Green Infrastructures to Mitigate the Urban Surface Water Flooding Risk: Identifying and Planning the Priority Areas in Ghent

Groene infrastructuur voor de mitigatie van wateroverlast in stedelijke gebieden: identificeren en plannen van prioritaire gebieden in Gent

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AHP	Analytic Hierarchy Process
AI	Aggregation Index
BMPs	Best Management Practices
CRED	Centre for Research on the Epidemiology of Disasters
CONNECT	Connectivity Index
COHESION	Patch Cohesion Index
EPA	Environmental Protection Agency, U.S.
ENN	Euclidean nearest distance
ED	Edge Density
GI	Green Infrastructure
GIS	Geography Information System
IPCC	Intergovernmental Panel on Climate Change
IJI	Interpersion and Juxtaposition Index
LID	LowImpact Development
LPI	Largest Patch Index
LSI	Landscape Shape Index
MHURD	Ministry of Housing and Urban-Rural Development, China
MWR	Ministry of Water Resources, China
MF	Ministry of Finance
NACWA	National Association of Clean Water Agencies, U.S.
NDRC	National Development and Reform Commission, China
NRDC	Natural Resources Defense Council, U.S.
NumP	Number of Patches
PSCoV	Patch Size Coefficient of Variation
PROX	Proximity Index
PLAND	Percentage of Landscape
SuDs	Sustainable Urban Drainage Systems
TE	Total Edge
T20	Statistically occurs once every twenty years
TCAI	Total Core Area Index
WSUD	Water Sensitive Urban Design

Executive summary

Flood is a significant global issue in recent years, especially the urban surface water flood, as it poses growing threats to the urban areas. The urban surface water flood is one of the most common natural hazards, which do not only cause massive physical flood water disturbance but also socio-economical losses, such as public health issues, public transportation disorders, and building damages, etc. Over the past several decades, the negative impacts of the urban surface water flooding events have affected many cities across the world such as New York and London in developed countries, as well as Beijing, Wuhan, and Bangkok in developing countries. The number and scale of flood damage in the urban areas will continue to increase during the next (several) decades due to two major reasons, one is the global trend in urbanization which leads to a higher density of cities and the other is the climate change which will result in more frequently extreme weather events.

Since the 1990s, green infrastructure practices have emerged as a supplementary approach of the centralized grey infrastructure to cope with the issue of increasing urban surface water flooding. The urban surface water flooding mitigation is important to adapt to climate change and to enhance the sustainability and resilience of the urban communities. Despite the great effectiveness of the urban green infrastructures in alleviating the stormwater runoff, there is comparatively little research available for planners and designers to determine an appropriate strategy for the green infrastructure planning. A group of studies indicated that green infrastructure has been experience-based, lacking strategy and resulted in sub-optimal outcomes. Additionally, the runoff reduction capacity of the green infrastructure needs to be elucidated. More knowledge on the runoff reduction capacity of the existing green infrastructure on a local scale could assist the decision-making of the green infrastructure planning.

Hence, this PhD study was carried out with four objectives: (1) to investigate the challenges and issues of green infrastructure planning to mitigate the urban surface water flooding risk; (2) to assess the stormwater runoff reduction capacity of the existing green infrastructure in the city of Ghent; (3) to develop a methodology to identify the priority areas for green infrastructure technologies to mitigate the urban surface water flooding risk; (4) to investigate to what extent the current green action projects of Ghent (2012) are being planned in the

areas so as to optimize the benefits of the urban surface water flooding risk mitigation and to provide green infrastructure recommendation on suitable site.

A content-based evaluation of the Sponge City plans in eight selected cities in China is based on a list of criteria that were conducted to investigate the challenges and issues of the green infrastructure planning. Based on the lessons learned from this study, suggestions for a future up-scaling of Sponge City for other cities is proposed, i.e. 1) Proper methods, such as the equal consideration, analytic hierarchy processes (AHP) and experts' interviews should be adopted in the goal setting section to define the important weights of the assigned goals due to the existence of spatial priority for different Sponge City goals; 2) More effective participation mechanisms should be adopted to improve the Sponge City public participation; 3) The urban and socio-economic context should not be overlooked for the strategic green infrastructure planning. It was found in the investigation of planning aspect that biophysical indicators were considered, while the socio-economic related indicators of the suitability analysis appear to be overlooked. A methodology that takes the socio-economic aspect into consideration for identifying priority areas for green infrastructure technologies is developed in chapter 4; 4) A spatial recommendation of certain types of green infrastructure technologies could be provided according to the local context.

The runoff reduction capacity of the existing green infrastructure in Ghent was assessed by adopting an empirical model. The method to assess the runoff reduction capacity of green infrastructure should consider the role of landscape pattern. There is a general acknowledgement that the impact of the landscape pattern of green infrastructure on the runoff reduction is significant. The empirical model adopted in this study includes two variables, i.e. runoff coefficient and landscape metrics. The results show that the grasslands contribute the most to the stormwater runoff reduction of 11.83 million m^3 and that forests controlled the lowest runoff of 4.48 million m^3. The agricultural land has the highest reduction amount per square kilometer of 0.35 million m^3/km^2 and Forests the lowest of 0.19 million m^3/km^2. The spatial distribution of the runoff reduction capacity of green infrastructure indicates that the high capacity of green infrastructure is mainly concentrated in the southwestern and northeastern suburban areas. The core areas are scattered with less green infrastructure and a low runoff reduction capacity.

A GIS-based multi-criteria evaluation method is developed to identify the priority areas to site the green infrastructure, based on five criteria: 1) the stormwater runoff mitigation; 2) the protection of the social flood vulnerable group; 3) the protection of flood sensitive area road infrastructures; 4) the flood sensitive area buildings' protection and 5) the environmental justice. The weights of the five criteria are defined by the Analytic Hierarchy Process. The planning approach to site the green infrastructure focuses particularly on mitigating the urban surface water flooding risks and to demonstrate the manner in which the method could be applied using a case study of Ghent.

The green action projects of Ghent (2012) were investigated to see whether the current projects are being planned in the areas to optimize the benefits of the urban surface flooding risk mitigation. The study compares the green action projects of Ghent with the mapping results of the priority neighborhoods (generated in chapter 4 regarding the urban surface flooding risks mitigation) to investigate two aspects, i.e. to what extent do the current green action projects fulfill the needs for the strategic priority to mitigate the urban surface water flooding risks and the neighborhoods where there is a need for green infrastructure technologies (but no green action projects currently planned). Two projects, i.e. Baudelohof and Rijsenbergpark, located in high priority neighborhoods are selected as case studies to propose potential green infrastructure technologies recommendation at the neighborhood scale. These two case studies can provide a springboard for filling gaps between analysis (methodology in chapter 4 to identify priority areas to place green infrastructure technologies) and practices (potential green infrastructure technologies recommendations in high priority areas on site). The results can provide suggestions for the green infrastructure planning and ensure the function delivery to address one of the key issues of Ghent to build a climate robust city.

Samenvatting

Gedurende recente jaren werden overstromingen een belangrijk globaal probleem (en vooral het stedelijk oppervlaktewater) en dit omdat het een groeiende dreiging vormt voor stedelijke gebieden. Stedelijke oppervlaktewateroverstromingen vormen één van de meest gangbare natuurlijke risico's, die niet enkel massale overlast (door fysische overstromingen) veroorzaken maar ook socio-economische verliezen zoals openbare gezondheidskwesties, verstoring van het openbaar transport, schade aan gebouwen enz. Gedurende de voorbije decennia hebben de negatieve invloeden van de stedelijke oppervlaktewateroverstromingen wereldwijd veel steden getroffen zoals New York en Londen in ontwikkelde landen (maar ook Beijing, Wuhan en Bangkok in zich ontwikkelende landen). Het aantal overstromingen en de omvang van de hierdoor veroorzaakte schade in de stedelijke gebieden zal blijven toenemen gedurende de komende decennia door 2 hoofdredenen, waarvan één de wereldwijde trend tot verstedelijking (die leidt tot dichter bevolkte steden). De tweede reden is de klimaatverandering, die zal resulteren in meer frequente en extremere weersomstandigheden.

Sinds de jaren 1990 verschenen er groene infrastructuurtoepassingen als een aanvullende aanpak/benadering van de gecentraliseerde grijze infrastructuur om een oplossing te bieden voor de toegenomen problematiek van stedelijke oppervlaktewateroverstromingen. Het matigen hiervan is belangrijk om zich aan te passen aan de klimaatverandering en de duurzaamheid en weerstand te verhogen van de stedelijke gemeenschappen. Ondanks de grote effectiviteit van de stedelijke groeninfrastructuur ter verlichting van de watertoevoer veroorzaakt door storm, is er ter vergelijking weinig research beschikbaar voor de planners en ontwerpers om een geschikte strategie te bepalen voor het plannen van deze groene infrastructuur. Een reeks studies heeft aangegeven dat groeninfrastructuur gebaseerd is op de praktijk en een gebrek vertoont aan strategie, en dat dit heeft geleid tot ondermaatse resultaten. Bovendien is het nodig dat de waterafvoercapaciteit van groeninfrastructuur moet worden uitgeklaard. Er is meer kennis vereist over deze capaciteit om de besluitvorming bij de planning van groeninfrastructuur op het lokaal niveau te ondersteunen.

Deze PhD studie werd bijgevolg uitgevoerd met vier streefdoelen voor ogen: (1) de uitdagingen (en problematiek) van de groeninfrastructuurplanning te onderzoeken met de bedoeling om het risico op overstroming door stedelijk oppervlaktewater te matigen; (2) het

landschapspatroon te analyseren en de reductiecapaciteit van het regenwater van de bestaande groene infrastructuur in de stad Gent te beoordelen; (3) een methodologie te ontwikkelen om de prioritaire gebieden voor groenvoorzieningtechnologie te identificeren om het risico op overstroming te matigen; (4) te bekijken in welke gradatie de huidige groenprojecten van Gent (2012) gepland worden om de voordelen van deze oplossingen (tot matiging van het risico op overstromingen door stedelijk oppervlaktewater) te optimaliseren en aanbevelingen voor groeninfrastructuur op aangepaste locaties te kunnen doen.

Een op inhoud gebaseerde evaluatie van de Sponge City plannen in 8 geselecteerde Chinese steden (die steunen op verschillende criteria) werd uitgevoerd om de uitdagingen en problemen te onderzoeken m.b.t. de groene infrastructuurplanning. Er werden lessen getrokken uit deze studie en ook suggesties voor toekomstige schaalvergroting van Sponge City voor andere steden voorgesteld, zoals 1) Degelijke methodes, zoals gelijkmatige overweging, analytische hiërarchische processen (AHP) en interviews door experten zouden gehanteerd moeten worden (in het doelstellingsgedeelte) om het belang van de toegewezen doelstellingen te definiëren (te wijten aan de ruimtelijke prioriteit van de verschillende Sponge City doelen); 2) Effectievere participatiemechanismes zouden benut moeten worden om de publieke deelname van Sponge City te verbeteren; 3) De stedelijke context en socio-economische factoren zouden niet over het hoofd gezien mogen worden m.b.t. de strategische groen-infrastructuurplanning. Bij het onderzoek over de planningsaspecten bleek dat biofysische indicatoren werden bekeken maar dat sociaal-economisch gerelateerde indicatoren bij het haalbaarheidsonderzoek over het hoofd werden gezien. In hoofdstuk 4 wordt een methodologie ontwikkeld die de sociaal-economische aspecten mee betrekt bij het identificeren van prioritaire gebieden voor groeninfrastructuur.; 4) Naargelang de lokale context kan een ruimtelijke aanbeveling worden gedaan voor het inzetten van bepaalde types groeninfrastructuur.

De ruimtelijke kenmerken en het landschapspatroon van de stad Gent werden ontleed door middel van een empirisch model. De methode om te evalueren hoe groot de reductie van de waterafvoercapaciteit is door het gebruik van groeninfrastructuur, moet ook de rol van het landschapspatroon bekijken. Algemeen wordt aangenomen dat de impact van het landschapspatroon van groeninfrastructuur op de afvoer capaciteit belangrijk is. Het empirisch model waarmee in deze studie wordt gewerkt, houdt twee variabelen in, met name de waterafvoercoëfficiënt en de landschapscijfers. De resultaten bewijzen dat grasland het meest bijdraagt tot de stormwaterafvoer-vermindering van 11.83 miljoen m^3 en dat bossen de laagste afvoer vertonen van 4.48 miljoen m^3. De landbouw-gebieden hebben de hoogste hoeveelheid reductie per vierkante kilometer met 0.35 miljoen m^3/km^2 en bossen vertonen de laagste hoeveelheid met name 0.19 miljoen m^3/km^2. De ruimtelijke verdeling van de verminderde waterafvoercapaciteit (van de groeninfrastructuur) geeft weer dat de hoge mate aan groen vooral geconcentreerd is in de zuidwestelijke en noordoostelijke voorstedelijke gebieden. De kerngebieden zijn verspreid met minder groeninfrastructuur en een kleinere hoeveelheid verminderd waterafvoervermogen.

Een op GIS gebaseerde multi-criteria evaluatiemethode (om de voorrangsgebieden op groene infrastructuur te identificeren) werd ontwikkeld, gebaseerd op 5 voorwaarden: 1) de matiging van de stormwaterafvoer; 2) bescherming van een kwetsbare sociale groep tegen zondvloed; 3) bescherming van de overstromingsgevoelige weginfrastructuur; 4) overstromingsgevoelig gebied: bescherming van gebouwen en 5) rechtvaardigheid op het vlak van milieu. Het belang van deze 5 criteria werd gedefinieerd door het Analytisch Hiërarchisch Proces.
De geplande aanpak van de groeninfrastructuur focust zich meer in het bijzonder op het matigen van het risico op overstroming door stedelijk oppervlaktewater en toont aan hoe de methode toegepast kan worden d.m.v. een case study in Gent.

De groenprojecten van Gent (2012) werden onderzocht m.b.t. het feit of de lopende projecten gepland werden ter optimalisering van de voordelen tot matiging van het risico op stedelijke oppervlaktewater-overstromingen. De studie vergelijkt de groene projecten in Gent met het kaartresultaat van voorrangswijken (samengesteld in hoofdstuk 4 in relatie tot het matigen van het overstromingsrisico als gevolg van stedelijk oppervlaktewater) om dit risico op overstroming te matigen en om het vanuit 2 aspecten te onderzoeken, met name in welke gradatie de huidige groene projecten de behoeften vervullen m.b.t. de strategieprioriteit om het risico op overstroming door stedelijk oppervlaktewater te matigen en in de wijken waar er nood is aan groeninfrastructuur (maar er momenteel geen plannen zijn voor groene projecten). Tweeprojecten, het Baudelohof en het Rijsenbergpark, gesitueerd in buurten met hoog prioriteitsgehalte, werden als case-study geselecteerd om potentiële groeninfrastructuurtechnologieën op buurtniveau aan te bevelen. Deze twee case-studies kunnen een voorbeeld zijn om gaten te dichten tussen de analyse (de methodologie ontwikkeld in hoofdstuk 4 om prioritaire gebieden te identificeren waar groeninfrastructuur kan worden voorzien) en de praktijk (de potentiële aanbevelingen voor groeninfrastructuurtechnologieën in gebieden met hoog prioriteitsgehalte). De resultaten kunnen suggesties aanbieden voor de planning aangaande deze projecten en verzekeren dat deze zal bijdragen tot de aanpak van één van de belangrijkste problemen van de stad Gent om een stevige klimaatbewuste stad te creëren.

Chapter 1 Introduction

1 Problem statements

Floods are a significant global issue, which pose a high threat to humans and properties (Ramos, Creutin, & Leblois, 2005; Kundzewicz et al., 2005; Shankman, Keinm, & Song, 2006; Pitt, 2007; Baldassarre et al., 2010). The United Nations (2012) reported that floods have become the most frequent and significant hazard for 633 largest cities or urban agglomerations worldwide. According to the Centre for Research on the Epidemiology of Disasters' (CRED) report of the "Natural disaster in 2017", nearly 60 % of the people was affected by disasters in 2017 caused by floods, while 85% of the economic damages was due to storm (Centre for Research on the Epidemiology of Disasters (CRED), 2018). Between 1970 and 2006, the total flood losses amounted to \$140 billion, with an average annual loss of \$3.8 billion in total for 31 European countries (Barredo, 2009). The number and scale of the flood damage will continue to increase during the next 50 years due to two major global themes, i.e. climate changes resulting in more frequently extreme weather events and global trends in urbanization, leading to the growth of the population and economic assets in the flood prone areas (Jha et al., 2011; Kundzewicz et al., 2013; Jeffrey, 2014).

Climate change is likely to result in an increased incidence of extreme weather events (Zahmatkesh, Karamouz, Goharian, & Burian, 2014; Kuo, Gan, & Gizaw, 2015). According to the Intergovernmental Panel on Climate Change (IPCC), the frequency of heavy precipitation (or the ratio of heavy falls to the total rainfall) will augment in the 21st century in many global areas (IPCC, 2012). The European 'Mayors Adapt' also indicated that climate change will affect almost all cities across Europe. Many cities are expected to suffer from catastrophic extreme weather events more often as the frequency, intensity and duration of these events are expected to rise (European Covenant of Mayors, 2014). Chen (2013) indicated that - by the end of the 21st century - the days of medium rain, large rain and heavy rain in China are projected to significantly increase in temperature at a rate of 1.5%/℃, 6.0%/℃ and 27.3%/℃, respectively.

Urbanization is an ongoing trend in the early 21st century, especially in the low to middle income developing countries (Mosel et al., 2016). In 1950, about 30 percent of the world's population lived in urban areas and by 2050, 66 percent of the world's population is expected to live in the urban regions (United Nations, Department of economic and social affairs, 2015). The world population is expected to reach 8.5 billion in 2030, 9.7 billion in 2050 and 11.2 billion in 2100, even assuming that the fertility levels would decline. More than half of the global population growth between 2015 and 2050 is expected to occur in Africa. Asia is projected to be the second largest contributor to the future global population growth, adding 0.9 billion people between 2015 and 2050, followed by northern America, Latin America, and the Caribbean and Oceania. Europe foresees to have a smaller population in 2050 than in 2015 (United Nations, Department of Economics and Social Affairs, & Population Division, 2015). This transition continues relentlessly, driven by economic opportunities. According to the consulting firm McKinsey Global Institute, 60 percent of the global gross domestic product is produced in only 600 urban centers in 2011 and this concentration of economic activity in the urban area is expected to grow (MaKinsey Global Institute, 2011).

The urban surface water flood is known as the most common and destructive natural hazards, resulting in considerable direct losses (e.g. personal injury and property damage) and increasing the indirect impact (e.g. interruption of public services and economic activities), especially in the urbanized areas where the majority of flood damage occurs (Vinet, 2008; A. K. Jha, Bloch, & Lamond, 2012; Yin, Yu, Yin, Liu, & He, 2016; Sperotto et al., 2015). Floods are becoming more complicated to manage in the urban areas because of the high concentration in population and the economic assets exposed within the urban settlement (The World Bank, 2012). The surface water flooding is combined flooding. It includes pluvial flooding (rainfall overland flow or ponding before the runoff enters any watercourse or drainage system or when it cannot enter the system because it overwhelms the capacity), sewer flooding (water leaks from the sewerage system) and groundwater flooding (occurs when the natural underground drainage system cannot drain the rainfall (away) quick enough, causing the water table to rise above the ground surface) (Kaźmierczak & Cavan, 2011). Houston et al. (2011) estimated that almost 2 million people in the urban areas (settlements with a population over 10,000) face an annual 0.5 percent (1 in a 200-year) probability of surface water flooding. By 2025, 3.2 million people in the urban areas face an annual 0.5 percent probability of surface water flooding.

Over more than a century, urban engineered infrastructures have been constructed in response to the increasing urban flood risk (Yazdanfar & Sharma, 2015). The urban engineered infrastructure or ‘grey infrastructure’ includes levees, dams, floodwalls, channelization, weirs, pipes, drainage and sewer systems. Despite the extensive implementation of the engineered infrastructures, cities around the world remain vulnerable to surface water flooding (Liao, Le, & Nguyen, 2016). According to the report of the Sewer System Improvement Program 2017 in San Francisco, most cities in the world still use the combined sewer system to deal with the waste and the stormwater runoff, which is not sufficient anymore when intense downpour occurs (San Francisco Public Utilities Commission, n.d.). Additionally, the public utilities are grappling with aging infrastructure and the maintenance of the engineered infrastructure is very expensive.

The combination of the increasingly frequent occurrence of extreme weather events, high population density and economic assets, and the inefficacy and costs of grey infrastructure have led to a growing interest in exploring a more integrated approach. The planners face challenges to manage the increasing urban surface water floods and to adapt the urban stormwater drainage systems to ensure the public safety and improve life quality. Besides, the growth of the informal and poorly planned settlements (where urban poor residents tend to concentrate) further complicates this picture (A. Jha et al., 2011). Several studies have noted that the urban population is at growing risk, while the urban poor may be especially vulnerable to natural hazards (Moser & Satterthwaite, 2008; O'Brien, Pelling, & Patwardhan, 2012; The World Bank, 2012).

In the framework of the impact of the frequent urban flood events, climate change, urbanization, and the inefficacy of grey infrastructure, green infrastructure has emerged as a complement or even a situational replacement of the grey infrastructure. The central problem statement of this PhD is to identify and plan green infrastructure to cope with the urban surface water flooding issue. The next section will focus on understanding the concept of green infrastructure.

2 Concept of green infrastructure

This section includes three parts. Section 2.1 provides an overview of the literature on the concept of green infrastructure and describes how the concept of green infrastructure is interpreted in this dissertation. Section 2.2 describes the types of green infrastructure. Section 2.3 provides the state-of-the-art of researches and practices of the effect of green infrastructure to manage stormwater runoff.

2.1 *What is green infrastructure?*

Though the term green infrastructure was proposed during the 1990s, the ideology originates from the 19^{th} century with the concept of green space (Williamson, 2003). The emergence of urban parks in the 1850s marked the embryonic stage of the green space. In this period, the primary goal of green space was to improve the environment and to serve the public (Taylor, 1999). Later (from the 1960s to the 1990s), theories of ecology, landscape ecology as well as concepts of ecological networks have been developed. These theories included biological and ecological protection and provided eco-services to the public (Wiens, 1992). Recently (from the 1990s onwards), various conceptions of green infrastructure have been developed (Wright, 2011). The definitions of green infrastructure are broad and varied, ranging from large-scale open space preservation, interconnected networks that sustain the ecosystem and provide socio-economic benefits, constructed wetlands, street trees, engineered green spaces that infiltrate the runoff (Benedict, 2000; Benedict Mark A., Edward T. McMahon, 2006; CUDEM, 2006; Youngquist, 2009; Shyduroff, 2016).

The green infrastructure terminology originates from the report of the President's Council on Sustainable Development released in 1999 in the U.S. (The President's Council for Sustainable Development, 1999). By the 1990s, sustainability was becoming a national and international goal (Benedict Mark A., Edward T. McMahon, 2006). The President's Council on Sustainable Development initiated efforts to apply the concept of sustainable development in the United States. The President's Council has become a symbol of national commitment to sustainable development. In its May 1999 report, the Council identified green infrastructure as one of the five strategies for achieving sustainability. The concept of green infrastructure was defined as follows (The President's Council for Sustainable Development, 1999, P.76):

> "Green infrastructure is the network of open space, airsheds, watersheds, woodlands, wildlife habitat, parks and other natural areas that provides many vital services that sustain life and enrich the quality of life." To obtain these benefits, many communities are increasingly promoting place-based approaches to conserve, protect and restore local and regional systems of natural resources and amenities. "The objectives of these green infrastructure strategies are somewhat different from those of traditional conservation efforts. While traditional conservation focuses on environmental restoration and preservation, it often neglects the pace, shape, and

location of development in relationship to important natural resources and amenities. Green infrastructure strategies actively seek to understand, leverage, and value the different ecological, social, and economic functions provided by natural systems in order to guide more efficient and sustainable land use and development patterns as well as protect ecosystems."

For the following six to seven years, the green infrastructure was developed primarily as an interconnected network that recognized to protect and enhance the connective natural features on a regional or landscape scale (Benedict & McMahon, 2002; Countryside Agency, 2006; Tzoulas et al., 2007). Green infrastructure referred to an interconnected network of natural area, including the open spaces, waterways, woodlands, wildlife habitat, parks that provided services to maintain the ecological processes, sustained the air and water resources and contributed to enrich the health and life quality for people (The President's Council for Sustainable Development, 1999). Green infrastructure was conceptualized as a network of hubs, links, and sites (Fig. 1-1). Hubs anchor the green infrastructure network and provide an origin or destination for wildlife or ecological processes moving to or through it. Hubs are large, unfragmented areas of woodlands, wetlands, and other natural areas. Sites are the most extensive and most connected green element type present. The link is the connection that connects the site and hub areas. The links are sometimes referred to as "greenways" (Benedict & McMahon, 2002).

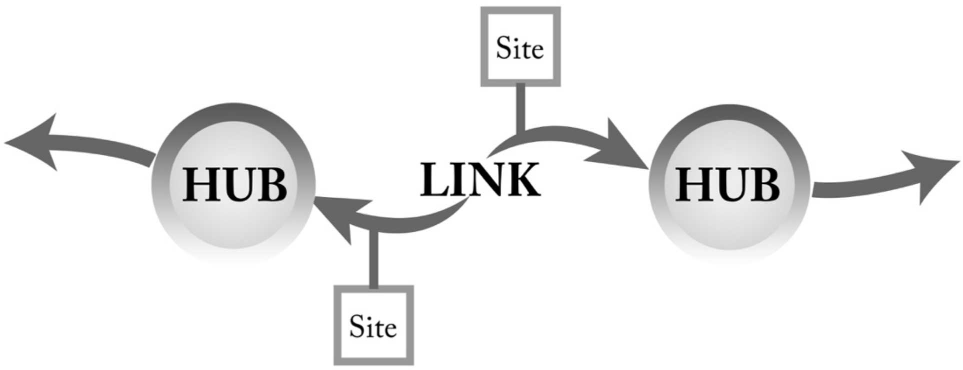

Figure 1-1 Conceptual green infrastructure diagram: a network of core areas, hubs and corridors (source: Benedict & McMahon, 2002)

In 2007, the establishment of the "Green Infrastructure Statement of Intent" further interpreted the usage of the term green infrastructure in an urban context (US EPA, NACWA, NRDC, LIDC, & ASIWPCA, 2007). The statement was signed by the U.S. Environmental Protection Agency (EPA), National Association of Clean Water Agencies (NACWA), Natural Resources Defense Council (NRDC), Low Impact Development Centre (LID) and Association of State and Interstate Water Pollution Control Administrators (ASIWPCA). It defined the green infrastructure as follows (US EPA et al., 2007, P.2):

> “a cost-effective and an environmentally preferable approach to reduce stormwater and other excess flows entering combined or separate sewer systems in combination with, or in lieu of, centralized hard infrastructure solutions”.

This report redefined the Green Infrastructures as the Green Storm Water Infrastructure, emphasizing the water regulating effect of the green infrastructure to deal with the stormwater quantity and quality on site.

Since the green infrastructure had been developed in the 1990s, various definitions coexist (Benedict, 2000; Countryside Agency, 2006; Youngquist, 2009; Shyduroff, 2016). Interpretations of green infrastructure vary between disciplines and geographic regions (Mell, 2010; Kimmel et al., 2013). The definition of green infrastructure of specific organizations or researches is shown in Table 1-1.

Table 1-1 The definition of green infrastructure of specific organizations or researches

Benedict & McMahon, (2002), P.7	“Green infrastructure is defined as an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations. green infrastructure is the ecological framework needed for environmental, social and economic sustainability, in short it is our nation’s natural life sustaining system. Green infrastructure differs from conventional approaches to open space planning because it looks at conservation values and actions in concert with land development, growth management and built infrastructure planning”
Countryside Agency, (2006), P.3	“The physical environment within and between our cities, towns and villages. It is the network of open space, play space, waterways, gardens, woodlands, green corridors and open countryside that brings many social and environmental benefits. These include nature conservation, recreation, landscape and regional development and promotion. Green infrastructure spans administrative and political boundaries. It is publicly and privately owned, semi natural and manmade”
Dunn, (2007), P.3	“Green infrastructure is the use of soil, trees, vegetation, and wetlands and open space (either preserved or created) in urban areas to capture rain while enhancing wastewater and stormwater treatment”

Ahern, (2007), P.1	"Green infrastructure is an emerging planning and design concept that is principally structured by a hybrid hydrological/drainage network, complementing and linking relict green areas with built infrastructure that provides ecological functions"
U.S. Environmental Protection Agency, (2008), P.4-5	"Systems and practices that use or mimic natural processes to infiltrate, evapotranspiration (the return of water to the atmosphere either through evaporation or by plants), or re-use stormwater or runoff on the site where it is generated"
Natural England, (2009), P.15	"Green Infrastructure is a strategically planned and delivered network comprising the broadest range of high-quality green spaces and other environmental features. It should be designed and managed as a multifunctional resource capable of delivering those ecological services and quality of life benefits required by the communities it serves and needed to underpin sustainability. Its design and management should also respect and enhance the character and distinctiveness of an area with regard to habitats and landscape types. Green Infrastructure includes established green spaces and new sites and should thread through and surround the built environment and connect the urban area to its wider rural hinterland. Consequently, it needs to be delivered at all spatial scales from sub-regional to local neighbourhood levels, accommodating both accessible natural green spaces within local communities and often much larger sites in the urban fringe and wider countryside"
Liverpool City Council Planning Service, (2010), P.10	"The city's life support system – the network of natural environmental components and green and blue spaces that lies within and around Liverpool which provides multiple social, economic and environmental benefits"
The Center for Leadership in Global Sustainability (CLiGS), (2013), P.1-2	"Green infrastructure is more than a bioswale or a green roof or a forested corridor- it's a different way of thinking about infrastructure. Understood as a multi-scale network of ecological features and systems that provide multiple functions and benefits, it provides a systems approach to planning and development that recognizes the value of ecosystem services and strives to integrate and enhance those ecosystem services within our built environment. Green infrastructure is not limited to a particular type of technology or feature doing a specific job; it's the result of a wide network of institutions, organization, agencies, businesses, and citizens bringing ecosystem services back into planning and development. It's ultimately about people and organizations making that choice. Realizing green infrastructure's full potential requires coordination and collaboration across multiple boundaries- political, jurisdictional, agency, organizational, sectoral, disciplinary, professional, to name just a few. The most significant challenge for advancing a robust and integrated form of green infrastructure may be one of leadership and collective action"

European Commision, (2013), P.3	"A strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, the green infrastructure is present in rural and urban settings"
Carpenter, Todorov, Driscoll, Montesdeoca, (2016), P. 665	"Green infrastructure uses vegetation and soil to manage rainwater and associated stormwater runoff by linking natural processes with the built environment to increase storage or promote water loss by enhancing infiltration or evapotranspiration."
Berland et al., (2017), P. 168	"Green infrastructure (also termed green stormwater infrastructure) leverages the properties of soil and vegetation to enhance watershed or sewer shed detention capacity, and in this way, manages stormwater volume."
U.S. Environmental Protection Agency, (2018)	"Green infrastructure is a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits. While single-purpose gray stormwater infrastructure - conventional piped drainage and water treatment systems - is designed to move urban stormwater away from the built environment, green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits."

The key concept of this dissertation, green infrastructure (GI), is generally accepted with two dimensions (the Center for Leadership in Global Sustainability (CLiGS), 2013; Kwak, 2016; Berland et al., 2017). The report "Greening the Grey" (the Centre for Leadership in Global Sustainability (CLiGS), 2013) summarized various green infrastructure definitions into two categories, i.e. the green infrastructure as a strategy to manage the urban stormwater by using ecological features and processes and green infrastructure as an approach to enhance the connective network of nature and open space in the landscape. Kwak (2016) also indicated that the green infrastructure can be accepted in two dimensions, i.e. referring to green networks and aiming to provide the environmental connections between green spaces to enhance the ecological functions and the second concept of green infrastructure specifically focus on the stormwater management system to alleviate the stormwater runoff issues. In this dissertation, green infrastructure specifically considered as green stormwater management infrastructure. Green infrastructure refers to a complement to grey infrastructure and as part of a broader, more integrated, cost-effective and environmental preferable flood risk management system. Green infrastructure is a planned network of natural or man-made open space and landscape features that utilize natural processes to manage the stormwater runoff.

The elements or features which are considered part of the green infrastructure will be further explored in the following section.

2.2 *Types of green infrastructure practices*

Green infrastructure exists in a great variety of structures, shapes, and types. Green infrastructure types can be classified in various ways, e.g. spatial scale (e.g. city-region, city, city district, parcel), land use (e.g. park, greenway, nature reserve), surface characteristics (e.g. degree of permeability or of vegetated surfaces) or vegetation structure (e.g. parks, grassland, woodland, waterside zones) (Mell, 2010; Moseley, Marzano, Chetcuti, & Watts, 2013; Young, Zanders, Lieberknecht, & Fassman-Beck, 2014; Connop et al., 2015; Bartesaghi Koc, Osmond, & Peters, 2017). For instance, Bartesaghi Koc et al., (2017) classifies the green infrastructure into four main types, i.e. tree canopy, green open spaces, green roofs, and vertical greenery systems. Hehn (2016) types it into 13 categories, including street trees, green roofs and walls, amenity spaces, derelict lands, water management spaces, parks and gardens, land use for urban agricultural land, civic spaces, outdoor sports facilities, green corridors, natural and semi-natural spaces, and agricultural land. The United States Environmental Protection Agency proposed ten types of green infrastructure practices, including permeable pavements, rain gardens, bio-retention cells, vegetative swale, infiltration trenches, green roofs, planter boxes, rainwater harvesting, rooftop (downspout) disconnection, urban tree canopies (The United States Environmental Protection Agency, 2012).

The view of what constitutes green infrastructure is linked to the main aim and purpose of the research (Hehn, 2016; Chenoweth et al., 2018). For instance, researches focusing on the multi-functionality of the green infrastructure and its contribution towards both socio-economic and environmental goals may take a broader stance on what constitutes green infrastructure than researches that consider green infrastructure as a tool for biodiversity conservation and ecosystem services' delivery (Hehn, 2016). In this PhD study, the types of green infrastructure in chapter 3 and 4 includes various natural green spaces (Votsis, 2017; Capotorti et al., 2019; Gavrilidis, Niță, Onose, Badiu, & Năstase, 2019; Girma, Terefe, Pauleit, & Kindu, 2019), i.e. forests, agricultural lands, grasslands, that affect the hydrologic processes. The agricultural lands will be considered as an element of green infrastructure in these chapters. Hehn (2016) indicates the variety of the definition of the elements that are part of the green infrastructure according to the context in which they are employed. For instance, the agricultural land may not be considered part of the green infrastructure in landscape ecology, as the main focus is the provision of migration corridors for species. On the other hand, it may be counted part of green infrastructure from the perspective of mimicking natural processes to manage the stormwater runoff. Beyond these various forms of natural green spaces, green infrastructure in chapter 5 refers to more technical and engineered types, e.g. permeable pavement, rain garden, green roof etc. Table 1-2 provides a detailed description of ten types of more technical and engineered green infrastructure practices proposed by the United States Environmental Protection Agency (The United States Environmental Protection Agency, 2012).

Table 1-2 Types of flood related green infrastructure practices, source: The United States Environmental Protection Agency (2012)

Types	Description	Level
1. Permeable pavements	Porous paved surfaces that allow the rainwater runoff to infiltrate into soils. There are many different types of permeable pavements, including pervious asphalt, concrete and interlocking paves.	Site corridor
2. Rain gardens	Shallow vegetated areas planted with grasses, flowers, and other plants that allow the rainwater runoff to infiltrate through the vegetation and soil. Rain gardens can also help filter out pollutants in the runoff. More complex rain gardens connected with drainage systems are often referred to as bioretention cells.	Site
3. Bioretention cells	Larger and more complex infrastructure than rain gardens and designed with an underdrain to connect to the storm drain system. Bioretention cells are larger and deeper with underdrains that can mitigate larger amounts of runoff and allowing the water to filter through soil and vegetation.	Site
4. Vegetative swales	Channels or depressed areas with sloping sides with grass and other vegetation. They slow down the conveyance of the collected runoff and allow it more time to infiltrate into the soil.	Site corridor
5. Infiltration trenches	Narrow ditches filled with gravel that intercept the runoff. They provide storage volume and more time for the captured runoff to infiltrate into the soil.	Site
6. Green Roofs	Green roofs consist of multiple layers including plants, engineered soils, subsurface drainage pipes, and a waterproof membrane. Green roofs have two common types: intensive with a thicker soil supporting a wide variety of plants and extensive which covered only a light layer soil and minimal vegetation.	Site
7. Planter boxes	Structures with low vertical walls filled with gravel, soil, and	Site

	vegetation that collect and absorb the runoff. They are ideal for space-limited sites in dense urban areas.	
8. Rainwater harvesting	Rain barrels and cisterns to collect and store water for later use.	Site
9. Rooftop (downspout) disconnection	Allows rainwater to discharge to pervious areas instead of directly into the storm drains.	Site
10. Urban tree canopy	The layer of leaves and branches that cover the ground while viewed from above. They can reduce and slow down the rainwater runoff.	Site corridor

1. Permeable pavements

Permeable pavement is a porous paved surface that allows the runoff to slowly infiltrate into the soil below (Selbig, Buer, & Danz, 2019). Fig. 1-2 shows the diagram of three design approaches, i.e. full infiltration, partial infiltration, or no infiltration of permeable pavement. Permeable pavement is primarily used to promote full infiltration of runoff into the soil subgrade. When soil subgrades have low infiltration rates, partial infiltration into the soil subgrade occurs and the remaining water exits via underdrains. For the designs that require no infiltration, permeable pavement systems are enveloped with a geomembrane and the stored water exits via underdrains (Hein, 2014).

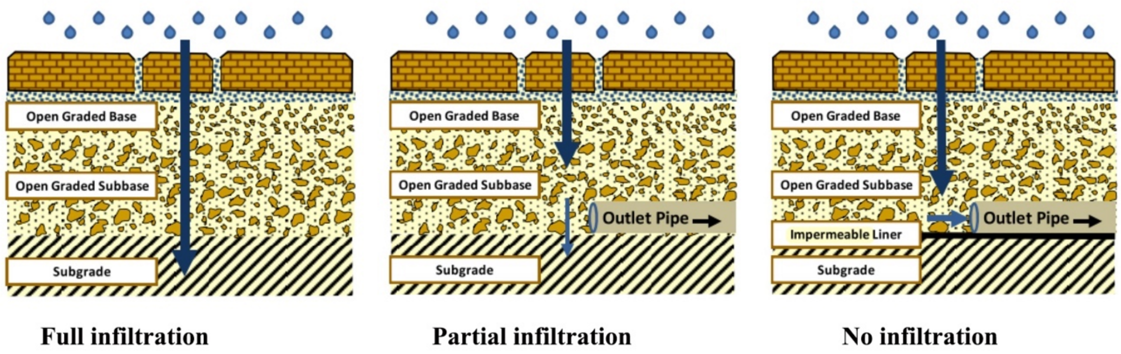

Figure 1-2 Permeable pavement diagram, source: (Hein, 2014)

2. Rain gardens

Rain gardens are shallow vegetated areas planted with grasses, flowers, and other plants that allow the rainwater runoff to infiltrate through the vegetation and soil. A slotted or perforated pipe underdrainage system within a drainage layer is included at the bottom of a rain garden if the rain garden is connected to the stormwater pipeline in the street (Christchurch City Council, 2016).

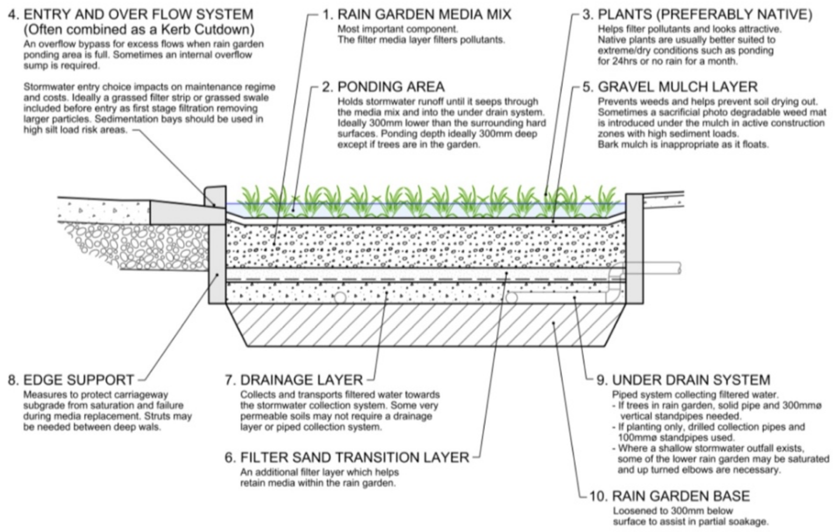

Figure 1-3 Rain garden diagram, source: Christchurch City Council, (2016)

3. Bioretention cells

Bioretention cells are usually larger and more complex than rain gardens. Bioretention cells are designed with an underdrain to connect to the storm drain system. A bioretention cell is designed as a terrestrial depression vegetated with a variety of species. The vegetative depression allows stormwater to be retained at the cell surface before it infiltrates through an underlying bioretention media layer (Paus & Braskerud, 2014).

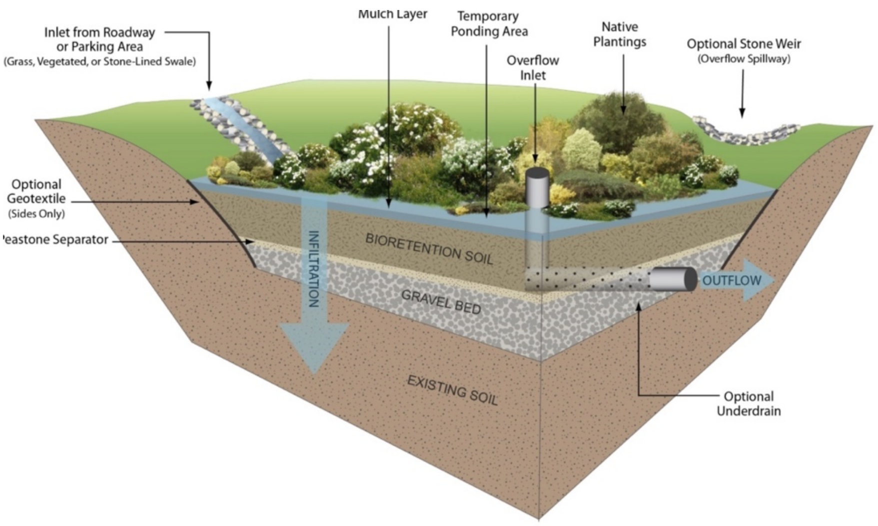

Figure 1-4 Bioretention cells diagram, source: Massachusetts Department of Environmental Protection, (n.d.)

4. Vegetative swales

A vegetative swale is a flat-bottomed linear channel with slopping sides with grass and other vegetation. The vegetative swale can collect, store, and infiltrate the stormwater runoff (Leroy et al., 2016).

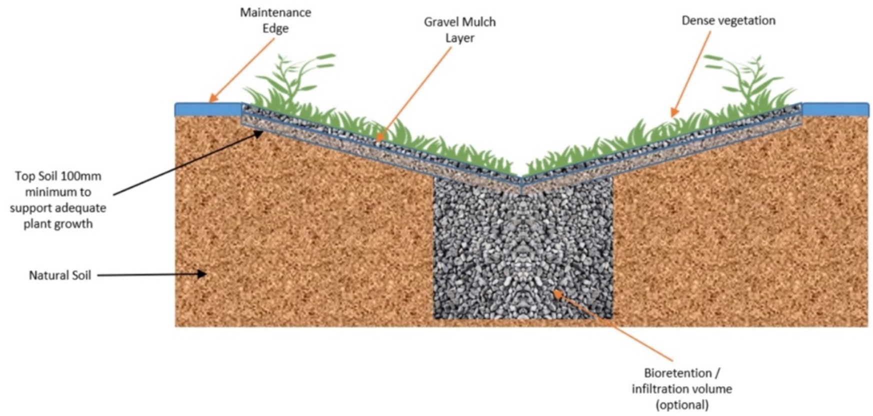

Figure 1-5 Vegetative swale diagram, source: Water Sensitive SA, (n.d.)

5. Infiltration trenches

The infiltration trench is a narrow ditch filled with gravel that intercepts the runoff.
An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives the stormwater runoff. The latter is stored in the void space between the stones and infiltrates through the bottom and into the soil (California Stormwater Quality Association (CASQA), 2003).

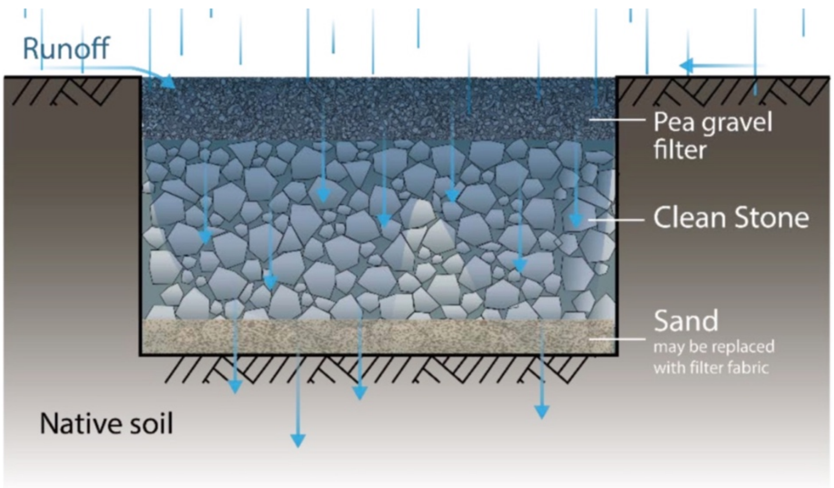

Figure 1-6 Infiltration trench diagram, source: "Infiltration Trench Factsheet" (n.d.)

6. Green Roofs

Green roofs consist of multiple layers including plants, engineered soils, subsurface drainage pipes and a waterproof membrane. There are two main types of green roofs, i.e. extensive roofs and intensive roofs. Extensive roofs have a thin soil layer and feature succulent plants that can survive in harsh conditions. Extensive roofs require little maintenance once they are established and are generally cost-effective. Intensive roofs have a thicker soil layer and should be considered as a landscape with plants found in parks and gardens (GSA (General Services Administration), 2011).

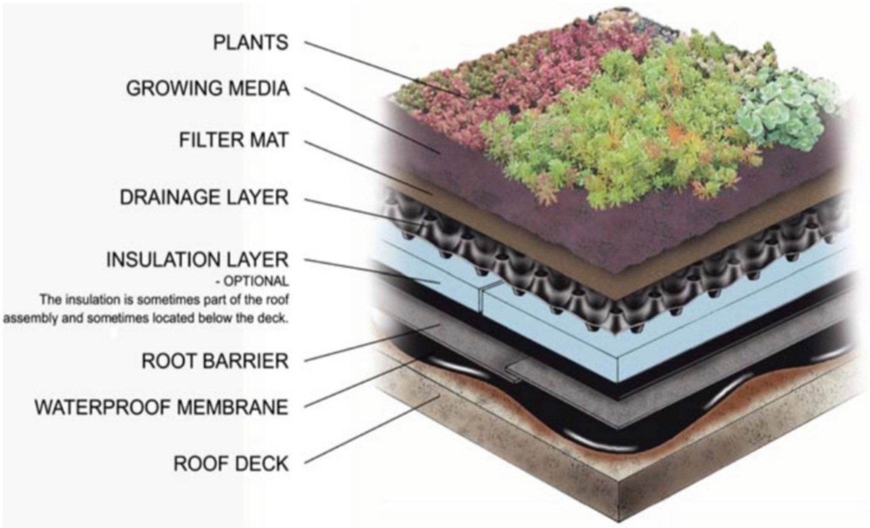

Figure 1-7 Green roof diagram, source: (Tolderlund, 2010)

7. Planter boxes

Planter boxes are structures with low vertical walls and open or closed bottoms filled with gravel, soil, and vegetation. A planter box can collect and absorb the runoff. They are ideal for space-limited sites in high-intensity urban areas (The United States Environmental Protection Agency, 2012).

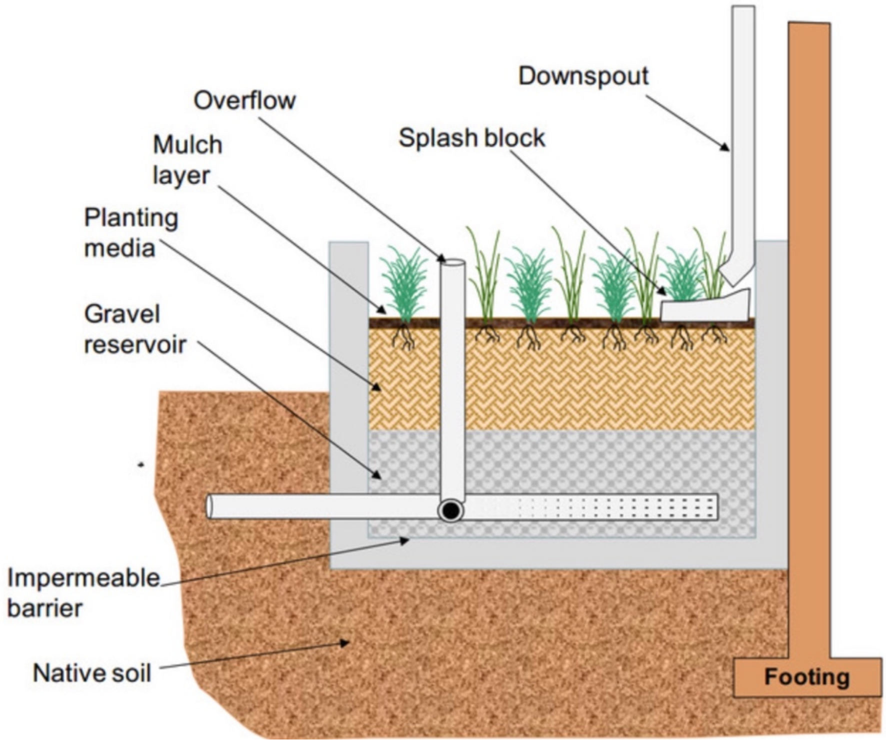

Figure 1-8 Planter boxes diagram, sources: (Mihalic, 2015)

8. Rainwater harvesting

The rainwater harvesting system includes rain barrels and cisterns to capture and store water. The rainwater harvesting system collects water from a roof and stores it for later use such as on lawns, gardens, or indoor plants (The United States Environmental Protection Agency, n.d.). It could reduce the stormwater flow from the building roofs.

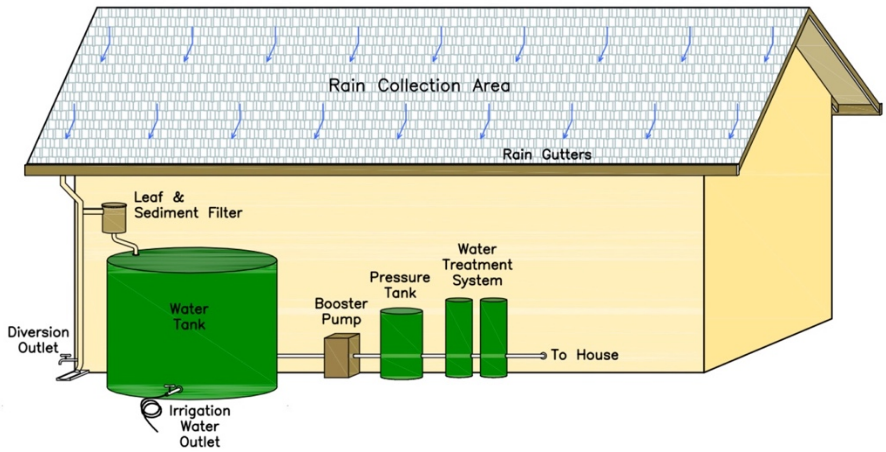

Figure 1-9 Rainwater harvesting diagram, source: Geologic and environmental consulting, (n.d.)

9. Rooftop (downspout) disconnection

The rooftop disconnection allows the rooftop rainwater to discharge to previous landscape areas and lawns instead of directly into the storm drainage system. The rooftop disconnection allows stormwater to infiltrate into the soil. The rooftop disconnection practices can reduce the amount of stormwater that enters the storm or combined sewers' system.

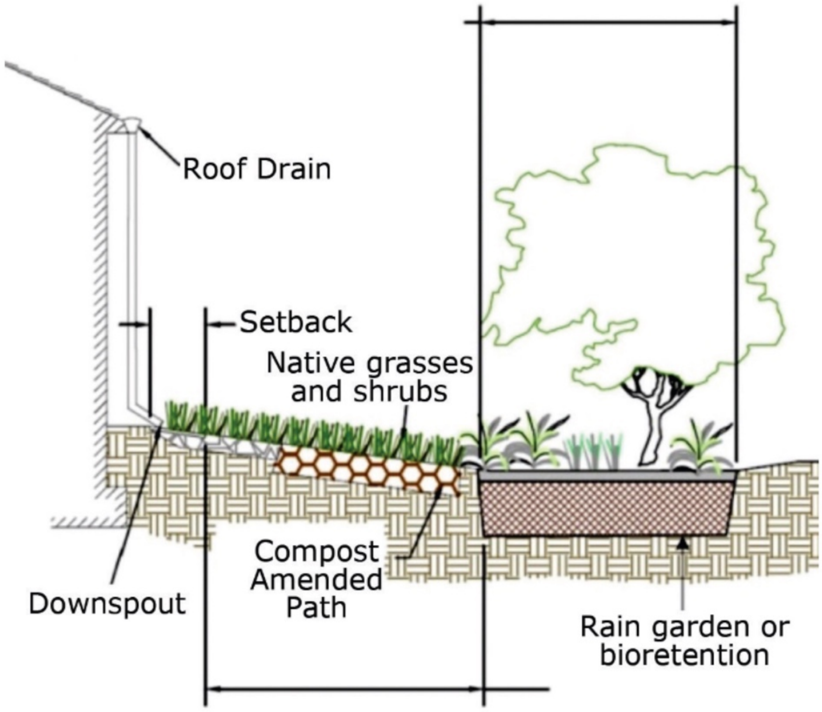

Figure 1-10 Rooftop (downspout) disconnection diagram, source: Sample, (2013)

10. Urban tree canopy

The urban tree canopy is the layer of tree leaves and branches that cover the ground while viewed from above. It intercepts rain in their leaves, thereby reducing and slowing down the stormwater runoff.

2.3 *Green infrastructure and their potential for sustainable stormwater management*

Green infrastructure has the potential to filter and collect the rainwater runoff, thus reducing the amount of untreated runoff, alleviating the pressure on aging and undersized sewer system during heavy precipitation and mitigating the flooding hazard (Mentens, Raes, & Hermy, 2006; Qin, 2013; Stovin, Poë, De-Ville, & Berretta, 2015; Copeland, 2016). Other potential benefits of green infrastructure have also been widely acknowledged, e.g. the urban heat island amelioration (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Emmanuel &

Loconsole, 2015), stormwater quality improvement (Leroy et al., 2016; J. Chen et al., 2019), air quality improvement (Jayasooriya, Ng, Muthukumaran, & Perera, 2017; Rafael et al., 2018), life quality promotion (Tzoulas et al., 2007), etc. The benefits of green infrastructure can be classified into four groups, i.e. environmental benefits, social benefits, climate change adaptation and mitigation benefits and biodiversity benefits. Environmental benefits include clean water provision, air and water pollutants' removal, pollination enhancement, soil protection, rainwater retention, increased pest control, land quality improvement, land take and soil sealing mitigation. Social benefits include human health and wellbeing, job creation, local economy diversification, greener cities, higher property values, and local distinctiveness, more integrated transport and energy solutions, tourism, and recreation opportunities' enhancement. Climate change and mitigation benefits include flood alleviation, ecosystem resilience strengthening, carbon storage and sequestration, urban heat island effects' mitigation, disaster prevention. Biodiversity benefits include habitats of wildlife improvement, ecological corridors, and landscape permeability (European Commission, 2013). There is growing body on literature review of the multi-benefits of green infrastructure, which indicated that the green infrastructure planning should not only consider stormwater runoff management (Demuzere et al., 2014; Wang & Banzhaf, 2018). This PhD nevertheless focus and provides insights of identifying and planning green infrastructure technologies regarding urban surface water flooding risk mitigation. Future researches can combine the investigations in this study with other potential benefits, e.g. urban heat island effect alleviation, stormwater quality improvement, accessibility etc., regarding the local context in the process of green infrastructure planning.

The stormwater runoff is the major source of surface water flooding (Jaafar, Ismail, Tajjudin, Adnan, & Rahiman, 2016). The effect of the green infrastructure to reduce the rainwater runoff has been extensively studied (Nagase & Dunnett, 2012; Liu, Chen & Peng, 2014; Zhang et al., 2015; Calderón-Contreras & Quiroz-Rosas, 2017). Kim, Lee & Sung (2016) indicated that the flooding probabilities could be reduced by over 50 % of urban green spaces. Vanuytrecht et al. (2014) demonstrated that the sedum-moss vegetation and grass-herb vegetation green roof can decrease 61-75% of the stormwater runoff in summer and 6-18% in winter, respectively. Liu et al. (2014) demonstrated that the green infrastructure can eliminate the stormwater runoff of the 1- and 2- year recurrence intervals and reduce the volume and peak flow of the stormwater runoffs of 5- and 10- year recurrence interval runoffs by 94.2% and 85.6% and 97.1% and 93.1%, respectively. Mentens, Raes, & Hermy (2006) showed that the roof greening on just 10% of the buildings would result in a rainwater runoff reduction of 2.7% (for the region) and 54% for the individual buildings.

With an increasing pressure on the municipality and cities to mitigate the flood hazards, the green infrastructure was entering the urban planning as a cost-effective approach to reduce the stormwater runoff volume entering the sewer system, thus reducing the number of urban surface flood events (The Center for Leadership in Global Sustainability (CLiGS), 2013). Gradually, the green infrastructure became formally incorporated into the runoff control plans of different municipalities and stormwater utilities. Many water utilities began to model the ability of green infrastructure to reduce the rainwater runoff and instituted a variety of pilot projects. Examples for green infrastructure approaches range from city-wide stormwater management systems to small scale ecological engineering approaches such as decentralized stormwater facilities including rain gardens, green roofs or bio-swales (Ashley, Nowell, Gersonius, & Walker, 2011; City of Chicago, 2014; Nguyen et al., 2019).

The adoption of green infrastructure practices to manage the urban rainwater runoff has increased in many cities during the past two decades (Economides, 2014; NYC Environmental Protection, 2015; A. Santos, Branquinho, Goncalves, & Santos Reis, 2015; Liu & Jensen, 2018). American cities (such as New York and Philadelphia) are peer cities in adopting green infrastructure to cope with urban stormwater runoff (Economides, 2014). New York became the first municipality to use green infrastructure to solve combined sewer overflow problems. By greening the NYC’s streets, sidewalks and other public property and incentivizing retrofits on the provided property, the goal of green infrastructure program is to reduce 1.67 billion gallons a year by 2030 (NYC Environmental Protection, 2018). Philadelphia became the first city to include green infrastructure in its long-term plan for reducing the combined sewer overflow. Philadelphia will have invested approximately $2.4 billion to initiate the largest green stormwater infrastructure program ever envisioned in the United States. The plan aims to develop a sustainable Philadelphia by greening the neighborhoods, restoring the waterfronts, improving the outdoor recreation spaces and enhancing the quality of life. At least one-third of the existing impervious cover in the combined Sewer System drainage areas will be greening over the next two and a half decades (Philadelphia Water Department, 2011). Chicago is also widely recognized as an early-adopter of the green stormwater infrastructure strategies. The city of Chicago has pioneered the installation of green roofs, gardens, the use of permeable pavements in alleys and streets and land use regulations that require greater levels of the on-site stormwater management by means of green infrastructure practices (City of Chicago, 2014). European cities, such as Barcelona and Lisbon, started to integrate green infrastructure planning into their master planning, including greenways, green gardens, and green roof projects to improve the water management system, reduce the heat island effects and ensure a timely and coordinated response to extreme events (Ajuntament de Barcelona, 2013; Santos, Branquinho, Goncalves, & Santos Reis, 2015). In Asia, the national water agency of Singapore launched the ambitious program of Active, Beautiful, Clean (ABC Waters) in 2007. The government of Singapore decided that a more sustainable approach was needed in order to treat the stormwater on-site before discharging the water into pubic drains. The ABS Water program integrated design elements, including rain gardens, bio-retention swales and wetlands have not only improved the water quality but also increased the biodiversity in the surrounding areas. Projects under the ABC program follow the guidelines relating to the surface water drainage, flood control, stormwater quality and public health risks. Singapore has identified over 100 potential locations for the implementation of the projects by 2030 (Centre for Liveable Cities Singapore, 2017). The Chinese government approved the development of 16 pilot Sponge Cities that would use ecological technologies to manage the rainwater in 2015. The primary goal of the Sponge City is to eliminate waterlogging by retaining 70-90% of the average annual rainwater onsite by applying the green infrastructure (Li, Ding, Ren, Li & Wang, 2017). To support the infrastructure retrofits using green infrastructure through this initiative, the Chinese government provides each Sponge City US$63 million annually for three years (Anees Soz, Kryspin-Watson, & Staton-Geddes, 2016).

3 The research gaps of the green infrastructure planning to prevent the urban surface water flooding

With an increasing recognition of the effect of green infrastructure on the hydrological process, there is a growing demand for green infrastructure planning to play a greater role in the stormwater management (Carmon & Shamir, 2010). However, despite the increasing awareness and the green infrastructure implementation worldwide (to manage the stormwater runoff), the green infrastructure planning has been experience-based, lacking strategy and resulted in sub-optimal outcomes (Schuch, Serrao-Neumann, Morgan, & Low Choy, 2017; Kuller, Bach, Ramirez-Lovering, & Deletic, 2018; Kuller, Bach, Roberts, Browne, & Deletic, 2019). For instance, Kuller et al. (2018) investigated the relationship between the green infrastructure and urban context, i.e. a biophysical, socio-economic, and urban form, in Melbourne. The result indicated that opportunistic green infrastructure planning leads to unintentional outcomes that fail to provide full potential of green infrastructure benefits. The nationwide Sponge City policy in China is issued to cope with serious urban waterlogging issues. The Sponge City policy was issued by China's Ministry of Finance, Ministry of Housing and Urban Construction, and Ministry of Water Resources in 2014 (Ministry of housing and urban-rural development, 2014). With the establishment of the Sponge City policy, thirty cities in 2015 and 2016 were issued by the central government so as to explore and carry out the Sponge City plans. Despite the large scale and fast implementation in these pilot cities, the Sponge City planning and design is still in an exploratory stage (Li et al., 2017). Li et al. (2017) indicated that the research foundation for Sponge City is rather weak. The rapid implementation of Sponge City measures is largely based on very little research domestically and locally. Nguyen et al., (2019) investigated the Sponge City and indicated that the uncertainties in the green infrastructure planning and design of Sponge City are one of the most serious problems which could risk failure for the sponge city implementation.

It is therefore important to identify the challenges and issues of green infrastructure planning and design. The study could provide insights into green infrastructure planning and design for sustainable water management on a city scale. A content-based evaluation of the green infrastructure plans is necessary to provide understanding, from which experiences and lessons can be drawn for other cities and to facilitate a future quantitative and qualitative sustainable water management planning. Pilot sponge cities will be good case studies to provide an opportunity to study the current green infrastructure planning and design aspect, since it is a nationwide policy with 30 pilot cities. Xia et al. (2017) describe Sponge City as a breakthrough for the urban planning in China that encourages the urban water management to be integrated with the urban planning on a city scale.

One of the main issues is that the current green infrastructure implementation is experience-based and lacks a strategic planning approach to efficiently locate green infrastructure in the suitable areas (to optimize its potential so as to provide benefits for the stormwater management). It is important to acknowledge that simplistic blueprints will be insufficient to address the complex issues that are associated with the urban context. Green infrastructure technologies should be located in suitable locations in order to efficiently optimize their potential. A group of studies point out that the indicators determine the suitability locations for the green infrastructure technologies (Madureira & Andresen, 2014; Meerow & Newell, 2017). Various biophysical indicators (from the aspect that green infrastructure technologies need a place), such as hydrology, soil, slope, are considered. However, the socio-economic indicators (from the aspect that a place that needs green infrastructure technologies), i.e. the social flood vulnerable group, land use, buildings, road network, appear to be overlooked. Recent literature suggests that the spatial indicators (including the socio-economic aspect) can impact the green infrastructure functioning (Barbosa, Fernandes, & David, 2012). Strategic consideration of socio-economic related indicators is important for an optimal green infrastructure implementation in order to deliver the (water regulating) services that society is requiring. Therefore, it is important to develop a quantitative approach (taking the socio-economic indictors into consideration) to identify priority areas for green infrastructure planning to mitigate urban surface water flooding risk.

Besides, the runoff reduction capacity of the green infrastructure needs to be elucidated. More knowledge on the runoff reduction capacity of the existing green infrastructure on a local scale could assist the decision-making of the green infrastructure planning (Lanzas, Hermoso, de-Miguel, Bota, & Brotons, 2019). The model to measure the runoff reduction capacity of green infrastructure should consider the role of landscape pattern. There is a general acknowledgement that the impact of the landscape pattern of green infrastructure on the runoff reduction is significant (Liu, Wang, & Duan, 2012; Kim & Park, 2016; Boongaling, Faustino-Eslava, & Lansigan, 2018; Su et al., 2018; Bin, Xu, Xu, Lian, & Ma, 2018; Peng et al., 2019). The landscape pattern includes two main components, i.e. the composition and configuration (Antrop & Van Eetvelde, 2017). The composition means the variety and relatively abundant patch types within the landscape. The composition of the landscape is quantified using the proportions of different land cover types. The configuration refers to the spatial characteristics, arrangements, positions or geometric complexity of the patches (Shihong Du, Xiong, Wang, & Guo, 2016). For instance, Kim and Park (2016) investigated the effect of landscape patterns on the peak runoff in four Texas MSAs. The mean annual peak runoff depth is used as a dependent variable and eight landscape pattern metrics, i.e. percentage of landscape, edge density, shape index, contiguity index, proximity, Euclidean nearest distance, connectedness, cohesion, are selected as independent variables. Other correlates, such as precipitation, slope, soil permeability, impervious rate, of runoff reduction capacity are measured as control variables. The outcome suggests that larger, less fragmented and more connected landscape patterns are more likely to mitigate the mean annual peak runoff. Bin et al. (2018) evaluated the impact of the landscape pattern on the surface runoff in the Haihe River Basin. The outcome clarifies that the increase of the value of the largest patch index (LPI), Euclidean nearest distance (ENN), contagion index (CONTAG), and aggregation index (AI) causes a decrease in the runoff depth. It is important to assess the spatial distribution of the runoff reduction capacity of the existing green infrastructure. Overall, this dissertation is conducted with the assumption to contribute to green infrastructure planning for sustainable management of the stormwater runoff (by addressing the research questions in the following section) and thus to reduce the urban surface water flood risk.

4 Research questions and objectives

This dissertation aims to address the fundamental research question "how to identify and plan green infrastructure to mitigate the urban surface water flooding risk". In order to handle this research question, this dissertation tries to address the following specific research questions and related objectives:

1. Which are the challenges and issues of the current green infrastructure planning to mitigate the urban surface water flooding risk (chapter 2)?

→ research objectives: to investigate the Sponge City plans (China) and to define the challenges and issues of the green infrastructure planning to mitigate the urban surface water flooding risk. Pilot sponge cities provide a good opportunity to study the issues of green infrastructure planning (since it is a nationwide policy with 30 pilot cities in China). The Sponge Pilot cities applied green infrastructure technologies on city scales (Xia et al. 2017). The experiences and lessons of the green infrastructure planning of Sponge City could facilitate future quantitative or qualitative sustainable water management planning.

2. What is the runoff reduction capacity of the existing green infrastructure regarding the surface water flooding risk mitigation in an urban context (chapter 3)?

→ research objectives: to assess the runoff reduction capacity of the existing green infrastructure in the city of Ghent. The objective contributes to the knowledge of the runoff reduction capacity of the green infrastructure that could assist the decision-making of the green infrastructure planning.

3. How should priority areas for green infrastructure practices be identified so as to mitigate the urban surface water flooding risk (chapter 4)?

→ research objectives: to develop a methodology to identify the priority areas for green infrastructure practices so as to mitigate the urban surface water flooding risk in an urban context, and applied the methodology in the city of Ghent.

4. Which green infrastructure recommendation could be provided on site in order to mitigate the urban surface water flooding risk (chapter 5)?

→ research objectives: to investigate to what extent the current green action projects of Ghent (2010) are being planned (in the areas) to optimize the benefits of the urban surface water flooding risk mitigation and to provide green infrastructure recommendations on suitable site.

5 Site context: the case study of Ghent

The case study selection of the municipality of Ghent is due to three reasons. Firstly, the city of Ghent is fairly sensitive to the water nuisance of sewers in case of a T20 (statistically occurs once every twenty years) rain shower occurrence (Ghent Administration, 2016). Secondly, the high urbanization density and economic asset concentration in Ghent (the capital and largest city of East Flanders) is making the flood damage more significant. Thirdly, one of the main goals of the climate adaption plan 2016-2019 for Ghent is to reduce the water nuisance by greening the city and this PhD will facilitate planners to identify and plan the green infrastructure to reduce the water nuisance.

5.1 *Background*

Ghent is the capital and the largest city of the province of East Flanders in Belgium (Fig. 1-11). The city originally started as a settlement at the confluence of the River Scheldt and Lys. It measures about 50 km from the coastline. The municipality area covers an area of 156,2 km^2 and has 262,219 inhabitants at the beginning of 2019.

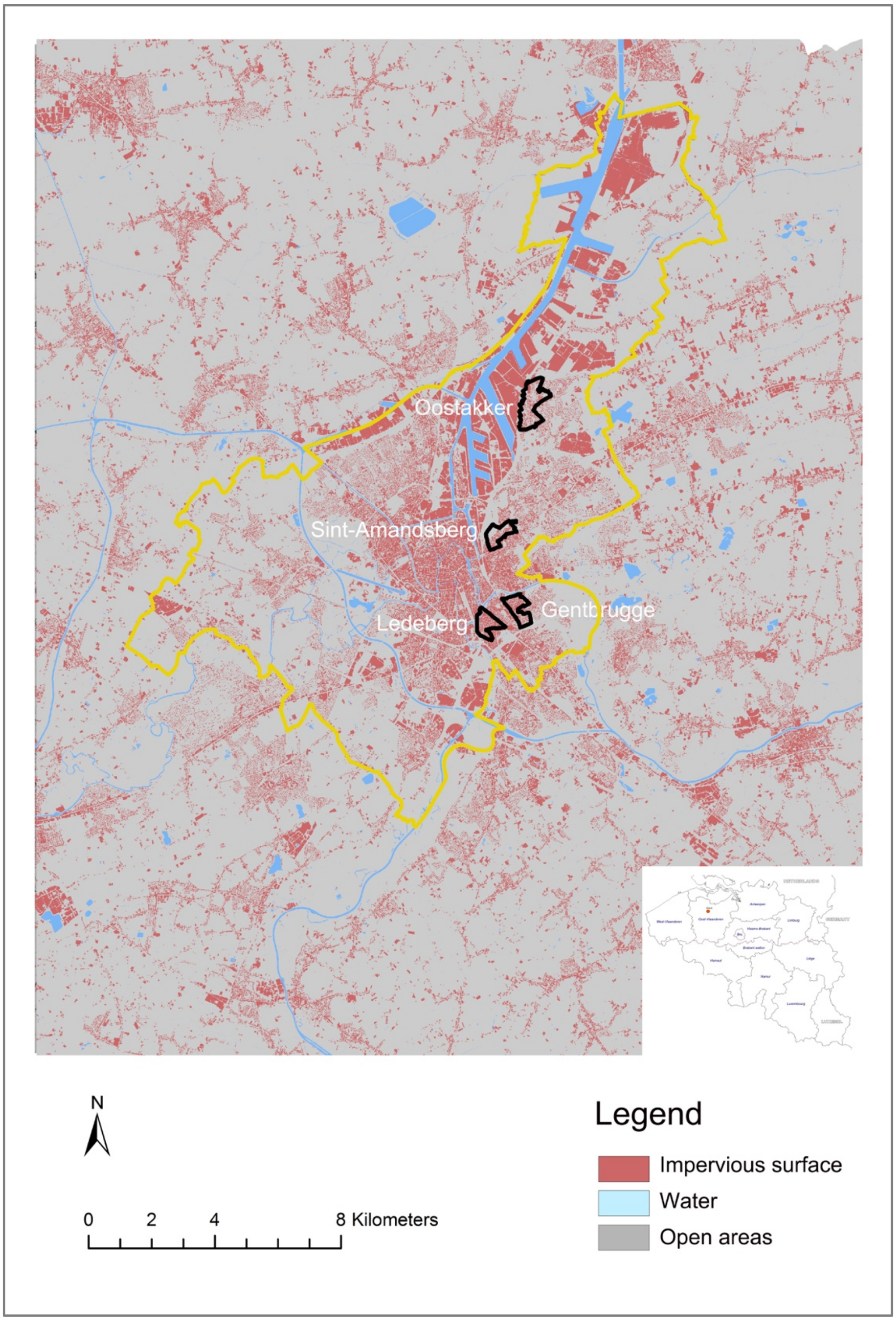

Figure 1-11 The study area, the yellow edge defines the boundary of the municipality of Ghent (Source: Flanders Information Agency, 2012, modified by the authors)*, the black edge defines sectors (identified by the city of Ghent), i.e. Ledeberg, Gentbrugge, Sint-Amandsberg, and Oostakker, that are most sensitive to water on the street or large portions of sewer covers flood in case of a T20 (statistically occurs once every twenty years) rain shower (Ghent Administration, 2016)*

Ghent is home to a vast group of residents, including flood vulnerable populations such as the elderly, small children, unemployed, etc. There were 50.1 % females (or 131,501 in absolute figures) and 49.9 % males (or 130,718) in 2019 (Fig. 1-12).

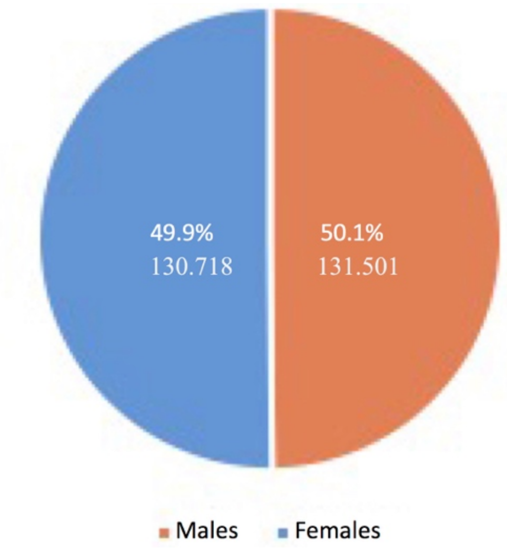

Figure 1-12 The gender population structure in Ghent (Statistics Belgium, 2019)

The age of the residents is predominantly 30-64 (46.0 %), followed by 15-29 (21.1 %), 65+ (16.7 %) and 0-14 (16.2 %) in 2011 (Fig. 1-13).

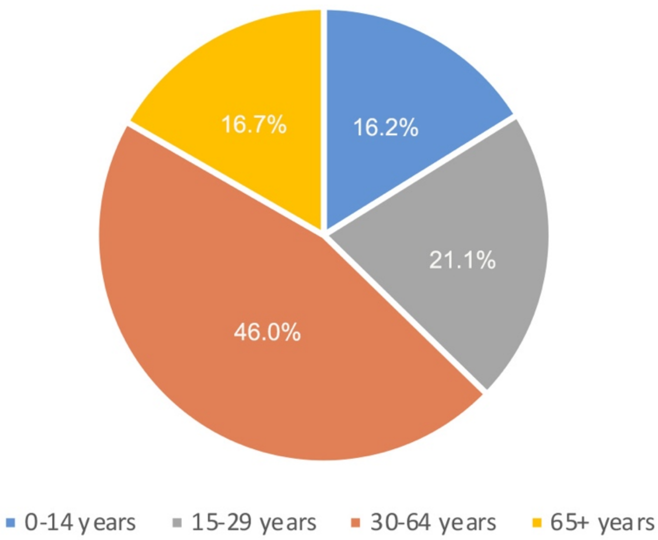

Figure 1-13 The age group in Ghent (Statistics Belgium, 2019)

The nationality composition is predominantly Belgium (85.2 %), followed by the EU (8.8 %) with a small number of Asia (3.8 %), Africa (1.5 %), and other/unknown nationality (0.7 %) in 2019 (Fig. 1-14).

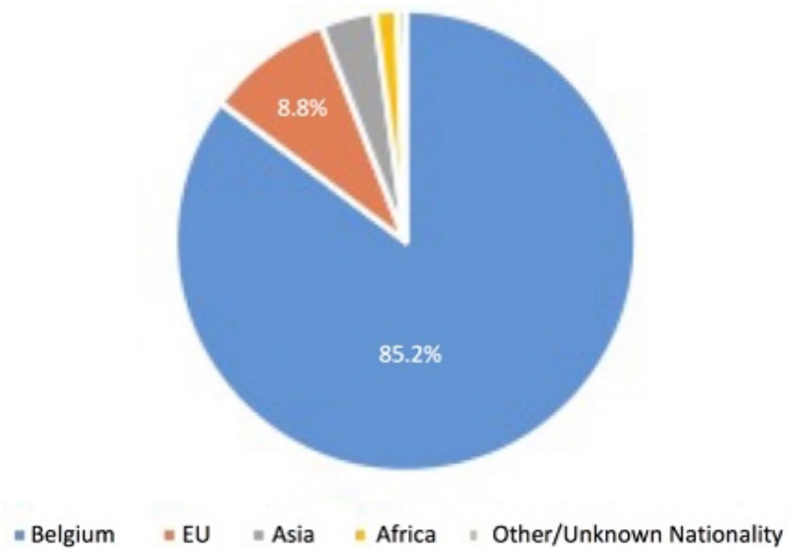

Figure 1-14 The Nationality composition in Ghent (Statistics Belgium, 2019)

Ghent is highly urbanized with a high density of buildings and hard paving. Around 46 % of the soils are covered with buildings or paving in Ghent. Downtown, the surface hardening rate is even higher than 80 % (Ghent Administration, 2016). As shown in Fig. 1-15, the existing green structure in Ghent is characterized by large concentrated natural and open areas in the southwest and northeast suburban areas. The green areas are relatively smaller in downtown areas (Groendienst Stad Gent, 2012).

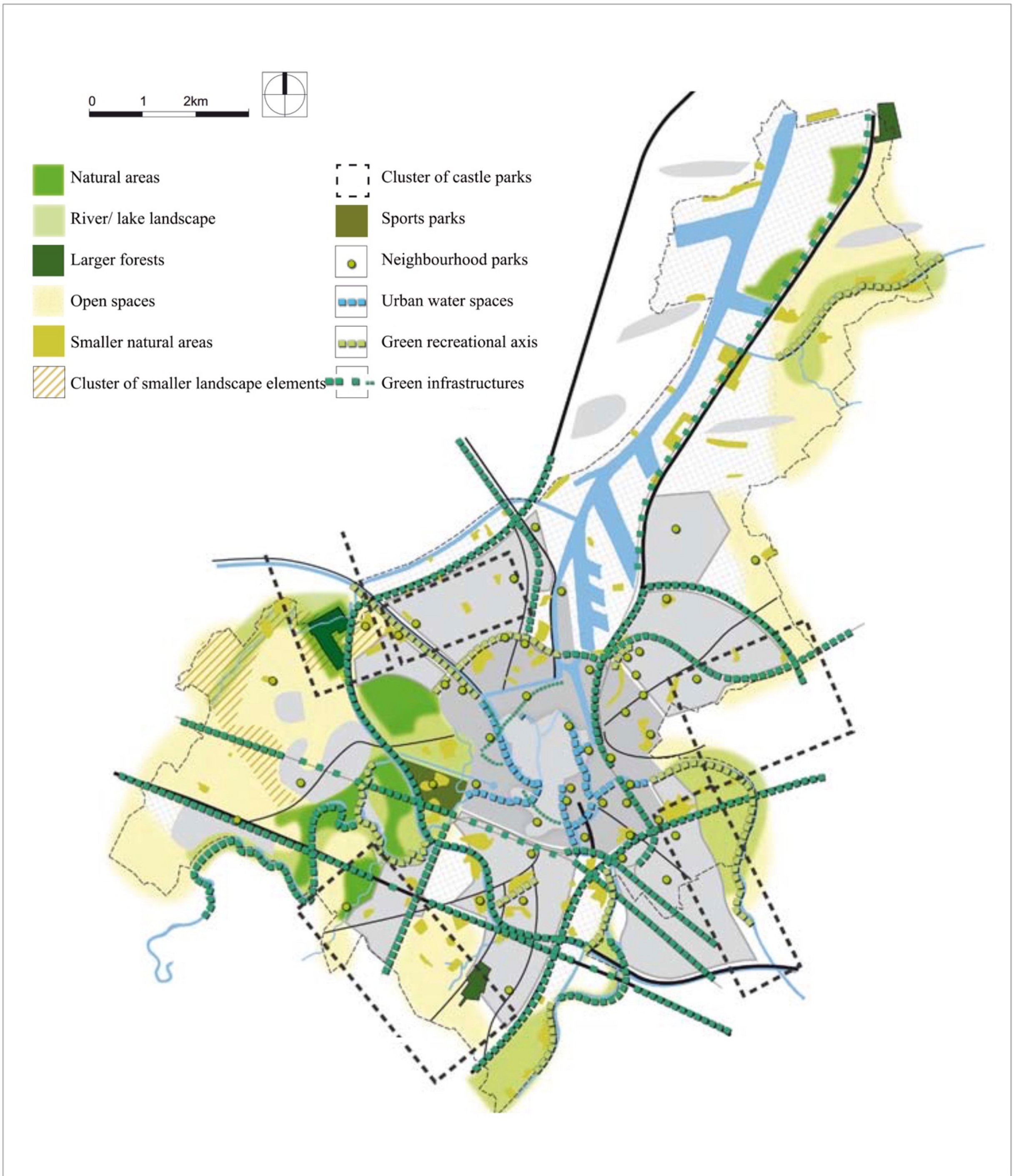

Figure 1-15 Existing spatial green structure in Ghent, source: Groendienst Stad Gent, (2012)

The existing green areas in Ghent are relatively fragmented (Fig. 1-16). The western outskirts of Ghent, the Gentbrugse Meersen-Dam valley, the Scheldemeersen and the castle park site in Zwijnaarde have large, unfragmented green areas. The north of Ghent is dominated by the harbor located around the canal Ghent-Terneuzen, with a lot of agricultural lands. The eastern outskirts of the city are characterized by highly fragmented outskirts of the town with remnants of agricultural land and parks. Finally, the build-up city center (grey color) is visible, intersected by linear green elements along with the infrastructures and water (Groendienst Stad Gent, 2012).

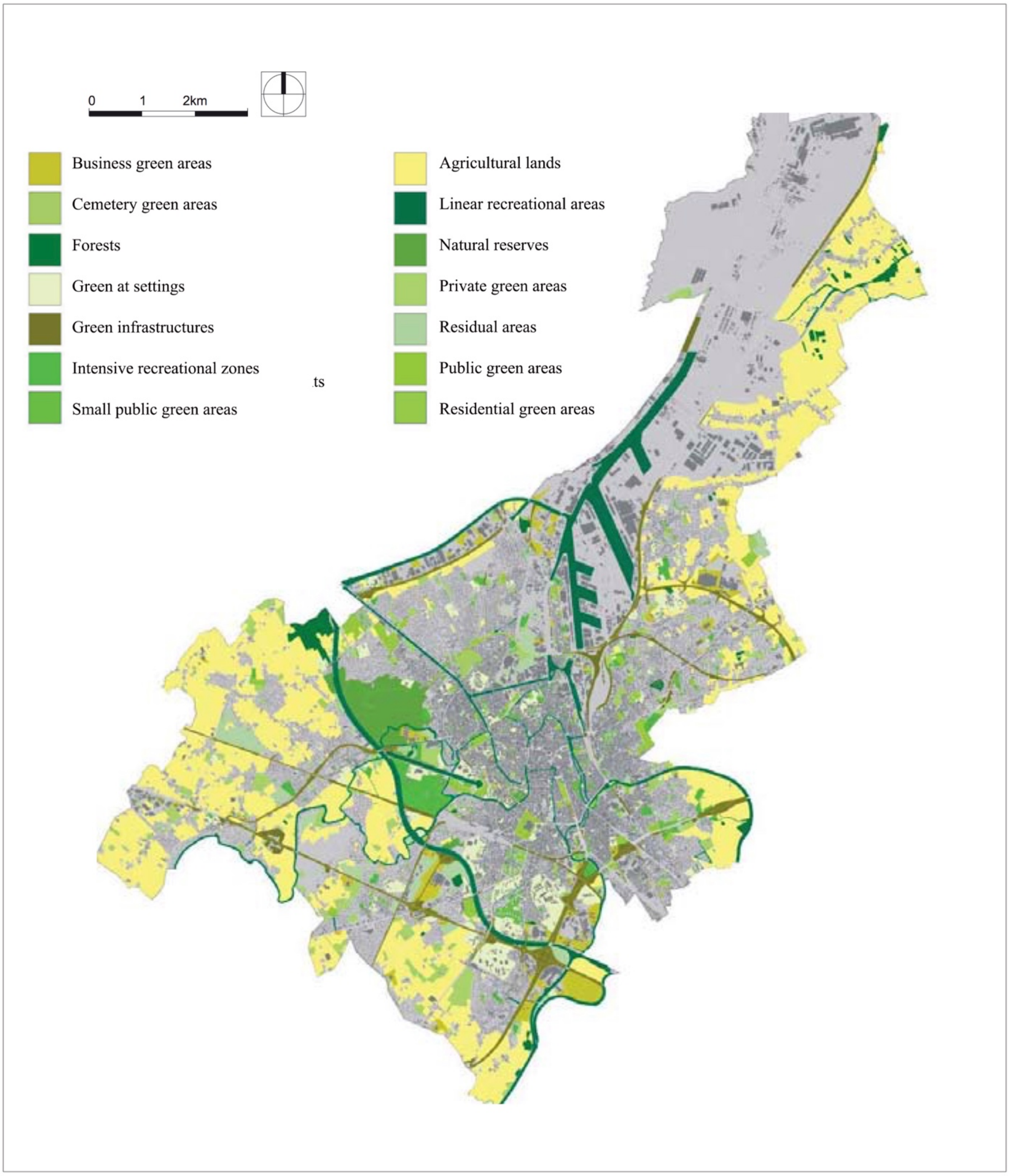

Figure 1-16 Existing green space map according to the use in Ghent, source: Groendienst Stad Gent, (2012)

5.2 *Urban water issue*

The water system in Ghent is characterized by human manipulation and consists of canals and locks. The canals and locks ensure that the water level in the center of the city could be kept on an artificially fixed level. The Lys and upper Scheldt rivers provide a large water proportion. The construction of the Ringvaart began in 1950 and was officially inaugurated in 1969. The Ringvaart canal distributes the water flow from the Lys and Scheldt rivers across the outflowing axes. These outflowing axes are the Ghent-Ostend canal, Ghent-Terneuzen canal, Schipdonk canal, and the lower Scheldt or sea Scheldt. Two-thirds of the water flow from the Lys river is diverted away from Ghent via the Lys diverting canal (*Afleidingskanaal*) near Deinze and one-third of the water flow directly goes towards the Ringvaart (Fig. 1-17). The water volume flows from the Lys and Upper Scheldt rivers are primarily determined by the precipitation in Northern France and Wallonia. The constructed canal system of the Ringvaart diverted the water around the city, keeping the city center safe from fluvial flooding (virtually at all times). The elevated water levels do cause flooding from the Lys and upper Scheldt rivers in parts of the city outside the Ringvaart canal. The areas of Zwijnaarde, Sint-Denijs-Westrem, Afsnee, Gentbrugge, Drongen, Mariakerke, and Wondelgem may suffer from fluvial flooding (Ghent Administration, 2016).

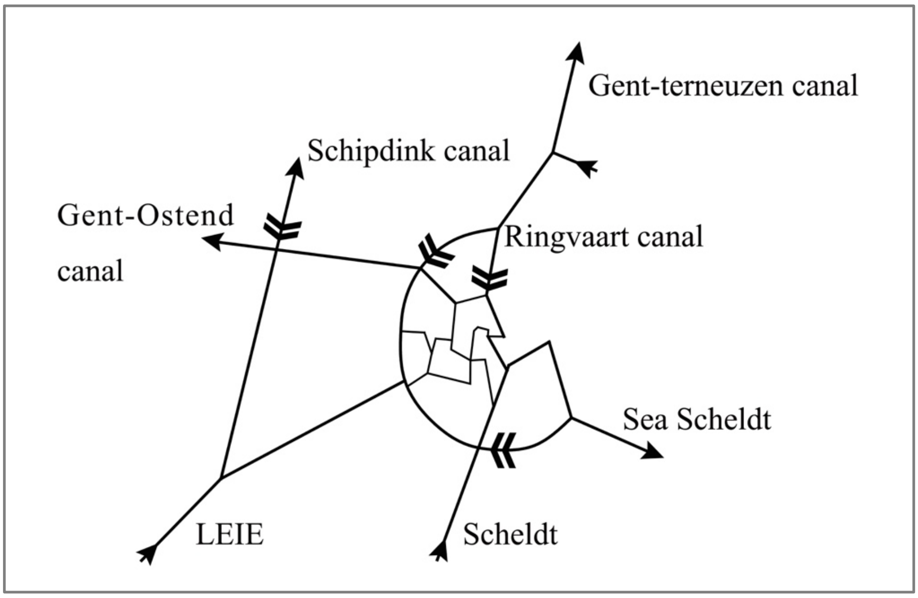

Figure 1-17 The water system in Ghent (sources Ghent Administration, 2016)

In 2015, the city of Ghent analyzed the water network, water nuisance and vulnerability. The water nuisance includes two types: water nuisance from waterways after intensive precipitation that exceeds the capacity of the riverbed (fluvial flood) and water nuisance from sewers after extreme showers (pluvial flood), a phenomenon that is more typical during the summer period. The results indicate that the center is well-protected against river nuisance due to the canal systems in and around Ghent. The most frequent form of water nuisance in the city is water flowing onto the streets (Ghent Administration, 2016). In certain areas, the sewer systems are unable to cope with the precipitation when the intensity of the showers is too large. When intensive precipitation occurs, the drainage system is not able to cope with the amount of water, which will result in surface water flooding. This is a typical summer phenomenon: a vast amount of precipitation in a short amount of time. According to the climate adaptation plan 2016-2019 of Ghent, a large portion of sewers would cover flood in case of a T20 (statistically occurs once every twenty years) rain shower. The areas of Ledeberg, Gentbrugge, Sint-Amandsberg, and Oostakker are the most sensitive to water on the street (Fig. 1-11). In Sint-Amandsberg and Oostakker, 44 percent of the sewers would cover floods in case of a T20 rain shower (Ghent Administration, 2016).

5.3 *Climate adaptation plan in Ghent*

Climate change hits cities in Flanders. Ghent is one of such cities. Heat waves, prolonged bouts of winter precipitation, and extreme summer storms entail risks. The MIRA climate report shows that the annual average precipitation is 13 % above the level at the beginning of the measurements in 1833. The number of days with heavy precipitation in Flanders has increased from 3 to 6 (days) per year since the early 1950s (Flanders Environment Agency, 2015). The climate forecasts indicate that intense summer rain showers will become more frequent in Ghent and a rain shower that currently occurs every 20 years will in the future perhaps once every 5 or 2 years (Ghent Administration, 2016).

In the framework of the urban water issue and climate change, a better water management has been one of the most important goals of Ghent (Ghent Administration, 2016). Ghent has already highlighted the need for urban design elements of green infrastructure against water nuisance, such as bio-swales, rain gardens, wetlands, etc. Ghent was also one of the first cities in Flanders to sign the 'Mayors Adapt', the European Covenant of Mayors, in 2014. The 'Covenant of Mayors Initiative on Climate Change Adaptation' or in short 'Mayors Adapt' was launched by the European Commission for climate adaption in March 2014 (European Commission, 2014). The European Commission is conscious about the vulnerability of the cities and seeks to enhance the resilience of the European cities to cope with the consequences of climate change. The efforts for making the city climate-robust should be seen as a major part of future planning. This adaption plan takes measures by eliminating impervious surfaces, retaining water and allowing it to infiltrate. With this initiative, Ghent committed to develop a climate adaptation strategy and to draw up an action plan with measures to adapt the urban environment to climate change, e.g. green climate axes (Fig. 1-18) (City Council, 2014). The green climate axes are long, continuous lines where greenery, open water and unpaved space take precedence (Delva Landscape Architecture, n.d.). 'Greening' the city is an essential principle of a climate-robust city. The proposed adaptations focus on four aspects, i.e. more green areas, more space for water, prevention of soil sealing and maximization of the city's sponge effect.

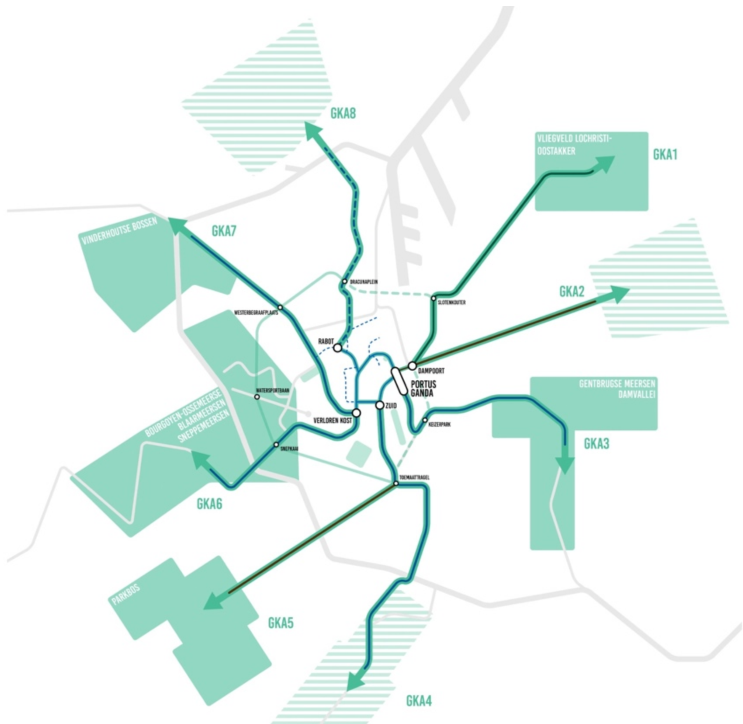

Figure 1-18 The eight green climate axes of Ghent (Source: Delva Landscape Architecture, n.d.)

The city of Ghent has highlighted the necessity to maximize the city's sponge effect. The term 'sponge effect' refers to the local catchment, retention, re-usage, infiltration of buffering and delayed the drainage of rainwater (Ghent Administration, 2016). This means there will be no drainage of rainwater under normal circumstances but that all rainwater from the buildings and hardened surfaces is treated on-site, i.e. locally retained, used, or gradually returned to the surrounding nature via the above-ground infiltration solutions. The city of Ghent focuses on four points to maximize the sponge effect, i.e. (1) fewer hardened surfaces; (2) water-permeable surface hardening in car parks, driveways, residential plots and alleys without heavy transport; (3) green footpaths; (4) infiltration solutions, i.e. bio-swales, bio-retention etc. with a preference for above- ground systems as they are more natural and accessible for maintenance. It is important that these greening measures regarding climate adaptation are integrated into the city planning and implementation processes.

6 Structure of the dissertation

The dissertation is organized into three main parts, i.e. to investigate the challenges and issues of green infrastructure planning (chapter 2); to provide insights for a better understanding of the landscape patterns and stormwater runoff reduction capacity of the existing green infrastructure (chapter 3); to develop a planning approach to identify the priority sites for green infrastructure and provide green infrastructure technologies recommendation on suitable sites (chapter 4 and 5) (Fig. 1-19). This dissertation has six chapters.

Chapter 1 deals with the introductory part of the dissertation. This chapter explains the research background, problem statement, concepts, research questions and objectives as well as an introduction to the case study of Ghent.

Chapter 2 conducts a content-based evaluation of the Sponge City plans in eight selected pilot cities in China. The evaluation criteria include five groups: goals (4 criteria), participation (3 criteria), strategic planning (2 criteria), design principles (3 criteria) and policies (2 criteria). This chapter explains the issues on the planning practices of green infrastructure and provides suggestions for the future up-scaling of the green infrastructure implementation for other cities.
This chapter has been submitted to the Journal of Urban Planning and Development (Luyuan Li, Pieter Uyttenhove, Veerle Van Eetvelde, Xin Cheng, Xueying Tu, Diechuan Yang. The challenges of the planning and design practices of Sponge City plans - a case study of eight pilot cities in China, Journal of Urban Planning and Development).

Chapters 3 to 5 use the case of Ghent to explore the different research objectives as described above.

Chapter 3 assesses the runoff reduction capacity of different types of existing green infrastructure, i.e. forests, grasslands and agricultural land, in the city of Ghent. An empirical model from Zhang, Xie, Li & Wang (2015) was adapted to estimate the runoff reduction capacity on a local scale. The model includes two determinants, i.e. the runoff coefficient and landscape pattern metrics. The results provide the spatial distribution of the runoff reduction capacity of the existing green infrastructure. The study provides potential runoff reduction capacity improvement through green infrastructure management, i.e. by increasing the ratio of the high capacity of green infrastructure type or to increase the aggregation and connectivity degree of the specific green infrastructure type.
This chapter is published by the International Journal of Sustainable Development & World Ecology (Luyuan Li, Veerle Van Eetvelde, Xin Cheng, Pieter Uyttenhove (2020), Assessing stormwater runoff reduction capacity of the existing green infrastructure in the city of Ghent, International Journal of Sustainable Development & World Ecology, https://doi.org/10.1080/13504509.2020.1739166)

Chapter 4 develops a methodology to identify the priority sites for the green infrastructure implementation to mitigate the urban surface water flooding risk. This chapter introduced a GIS-based multi-criteria evaluation method and aims to improve the urban sustainability and resilience against the urban surface water flood risk. The model includes five criteria, i.e. the stormwater runoff mitigation, social flood vulnerable group protection, flood sensitive area road infrastructure protection, flood sensitive area building protection, and environmental justice. The priorities of the five criteria are defined by the Analytic Hierarchy Process. The mapping results can facilitate planners to locate green infrastructure measures in the areas that are in need of those regarding the urban surface water flooding risk mitigation.
This chapter is published in Landscape and Urban Planning (Luyuan Li, Pieter Uyttenhove, Veerle Van Eetvelde (2020), Planning green infrastructure to mitigate urban surface water flooding risk - A methodology to identify priority areas applied in the city of Ghent, Landscape and Urban Planning, https://doi.org/10.1016/j.landurbplan.2019.103703).

Chapter 5 investigates the existing green action projects through comparing the green action projects of Ghent (2010) with the mapping results of priority neighborhoods to mitigate the urban surface flooding risk (chapter 5). The chapter analyzes to what extent the current green action projects fulfill the needs to mitigate the urban surface water flooding risk.

Two projects, i.e. Baudelohof and Rijsenbergpark, located in high priority neighborhoods (identified in chapter 4) are selected as case studies to provide potential green infrastructure technologies recommendation at neighborhood scale. The study also maps the neighborhoods in need of green infrastructure (but where currently no green action projects are being planned).

Chapter 6 presents the general discussion and conclusion part of the dissertation. This chapter also contains possible future investigations.

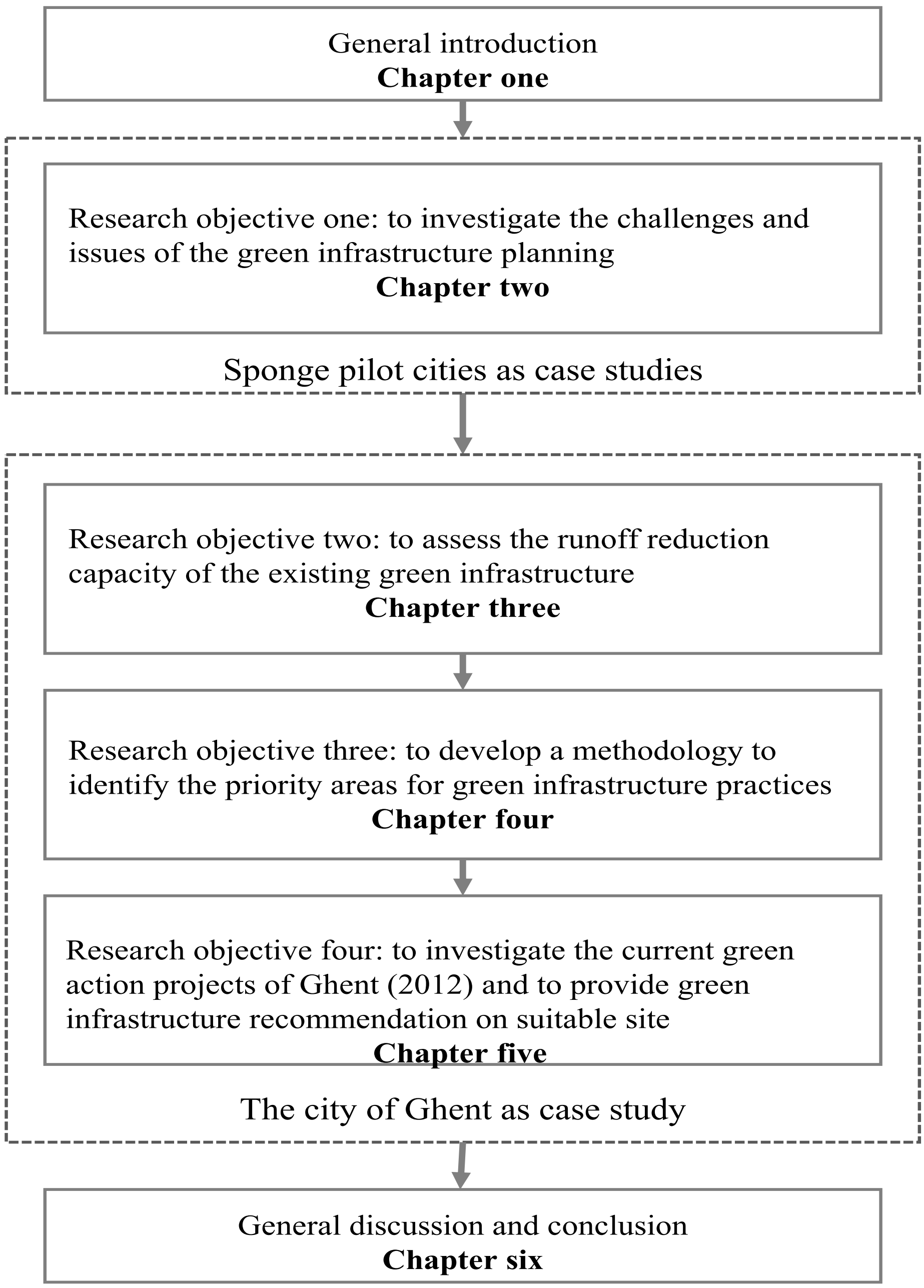

Figure 1-19 Summary of the dissertation outline

Table 1-3 shows the overview of the datasets used in this PhD study.

Table 1-3 Overview of the datasets (The '' marked the datasets used in the chapter)*

Dataset	**Organization**	**Data date**	**Format**	**Data location URL**	**Chapter**		
					3	**4**	**5**
Land cover data	Flanders Information Agency	2012	shapefile	https://www.geopunt.be/over-geopunt/bronnen	*		
Basic map-GRBgis	Flanders Information Agency	2017	shapefile	http://www.geopunt.be/catalogus/datasetfolder/7c823055-7bbf-4d62-b55e-f85c30d53162		*	*
Regional plan	Flemish Planning Agency for Environment	2014	shapefile	http://www.geopunt.be/catalogus/datasetfolder/0e7f5e73-df16-43b2-9c82-03a4f429d84a		*	
Flood-sensitive areas	Flanders Information Agency	2017	shapefile	http://www.geopunt.be/catalogus/datasetfolder/f5b2c84c-0d78-4efa-a97d-7cd172726572		*	
Statistical sector	Flanders Geographic Information Agency	2011	shapefile	http://www.agiv.be		*	

Chapter 2 The challenges of green infrastructure planning and design - a case study of eight sponge pilot cities in China

1 Introduction[1]

Urban flooding is a serious global phenomenon that causes widespread devastation and economic damage (Ramos, Creutin & Leblois, 2005; Pitt, 2007; Baldassarre et al., 2010; Jha, Bloch & Lamond, 2012). Over the past several decades, the negative impact of flood events, especially urban waterlogging events, have affected many cities across the world, such as New York and London in developed countries as well as Beijing, Wuhan and Bangkok in the developing countries (Pitt, 2007; Vinet, 2008; Barredo, 2009; Yin, Yu, Yin, Liu & He, 2016). China is the most affected country concerning flood events in Asia, followed by India, Indonesia and Bangladesh (Jha et al., 2011). According to the flood investigation report of the Ministry of Housing and Urban-Rural Development, 62 percent of the 351 investigated cities in China suffered from urban surface waterlogging, of which 137 cities underwent flood events (more than three times from 2008 to 2010) (W. Wang, Chen, Liu, & Wei, 2012). The direct economic losses of these flood events reached \$50.5 billion (Xu, Li, Zhang & Du, 2016). The urban flood issues in many Chinese cities will continue to increase due to the urbanization trend, demographic growth, and climate change (Jiang, Zevenbergen & Ma, 2018). According to the sixth census in 2010 in China, the urbanization rate amounts to 49.68 % and still evolves in rapid growth. The population base in China is large with 666 million people living in the city areas. The urbanization rate will approach 70 % by 2050, which means that there will be nearly 1.1 billion people living in the urban areas (Wu, 2011). The rapid urbanization and intensive constructions in China have resulted in a high rate of impervious surface, which will increase the volume and velocity of the surface water runoff and thereby the probability of the flood events (Arnold & Gibbons, 1996). Next to urbanization, climate change is another driving factor that increases the flood hazards across China (Duan, He, Nover & Fan, 2016). The long-term changes in extreme precipitation in both frequency and intensity have been observed during recent decades, thereby boosting flood hazards in many cities across China (Ding et al., 2007; Fan & Chen, 2016). Even

[1] *This chapter is modified from Li, L., Uyttenhove, P., Van Eetvelde, V., Cheng, X., Tu, X., Yang, D., The challenges of planning and design practices of Sponge City plans- a case study of eight pilot cities in China. Journal of Urban Planning and Development (Submitted)*

though the extensive construction of a centralized grey infrastructure (human-engineered and centralized system), such as pipes, pumps, ditches, detention ponds and drainage and sewer systems, many cities across China remain vulnerable to surface water flood risks due to the urbanization trends and climate change (Wang, Sun, & Song, 2017). Hence, relying solely on a centralized grey infrastructure is not sufficient, it is rather urgent to find effective supplementary ways to cope with these increasing risks (Dong et al., 2017; Liu & Jensen, 2018).

In the framework of the current climate change and the impact of the frequent urban flood events, China has established the nationwide Sponge City policy in 2014. The latter was issued by China's Ministry of Finance, Ministry of Housing and Urban Construction and Ministry of Water Resources (Ministry of housing and urban-rural development, 2014). Sponge City policy is a nationwide initiative intended to cope with serious urban waterlogging issues in China. Sponge City vividly illustrates a system that adopted ecological measures in greening the grey infrastructure to capture, control and re-use the stormwater cost-effectively and sustainably (Liu, Jia & Niu, 2017). The 'green' refers to green infrastructure, e.g. green roof, bio-retention cell, permeable pavement etc., while the 'grey' means grey infrastructure, e.g. pipes, pumps, ditches, and drainage and sewer systems (Qiao, Liao, & Randrup, 2020). For instance, bio-retention cell is designed with an underdrain to connect to the drainage system. A bioretention cell is vegetated with a variety of species. The vegetative depression allows rainwater to be retained at the cell surface before it infiltrates through an underlying bioretention layer (Paus & Braskerud, 2014). The primary goal of the Sponge City is to eliminate waterlogging by retaining 70 % - 90 % of the average annual rainwater on-site by applying green infrastructure (Li, Ding, Ren, Li & Wang, 2017).

The governance of the Sponge City implementation is a top-down administration among governments on different levels (Fig. 2-1). The political system in China is organized according to a hierarchy in which local governments are supposed to implement the decisions made by the central government (Dai, Rijswick, Driessen, & Andrea, 2018). The Sponge City plan is initiated and evaluated by the central government and implemented on a local level. The respective municipality is responsible for the planning and construction of the sponge City projects on a city level. Governments on local administrative levels are responsible for the implementation, mobilization, organization and coordination of the Sponge City (Jiang, Zevenbergen, & Fu, 2017). The local government has allocated the responsibility for the

Sponge City implementation to many different departments, including the Water Affairs Bureau, Municipal Construction Commission, Municipal Planning Bureau, Municipal Finance Bureau, etc. (Dai et al., 2018).

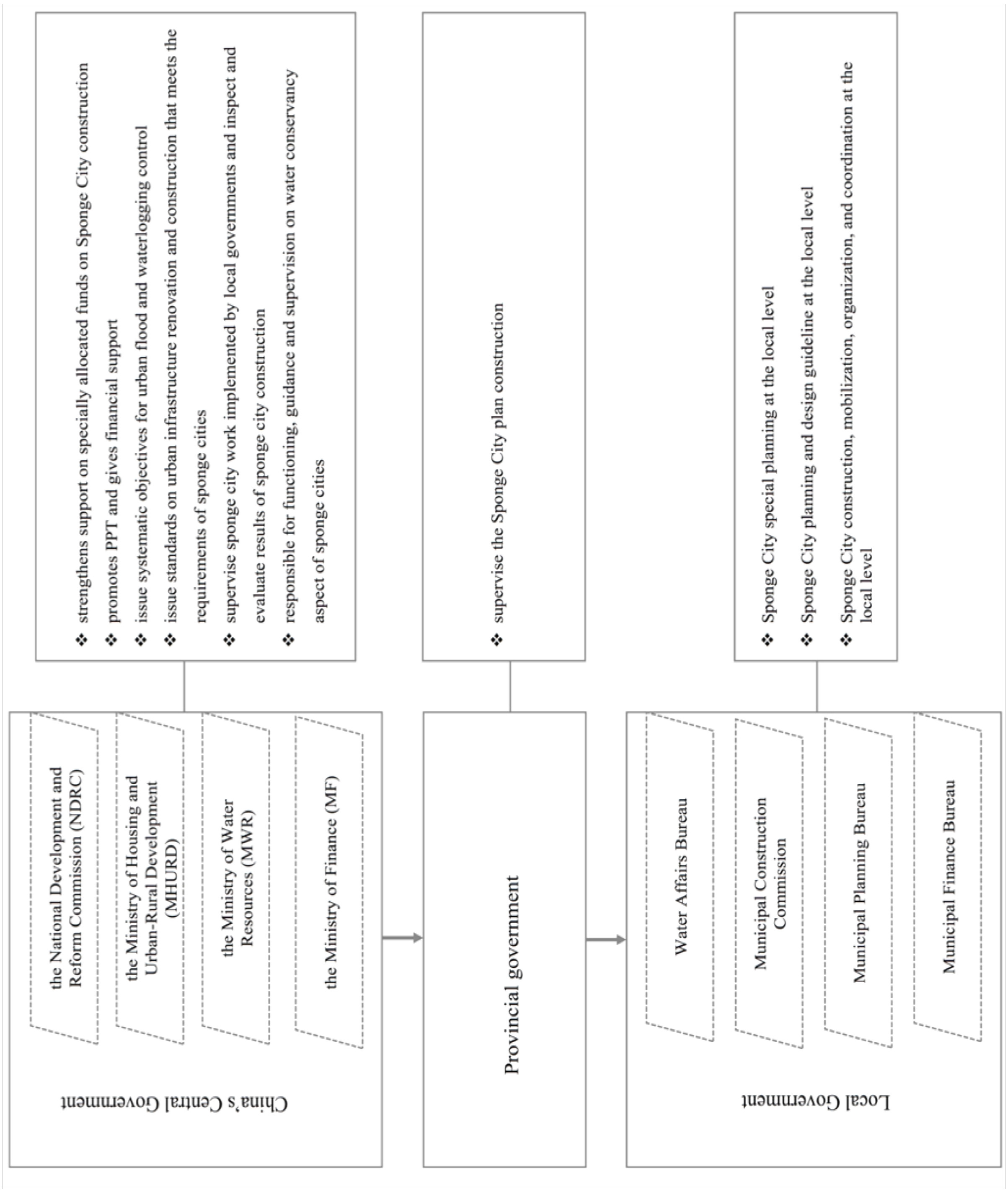

Figure 2-1 The Governance of the Sponge City Implementation, source: Dai et al., (2018)

The evaluation system is the central government's main mechanism to ensure the implementation of the Sponge City on a local level. The provincial government will closely supervise the Sponge City implementation and the government officials will be held accountable if the implementation process would be delayed. The local municipal government must sign a responsibility statement with the provincial government. Using this supervision system, the central and the provincial government can ensure the Sponge City implementation on the local level (Dai et al., 2018).

With the establishment of the nationwide Sponge City policy, the central government issued thirty cities respectively in 2015 and 2016 to explore and carry out the Sponge City plans, including the megacities of Beijing, Shanghai and Shenzhen (Fig. 2-2). Xia et al. (2017) indicated that the Sponge City plans are a breakthrough for the urban planning in China, as a policy to enhance the urban sustainability and resilience and to integrate the urban water management into the land use development on a metropolitan scale. Despite the implementation in these pilot cities, the green infrastructure planning and design of Sponge City is still in an exploratory stage. In the context of the green infrastructure planning, goals like the stormwater runoff mitigation and quality improvement have been considered as principles to transform the land use practices towards more sustainable ones. Kuller et al. (2017) suggested that a good planning practice of the green systems should be regard green infrastructure technologies as an integral part of the urban form, which considers the green infrastructure technologies as a location choice (based on a solid dataset). The design practice is the on-site level following the planning. The design guideline includes three components: 1) the types of green infrastructure technologies; 2) the design principle of each type of green infrastructure technologies (the spatial suggestion to integrate these technologies into the local buildings, roads, open spaces and waterways); 3) examples of the spatial layout of green infrastructure technologies into local buildings, or roads, or waterways.

China has followed the strategy of "learning by doing" and thus those thirty pilot cities allow lessons and experiences for the green infrastructure planning and design for sustainable water management in other world cities (Jiang et al., 2018). Though large scales of attempts and practices have been carried out in many cities across China, insufficient attention was paid to the experimentation-based learning via pilot cities. There are some studies (Li et al., 2017; Jiang et al., 2018) that analyzed the Sponge City plans from aspects such as policy initiatives, governances, implementation challenges, etc. For instance, Li et al. (2017) surveyed the obstacles of the Sponge City construction in China from a technical, physical, regulatory and financial, public acceptance to the inter-agency cooperation and data sharing. Jiang et al. (2018) reviewed the challenges, such as the technological complexity, governance capacity and financial issues faced by China in addressing the urban pluvial flooding with a particular eye on the policy initiative called Sponge City. However, these studies do not specifically relate to planning or design aspects, while the quality of the planning and designing process ultimately determines the implementation and success of the Sponge City systems. Opportunistic green infrastructure planning leads to unintentional outcomes that fail to locate the green infrastructure on the location where it is needed the most and provides the full potential of the green infrastructure benefits (Kuller et al., 2018). Researches from the planning and designing aspects to evaluate the sponge city plans are scarce. The research involved in the planning and designing aspect of the urban water management remains underexposed (Kuller, Bach, Ramirez-Lovering & Deletic, 2017). The uncertainties in green infrastructure planning and design are serious problems that could trigger the failure of sustainable water management (Nguyen et al., 2019). As a result, Sponge City might be a technologically optimized system that fails to plan in the most priority areas and delivers potential services due to weak planning and design.

Recognizing the significant important of the green infrastructure planning and design and the knowledge gap (meaning that insufficient attention has been paid to this aspect), this chapter aims to provide more information regarding the green infrastructure planning and design of Sponge City by establishing a content-based evaluation of the Sponge City plans in eight selected pilot cities based on a list of criteria (Table 2-3). The assessment of the Sponge City plans consists of (1) the evaluation of the Sponge City planning and (2) the evaluation of the Sponge City design guidelines. This study will contribute to the understanding of the planning and design of green infrastructure, from which experiences and lessons could be drawn for other cities and could facilitate future quantitative and qualitative sustainable water management planning.

2 Data collection of eight pilot cities

In total, there are 30 'Sponge City' pilot cities issued respectively in China in 2015 and 2016 (Fig. 2-2). As not all the original Sponge City plans or related documents of all the thirty pilot cities were accessible for this study, the cities with a key updated planning and designed documents or related material of the Sponge City special planning will thus be selected as sample cities. After a preliminary review of the open sources and literature, eight cities have been selected, namely Wuhan, Shenzhen, Zhuhai, Pingxiang, Hebi, Nanning, Chongqing, Ningbo in order to review and evaluate their Sponge City plans. The location of the sample cities is shown in Fig. 2-2.

Figure 2-2 Spatial distribution of the sponge pilot cities. The bigger red dot refers to the selected pilot cities from 2015 to be evaluated and the smaller red dot refers to the selected pilot cities from 2016 (to be evaluated)

The eight sample cities represent a broad geographic distribution across China which are also renowned for their Sponge City planning experiences. Literature was obtained and collected from different sources, including the official city planning website of the pilot cities, published plans, documents, and researches. A list of key plans or related documents of sample cities reviewed in this chapter is shown in Table 2-1. There are two types of key documents: (a) a planning document that is describing the general strategy of the Sponge City and how it is applied to the pilot city and (b) a designed document explaining the design principles and the manner in which the Sponge City plan is implemented.

Table 2-1 Reviewed (a) planning and (b) designed documents of the sample cities

Cities	**Reviewed planning and designed documents**	**(a)**	**(b)**	**Comments**
Wuhan	- Wuhan Sponge City special planning (Wuhan Bureau of Land Resources and Planning & Wuhan Planning Institute, 2016) - Wuhan Sponge City planning and design guidelines (Wuhan Water Authority, 2015)	X (x)	 X	Full original documents
Shenzhen	- Shenzhen Sponge City Special Planning and Implementation Plan (Shenzhen Planning and Land Resources Committee, 2016) - Shenzhen comprehensive technical specifications of the Low impact development (Shenzhen Water Authority, 2015) - Guidelines for the Shenzhen Spongy Park and greenbelts' Construction (Shenzhen City Authority & Shenzhen Forestry Bureau, 2016)	X	X X	Full original documents
Zhuhai	- Zhuhai City River and Lake Water System Low Impact Development Special Plan (Guangdong Institute of Water Resources and Hydropower Research, 2016) - Zhuhai Sponge City Drainage Special Planning (2015-2020) (Zhuhai Planning and Design Institute, 2016) - Zhuhai Sponge City Planning and Design Standards and Guidelines (Zhuhai Housing and Urban-Rural Planning and Construction Bureau, 2017)	X X X	 X	Full original documents

Pingxiang	- Pingxiang Sponge City Planning and Design Guidelines (Pingxiang City Planning Bureau, 2015)	X	X	Full original documents
Hebi	- Hebi Sponge City Planning and Implementation Guideline (Hebi Government, 2015b)	X	X	Full original documents
Nanning	- Experience of the Sponge City Master Plan: A case study of Nanning city (W. Zhang et al., 2016); - Nanning Sponge City Planning and Design Guidelines (China Urban Planning and Design Institute, 2015)	X (x)	X	Secondary data research papers on the Sponge City planning (but the research clearly indicates the planning goals, methods, figures, data); Full original of the technology guidelines
Chongqing	- Chongqing Changshou District Sponge City Special Planning Figures (2016-2025) (Chongqing Changshou District Planning Bureau, 2017) - Chongqing Sponge City Planning and Design Guidelines (Chongqing Urban and Rural Construction Committee, 2016)	X (x)	X	Sponge City planning original figures (indicates the planning approach, data); Full original of the technology guidelines
Ningbo	- Ningbo Sponge City Special Planning (2016-2020) (Ningbo government, 2016) - Ningbo Sponge City Planning and Design Guidelines (Ningbo Housing and Urban-Rural Development Committee, 2017)	X (x)	X	Part of the Sponge City planning; Full original of the technology guidelines
X - fully indicate the marked plan type; (x)-small part of the documents indicates the marked plan type				

Though this study does not evaluate all pilot cities, the sample of eight cities varies in size, climate, various water system characteristics and economic and demographic situations, which are sufficient for the objective of this study. The basic description of the eight selected cities is shown in Table 2-2.

Table 2-2 Sample cities' profile and a basic description of the urban characteristics and climate conditions

Cities	**Municipal area (sq. km)**	**Municipal population (* 1,000 persons)**	**Population density (person/ sq. km)**	**(a) Urban characteristics and (b) climate conditions**
Wuhan	8,569.2	10,760.6	1,256	(a) Located at the confluence of Hanshui and

				Yangtze rivers; the urban areas are dominated by plains with a small number of hills; a great number of lakes and ponds within the city; one of the four “Furnace Like” cities (b) Precipitation 1,315 mm per year, urban waterlogging issues, water pollution, heatwaves
Shenzhen	1,997.3	11,900.8	5,962	(a) Located within the Pearl River Delta; bordering Hong Kong to the south; the terrains of Shenzhen are relatively high in the southwest and low in the northwest and most of the areas are low hills with some tablelands, the west areas are the coastal plains; over 160 rivers or channels flow through Shenzhen (b) Precipitation 1,970 mm per year, urban waterlogging issues
Zhuhai	1,732.3	1,670.5	967	(a) Located within the Pearl River Delta; bordering Macao on the south; the urban areas are mainly composed of hills, plains, sea-beach wetlands and low mountains (b) Precipitation 1,831mm per year, urban waterlogging issues
Pingxiang	3,831.0	1,910.4	499	(a) A bordering city between Jiangxi and Hunan provinces; the urban areas are relatively flat and most areas around the city are hilly and mountainous (b) Precipitation 1,569 mm per year, urban waterlogging issues, water scarcity
Hebi	2,182.0	1,631.0	751	(a) Situated in mountainous terrains at the edge of the Shanxi plateau; the urban areas are located in the hilly area and the terrain is relatively flat (b) Precipitation 559 mm per year, urban waterlogging issues, water pollution, water scarcity
Nanning	22,112.0	7,060.2	319	(a) Located in southern China near the Vietnam border; situated in a hilly basin and the Qingxiu Mountain dominates the southern part of the city; known as the "Green City" because of its abundant parks with a tropical lush green landscape (b) Precipitation 1,310 mm per year, urban waterlogging issues

Chongqing	1,494.5	30,480.4	369	(a) Situated at the transitional area between the Qinghai-Tibet Plateau and the plain on the middle and lower reaches of the Yangtze Rivers; the central urban area is built on mountains and partially surrounded by the Yangtze and Jialing river, with a unique spatial structure known as "mountain city" and a "city on rivers"; one of the "Three Furnaces" of the Yangtze River, along with Wuhan and Nanjing (b) Precipitation 1,108 mm per year, urban waterlogging issues, heatwaves
Ningbo	9,817.0	5,901.0	602	(a) A major port and industrial hub located in east China; the city is sandwiched between the ocean and low-lying mountains to the southwest with coastal plain and valleys in between (b) Precipitation 1,400 mm per year, urban waterlogging issues, heatwaves.

Data sources: Wuhan Statistical Yearbook (Wuhan Statistic Bureau, 2017); Shenzhen Statistical Yearbook 2017 (Shenzhen Statistics Bureau, 2017); Zhuhai Statistical Yearbook 2017 (Zhuhai Statistic Bureau, n.d.); Pingxiang Population 2016 (Pingxiang Government, 2017); Pingxiang City Profile (Pingxiang Government, 2015); Hebi National Economic and Social Development Statistics in 2016 (China Statistics Information Network, 2017); Hebi City Profile (Hebi Government, 2015a); Chongqing Statistical Yearbook 2017 (Chongqing Statistic Bureau, 2017); Guangxi Population Data (Gaungxi Statistic Bureau, 2017); Nanning City Profile (Nanning Government, 2015); Ningbo Statistical Yearbook 2017 (Ningbo Statistic Bureau, 2017); Wuhan City Profile (Han & Wu, 2004; “Wuhan City Profile,” n.d.); Shenzhen City Profile (“Shenzhen City Profile,” n.d.); Zhuhai City Profile (“Zhuhai City Profile,” n.d.); The Profile of Pingxiang (Pingxiang Government, n.d.); Hebi City Profile (Hebi Government, 2015a); Nanning City Profile (Nanning Government, 2015); Chongqing City Profile (Chongqing Government, n.d.); Ningbo City Profile (Ningbo Government, n.d.)

3 Method

A contents’ analysis was performed so as to evaluate the Sponge City plans of eight selected cities, based on a list of criteria as shown in Table 2-3. The set of criteria was adapted from Woodruff & BenDor (2016). Woodruff & BenDor (2016) developed the criteria which consist of four parts, i.e. the goal- setting, public participation process, fact base and policies, to evaluate the quality of the land-use planning that integrates the ecosystem services. The fact base has been adapted concerning two key components, i.e. the strategic planning and design principle. The strategic planning includes two criteria, developed from the researches of Kuller et al. (2017). Kuller et al. (2017) proposed that a good planning practice of the green systems should consider green infrastructure technologies as a location choice (based on a solid dataset). The suitable location for the green infrastructure technologies can be investigated with two groups of indicators, i.e. "green infrastructure technologies need a place" and "a place needs green infrastructure technologies", which highlight the reciprocal relation between the green system and the urban context. "Green infrastructure technologies need a place" represents the suitability of a location from the perspective of technological operations, such as the soil, slope, hydrology, land availability and development opportunity and constraints, etc. "A place needs green infrastructure technologies" represents the suitability of a location from the perspective of the areas that need green infrastructure technologies the most, such as flood hazard sensitive areas, water pollution, the presence of centralized drainage, population density, flood-prone areas buildings and roads concentrations etc. The design guidelines can be evaluated by three criteria: 1) have the types of green infrastructure technologies clearly defined? 2) has the design principle (spatial suggestion) of each type of green infrastructure technologies been provided? 3) Does the guideline include examples to explain the design principle or spatial layout to integrate these technologies into the local buildings, roads, open spaces, and waterways? Since this chapter mainly focuses on the planning and design aspects of green infrastructure, the criteria of the policy part are not included. Thus, the evaluation criteria set include four groups: goals (4 criteria), participation (3 criteria), strategic planning (2 criteria), and designing guidelines (3 criteria).

Table 2-3 Sponge City Plans' Evaluation Criteria (based on Woodruff & BenDor, 2016)

1. Goals: the plan should clearly identify and explain the desired Sponge City (planning and design) outcomes
1.1 Has the goal been defined?
1.2 Does the plan contain data/a statement/an analysis that represents the goals defined based on the analysis of an urban environmental, social and economic context (e.g. Urban location, natural geography, socio-economic status, precipitation, hydrology, water characteristics)?
1.3 Have synergies and trade-offs between different Sponge City planning goals (Sponge City technologies' functions) been discussed?
1.4 Has the methodology been adopted to define the synergies or trade-offs between the different Sponge City planning goals?
2. Participation: the plan should integrate public participation to communicate information and to solicit feedback

2.1 Has the plan been presented to the public (including objective information to assist problem understanding)?
2.2 Are the different land-use development scenarios being presented in the public participation process?
2.3 Does the participation process solicit public preferences and feedback?
3. Strategic planning: the plan should be built on a solid data foundation
3.1 Have indicators (e.g. the flood hazard sensitive areas, water pollution, the presence of centralized drainage, population density, flood-prone areas buildings and roads concentrations etc.) been identified concerning the locations that need green infrastructure technologies? 'Place need green infrastructure technologies'- factors determining the priorities of a location from the perspective of the 'needs' of a location. The indicators represent a primary objective of green infrastructure and the measures should be taken in the location that meets those criteria and which needs the water sensitive measures the most
3.2 Have indicators (e.g. the soil, slope, hydrology, land availability, development opportunity and constraint, etc.) for the location suitable for the green infrastructure technologies' implementation been identified? 'Green infrastructure technologies need a place'- factors determining the suitability of a location from the perspective of technological operations
4. Design guidelines: technical implementation
4.1 Have the types of green infrastructure technologies clearly been defined using text, graphs?
4.2 Have the design principle of each type of green infrastructure technologies been provided, e.g. water regulation benefits, plant ecophysiology and site requirements to provide the spatial selection of the technologies?
4.3 Does the guideline include examples to explain the designing principle and spatial layout to integrate the green infrastructure technologies into local buildings, roads, open spaces or waterways?

The evaluation of the Sponge City plans is organized based on four parts of the criteria as listed in table 3. The special planning documents are primarily used to analyze the goals and strategic planning. The designing guideline is mainly used for analyzing the designing guidelines. The information and data retrieved from open sources, such as the official city planning websites of the sample cities, news, Sponge City annual progress reports and literature are mainly employed to analyze the participation, policies and are also supplementary to other parts.

4 Results and Discussion

The evaluation results of each criterion (the manner in which they are reflected in the different sections of the Sponge City plans for the eight sample cities) are demonstrated in Table 2-4.

Table 2-4 Evaluation results of the eight sample cities

	Cities	Wuhan	Shenzhen	Zhuhai	Pingxiang	Hebi	Nanning	Chongqing	Ningbo
GOALS	1.1 Has the goal been defined?	*	*	*	*	*	*	*	*
	1.2 Does the plan contain statements/data/ graphs' analyses to define the goal?	□	■	⬕	X	■	⬕	□	□
	1.3 Have synergies and trade-offs between different Sponge City planning goals been discussed?	X	X	X	X	X	X	X	X
	1.4 Has the methodology been adopted to define the synergies or trade-offs between the different Sponge City planning goals?	X	X	X	X	X	X	X	X
PARTICIPATION	2.1 Has the plan been presented to the public?	◐	● ◭ (#)	●	○ ◭	◐ ▲ (#)	● ◭	●	○ ◭
	2.2 Are the different land-use development scenarios being presented in the public participation process?	X	X	X	X	X	X	X	X
	2.3 Does the participation process solicit public	X	#	X	X	X	X	X	X

	preferences and feedback?								
STRATEGIC PLANNING	3.1 Have indicators been identified concerning the locations that need green infrastructure technologies?	⬖	◆	◆	⬖	⬖	⬖	⬖	⬖
	3.2 Have indicators for the location suitable for the green infrastructure technologies' implementation been identified?	◈	◈	◈	◈	◈	◈	◈	◈
DESIGN PRINCIPLE	4.1 Have the types of green infrastructure technologies clearly been defined using text, graphs?	*	*	*	*	*	*	*	*
	4.2 Have the design principle of each types of green infrastructure technologies been provided?	*	*	*	*	*	*	*	*
	4.3 Does the guideline include examples to explain the designing principle and spatial layout to integrate the green infrastructure technologies	*	*	*	*	*	*	*	*

	into local buildings, roads, open spaces and waterways?								

X = No /Not discussed /No methodology adopted; * = Clearly defined/explained; # = Public suggestions adopted by the government; ■ = Contains text, data and graphs' analysis; ◩ = Contains text and data analysis; □ = Contains text analysis; ● = Online Publicity of Sponge City plans, documents and related constructions, 30 days; ◐ = Online Publicity of Sponge City plans, documents and related constructions, 10 days; ○ = No information available of online publicity; ▲ = Mass media (TV, newspapers, websites, newsletters and other forms) and data platform to educate the public of Sponge City strategy; ◭ = Data platform to educate the public of Sponge City strategy; (#) = Other forms of information communication, e.g. Sponge City management hearing, Sponge City construction forum; ◆ = Contains related indicators of flood sensitive area and water pollution areas' distribution and socio-economical related indicators (e.g. cultural heritage protection); ◐ = Contains related indicators of flood sensitive area and water pollution areas' distribution; ◈ = Contains biophysical related indicators

4.1 *Goals*

The goal setting includes four criteria (Table 2-3). The Sponge City plans of the eight selected pilot cities are investigated to check for each criterion in the goal setting part. For instance, the first criterion in goal setting is "1.1 Has the goal (of the green infrastructure planning) been defined?". The city of Shenzhen defined the goal of green infrastructure planning and written in the planning document as "in restoring the water ecology, improving the water environment, conserving the water resources and improving the water safety" (Shenzhen Planning and Land Resources Committee, 2016), then a '*' represents clearly defined (the goal of green infrastructure planning of Sponge City plan) is marked in the Table 2-4. The evaluation results of the goal settings (Table 2-4) indicated that all eight sample cities have defined the goal of the Sponge City plan. Two cities, Shenzhen and Hebi, contain statements, data and graphs to define the goal (based on the analysis of the urban environmental, social and economic context); two cities, Zhuhai and Nanning, contain text and data analysis, three cities, Wuhan, Chongqing, Ningbo, contain text analysis in their plans; One city, Pingxiang, defined the goals without indicating a comprehensive city analysis context in the planning documents.

According to the Sponge City planning documents, all eight sample cities have set the goal of Sponge City planning in restoring the water ecology, improving the water environment, conserving the water resources and improving the water safety. The Sponge City goal set in many pilot cities has been largely confined to the standardized national Sponge City policy. Li et al. (2017) indicated that the rapid implementation of Sponge City in many pilot cities with such ambitious goals is largely based on little local researches. Many pilot cities adopted the standardized and ambitious goals without considering the local water issues and urban characters. A cross-check with researches and national level datasets on the floods (EM-DAT, 2015; Sang & Yang, 2017), water quality (Zhou et al., 2017), heats (Dian-Xiu, Ji-Fu, Zheng-Hong, You-Fei, & Rong-Jun, 2014) and water scarcity (The Ministry of Water Resources of the People's Republic of China, 2016) of China revealed that all of the selected cities are located in regions affected by floods; two cities, i.e. Wuhan and Hebi are located in regions with a water quality level at (or lower than) level Three. The water quality is categorized into five types (I to V), ranging from good to poor according to the water quality standards (GB3838-2002) for surface water in China, as shown in Table 2-5 (Ministry of Environmental Protection of the People's Republic of China, 2002); three cities i.e. Wuhan, Chongqing, Ningbo, located in regions that were affected by heatwaves; two cities i.e. Hebi, Pingxiang, located in regions affected by water scarcity. Therefore, the goals settings of Sponge City should be custom-made (depending on the location-based issue of the city).

Table 2-5 Surface Water Quality Standards (GB3838-2002) in China

	COD (mg L^{-1})	**$NH_4^+ - N$(mg L^{-1})**	**DO (mg L^{-1})**
Level I	≤ 2.0	≤ 0.15	≥ 7.5
Level II	$2.0 < COD \leq 4.0$	$0.15 < NH_4^+ - N \leq 0.50$	$6.0 \leq DO < 7.5$
Level III	$4.0 < COD \leq 6.0$	$0.50 < NH_4^+ - N \leq 1.00$	$5.0 \leq DO < 6.0$
Level IV	$6.0 < COD \leq 10.0$	$1.00 < NH_4^+ - N \leq 1.50$	$3.0 \leq DO < 5.0$
Level V	$10.0 < COD \leq 15.0$	$1.50 < NH_4^+ - N \leq 2.00$	$2.0 \leq DO < 3.0$

Other criticism (in the goal setting section) that there are no sample cities that discussed or adopted a method to define the synergies and trade-offs between different Sponge City goals (Marked as ‘X’ in 1.3 and 1.4 represents ‘not discussed/ no methodology adopted’ in Table 2-4). This might lead to the situation that the Sponge City measures are located in areas that do not cope with the main city issues. Large-scale promotions would not be straightforward to the fulfillment of the sum of the individual goals. Madureira & Andresen (2014) indicated the existence of spatial priorities of different functions and confirmed that suitable locations for the green infrastructure technologies would be reasonably different in the light of the favored goals, e.g. stormwater runoff reduction, water quality improvement, heat wave alleviation. Due to the existence of the spatial priority of Sponge City measures regarding different planning goals, the approaches (such as equal consideration, analytic hierarchy process (AHP), experts’ interviews) are necessary to define the synergies and trade-offs between different Sponge City goals (Madureira & Andresen, 2014; Meerow & Newell, 2017). Equal consideration means that different goals are considered to have the same important weight. The Analytic Hierarchy Process (AHP) was introduced by Thomas Saaty in 1980 (Saaty, 1980). The Analytic Hierarchy Process (AHP) is a measurement approach through pairwise comparison and relies on the experts’ judgements so as to derive the important weight of the variables. Experts in this context refer to stakeholders, such as urban planners and designers, academic researchers specialized in urban planning/ green infrastructure planning, members of urban planning institute, researches of water and sewerage department etc., who know the local context and could assist to define the important weight of the goals, e.g. stormwater runoff reduction, water quality improvement, heat wave alleviation etc., of the Sponge City plan. Sponge pilot cities could either benefit from one certain goal or compromise among several goals based on the sample cities’ urban context. For instance, Meerow and Newell (2017) developed a stakeholder-driven approach to define the spatial trade-offs and synergies of the locations where green infrastructure could be strategically located to maximize the multi-functionality. In their study, expert surveys were involved to identify the priority of each factor.

4.2 *Participation*

The eight sample cities performed poor in (the matter of) public participation. The main participation method is publicity (of the Sponge City planning documents and related construction plans) on the official city plan website. Four cities Shenzhen, Zhuhai, Nanning and Chongqing execute online publicity of the Sponge City plans, documents and related constructions for 30 days (marked as '●' in 2.1 of Table 2-4). Two cities, Wuhan and Hebi, carry out online publicity of Sponge City plans, documents and related constructions for 10 days and Pingxiang and Ningbo show no available information on online publicity (marked as '◐' in 2.1 of Table 2-4). There are five cities: Shenzhen, Pingxiang, Hebi, Nanning and Ningbo that include mass media (TV, newspapers, websites, newsletters and other forms) or data platforms to spread the information and to educate the public concerning the Sponge City plans (marked as '▲ / ◭' in 2.1 of Table 2-4). Two cities (Shenzhen and Hebi) include a more effective approach to communicate with the public, such as the sponge city management hearing and Sponge City construction forum (marked as '(#)' in 2.1 of Table 2-4). There is one city, Shenzhen, that adopted suggestions from the public.

Stelzle & Noennig, (2017) classified the participation impact level into four groups, i.e. information, consultation, collaboration and empowerment. The information represents the level that provides information on understanding the problems and offering solutions to the public. The consultation represents the level in which the public feedback will be obtained regarding the analysis and decisions. The collaboration demonstrates the level in which the public participates in view of the process of the alternatives' development and preferred alternatives' identification. The empowerment represents the level of final decision- making in the hand of the public. The public participation level of the sample cities is mainly situated on the information level. The participation methods, such as the publicity on the official city planning website, could hardly serve as an effective platform to encourage the public participation. The public has limited access to information so as to understand the Sponge City policy, thus the public hardly puts forward opinions to the local government. Dai et al. (2018) indicated that public participation is not a compulsory component of the Sponge City plan. In general, legislative provisions for the public participation in China are still confined to abstract principles. Though non-government stakeholders have gained more attention during the past decade, they have not yet played an important role in the policy-making process and no institutionalized channels exist allowing them to influence the decision-making. However, it would be more sustainable to involve non-government stakeholders in the process of the Sponge City planning and design. More participation mechanisms, such as public hearings, deliberative polling, focus groups are suggested to improve the effectiveness of the public participation. The participation process could enable planners, researches, policymakers to gain a fuller picture of the strength and weaknesses of plans from interventions and thus increase the planning quality (Rossi, Lipsey, & Freeman, 2004; Cornwall & Aghajanian, 2017).

4.3 *Strategic planning*

The green infrastructure planning of the Sponge City plan of the eight selected pilot cities was investigated using two groups of indicators. The two groups of indicators, i.e. "green infrastructure technologies need a place" and "a place needs green infrastructure technologies" are key components for identifying a suitable location for the green infrastructure technologies (Table 2-3). The evaluation results of the green infrastructure planning section indicated that all sample cities contain a data analysis from the perspective of technical operations (Biophysical indicators), e.g. soil, slope, hydrology, land use and availability, to identify the priority areas so as to locate the green infrastructure technologies (marked as '◈' in Table 2-4). Six cities Wuhan, Pingxiang, Hebi, Nanning, Chongqing and Ningbo consider indicators of flood sensitive areas and water pollution distribution from the perspective that the priority areas that need the green infrastructure technologies the most (marked as '⬖' in Table 2-4). Two cities, Shenzhen and Zhuhai, not only include the aforementioned data analysis but also socio-economic related indicators, e.g. the cultural heritage protection and the economical concentration areas' protection (marked as '◆' in Table 2-4).

It was found that biophysical indicators were considered, while the socio-economic related indicators of the suitability analysis appear to be overlooked in the green infrastructure planning of Sponge City plans. Urban areas (that may highly benefit from green infrastructure) may thus be overlooked. Recent literature suggests that the spatial indicators, including socio-economic and urban context, could influence the functioning of the green infrastructure technologies (Barbosa et al., 2012). Strategic consideration of the urban context and socio-economic related indicators is important for the optimal green infrastructure implementation so as to deliver water regulating services the society is requiring. A methodology that takes the urban context and socio-economic related indicators into account in order to identify priority areas for green infrastructure planning to mitigate urban surface water flooding risk is developed in chapter 4.

The green infrastructure technologies are highly site-specific due to the spatial variability of the local environment, water characteristics, biophysical conditions, socio-economic factors, which calls for a shift from the general consensuses to the local assessments. However, the Sponge City plans' data analysis is, in general, very limited and mainly involved in the technical implementation and physical hazard reduction. Shao et al. (2016) indicated that the Chinese data collection and integration for Sponge City plans were relatively weak and needed improvement. Multiple engineered, social and economic datasets, such as the urban land use, hydrology, geography, water resources, demographics, economic concentration areas and surface temperature should be applied to build an integrated, multi-objective urban water system approach.

4.4 *Design guidelines*

The design guideline of the eight pilot cities was investigated based on three criteria (Table 2-3). The results indicated that all sample cities have clearly defined the types of green infrastructure technologies and provided technical guidelines and examples, on which the water regulation function, plant ecophysiology and site requirements of green infrastructure technologies were based to deliver designing principles to integrate technologies into buildings, roads, open spaces and waterways (marked as '*' to represent clearly defined/ explained in Table 2-4). It is helpful for designers to a certain extent.

However, the designing principles of all these cities are very simple and general. The Sponge City technical guideline was largely confined to the GB50014-2006 code of practice, established by the Ministry of Housing and Urban-rural Development (Ministry of housing and urban-rural development, 2014) in 2014. The design guideline is very similar between the sample pilot cities, while the local sample cities' condition is significantly different. Since the local conditions have a specific relevance to the spatial selection of the green infrastructure technologies. It would be good to specify that certain types of green infrastructure technologies are preferred for some cities. For instance, cities with water scarcity issues, should consider types of green infrastructure technologies to re-use or circulate rainwater, while cities with surface water flooding and quality issue, should consider types of green infrastructure technologies to reduce runoff without contaminating the soil. A more tailored guideline could be developed according to the local conditions.

5 Conclusion

This chapter evaluates eight sample cities and identified a wide array of challenges on the planning and design practice of the Sponge City plans. Based on the findings, we proposed recommendations to improve the future Sponge City development in China: 1) The goal setting of the Sponge City program should be based on the urban context, i.e. the biophysical, socio-economic and urban form, instead of directly taking guidelines from the standard (central government) guidelines with little research of the local conditions. Proper methods, such as the equal consideration, analytic hierarchy process (AHP) and experts' interviews should be adopted in the goal setting section so as to define the important weights of the assigned goals due to the existence of the spatial priority of different Sponge City goals; 2) More effective participation mechanisms such as public hearings, deliberative polling, focus groups could be adopted to improve the Sponge City public participation; 3) The urban context and socio-economic aspect should not be overlooked for the strategic green infrastructure planning. A methodology that takes the urban context and socio-economic aspect into consideration for green infrastructure planning to mitigate urban surface water flooding risk is developed in chapter 4. Spatial indicators, including the urban context and socio-economic, could play a significantly important role in the function of the green infrastructure. Multiple engineered, social and economic datasets should be built in order to support the identification of the priority areas for the Sponge City measures; 4) A spatial recommendations of certain types of green infrastructure technologies could be provided according to the local context.

Chapter 3 Assessing the stormwater runoff reduction capacity of the existing green infrastructure in Ghent

1 Introduction[2]

The stormwater runoff is the major source of surface water flooding in the urban communities (Jaafar et al., 2016). It is a serious global phenomenon that causes devastation and economic damages widespread (Ramos, Creutin, & Leblois, 2005; Pitt, 2007; Vinet, 2008; Baldassarre et al., 2010; Jha, Bloch, & Lamond, 2012). Over the past several decades, the negative impacts of the urban surface water flooding events have affected many cities across the world, such as New York and London in developed countries as well as Beijing, Wuhan and Bangkok in developing countries (Yin, Yu, Yin, Liu & He, 2016). The combined effect of global climate change and the urbanization trend will likely magnify the urban surface water flooding events in many world regions. Climate change is expected to augment the frequency of extreme weather events, including heavy rain and storm (Santos & Corte-Real, 2006; Carter, Cavan, Connelly, Guy & Handley, 2015). The Intergovernmental Panel on Climate Change (IPCC) indicated that the frequency of heavy precipitation or the ratio of heavy falls (to total rainfall) will increase in the 21st century in many global areas (IPCC, 2012). According to the report of the global urbanization prospects, the urban population will also continue to grow during the next decade and the world urban population will rise to 7.4 billion people and thus account for 66 % of the world population by 2050 (United Nationa et al., 2014).

Hence, answering the challenges of urban surface water flooding will be a substantial issue in the coming decades regarding the urban planning. The green infrastructure has been developed as one of the possible alternative approaches to mitigate the stormwater runoff and often proved to be cost-effective and broadly applicable, as well as to afford other benefits

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[2] *This chapter is based on a published paper (Luyuan Li, Veerle Van Eetvelde, Xin Cheng, Pieter Uyttenhove (2020), Assessing the stormwater runoff reduction capacity of the existing green infrastructure in the city of Ghent, International Journal of Sustainable Development & World Ecology, https://doi.org/10.1080/13504509.2020.1739166)*

(Wang, Bakker, Groot & Wörtche, 2014; Gao, Yu, Wang, & Vejre, 2019; Yang, Yu, Jørgensen, & Vejre, 2020). The urban green infrastructure can regulate the runoff by infiltration, evapotranspiration or runoff re-use and thereby alleviating the pressure on the aging or undersized sewer systems (Copeland, 2016). The effect of the green infrastructure on the runoff reduction has been studied extensively (Liu, Chen & Peng, 2014; Woo & Park, 2016; Calderón-Contreras & Quiroz-Rosas, 2017; Kim, Lee, & Sung, 2016) and indicated that the flooding probabilities could be reduced by over 50% of urban green space. Vanuytrecht et al. (2014) demonstrated that the sedum-moss vegetation and grass-herb vegetation green roof could decrease the stormwater runoff in summer by 61-75 % and by 6-18 % during winter, respectively. Liu et al. (2014) made clear that the green infrastructure could eliminate the stormwater runoff of the 1- and 2-year recurrence intervals and reduce the volume and peak flow of the stormwater runoffs (of 5- and 10-year recurrence interval runoffs) by 94.2 % and 85.6 % and 97.1 % and 93.1 %, respectively. Hence, the runoff reduction capacity of the green infrastructure needs to be elucidated for a better support of the green infrastructure planning (Matthews, Lo, & Byrne, 2015; Carter, 2018). More knowledge on the spatial distribution of the runoff reduction capacity on a local scale would assist the decision making of urban green space planning (Lanzas et al., 2019). The urban green infrastructure planning is the most important governance tool to integrate and maintain the provision of the benefits of green infrastructure in the urban areas (Yu et al., 2020). The estimation and mapping of the runoff reduction capacity could help urban planners to enhance the green infrastructure into planning practice as a measure to reduce the urban flood hazards.

The existing studies to understand and measure the runoff reduction capacity of landscapes have been widely utilized to calculate models, such as the stormwater management model (SWMM), SWAT, soil conservation service curve number (SCS-CN) and CITY-green (Gill, Handley, Ennos, & Pauleit, 2007; Zellner, Massey, Minor, & Gonzalez-Meler, 2016; Luan et al., 2019; Du et al., 2019). The aforementioned studies did not yet consider the role of the landscape pattern on the runoff reduction (Zhang et al. 2015). The landscape pattern is generally being considered to include two main components, i.e. the composition and configuration (Antrop & Van Eetvelde, 2017). The composition means the variety and relatively abundant patch types within the landscape. The composition of the landscape is quantified using the proportions of different land cover types. The configuration refers to the spatial characteristics, arrangements, positions or geometric complexity of the patches

(Shihong Du et al., 2016). Various studies (Kim & Park, 2016; Boongaling, Faustino-Eslava, & Lansigan, 2018; Bin, Xu, Xu, Lian, & Ma, 2018; Peng et al., 2019) have shown that general landscape structures are significantly affecting the surface runoff. For instance, Kim and Park (2016) investigated the effect of the landscape patterns on the peak runoff in four Texas MSAs. The outcome suggests that larger, less fragmented and more connected landscape patterns are more likely to mitigate the mean annual peak runoff. Bin et al. (2018) evaluated the impact of the landscape pattern on the surface runoff in the Haihe River Basin. The outcome clarifies that a rise of the largest patch index (LPI), Euclidean nearest distance (ENN), contagion index (CONTAG) and aggregation index (AI) causes a decrease in the runoff depth.

The landscape pattern is one of the characteristics of the urban green infrastructure. The spatial pattern of the urban green infrastructure might have an impact on their potential for runoff reduction. Zhang et al. (2015) developed an empirical model to investigate the effect of the green infrastructure on the stormwater runoff reduction in Beijing. This model includes two landscape metrics, i.e. the largest patch index (LPI) and aggregation index (AI). However, the selection of the two landscape metrics in their study was only based on the study of Liu, Wang, & Duan, (2012). Liu et al. (2012) indicated that the landscape-level metrics of the largest patch index (LPI) and the aggregation index (AI) are correlated with the runoff reduction capacity in Dongting Lake area in China. The relation of the landscape pattern and runoff reduction capacity in the Dongting area might not be suitable to be applied in Beijing. Therefore, several studies (Liu, Wang, & Duan, 2012; Woo & Park, 2016; Kim & Park, 2016; Boongaling, Faustino-Eslava, & Lansigan, 2018; Bin, Xu, Xu, Lian, & Ma, 2018; Peng et al., 2019), which focused on the effect of landscape on the hydrological process were reviewed in this chapter to define the set of landscape metrics to be included in the empirical model. The details of the landscape metrics in the model will be elaborated in the method section.

In this context, this study aims to assess the green infrastructure runoff reduction capacity on a local scale through an empirical model adapted from the research of Zhang et al., (2015). The study is carried out in Ghent (Belgium) and is addressing the following questions: (1) What is the spatial structure of the existing green infrastructure? (2) What is the runoff reduction capacity of the existing green infrastructure? The model outcomes could facilitate urban planners to estimate the runoff capacity of the existing green infrastructure. The mapping results could be used to assist the green infrastructure planning.

2 Study area

This chapter takes Ghent as case study (located in East-Flanders in Belgium) (Fig. 3-1). The municipality area covers an area of 156.2 km^2 and has a total population of 262,219 (in 2019). The average population density exceeds 460 inhabitants/km^2 in Ghent. The report of the Ghent Climate Adaptation Plan 2016-2019 indicated that an average of 46 percent of land surface is covered with buildings or concrete hardening (Ghent Administration, 2016). In the downtown area, the surface hardening even exceeds 80 percent. A high percentage of the impervious surface increases the stormwater runoff volume, thereby augmenting the local water nuisance during the frequent rain shower seasons.

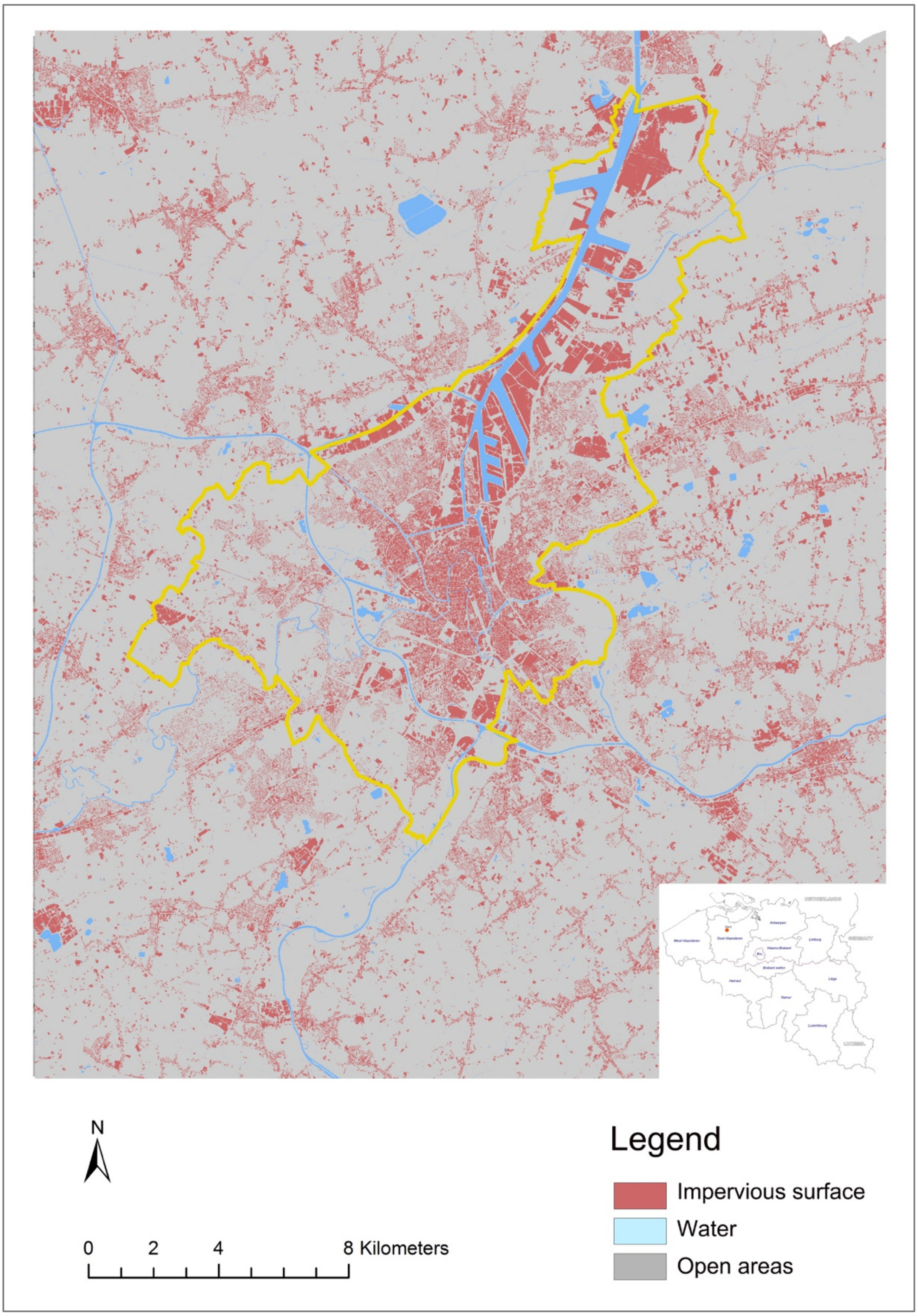


Figure 3-1 The study area, the yellow edge defines the administrative boundary of Ghent. Open areas (grey areas in the map) are defined as open land pieces that have no buildings or other built structures, (Source: Flanders Information Agency, (2012)*, modified by the authors)*

In 2015, the city of Ghent conducted an analysis of the water network, water nuisance and vulnerability. The results indicated that the center is well protected against river nuisance, while fairly sensitive to the surface water bodies. The drainage system is not able to cope with the amount of rain water, when intensive precipitation occurs. The water nuisance of the surface water bodies might endanger the human safety, damage the infrastructure and disrupt the service delivery. The climate forecasts indicate that extreme weather events will occur more frequently. By the end of this century, the rainfall (that used to occur every hundred years) is now expected to happen every ten years (Ghent Administration, 2016). The city of Ghent has highlighted the need for elements of green infrastructure against the water nuisance, such as bio-swales, rain gardens, wetlands, etc. (Ghent Administration, 2016). Ghent was one of the first cities in Flanders to sign the 'Mayors Adapt', the European Covenant of Mayors (in 2014). The 'Mayors Adapt' is an adaptation plan that describes measures such as eliminating impervious surfaces, retaining water and allowing it to infiltrate.

3 Methods and data

The method in this study comprises two steps, i.e. the analysis of the spatial characteristics of the existing green infrastructure and the assessment of the stormwater runoff reduction capacity of the existing green infrastructure.

3.1 *Analyzing the spatial characteristics of the existing green infrastructure*

The land cover data of Ghent (Flanders Information Agency, 2012) was used to investigate the spatial composition and configuration of the green spaces. The original land cover data classification grouped the existing land cover in the following categories i.e. buildings, roadways, other covers, railways, water, other uncovers, agricultural land, trees and grasses. The land cover categories were reassigned into five categories i.e. the impervious surfaces, agricultural land, grasslands, forests and water (see Table 3-1). In a precipitation event, the rainwater runoff would be routed through different hydrological process in each category e.g. impervious surface (buildings, footprints, roads, pavements, parking lots, etc.), green infrastructure, water bodies, which depend on the natural factors of the surfaces (Liu et al., 2014). The green infrastructure is categorized into three groups i.e. the agricultural land, grasslands and forests.

Table 3-1 Reassignment of the land cover in the study areas

Categories reassignment	**Categories in original Land cover data** (Flanders Information Agency, 2012)

Impervious surfaces	Buildings; roadways; railways; other covers; other uncovers
Agricultural land	Agricultural land
Grasslands	Grasses
Forests	Trees
Water	Water

Based on a literature review, a set of three categories of landscape metrics i.e. the size/shape, isolation and connectivity were selected to investigate the special characteristics of green space in this study, as shown in Table 3-2. According to peer research (Liu, Wang, & Duan, 2012; Kim & Park, 2016; Boongaling, Faustino-Eslava, & Lansigan, 2018; Bin, Xu, Xu, Lian, & Ma, 2018; Peng et al., 2019), these three categories indicated a significant correlation with the hydrologic processes.

Table 3-2 Description of the set of landscape metrics to be investigated on both a landscape and class level

Metrics		**Measurement, Source: McGarigal, (2015)**
Size, shape and edge	Percentage of landscape (PLAND)	The percentage area shares of the corresponding class. This metric provides information on the landscape composition
	Largest patch index (LPI)	The area of the largest patch of the corresponding patch type divided by the total landscape area, LPI $= \frac{\max(a_i)}{A}$, a_i= area of patch I, A = total landscape area. This metric provides information on the landscape composition
	Edge density (ED)	The total perimeter of patches to a unit area, ED= E/A (10,000), E= sum of perimeters, A= total landscape area. This metric provides information on the landscape configuration
	Landscape shape index (LSI)	The total perimeter of patches of the corresponding class divided by the minimum length of the class edge possible for a maximally aggregated class, LSI $= \frac{e_i}{\min e_i}$, e_i = total perimeter of class I in terms of cell surface number, $\min e_i$ = the minimum total perimeter of class I in terms of the cell surface number. This metric provides information on the landscape configuration
Isolation	Proximity (PROX)	Sum of all patch areas of the corresponding patch type, whose edges are situated within the 800-meter radius, divided by the nearest edge-to edge distance squared (m^2), Prox $= \sum_{j=1}^{n} \frac{S_{ij}}{h_{ij}^2}$, S_{ij} = area of patch ij, Z_i = distance

		between patch ij and patch ij, based on the patch edge-to-edge distance within the 800-meter radius. This metric provides information on the landscape configuration
	Euclidean nearest distance (ENN)	The distance to the nearest patch of the same type, $\text{ENN} = h_{ij}$, h_{ij} = the edge-to-edge distance from patch ij to the nearest neighbouring patch of the same type. This metric provides information on the landscape configuration
	Aggregation index (AI)	Number of alike adjacencies involving the corresponding patch type, divided by the maximum possible number of alike adjacencies, $\text{AI} = \left[\frac{g_i}{\text{maxg}_i}\right](100)$, g_i = number of alike adjacencies between the pixels of patch type I, maxg_i = maximum number of alike adjacencies between the pixels of patch type i. This metric provides information on the landscape configuration
	Number of patches (NumP)	Total number of patches of a particular landscape type. This metric provides information on the landscape configuration
Connectivity	Connectedness (CONNECT)	Number of joining between all patches of the same patch type divided by the total number of possible joining between all patches within the 800-meter radius, $\text{CONNECT} = \left[\frac{\sum_{j=k}^{n} C_{ijk}}{\frac{n_i(n_i-1)}{2}}\right] \times 100$, C_{ijk}= joining between patch j and k (0= unjointed, 1= joined) of the patch type (i) within 800-leter radius, n_i= number of patches in the landscape of patch i. This metric provides information on the landscape configuration
	Cohesion (COHESION)	$\text{COHESION} = (1 - \frac{\sum p}{\sum p\sqrt{a}})(1 - \frac{1}{\sqrt{N}})^{-1}$, P = patch perimeter, a= patch area, N= the number of pixels on the map. This metric provides information on the landscape configuration

The aim of the investigation on the spatial characteristics of green space in Ghent was to provide better insights regarding the green space management in view of the urban surface water flooding mitigation. The correlations of the landscape-level metrics and runoff reduction capacity are shown in Table 3-3, based on the peer studies (Liu et al., 2012; Kim & Park, 2016; Bin, Xu, Xu, Lian, & Ma, 2018). The landscape-level metrics examine the spatial structure in multi-class patch mosaics (Liu, Wei, Li, & Li, 2016). ArcGIS 10.3 and Fragstats 4.2 were used for data mining and measuring.

Table 3-3 The correlation of the selected landscape metrics and the runoff reduction capacity based on peer studies

1. A higher percentage of green space (PLAND) leads to a more effective runoff reduction capacity
2. A higher value of LPI leads to a more effective runoff reduction capacity
3. A higher aggregation degree (PROX, ENN, AI) leads to a more effective runoff reduction capacity
4. A higher connectivity degree (CONNECT) leads to a more effective runoff reduction capacity
Source : Liu et al., (2012) ; Kim & Park, (2016) ; Bin, Xu, Xu, Lian, & Ma, (2018)

3.2 *Assessing the runoff reduction capacity of the existing green infrastructure*

The empirical model (Formula 2) from the research of Zhang, Xie, Li & Wang (2015) was adapted to estimate the stormwater runoff reduction capacity of green infrastructure. Zhang, Xie, Li & Wang (2015) combine an empirical model with landscape pattern metrics to estimate the runoff volume. The empirical model that determines the stormwater treatment volume include three variables, i.e. precipitation, runoff coefficient, percentage of site in different landcover types (Collins, Hirschman, Hoffmann, & Schueler, 2009). The runoff coefficient is utilized to convert the precipitation amounts into the runoff. The value of the coefficient is based on the climate conditions and the physiographic characteristics of the drainage area, ranging from zero to one. A high coefficient value represents a low evapotranspiration, infiltration and high runoff amount and a low value represents the opposite. The land cover runoff coefficient was derived from the research of Zhang et al. (2015), as shown in Table 3-4.

Table 3-4 The stormwater runoff coefficient for different land cover types (based on Zhang et al. (2015))

Land cover types	**Stormwater runoff coefficient**
Impervious surfaces	0.85
Agricultural land	0.5
Grasslands	0.25
Forests	0.15
Water	0

As described in the introduction, peer studies have proven the effect of the landscape patterns on the surface runoff retention capacities. Since the landscape metrics can be used to quantify the landscape pattern, the model used to assess the runoff reduction capacity includes the landscape metrics. The selection of the landscape metrics is based on a review of studies (Liu, Wang, & Duan, 2012; Kim & Park, 2016; Boongaling, Faustino-Eslava, & Lansigan, 2018; Bin, Xu, Xu, Lian, & Ma, 2018; Peng et al., 2019) that analyzed the correlation of the landscape patterns and the runoff reduction or flood mitigation capacity. Different cases in other studies (Liu et al., 2012; Kim and Park, 2016; Bin et al., 2018) demonstrated that the degree of fragmentation and connectivity of landscapes has an impact on the runoff reduction capacity. Therefore, the aggregation index (AI) and connectivity (CONNECT) are introduced as variables to be calculated on a class level (in the model) to assess the runoff reduction amount, as shown in Formula (1):

$$\mathrm{PAI_i} = \mathrm{AI_i} * \mathrm{CONNECT_i} \quad (1)$$

$\mathrm{AI_i}$ represents the aggregation index in the $\mathrm{i^{th}}$ urban green space patch.
$\mathrm{CONNECT_i}$ stands for the connectivity index in the $\mathrm{i^{th}}$ urban green space patch.
PAI_i is the aggregative index of $\mathrm{AI_i}$, $\mathrm{CONNECT_i}$.
A linear scale transformation will be adopted to rescale the value of PAI from 0 to 1, represented as $\mathrm{PAI_i'}$. The detailed description of the two selected metrics is shown in Table 3-2. Formula (2), adopted from the research of Zhang, Xie, Li & Wang (2015), shows the empirical model to calculate the runoff reduction capacity of the $\mathrm{i^{th}}$ urban green space patch:

$$\mathrm{R_i} = \mathrm{P} * \mathrm{PAI_i'} * (1 - \mathrm{y_i}) * \mathrm{A_i} \quad (2)$$

$\mathrm{R_i}$ is the volume of the stormwater runoff reduction of the $\mathrm{i^{th}}$ urban green space patch.
P demonstrates the average annual precipitation.
PAI_i represents the combined value of $\mathrm{AI_i}$ and $\mathrm{CONNECT_i}$.
$\mathrm{y_i}$ stands for the runoff coefficient of the $\mathrm{i^{th}}$ landscape patch.
$\mathrm{A_i}$ is the area of the $\mathrm{i^{th}}$ land cover patch.
Formula (3), adopted from the research of Zhang, Xie, Li & Wang (2015), refers to the total runoff reduction amount of all the land cover patches.

$$\mathrm{TR} = \sum_{\mathrm{i=1}}^{\mathrm{n}} R_i \quad (3)$$

TR is the total runoff reduction amount of all land cover patches.
R_i shows the runoff reduction amount of the $\mathrm{i^{th}}$ urban green space patch.

The flowchart beneath is summarizing the methodology and data sources applied in the case study of (the city of) Ghent and is shown in Fig. 3-2.

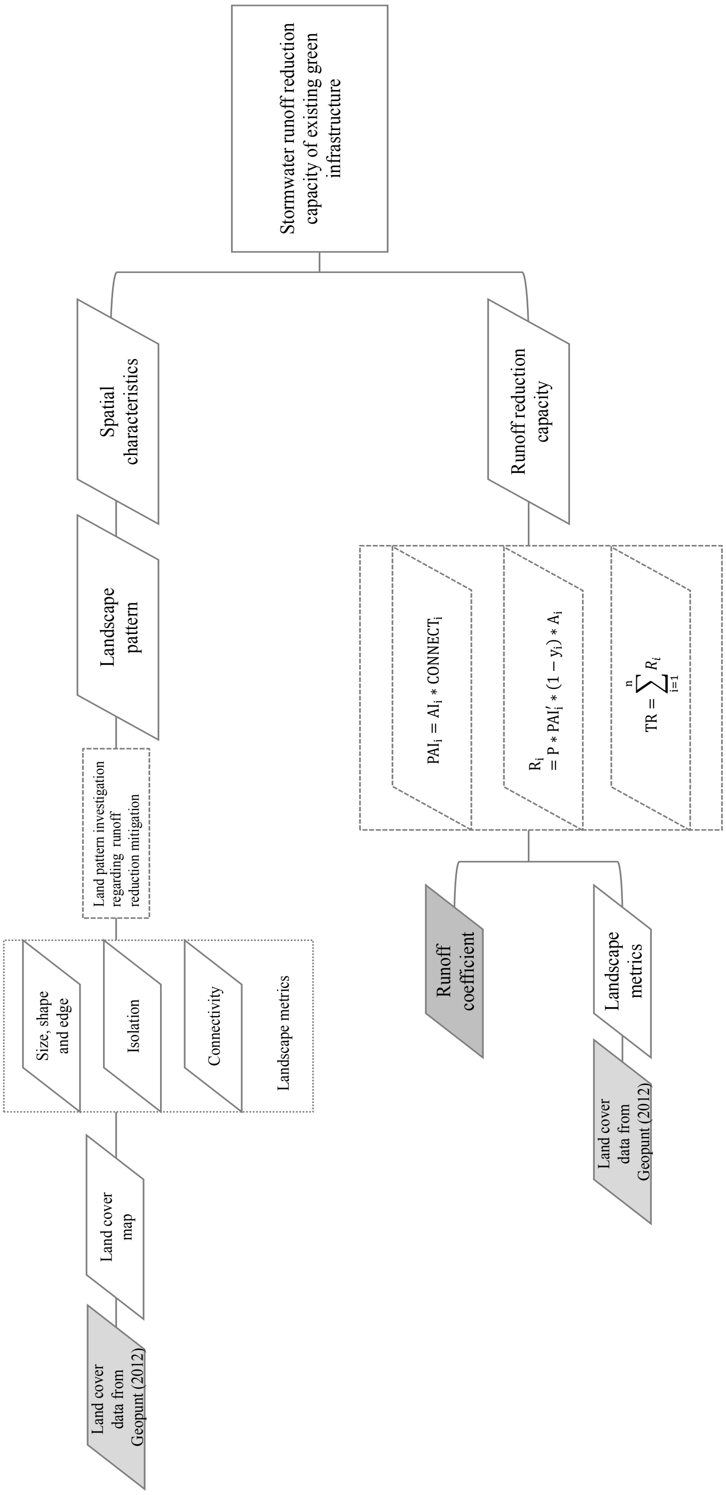
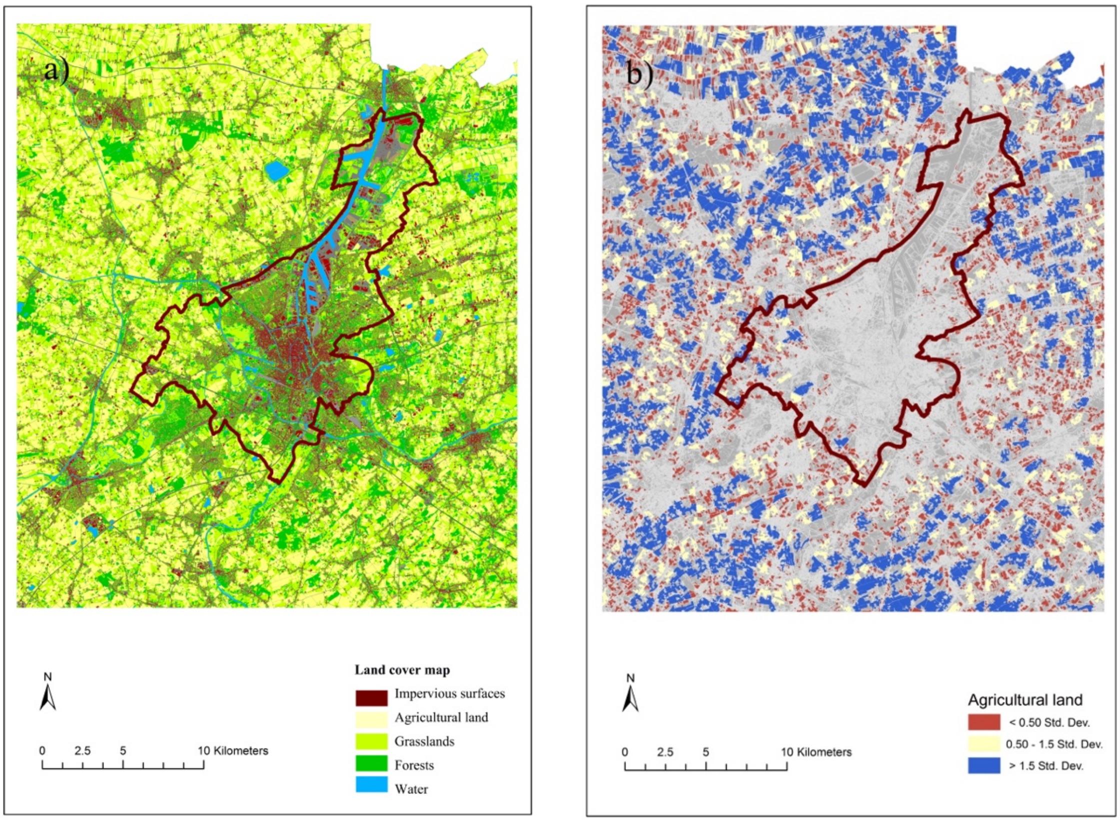


Figure 3-2 Flowchart summarizing the methodology applied in the city of Ghent (Grey rectangle shapes represent the data from Flanders Information Agency, (2012) *or the data adopted from other research; squares in the dotted line represent measures; rectangles in full line are layers that have been created or calculated from the original data)*

4 Results

4.1 *Land cover and the distribution of green infrastructure in the study area*

The land cover map of the study area is shown as Fig. 3-3 (a). The red line defined the boundary of the municipality of Ghent. The total green infrastructure in the municipality of Ghent is 88.6 km^2. Grasslands occupied the largest area of green infrastructure with 52.3 km^2, followed by forests and agricultural land with 23.3 km^2 and 12.9 km^2, respectively.



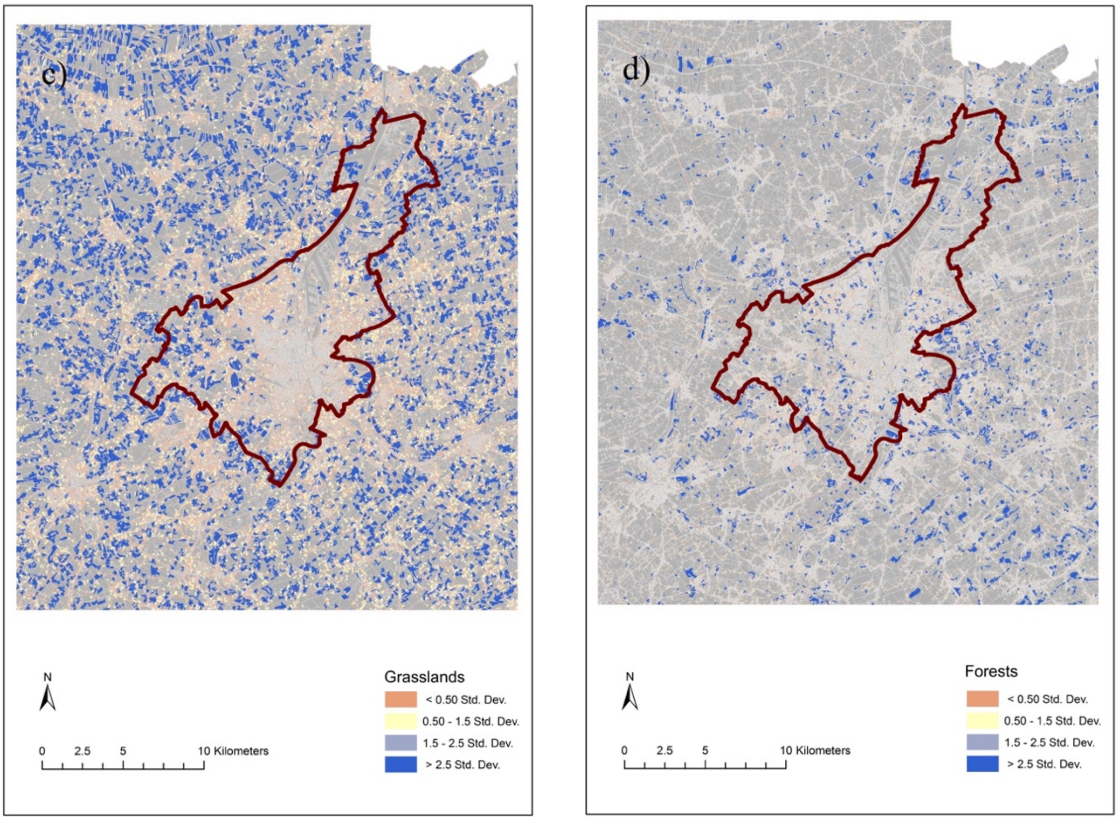


Figure 3-3 (a) Land Cover Map of the study areas in 2012, the red edge defined the boundary of the city of Ghent, source: Flanders Information Agency, (2012)*; (b) Spatial distribution of the patch size of the agricultural land; (c) Spatial distribution of the patch size of grasslands; (d) Spatial distribution of the patch size of forests. The patch size is divided by the standard deviation.*

The spatial distribution of the urban land cover in Ghent indicates that the impervious surfaces occupied the largest surface measuring 38.15 %, followed by grasslands with 33.17 %, forests with 14.77 %, agricultural land with 8.19 % and water with 5.71 %, as shown in Table 3-5.

Table 3-5 Urban land cover areas and percentage in Ghent

Land cover types	**Land cover areas (CA) (km^2)**	**Percentage of landscape (PLAND) (%)**
Impervious surfaces	60.15	38.15
Agricultural land (1)	12.92	8.19
Grasslands (2)	52.31	33.17
Forests (3)	23.30	14.77
Water	9.01	5.71

The current agricultural land in the study areas is distributed around the municipality of Ghent. Inside Ghent, the current agricultural land is mainly concentrated in the southwest and northeast suburban areas, as shown in Fig. 3-3 (b). The size of the agricultural land patches is relatively big. Grasslands are distributed across the whole study area, as shown in Fig. 3-3 (c). The bigger size in grassland patches is mainly concentrated in the southwest and northeast suburban areas and a smaller size is mainly concentrated around the core areas of Ghent. Forests (trees) are scattered across the study area, as shown in Fig. 3-3 (d). The patch size of the forests is relatively small. The lager patches of forests are located around the suburban areas of the municipality of Ghent.

4.2 *Landscape patterns of the existing green infrastructure regarding the surface flood risk mitigation*

Since the green infrastructure in the municipality of Ghent is not isolated from the surrounding green infrastructure, an expanded rectangle (with a total area of 1,095 km^2) including the municipality of Ghent is therefore considered as the whole area wherein the landscape metrics have to be calculated. The runoff reduction volume is only calculated of the area of the municipality of Ghent. The latter are analyzed on two levels, i.e. the landscape and the class level. The calculation results are demonstrated in Table 3-6.

Table 3-6 The landscape metrics' calculation results

Landscape Metrics		**Class level**			**Landscape level (MN)**
		Agricultural land	**Grasslands**	**Forests**	
Area, edge and shape	PLAND	36.41 (322 km^2)	47.49 (418 km^2)	16.10 (140 km^2)	--
	LPI	0.99	1.67	0.30	1.67
	ED	72.17	114.07	74.24	130.24
	LSI (MN)	1.64	1.38	1.18	1.28
Isolation	PROX (MN)	186.76	483.34	15.69	189.51
	ENN (MN)	91.72	68.49	80.48	77.18
	AI	82.12	67.58	52.26	70.41
	NumP	3,549	16,623	28,044	48,216

Connectivity	CONNECT	0.39	0.31	0.22	0.24
	COHESION	96.68	97.57	86.22	96.64

1. The area, edge and shape of the patches

In the whole calculation area (including the surrounding areas of the municipality of Ghent), the green infrastructure occupied 880 km^2. Grasslands occupy the largest area with 47.49 %, followed by the agricultural land occupying 36.41 % of the total urban green space. Forests (with their important role in rain water retention) occupy only 16.10 % of the total urban green space. The value of LPI on the landscape level is 1.67. The LPI value of the agricultural land, grasslands and forests is 0.99, 1.67 and 0.30, respectively. Grasslands possess the highest LPI value among the three green infrastructure types, indicating that grasslands are the dominant patch type in the landscape. The value of ED on the landscape level is 130.24. On a class level, the ED value of grasslands is the highest among all green space types, measuring 114.07. The ED value of the forests and agricultural land amounts to 74.24 and 72.17, respectively. The value of LSI on a landscape level is 1.28. The LSI values on a class level for the agricultural land, grasslands and forests measure 1.64, 1.38 and 1.18, respectively.

2. The isolation of the patches

The value of PROX on a landscape level is 189.51. The value of PROX on a class level of the agricultural land, grasslands and forests amounts to 186.76, 483.34 and 15.69, respectively. The value of ENN on a landscape level measures 77.18 and the class level of the agricultural land, grasslands and forests is 91.72, 68.49 and 80.48. The value of AI on a landscape level is low with 70.41. The AI value of the agricultural land is the highest among all green space types with 82.12. The value of the grasslands and forests are calculated as 67.58 and 52.26, respectively. The total number of patches in the study area is 48,216. The patch number of the agricultural land, grasslands and forests is 3549, 16623 and 28044, respectively.

3. The connectivity of the patches

The value of CONNECT on a landscape level is 0.24 and the class level of the agricultural land, grasslands and forests measures 0.39, 0.31 and 0.22, respectively. The value of COHESION of the agricultural land, grasslands and forests is 96.68, 97.57 and 86.22, respectively. The results indicate that the connectivity degree of the urban green space in Ghent is rather low.

4.3 *Stormwater runoff reduction capacity of the green infrastructure*

The spatial distribution of the runoff reduction coefficient of the different land cover types is shown in Fig. 3-4.

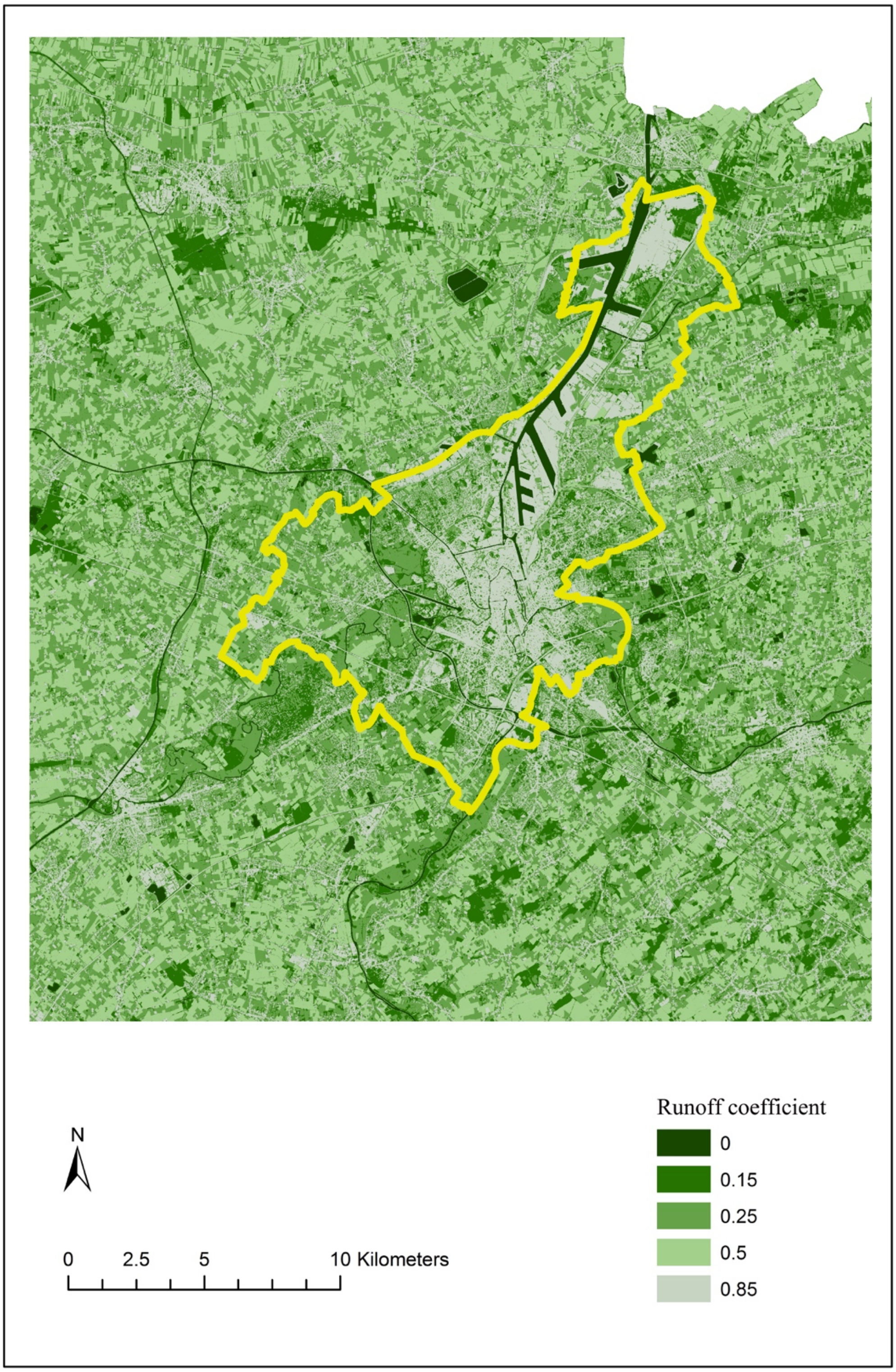


Figure 3-4 Runoff Coefficient in the study area

The calculation results of AI, CONNECT of different green infrastructure types in the areas of the municipality of Ghent are shown in Table 3-7. The agricultural land recorded the highest value of both AI and CONNECT, representing that agricultural land have the highest degree of aggregation and connectivity of the three selected green infrastructure types in Gent. Consequently, agricultural land has a high PAI value, thus promoting the role of runoff reduction (Table 3-7). In contrast, forests recorded the lowest value of both AI and CONNECT, representing the lowest degree of aggregation and connectivity of the three green infrastructure types. Forests have a low value of PAI, resulting in the poor role of runoff reduction.

Table 3-7 The calculation results of Aggregation index (AI), Connectivity index (CONNECT), PAI, PAI' of different land cover types

Land cover types	**AI**	**CONNECT**	**PAI**	**PAI'**
Impervious surfaces	77.43	1.75	135.50	0.45
Agricultural land	88.03	3.17	279.06	0.93
Grasslands	69.49	1.74	120.91	0.40
Forests	60.99	1.47	89.66	0.30
Water	85.81	2.14	183.63	0.61

As shown in Table 3-8, the total amount of stormwater runoff reduction of the selected green infrastructure in Ghent is 28.04 million m^3. Grasslands provide the largest stormwater runoff reduction of 11.83 million m^3 and forests controlled the lowest runoff of 4.48 million m^3. The reduction amount per square kilometer, i.e. the amount of runoff reduction per square kilometer of the particular land cover type, is adopted to analyze the reduction capacity of green infrastructure in Ghent. Agricultural land has the highest reduction amount per square kilometer of 0.35 million m^3/km^2. Forests have high potential of runoff reduction capacity due to a high runoff reduction coefficient, while its reduction amount per square kilometer is only 0.19 million m^3/km^2. An increase in the AI or CONNECT expands the role of stormwater runoff reduction facilitated by green infrastructure. Grasslands occupied the largest percentage of the all the green infrastructures, but its reduction amount per square kilometer is only 0.23 million m^3/km^2. The runoff reduction ratio, i.e. the percentage of the runoff reduction amount of the annual rainfall, is also adopted to analyze the reduction capacity of green infrastructure in Ghent. The runoff reduction rate of green infrastructure in Ghent is 17.6%, with 3.8%, 10%, and 3.8% of agriculture lands, grasslands, and forests, respectively.

Table 3-8 Stormwater runoff reduction amount and the ratio of different land cover types

Land cover types	Reduction amount (million m3)	Reduction amount Per square kilometer (million m^3/km^2)	Reduction ratio of the total (%)
Impervious surfaces	3.06	0.05	2.6
Agricultural land	4.53	0.35	3.8
Grasslands	11.83	0.23	10
Forests	4.48	0.19	3.8
Water	4.14	0.46	3.5
Total	28.04	0.24	23.7

The spatial distribution of runoff reduction capacity of green infrastructure across Ghent is shown in Fig. 3-5. The mapping results clearly show several urban priority areas. The high runoff reduction capacity of green infrastructure is mainly concentrated in the southwest and northeast suburban areas. The areas surrounding downtown are distributed with small size green infrastructure patches and median runoff reduction capacity. The core areas scattered with less green infrastructure patches and low runoff reduction capacity.

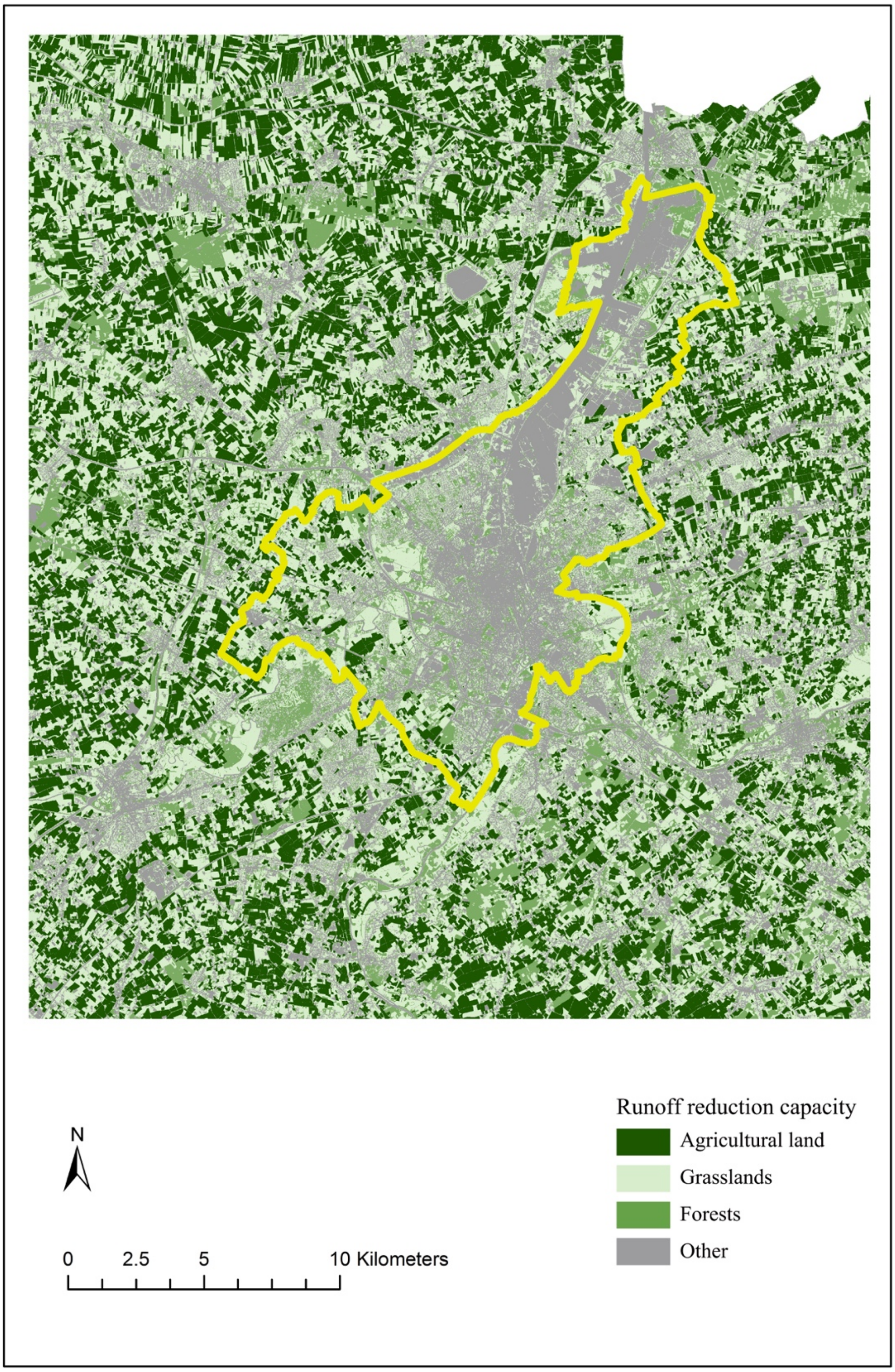


Figure 3-5 Spatial distribution of the runoff reduction capacity of each green infrastructure type

5 Discussion

The study provide insight to the spatial characteristics and runoff reduction capacity of the existing green infrastructure. Three spatial recommendations were given based on the results of the investigation of the spatial characteristics of the existing green infrastructure. The focus should be put on the optimization of the runoff reduction capacity by providing a larger, more aggregated and connected green infrastructure. Firstly, optimizing the runoff reduction capacity of green infrastructure can be obtained by increasing the total percentage of the urban green infrastructure and by providing larger patches. The correlation of the selected landscape metrics and runoff reduction capacity (based on peer studies) indicated that the augmentation of the LPI would lead to a more effective runoff reduction capacity (Table 3-3). The green infrastructure actions, such as expanding the existing green infrastructure (increase the patch size), combining the green infrastructure with buildings and constructions (to raise the green infrastructure ratio in high building density areas with limited available land), de-paving the sidewalk with green infrastructure, could be taken to optimize the runoff reduction capacity. Secondly, green actions in Ghent could be taken to increase the aggregation degree of the urban green infrastructure, e.g. to place the new green action projects clustered with the existing green infrastructure. The peer case studies (Liu et al., 2012; Kim and Park, 2016; Bin et al., 2018) demonstrated that the increase of the values of PROX, ENN, AI on a landscape level led to the decrease of the runoff amount. Thirdly, the green infrastructure actions, such as extending the green axis to link the existing green infrastructure cores and corridors, could be taken to optimize the runoff reduction capacity. The increase of the CONNECT value on a landscape level causes the decline of the runoff amount (Kim and Park (2016).

The results of the runoff reduction capacity (of green infrastructure) assessment show that the green infrastructure in Ghent could control 28.04 million m^3 of the stormwater runoff. The three urban green infrastructure types contribute to different runoff amounts with various flood reduction potentials. The stormwater runoff reduction capacity varies according to the land cover type and the landscape pattern (of the green infrastructure). The average reduction amount of different land cover types ranges from 0.05 to 0.46 million m^3/km^2. Grasslands contribute the most to the runoff reduction among the green infrastructure types. The variation shows potential for urban flood risk reduction improvement through urban green space management in Ghent, i.e. by increasing the ratio of high capacity green infrastructure types or the aggregation and connectivity degree of specific green infrastructure types. For instance, the AI and CONNECT values of forests recorded the lowest value among the three green infrastructure types, resulting in a poor role of the stormwater runoff reduction. Therefore, a decrease of the fragmentation and increase in connectivity of forests in Ghent should be recommended for the green infrastructure management. In addition, the core areas in Ghent are recorded with less green infrastructure patches and low runoff reduction capacity, while the core areas have higher urban surface water flooding risks than other areas. Increasing the flood risk resilience in the core areas, e.g. increase the patch size of the existing green infrastructure, combined green infrastructure (such as green roofs or green walls with buildings, de-paving the unnecessary hardening, under the constraints of urban morphology) should be taken into consideration. The City Center and inner areas possess low levels of green infrastructure and are key targets for the future city investment.

The present study has limitations. The runoff coefficient in the empirical model was derived from the research of Zhang et al. (2015) in the region of Beijing. The land cover, geography and hydrological conditions might differ from Ghent. However, there is no hydrological research to assess the runoff reduction coefficient of the land cover in Ghent. Future study could investigate the runoff coefficient of the land cover in Ghent. Despite this limitation, the study results could provide the local authorities and public with a good plan for the urban green space.

6 Conclusions

It is a widely recognized fact (across policy and practice guidance) that the delivery of urban green infrastructure in the built environment is critical to flood risk mitigation. This study analyzes the spatial characteristics and assesses the runoff reduction capacity of the existing green infrastructure in Ghent. The mapping results provide a better knowledge of the spatial distribution of the runoff reduction capacity on a local scale and facilitate green infrastructure planning. The functionality of the green infrastructure depends on its location and pattern. Implementing green infrastructure without provision for overall networking and clustering would be less effective (due to the fact that the location of the new green projects will affect the value of landscape metrics, and thus impact the runoff reduction capacity). The findings of this study assist policy makers and urban planners for the further development and implementation of green infrastructure in view of a more effective rainwater runoff management.

Chapter 4 Planning green infrastructure to mitigate the urban surface water flooding Risk - a methodology to identify the priority areas applied to the city of Ghent

1 Introduction[3]

Flood has been a significant global issue during recent years, especially the urban surface water flood, as it poses growing threats to the urban areas (Ramos, Creutin, & Leblois, 2005; Zbigniew W. Kundzewicz et al., 2005; Shankman David, Barry D. Keim, 2006; Baldassarre et al., 2010). The surface water flooding consists of a combined flooding in the urban areas. It includes pluvial flooding (that results from the rainfall overland flow before the runoff enters any watercourse or drainage system or when it cannot enter the system because it overwhelms the capacity), sewer flooding (sewage water leaks from the sewerage system) and groundwater flooding (occurs when the natural underground drainage system cannot drain the rainfall quick enough, causing the water table to rise above ground surface) (Kaźmierczak & Cavan, 2011). The urban surface water flood is one of the most common natural hazards, which is responsible for a massive physical flood water disturbance but also for socio-economical losses, such as public health issues, public transportation disorders and building damages (Vinet, 2008; Jha, Bloch, & Lamond, 2012; Yin, Yu, Yin, Liu, & He, 2016; Sperotto et al., 2015). According to the European Environment Agency report on Urban adaptation to climate change in Europe 2016, flood events cause massive losses of economic assets in many European cities (European Environment Agency, 2016). For instance, the flood damage to the community services in Dresden in 2002 accounted for 80 million Euro and the flash flood damage to buildings in Genoa in 2014 accounted to 100 million Euro (European Environment Agency, 2016). The research of Barredo (2009) indicated that the total flood losses from 1970 to 2006 reached 140 billion dollars in 31 European countries, with an average annual loss of 3.8 billion. The number and scale of flood damage in the urban areas will continue to rise during the next decades due to two major reasons: one is the

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[3] *This chapter is based on a published paper (Li, L., Uyttenhove, P., Van Eetvelde, V. (2020). Planning green infrastructure to mitigate urban surface water flooding risk- A methodology to identify priority areas applied in the city of Ghent. Landscape and Urban Planning, https://doi.org/10.1016/j.landurbplan.2019.103703). The introduction of the published paper is shortened to avoid redundancy with the general introduction of the PhD dissertation.*

global trend in urbanization leading to dense cities; the other concerns climate change resulting in more frequent (and extreme) weather events (Jha et al., 2012; Zbigniew et al., 2013; Jeffrey, 2014). The European 'Mayors Adapt' indicates that climate change will affect almost all cities across Europe. Many cities are expected to suffer catastrophic and extreme weather events more often as the frequency, intensity and duration of these events are expected to increase (European Covenant of Mayors, 2014).

For centuries, traditional approaches called 'grey infrastructure' have been developed to manage the stormwater and wastewater. Grey infrastructure typically refers to the human-engineered and centralized water management approaches including pipes, pumps, ditches, detention ponds and drainage and sewer systems. Grey infrastructure is certainly important for the rainwater and wastewater management; however, the efficiency of the grey infrastructure is critical. Despite the extensive implementation of the grey infrastructure, many cities remain vulnerable to the urban surface water due to increased flood hazards and aging of the grey infrastructure (Liao, Le, & Nguyen, 2016; Dong, Guo, & Zeng, 2017). According to the report of the Sewer System Improvement Program of 2017 in San Francisco, most world cities are still using the combined sewer system to deal with the waste and stormwater runoff, though these systems are not sufficient anymore when intense downpour takes place (San Francisco Public Utilities Commission, n.d.). Additionally, public utilities are grappling with the aging infrastructure as the maintenance of the engineered infrastructure is very expensive. These problems ask for a solution, namely the development of more innovative approaches.

Since the 1990s, green infrastructure practices have emerged as a supplementary approach of a centralized grey infrastructure. A large number of studies have shown its effect on managing the runoff and by enhancing the society resilience and the natural environment (Calderón-Contreras & Quiroz-Rosas, 2017; Shackleton et al., 2015). During heavy precipitation events, green infrastructure can process the water body by infiltration, evapotranspiration or runoff re-use, thereby alleviating the pressure on the aged or undersized sewer systems (Copeland, 2016). By increasing the urban surface water flood hazards, relying solely on the traditional and aged grey infrastructure is not sufficient, that is the reason why many cities in the world have adopted green infrastructure solutions as a strategy to address the increasing urban flooding issue. China's Ministry of Finance, Ministry of Housing and Urban Construction and Ministry of Water Resources jointly issued the document of the Sponge City construction guidance in 2015: sixteen cities in China became pilot cities so as to address the urban flooding issue (by adopting green infrastructure). In the pilot areas, the goal was to develop green infrastructure during three years to infiltrate or re-use 70 percent of the stormwater on-site. American cities, such as Washington DC and New York City are peer cities in adopting green infrastructure so as to cope with the urban stormwater management (Economides, 2014). European cities, such as Barcelona and Lisbon, started to integrate green infrastructure planning into their master planning including greenways, green gardens and green roof projects to improve the water management, to reduce the heat island effects and to ensure a timely and coordinated response to extreme events (Ajuntament de Barcelona, 2013; Santos, Branquinho, Goncalves, & Santos Reis, 2015).

Though an increasing awareness is visible concerning the effect of green infrastructure in the flood risk mitigation, the green infrastructure planning has been experiences based, and lack of strategy and resulted in sub-optimal outcomes (Schuch, Serrao-Neumann, Morgan, & Low Choy, 2017; Kuller, Bach, Ramirez-Lovering, & Deletic, 2018). For instance, Kuller et al., (2018) investigated the relation between the green infrastructure in Melbourne and the urban context, i.e. in a biophysical, socio-economic and urban form. The results showed that an opportunistic green infrastructure planning leads to unintentional outcomes which fail to provide a full potential of green infrastructure benefits. Maruani and Amit-Cohen (2007) reviewed the existing approaches and methods of the green space planning and divided them into nine groups, i.e. the opportunistic model, space standards, park system models, garden-cities, shape-related models, landscape related models, ecological determinants, protected landscapes and biosphere reserves. Among them, qualitative models (such as the park system model and the shape-related model) have been easily adopted by planners or designers in either a single or combined way of green infrastructure planning on an urban scale. The park system model represents an interconnected system of parks and gardens. The shape-related model represents green space (defined by a certain shape) such as green belts, green hearts, green fingers or green ways. These models do not foresee strategies to site the green infrastructure in the areas needing it the most and lack sufficient responses for providing benefits to target neighborhoods. It is important to acknowledge that simplistic blueprints will be insufficient to resolve the complex issues associated with the ecosystem service provisions. Green infrastructure planning has to be suitable for specific localities.

In response, some quantitative urban planning approaches seek for a more careful placement of the green infrastructure and emerged during the past decades (Madureira & Andresen, 2014; Norton et al., 2015; Meerow & Newell, 2017). Norton et al., (2015) suggested a framework on green infrastructure planning so as to mitigate the urban heat island effect. The priority areas were identified by three groups of data: thermal remote sensing data, vulnerable urban neighborhoods and the existing green space zone. Madureira & Andresen (2014) identified the priority area for green infrastructure planning by two criteria, i.e. the local temperature regulation and population proximity to public green space. They used equal importance to leverage the two indicators, which may not fit the real situation. Meerow & Newell (2017) developed an integrated stakeholder-driven modeling approach to strategically plan green infrastructure in order to maximize the multi-functionality. The study includes six indicators, i.e. the stormwater management, social vulnerability, green space, air quality, urban heat island amelioration and landscape connectivity. CH2MHILL (2014) conducted a suitability analysis to determine the priority areas for green infrastructure planning. The city of New Haven suffered frequently from combined sewer overflow events due to the aging of grey infrastructure systems and a changing climate, which is also the case in many U.S. cities. The suitability analysis in this study selected five indicators including the soil type, groundwater depth, surface pavement, parcel and sewer shed type. However, we are lacking strategically-based green infrastructure planning models to protect against the urban flood risk mitigation. This is important because green infrastructure benefits are highly localized, thus site decisions have significant implications for the local environment. A growing amount of studies points out the indicators that determine the suitability of a location for the green infrastructure implementation (Madureira & Andresen, 2014; Meerow & Newell, 2017). Various indicators are considered for the placement of the green infrastructure such as hydrology, soil, slope and land use. However, the socio-economic factors of green infrastructure practices appear to be overlooked (Kuller et al., 2018). Urban areas that may highly benefit from green infrastructure might thus be neglected. Recent literature suggests that the spatial indicators (including socio-economic and urban forms) could impact the green infrastructure functioning (Barbosa et al., 2012). Strategic consideration of the urban context (in terms of socio-economic and urban forms) related indicators is important for an optimal green infrastructure implementation in order to deliver the (water regulating) services that society is requiring.

Therefore, this chapter aims to introduce a quantitative evaluation method to identify priority areas for the green infrastructure planning. We propose a GIS-based multi-criteria evaluation method and aims at improving the urban sustainability and resilience against the urban surface water flood risks, which comprises five indicators: 1) stormwater runoff mitigation; 2) social flood vulnerable group protection; 3) flood sensitive area road infrastructure protection; 4) flood sensitive area buildings' protection and 5) environmental justice. The important weight of five indicators is defined by the Analytic Hierarchy Process. The approach is designed to facilitate green infrastructure on a citywide scale, a detailed technological suitability assessment on smaller spatial scales should be considered for a GI implementation. A strategic approach can help planners to ensure that the flood risk mitigation function is being provided in areas needing it the most. The methods (and resulting maps) could help the urban planners, administrators and stakeholders to identify the priority areas for the green infrastructure planning, to mitigate the urban surface flood risks and to integrate these with the urban land use planning.

2 The city of Ghent

Ghent is located in East Flanders in Belgium (Fig. 4-1). The municipality area covers an area of 156,2 km2 and has a total population of 262,219 of 2019. The Climate Adaptation Plan 2016 - 2019 of Ghent shows that an average of 46 percent of the land surface is covered with buildings or concrete pavements (Ghent Administration, 2016). The surface hardening in the downtown areas even exceeds 80 percent. A high percentage of the impervious surface increases the stormwater runoff volume, thereby increasing the local water nuisance during the rain shower season.

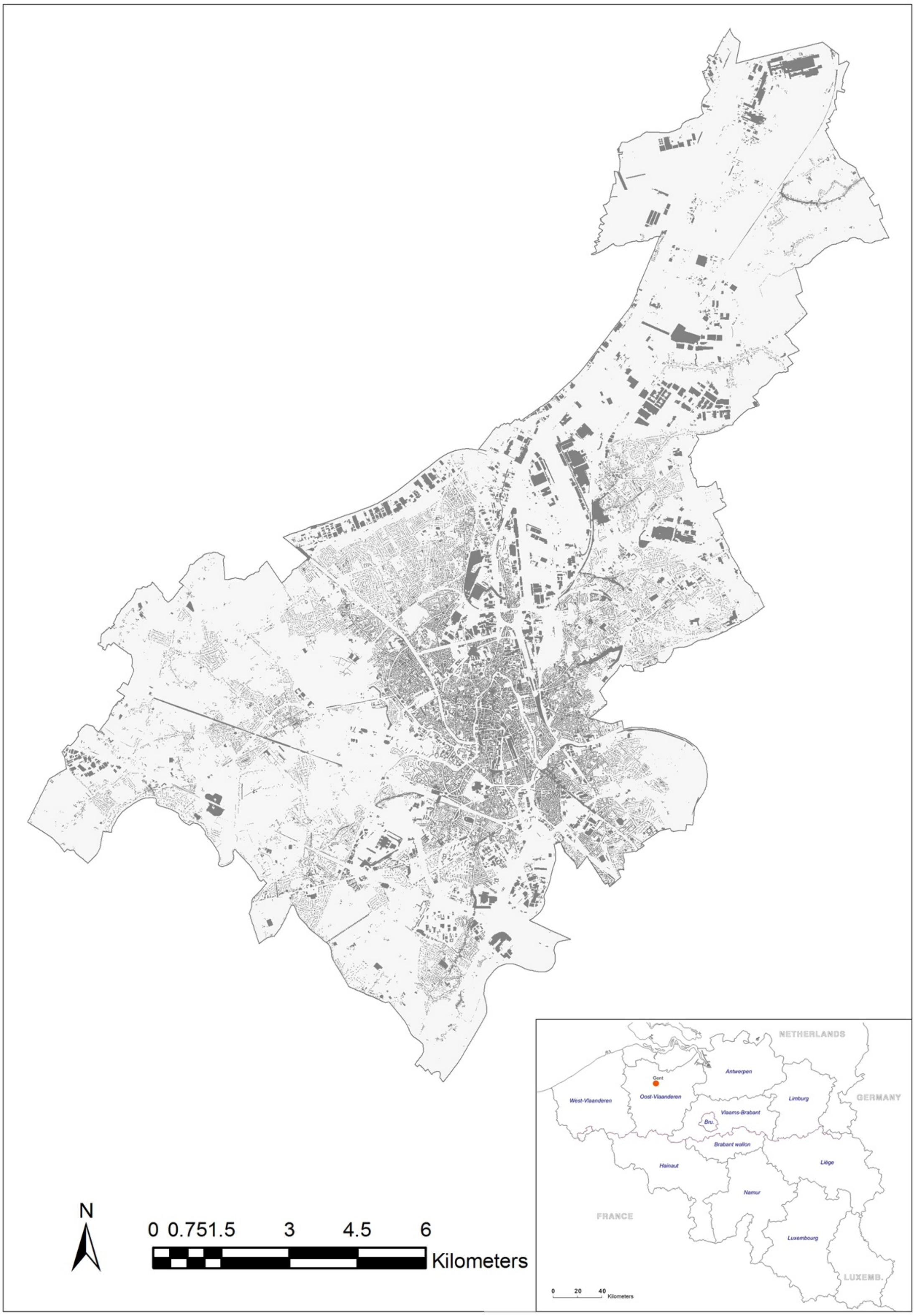


Figure 4-1 The city of Ghent. The grey blocks are built up area (Single- and multi-family residential areas, business areas and industrial areas) (Source: Flanders Information Agency, (2017)*, modified by the authors)*

The city of Ghent analyzed the water network, water nuisance and vulnerability in 2015. The results indicate that the center area is well-protected against river nuisance due to the canal system in (and around) Ghent. However, the city is fairly sensitive to water nuisance of the surface water body in the urban area. When intensive precipitation occurs, the drainage system is not able to cope with the water amount, which will result in surface water flooding. It might endanger human safety, damage the infrastructure and disrupt the service delivery. Climate forecasts show that extreme weather events will happen more frequently. By the end of this century, we expect that rainfall (which has occurred every hundred years) might take place every ten years instead. The city of Ghent has already highlighted the need for elements, such as bio-swales and rain gardens, to protect against surface water bodies. Ghent was one of the first cities in Flanders to sign the 'Mayors Adapt', the European Covenant of Mayors, in 2014. This adaption plan takes measures, such as eliminating impervious surface, retaining, or infiltrating water, to build a climate robust city.

3 A method to locate green infrastructure in order to mitigate the urban surface water flood risk

A GIS-based multi-criteria evaluation method was developed to identify priority areas to locate the green infrastructure by mitigating the flood risk on an urban scale. The approach could facilitate the green infrastructure being planned and situated on a location that enhances the urban resilience against the surface water flooding risk. The research of Crichton (1999) suggested that flood risks could be seen as a risk triangle interaction between hazards, vulnerability and exposure. Hazards refer to the frequency and severity of the flood events, vulnerability demonstrated the damage or loss of properties to the hazard and exposure reflects the properties exposed to the hazard. Furthermore, Kaźmierczak and Cavan (2011) analyzed the surface water flooding risks to communities and provided insight into the relations between vulnerability, hazard and exposure. The results suggested that the climate adaptation responses should consider the social and demographic characteristics of the population. Different studies have indeed indicated that the impact of the flood events goes significantly exceeds the physical water disturbance (Ramos et al., 2005; Rufat, Tate, Burton, & Maroof, 2015; Yin et al., 2016; Pregnolato, Ford, Glenis, Wilkinson, & Dawson, 2017). Therefore, considering the green infrastructure planning to build flood resilient cities should also count the flood impact on the socio-economic aspects. Three categories were included in the model to identify the priority areas for the green infrastructure planning, i.e., 1) hazard mitigation by identifying potential high stormwater runoff volume areas using the Rational Method; 2) vulnerability flooding receptors by identifying vulnerable neighborhoods with a high number of social flood vulnerable residents, flood-prone buildings and flood-prone road infrastructure; 3) exposure to flooding by identifying the sectors that lack green space (because the environmental context affects the people exposure to flooding). When combining these three groups of indicators, the neighborhoods with the highest priorities for green infrastructure planning have been identified. These three categories comprise five indicators: stormwater runoff mitigation, social flood vulnerable group, flood sensitive area road infrastructure protection, flood sensitive area buildings' protection and environmental justice (as shown in Table 4-1). We apply the linear scale transformation to standardize the values of all indicators from zero to ten. The linear transformation function is a standardization that uses the minimum and maximum values as scaling points for a simple linear transformation. The important weight of each indicator is defined by the Analytic Hierarchy Process (AHP) introduced by Thomas Saaty in 1980. The Analytic Hierarchy Process (AHP) is a measurement approach which functions through a pairwise comparison and relies on the judgements of experts to derive important weights of the variables. although the AHP method has the disadvantage that the number of pairwise comparisons might become very large (n (n−1)/2, n is the number of variables) and thus become a lengthy task, it proves useful to derive important weights of the variables in the model. The analytical unit is the statistical sector. The term 'statistical sector' was introduced by the National Institute of Statistics in 1970 and constitutes the smallest administrative entity (for which socio-economic data are available in Belgium). The city of Ghent has a total of 201 statistical sectors. The flowchart (summarizing the methodology and data sources applied in the case study of Ghent) is shown in Fig. 4-2.

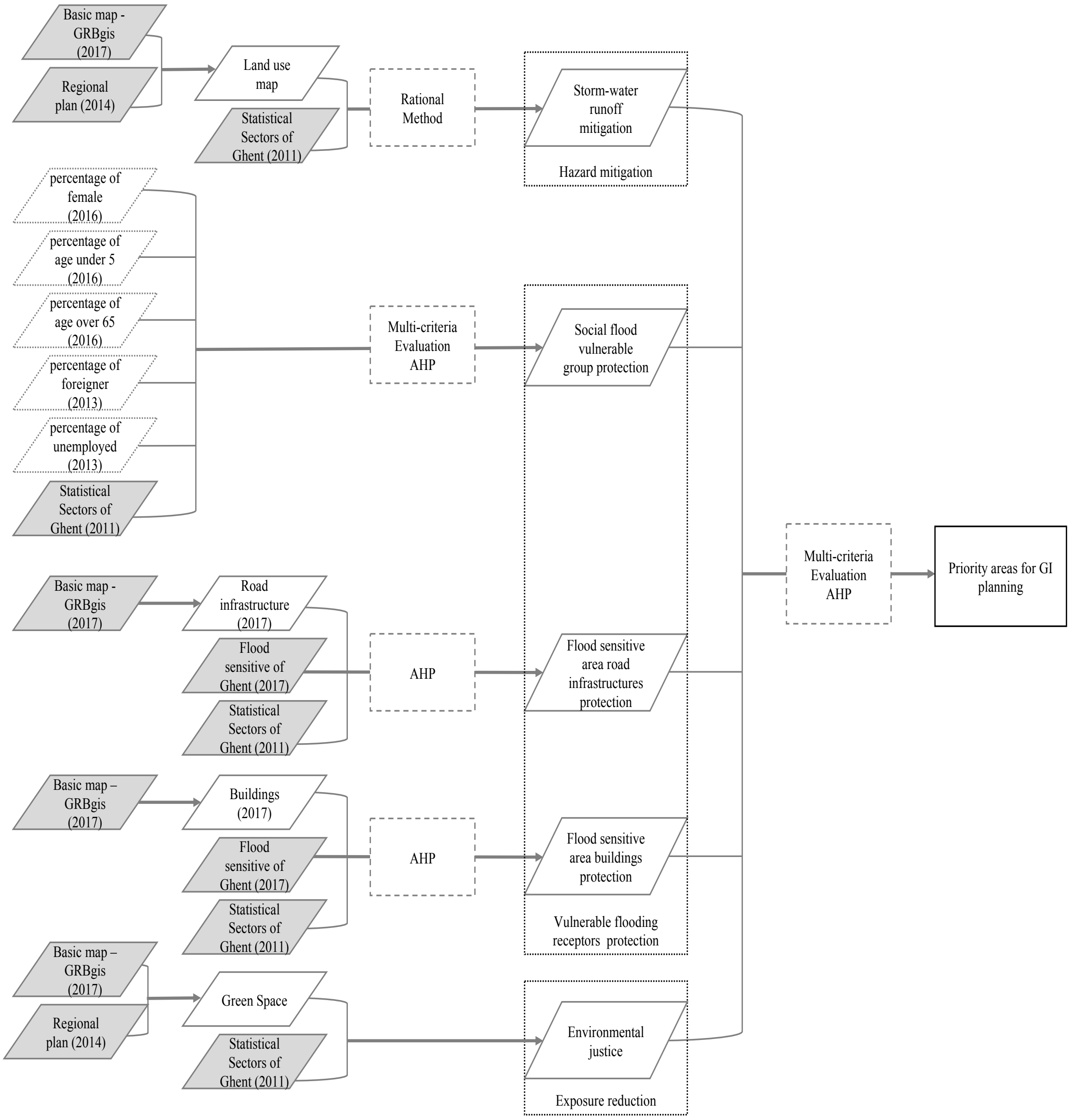


Figure 4-2 Flowchart summarizing the methodology applied in the city of Ghent (Grey rectangle shapes represent the original key data source, see the overview of datasets in Appendix B; rectangles in the dotted line represent the demographic data from the city of Ghent; squares in dotted lines represent the adopted measures; rectangles in a full line are layers that have been created or calculated from the original data. AHP: Analytic Hierarchy Process)

3.1 *Indicators to identify the priority areas for the green infrastructure planning*

Table 4-1 The measurements and data sources of the five model indicators

Category	Indicator	Measurement	Data sources
Hazard	Stormwater runoff	Rational method	Basic map - GRBgis (2017);

mitigation	mitigation		Regional plan (2014)
Vulnerable flooding receptors' protection	Social flood vulnerable group	Identify the spatial location of the social flood vulnerable population	Population Register in the City of Ghent (2016); Social Security, Labor Market and Social Protection Database (2013)
	Flood sensitive area road infrastructure protection	Identify the potential flood-prone road infrastructure	Basic map - GRBgis (2017); Flood-sensitive areas (2017)
	Flood sensitive area buildings' protection	Identify the potential flood-prone buildings	Basic map - GRBgis (2017); Flood-sensitive areas (2017)
Exposure reduction	Environmental justice	Identify the areas that are lacking the existing green space	Basic map - GRBgis (2017)

1. Stormwater runoff mitigation

The priority areas to mitigate hazards are defined by identifying the sectors with a potentially high stormwater runoff by means of the rational method. This method was originally proposed by Mulyany in 1850 (O'Loughlin, Huber, & Chocat, 1996). Because of the urbanization, the percentage of land covered by impervious surfaces had been increasing. The high percentage impervious coverage increased the surface runoff volume, (therefore) creating a combined sewer system overflow and a surface water flooding event, especially during heavy rainfall (Arnold & Gibbons, 1996). According to the rational method, each type of land use has a certain percentage of water runoff, which is called the runoff coefficient. The average value of the runoff coefficient of various surface types from Thompson's research (2006) is used in this study and visible in Table 4-2.

Table 4-2 Runoff coefficient

Description	**Runoff coefficient**
Single-family residential	0.40
Multi-family residential	0.65
Parks and open space	0.20
Business area	0.70
Governmental area	0.60
Industrial	0.80
Transportation and Utilities	0.85

Vacant and no structure	0.30
Water	0
Source: adapted by Thompson, 2006	

We first reassign the land use categories to match the categories of the runoff coefficient table and then multiply the runoff coefficient with the area percentage of the correlated type of land use (within each statistical sector). This indicator was assessed using the data of the statistical Sectors of Ghent (Flanders Geographic Information Agency, 2011), the regional plan of Ghent (Flemish Planning Agency for Environment, 2014) and the full map of Ghent (2017) (Flanders Information Agency, 2017a). The full map of Ghent grouped the existing land use data into four main categories, i.e. buildings, waterways, road networks and open areas. We documented the existing building functions based on the land use attributes from the regional plan (correction in 2014). The reassignment of the land use categories is shown in Table 4-3. This result is then standardized from 0 to 10, 10 representing the highest priority and 0 being the lowest.

Table 4-3 Reassignment of the land use categories

Categories in Runoff Coefficient	**Categories in original land use data**
Single-family residential area	Residential area; residential areas with a rural character; residential expansion areas; areas for urban development
Multi-family residential area	Residential areas with cultural; historical or aesthetical value
Parks and open space	Parks; housing parks; green areas; greening buffer zones; depots for nomads or caravan dwellers; natural areas; nature reserves (with scientific value); nature educational infrastructure; forest areas; agricultural areas; scenically valuable agricultural areas; valley areas, residual areas
Business area	Regional business parks with a public character; local business parks with a public character; areas for trade fair activities and large-scale cultural activities; office and service areas; special reservation areas
Industrial area	Industrial areas; areas for industrial expansion; areas for craft businesses and areas for small and medium-sized enterprises; exploitation areas; areas for seaports and water-bound companies
Transportation and Utilities	Roadways; railways; civil engineering constructions; areas for community facilities and public utilities; service areas; areas for day recreation; areas for (day and stay) recreation; areas for

	accommodation and renovations; teleport; motorways
Water	Water

2. Social flood vulnerable group

Social flood vulnerability groups refer to the comparative incapacity of residents to deal with the environmental hazards. Strategically located green infrastructure could reduce these social inequities. Various social flood vulnerable measures have already been proposed (Thrush et al., 2005; Villordon et al., 2014; Nkwunonwo, 2017). Rufat, Tate, Burton, & Maroof, (2015) reviewed the case studies and implementations concerning the measurements of the social vulnerability to flood events. The research indicated that the demographic characteristics and socio-economic statuses are among the most prominently measured characteristics regarding the social vulnerability to flooding. Based on the literature reviews, we selected five indicators (including the percentage of females, the percentage aged under 5, the percentage aged over 65, the percentage of foreigners and percentage of unemployed from 18 to 65 within each statistical sector). The data source to assess the social flood vulnerable neighborhoods are gathered from the Population Register of the city of Ghent of 2016 (The city of Ghent, 2016) and the Social Security, Labor Market and Social Protection Database of 2013 (The city of Ghent, 2013). The value of these five variables will be rescaled. The AHP (Saaty, 1980) was adopted to derive the important weights of these five demographic variables. Researches who have talks, interviews, exchange ideas with specific stakeholders, such as experts/ scientist specialized in demography, social vulnerability to flood events (in this context), are suggested to conduct the pairwise comparison of the importance of the demographic variables. While in this study, the pairwise comparison was conducted by the author based on the study of the literature. For instance, Zahran, Peek, & Brody (2008) indicated that children are considered more vulnerable to disasters than other social groups due to their physical size, psychological level and behavioral development, and complete or partial dependence on adults for various forms of support. Rufat et al., (2015) analyzed 67 flood disaster case studies (1997 – 2013) to identify the leading drivers of social vulnerability to damaging flood events. The results indicated that the demographic characteristics, e.g. age, race, gender, are the most frequently appearing indicators of social vulnerability in flood events, and the socio-economic status, e.g. income, have the second highest frequency. The frequency of the characteristic could be interpreted as a measure of importance (leading drivers of social vulnerability) in the flood events. (However, the author also indicated that it might also depend on the focus of the statistics) As shown in Table 4-4, the pairwise comparison of the importance of these five demographic variables was conducted, in which the importance of a variable (compared to all other variables) is expressed by a score (5 by 5 comparisons). Scores are given according to the scale proposed by Saaty. For instance, if variable A (e.g. percentage of age under 5) is more important than variable B (e.g. percentage of females), this relation is given a score of 3 to 9, depending on how much more important it is. If the variable A is less important than variable B the score will be 1/3 to 1/9. The weights are then calculated by normalizing the scores of the matrix by dividing each score by the sum of the variables' column. Finally, the weight of the variable is equal to the sum of the normalized values. They are then overlaid to generate the social flood vulnerable neighborhoods. The results will be standardized from 0 to 10, representing the priority neighborhoods so as to protect the socially vulnerable groups.

3. Flood sensitive area road infrastructure protection

The vulnerability receptors for flooding in this method not only includes the vulnerable residents but also the potentially flood-prone road infrastructure and buildings. The road network is particularly vulnerable to the pluvial flood events, which do not only involve the infrastructure damage but also the transportation disruption (Pregnolato, Ford, Wilkinson, & Dawson, 2017). More seriously, peer researches have indicated that almost half of the pluvial flood casualties involve people driving through flooded roadways or escaping the rapid rise of the open water (Drobot, Benight, & Gruntfest, 2007). The identification of the flood risk road infrastructure area is performed in GIS by overlaying the flood sensitive areas with the road network area, by means of the data on the flood sensitivity of Ghent (Flanders Information Agency, 2017b) and the existing road networks of Ghent (Flanders Information Agency, 2017a). The flood sensitive map contains the effective flood-sensitive areas and the possible flood-sensitive areas. The overlay generates three groups of road infrastructure, i.e. the effective flood-sensitive area road infrastructure, possible flood-sensitive area road infrastructure and non-floodsensitive area road infrastructure. The AHP was adopted to derive important weights of the three groups of road infrastructure. Researches who have talks, interviews, exchange ideas with specific stakeholders, such as urban planners, traffic engineers, members in urban planning institutes, members in transportation bureaus etc. (in this context), are suggested to conduct the pairwise comparison of the important weights of the three groups of road infrastructure to be protected against pluvial floods. In this part, the pairwise comparison was conducted by the author. Subsequently, the area percentage of each category of road infrastructure is calculated within the statistical sectors and then multiplied by its weight. The result is then standardized from 0 to 10, representing the priority neighborhoods to protect the flood sensitive area road infrastructure.

4. Flood sensitive area buildings' protection

Buildings are also vulnerable to flooding. It causes huge losses to objects and artworks that are attached to the buildings (Drdácký, 2010). The identification of the flood risk area buildings is defined by overlaying the flood sensitive map with buildings, using the data on flood sensitivity of Ghent (2017) and the existing buildings of Ghent (2017) (Flanders Information Agency, 2017a). The details of the calculation are the same for the identification of the priority neighborhoods to protect the flood sensitive area road infrastructure. The result is then standardized from 0 to 10, representing the priority neighborhoods to protect the flood sensitive area buildings.

5. Environmental injustice reduction

The land use and proportion of green space within a certain area influences the surface water behavior and therefore affects the exposure to flooding. Urban areas have a range of traditional green space features that are protected from development (and could act as natural buffers against storm surge). Priority neighborhoods could be defined by identifying the percentage existing green space within the sectors and thus indicate where the green infrastructure is lacking. So as to generate this dataset, our study calculates the percentage on total green area within each statistical sector, resulting in an estimation of sectors with less green space. The data used to assess this indicator are gathered from the regional plan of Ghent (2014) and the full map of Ghent (2017) (Flanders Information Agency, 2017a). We created a layer of open areas from the basic map of Ghent and then documented the function based on the land use attribution from the regional plan (correction in 2014). The green space counted in this case study includes parks, residential parks, green areas, greening buffer zones, depots for nomads or caravan dwellers, nature areas, forest areas, agricultural areas, valley areas and residual areas. Afterwards, the results (representing the priority neighborhoods to reduce the environmental injustice of flood exposure) were rescaled from 0 to 10.

3.2 *Overlay of five indicators*

One of the major criticisms is that the green infrastructure planning does not select indicators that determine the suitable location (Madureira & Andresen, 2014). The spatial policy for green infrastructure would be different depending on the favored indicators. Due to the existence of spatial synergies and conflicts between the five indicators, a spatial multi-criteria evaluation method will be adopted, overlaying the five indicators and representing the priority location of the green infrastructure. A spatial multi-criteria evaluation is a basic tool in GIS. The important weight of each five criteria will be defined by the Analytic Hierarchy Process. Stakeholders, such as urban planners, researchers specialized in social vulnerability to floods, researchers specialized in green infrastructure planning, can contribute to the pairwise comparison of the important weights of the five indicators to be protected against the floods. In this part, the pairwise comparison was conducted by the author. In the city of Ghent, hazard mitigation is considered more important than the vulnerable flooding receptors' protection and exposure reduction. According to the climate adaptation plan (2016-2019) of Ghent, the city would be fairly sensitive to the water nuisance of sewers in case of a T20 (statistically occurs once every twenty years) occurrence (Ghent Administration, 2016). In the current situation, precaution in mitigating runoff might have a higher weight than vulnerable receptors' protection, while the weights of each indicators would change as the situation evolves.

4 Results and discussion

The layers created by means of the demographic data from Ghent are shown in Fig. 4-3, i.e. the percentage of females (Fig. 4-3a), percentage of people aged under 5 (Fig. 4-3b), percentage of individuals aged over 65 (Fig. 4-3c), percentage of foreigners (which means non-EU and non-Turk & Maghreb and originally from other countries) (Fig. 4-3d) and percentage of the unemployed from age 18 to 65 (Fig. 4-3e) within each statistical sector.

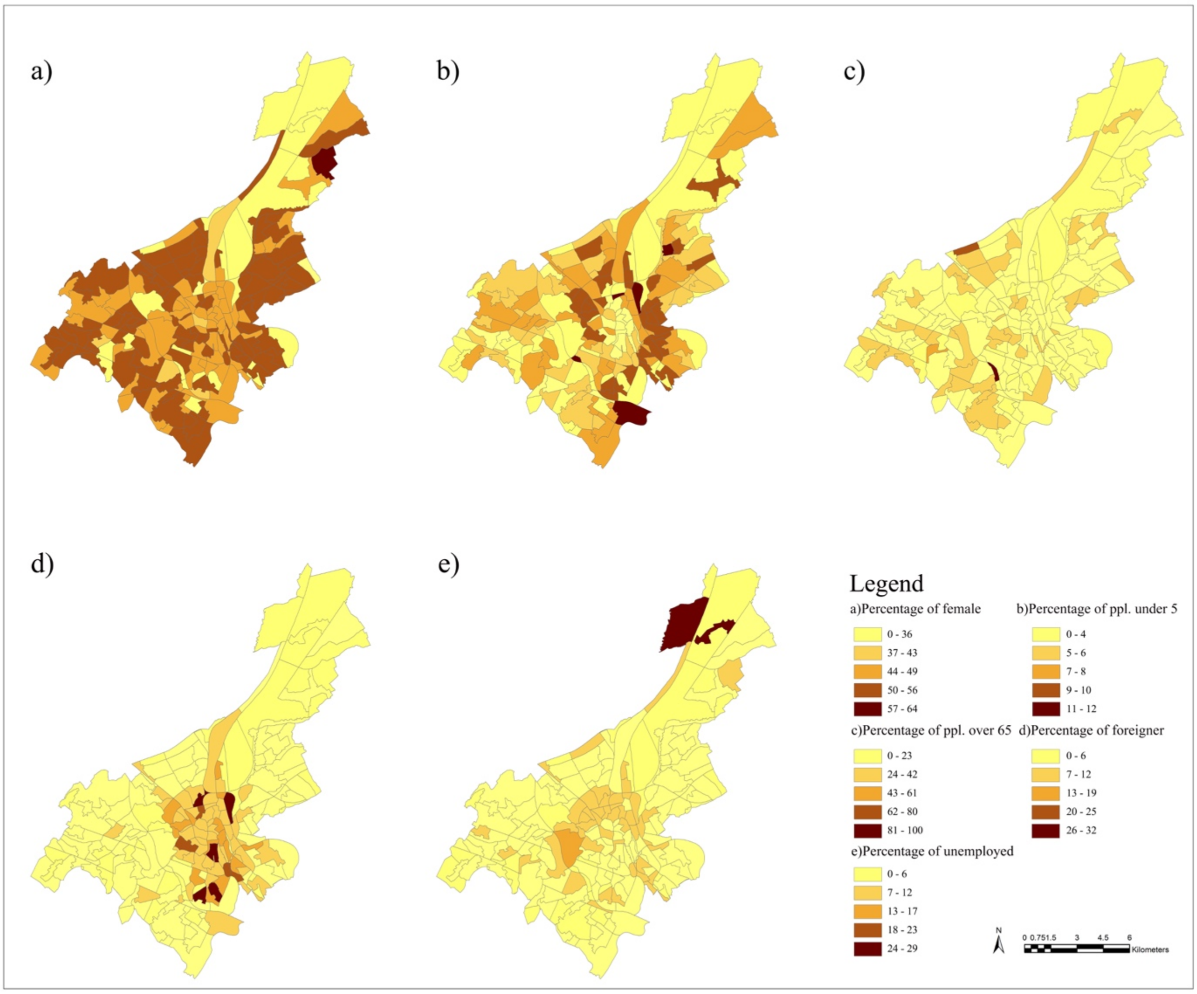


Figure 4-3 Social Flood Vulnerable Neighborhoods across the City of Ghent (Map (a) presents the percentage of females; map (b) and (c) present the population aged below 5 and over 65 respectively; map (d) represents the percentage of foreigners (non-EU and non-Turk & Maghreb and originally from other countries); map (e) shows the percentage of the unemployed from 18 to 65)

The population density in Ghent is 1,638 people per square kilometer. The percentage females is in general spatially distributed across the city of Ghent (Fig. 4-3a). The sectors characterized with a high percentage in population under 5 and over 65 are scattered through the sub- and peri-urban areas (Fig. 4-3b&c), while sectors with a high percentage of foreigners are concentrated around the town center (Fig. 4-3d). The high percentage of unemployed is located in the northern areas around the town center and some edging sectors of Ghent (Fig. 4-3e). The weights of the five demographic indicators are defined by using the Analytic Hierarchy Process, as shown in Table 4-4. In our calculations (Table 4-4), percentage of age under 5 and percentage of age over 65 were considered to be the most decisive variables (total weight of 0.75). The percentage of females, percentage of foreigners and percentage of unemployed have weights of 0.04, 0.08 and 0.13, respectively. The five demographic variables were overlaid, resulting in a social flood vulnerability map for the case study area:

Social flood vulnerable group map = 0.04 * percentage of females' map + 0.50 * percentage of aged under 5 map + 0.25 * percentage of aged over 65 map + 0.08 * percentage of foreigners' map + 0.13 * percentage of the unemployed map

Table 4-4 Calculation of the weights based on the Saaty's matrix for the determination of the important weights of the five demographic variables

(a)	**percentage of females**	**percentage aged under 5**	**percentage aged over 65**	**percentage foreigners**	**percentage unemployed**
percentage of females	1	1/9	1/7	1/3	1/3
percentage aged under 5	9	1	3	5	5
percentage aged over 65	7	1/3	1	3	3
percentage foreigners	3	1/5	1/3	1	1/3
percentage unemployed	3	1/5	1/3	3	1
Sum	23	83/45	101/21	37/3	29/3

(b)	**percentage of female**	**percentage of age under 5**	**percentage of age over 65**	**percentage of foreigners**	**percentage of unemployed**	**Weight**
percentage of females	0.05	0.06	0.03	0.03	0.03	**0.04**
percentage ages under 5	0.39	0.54	0.62	0.41	0.53	**0.50**
percentage aged over 65	0.30	0.18	0.21	0.24	0.31	**0.25**
percentage of foreigners	0.13	0.11	0.07	0.08	0.03	**0.08**
percentage of the unemployed	0.13	0.11	0.07	0.24	0.10	**0.13**

The weights to define the importance of the three groups on road infrastructure and buildings, i.e. the non-flood sensitive area, possible flood-sensitive area and effective flood-sensitive area are shown in Table 4-5. In our calculations (Table 4-5), the effective flood-sensitive area road infrastructure/buildings was considered as the most decisive variable (weight of 0.71). No flood-sensitive area road infrastructure and possible flood-sensitive area road infrastructure have weights of 0.05 and 0.24. The three maps were overlaid, resulting in the priority neighborhoods of the flood sensitive areas' road infrastructure and buildings' protection:

The priority neighborhoods of the flood sensitive areas road infrastructure and buildings' protection map = 0.05 * No flood-sensitive area road infrastructure/buildings' map + 0.24 * possible flood-sensitive area road infrastructure/buildings' map + 0.71 * effective flood-sensitive area road infrastructure/buildings' map.

Table 4-5 Calculation of the weights based on the Saaty's matrix for the determination of important weights of the three flood-sensitive areas

(a)	**no flood-sensitive area road infrastructure/buildings**	**possible flood-sensitive area road infrastructure/buildings**	**effective flood-sensitive area road infrastructure/buildings**
no flood-sensitive area road infrastructure/buildings	1	1/7	1/9
possible flood-sensitive area road infrastructure/buildings	7	1	1/5
effective flood-sensitive area road infrastructure/buildings	9	5	1
Sum	17	43/7	59/45

(b)	**no flood-sensitive area road infrastructure/ buildings**	**possible flood-sensitive area road infrastructure/ buildings**	**effective flood-sensitive area road infrastructure/ buildings**	**Weight**
no flood-sensitive area road infrastructure/ buildings	0.06	0.02	0.08	**0.05**
possible flood-sensitive	0.41	0.16	0.15	**0.24**

area road infrastructure/ buildings				
effective flood-sensitive area road infrastructure/ buildings	0.53	0.82	0.77	**0.71**

The mapping results of the five indicators are shown as follows: stormwater runoff mitigation (Fig. 4-4a), social flood vulnerable group (Fig. 4-4b), flood sensitive area road infrastructure protection (Fig. 4-4c), flood sensitive area buildings' protection (Fig. 4-4d) and environmental justice (Fig. 4-4e).

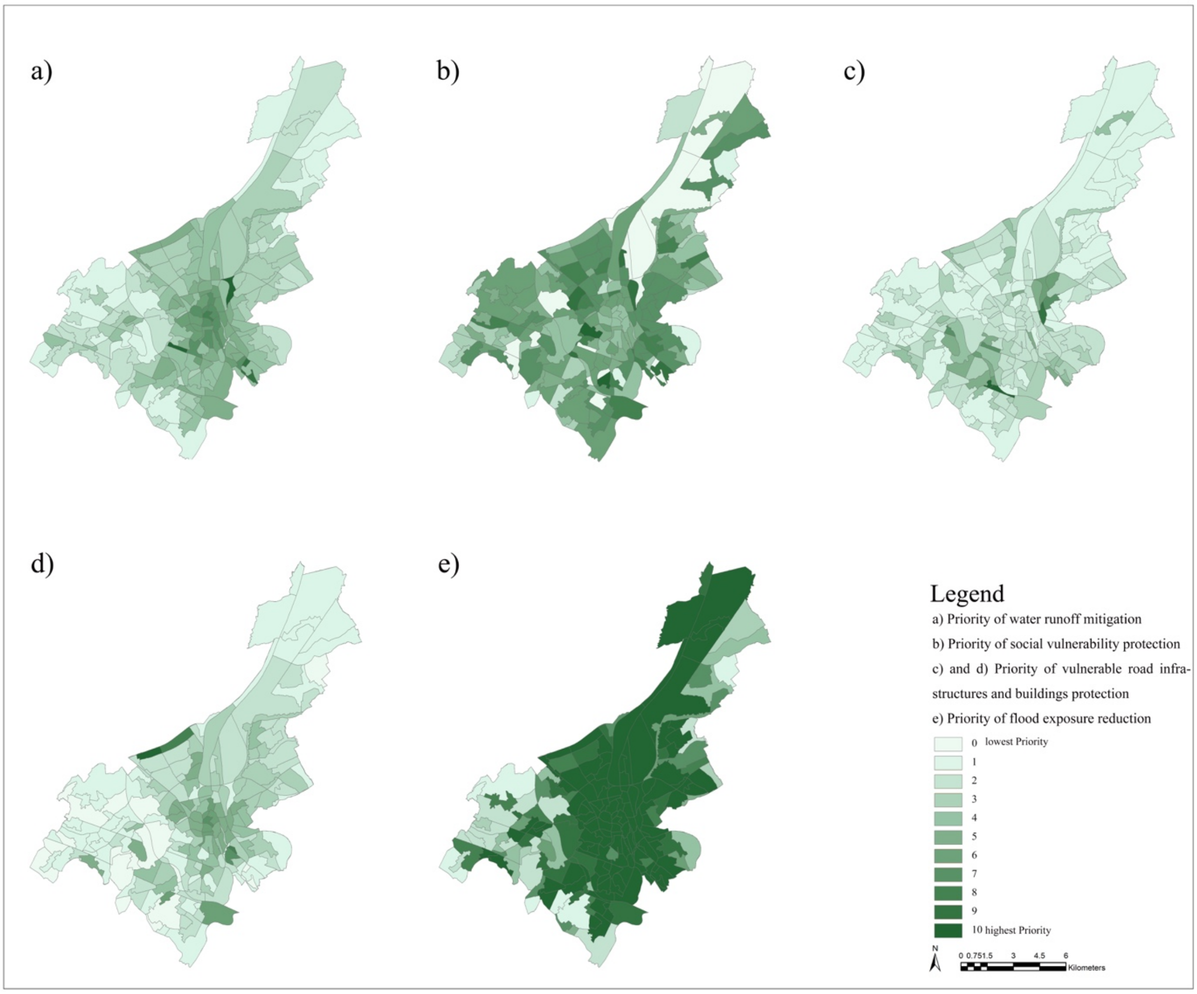


Figure 4-4 Priority neighborhoods defined by the five indicators (Map (a) presents the priority neighborhood of the stormwater runoff mitigation; map (b) presents the priority neighborhood of the social flood vulnerable group protection; map (c) and (d) represent the priority neighborhood of the flood sensitive areas road infrastructure and buildings' protection; map (e) presents the priority neighborhood of the flooding exposure reduction)

The priority neighborhoods to mitigate the water runoff are concentrated in the built-up areas of Ghent, which is determined by factors that are associated with land use and surface hardening (Fig. 4-4a). The social flood vulnerable groups are spatially distributed across the city of Ghent (Fig. 4-4b). The high priority neighborhoods (to protect the flood sensitive areas' road infrastructure) are located around the suburban areas (Fig. 4-4c), while the priority to protect buildings is concentrated in the town center (Fig. 4-4d). Sectors located downtown share a low percentage green space, representing a higher exposure to flood hazards (Fig. 4-4e). The weights of the five criteria are defined by using the Analytic Hierarchy Process (as shown in Table 4-6). In our calculations (Table 4-6), the stormwater runoff mitigation and social flood vulnerable group factors were considered to be the most decisive indicators (total weight of 0.70)., flood sensitive area road infrastructure protection, flood sensitive area buildings' protection and environmental justice possess weights of 0.17, 0.09 and 0.04, respectively. The five indicators were overlaid, resulting in priority Neighborhoods to Locate the Green Infrastructure:

The priority neighborhoods to Locate the Green Infrastructure map = 0.45 * stormwater runoff mitigation map + 0.25 * social flood vulnerable group map + 0.17 * flood sensitive area road infrastructure protection map + 0.09 * flood sensitive area buildings' protection map + 0.04 * environmental justice map

Table 4-6 Calculation of the weights based on the Saaty's matrix for the determination of the important weights of five indicators

(a)	**stormwater runoff mitigation**	**social flood vulnerable group**	**flood sensitive area road infrastructure protection**	**flood sensitive area buildings' protection**	**environmental justice**
stormwater runoff mitigation	1	3	3	5	7
social flood vulnerable group	1/3	1	3	3	5
flood sensitive area road infrastructure protection	1/3	1/3	1	3	5
flood sensitive area buildings' protection	1/5	1/3	1/3	1	3

environmental justice	1/7	1/5	1/5	1/3	1
Sum	211/105	73/15	113/15	37/3	21

(b)	**stormwater runoff mitigation**	**social flood vulnerable group**	**flood sensitive area road infrastructure protection**	**flood sensitive area buildings' protection**	**environmental justice**	**Weight**
stormwater runoff mitigation	0.50	0.61	0.40	0.41	0.33	**0.45**
social flood vulnerable group	0.17	0.21	0.40	0.24	0.24	**0.25**
flood sensitive area road infrastructures protection	0.17	0.07	0.13	0.24	0.24	**0.17**
flood sensitive area buildings protection	0.10	0.07	0.04	0.08	0.14	**0.09**
environmental justice	0.06	0.04	0.03	0.03	0.05	**0.04**

Using GIS S-MCE, we overlay the results of the five criteria. This generates a map of priority neighborhoods for the green infrastructure planning in mitigating the urban surface water flooding risk in the city of Ghent (Fig. 4-5).

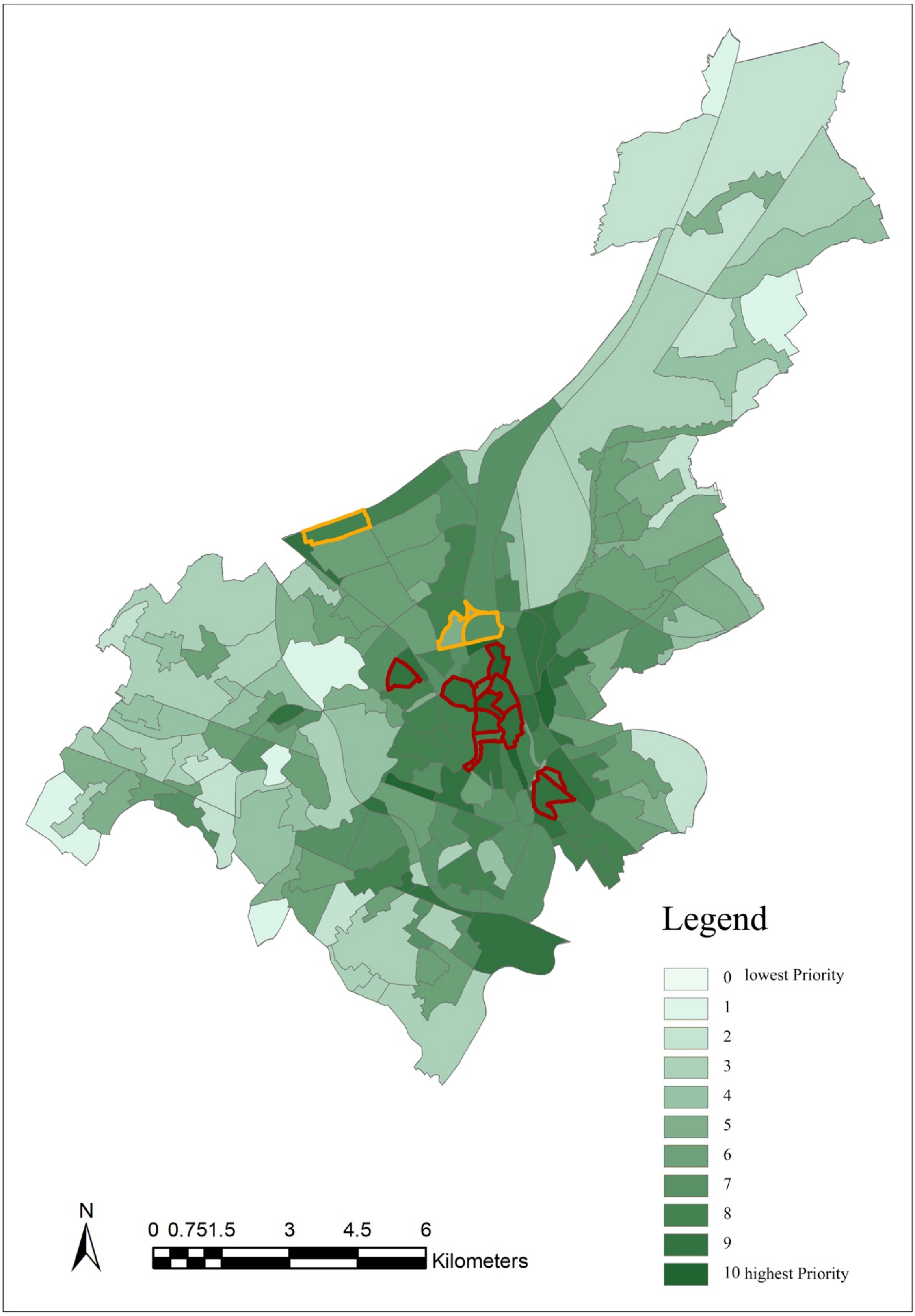


Figure 4-5 Priority neighborhoods to locate the green infrastructure to mitigate the flood risk (Sectors with a dark red edge have more than 50 percent single- and multi-family areas; sectors with an orange edge have more than 30 percent business and industrial areas)

The results reveal that some neighborhoods have a larger need for green infrastructure than other city parts concerning the urban surface water flood risk alleviation. An interpretation of the results reveals that the location of the current green space across the city does not align with most priority areas identified by this method (Fig. 4-5). The current green space is mainly concentrated in the south-west suburban areas of Ghent (Fig. 4-4e). The city climate adaption plan of 2016-2019 has claimed that water management is one of the most important issues for Ghent (to become a climate robust city (Ghent Administration, 2016)). Yet the existing green space is not located in the areas needing it the most. For instance, neighborhoods located downtown, such as Zuidpark, De Kuip, Sint-Pieters etc. are considered to have higher priority to locate the green infrastructure for providing stormwater management functions. The relation between the urban land use, spatial structure and priority sectors could guide the green infrastructure planning and design. Depending on the sector type (proportion of different land-use categories), it might be necessary to invest in different types of green infrastructure. For example, the sectors indicated with dark red edges (Fig. 4-5) represent regions/areas with more than 50 percent single- and multi-family areas, suggesting that the small-scale green infrastructure constructions such as green roofs, green walls and rain gardens. Wetlands need large areas and could become mosquito breeding grounds or drowning hazards could not be properly implemented in high-density residential areas. The sectors indicated with orange edges stand for areas with more than 30 percent business and industrial regions, suggesting large-scale green infrastructure constructions such as urban parks, urban forests, etc.

In this study, the selection of the social flood vulnerability indicators is based on the existing studies of the most prominent measures. The green infrastructure implementation applied in other cities could further involve interviews with local administrators and consultations with the local social and health professionals so as to get a deep understanding of the local context. The green infrastructure planning method in our research focuses on the urban surface water flooding risk mitigation. However, there is a growing body on literature review that is supporting the multi-benefits of green infrastructure, which highlights that the green infrastructure planning should not only consider water management (Demuzere et al., 2014; Wang & Banzhaf, 2018). Although we are aware of this, our method proves nevertheless useful for the urban planners, designers and administrators. It enables to identify the location in which green infrastructure has the biggest potential to foster the social and economic resilience against flood hazards, especially for cities that mainly aim at reducing the waterlogging. For instance, many cities in China are suffering from urban flood events, targeting to mitigate the urban flood risk by adopting green infrastructure under a 'Sponge City' policy. Also, one of the main goals of the green infrastructure planning in Ghent is to enhance the resilience of the city against flood risks in the future (Ghent Administration, 2016). The method proposed in this study can be combined with other potential functions based on the local context analysis of local authorities involved in the green infrastructure planning. Furthermore, there is an urgent need for research of the green infrastructure typology of water regulation benefits, plant ecophysiology, water use and site requirements. This will inform the spatial selection of the green infrastructure, which is significant for a successful implementation.

5 Conclusions

The progress of climate change and expansion of the urban populations make it increasingly important to mitigate the urban surface flood risk. The urban green infrastructure policy should always possess an important strategy for the planning of climate change adaptation due to the great effectiveness in alleviating the stormwater runoff and in maintaining the sustainability and resilience of the city.

Despite the increasing amount of green infrastructure practices to cope with climate extremes events in the urban areas, the quantitative approaches remain limited and less adopted by the city planners. We propose a quantitative method in this chapter to cope with the flood risk management in urban areas through the identification of priority neighborhoods. We initially applied the method to the city of Ghent but the latter is designed to be applicable to other cities. It includes five criteria, which contain the stormwater runoff mitigation, social flood vulnerable group protection, potential flood-prone areas road infrastructure protection, potential flood-prone areas buildings' protection and the flooding exposure inequities' reduction. This approach facilitates the urban planners, administrators and stakeholders to effectively plan green infrastructure in the areas that are most appropriate to alleviate the surface water flooding risk and to integrate the green infrastructure planning into the urban land use planning.

Chapter 5 Investigating the current green action projects of Ghent with the spatial priority sites for new planning green infrastructure technologies

1 Introduction

Like most cities, Ghent is susceptible to the effects of climate change. According to the MIRA climate report of 2015, the number of days with heavy precipitation (1951- 2013) and the maximum amount of precipitation in 5, 10, and 15 days (1880-2013) have increased significantly in Belgium (Flanders Environment Agency, 2015). The number of problematic floods has significantly risen in Belgium since the 1970s (Flanders Environment Agency, 2015). Climate change is one of the factors responsible for the flood issue increase. The rise in population and welfare determines the damage caused by floods to a large extent. Ghent is home to a vast group of residents (262,219 inhabitants, 1,677 inhabitants/km^2), including an at-risk population such as the elderly and small children. In 2015, the city of Ghent analyzed the water network, water nuisance and vulnerability. The water nuisance includes two types: the water nuisance from waterways after intensive precipitation that exceeds the capacity of the riverbeds (fluvial floods) and the water nuisance caused by sewers after extreme showers (pluvial floods), a phenomenon that is more typical during summer. The results indicate that the center is well-protected against river nuisance due to the canal system in and around Ghent. The most frequent form of water nuisance in the city is water flowing onto the streets (Ghent Administration, 2016). In certain areas, the sewer systems are unable to cope with the precipitation as the shower intensity is too heavy. When intensive precipitation occurs, the drainage system is not able to deal with the water amount, which will result in surface water flooding.

In the framework of the urban water issue, a better water management is one of the most important aims of Ghent. Ghent was one of the first cities in Flanders to sign the European Covenant of Mayors 'Mayors Adapt' for the adaptation to climate change (European Covenant of Mayors, 2014) and the city is working on the development of a climate robust city. The adaptation takes place by focusing on green and water within the city, including eliminating the hardened surfaces, retaining water and allowing it to infiltrate. Ghent has highlighted the necessity to maximize the city's sponge effect (Ghent Administration, 2016).

The term ‘sponge effect’ refers to the local catchment, retention, re-usage, infiltration of buffering and delayed drainage of rainwater (see chapter 2). This means that there will be no drainage of the rainwater under normal circumstances but that all rainwater from the buildings and hardened surfaces is treated on-site, i.e. locally retained, used or gradually returned to the surrounding nature via above-ground infiltration solutions. The city of Ghent focuses on four points to maximize the sponge effect, i.e. (1) fewer hardened surfaces; (2) permeable pavements in car parks, driveways, residential plots and alleys without heavy transport; (3) green footpaths; (4) infiltration solutions, i.e. bio-swales, bio-retention, etc. (as explained in the section of types of green infrastructures in chapter 1). It is important that these greening measures regarding the climate adaptation will also be integrated into the city policy plans and infrastructure planning and implementation processes. In 2012, the city of Ghent developed a Green Action Plan, providing information on the location where actions (on the urban environment adaptation to climate change) should be taken in the city (Groendienst Stad Gent, 2012). The Green Action Plan provides information on the locations where the actions will be taken so as to maximize the benefits that could be delivered by the green infrastructures. The Green Action Plan of Ghent (2012) has in total 43 green action projects.

This chapter aims to investigate to what extent the current green action projects of Ghent (2012) are being planned in the priority areas (so as to optimize the benefits of the urban surface water flooding risk mitigation). Two aspects are investigated, i.e. whether the green action projects of Ghent (2012) are being planned in the priority areas, and where the neighborhoods that have a high priority for green infrastructure planning but are not planned with green action projects. Two green action projects that are located in high priority areas (identified in chapter 4) are selected as case studies to provide green infrastructure technologies recommendation at the neighborhood scale. These two case studies can provide a springboard for filling gaps between the analysis (methodology in chapter 4 to identify priority areas to place green infrastructure technologies) and real-live practices (provide potential green infrastructure technologies recommendations in high priority areas on site). The results can provide suggestions for green infrastructure planning and ensure help to address one of the key issues of Ghent so as to build a climate robust city.

2 Methods

The method includes two steps: 1) to assess whether the current green action projects are being put in the priority areas (generated in chapter 4) to mitigate the urban surface water flooding risks; 2) to map where the high priority neighborhoods currently without the green action projects. The relationship between the location of the current green action projects of Ghent (2012) and the mapping results of priority neighborhoods to plan green infrastructure technologies (generated in chapter 4) were investigated using spatial analysis technique, i.e. overlaying. This chapter uses the data of the Green Action Plan of Ghent 2012 (Groendienst Stad Gent, 2012), the priority neighborhoods for the green infrastructure implementation to mitigate the urban surface flooding risks (generated in chapter 4) and the aerial image of the study area (Esri, USGS, 2019). In total there are 43 projects of the Green Action Plan of Ghent (2012). The priority neighborhoods to mitigate the urban surface water flooding risks by new planning green infrastructure technologies were generated in chapter 4, with 0 representing the lowest priority and 10 the highest priority (Fig. 4-5). The priority areas were identified based on five indicators (chapter 4), i.e. storm-water runoff mitigation, social flood vulnerable group protection, flood sensitive areas road infrastructure, flood sensitive areas buildings protection, and flooding exposure reduction. The Green Action Plan of Ghent (2012), the priority sites (to introduce green infrastructure technologies), and aerial images of the study area are overlaid to analyze whether the green action projects of Ghent are being planned in the areas to optimize the benefits of the urban surface flooding risk mitigation, as shown in Fig. 5-1.

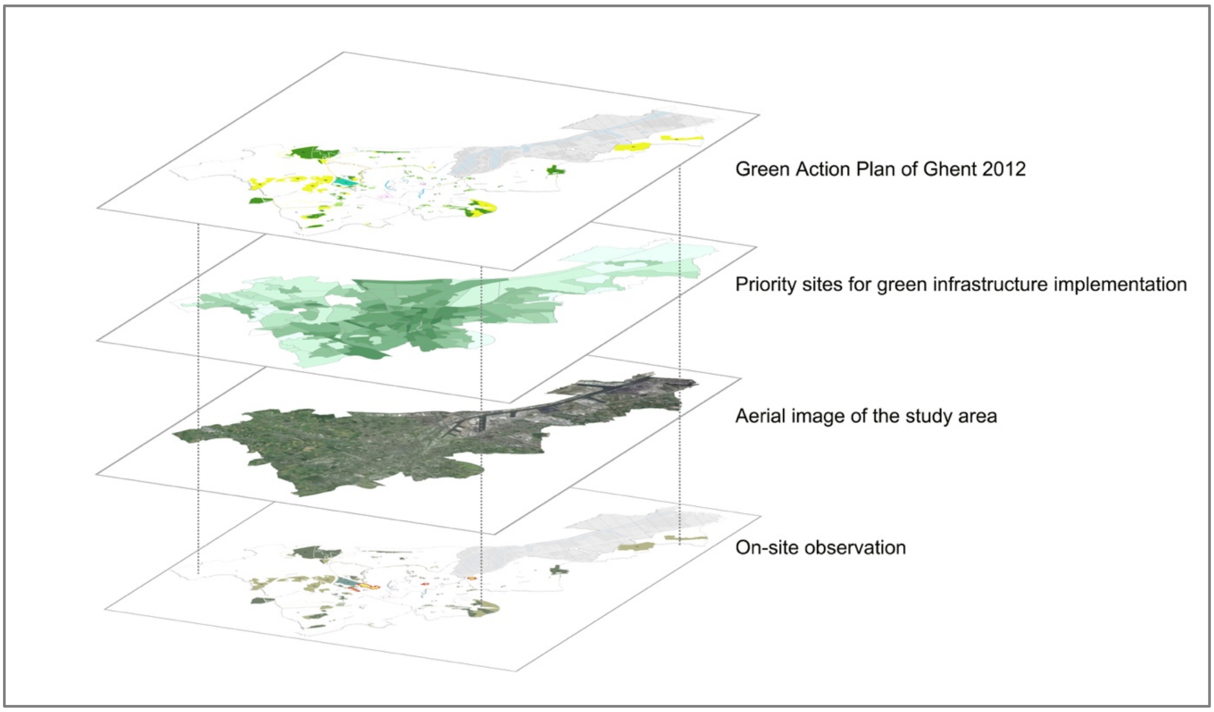


Figure 5-1 Overlay of the Green Action Plan of Ghent 2012, priority sites for the green infrastructure implementation and aerial image of the study area

The priority scores of the neighborhoods in which a certain green action project is located were obtained using an overlaying technique. The results of the priority scores of the 43 green action projects were then used to generate the histogram figure. A histogram shows the distribution of the priority scores of the green action projects. The spatial priority scores of the 43 green action projects were classified into three groups, i.e. 1-3, 4-7, and 8-10. Three projects of the low priority group, three projects of the median, and two projects of the high priority groups were selected as case studies. The selection of case studies represents a broad geographic distribution across Ghent, including the high building density downtown areas, low building density suburban areas, etc. Afterward, potential green infrastructure technologies recommendation is provided for the two projects of the high priority groups. Green infrastructure technologies proposed by the city of Ghent (Ghent Administration, 2016), such as green roofs, water-permeable surface hardening in the car parks, driveways (without heavy transport), residential plots, rain garden, vegetative swale, fewer hardened surfaces, are used to provide green infrastructure recommendations on site (for the two high priority study case areas). For each of the site, the spatial structure, an area-covering plan document as well as the calculation of the potential runoff reduction effect of the proposed green infrastructure technologies is done.

An empirical model from the study of Collins, Hirschman, Hoffmann, & Schueler (2009) was used to calculate the potential stormwater runoff reduction amount of the proposed green infrastructure technologies (Formula 1). The formula includes three variables, i.e. precipitation, runoff reduction rate, area of the proposed green infrastructure technologies. The average annual precipitation in Ghent is 754 mm (AM Online Projects, n.d.). The reduction rate means the percentage of the stormwater volume reduced through green infrastructure technologies. The reduction rate of the proposed green infrastructure technologies was derived from literature review (Table 5-1). Zhang et al., (2015) investigated the capacity of green roofs to reduce stormwater runoff and the results showed that the green roof can effectively retain runoff, ranging from 35.5% to 100%, with an average reduction rate of 77.20%. Therefore, the average annual runoff reduction volume of the proposed green roof per square meter in Ghent is 0.58 m^3. Liu, Li, & YU (2020) investigated the hydrology performance of two types of permeable pavements. The results indicated that these two types of permeable pavements can reduce stormwater volume by 40.2% and 41.9%, respectively. This study used the average reduction rate of these two types of permeable pavements, i.e. 41.05%, to calculate the runoff reduction volume of the proposed permeable pavement. Therefore, the average annual runoff reduction volume of the proposed permeable pavement per square meter is 0.31 m^3. Hou et al., (2020) evaluated the runoff reduction capacity of rain gardens and the result indicated that the runoff reduction rate of rain gardens was ranging from 31.89% to 100%, with an average reduction rate of 65.95%. The average annual runoff reduction volume of the rain garden per square meter is 0.50 m^3. Shafique, Kim, & Kyung-Ho (2018) investigated the rainfall runoff reduction capacity of vegetative swales and the results suggested that the reduction rate of vegetative swales was ranging from 40% to 75%, with an average reduction rate of 57.50%. The average annual runoff reduction volume of vegetative swale per square meter is 0.43 m^3.

Table 5-1 The runoff reduction rate of the proposed green infrastructure technologies

Proposed green infrastructure technologies	**Runoff reduction rate**	**Runoff reduction per square meter (m^3/m^2)**
Green roofs	77.20%	0.58
Permeable pavements	41.05%	0.31
Rain gardens	65.95%	0.50
Vegetative swale	57.50%	0.43

Source: Zhang et al. (2015), Liu et al. (2020), Hou et al. (2020), Shafique et al. (2018)

$$R_i = P * y_i * A_i \quad (1)$$

R_i is the volume of the stormwater reduction of the i^{th} proposed green infrastructure technology.

P demonstrates the average annual precipitation.

y_i stands for the stormwater reduction rate of the i^{th} proposed green infrastructure technology.

A_i is the area of the i^{th} proposed green infrastructure technology.

Formula (2), refers to the total stormwater reduction amount of all the proposed green infrastructure technologies.

$$TR = \sum_{i=1}^{n} R_i \quad (2)$$

TR is the total stormwater reduction amount of all the proposed green infrastructure technologies.

R_i shows the stormwaterreduction amount of the i^{th} proposed green infrastructure technology.

3 Results

3.1 *The extent to which the current green action projects fulfill the needs to mitigate the urban surface water flooding risks*

As shown in Fig. 5-2, the histogram represents the distribution of the priority scores of the green action projects. For the green action projects with more than one corresponding spatial priority score, the average value (rounding) will be taken. The figure shows that most of the green action projects are located in the areas with a priority score of 6, 7, 8, and 9.

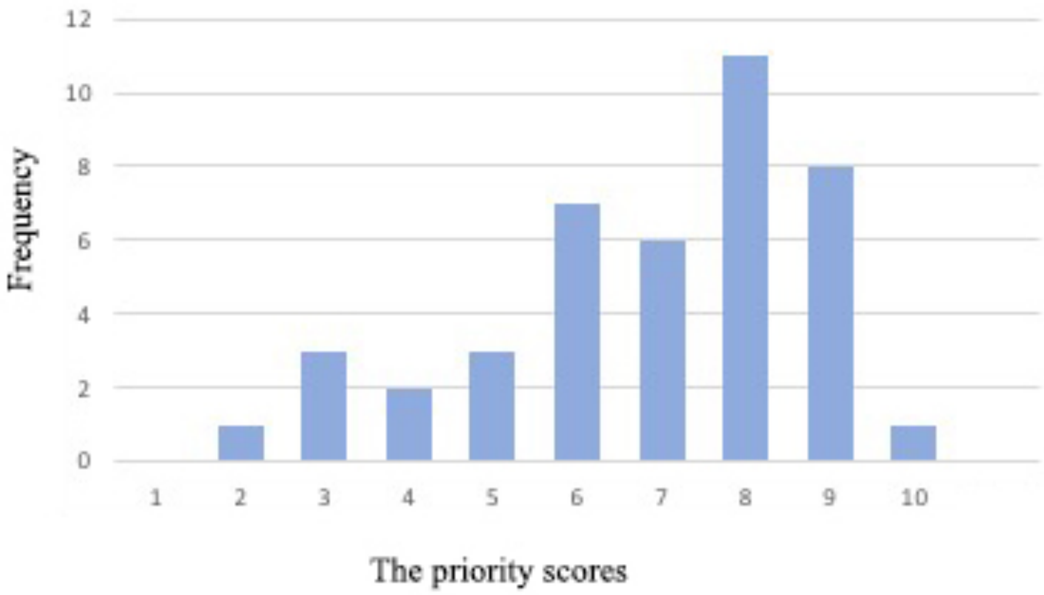


Figure 5-2 The histogram of the corresponding spatial priority scores of the green action projects, the project of Groenas 1 Oostakker: Bufferzone Volvo (26) has not been counted in the histogram due to the data unavailability

Table 5-2 shows the results of the spatial corresponding priority scores of the green action projects. The results showed that most of the green action projects in Ghent are planned in the areas so as to optimize the benefits of the urban surface water flooding risks' mitigation.

*Table 5-2 The priority scores of the corresponding spatial location of the green action projects (a bold * represents that certain green action projects are mainly located in this priority area and (*) that for other scores, there are no data available for 26. Groenas 1 Oostakker: Bufferzone Volvo)*

Green action projects	**The priority scores for the green infrastructure implementation to mitigate the urban surface water flooding risks**									
	1	2	3	4	5	6	7	8	9	10
1. Baudelohof									*	
2. De Lieve									*	
3. Citadelpark						*				
4. Rabotpark/ Trambrugsite/ Gasmetersite							*	(*)		(*)
5. Park De Vijvers								*	(*)	
6. Westeringsspoor								*		
7. Azaleapark						*			*	
8. Watersportbaan/								*		

Neermeersen										
9. Arbedpark Zuid									*	
10. Sint-Baafskouterpark/ Rozebroeken					*	(*)				
11. ACEC-park								*		
12. Park Betoncentrale Oude Dokken									*	
13. Wijkpark Achterdok Oude Dokken									*	
14. Rijsenbergpark								(*)		*
15. Papiermolenstraat							*			
16. Wolterslaanpark									*	
17. Duifhuispark							*			
18. Bloemekenspark					*			(*)		
19. Vogelzang, tuin Villa Voortman, speelterrein Tolhuis, Tuin van Kina							*			(*)
20. Groenas 1 Oostakker: Groene Banaan							*		*	
21. Achtervisserij								*		
22. Coupure								*		
23. Groenpool Oud Vliegveld		*			*					
24. La Sapiniere								*		
25. Westveldpark						*				
26. Groenas 1 Oostakker: Bufferzone Volvo	-									
27. Groenpool Gentbrugse Meersen		*			(*)	(*)		(*)		
28. De Porre								*		
29. Papeleupark									*	
30. Groenpool Parkbos		*	*			*			*	
31. Nieuw Gent								*		
32. Wijkpark Hekers						*				
33. Eiland Zwijnaarde									*	
34. The Loop/ Bos Maria Middelares						(*)	*			
35. Overmeers						*				
36. Paul van Tieghem de ten Berghepark						*			(*)	

37. Vyncke Bovyn						*				
38. R4 Buffer						*			(*)	
39. UCO Site De Lieve Wondelgemse Meersen							*			
40. Groenpool Vinderhoutse Bossen			*		(*)					
41. Stedelijk groengebied Bourgoyen-Ossemeersen-Malem Halfweg-Blaarmeersen	*			*	*					
42. Leievallei	*	*	*		*	*	*			
43. Moervaartvallei	*		*	*						

Fig.5-3 shows the three groups, i.e. 1-3, 4-7, and 8-10, priority scores of the green action projects. There are four projects with priority scores of 1-3, 18 projects with priority scores of 4-7, and 20 projects having priority scores of 8-10.

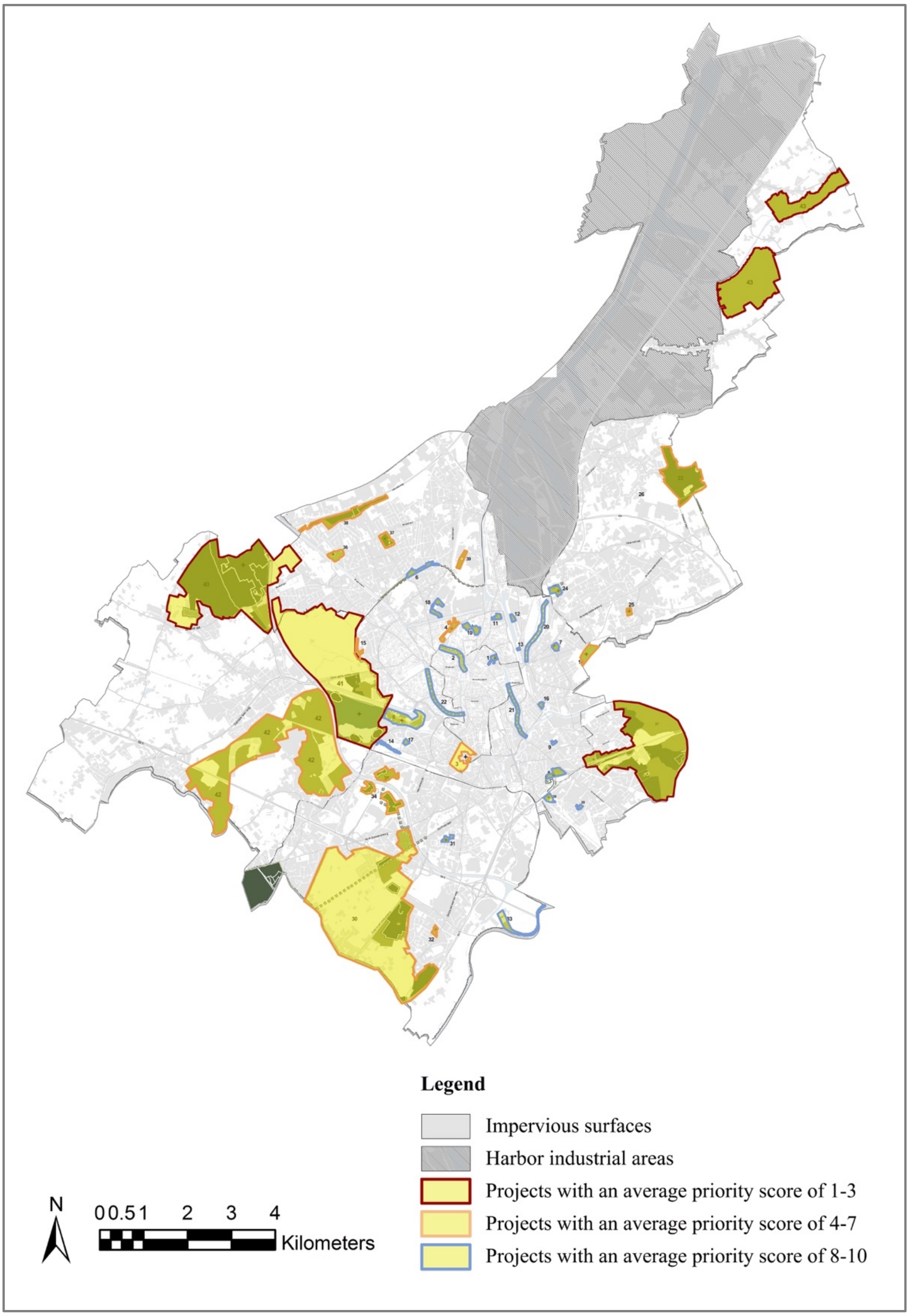


Figure 5-3 The location of the three groups with the corresponding spatial priority scores of the green action projects. The red edge defined the group of projects with an average priority score of 1-3, the orange edge defined the group of projects with an average priority score of 4-7, the blue defined the group of projects with an average priority score of 8-10. There is one project that does not have a defined edge, i.e. Groenas 1 Oostakker: Bufferzone Volvo (26), source: modified by the Groendienst Stad Gent, (2012)

(1) Sample green action projects located in the low priority areas with score 1-3

There are four projects located in the areas with an average priority score of 1-3, i.e. the Groenpool Gentbrugse Meersen (27), Groenpool Vinderhoutse Bossen (40), Stedelijk groengebied Bourgoyen-Ossemeersen-Malem Halfweg-Blaarmeersen (41) and Moervaartvallei (43). These projects are located in the areas with low priority scores due to the high percentage existing green space and the low residents and properties' concentrations exposed to potential flood hazards. Three projects were selected as casestudies, i.e. the Groenpool Gentbrugse Meerse (27), Groenpool Vinderhoutse Bossen (40), Stedelijkgroengebied Bourgoyen-Ossemeersen-Malem Halfweg-Blaarmeersen (41), as shown in Fig. 5-4.

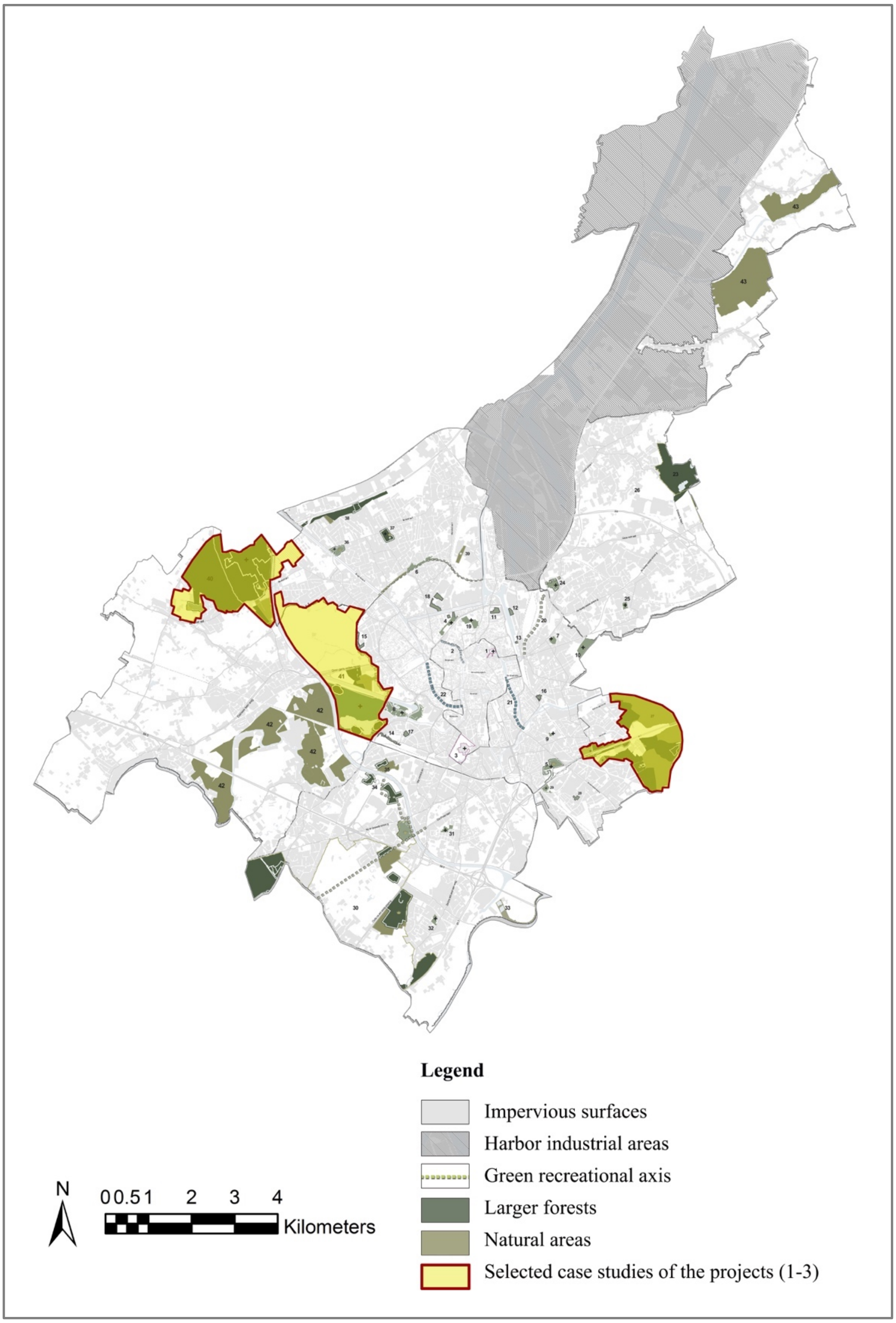


Figure 5-4 Selected case studies of the green action projects that located in the areas with an average priority score of 1-3 (the red edge defined the selected projects.) source: modified by the Groendienst Stad Gent (2012)

1. Groenpool Gentbrugse Meersen (27)

Figure 5-5 The yellow edge defined the green action project Groenpool Gentbrugse Meersen, source: Esri, USGS, 2019.

The Groenpool Gentbrugse Meersen is mainly located in the areas with priority scores of 2 (Table 5-1). The Groenpool Gentbrugse Meersen is located in the east suburban areas of Ghent (Fig. 5-4). The area is largely agricultural lands and possesses a small share of forests and residential areas (Fig. 5-5). It offers green space to the eastern part of the city. This project intends to realize new forests, to expand the existing natural core, to upgrade the district parks and to create recreational infrastructure. The goal of the project is to provide sufficient recreational greenery on different scale levels, to preserve nature and forest areas, to increase nature quality and to promote an effective forest expansion (Groendienst Stad Gent, 2012).

2. Groenpool Vinderhoutse Bossen (40)

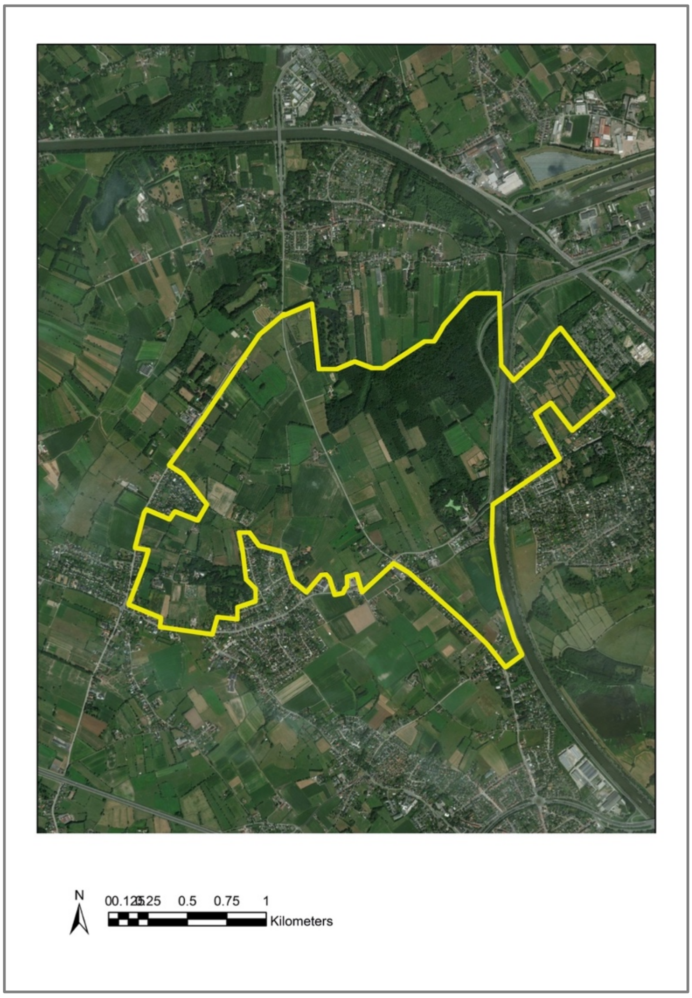


Figure 5-6 The yellow edge defined the green action project Groenpool Vinderhoutse Bossen, source: Esri, USGS, 2019.

The Groenpool Vinderhoutse Bossen is mainly located in the areas with priority scores of 3 (Table 5-1). It is located in the northwest suburban area of Ghent (Fig. 5-4). The area includes largely agricultural lands, forests and a small share of residential areas (Fig. 5-6). The Groenpool Vinderhoutse Bossen offers green space for the northwestern quadrant of the city on a large scale. This project intends to upgrade the district parks and the existing forests and to create a new forest, to upgrade the existing nature center and to create the recreational infrastructure. The goal of the project is to provide sufficient recreational greenery on different scale levels, to preserve nature and forest areas, increase the quality of nature and to promote an effective forest expansion (Groendienst Stad Gent, 2012).

3. Stedelijk groengebied Bourgoyen-Ossemeersen-Malem Halfweg-Blaarmeersen (41)

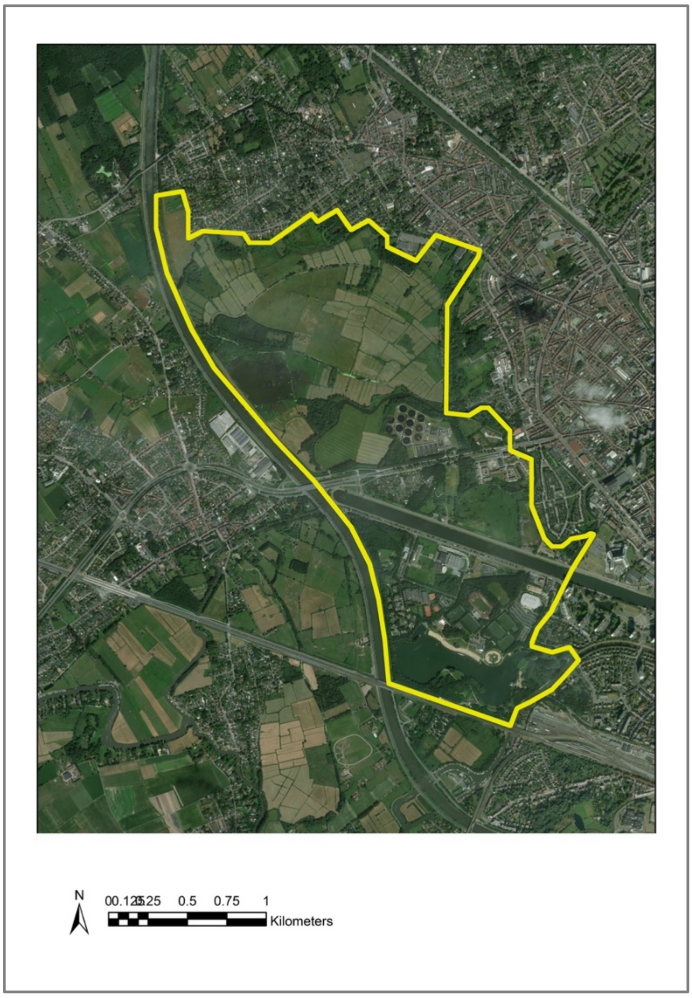


Figure 5-7 The yellow edge defined the green action project Stedelijk groengebied Bourgoyen-Ossemeersen-Malem Halfweg-Blaarmeersen, source: Esri, USGS, 2019.

The Stedelijk groengebied Bourgoyen-Ossemeersen-Malem Halfweg-Blaarmeersen is located in the areas with a priority score of 1, 4 or 5 (Table 5-1). The project is located in the west suburban areas of Ghent (Fig. 5-4). The area largely contains agricultural lands, forests and a small share of residential areas (Fig. 5-7). This project takes action to upgrade the urban green area, to integrate the site to the larger natural center, to upgrade the forest network and small natural core and to create recreational infrastructure. The goal of the project is to provide sufficient recreational greenery on different scale levels, to preserve nature and forest areas, to increase the quality of nature, to promote an effective forest expansion and to develop a soft recreational green network (Groendienst Stad Gent, 2012).

(2) Sample green action projects located in the median priority area with score 4-7

Eighteen projects are located in the areas with an average or main priority score of 4-7. Three projects have been selected as case studies, i.e. the Rabotpark/ Trambrugsite/ Gasmetersite (4), Groenpool Oud Vliegveld (23), Groenpool Parkbos (30), as shown in Fig. 5-8.

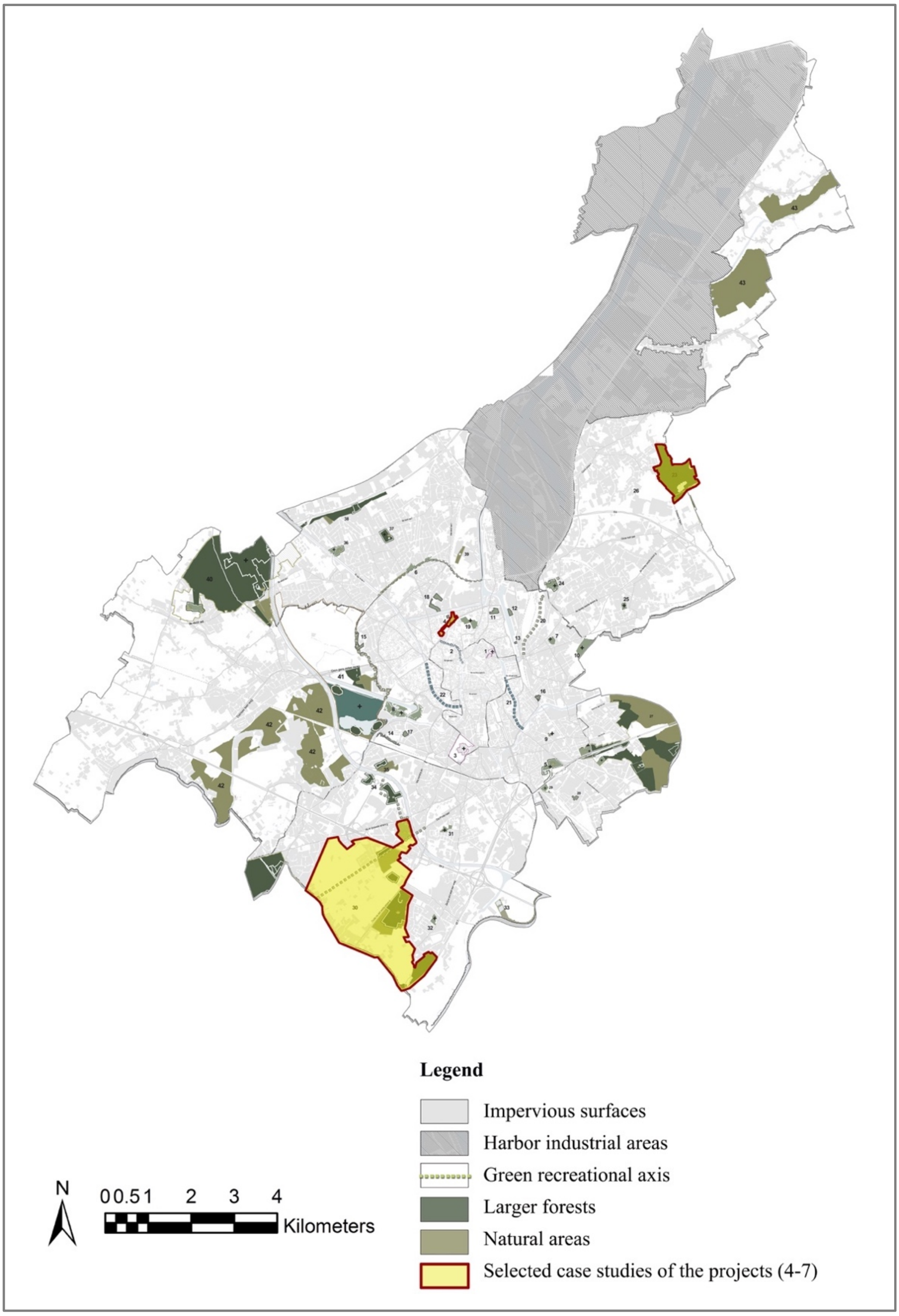


Figure 5-8 Selected case studies of the green action projects that located in the areas with an average or main priority scores of 4-7 (the red edge defined the selected projects) source: modified by the Groendienst Stad Gent (2012)

1. Rabotpark/ Trambrugsite/ Gasmetersite (4)

Figure 5-9 The yellow edge defined the green action project Rabotpark/ Trambrugsite/ Gasmetersite, source: Esri, USGS, 2019.

Rabotpark is mainly located in the area with a priority score of 7 (Table 5-1). It is situated in the downtown area of Ghent (Fig. 5-8). The area of the Rabotpark measures 4.7 hectares. This project aims to expand the existing neighborhood park and to create recreational infrastructure. The goal of the project is to provide sufficient recreational greenery on different levels and to augment the quality of the public space (Groendienst Stad Gent, 2012). Approximately 80% of the residents will have a 10 m^2 neighborhood park within 400 meters after the realization of these neighborhood parks.

2. Groenpool Oud Vliegveld (23)

Figure 5-10 The yellow edge defined the green action project Groenpool Oud Vliegveld, source: Esri, USGS, 2019.

The Groenpool Oud Vliegveld is located in the area with a priority score of 2 and 5 (Table 5-1) and is situated in the northeast suburban areas of Ghent (Fig. 5-8). The area has a large part of agricultural lands and a small share of forests and residential areas (Fig. 5-10). The Groenpool Oud Vliegveld offers large-scale green space for the north-eastern quadrant of the city. This project wants to realize new forests, to expand the existing natural core and to create recreational infrastructure. The goal of the project is to provide sufficient recreational greenery on different scale levels, to preserve the natural areas, to increase the quality of nature and to promote an effective forest expansion (Groendienst Stad Gent, 2012).

3. Groenpool Parkbos (30)

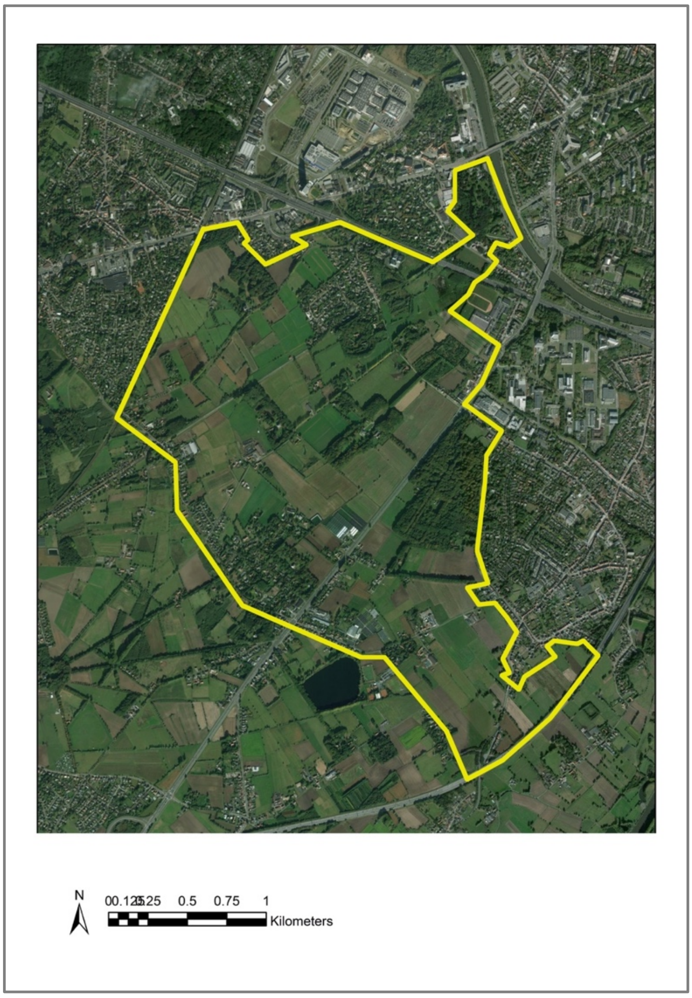


Figure 5-11 The yellow edge defined the green action project Groenpool Parkbos, source: Esri, USGS, 2019.

The Groenpool Parkbos is located in the area with a priority score of 2, 3, 6, and 9 (Table 5-1). The Groenpool Parkbos is located in the south suburban areas of Ghent (Fig. 5-8). The area has a large amount of agricultural lands, forests and a small share of residential areas (Fig. 5-11). This project takes action to realize new forests, to strengthen and expand smaller nature centers, to upgrade the neighborhood and castle parks and to create recreational infrastructure. The goal of the project is to provide sufficient recreational greenery on different scale levels for the local residents, to preserve nature and forest areas, to increase nature quality, to promote an effective forest expansion and to develop a soft recreational green network (Groendienst Stad Gent, 2012).

(3) Sample green action projects located in high priority areas with score 8-10

There are twenty projects located in the neighborhoods with an average or main priority score of 8-10. Two projects, i.e. Baudelohof and Watersportbaan/ Neermeersen, located in high priority neighborhoods (identified in chapter 4) are selected as case studies to propose potential green infrastructure technologies recommendation at the neighborhood scale, as shown in Fig. 5-12. The case studies can provide a springboard for filling gaps between the analysis (methodology in chapter 4) and the design practices. Based on the results of priority neighborhoods identified in chapter 4, this section shows examples of potential green infrastructure technologies on the two different sites.

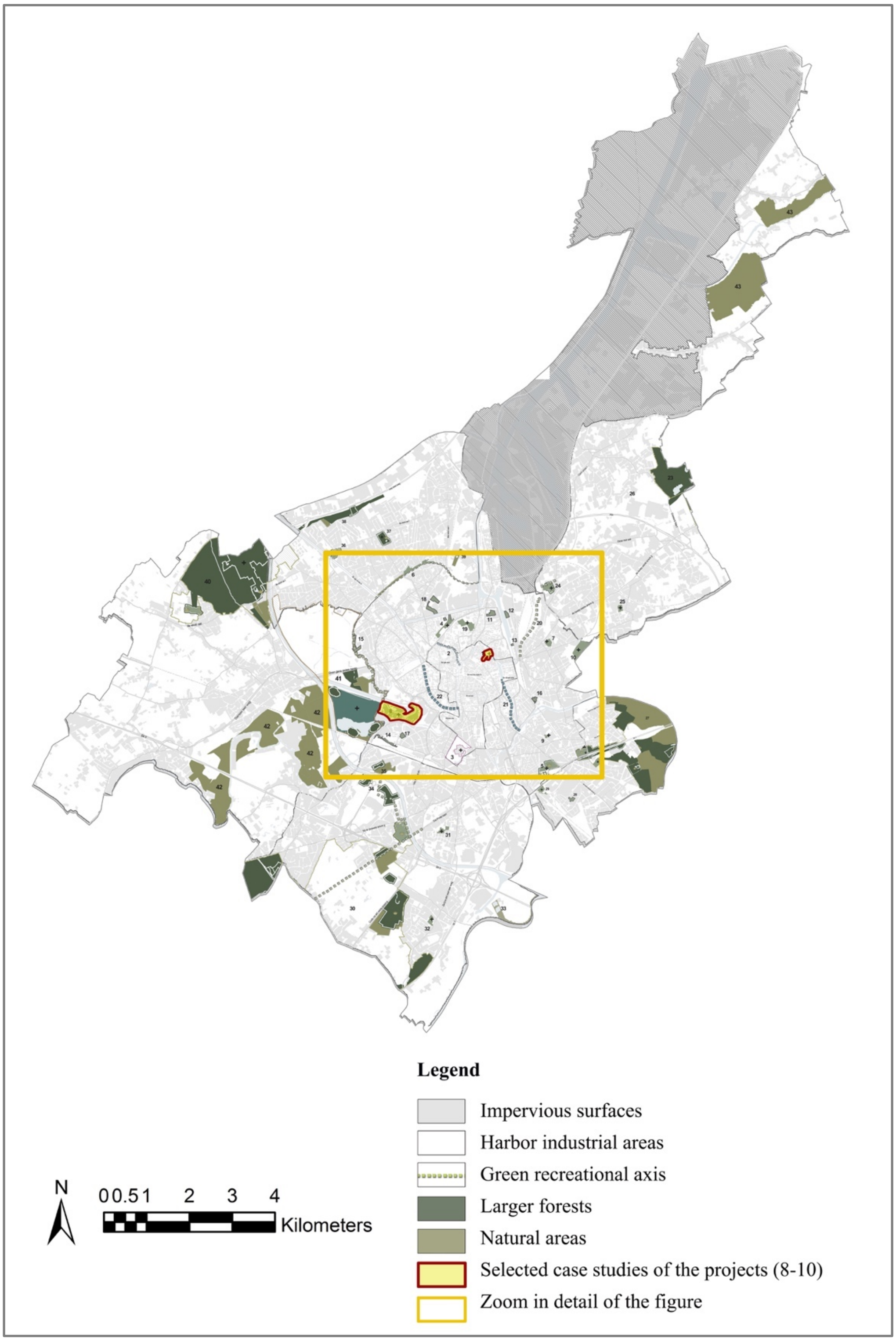


Figure 5-12 Selected case studies of the green action projects that located in the areas with priority score 8-10 (the red edge defined the selected projects, the yellow frame is the zoom-in detail of the Fig. 5-12) source: modified by the Groendienst Stad Gent (2012)

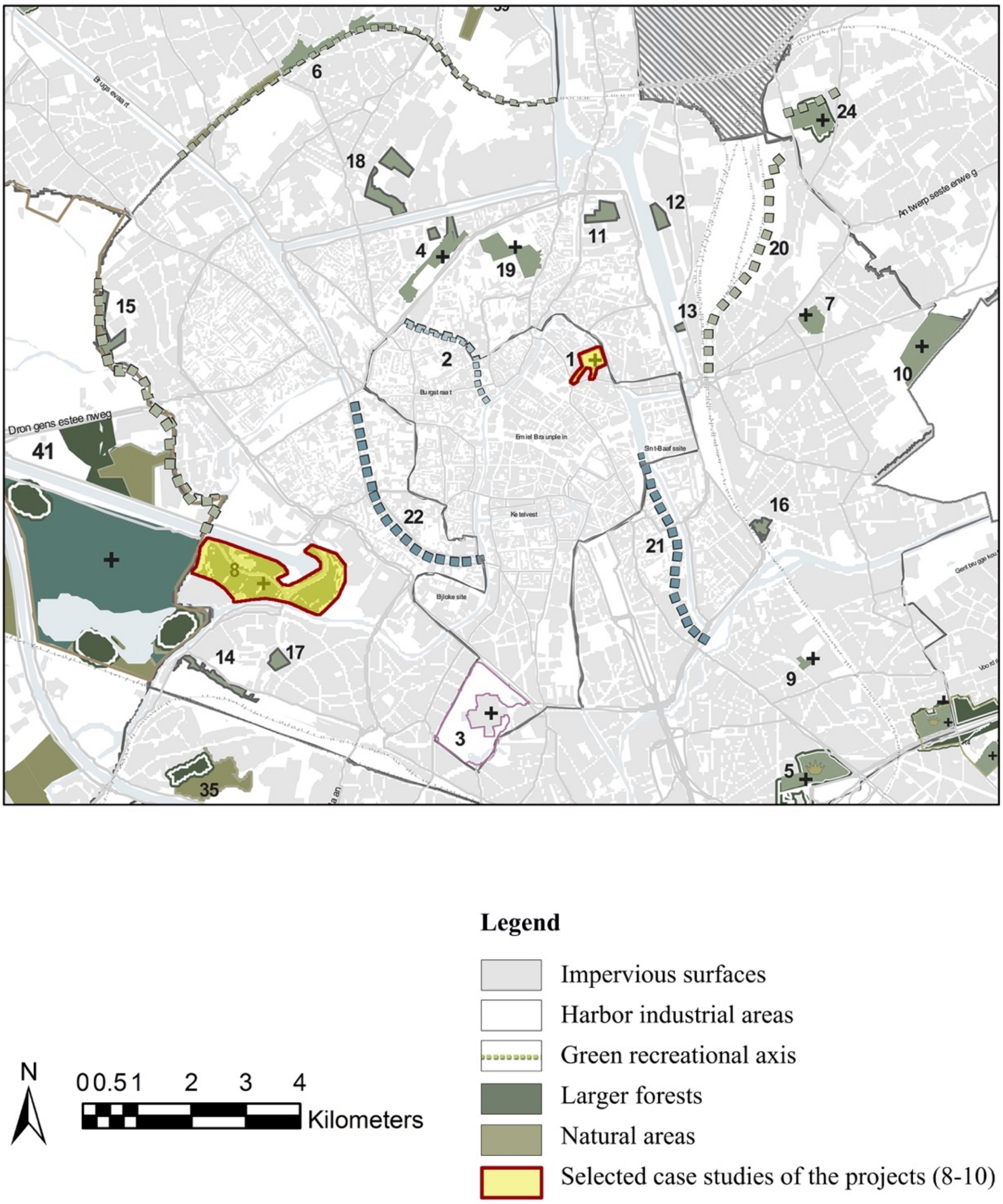


Figure 5-13 The zoom-in detail of the selected case studies of the green action projects that located in the areas with priority score 8-10 (the red edge defined the selected projects) source: modified by the Groendienst Stad Gent (2012)

1. Baudelohof (1)

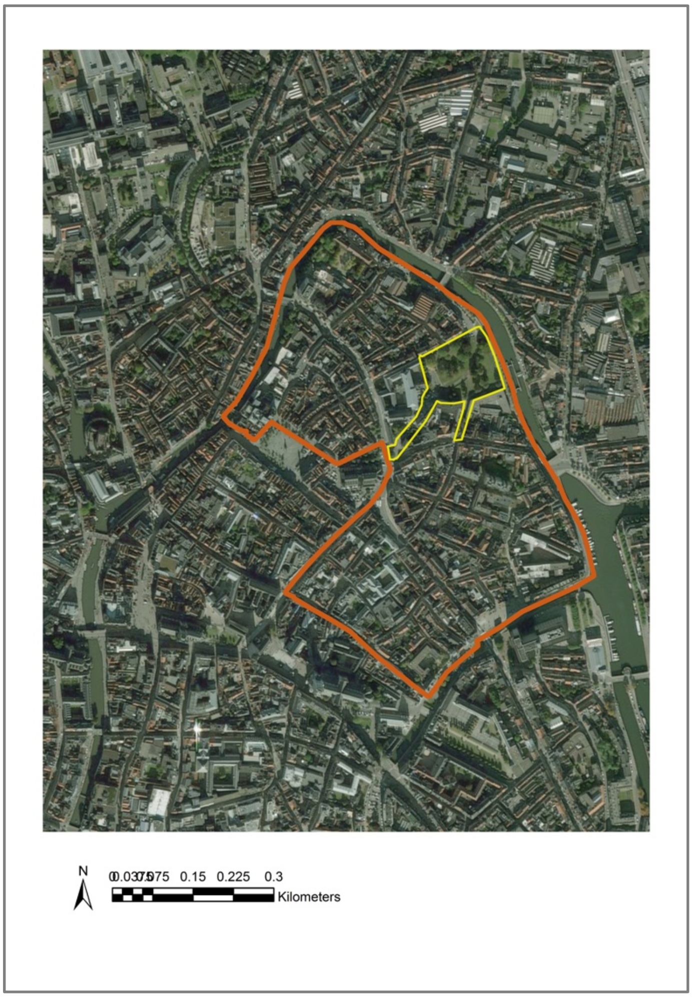


Figure 5-14, The yellow edge defined the boundary of the green action project of Baudelohof, the orange edge defined the boundary of the neighborhood Sint-Jacobs, source: Esri, USGS, 2019.

The green action project of Baudelohof is located in the downtown area of Ghent, as shown in Fig. 5-12. It is situated in the neighborhood Sint-Jacobs (Fig. 5-14), with a priority score of 9 to site the green infrastructure in order to mitigate the urban surface water flooding risk. Baudelohof acts as a green lung for the neighborhoods in which they are located. Due to the specific location, Baudelohof has an attraction on an urban level and also offers spaces for urban events. The park of Baudelohof needs reinforcement in the neighborhood. The project wants to redesign the park. The goal of the project is to augment the quality of public green space (Groendienst Stad Gent, 2012a).

1.1 Spatial structure and population

The neighborhood Sint-Jacobs covers an area of 31 hectares (Flanders Information Agency, 2012). 84.8% of the land surface is covered with buildings or pavements in this neighborhood, while in the city of Ghent, the average rate of hardening is around 46% (Ghent Administration, 2016). Only 10.0% area existing green land cover, with 5.1% forests and 4.9% grasslands (Flanders Information Agency, 2012). As shown in Fig. 5-15, the neighborhood Sint-Jacobs is covered with multi-family residential buildings with high density (Flanders Information Agency, 2017a).

Figure 5-15 The land use of the neighborhood Sint-Jacobs, source: Flanders Information Agency, (2017a)

This neighborhood has a total population of 2,682 in 2016 (The city of Ghent, 2016). There are 48.5 percent females, 14.5 percent of the population is aged over 65. 4 percent of the population is aged under 5 (The city of Ghent, 2016), 13.7 percent foreigners and 7 percent unemployed people aged from 18 to 65 (The city of Ghent, 2013). The population density in the area is 8,652 per sq. km, whereas the average population per sq.km of Ghent is 1,679.

1.2 An area-covering plan document that indicated the proposed green infrastructure at the neighborhood scale

The recommendation of the potential green infrastructure technologies in Sint-Jacobs takes the following neighborhood context into account:

1) Buildings with flat or gentle slope are suitable site for green roofs;
2) Existing parking lots, residential plots, hardening driveways without heavy transport can be considered the suitable location for permeable pavements or grass joints;
3) Rain gardens can be adjacent to or included in existing concrete squares or along the driveways;
4) Vegetative swales are proposed to place along pedestrian streets or bike lanes for providing closer user-oriented experiences;

The area-covering map shows the potential green infrastructure recommendations in the neighborhood Sint-Jacobs based on the aforementioned principles and on-site observation (Fig. 5-16). The proposed green infrastructure technologies directly affect holding volumes of storm-water without heavy structural installation. The on-site observation shows the space along pedestrian streets or bike lanes for vegetative swales in this neighborhood is limited. Therefore, vegetative swales were not proposed in this neighborhood.

Figure 5-16 Area-covering map of green infrastructure recommendation on site in the neighborhood of Sint-Jacobs

1.3 The potential of the proposed green infrastructure technologies

The proposed green infrastructures in the neighborhood Sint-Jacobs, including green roofs, permeable pavements, and rain gardens, can control a total amount of runoff around 36,990.6 m^3 (Table 5-3). The total area of the proposed green roofs is around 35,230.7 m^2. The total runoff reduction amount of the proposed green roofs is 20,433.4 m^3. The total area of the permeable pavements proposed on parking lots, residential plot is 2,330.6 m^2. The total runoff reduction of the proposed permeable pavements (on parking lots, residential plots) is 722.5 m^3. The total area of the roads in the neighborhood of Sint-Jacobs is 1,209.1 m^2. All the roads in the neighborhood of Sint-Jacobs are not fast transit and have the potential to be replaced with permeable pavement. The total potential runoff reduction amount with the roads in the neighborhood of Sint-Jacobs is 15,230.2 m^3. The total area of the proposed rain gardens is 1,209.1 m^2. The total runoff reduction amount of the proposed green gardens is 604.5 m^3.

Table 5-3 The runoff reduction amount of the proposed green infrastructures in the neighborhood Sint-Jacobs

Proposed GI types	**Areas (m^2)**	**Runoff reduction per square meter (m^3/m^2)**	**Runoff reduction amount (m^3)**
Green roofs	35,230.7	0.58	20,433.4
Permeable pavements (Parking lots)	2,330.6	0.31	722.5
Permeable pavements (Other roads)	49,129.7	0.31	15,230.2
Rain gardens	1,209.1	0.50	604.5
Total	--	--	36,990.6

2. Watersportbaan/ Neermeersen (8)

Figure 5-17, The yellow edge defined the boundary of the green action project of the Watersportbaan, the orange edge defined the boundary of the neighborhood Neermeersen, source: Esri, USGS, 2019.

The green action project of the Watersportbaan is located in the western part of Ghent, as shown in Fig. 5-12. The Watersportbaan is located in the neighborhood Neermeersen (Fig. 5-17), with a priority score of 8 to site the green infrastructure to mitigate the urban surface water flooding risk. The project takes action to redesign the existing neighborhood park. The goal of the project is to provide sufficient recreational greenery on various scale levels and to increase the quality of public greenery (Groendienst Stad Gent, 2012).

1.1 Spatial structure and population

The neighborhood Neermeersen covers an area of 65.5 hectares (Flanders Information Agency, 2012). 43.8% of the land surface is covered with buildings or pavements in this neighborhood (Flanders Information Agency, 2012). There is 42.6% of existing green land cover in the neighborhood of Sint-Jacobs, with 19.3% forests and 23.3% grasslands (Flanders Information Agency, 2012). The neighborhood is mostly single-residential and transportation, communication and utility buildings with a low building density (Fig. 5-18).

Figure 5-18 The land use of the neighborhood Neermeersen, source: Flanders Information Agency, (2017a)

The neighborhood Neermeersen has a total population of 2,508 in 2016 (The city of Ghent, 2016). There are 53.7 percent females, 30 percent of the population is aged over 65, 9.4 percent of the population is aged under 5 (The city of Ghent, 2016), 23.5 percent foreigners and 12 percent unemployed people aged from 18 to 65 (The city of Ghent, 2013). This neighborhood is an area of high social vulnerability, especially a high percentage of the population is aged over 65. The population density in Neermeersen is 3,829 per sq. km, whereas the average population per sq.km of Ghent is 1,679.

1.2 An area-covering plan document that indicated the proposed green infrastructure at the neighborhood scale

The examples of the potential green infrastructure technologies on site are provided based on the principles (explained in the methodology). The area-covering map shows the green infrastructure recommendations in the neighborhood Neermeersen (Fig. 5-19).

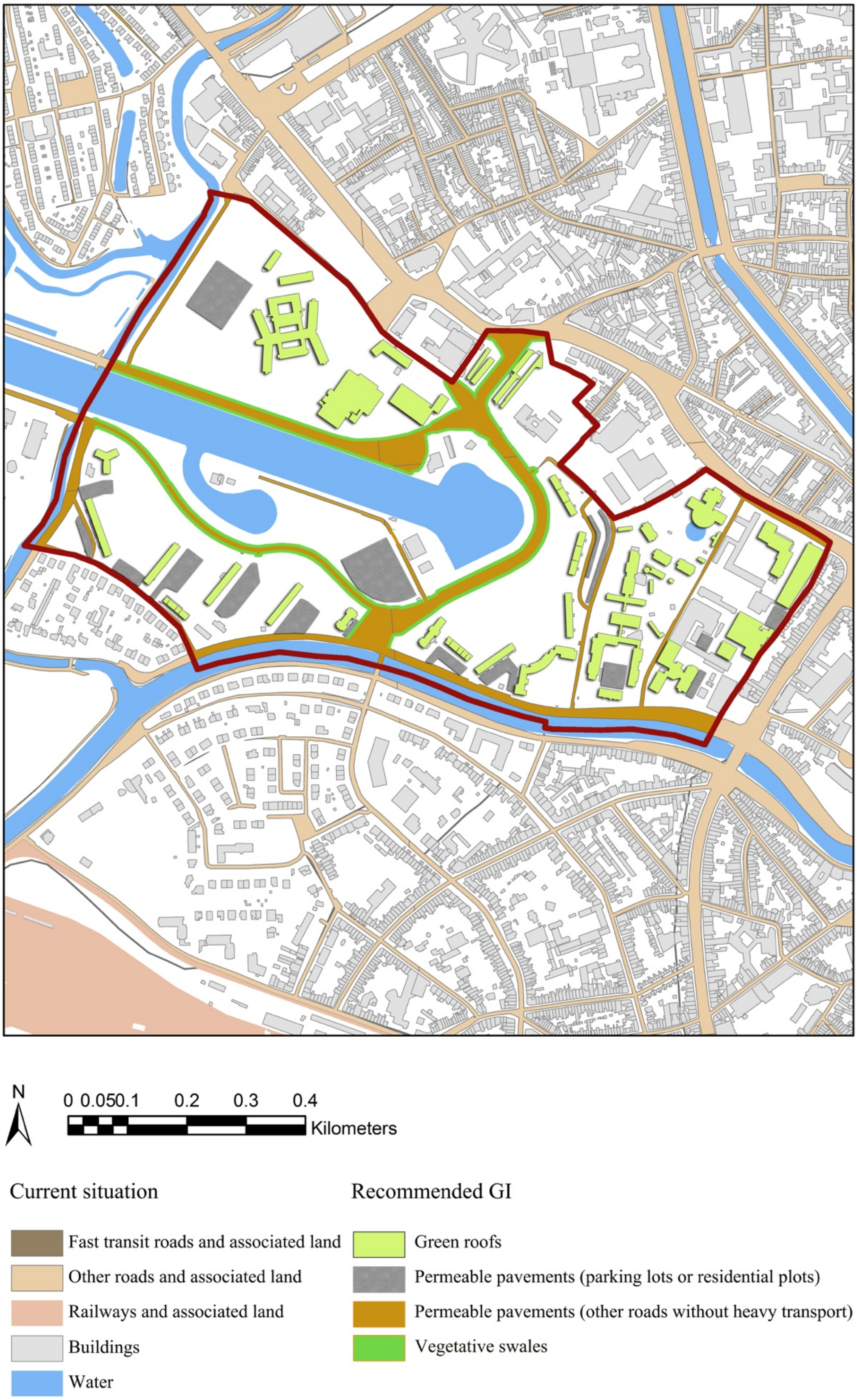


Figure 5-19 Area-covering map of green infrastructure recommendation on site in the neighborhood of Neermeersen

1.3 The potential of the proposed green infrastructure technologies

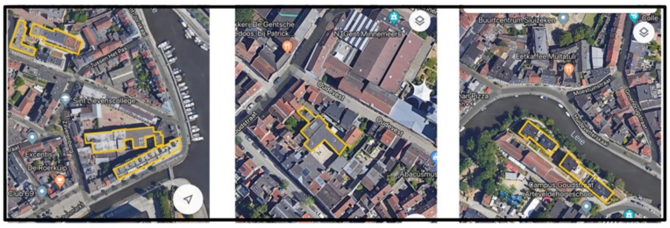
The proposed green infrastructures in the neighborhood Neermeersecan control a total amount of runoff around 72,058.8 m^3 (Table 5-4). The area of the proposed green roof is around 60,794.7 m^2, and thus can reduce a total runoff amount of 35,260.9 m^3. The area of the proposed permeable pavements on parking lots and roads are 34,849.5 m^2 and 72,906.5 m^2, respectively. The runoff reduction amount of the proposed permeable pavements (on parking lots, residential plots) is 10,803.3 m^3. The total potential runoff reduction amount with roads replaced by permeable pavements is 2,112.0 m^3. The total area of the proposed vegetative swales is 7,892.0 m^2. The total runoff reduction amount of the proposed vegetative swales is 3,393.6 m^3.

Table 5-4 The runoff reduction amount of the proposed green infrastructures in the neighborhood Neermeersen

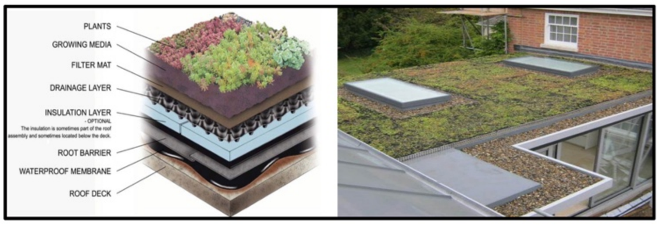
Proposed GI types	**Areas (m^2)**	**Runoff reduction per square meter (m^3/m^2)**	**Runoff reduction amount (m^3)**
Green roofs	60,794.7	0.58	35,260.9
Permeable pavements (Parking lots)	34,849.5	0.31	10,803.3
Permeable pavements (Other roads)	72,906.5	0.31	22,601.0
Vegetative swales	7,892.0	0.43	3,393.6
Total	--	--	72,058.8

Examples of green infrastructures that potentially can be placed in some of the sites are shown in Fig. 5-20.

a) Green roofs are proposed for houses with flat roofs



Current situation



Green roof

b) Permeable parking lots, cobblestones and grass joints are proposed in the parking space

Current situation

Grass joints permeable pavement

c) Permeable pavements are proposed in small alleys with less traffic

Current situation

Permeable pavement cobblestone pavement

d) Rain gardens are proposed in the existing concrete squares or along the driveway roads

Current situation

Rain garden

e) Vegetative swales are proposed along pedestrian streets or bike lanes

Current situation

Vegetative swales

Figure 5-20 Examples of the potential green infrastructure in suitable sites, sources of images are shown in Appendix A

3.2 *Areas in which the identified needs are not currently planned with green action projects*

There are twelve neighborhoods, i.e. Eikendreef, Over de meersstraat, Groendreef, Rooigem, Tolhuis, De Kuip, Kouter, Gent-Centrum-Zuid, Sint-Pieters Station, Zuidpark, Ledeberg-Centrum, identified as high priority (with a priority score of 9 or 10) to site the green infrastructure without current green action projects, as shown in Fig. 5-21. The yellow edge designed the neighborhoods for which green action projects were suggested to site the green infrastructure and optimize the function of surface water flooding risk mitigation.

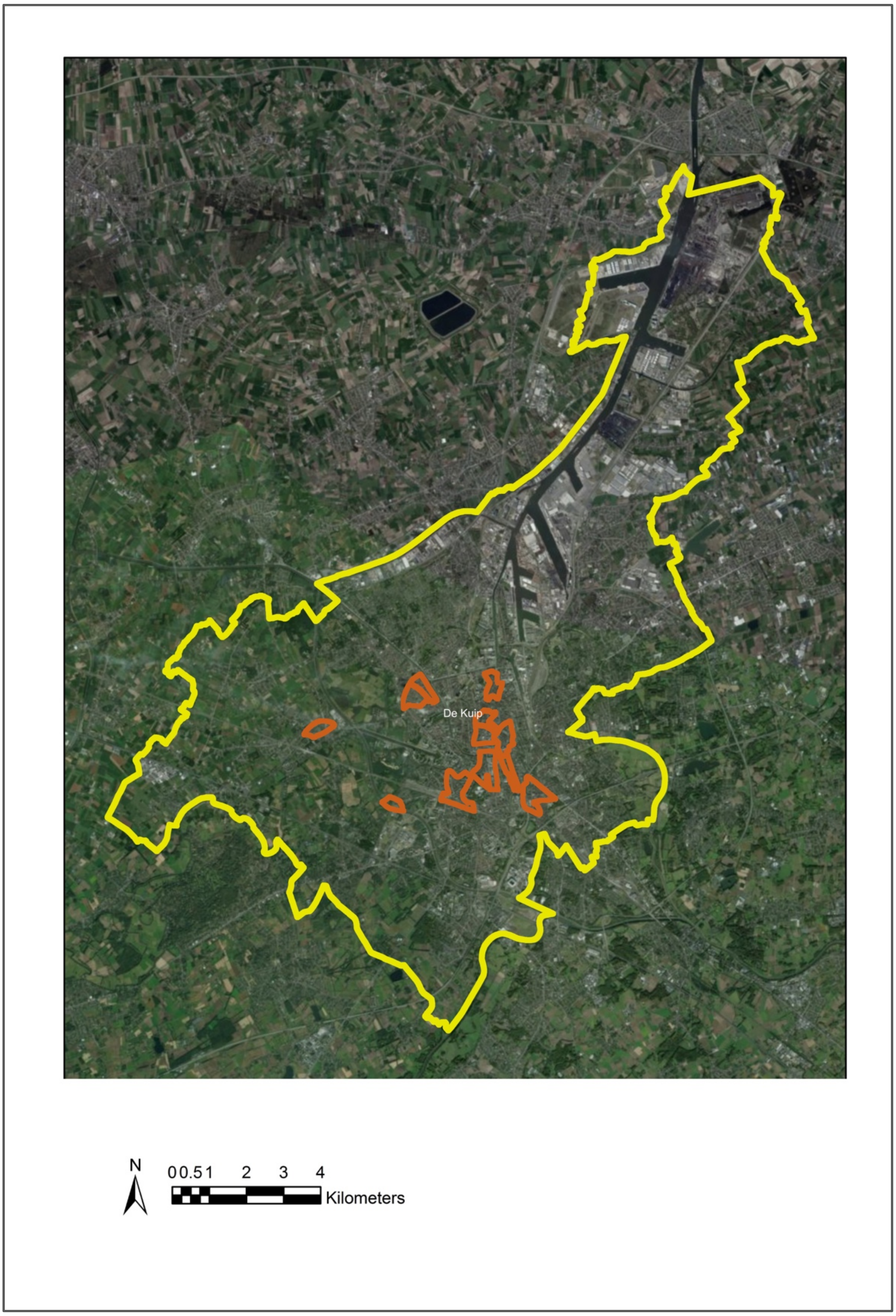


Figure 5-21 The yellow defines the border of the municipality of Ghent, the orange edge defined the boundary of the identified neighborhoods with a high priority without current green action projects, source: Esri, USGS, 2019.

4 Discussion

This chapter investigates to what extent the current green action projects of Ghent (2012) are being planned so as to optimize the benefits of the urban surface water flooding risks' mitigation.

There are in total 43 green action projects of Ghent (2012), four projects (among them) located in the areas having an average or main priority score 1-3 (Fig. 5-3). These four projects are large green areas with a large share of agricultural land, forests and natural core. These areas have a low priority score for green infrastructure to mitigate the urban surface flooding risks due to a low percentage of concrete surface hardening, a low population density, less concentrated buildings and roads and an originally high percentage of green area. These four projects are not located in the neighborhoods that need it the most to mitigate the urban surface water flooding risks (according to the mapping results of the priority areas to place green infrastructure technologies to mitigate surface water flooding risk in chapter 4). However, these four projects were strategically planned from the consideration of increasing accessibility to the green area for the residents, to conserve the natural area and to increase life quality. According to the report of the urban green structure plan in Ghent 2012, only one-third of the population in Ghent has a 10 m^2 per resident neighborhood green space within a distance of 400 m from the house (Groendienst Stad Gent, 2012a). The accessibility analysis was also carried out for the four green poles, i.e. the Groenpool Oud Vliegveld, Groenpool Gentbrugse Meersen, Groenpool Parkbos and Groenpool Vinderhoutse Bossen. It turns out that almost 90 % of the population of Ghent lived within 5km of a green pool but there is only 36 m^2 per inhabitant of green space. This is far below the standard of the Flanders spatial structure plan of 100m^2 per inhabitant of green space within 5 km (Groendienst Stad Gent, 2012). These four projects might not be the most priority location for the urban surface flooding risk mitigation, while they are important from the aspect of green space accessibility, natural area conservation and life quality improvement. The green pools around the city are being expanded to a large public and accessible to the nature and forest areas, with a chain of recreational opportunities for the residents.

There are twenty projects located in the area with an average or main priority score of 8-10 (Fig. 5-3). Two projects, i.e. Baudelohof (1) and Watersportbaan/ Neermeersen (8), were selected as case studies to investigate and provide green infrastructure technologies recommendation regarding urban surface water flooding risk mitigation (Fig. 5-12). The neighborhood context, i.e. the land use, building density and demography were analyzed to provide information for the green infrastructure implementation in the area. The area-covering map shows examples of green infrastructure recommendation on site rather than as a specific technical guidance. It does not fully guarantee its feasibility, and should be adjusted according to actual conditions, such as cost, property rights, the soil condition etc., before green infrastructure technologies implementation. For instance, the sites proposed with permeable parking lots might have a low water infiltration rate of the soil type, making it less efficient to construct permeable parking lots in the area.

There are twelve high priority neighborhoods without plans with green action projects (Fig. 5-21). These twelve neighborhoods are areas with the highest need for green infrastructure to mitigate the urban surface water flooding risk. They are concentrated in the city center and inner areas. Most of the neighborhoods are high building density residential areas with limited potential space for green infrastructure technologies development. The imbalance between the green action projects and the needs for green infrastructure in some neighborhoods raises several challenges, compounded by the fact that there will be extremely limited space and opportunities to create new areas for green space within the neighborhood (mostly urban center and inner-city area). These challenges can take forward through the recommended small-scale green infrastructure technologies, such as green roofs, green walls, rain gardens, rooftop (downspout) disconnection (to incorporate green infrastructure technologies into the buildings, constructions, new development areas), permeable pavements (to innovate the existing concrete surface hardening areas) etc. (e.g. Fig. 5-16 and Fig. 5-19 show examples of green infrastructure technologies recommendation on site).

5 Conclusion

This chapter investigated whether the green action projects of Ghent are being planned to optimize the benefits of the urban surface flooding risk mitigation. The results show that most of the green action projects are being executed in the areas with a high priority score for green infrastructure technologies implementation. Two projects, i.e. Baudelohof and Watersportbaan/ Neermeersen, that located in high priority areas are further selected as case studies to provide area-covering green infrastructure technologies recommendation at the neighborhood scale. The potential runoff reduction effect of these proposed green infrastructure technologies (interventions) was quantified. The study can provide suggestions for green infrastructure planning to help to address one of the key issues (water nuisance caused by extreme rain showers) of Ghent so as to build a climate robust city.

Appendix A

Sources of images of Fig. 5-20

Green infrastructure types	**Sources of images**
Permeable pavements	Masonty Design, (n.d.); Interlocking Concrete Pavement Institute, (n.d.)
Grass joints	Architects Data File, (2015)
Rain gardens	New York Environmental Protection, (2017); Ghent Administration, (2016)
Green roofs	Tolderlund, (2010); IKO polymeric, (n.d.)
Grass blocks	Tomazin, (2019)
Vegetative swales	Natural Resources Conservation Service- U.S. Department of Agriculture, (2002)

Chapter 6 Summary of the findings and conclusions

This chapter is devoted to the summary of the major findings of the dissertation. This dissertation provides a better understanding of identifying and planning of green infrastructure to mitigate urban surface water flooding risk. In order to address this main objective, four specific objectives were investigated. The subsections of the summary are outlined based on the specific objectives of the dissertation, which are presented as separate chapters in this dissertation.

1 Putting the research objectives in perspective

1.1 *Research objective 1: To provide a better understanding of the GI planning through the evaluation of the Sponge City plans of the eight selected pilot cities*

Investigating the Sponge City Plans and defining the challenges and issues of green infrastructure planning for a sustainable water management were the focus of chapter 2. Despite large scales of attempts and practices that have been carried out in many cities across China, insufficient attention has been paid to the experimentation-based learning via pilot cities. Researches to evaluate the sponge city plan from the planning and designing aspects are limited. The quality of the planning and designing process ultimately determines the success of the Sponge City implementation. It is important to learn from the experiences for the efficiency of the future Sponge City planning and design. Researches that involved in the planning and designing aspect of the urban water management remains underexposed (Kuller, Bach, Ramirez-Lovering & Deletic, 2017). The uncertainties in the Sponge City planning and design are very serious problems that could bring failure to the Sponge City implementation (Nguyen et al., 2019). Recognizing the importance of the Sponge City planning and design and the knowledge gap that insufficient attention has been paid to this aspect, this chapter established a content-based evaluation of the Sponge City plans in eight selected pilot cities.

Based on the lessons learned from this study, suggestions for a future up-scaling of Sponge City for other cities is being proposed, i.e. 1) Proper methods, such as the equal consideration, analytic hierarchy process (AHP) and experts' (As mentioned in chapter 2, experts here refer to urban planners and designers, academic researchers specialized in urban planning/ green infrastructure planning, members of urban planning institute, researches of water and sewerage department etc., that know the local context and could assist to define the important weight of the goals, e.g. stormwater runoff reduction, water quality improvement, heat wave alleviation etc., of the Sponge City plan.) interviews should be adopted in the goal setting section in order to define the important weights of the assigned goals due to the existence of spatial priority of various Sponge City goals; 2) More effective participation mechanisms such as public hearings, deliberative polling, focus groups could be adopted to improve the Sponge City public participation; 3) The urban context and socio-economic aspect should not be overlooked for the strategic green infrastructure planning. It was found that biophysical related indicators were considered, while the socio-economic related indicators were overlooked in the green infrastructure planning of Sponge City. A methodology that takes the urban context and socio-economic aspects into consideration for green infrastructure planning to mitigate surface water flooding risk is thus developed in chapter 4; 4) A spatial recommendations of certain types of green infrastructure technologies could be provided according to the local context.

1.2 *Research objective 2: To assess the stormwater runoff reduction capacity of the existing green infrastructures*

Assessing the stormwater runoff reduction capacity of the existing green infrastructure (of Ghent) was the main focus of chapter 3. The runoff reduction capacity of green infrastructure needs to be elucidated for a better support for green infrastructure planning (Matthews, Lo, & Byrne, 2015; Carter, 2018; Lanzas et al., 2019). The calculation of runoff reduction capacity of green infrastructure should take landscape pattern into consideration. A group of studies (Kim & Park, 2016; Boongaling, Faustino-Eslava, & Lansigan, 2018; Bin, Xu, Xu, Lian, & Ma, 2018; Peng et al., 2019) have demonstrated the effect of the landscape pattern on the capacity of the runoff reduction of green infrastructures. The landscape pattern is one of the components of green infrastructures. Landscape pattern is generally considered to contain two main components, i.e. the composition and configuration. There are some models, such as the stormwater management model (SWMM), soil conservation service curve number (SCS-CN) and CITY-green to measure the runoff reduction capacity of landscapes (Gill, Handley, Ennos, & Pauleit, 2007; Zellner, Massey, Minor, & Gonzalez-Meler, 2016; Luan et al., 2019; Du et al., 2019). However, these models do not consider the landscape patterns and usually need large time and data, making it less accessible to the urban planners and decision-makers. This chapter adopted an empirical model from Zhang, Xie, Li & Wang (2015). The model includes two variables, i.e. runoff coefficient and landscape metrics to assess the stormwater runoff reduction capacity of different green infrastructure types, i.e. the forests, grasslands and agricultural lands.

The results show that grasslands contribute the most to the stormwater runoff reduction amount of 11.83 million m^3 and that forests control the lowest runoff of 44.8 million m^3. The agricultural land has the highest reduction amount per square kilometer of 0.35 million m^3/km^2 and forests the lowest with 0.19 million m^3/km^2. The spatial distribution of the runoff reduction capacity of green infrastructure indicates that the high capacity of green infrastructure is mainly concentrated in the southwest and northeast suburban areas. The core areas are scattered with less green infrastructures and a low runoff reduction capacity.

1.3 *Research objective 3: To develop an approach to identify the priority sites for the GI implementation*

Developing an approach to identify the priority locations for the green infrastructure implementation to mitigate the urban surface water flooding risk was the focus of chapter 4. Despite the great effectiveness of the urban green infrastructure in alleviating the stormwater runoff, little research exists for the planners and designers to determine an appropriate strategy for the green infrastructure planning. The green infrastructure planning has experiences based, and resulted in sub-optimal outcomes (Schuch, Serrao-Neumann, Morgan, & Low Choy, 2017; Kuller, Bach, Ramirez-Lovering, & Deletic, 2018). For instance, Kuller et al., (2018) investigated the relationship between the green infrastructure in Melbourne and the urban context, i.e. the biophysical, socio-economic and urban forms. The results indicated that opportunistic green infrastructure planning leads to unintentional outcomes that fail to provide the full potential of the green infrastructure benefits. In response, quantitative urban planning approaches seeking for a more careful placement of green infrastructure have emerged during the last decades (Madureira & Andresen, 2014; Norton et al., 2015; Meerow & Newell, 2017). However, a strategic green infrastructure planning model to protect against urban surface water flooding risk is lack. A growing amount of studies have demonstrated that indicators would determine the suitability of a location for the green infrastructure implementation (Madureira & Andresen, 2014; Meerow & Newell, 2017). The study in chapter 2 (to investigate the Sponge City) found that biophysical related indicators, e.g. hydrology, soil condition, slope, were considered, while the socio-economic related factors were overlooked. Urban areas that may highly benefit from green infrastructure technologies might thus be neglected. Strategic consideration of the socio-economic related indicators is important for an optimal green infrastructure implementation in order to deliver the water regulating services that society is requiring.

This chapter thus developed a GIS-based multi-criteria evaluation method (that takes socio-economic aspects into consideration) to identify the priority areas to site green infrastructure technologies, based on five criteria: 1) stormwater runoff mitigation; 2) social flood vulnerable group protection; 3) flood sensitive area road infrastructure protection; 4) flood sensitive area buildings' protection and 5) environmental justice. The weights of the five criteria are defined by the Analytic Hierarchy Process. A strategic approach can help planners to ensure that the flood risk mitigation function is provided in areas that need it the most. The method and resulting maps can help the urban planners, administrators and stakeholders to identify the priority areas for the green infrastructure planning to mitigate the urban surface water flooding risk.

1.4 *Research objective 4: Investigating the current green action projects of Ghent (2012)*

Investigating whether the green action projects of Ghent are being planned in the areas to optimize the benefits of green infrastructures to mitigate urban surface flooding risk was the focus of chapter 5. The investigated results indicated that most of the green action projects are being located in the areas so as to optimize the function of urban surface water flooding risk mitigation. Two projects that located in high priority areas to place green infrastructure technologies to mitigate urban surface water flooding risk were further selected as case studies to provide green infrastructure technologies recommendation at the neighborhood scale (See area-covering map shown as Fig. 5-16 and Fig. 5-19). These two case studies can provide a springboard for filling gaps between analysis (methodology in chapter 4 to identify priority areas to place green infrastructure technologies) and practices (potential green infrastructure technologies recommendations in high priority areas). The potential of these proposed interventions to reduce stormwater runoff is quantified (Table 5-3, and Table 5-4). The results provide suggestions for the green infrastructure planning and ensure the delivery to help to address one of the key issues (water nuisance caused by extreme rain showers) of Ghent to build a climate robust city.

2 General conclusion and future research

This dissertation has aimed to contribute to the understanding of green infrastructure planning to mitigate the urban surface water flooding risk. chapter 2 takes the case of Sponge

City to investigate the issues of green infrastructure planning and design. One of the main issues found in this chapter was that the socio-economic related indicators were overlooked in the green infrastructure planning of Sponge City plans. chapters 3 to 5 use the case of Ghent as case study. The dissertation has then assessed the runoff reduction capacity of the existing green infrastructure (chapter 3) and developed an approach to identify the priority areas to facilitate the green infrastructure planning (chapter 4). The approach (developed in chapter 4) can be applied in other cities. It enables to identify the priority areas in which green infrastructure technologies has the biggest potential to mitigate urban surface water flooding risk. For instance, some huge cities (that mainly aim at building Sponge City) with a population exceeding ten million people in China. The study in chapter 5 (to investigate the current green action projects of Ghent and to provide area-covering green infrastructure technologies recommendation maps) can bring the gaps between analysis (methodology in chapter 4) and practices (potential green infrastructure technologies recommendations in high priority areas). There are twelve neighborhoods that suggested to plan green infrastructure technologies are currently without green action projects (Fig. 5-21). These neighborhoods are concentrated in the city center and inner areas. Most of them are high building density residential areas with limited potential spaces for green infrastructure technologies development. The conflicts between the needs for green infrastructures and limited potential spaces can take forward through the recommended small-scale green infrastructure technologies (area-covering maps shown in Fig. 5-16 and Fig. 5-19) to incorporate the green infrastructure technologies into the buildings, constructions, new development areas etc.

Simultaneously, it also suggests a variety of future research. Two other topics for further research were suggested. Firstly, this dissertation assesses the runoff reduction capacity of the existing green infrastructures based on an empirical model adapted from Zhang, Xie, Li & Wang (2015). The model includes two variables, i.e. the runoff reduction coefficient and landscape metrics. The selection of the landscape metrics is based on peer researches (N. Liu, Wang, & Duan, 2012; Kim & Park, 2016). While the urban context, land use, soil types, hydrologic environment and urban drainage system may differ in various regions, thus might manifest different correlations in landscape patterns and runoff reduction capacity. Therefore, the relation of the landscape pattern and runoff reduction capacity still needs to be explored in different regions, e.g. a highly developed metropolis in China. Secondly, there is a growing body on the literature review of the multi-functions of green infrastructure, which suggests that the green infrastructure planning should not only consider stormwater runoff mitigation

(Demuzere et al., 2014; Wang & Banzhaf, 2018). Though we are aware of this, this PhD study provides nevertheless insights of green infrastructure planning for the urban planners, administrators regarding urban surface water flooding risk mitigation. Future studies can combine the investigation in this study with other potential functions involved in the green infrastructure planning regarding the urban context.

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