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Resilient transport systems to reduce urban vulnerability to floods in emerging-coastal cities: A case study of Ho Chi Minh City, Vietnam

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ABSTRACT

The role of transportation is becoming ever more important as cities are spatially expanded along with urban development, yet highly agglomerated by complex activities over their geographic territory. Flooding incidents in cities across the world have exposed the vulnerability of transport networks which can result in significant, lasting disruption. This appears to be overlooked in emerging-coastal cities, especially prone to flooding as plans for transport development, are ultimately driven by economic drivers resulting in uncontrolled urbanisation. By using a combined method of hydrological flood modeling and GIS analysis, this paper demonstrates the increasing vulnerability of the transport system in Ho Chi Minh City based on current plans for transport development. The paper highlights the need to consider a new approach to transport planning and advocates the application of a Resilient Transport System (RTS) which can be integrated into potential revisions of city master plans to help Ho Chi Minh City (HCMC) shift from resistance to resilience to extreme floods. The focal point of the concept is the spatial transfer of transport flows based on a pre-organised structural and flexible transport system constituted by links, nodes and relevant services in 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 disruptions.

1. Introduction

1.1. *Urban development and resilience of transportation: An approach from flood vulnerability*

1.1.1. *The context of urban development and importance of a resilient transport system*

With the increasing concentration of the world's population in urban areas set to reach around 60% by 2030 (United Nations, hereafter “UN”, 2016), cities around the world are increasing both in size and scale. Such growth means that everyday life becomes more dependent on the complexity of urban infrastructure such as transportation (Rogers et al., 2012; Desouza and Flanery, 2013). Transport plays a vital role in maintaining the consistency of daily life (Wang, 2015; Desouza and Flanery, 2013; Xenidis and Tamvakis, 2012). Indeed, daily activities depend on urban road systems which not only allow for mobility and for transportation of goods but also serve as the primary means of rescue or of delivering aid to communities when a city is faced with an extreme flood event (Mattsson and Jenelius, 2015). Particularly in coastal areas, sea-level rise and extreme weather have also increasingly been attributed to the flood threat (Suarez et al., 2005; Beniston et al., 2007; Knutson et al., 2010 cited in Kermanshah and Derrible, 2017). Additionally, flood vulnerability is also compounded by inadequate planning and management of the growth of built-up areas on floodplains, and impacts of climate change such as Sea Level Rise (SLR) (Zevenbergen et al., 2008). Due to the pressure of development, the establishment of new urban areas has necessitated the expansion of transport networks. This in turn results in an increase in critical transport routes becoming more vulnerable to flood risks if they are expanded on low-elevated lands. Consequently, floods have emerged as an increasing threat to urban transportation.

Flooding can have different effects on urban transport systems. With respect to frequency and degree of damage, Wang (2015) classifies the potential disruptions to transportation into three categories (disasters, day-to-day variations and ongoing long-term changes). For flood effects, this can be simplified within two degrees: regular floods

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(periodic/ slight effect) or extreme floods (rarely/ combined effects), which arecommon in the coastal cities of Southeast Asia (WB, 2010; ADB, 2010). The urban flood impacts depend not only magnitude but also other factors such as the concentration of people and assets at particular locations, and also preparedness in relation to spatial planning for flood resilience. For examples, New Orleans in 2005, Manila in 2009 and Bangkok in 2012 have exemplified the high losses and damages due to the illegal settlement on low-lying land and inaccessibility of the road networks constrained emergency evacuation, besides the unexpected event (Duy et al., 2017b). In a large-scale disaster situation, appropriate evacuation routes and tactical transport schemes are considered a vital component of emergency plans for urban resilience (Suk-Na and Banerjee, 2015; Coaffee and Lee, 2016). These prove the importance of transportation in urban resilience to both regular and extreme floods, and highlight the need of planning for resilient development in long-term.

Resilience of a transportation network, defined by the UK 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", thus this can be translated to the objective to ensure a continuation of travelling (at certain levels), quick restoration of services and routes, and sufficient communication to end-users when dealing with disturbances. Although, resistance to flooding can be engineered at certain locations, the overall resilience of the whole network can be improved by providing additional options such as diversionary routes, or alternative modes in adaptation to different flooding levels. Hence, this is relevant to the urban plans for transport development, which need to address to what extent such networks become vulnerable to different flood levels.

1.1.2. *Flood vulnerability assessment as the base for resilient development*

Studies of flood vulnerability assessment of transportation have developed flood simulations based on hydrological models and network analysis using GIS computational tools. There are two distinct traditions of vulnerability analysis on urban transport networks such as topological based on graph theories, and system-based on demand and supply side (Mattsson and Jenelius, 2015). The first one requires definite network data to enable a detailed analysis while the second needs extensive data about demand, supplies and available models to simulate consequences (ibid). In practice, the first can be seen an appropriate method to establish a digitalised network which can be extracted or redrawn from an integrated map of transport plans in some emerging-cities in developing countries, where data of travel demand and supply are still difficult to obtain. In cooperation, the use of a hydrological model for flood simulation provides an important contribution to mitigating future flood losses and damages, informing spatial analyses based on GIS tools to map inundations and consider their impacts (Wang et al., 2010; Kermanshah and Derrible, 2017). When dealing with extreme events, Koetse and Rietveld (2009) suggest identification of the significantly vulnerable locations and routes which are critical for accessibility to essential urban facilities in case of emergency. Supporting tools can be used to undertake relevant vulnerability assessments.

For example, Kermanshah and Derrible (2017) used geographic-analysis based on GIS to assess "robustness of road systems by means of network topological indicators" in New York and Chicago. Using travelling demand data, this research investigated changes in the number of trips completed before and after the events by measuring the proportional losses of infrastructure segments (e.g. total length of roads or intersections affected) referred to a determination of road exposed to an extreme flood in simulation (ibid). For other studies to smaller cities, (Pregnolato et al., 2017) constructed a framework for a coordination of observation and video analysis supplemented to quantitative analyses to estimate travel time delayed by flood disruptions in different scenarios ("flood depth disruptions") in Newcastle Upon Tyne, UK; while Yu et al. (2017) used GIS network analysis tool to examine the availability of emergency services delivered to "flooded road hotspot" which is manifested to a wider-flood impacts in York, United Kingdom.

As the focus of this paper to better understand the flood impacts in HCMC, a mega-coastal city of a developing country in Southeast Asia, several projects have used various flood simulation techniques to investigate flood vulnerability. For example, using mean sea level data, Thinh et al. (2009) investigated tidal flooding related to an event in 2008 and identified nine vulnerable administrative districts, five of which were directly adjacent to water bodies. Storch and Downes (2011) used satellite data to highlight the increased flooding vulnerability of new built-up areas, in case of the worst-scenario at + 2.5 m ASL flooding surface, from 45% (230 km^2) in 2010 to 59% (450 km^2) by 2025, with a notice in the South and the East. The most comprehensive work to date was compiled by ADB (2010) which highlighted that 54% of the existing urban area of HCMC was now affected by regular floods and 71% of the area of this city would be at risk of combined floods by 2050. According to this report, flood maps by ADB (2010, pp. 15–16) showed "current and planned road infrastructure affected by projected extreme floods by 2050". A measurement of roads affected has been identified (ADB, 2010); but it is critical point that the current elevation of the transportation network has not been considered. This is because detailed data on the actual elevation of the surface of transport structures is limited in this city, thus other interpretations are required for a more robust vulnerability assessment.

Generally in respect of a target for flood resilience development of urban transportation systems, several studies have addressed vulnerability assessment. Each study has established an appropriate framework for specific cases with different characteristics. This results from the diversity of urban scale and data availability which are very important to a research success. For example, travel demand data can be readily obtained for the cases of New York and Chicago, but this is unavailable in many cities in developing countries such as HCMC, which has not established a sufficiently organised system for such big data. Therefore, an appropriate framework needs to be designed for each particular case in order to meet the different research objectives.

1.2. *Flood vulnerability and flood resilience*

1.2.1. *Flood vulnerability and the relation to resilience*

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 et al. 2009; Hufschmidt 2011; Scheuer et al. 2010; Willroth et al. 2010; Fuchs et al. 2011). This has led to an index to assess flood vulnerability consisting of three indicators (Balica et al. 2012), which is readily extendable to transport systems, as follows:

- *Exposure*, this can be extended to transport networks, as an increasing number of links, which are predicted to be affected by flooding.
- *Susceptibility*, this considers the factors influencing the degree of flood arising from changes in urban hydrometeorology, which can have the potential to exacerbate the impacts.
- *Resilience*, is defined as the ability to self-reorganise the network, and referred to 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 potential impacts.

Based upon these indicators, each transport link can be initially assessed as vulnerable to flooding if it is located (or planned) to cross a flood plain, referred to the exposure (Fig. 1a). Thus, flood extent needs to be simulated from hydrological modelling and as such there exists an opportunity to further refine the process by providing probabilistic information pertaining to flood depths (*see* Fig. 1b). Focussing on the critical links/ nodes, the level of susceptibility to flooding can then be

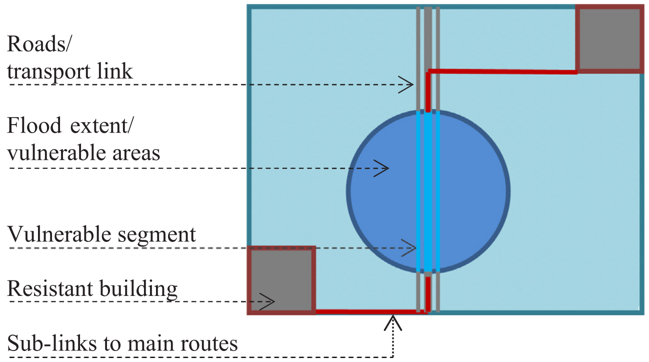


Fig. 1. a: Flood vulnerability: urban areas/ transport segment (the upper); b: Difference between “affected” and “vulnerable” level (the lower).

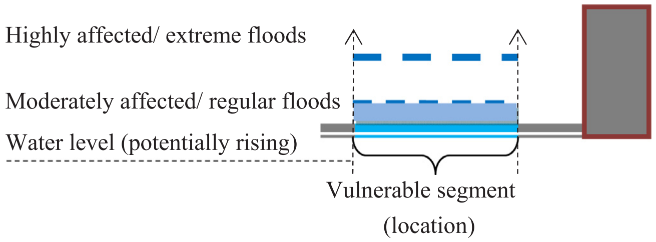


Fig. 1. (*continued*)

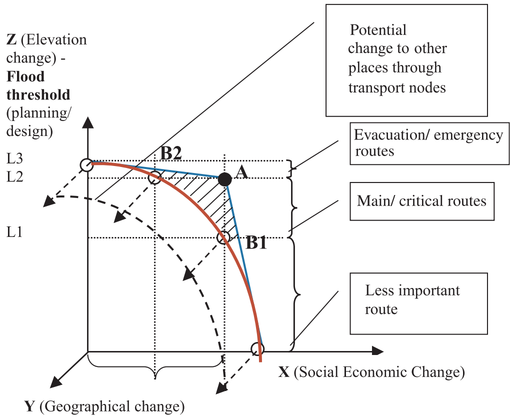
analysed using their spatial features (e.g. locations of flood sources such as water bodies). This approach permits an investigation into existing resistance as well as the implications of planning interventions / developments in resilience development in order to reduce vulnerability.

1.2.2. Flood Resilience: A development in transportation based on resilient properties

Since the early resilience concept by Holling (1973), scholars have attempted to develop this approach to deal with potential environmental shocks in cities. Intergovernmental Panel on Climate Chance (2007, p. 86) affirmed that resilience is “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”. Subsequently, resilience theories can be interpreted as: engineering or ecological (Holling, 1996). Whilst the engineering emphasis is on the ability to ‘bounce-back’ to normal status (Wang and BlackMoore, 2009), the ecological focus is on the capacity of persistence or survival (Walker et al., 2004). These interpretations are useful to clarify in terms of more understanding in theory, but can co-exist during urban development process in practice. Cities are actually constituted by different urban components (Desouza and Flanery, 2013), such as physical infrastructure including flood protection and transport system, which can be historically established, and evolved on the basis of resistance. Thus further resilient development should coordinate with existing resistant systems instead abandonment. For example, many cities have been built on riverbanks integrated with main roads along water bodies (e.g. the riverbanks along Thames River in London, or along Seine River in Paris), regarding to as the resistant systems to protect from tidal flooding risk. Hence an absolute replacement of such systems is likely impossible, while residents tend to believe in a system which expresses its physical strength. Thus urban resilience development is only feasible if part of long-term planning particularly for urban infrastructure development in respect of a coordination with existing resistant systems.

Based on the concept of ecological resilience in a planning, Liao (2012) proposed a shifting process from resistance to “urban resilience to floods”, as the capability of a city, which can tolerate flooding and reorganise itself in order to minimize potential fatalities and injuries while maintaining its socioeconomic identity. This concept actively advocates ‘floodable areas’ in urban planning, and a reduction in the value of thresholds in order to increase the rate of tolerable socio-economic fluctuation (Fig. 2). Linked to this, McDonal and Walker (2007) highlighted that a resilient system as a complex system should obtain the capacity of adaptability to manage on-going status away from the thresholds and transferring to another kind of the system. Until a tipping point is reached, a network will naturally self-organise in adaptation to different thresholds of flooding. The question is to identify what level of flooding is acceptable before its presence begins to constrain daily activities and ultimately, urban development.

With respect to transportation, it is argued that an acceptance of occasional floods within a city will in itself constrain urban development if the accessibility of the transport system is not adequately considered. For example, whilst new residential developments can be designed for short-term resistance to current flooding (e.g. higher elevation to accumulated flood levels), the flood impact to transportation and to other specialised functional areas not only impact on connectivity of such local communities, but also cause disruptions to a whole urban transport system leading to obstructions to urban activities (e.g. work, education, commerce and healthcare). Liao (2012) does not clarify how a resilient city can be organised to include floodable areas in terms of spatial dimensions in planning, and the involvement of the urban transport network. Indeed, proved in flood incidents in some



Notes: 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)

Fig. 2. Shifting from resistance to resilience to flooding.

coastal cities (e.g. New Orleans 2005, Manila 2009 and Bangkok 2011), urban transport system is a vital element in maintaining urban commuting during moderate floods, and also helping cities quick recovery from extreme floods (Duy et al., 2017ab).

Xenidis and Tamvakis (2012) stated the need for engineering resilience to help a transport system regain balance and return to normalcy, while Wang (2015, p. 182) considered transport systems as comparable to ecological resilience systems, referring to the "self-organising and adaptive" ability. With a link to flood threshold within a resilient system, a transport network will self-organise under different thresholds of flooding until a tipping point is reached. This requires an identification of what potential levels assigned for particular thresholds should be addressed in spatial planning for transport development in different urban areas. If also referred to as a resilient system, a transport system can be planned for resilient development based on the four properties proposed by Bruneau et al. (2003):

i) *Robustness:* physical strength to withstand a disturbance;
ii) *Redundancy:* substitution of system components;
iii) *Resourcefulness:* identifying problems and mobilise resources;
iv) *Rapidity:* capacity of timely restoration.

Under the context of emerging-coastal cities, rapid urbanisation has necessitated major development of urban infrastructure, planned and designed with a certain capacity of physical strength, normally in line with resistant planning and implementation. Thus robustness is considered as the immediate key property, allowing a potential move from resistance to (engineering) resilience, whilst redundancy can be seen as an equally important target, as it ensures the 'survival' of the whole system regarding the objective of an ecological resilient system. In transportation, Berdica (2002) believes that the preparedness of various options of transport routes (or modes) between departures and destinations can mitigate the serious impacts on some parts of the system in the case of disturbance. As an area of less focus, resourcefulness and rapidity can be gradually evolved in the longer term, depending on the development conditions of each city. For instance, urban areas vulnerable to flooding should be planned for a high number of transport modes and means ready to deal with different flood scenarios, but this requires budgets for initial investment and maintenance; e.g. spare public transport vehicles and parking places. Such costs can be minimised by an effective forecasting ability, employing early warning systems in relation to different modelled scenarios.

In fact it is hard to evaluate the sufficiency of urban resources and restoration capacity (in terms of time) 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 (Coaffee and Lee, 2016). However, each simulation model also contains uncertainties due to the potential assumptions and data limitations, which are notable barriers, particularly in developing countries. 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.

In summary, it is well established that resilience can reduce vulnerability (Turner et al., 2003; Berkes, 2007; and Balica et al., 2012). Represented as a key component, the resilience of a transport system can be developed on the base of the four properties, among which robustness and redundancy are preferable to develop under the context of emerging-coastal cities in developing countries e.g. Southeast Asia, for a shift from the existing resistant systems to resilient systems, as they have experienced a rapid urbanisation process driven by economic development. A long with a longer-term strategy, the resourcefulness and rapidity can be developed in the light of urban economic development ensured for higher investments in urban infrastructure system and forecasting system. Improving urban resilience to floods (or other natural disasters) needs not only to include visionary thinking about the effects on a comprehensive system but also long-term planning within an appropriate framework.

1.3. *The role of urban planning framework*

Urban planning for land-use and transport are intertwined in terms of spatial dimensions (Waddell, 2011; Southworth and Ben-Joseph, 1995; Paulley and Webster, 1991). As spatial plans for urban development are approved, these act as a driver for an expansion of the road network leading to new critical (and potentially vulnerable) links and nodes. This can be seen as an important point when considering a resilience development plan for transport systems which can have potential interactions with other areas (e.g. urban space development) across different scales.

In terms of flood management, Zevenbergen et al. (2008) emphasises the spatio-temporal relationship evident at the varying scales of catchment, city and building. At each scale, flood vulnerability can be measured and reduced using indicators of exposure and sensitivity, with resilient development at each level enhancing resilience at others (ibid). However the spatial traversing across different levels proposed by Zevenbergen et al. (2008) inadequately addresses the interlinking role of the physical transport network as a city becomes more vulnerable to flooding. Thus this concept can be extended for resilient development in transport planning particularly at city level by classifying roads group based on flood thresholds, in particular the use of 'hardened and elevated' routes linking major nodes, which also interlink to minor nodes, and to functioned areas. Of the three levels identified, it is clear that the local / city scale (in the middle) remains key and allows for the most intensive application of measures, as well as encouraging the general shift from engineering to ecological resilience.

Overall, despite the theoretical basis evident in the planning literature, the actual practical application of resilience concepts in transportation remains insufficient particularly in emerging-coastal cities in developing countries. By using a combined method of flood simulation and spatial analysis based on GIS for the case of Ho Chi Minh City (HCMC), this paper aims to show the increasing flood vulnerability of transportation in line with the current situation and the existing master plan. Along with the results, the aim is to develop flood resilience in transportation through a conceptual model of Resilient Transport System (RTS) which is tested for transport accessibility between the two sides of Saigon River, referred to as the city centre and new centre Thu Thiem in district 2 (one the most vulnerable districts to flooding in HCMC: Duy et al., 2017a). The paper also presents implications for HCMC, as the base for revisions to potential plans for transport development by 2030.

2. Ho chi minh city: A case study

With a territory of 2095 km2 and a population expected to be over 10 million by 2030, HCMC has a complex transport network spread across a large urban area. It is a growing megacity in the South of Vietnam and is one of 20 world-wide coastal cities vulnerable to flooding losses by 2050 (Hallegatte et al., 2013; UN, 2016). It is considered to be a "hotspot" in Southeast Asia (World Bank – "WB", 2010). The city continues to experience an increase in flood vulnerability in new suburbs especially in the East and the South in relation to rapid urbanisation and uncertain flood factors (Storch and Downes, 2011; Phi, 2013; and Duy et al., 2017a). Linked to this, potential flood effects to critical transport links between the city centre and three new development districts on the Eastern side of Saigon River can undermine flood resilience in this city, which needs to learn the lessons from other coastal cities, regarding to an assurance of transport accessibility particularly emergency routes for evacuation when facing with extreme floods (Duy et al., 2017b). This has raised a need in resilience development in transport system in terms of the on-going developments and

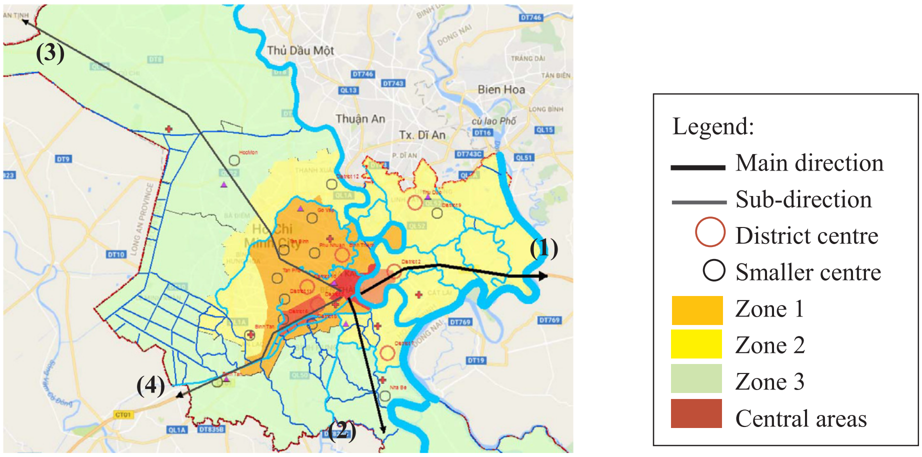


Fig. 3. a (the upper). Spatial structure of transport in HCMC. Source: TEDI-South (2010), with background map captured from Google (2017). b (the lower). Integrated map of transportation planning for HCMC by 2020 (a main part of HCMC). Source: TEDI-South (2010).

existing plans.

2.1. Transport development

Originally a small port city built on locally high ground (+4 - +8m, above sea level, hereafter called ASL) by the Saigon River, the transport system of HCMC has evolved significantly from the original grid network found in the old town. The administrative zones are classified as three zones (zone 1: 13 central districts including the current city centre, zone 2: 6 new development districts including the new centre, Thu Thiem; zone 3: 5 rural districts). The current city master plan, approved in 2010, showed the transport connections from the central areas (in zone 1) to sub-centres (in zones 2 and 3), via four transportation corridors (*see* Fig. 3a):

(1) East, in connection to district 2, 9, Thu Duc, on the right side of Saigon River;
(2) South-East, connecting to district 7, Nha Be, Can Gio;
(3) North-West, connecting to rural district 12, Cu Chi, Hoc Mon;
(4) West, connecting to Binh Chanh and other provinces in Mekong delta area of Vietnam.

Due to rising residential demand, urban expansion along (1) and (2) (beyond the main water bodies) has been dominant. In association with the master-plan, a plan for transport development by 2020 has since been approved, with a structure of a centripetal network constituted by transport nodes (major and minor) and various links, (TEDI-South, 2013). Along this plan, the on-going implementations can be summarised as follows (Fig. 3b):

(1) *Road network:* mainly ground-based with a total length of about 3265 km, including key arteries (e.g. East – West; North – South), ring roads, highways and elevated roads, but excluding minor roads (TEDI-South, 2013). The two national and international coach stations are located in the West and the East (in moving and developing progress). To solve the current congestion situation, high-elevated roads about 70.3 km is planned for investment. Additionally over-passes have been built at some critical nodes, with the average height about 4 – 5 m from current ground level.
(2) *Railway:* city lines (172 km) and national lines (697 km) are interconnected via seven depots (TEDI-South, 2013), and a national railway station located in the central area. In implementation, the first metro line, named Ben Thanh - Suoi Tien, has been constructed for potential operation by 2020, with an underground segment from the city centre (Ben Thanh market) to the western side of Saigon River, and the remaining segments highly-elevated (about 9 m from the ground) to Suoi Tien park.
(3) *Waterways:* navigable waterways cross the city approximately

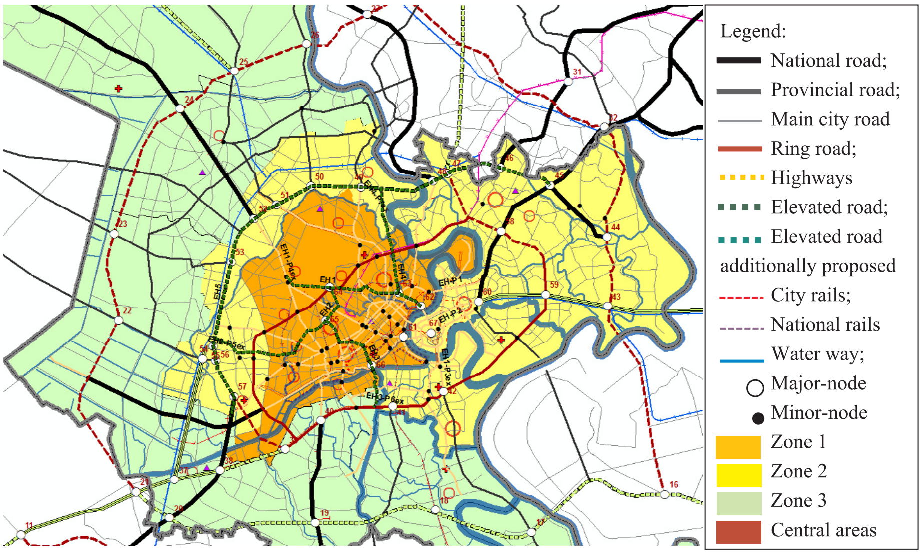


Fig. 3. (*continued*)

1200 km (including 848 km of rivers) (TEDI-South, 2013), mainly influenced by the Sai Gon and Dong Nai Rivers in connection to an additional network of river-branches such as Nhieu Loc - Thi Nghe, Ben Nghe-Tau Hu, and Kenh Doi - Te. The water bus has been in operation since 2017 with the first service along the Saigon River about 10.8 km.

(4) *Air travel:* the existing airport (Tan Son Nhat) in the North is now in operation above designed capacity (about 16.7 million passengers/ year: TEDI-South, 2013) and surrounded by built-up areas. Hence a proposal for a new airport (Long Thanh), located about 40 km from the centre, has been approved for new construction to complete by 2025, with an area about 5000 ha.

As such, the transportation system of HCMC is heavily reliant on the ground level road network, so any change in planning and management will influence not only following investments in urban infrastructure but also all constructions linked to accessibility (e.g. houses, drainage system). Watercourses, which used to be the main transport mode, are now near exclusively maintained for water discharge, general aesthetics although some main courses have been initially restored for public transport (water bus). The railway network is emerging as a new means for public transport, but this is still very much in its infancy. In the light of the master plan for spatial development and practical demands of property development especially in new development districts, infrastructure improvements have been planned and implemented through key projects such as developments of urban arteries (e.g. the West-East, the ring roads). The transport system has evolved during the urban development process, but flooding has emerged as a significant problem related to remarkable changes in urban hydro-meteorology. In relation to flooding risk, the weak points can be summarised and referred to the need for more adequate planning of resilience development in terms of*: i) ground-based network lacking in comprehensive classification of road levels for development, with an inherited transfer from current resistance constructions; and ii) insufficiently flexible organised structures requiring better (contiguous) links for transport accessibility in adaptation to different scenarios.*

2.2. Floods and the urban transportation

Flood impacts on urban transportation in HCMC are being increasingly monitored (see some examples in Fig. 4). Between 2003 and 2009, Phi (2013) identified 680 inundations; and flood data from the Steering Centre of The Urban Flood Control Program of HCMC - SCFC (2010 – 2016) shows that the number of inundations nearly doubled, about 1250 during the next seven years (2010 – 2016). As HCMC is so reliant on ground-based road network, with the motorbike being the most popular mode of choice even relatively low level flooding at just a few locations can be very problematic. Observation during a recent large-scale events proved that flood effects to key routes between the city centre (zone 1) and new urban areas (e.g. the three districts on the eastern side of Saigon River in zone 2) result in a wide-spread disruption to the whole network, particularly during peak hours (6-8AM; 4-6PM). For example, a large-scale flood on the 15th September 2015 caused over 60 localised inundations (SCFC, 2015), which disrupted urban transportation for a four hour period (including peak commuting time) until the tide subsided. This situation is not uncommon and has started to undermine the economic development of the city which is now in desperate need of long-term planning for flood management (Phi, 2013). The local government has implemented various investments in the transport system and while these have been engineered to add resistance to regular flooding, resilience to extreme events has not been fully considered as the uncertain changes in urban hydro-meteorology have not been recognised.

The Saigon River is the main water body connecting HCMC to the sea; however the tidal reach extends to the broader network of rivers and channels across the city (Fig. 5a). Although pluvial flooding does occur from local rains at some places, large-scale events tend to be caused by a combination with tidal flooding from the riverine network (especially in monsoon season: Phi 2013). 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 (Fig. 5b), while tidal levels have significantly increased at the urban rivers (Fig. 5c). 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 hydro-meteorological station on the Saigon River; for example, +1.42 m in 2005, +1.55 m in 2010, +1.68 m in 2013 and 2014, and even +1.71 m in 2017 (SRHC, 2010 – 2015). These levels are put into direct context given the fact that more than half of the city is under +1.5 m 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 summary, HCMC has experienced significant changes in urban hydro-meteorology due to the higher water level of the Saigon River, with high tides remaining a key factor not only overflowing low-lying lands adjacent to water bodies but also preventing water from escaping from the city. Although ongoing resistant solutions such as raising the elevation of some road developments at certain places can reduce some local floods, these are not feasible for implementation across the whole network and are also not sustainable in the long term. The increasing flood vulnerability in HCMC cannot be solved by engineering the city out of the problem alone. Instead, a more fundamental rethink in planning for transport systems is needed to improve the resilience of the transport network with respect to potential coordination with the current resistant system. Thus an assessment of flood vulnerability of critical urban areas and transport routes is necessary, and also informs the potential for reduced urban vulnerability to flooding.

3. Methodology & results

3.1. Methodology

In line with the objective of contributing to the revision of the government's general plan and transport plan to be completed by 2020, this research will create a flood simulation for 2015 (for calibration and validation), and for 2020 (for flood vulnerability assessment). Trend, maximum values and average increases are then stored for subsequent simulations (Table 1). In the case for 2015, the results were validated against observed levels at Phu An. Additionally, the flood extent is also 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. It utilises three important components: i) river network associated with cross-sections, ii) boundary inputs, and iii) processing parameters. It is developed from the work of Triet et al. (2008), which produced a comprehensive dataset for use with MIKE Zero including:

- A digitised network of water bodies including 372 river branches of the HCMC region which are influenced by the main rivers: Sai Gon, Dong Nai; and 2296 sections of this river network;
- Data inputs for 101 boundaries including 97 inflows and four water level, with the categories of "open, distributed source, point source", defined by the software. Among these, the three main sources mainly influencing the hydraulic results: Vam Kenh – Vung Tau (estuary), Dau Tieng and Tri An (upstream reservoirs);
- Other processing parameters (e.g. bed resistance)

For coordination, the outputs were transferred to ArcMAP for

a) Riverbank along transport routes

b) Upstream water (high tide) overflowing roads along river

c) An impact of flood on residence travelling in Thao Dien district 2 in relevance to adaptive capacity

d) Features of vehicles (common height of air intake) affected by floods

e) Overpass at Hangxanh roundabout, Binhthanh district (zone2)

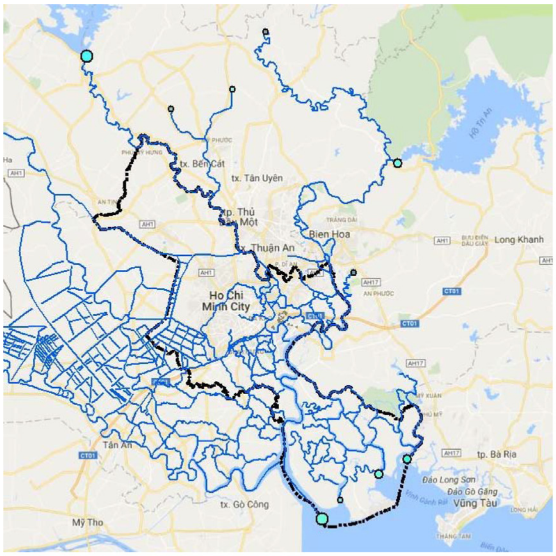
f) Increasing elevation of road redevelopment (TranNao street, district 2)

Fig. 4. Examples of transport developments and flood impacts.

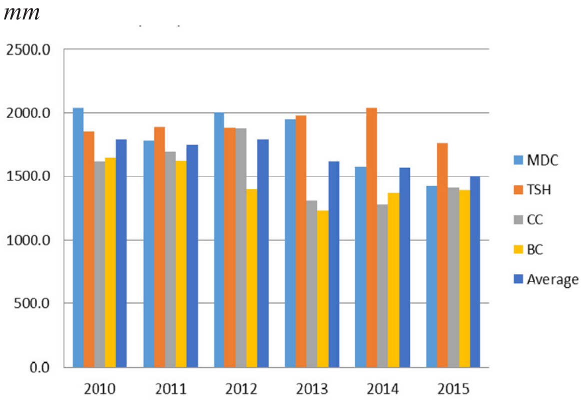
interpolation (about 1000 points on the river network, 15 m grid cell). A DEM (Digital Elevation Model) was interpolated from the elevation points (about 28,600 points, 15 m grid cell), surveyed on the existing surface of built-up areas such as pavements, in the same period as the hydrological model and the transport plan. The intersection between the WS and the DEM shows the flood extent (FE), 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), in order to identify vulnerable roads (VR) (*see* Fig. 6).

3.2. *Results*

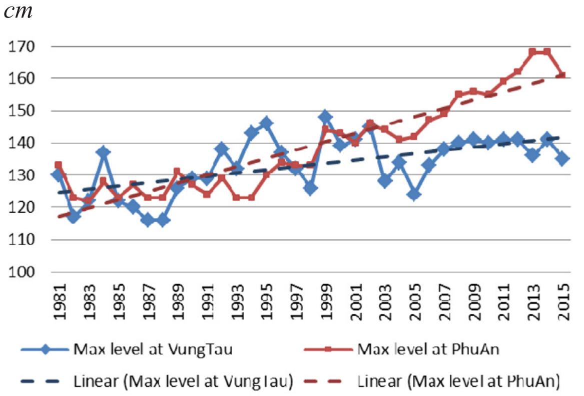
The city is expected to increase the FE and the VR from 23.45% and 23.6% in 2015, to 64.30% and 41.32% in 2020 respectively, with the highest depth of about 2.0 m (Table 2). Both FE and VR tend to increase up to level 3, and then remain stable till level 5. For urban areas, Fig. 6 indicates that the flood extent is mostly distributed in the new development districts surrounding the central districts located on low-lying land. 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 0.5 m), but will be more vulnerable to level 2 and 3 floods after 5 years. In correlation to the flood extent, the proportion of VR is predicted to decrease by 8% at level 1 (under 0.5 m), but to significantly



a) River network of HCMC region



b) Annual precipitation at four stations
Source: SRHC (2010 – 2015)



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

Fig. 5. River network and Changes in hydro-meteorological factors.

rise by about 9% and 15% at levels 2 and 3 respectively. The total length of VR is predicted to nearly double from 2015 to 2020. In general, the results show relative 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 3).

Through the initial results above, the flood vulnerability of the transport system of HCMC can be further assessed in terms of spatial scale:

- *Horizontally,* characterised by a centripetal structure, the ground-based network has some key routes extending from the city centre to surrounding areas, related to the decentralised location of the new urban areas. This expands the network scale and the interaction with the riverine network, which is considered as the source of fluvial floods. As a result, the network has more critical routes crossing flood plains, so the effects on these routes can lead to widespread disruption of the whole network.
- *Vertically*, due to the ground-based development without layering, the network has insufficient links which ensure connectivity between major nodes, with regard to the city centres or highly concentrated urban areas. The ease of exacerbating disruptions triggered by some critical routes or nodes is obvious. In relation to elevation development, the current plan fails to create systematic spatial harmony, 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.

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 from the city centre to the East and the South;
- The higher susceptibility to uncertain changes in urban hydro-metrology 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.

4. Resilient transport system (rts)

4.1. Conceptual model

In respect of the resilience literature introduced in the beginning, and the flood vulnerability assessments at the previous section, urban transport systems need to maintain their crucial function for essential services, or at least evacuation routes to escape from inundated places. With a focus on the context of HCMC as an emerging coastal city in Southeast Asia, the robustness and redundancy can be planned to develop along with resilient development, using the following fundamental principles:

- Horizontal development (Fig. 7a), referred to as a planarised network (X, Y), which can be broken down into different hierarchical levels (i.e. three levels: national/regional; city/district; and residence/community). This research emphasises the city or district levelwith connections between different vulnerable areas, in which transport 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. 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.

Table 1
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 weather stations
2020 (projection)	Projected rise of 38 mm/year by 2020, on average (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 h)

- Vertical development (Fig. 7b, c), 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, 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 (i.e. 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, these nodes 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, referred to as "floodable areas", 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 spatial transferability of transport flows, through alternative links and nodes and between modes/ means/ services, 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 scale when floods subside). The RTS relies on the following principles:

- Thresholds-based on elevation corresponding to flood levels (current levels and projected levels).
- Interconnected network (alternative routes/ transferable transport means at nodes) broken-down into three spatial levels: (1) National/ Regional, (2) Urban/ City, and (3) Community/ building.
- Transferable modes (e.g. rail, road, water ways and air) at major nodes/ junction in response to different flood thresholds.

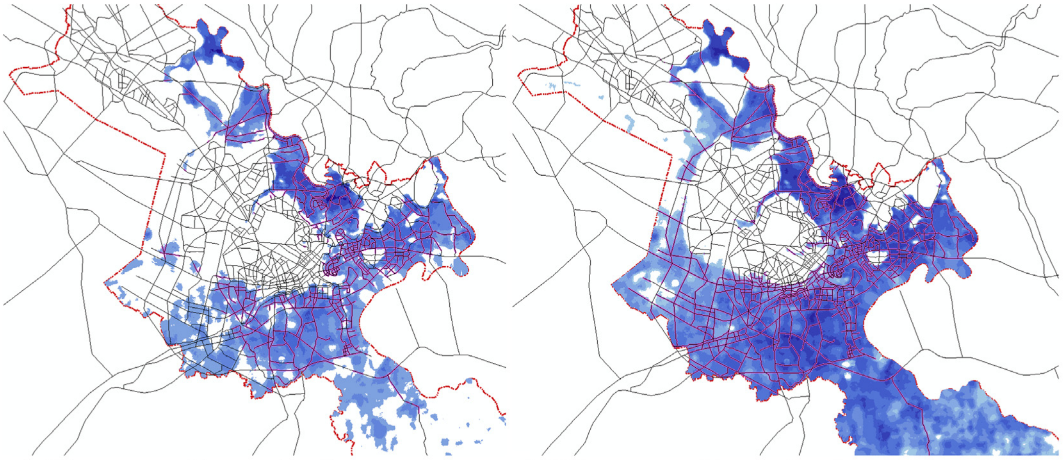
4.2. Application in HCMC

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 developed according to the current plan, but lacks elevation classification in the network, referred to as the key inadequacy of the plan. Instead, RTS offers fundamental principles, which can be applied by classifying different roads with respect to the flood vulnerability levels, referred to flood thresholds, and the current developmental conditions, as follows.

- ***Class 1/ layer 1*** (under + 2.5 m ASL, corresponding to flood vulnerability level 1 in Table 2/ threshold 1). A consideration here is that the most common vehicles (i.e. motorbikes) can naturally cope with this situation, as the heights of the engine and air intake are normally at about 0.3 m; and the common road developments are being raised by about 0.5 – 1.0 m (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*** (+ 4.0m – + 6.0 m ASL, corresponding to flood vulnerability levels 2 and 3 in Table 2/ threshold 2). This magnitude relates to some recent large-scale floods. As an initial move from resistance to resilience (engineering), increasing elevation (e.g. 2.5 m from the current ground level at + 1.5m ASL, 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 RTS, roads need to be prioritised for such a 'surface uplift' in significance with empty space underneath, particularly the urban arteries. 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*** (> + 6.0 m ASL, corresponding to flood vulnerability levels 4, 5 in Table 2/ threshold 3). 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 previously mentioned, due to the characteristics of transport development in HCMC, such RTS's application is mainly based on road network, while awaiting for development of the eight urban rail lines of which the first can be operated by 2020. Depended on the geographic location, majority of transport nodes are expected to be possible for a transfer at least two transport modes such as road and rail, or road and water. Particularly on the arteries along with the rail lines, some nodes could obtain three modes, referred to an indirect links – "walkable distance", for examples, the routes traversing nodes A58 – (rail) – B62 – (water bus) - A61 – (road) A69.

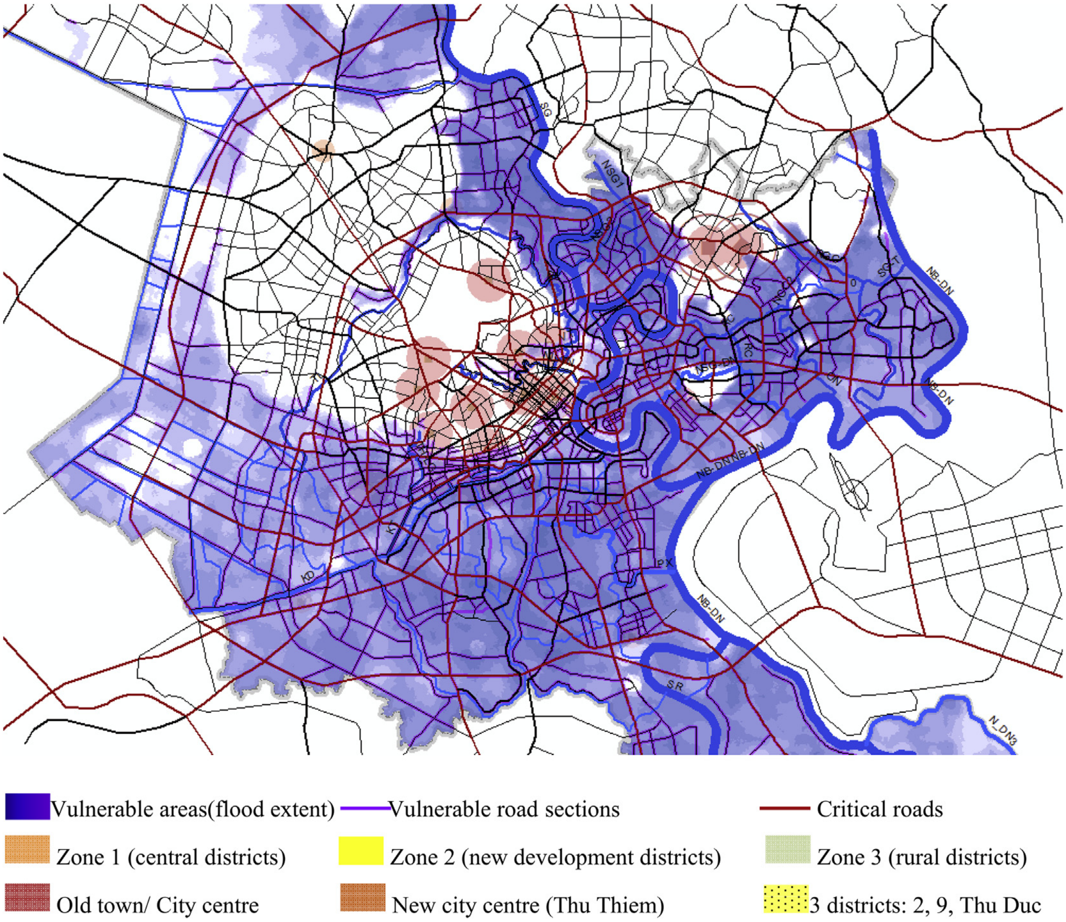
In summary, the application of such an RTS model could help the transport system of HCMC become more resilient to flooding, as the robustness and redundancy of the system are expected to be developed by: i) more available routes being substituted to vulnerable road



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

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

▇ Area vulnerable to floods; —— Main city road; —— Vulnerable sections



c) Critical routes including segments vulnerable to flooding by 2020

Fig. 6. Map of simulated flood events and sections of transport infrastructure vulnerable to floods.

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 emerging Internet of Things.

4.3. *Testing*

Aforementioned, some critical routes between the current centre (districts 1 and 3) and the new centre (Thu Thiem in district 2) and the three most vulnerable districts in HCMC need to be concerned when addressing the flood resilience in terms of transportation. Thus they are highlighted for a test for the application of RTS in this paper. Under two scenarios, the assumption is that a regular or moderate flood and an

Table 2
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) > 2 m	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.

Table 3
Flood simulation results compared with other studies.

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

extreme flood will happen with respect to the simulation in the section 3. With respect to the application of RTS and the use of 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). Regarding to transport accessibility between the two sides of Saigon River, people who are assumed to be located at stop 1 (node A58, close to the sub-centres of districts 9 and Thu Duc), and need to traverse Thu Thiem centre, stop 4 (node A67 in district 2) and the city centre, stop 5 (node A61 in district 1), to stop 7 (node A69, close to the airport in Tan Binh district) (Fig. 8a). For this case with an assumed flooding to roads in class 1 (line barriers/ restrictions), the network analysis tool found at least eleven options for travelling on routes of classes 2 and 3 *(some typical options in* Fig. 8b*)*.
- **Scenario 2 – S2** (dealing with flood levels 4, 5). People who are assumed to be located at Thu Thiem, need to be evacuated to the nearest safe area, an unflooded place which should be adjacent to emergency services such as a hospital. The network analysis tool found that at least two emergency routes are available, and identified as an '8 km distant service area'. With respect to the principle of RTS, 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 8 km 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) (Fig. 9).

This test provides an indication of the feasibility of applying the principles of RTS into the transport network of HCMC to regulate commuting on available routes as different substitutions for routes vulnerable to moderate floods, and to also prepare emergency routes for evacuation during extreme floods. This demonstrates an improvement in the robustness and redundancy of the system to avoid inaccessibility of transport on city scale.

4.4. Implications for policy in planning and management

Regarding to flood resilience, the application of RTS has implied some necessary policies required in planning for transport development along with the urbanisation processes in practice such as:

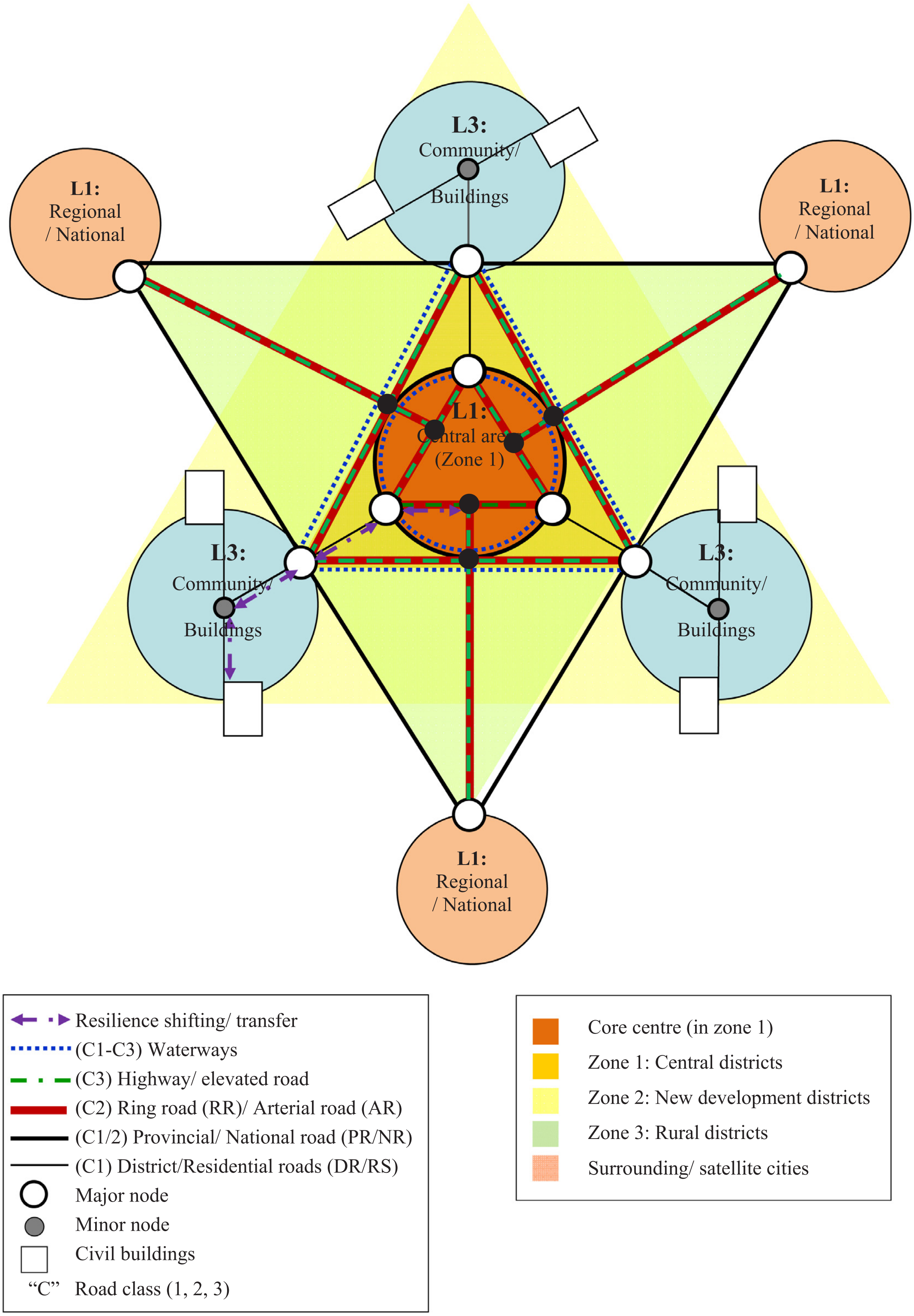
- Instead of the ground-based network, the transport system of HCMC should be planned for different elevation levels constituted by continuous and flexible links/ nodes, to help the city deal with both regular/ moderate floods (more alternative routes for travelling) and extreme floods (available routes for evacuation). With respect to the characteristic of a self-organising and adaptive system, the number and location of major/ minor nodes can be adjusted; subsequently, further links can be developed, in terms of number and direction, to increase the robustness and redundancy of the system.
- When deploying, the assignment of critical routes/ nodes can be changed in adaptation to different flood thresholds, and taking account of flood uncertainty as long as the spatial structure of the RTS is retained. The spatial transfer between resistant and resilient levels remains crucial when revising plans for transport and development of urban spaces. Road redevelopments have opportunities for hardening which can be designed in correspondence to a number of thresholds. However, increasing elevation should be limited to certain main roads, such as district (interlinking) roads in class 1 (as some on-going developments following the construction code in practice), some critical routes (arterial roads used for high intensive commuting in class 2, and emergency roads in class 3 including new "high-elevated roads" (with elevation can be equivalent to that of current overpasses, or elevated-rails). Keeping the area underneath clear of further development is recommended for the classes 2 and 3.
- With an integration of land-use planning and management, "floodable areas" can be accepted with the involvement of RTS. However, buffer spaces for transport system, referred to the resourcefulness, should be planned to allow for the gathering of the population during key times surrounding the major nodes in long-term development for the city. These areas are needed when transferring between different transport modes in terms of space for people gathering and vehicle parking.

5. Conclusion

5.1. Findings and contributions

In light of contemporary theories, flood resilience has been developed into urban transportation planning using a case study approach. By incorporating hydrological modelling and GIS analysis, a combined method has been used to clarify the relationship between urban resilience and vulnerability to floods. It has been asserted that development of resilience is essential as cities become increasingly vulnerable to flooding. In cooperation with the plans for transport development, this method can be used to anticipate the future vulnerability to extreme floods, as the basis for developing flood resilience.

This RTS is a development of resilient theories to overcome the inadequacy of existing strategies of urban planning. The heart of the RTS is an *the organisation of flexible and continuous links associated with switchable nodes to offer alternative routes, modes, means to allow the*

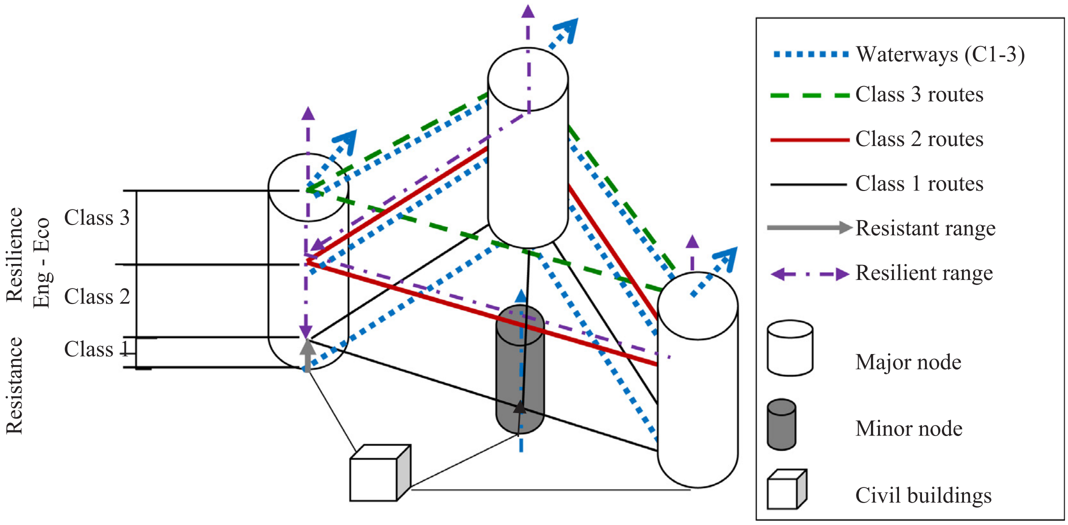


a) Horizontal development of RTS: integrated structure (transport network & urban space)

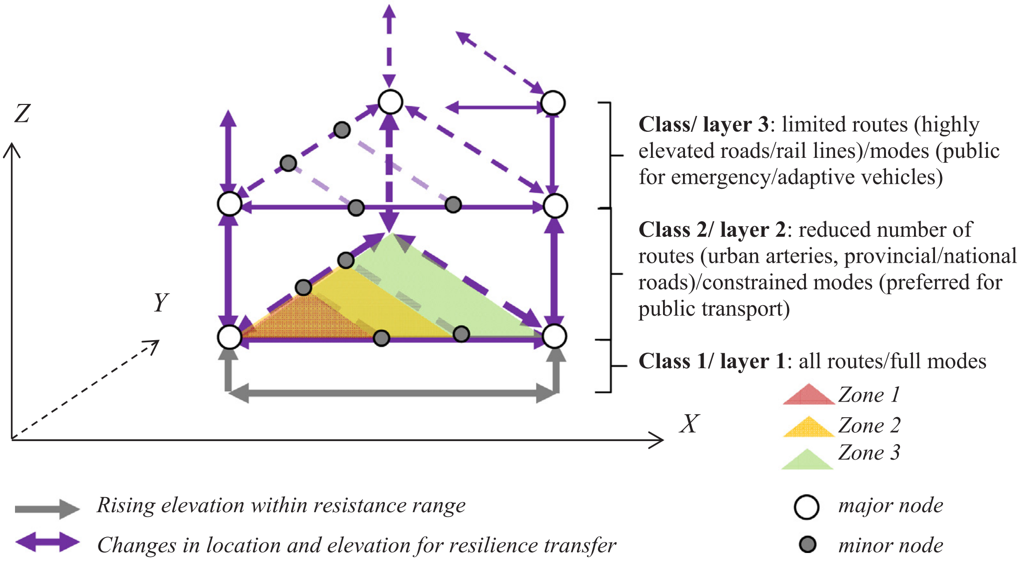
Fig. 7. Conceptual model of RTS.

spatial transfer (location and elevation) of commuting flows in adaptation to different flood magnitudes, referred to as the ability of self-organising potential changes in spatial scale (reduced to smaller scale in response to the increasing flood degree, and reverted to full scale as floods subside), and also with reference to the adaptive capacity of dealing with flood uncertainties. Elevated roads and watercourses are the two preferable modes due to the development characteristics of HCMC, and the lessons learnt from extreme flood incidents in other cities. While public transport is proposed for moderate floods, walking and cycling are also encouraged for adverse situations.

As a contribution to resilience knowledge, the innovation of this model is firstly the coordination between resistant and resilient



b) Vertical development of RTS: a flexible organisation based on links and nodes (switching/ transferring) between different elevations or beyond different locations



c) Spatial transfer of RTS: transport flows can be spatially transferred between:

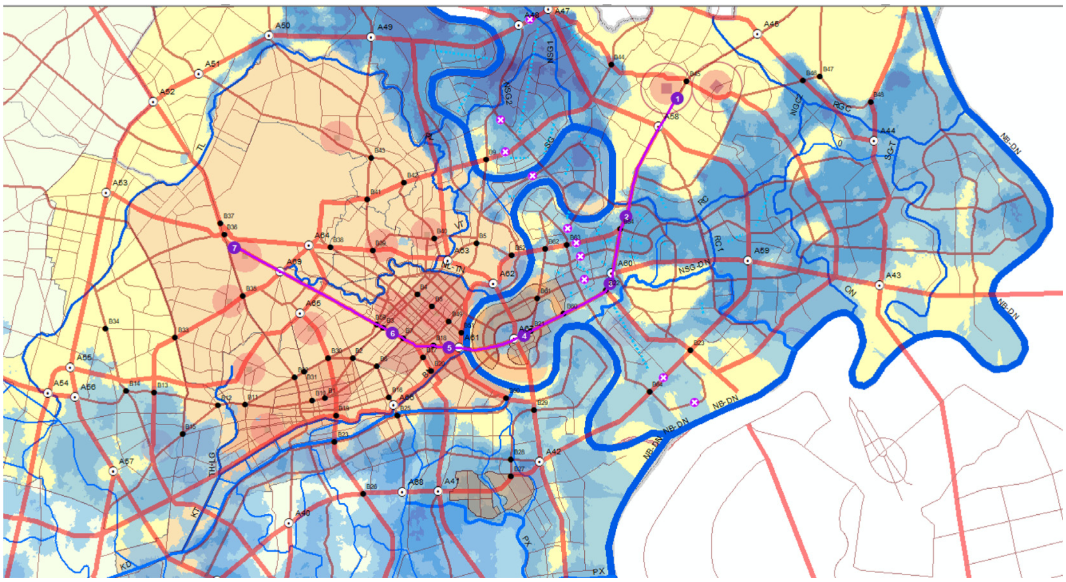
- *Same level/different locations*
- *Same location/different levels*
- *Different location/different levels*

Fig. 7. (*continued*)

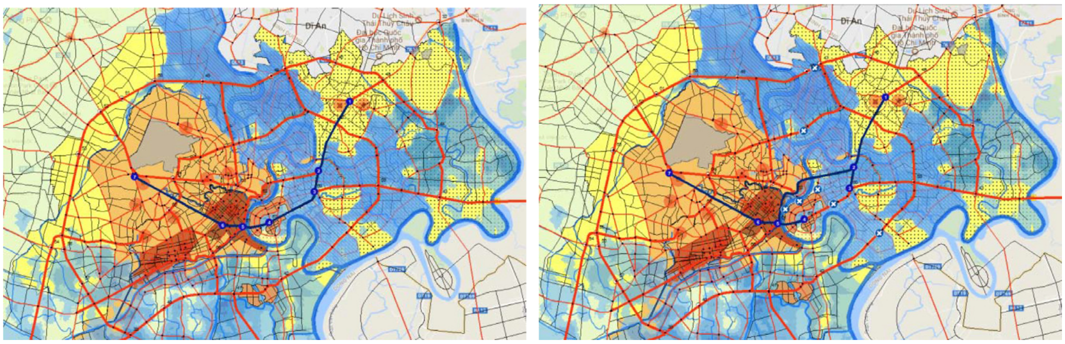
elements to build up an applicable system in a planning framework. Secondly, the flexible movement of transport flows between different spatial scales (horizontal and vertical in cooperation) can be seen as a main indication of a resilient transport system in response to flood uncertainties. Thirdly, resilience development of the transport system can become the orientation for subsequent flood management plans, urban design and building design in the future. Finally, the research has demonstrated the practical application of resilience theories in planning for a transport system in an emerging-coastal city such as HCMC.

5.2. Limitations and further work

The main aim of this research is to develop the resilience of the transport system in HCMC through a conceptual model based on flood vulnerability assessment. Such assessment requires a wide range of data which are relevant to different scientific areas, but these remain 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 megacity such as HCMC.

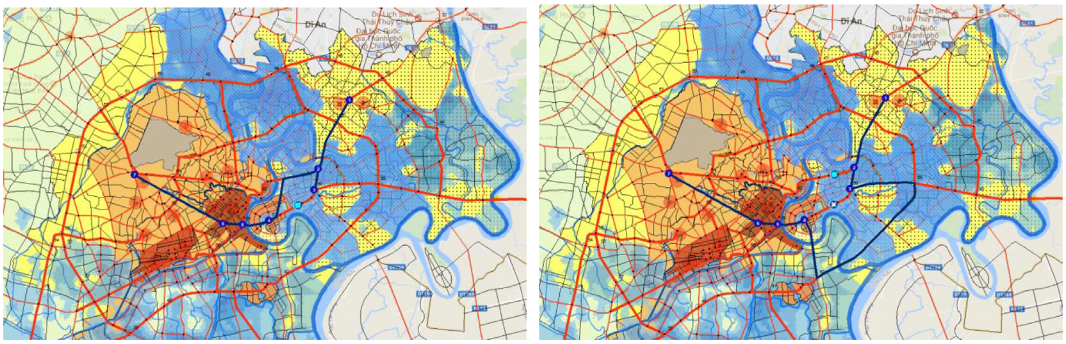


a) Alternative routes (eleven options) for travelling (magenta color: line and points)



b1) Option 1: 21.5 km

b2) Option 2: 21.6km



b3) Option 3: 21.8 km

b4) Option 4: 30km

b) 4 typical options (blue lines)

Fig. 8. Alternative routes for travel choices during moderate floods of levels 2 and 3.

With regards to uncertainties, the flood vulnerability assessment is based on the results of a hydrological simulation and GIS analysis. 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 RTS 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 RTS has some constraints. First, it is based primarily on two of the four properties of a resilient system, namely the robustness and redundancy. The other two properties have been addressed but with less emphasis. Second, applications have focused on planning at the urban level, while the two other scales (e.g. regional link to other cities, and catchment referred to neighbourhood) could be addressed to a lesser extent. Finally, the

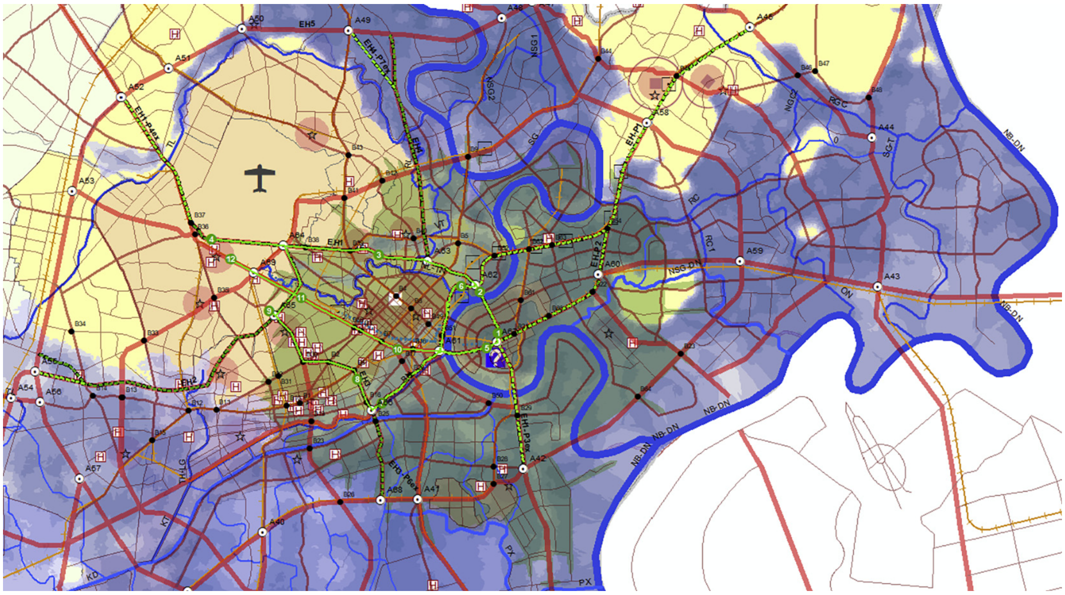


Fig. 9. An example of emergency routes (green lines) for evacuation (from Thu Thiem) in extreme flood levels 4, 5 within 8 km for service area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

evaluation of socio-economic effects have not been specified (e.g. number of people being affected) because of the lack of data.

Therefore, the research will be further developed as more data becomes available in order to move the conceptual model forward. Further work 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 (e.g. by 2030), with the application of IoT.
- A flood emergency plan (potentially integrated with fire emergency plans) can be developed from the results of this research, which has exemplified some navigable approach routes;
- The accuracy of flood simulation can be improved in smaller catchment 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.

Overall, 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.

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