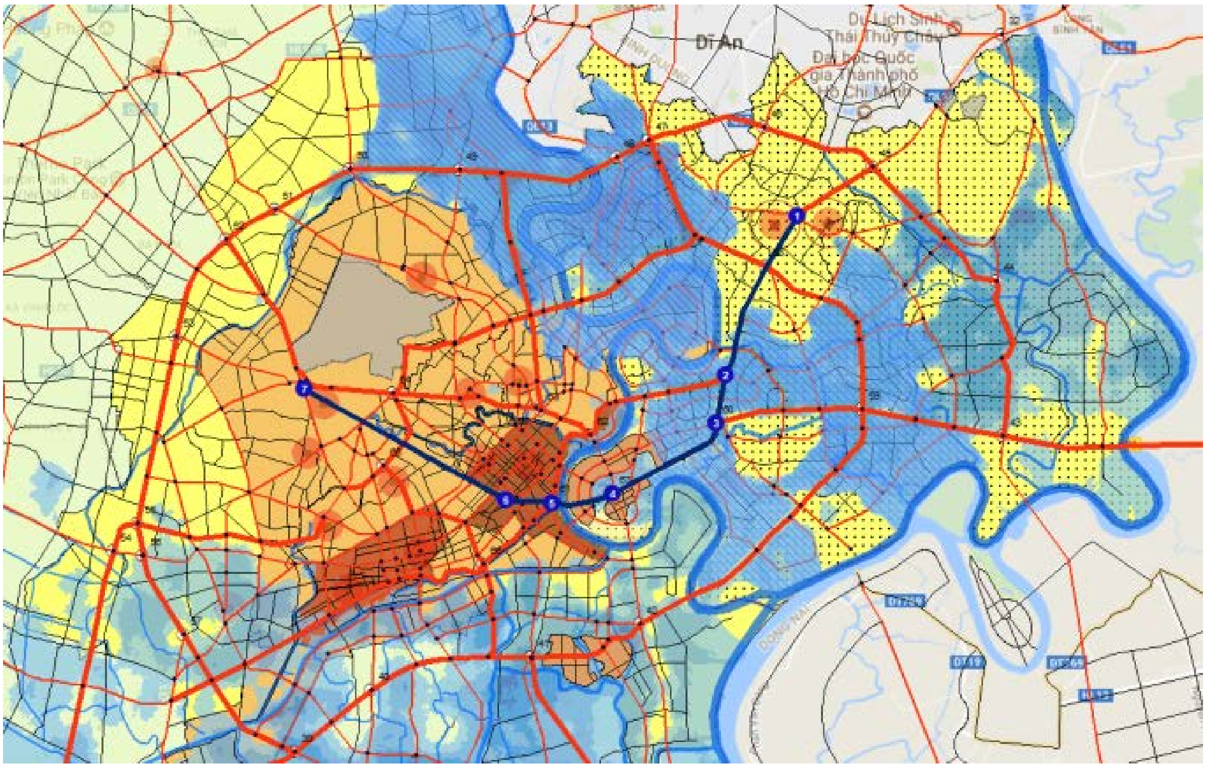
The initial conclusions in chapter 4 have identified the three most vulnerable districts on the Eastern side of the Saigon River: districts 2 and 9 and Thu Duc, over which, or to which, the accessibility of the transport network needs to be ensured. Thus some critical routes between the current centre (districts 1 and 3) and new city centre (Thu Thiem) and district centres in these new districts should be highlighted in the testing of the application of FRTS. Under two scenarios, the assumption is that a regular/moderate flood and an extreme flood will happen with respect to the simulation in the previous section. Using the ArcMap network analysis tool, the objective is to seek: i) alternative routes available if regular/moderate floods; ii) evacuation routes available if extreme floods.

- **Scenario 1 - S1** (dealing with flood levels 2 and 3/ thresholds 2). People who are assumed to be located at stop 1 (close to node 58, district 9), and need to travel from this stop, passing by Thu Thiem (district 2) and the city centre (district 1, 3), to stop 7 (towards node 52, Tan Binh district). For this moderate case, the network analysis tool found that at least four options are available *(Figure 6.10).* Although travel times could be extended by the longer journeys, they will probably be shortened by limiting the use of the routes to public transport.

- **Scenario 2 – S2** (dealing with flood levels 4, 5/ thresholds 3). People who are assumed to be located at Thu Thiem (district 2), need to be evacuated to the nearest safe area, an unflooded place which should be adjacent to emergency services such as a hospital *(Figure 6.11a, b).* The GIS analysis found that at least two emergency routes are available, and identified as an ‘8 km distant service area’. With respect to the principle of FRTS, walking and cycling are advocated for this emergency case. Within a two-hour window before peak water levels, there is the potential to cover distances of up to 8km to the nearest services (such as hospitals), or 10 km to the airport (assuming an average speed of walking of about 4-5 km/h, and cycling of 15 km/h) – see *Figure 6.11c*.

This test provides an indication of the feasibility of applying the structure, and classifying the principles of FRTS into the network of HCMC to help the city regulate commuting on available routes as a substitution for routes vulnerable to moderate floods, and to also prepare available routes for evacuation during extreme floods. This demonstrates an improvement in the robustness and redundancy of the transport network to avoid inaccessibility of transport on a city scale, also with reference to the potential isolation of the three most vulnerable districts discussed in chapter 4. Together with the highlighting of the connections along direction 1, similar tests could be carried out for other places, with the more varied options offered by the involvement of additional transport modes/ means or services.

a)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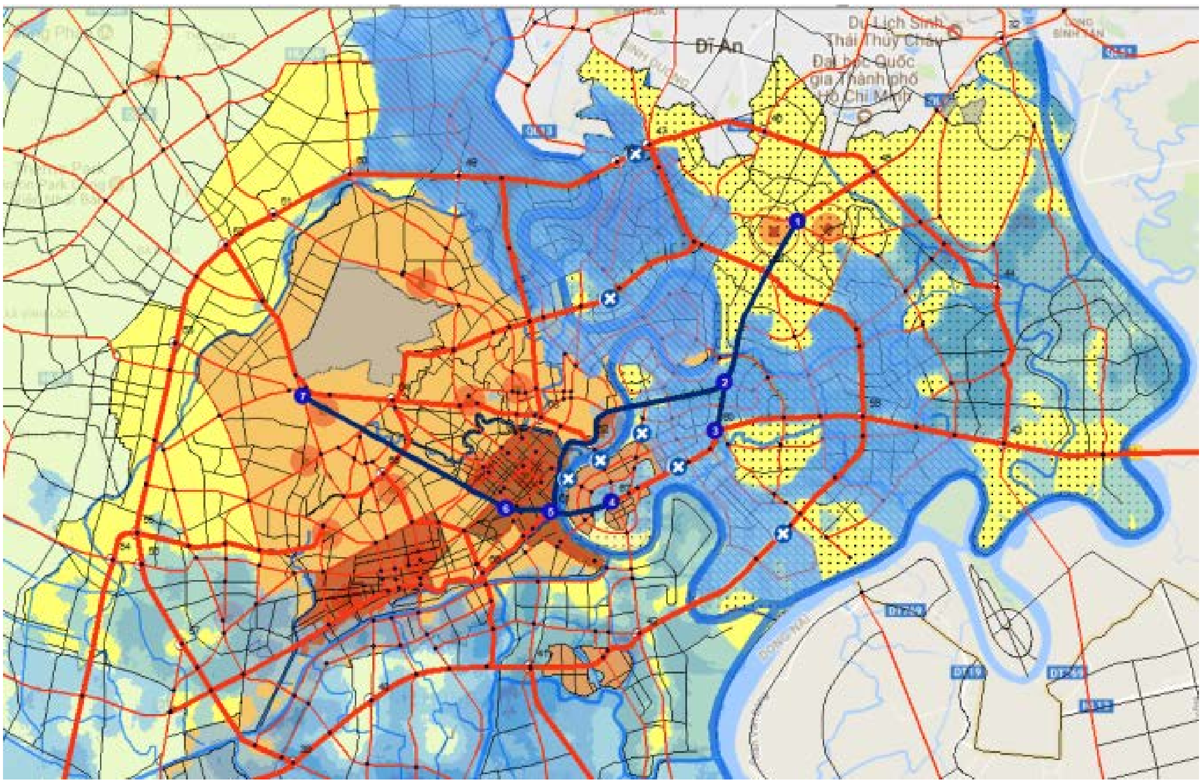
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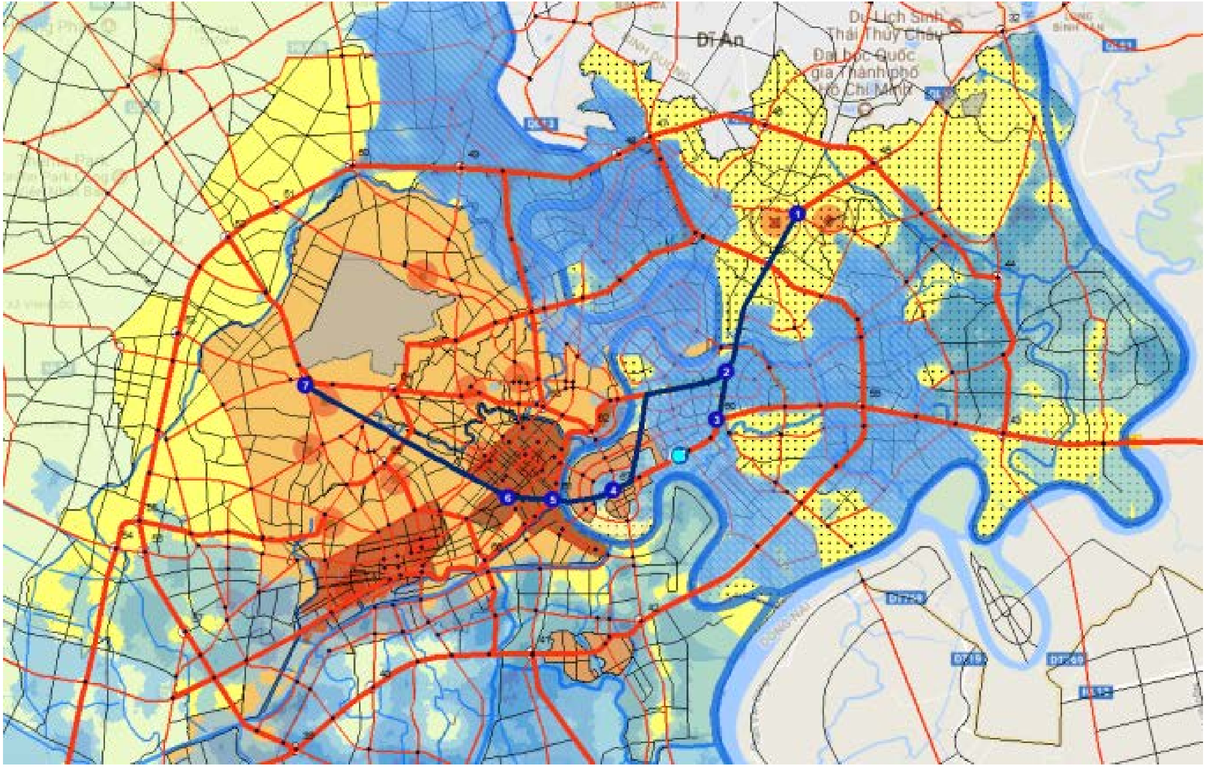

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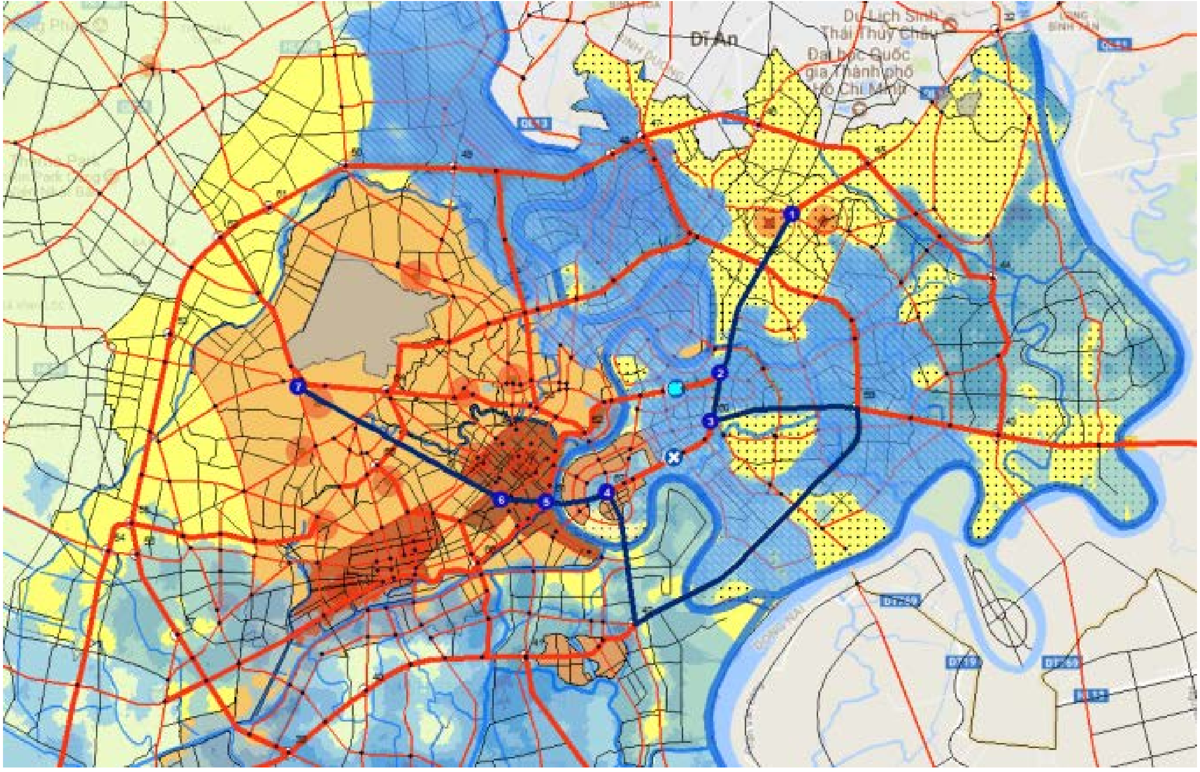
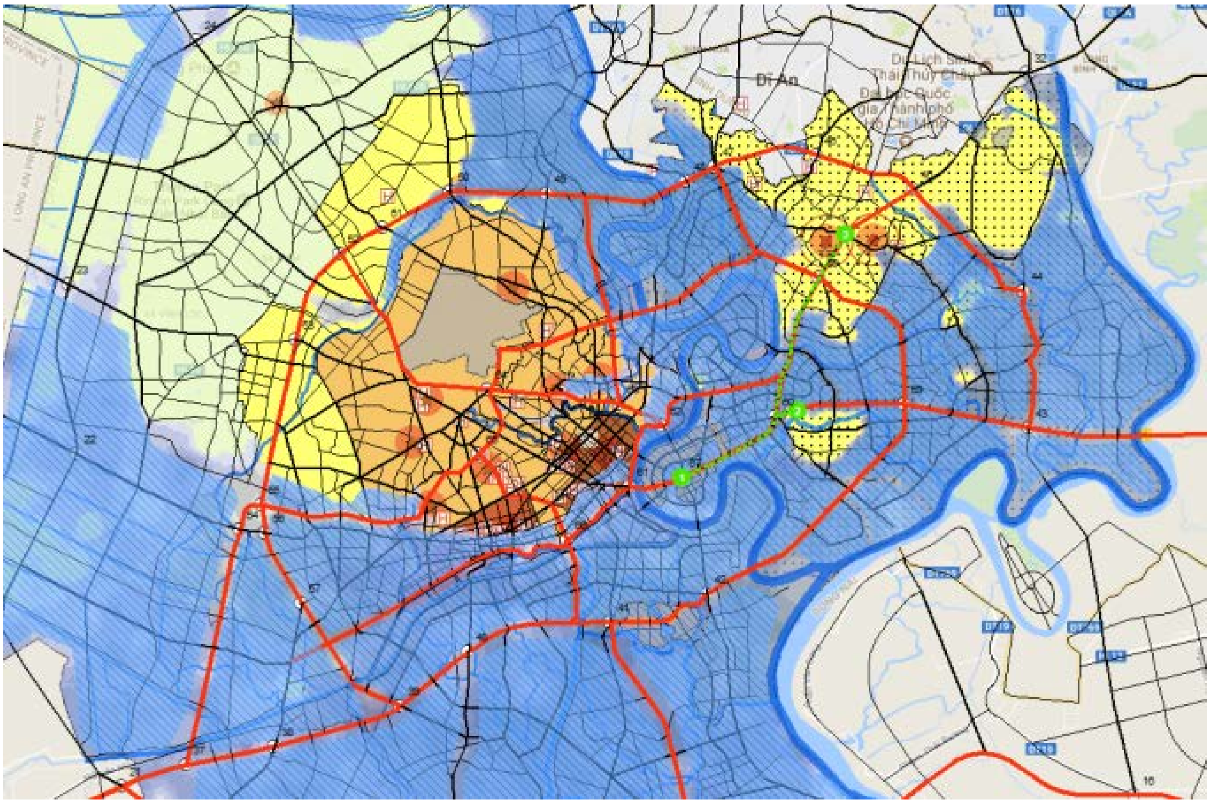


Figure 6. 10 Alternative routes (blue lines in a, b, c and d) for travel choices during moderate floods of levels 2 and 3: a) Option 1: 21.5 km; b) Option 2: 21.6km; c) Option 3: 21.8 km; d) Option 4: 30km

a)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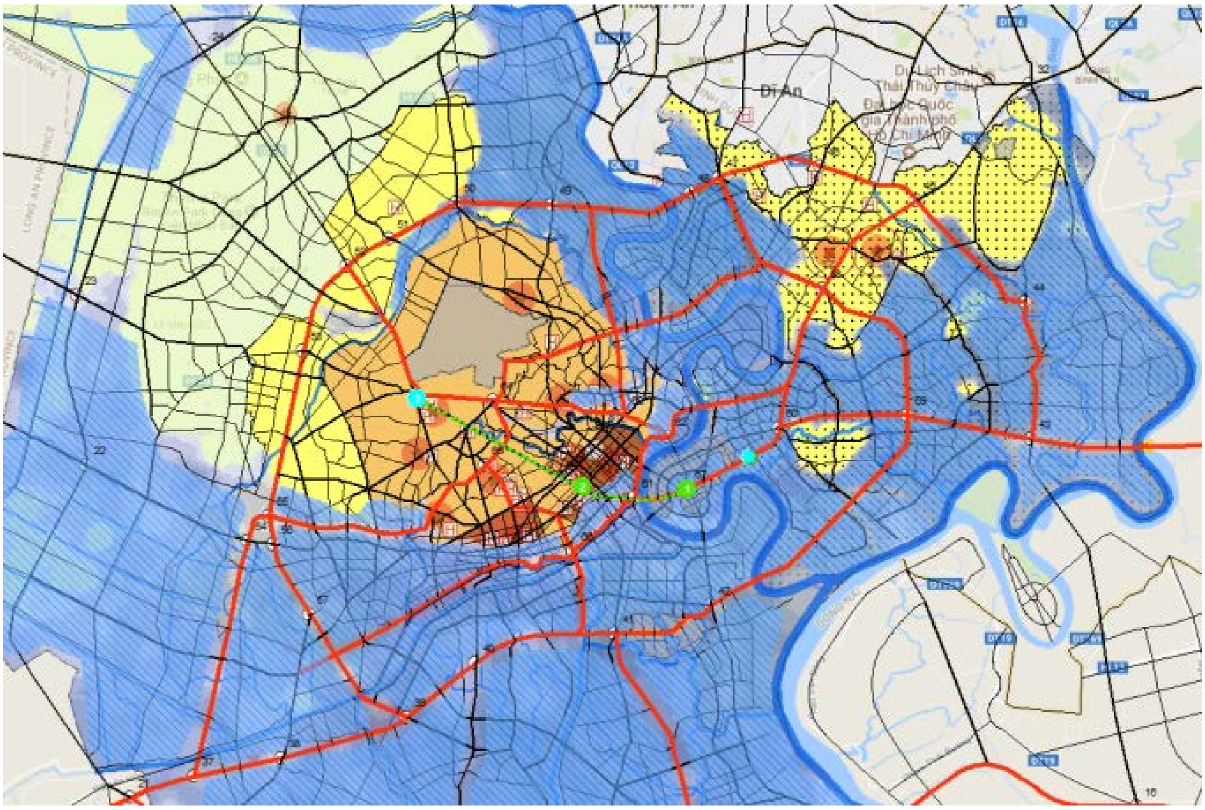
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c)

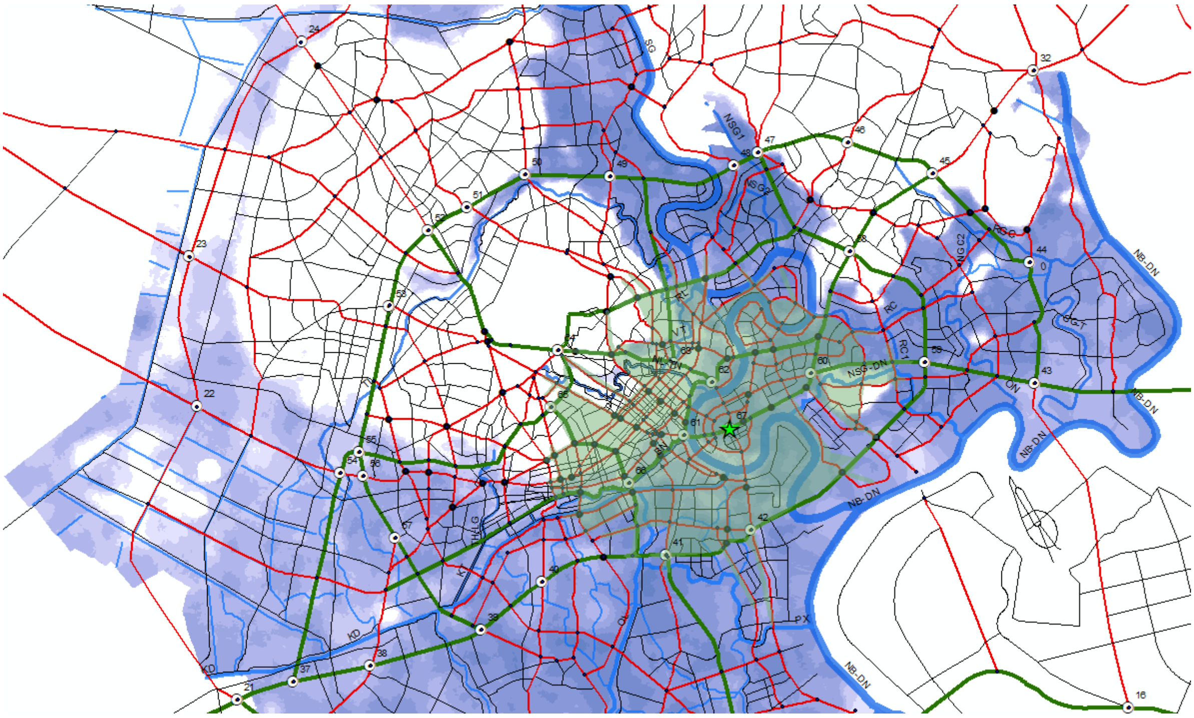


Figure 6. 11 Examples of emergency routes (green lines) for evacuation (from Thu Thiem district) in extreme level 3, 4 and 5 floods (a, b); and essential services (hospitals as refuges): a) Option 1: 11km; b) Option 2: 10.3km and c) Service area within 8km (hospital)

6.4. Summary

Including the analysis on transportation development and flood vulnerability assessment, this chapter has presented the FRTS model to improve resilience of the transport systems of HCMC. Linked to the fundamental principles from the literature review (chapter 2), it is a development of resilience theories from concept to application in the plans for transport development with respect to reducing flood vulnerability. *At the heart of the FRTS is the organisation of a spatial structure of links and nodes, which enables commuting flows to be spatially transferred between different locations referred to as horizontal development (X, Y), and levels, referred to vertical development (Z) in adaptation to different flood magnitudes.* Using the GIS tools for a simple test at city scale, the results have proven that the application of FRTS has increased alternative ways potentially supported by different transport modes, means and services in dealing with both moderate and extreme floods. This can be seen as an indication of improved engineering resilience to different flood scenarios.

Moreover, the combined method to assess flood vulnerability in the transport network by incorporating hydrological modelling and GIS analysis in this chapter also implies that thoroughly understanding the characteristics and changes in hydro-meteorological characteristics is essential to simulate and assess the flood vulnerability of the transport system of the city. For urban planners, this method can be used to anticipate future vulnerability to extreme floods, as the basis for developing resilience to flooding during a process of urban planning for development of transport. For HCMC, this has become the basis for the implications, followed by adjustments and blueprints in the following chapter.

Chapter 7

IMPLICATIONS, ROADMAP AND BLUEPRINTS

7.1. Introduction

The application test in the previous chapter has shown that the FRTS model can theoretically help HCMC improve the flood resilience of its transport system. In accordance to the planning framework in Vietnam, urban transport developments will be conducted in the general plan (city and regional level) as the master document, and subsequently continued in a transportation plan for further developments. Recently, the general plan has been accepted for a revision which should be completed by 2020, and this can be seen as an opportunity for potential integration of the results from this research. Thus, this chapter will explore the implications for understanding the flood factors and inadequacy existing in the current transport plans, and also refer to recommendations for transport development in the future. As the final outputs, potential adjustments to the revised plans are proposed and followed by road maps and blueprints as the outcomes from the application of the FRTS.

7.2. Implications

7.2.1. Flood factors to increasing impacts and trend of vulnerability

In HCMC, the changes in both urban hydro-meteorology and socio-economics are having considerable influences on flood vulnerability, as a consequence of the negative effect of rapid but unsustainable urban development, intertwined with climate change impacts. It is contended that there is an ambiguity in understanding the important features of flooding in HCMC and that high tides can be seen as the *background and periodic factor* whilst heavy rains are the *exacerbating and uncertain factor* in the rising water levels of the riverine network. With a link to the literature of flood vulnerability in section 2.2 (chapter 2), the flood susceptibility is the result of such combined effects, while the rising exposure to flooding is actually due to the inadequate urban development plans including transportation. Indeed, the flood events statistics by SCFC between 2010 and 2015, and the anecdotal evidences from the fieldtrips confirm that flooding has increased the impacts particularly on transportation in the city particularly since the rapid urbanisation in new development districts. Additionally, the results of flood vulnerability assessment from the previous chapter demonstrated that the urban transport system of this city is increasingly vulnerable to extreme floods in relevance to inappropriate spatial planning for transport development.

7.2.2. Inadequacy of planning for transport development

With respect to a link between this chapter and chapter 4, the city contains a large area of low-elevated wetlands, which have been gradually replaced by new built-up areas between which the transport connections are vulnerable to flooding due to the inadequate concern in planning. As the transport system of the city has been planned and developed on the basis of a ground-based network, the reliance on such a continued extension to the new urban areas situated on low-lying lands certainly makes the urban transportation easily affected by fluvial flooding in relevance to the setting of characteristics of large sprawling riverine network. Although property developments could raise the elevation of some local roads and the ground floors of resistant building against current flood levels, this is not sustainable in terms of large-scale deployment. Raising the elevation of the ground base for the whole network, also with reference to the ground of new urban areas accounting for over 50% of HCMC’s territory, is obviously infeasible because of the lack of backfill materials (e.g. soil, sand) and the detrimental effects on the equilibrium of the urban hydrological system, referred to permeable surface and natural water flows.

Through the case studies reviewed, HCMC has much to learn from New Orleans, Manila and Bangkok, in that uncontrolled urbanisation on new development areas on low-lying lands results in increasing flood vulnerability, while resistant systems such as existing flood defences, can be overwhelmed by extreme floods, to which resilience of the transport system has proven to be of real importance, in respect of transport accessibility during adversities. However, the local government of HCMC still continues with defensive strategies and short-term solutions, while ignoring softer, long-term approaches based upon effective planning. In fact, the worsening flood impact on transportation is considered to be a manifestation of the inefficiency and unsustainability of the current plan and on-going developments. The most significant inadequacy is the deficiency in vertical planning, in terms of elevation layering for different roads in relation with their location. Thus, it is obvious that there now exists a pressing need to improve flood resilience, which can be integrated in urban planning process for development, in line with the framework mentioned in chapter 1.

7.2.3. Opportunities for the FRTS to be applied in potential revisions of transport plans

With a general approach of urban flood resilience leading to a concern for the resilience of the transport system, there is a need to improve the robustness and redundancy by the focus on the horizontal in cooperation with vertical development in planning. Regarding to potentially minimising urbanisation on vulnerable lands, transport accessibility between compact urban areas should be addressed by elevating key and collective sections of critical routes that are assessed as vulnerable (into different classes mentioned in section 6.3.2), as well as retaining the remainder of the network. With a link between chapters 4, 5 and 6, critical routes between the two sides of the Saigon River (from the city centre to the three new districts 2, 9 and Thu Duc) need to be emphasised; particularly routes in classes 2 or 3 (e.g. the four routes mentioned in section 6.2.3). As such, the FRTS can be seen as an appropriate reference for HCMC when revising the urban plans for transport development, achievable through a planning framework which would initiate the shift to resilience, instead of a total abandonment of the existing resistant systems.

To a wider extent, there is also a need for cooperation in planning processes with other cities in the HCMC region in terms of workforce distribution related economic development. By constraining the growth of the population in HCMC, the number of people and assets exposed to flooding can be controlled. This not only reduces the pressure of accommodation in HCMC, but also retains a labour force for a sustainable development strategy for HCMC and its satellite cities. As such, the resilience of the transport system could be developed at a larger spatial level, with reference to the regional level of the FRTS.

7.3. Roadmap and blueprints

The main aims of applying the FRTS into the plan for transport development can be simply translated into: i) the increase in substitutes for critically vulnerable routes; and ii) emergency routes for evacuation, with the focus on the most vulnerable areas. To succeed, a process can be deployed in line with FRTS fundamentals, as the following steps:

i) Coordinating hydrological modeling and GIS analysis to show flood extents, in order to identify vulnerable roads, which will then be classified into three levels (based on the main function, e.g. arterial roads referenced to the current plan; observation and experience; and connectivity between transport nodes referred to urban centres or high density areas);

ii) Analysing, organising and re-classifying the priority of the three classes/levels based on the fundamental principles of FRTS (e.g. assigning critical routes into class 2 or 3, and emergency routes into classes 3) with reference to the current transport plan;

iii) Testing for scenarios relying on the levels of vulnerability assessment;

iv) Comparison with the existing master-plans to differentiate and to depict the new routes or segments proposed on the integrated map.

(See *Figure 7.1*)

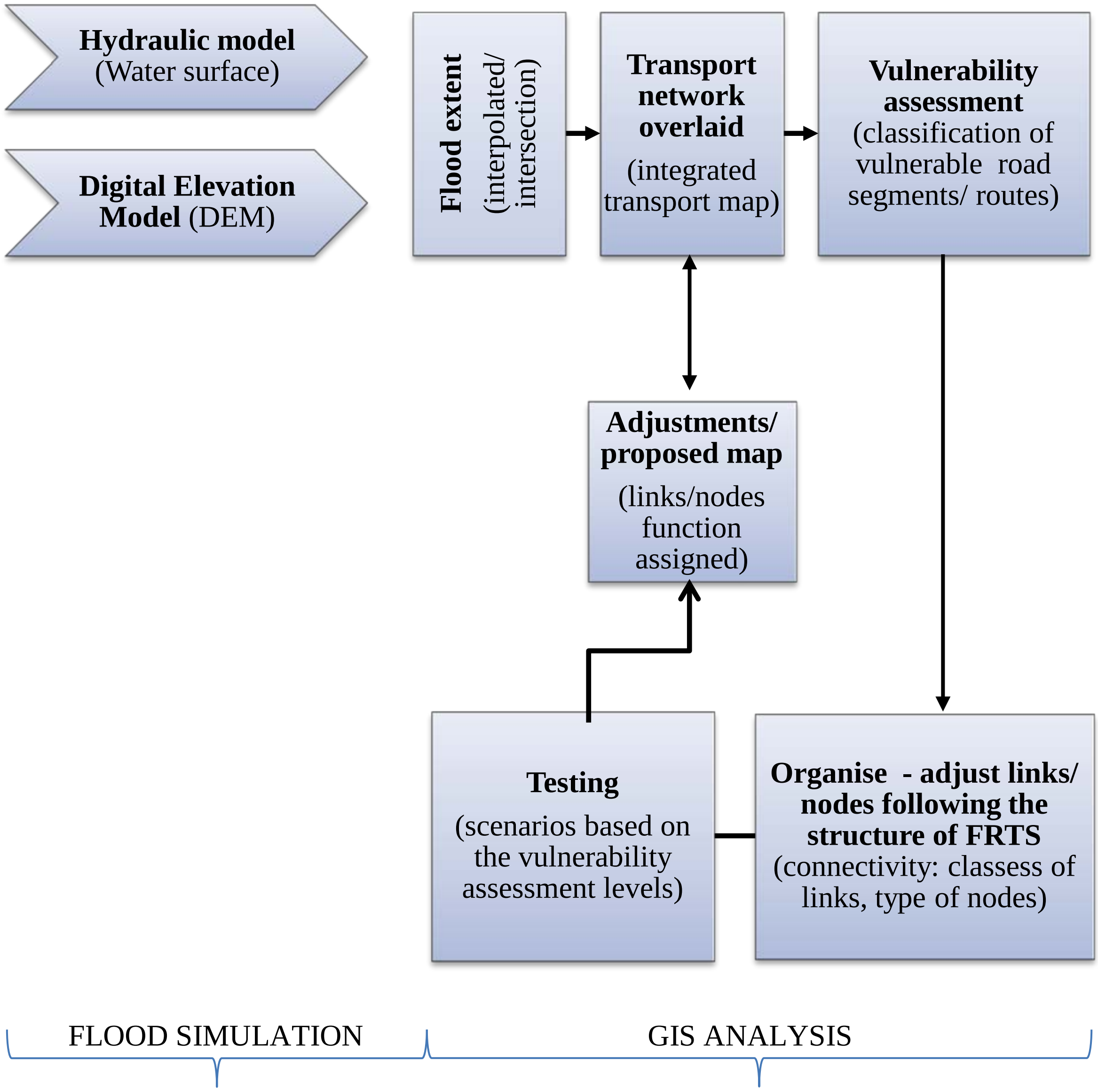
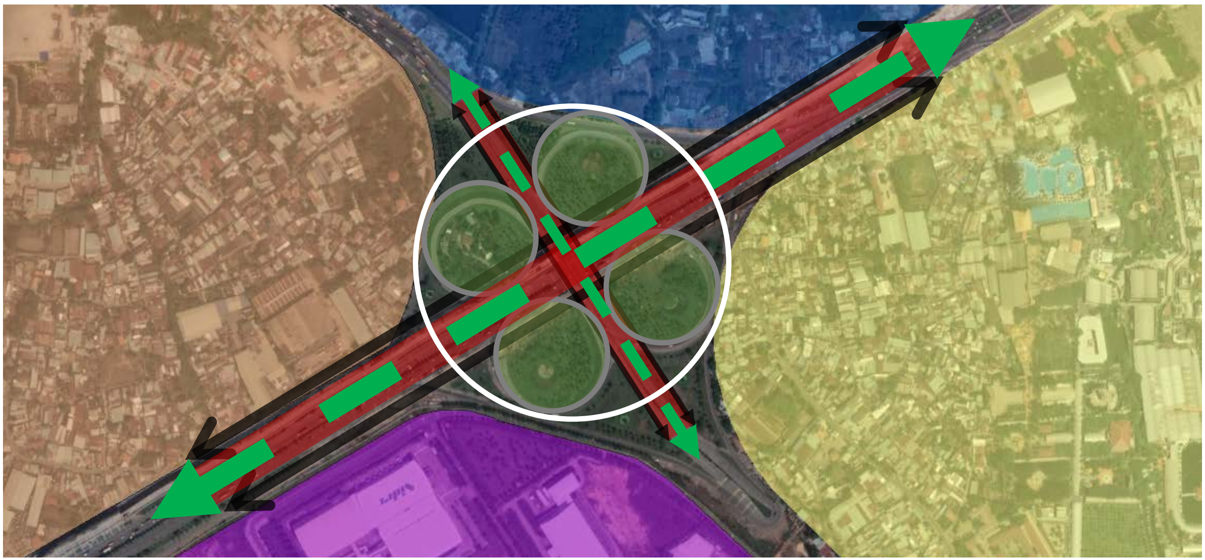


Figure 7. 1 Roadmap for FRTS application into the transport plan

━ National road
━ Provincial road
━ Main city road
- - Elevated road (already planned)
- - - - City rail
━ Ring road
- - - Elevated road (applied FRTS)
- - - - National rail
━ Waterways
○ Major node
● Minor node

Figure 7. 2 Proposed adjustment to the current plan for transport (layered onto Google map)



● Proposed temporary refuge spaces (elevated from the ground) at a major node

- - High elevated road (level 3); ▬ Road level 2; ━ Road level 1

Note: Class 1 (C1), Class 2 (C2), Class 3 (C3)

🟧 Infrastructure land; 🟨 Residential land; 🟦 Current education land; 🟪 Industrial land

Figure 7. 3 An example of major node (45) developed with respect to FRTS

Table 6 List of major nodes recommended for connections by the high-elevated roads and waterways, as a main part of FRTS application into the current plan

Node	**Location**	**Strategy**	**Description**
41 **->** **41A**	Intersection: Nguyen Van Linh St. and Nguyen Huu Tho St., Road 9A(district 7)	New	On an urban artery (Nguyen Huu Tho St.) and waterway to Ong Lon, Dia canal; at the centre of district 7 with two universities (RMIT and Ton Duc Thang), one bus stop
42	Intersection: Huynh Tan Phat St. and Nguyen Thi Thap St. (district 7)	New	Directly connected to Phu My bridge, close to one bus stop.
60	Intersection: Mai Chi Tho St. and Luong Dinh Cua St. (to CT01 highway, district 2)	New	On an artery traversing Thu Thiem (district 2) connected to district 9; close to new residences vulnerable to floods: Thu Thiem, An Phu- An Khanh, with two bus stops and Giong Ong To canal.
58	Intersection: National highway 52 and Do Xuan Hop, and ring-road 2 (planned) (district 9)	New	On an urban artery, and linked to a major node: the Thu Duc crossroad. Close to the centre of Thu Duc district (e.g. universities: Banking University of HCMC and Technology College); one bus stop.
45	Intersection: National highway 52 and National highway 1A (SuoiTien, district 9)	Upgraded (already elevated)	On main regional transport routes. Major transport hub for several concentrated areas (Suoi Tien park; National University, including five universities and Thu Duc hospital), Near several major bus stops.
48	Intersection: National highway 1A and National highway 13. (Thu Duc)	New	On a new urban artery; close to the main market (Dau Moi), one bus stop and the Saigon River
52	Intersection: National	New	Along an urban artery; close to four bus

	highway 1A and Truong Chinh St. (Binh Tan district)		stops
54/ 55	Intersection: National highway 1A and Regional road 10 (new highway)	New	At the Centre of Binh Tan district, close to Tan Tao industrial area; close to two bus stops nearby Tham Luong channel, which travels towards Long An province
61	Intersection: Ham Nghi St. and Ton Duc Thang St., close to the Thu Thiem tunnel	New	In the central area of the city centre (end of the Ham Nghi artery); near the Saigon River and Bach Dang park; and close to four bus stops.
62	Intersection: Nguyen Huu Canh St., Ngo Tat To St. and Thu Thiem bridge	Upgraded (already elevated)	In a high-density area located by new residences, but normally flooded, near the Saigon River and close to two bus stops.
63	Intersection: Dien Bien Phu St. and Nguyen Cuu Van road	New	On Dien Bien Phu artery, near Cau Bong canal; close to two bus stops.
64	Roundabout: Cong Hoa St. and Hoang Van Thu St.	Upgraded (already elevated)	On CongHoa artery. At the centre of TanBinh district, close to HoangVanThu park.
65	Corner: Thanh Thai St. & Bac Hai St.	New	In the centre of district 10, with several highly concentrated areas of education and leisure, such as Ho Chi Minh City University of Technology, and Le Thi Rieng park.
66	Intersection: Vo Van Kiet St. and Nguyen Van Cu St.	New	On Vo Van Kiet artery; near BenNghe canal; close to one bus stop.
67	Intersection: Mai Chi Tho Boulevard and Nguyen Co Thach St.	New	At the centre of Thu Thiem (district 2); on the artery from the West to the East.

Notes: 8 out of 60 current nodes retained and 8 additional nodes (41A, 61-67);

Table 7 List of elevated roads and waterways proposed to supplement the current plan

Name	**Links**	**Length**(km)	**Objective**
EH1 EH2 EH3 EH4 EH5	Between congested areas	70.70	In the plan 2010 to solve transport congestion
EH-P1	East – West route: from city centre (district 1) and the Eastern side of the Saigon River (districts 2, 9 and Thu Duc)	19.02	To ensure transport availability from the three most vulnerable districts to the city centre.
EH-P2	Between the old centre (district 1) and the new centre (Thu Thiem)	7.47	As above, especially connecting the new centre, ThuThiem.
EH1-P4ex	From Node 52 to EH1	4.60	To connect EH1 to National Highway 22.
EH2-P5ex	From Node 55 to EH2	1.64	To adjust EH2 orientation to node 55, and connect the Highway Tan Tao – Cho Dem.
EH4-P6ex	From Node 49 to EH4	2.36	To adjust EH4 to node 49, and connect to EH5 (Ring-road 1, Le Van Khuong St.
	Total:	**107.38**	
	Routes planned	70.70	In the plan approved in 2010
	New routes and extended routes	36.68	Proposed by this research

Note: *Maintaining five routes from the plan for transport 2010, with proposed extensions of four sections (P4ex, P5ex and P6ex), and two new routes (EH-P1 and EH-P2) proposed.*

Table 8 List of waterways

ID	**Name**	**Length** (km)	**Objective**
BL	Ben Nghe (channel)	3.31	Connection: West - East sides
DN	Dong Nai (river)	28.40	Main water body
KD	Kenh Doi (channel)	4.33	Main flow: West - East sides
KT	Kenh Te (channel)	8.85	Main flow: West - East sides
NB-DN	Nha Be-Dong Nai (river)	16.49	Main water body
NGC2	Nhanh Go Cong 2 (canal)	1.72	Connection: NGC - RGG
NSG1	Nhanh Sai Gon 1 (river)	6.40	Approach from nodes 47-48
NSG2	Nhanh Sai Gon 2 (river)	4.58	
NL-TN	Nhieu Loc-Thi Nghe (channel)	10.30	Connect to EH2
RC1	Rach Chiec 1 (river)	1.67	Link between RC & NSG-DN
NSGDN	Nhanh Sai Gon-Dongnai	10.74	Approach from node 60
OL	Ong Lon (channel)	12.40	Links: EH3, node 41, highway
ON	Ong Nhieu (channel)	6.90	Link: NGC&DN
PX	Phu Xuan (river)	10.45	Approach from node 41
RC	Rach Chiec (river)	6.66	Links: NGC2, ring-road 2, SG
RGC	Rach Go Cong (L1, canal)	7.65	Links: SGT, node 44,ring road 3
SG	Sai Gon (river)	102.82	Main water body
ST	SG_Tac (river)	12.98	Links: RGC, highway, NB-DN
SR	Soai Rap (river)	40.47	Main water body
TH-LG	Tan Hoa-Lo Gom (channel)	4.45	Connect to EH2
TL	TL-BC-RML (canal)	25.32	Links: node 52, EH1-P4ex, SG
RL	Rach Lang (canal)	3.90	Link: EH4 to SG
VT	Van Thanh (canal)	3.67	
	Total:	**334.46**	

Notes: 23/100 main watercourses are recommended for utilizing a part of the existing riverine network for contribution to flood resilience of transport system.

7.4. Summary

This chapter has addressed the implications for HCMC after the FRTS model with a test for application in the previous chapter. The roadmap and blue-prints for some potential adjustments to the current plans for transport development in HCMC are the main outcomes and these are expected to be useful for a process of revising the plans in accordance with the framework of Vietnam. Though some list of specific solution have been presented, the proposal for developing flood resilience of the transport system of HCMC could be improved in relation the critiques and further work, which will be mentioned in the following chapter.

Chapter 8

CONCLUSION

Using an integrated approach to flood vulnerability, flood resilience of urban transport systems has been explored in this thesis and on the basis of this a conceptual model has been developed and applied to the urban planning framework of HCMC. Through a structure of eight chapters, including three published papers (chapters 4 to 7), which correspond to the four research aims stated in the introduction, this thesis has demonstrated:

- Evidence of increasing flood vulnerability arising from both climate changes and inappropriate planning for rapid urbanisation on floodplains particularly in three new development districts on the Eastern side of the Saigon River in HCMC;
- The lessons for flood resilience development in particular the importance of the transport system as coastal cities have gradually become more vulnerable to flooding as a result of poorly planned development;
- The concept for a flood resilient transport system to help HCMC and also to inform other emerging-coastal cities to mitigate flood impacts through future urban planning and transport development; and
- Proposal for adjustments to the current plans for transport development in according to the urban planning framework in HCMC.

This chapter concludes with an overview of the significant findings and contributions of the work. It also discusses potential impacts, and offers some research critiques as the drivers for further study.

8.1. Findings and contributions

8.1.1. Evidence of increasing flood vulnerability in transport system of HCMC

HCMC is increasingly vulnerable to floods due to increased urban exposure arising from inappropriate urban planning for development leading to the increase in the number of new residences exposed to flooding, while the impacts from climate change manifested through a combination of more intensive rains and high tides is also increasing the likelihood of serious events. The evidence presented in the thesis agrees with the recommendations by Storch and Downes (2011) and Phi (2013), that the city urgently needs much more effective planning and management of new built-up areas, especially in the east and the south. Indeed, the worsening floods and increasing flood vulnerability are mainly down to the rapid urbanisation from the centre to low-elevated wetlands especially in the South and the East. This has resulted in not only the imbalance of flood management system, but also people and assets exposed to flood risk. Furthermore, the urban expansion process necessitates an extension of the ground-based transport network on low-lying lands risky to fluvial floods, leading to an increase in transport routes vulnerable to flooding, particularly the connections between the two sides of the Saigon River (the city centre and the three new emerging districts 2, 9 and Thu Duc), leading to potentially large-scale disruptions to the whole network. Thus, this has increased concerns over the flood resilience of the urban transport system.

8.1.2. The lessons of flood resilience development with the importance of transport system, as implications for HCMC and other emerging coastal cities in SAC

- The significant flood incidents in New Orleans, Manila and Bangkok, demonstrate that coastal cities have become more vulnerable to floods, and potential losses and damages can be mitigated by a prolonged strategy of shifting from resistance to resilience in urban planning by:
- Minimising new residential developments on floodplains;

- Enhancing the role of transportation in urban resilience to floods; and
- Improving the ability of forecasting extreme weather and communication between communities and government.

Informed by the perspective of emerging coastal cities in Southeast Asia, globalisation and economic growth are stimulating an ever greater level of investment, which has become a driving factor for revising plans for urban developments. These cities, which used to be adaptive to environmental challenges since their initial establishment, can adjust their strategies of developing flood resilience integrated into the process of urban planning for spatial development. With respect to leaving open outer spaces (water or green surfaces referred to floodable areas) and compact inner spaces, it is recommended that new urban accommodation should be allocated on high land, referred to as advanced land, while on-going or new developments on floodplains need to be rigidly controlled with more improvement of robustness and redundancy of transport accessibility for emergency, e.g the high-elevated roads for evacuation. Besides, governments should reconcile their budgets for further developments of flood defences; instead there should be soft solutions in spatial planning which can be achieved more efficiently. In practice, the rapid growth is presently causing problems, but it also provides fascinating opportunities for revising urban plans for urban development plans including transportation, with the potential application of a flood resilience model.

8.1.3. The Flood Resilient Transport System (FRTS): from a conceptual model to application in the urban planning framework in HCMC

Through the conceptual FRTS developed for potential application in HCMC, it is recommended that spatial organisation of links associated with nodes for transport interchange, referred to as offers for alternative routes, modes, means, or services can allow spatial transfer (location and elevation) of commuting flows in adaptation to different flood magnitudes. This indicates the ability of self-organising potential changes in scale (reduced in scale in response to the increasing flood degree, and reverted to full scale operation as floods subside), in adaptation to flood uncertainties. In relation to engineering flood resilience development, elevated roads and watercourses are the two preferred transport methods (in coordination with increasing the resilience of key transport nodes), due to their characteristics and current conditions of transportation development in HCMC. Indeed, the lessons learnt from extreme flood incidents also support the advance of these two transport modes in dealing with extreme floods.

As a contribution to flood resilience theory development in practice, the innovation of this model is firstly the possible shift from an existing resistant transport system to a resilient system through an urban planning framework, including the plans for transport development. Secondly, the flexible movement of transport flows between different spatial scales (horizontal and vertical in cooperation), referred to as transport accessibility between different urban areas, can become an motivation for more compact urban development on higher areas of land, in turn leaving more floodable areas as wet-lands. Thus, this encourages high density of construction with effective urban spatial uses at compact areas, while open space or buildings with empty spaces underneath for water absorption and storage is recommended for vulnerable areas. In other words, the FRTS not only provides more choices for travellers dealing with different levels of flood, but also creates further resilient strategies for urban design and building design in the future.

Besides, the use of the combined method of Flood Simulation and GIS-Analysis used by the research is expected to be applied by urban planners or researchers in other cities. Different hydrological models can be built on the basis of the hydro-meteorological characteristics of each city and the availability of data, while GIS-analysis can be carried out with respect to particular objectives, over different stages. Furthermore, the use of mapping overlaid on online maps (by Google, for example) is useful for planners in flood vulnerability analysis, or a comparison between the plans and the up-to-date implementation. Web-based applications such as My-Maps also support transferable data compiled from field trip observations, as the achievable demonstration through the case of HCMC.

8.1.4. Potential adjustments to the existing master plan for transport development in HCMC

With the aim to apply the FRTS structure and its principles to the current plan for transport development in HCMC, the proposed adjustments to the plans for transport development in HCMC from chapter 7 can be summarised as follows:

- Reclassify almost all main routes with a respect to the flood vulnerability assessment and spatial structure of the FRTS in order to improve elevation planning for transport development.

- Linked to the vulnerability assessment, flood thresholds should be balanced for sustainable development in practice, prioritising elevated development for critical routes, which should improve the spare capacity of individual elements and reduce the redundancy in the whole network. The more important and critical transport routes that are assessed; more different layers should be planned for elevation development; and

- For deployment, emphasise the predominance of elevated roads and waterways with some new elevated roads proposed (Table 6 and 7) for the routes already planned, and extend waterbus lines based on the existing water navigation routes, with links to other modes and means, especially cycling and walking.

These objectives could be accomplished if government authorities and stakeholders work together to find comprehensive pathways for planning and management, based on the national framework. For the governmental bodies in HCMC, this refers to cooperation between the Department of Transport, the Department of Urban Planning and Architecture, and the Centre for Steering Flood Control Programme. In essence, it is recommended that the city council should be in charge as the ‘key architect’, instead of the current separate implementation by different bureaux. On a larger scale, the local government of HCMC can seek cooperation with the local governments of surrounding cities to resolve relevant socio-economic issues, such as the balance in immigrant workers from these cities to HCMC. This research also underlines the importance of regional and urban planning, which has the involvement of the local governments of all cities in the HCMC region to deal with future sustainable development in terms of labour, accommodation and infrastructure. Besides, the governmental orgainisations in HCMC can seek experiences of flood management related to sustainable development from other cities in Southeast Asia such as Singapore. High-rise buildings allow this city, which has limited land for urbanisation and expansion, to continue to sustainably develop without flooding and still ensure green areas within city for water absorption.

8.2. Critique

The main aim of this research is to develop the resilience of the transport system in HCMC through a conceptual model based on the development of resilience theory, and flood vulnerability assessment for potential application in urban planning for transportation. Such assessment requires a wide range of data which are relevant to different scientific areas, but quite limited in Vietnam, a developing country. Thus the research contains some uncertainties and limitations, mainly allied to the characteristics of the simulation method, data availability and the complex issues of a mega-city such as HCMC.

With regards to uncertainties, the flood vulnerability assessment is based on the results of a hydrological simulation and GIS analysis. First, the water levels were obtained after running the hydrological model of Triet et al. (2008). This model consists of a digitised riverine network which could since have been influenced by the development of built-up areas, especially in new districts. Through field trips and with reference to Google Maps, this is the case in some small watercourses, but does not greatly impact on the results because the model was mainly established from the main rivers and major river branches, which are still strictly managed by the local government. The accuracy of water levels could be improved if coordinated with other models for underground water, with the involvement of the urban drainage system etc. These require more relevant research, with greater availability of appropriate data, which are hard to collect for the whole urban system in HCMC. On the other hand, flood magnitude could be alleviated by the on-going projects to improve the flood protection system (e.g. sluices, embankments etc.), but this research has proposed a worst-case scenario of extreme floods, which includes an assumption of these systems being breached.

Second, the identification of vulnerable areas and road segments relied on an intersection between the water surface and a DEM, which was surveyed by 2010. During the period from 2010 to 2015, some road developments have been raised, especially in new development districts, but potential elevation updates are not available for the whole city due to the lack of systematic data management in HCMC. The data from Lidar could be beneficial as they are up-to-date and have higher accuracy. However, this entails a high cost, which is beyond the funding of this research; it is also not possible to be conduct on an individual due to the large scale territory of HCMC and the regulations in Vietnam. To control such uncertainty, the results of the vulnerability assessment of this research still have the chance to be compared to the findings of other research, i.e. ADB (2010) and Storch and Downes (2011), and have also been generally validated with the observation data. Moreover, the advance of FRTS is the flexible spatial structure, referred to as the ‘self-organising capacity’ of a resilient system, which is expected to be able to deal with uncertain changes in the flood scenarios.

With respect to the limitations, the application of FRTS has some constraints. First, it has been built based primarily on two of the four properties of a resilient system, namely the robustness and redundancy of the transport system. The other two properties have been addressed but emphasised less. Second, its applications have focused on planning at the urban level, along with the main aim of this research, while the two other scales (e.g. catchment referred to regional link to other cities, and buildings referred to neighbourhood or community level) could be addressed to a lesser extent. This puts a constraint on the findings of this research as the study area was limited to the territory of HCMC with the focus on the transport system at the urban level. Finally, as mentioned in chapter 2 the research has been unable to fully address social resilience through assessing complex data especially in mega-cities in developing countries - the evaluation of the socio-economic effects have been addressed, but have not been specified to number of people being affected, such as travellers on intensive transport flows referred to economic losses etc. Indeed, the data on transportation flows are not regularly tracked for management, while this research did not have the resource for such data collection as HCMC is a mega-city with the complex and dynamic movement of people and settlement. As mentioned in the introduction, work in underway in HCMC to transfer much current paper based data to digital databases in the future, though this has only really begun in 2018, and the process is predicted to take several years.

In general, the research primarily attempts to develop transport system resilience through a conceptual planning model based on a case study of HCMC. This is intended for long-term application, rather than as a ‘complete resilience model’ for immediate use in solving the city’s flooding problems. Unlike cities in developed countries, data is quite limited and difficult to obtain in HCMC, and they are not organised into a comprehensive system. Moreover, research funding is limited to three years, so any limitations in the flood simulation and GIS analysis need to be accepted. For the vision, the potential situations of other emerging coastal cities in Southeast Asia only serve as a reference if they have similar characteristics to HCMC in terms of urban structure referred to the pattern of transport network and hydro-meteorology. The limitation of this research can become a driver for further research developments, and this requires cooperation between researchers in different areas instead of being individual work.

8.3. Potential impacts and further study

8.3.1. Impacts

This research attempts to contribute to the development resilience theory in urban transportation (from theories to application through an urban planning framework in practice), and to propose a combined method for flood vulnerability assessment. Both are expected to be useful for the process of future planning in HCMC. Following the conceptual model in chapter 5, the roadmap and blueprints in chapter 6 highlight the proposed adjustments to the general and transport plans. Since a regional plan for the region of HCMC was recently approved, at the end of 2017, a new revision of the ‘general plan’, which also includes a transport component, has been commissioned by the Department of Architecture and Planning, with the objective of completion by 2020. Subsequently, it is expected to generate a proposal for a revision of the transport plan by the Department of Transport, which can have some useful inputs to the potential application of this model in the future. This brings tremendous opportunities for the findings of this research to be applied in these planning projects. This also implies the opportunities for HCMC, as well as other emerging coastal cities in SAC, in planning for resilient development of transport systems.

8.3.2. Further study

Following the critique, it is obvious that the FRTS is still primarily at a conceptual stage, although the research has attempted to demonstrate its application with simulation tests. The outcomes from this research will be considered for potential application into the plans for transport development (in the general plan and the transport plan), in according to the urban planning framework of Vietnam, mentioned in the introduction. In fact, a practical test can only be confirmed after prolonged implementation over decades, due to the nature of the urban planning field. Indeed, existing models, and more importantly the paucity of required data, means there are limited options. The research will be further developed as more data becomes available in order to move the conceptual model forward. Further work therefore can be carried out regarding the case of HCMC; for example:

- Flood hazard maps integrated with the results from other flood models in drainage systems, underground water storage systems and early warning systems. Alongside these, model of economic estimation of losses from flooding and the benefits by FRTS can be developed as the basis for evaluating social economic effects; so that flood mitigation (potentially integrated with fire emergency plans) can be developed. Thus social resilience can be researched in more detail, in particular impacts on vulnerable residences and potential improvement in community resilience.

- The accuracy of flood simulation can be improved in smaller areas on the basis of a 2D hydrological model and more up-to-date higher resolution elevation data (e.g. LIDAR) to be used in further plans for project developments or urban designs. This can be useful for potential coordination with local infrastructure and building design.

- An early warning system, based on the spatial structure of FRTS, can be planned and designed for integration at the physical transport nodes, or along with links for flood progress updates and the forecasting of subsequent impacts with the application of IoT and mobile apps. This is also referred to as the strategy for potential improvement of communication in emergency.

Overall, *the focal point of the concept of FRTS is the spatial transfer of transport flows based on a pre-organised structural and flexible transport system constituted by links, nodes supported by terms of different levels of elevation and locations. The intrinsic value of its application to the transport plan is that a city can retain a certain capacity (probably on a smaller scale) of its transport system in order to mitigate potential impacts on urban activities resulting from flood disruption.* In nature, flooding originates from water which is rising and spreading out, no matter how we attempt to resist this “vital resource” for urban development since the early stage of establishment of almost all cities. Instead, trying to adapt to its presence, and preparing for resilience after its effects have been ascertained, is a better approach for urban planning and management. Thus developing urban space upwards is the message from this research for a broader field of knowledge in resilient planning for urban spatial development if we are trying to adapt to climate change in terms of flooding. This is likely to contrast with trends in some cities, which have plans for urban spatial development underground, and which result in a high level of investments but highly risk to flooding. Whilst many of the ideas remain conceptual, this research has attempted to demonstrate the potential application of FRTS through the case of HCMC. The main findings are also expected not only to be integrated into the planning process of urban space and transport development in HCMC, but also applied, or become useful lessons, for other emerging coastal cities in Southeast Asia.

Due to the continued growth of global population, worldwide cities have undergone continual concentration of people and assets, but naturally land area (high, unflooded land) is limited. Coastal cities have experienced ultimate urbanisation on less valuable land (low-elevated wetlands) particularly in developing countries. In line with resistance strategy, the raising of local elevations of urban ground in new developments areas is actually an unsustainable solution; it even makes these cities less resilient to extreme floods due to the high dependency on the resistant system. Therefore, this thesis concludes that flood resilience must be part of the long-term planning for transport development, in cooperation with spatial development strategies such as urban compactness and accepting that there are floodable areas within the city which should not be the focus of development.

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