Green Infrastructure Design and Evaluation Model for Resilient Sponge City Program Transitional Construction

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Thesis submitted to the University of Nottingham

for the degree of Doctor of Philosophy

November, 2020

Abstract

Green Infrastructure (GI) has gained tremendous interests in the Sponge City Programs (SCP) after being identified as one of the key strategies for achieving sustainability and resilience. More recently, in the context of China's socially motivated transformation to ecological civilization, ensuring high-quality urbanization is oriented towards sustainable economic, environmental, and social development.

Based on literature review, two research gaps were identified. Firstly, in terms of the macro-scale, there are limited studies on how to define and develop the multi-objective framework focused on resilient outcomes in SCP by integrating ecological and social resilience enhancements strategies. Secondly, in terms of the meso- and micro- scale research, there is a lack of comprehensive and quantitative evaluation system for the transitional development towards sustainability. This study aims at a GI planning and assessment model for SCP to achieve reinforced resilience and sustainable outcomes, especially for cities in Jiangnan water net area of china.

Consequently, the novelty of this research is primarily reflected in its potential to reshape the sponge project through the development of a high-quality GI planning and assessment model. The developed model contains enhanced resilience and sustainable strategies, and implementable solutions with multi-dimensional and multi-spatial functionalities for

satisfying the high-quality transitional trends and needs. The developed Basic Strategies and Pathways Framework (BSPF) laid emphasis on the impact analysis and evaluation within the whole GI planning process, by refining the impact evaluation process and integrating a more comprehensive key Performance Indicator Framework (KPIF). This KPIF incorporates a set of Key Performance Indicators (KPIs), which enabled the quantitative evaluation of the design alternatives, thus supporting robust decision making for the selecting the optimal solutions.

Furthermore, the developed BSPF model and KPIF were applied to the Siming Lake watershed case study. A water resilience centered, multi-objective and more resilient GI network model was identified for the whole watershed. At the meso-scale, this study utilized Stormwater Management Model (SWMM) and the Analytic Hierarchy Process (AHP) system to compare the effectiveness of multiple design scenarios. These scenarios were designed with different combination of site scale Green Stormwater Management (GSI) facilities (denoted as SS1–SS10), a basic GI scenario that only recovers green landscape without GSI facilities (denoted as SS11 and the current status quo benchmark (donated as SS12). After the comprehensive evaluation, the results show that SS4 presented the best performance with maximum benefits. At the micro-scale, four scenarios with different combination of additional GSI facilities (denoted as ZS1-ZS4) were developed and scenario ZS3 was identified as having the best performance.

Furthermore, based on the expert interviews and taking consideration of the GI planning and implementation barrier such as lack of funding and some inadequacies of the local social management system, targeting the meso-scale GI planning and management system is recommended as the key links of this model. For the multi-objective restoration of the key node of river Daxi estuary wetland site, the most important short-term construction measures of the plan includes the demolishing of buildings in areas with high flood risk and high ecological sensitivity and the functional renewal of some good quality buildings. On this basis, the coordination between various scales for the holistic management and implementation of supporting policy for SCPs GI Planning were discussed.

In brief, the developed model incorporates GI planning strategies for enhanced urban resilience to mutually benefit nature and people. This exploration emphasizes that multifunctional GI system should not only focus on the sustainability of the ecological resilience, but also simultaneously improve the social resilience and ensure cost effectiveness. The development of the BSPF model with KPIF, its application, evaluation, optimisation, and policy discussions collectively provide useful design and evaluation tools and valuable references for both designers and administrators who are undertaking similar planning projects.

Achievements

Journal Papers

1. **Jing Sun**, Ali Cheshmehzangi, Sisi Wang. Green Infrastructure Practice and a Sustainability Key Performance Indicators Framework for Neighbourhood-Level Construction of Sponge City Programme. *Journal of Environmental Protection*, 11, 82-109. January 2020

2. **Jing Sun**, Ali Cheshmehzangi, Sisi Wang. Comprehensive Evaluation of Green Infrastructure Restorative Practices for High-quality Transitional “Sponge Node” Renewal Programs in China. *Journal of* Urban Forestry & Urban Greening. Under review

3. **Jing Sun,** Ali Cheshmehzangi. Green Infrastructure Planning for Sponge City Construction in China: the Way, the Barriers and the Future of Sponge Eco-node Restoration. Conference paper (Poster). 2019

Project Report

Ali Cheshmehzangi, Ayotunde Dawodu, Bamidele Akinwolemiwa, **Jing Sun** Urban Design Project Report: Remodeling Ningbo's CBD based on three dimensions of energy, spatial and infrastructure. March 2017

Acknowledgements

Firstly, I would like to thank my supervisor Professor Ali Cheshmehzangi for providing me the opportunity to work on this research project, for his supervision and his endless support. Meanwhile I would like to thank members of staff and PhD colleagues who gave me helpful advices both for PHD research and life.

Most important of all, I would like to express my gratitude to my family for their understanding and encouragement. I am particularly grateful to my husband for his continued support.

Finally, my sincere appreciation also extends to the experts who have involved in this project completion, especially experts from the Liangnong government management office, the Ningbo sponge city construction leading group office, experts from the Ningbo Natural Resources and Planning agency as well as the Ningbo housing and Urban-Rural Development agency.

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Abbreviations

ATRCR	Annual Total Runoff Control Rate
AHP	Analytic Hierarchy Process
ASLA	American Society of Landscape Architects
AU	Australia
BC	Bio-Retention Cell
BMP	Best Management Practice
BS	Bio-Swales
BSPF	Basic Strategies and Pathways Framework
CAD	Computer Aided Design
CI	Consistency Index
COD	Chemical Oxygen Demand
CR	Consistency Ratio
CT	Concentration Time
CWA	Clean Water Act
ES	Ecosystem Services
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
GI	Green Infrastructure
GIS	Geographic Information Systems
GR	Green Roof
GSI	Green Stormwater Management
KPIF	Key Performance Indicator Framework

LID	Low Impact Development
MOF	Ministry of Finance
MHURD	Ministry of Housing and Urban Rural Development
MOWR	Ministry of Water Resources
MSPA	Morphological Spatial Pattern Analysis
NA	North America
NBS	Nature-based Solutions
NPS	Nonpoint Source
PP	Permeable Pavement
RI	Random Consistency Index
RG	Rain Gardens
SCP	Sponge City Program
SCDTG	Sponge City Development Technical Guide
SEPA	Scottish Environmental Protection Agency
SP	Security Pattern
SS	Suspended Solids
SUDS	Sustainable Urban Drainage Systems
SWMM	Water Management Model
TN	Total Nitrogen
TP	Total Phosphorus
TBL	Triple Bottom Line
TSS	Total Suspended Solids
UK	United Kingdom
UAV	Unmanned Aerial Vehicle

USA	United States of America
USEPA	United States Environment Protection Agency
USM	Urban Stormwater Management
WSUD	Water Sensitive Urban Design

Chapter 1 Introduction

1.1 Background of the Sustainable Stormwater Management and the Sponge City in China

The rise in impervious surface areas due to urbanization has been reported to produce substantial hydrological effects globally (Dietz, 2007, Choi and Deal, 2008, Ahiablame et al., 2012a, Bell et al., 2016, Jacobson, 2011, Kong et al., 2017, Guan et al., 2015). Previous studies have observed that urbanisation has altered both the water system and natural water process, thereby severely deteriorating the water ecosystem. (Chocat et al., 2001, Hlavínek and Zeleňáková, 2015, Dhakal and Chevalier, 2016, Nielsen et al., 2015, Jiang et al., 2018, Kim et al., 2017, Lin et al., 2018) The increase in impervious land surface areas in cities and the continuous utilisation of traditional pipe network for rapid rainwater drainage have fairly changed the natural water cycle as shown in Figure 1.1 and Figure 1.2.

Furthermore, the disturbance to this process is such that in a city with minimal anthropogenic activities, up to 90% of stormwater would be permeated (either absorbed by plants or evaporated into the ground/atmosphere) and only about 10% runoff are generated. With the development of urbanization, increasing housing development and road construction for the rising population, the use of forest and agricultural land areas have been altered by vast stretches of hard standing surfaces (pavements, highways, roads, and built-up areas), thereby inhibiting stormwater penetration into the earth and restricting ground water replenishment. In addition, stormwater are mostly transported to the nearest receiving water body by sewers resulting in substantial pollution due to the impurities accumulated from the washing off of impervious surfaces during its conveyance (Nielsen et al., 2015, Jiang et al., 2018). Consequently, the growth in impermeable surfaces results not only in rising surface runoff but also reduces the rate of groundwater recharge. This generates a number of issues such as floods, erosion, pollution, and decrease in groundwater levels (Kim et al., 2017, Lin et al., 2018).

Figure 1.2 shows the effect of urbanisation with the increasing runoff ratios before and after city construction based on the extent of increasing hard standing surfaces caused by housing development and road construction. It shows that after a city expansion, the runoff ratio can reach up to 50% and more in comparison to before development such as in a forest condition where the runoff ratio is about 10%. Figure 1.3 shows the hydrological alteration due to the site development: the post-development hydrograph depicts a shorter concentration time (Tc), an increase in the impermeability of entire site in comparison to the conditions before development. The resultant hydrograph shows a significant increase in the quantity of runoff flow (Q) and volume, as well as reduction in the time required for peak runoff (Smith et al., 2015).

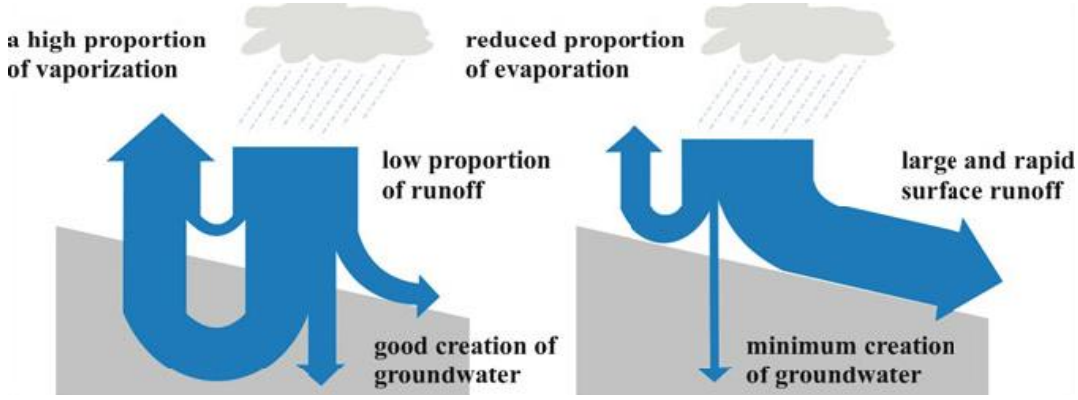


Figure 1.1 Water regime in permeable and hard standing surfaces (Hlavínek and Zeleňáková, 2015)

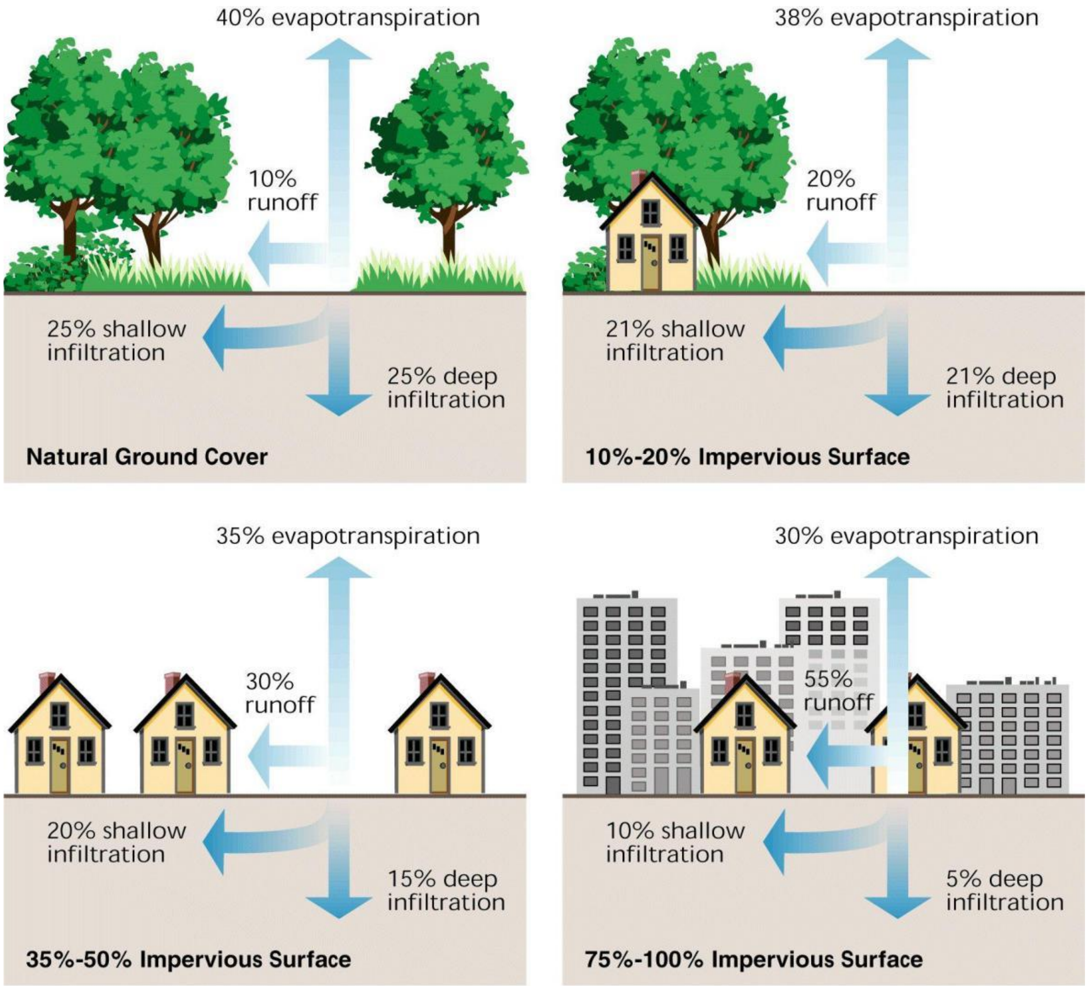


Figure 1.2 Water cycle with the urbanization (Cheng et al., 2003)

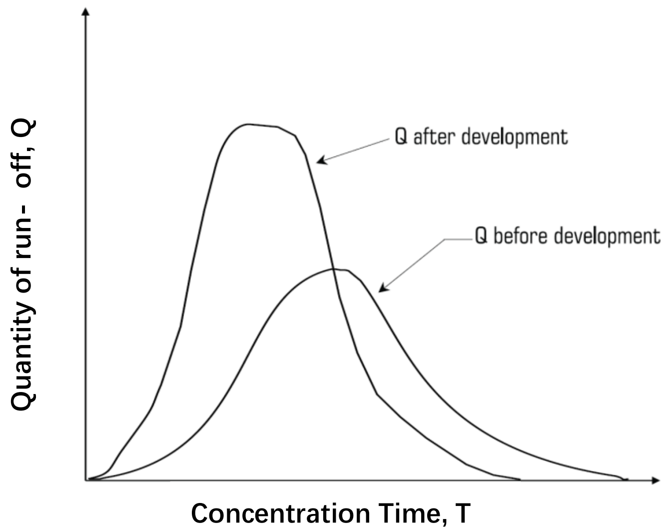


Figure 1.3 Hydrologic alteration due to the site development (Cheng et al., 2003)

Therefore, the impact of urbanisation patterns on natural hydrological systems include shallow groundwater levels due to the drop in groundwater recharge and base flow, an increase in the rate of runoff and volume, and overall decline in the quality of water from rivers and streams (Moscrip and Montgomery, 1997, Bhaskar et al., 2016). Such alterations to the natural world intensify the urban rain-island effect and result in the deterioration of aquatic environment, as well as significant ecological damage. Similar observations were detailed in various scholarly research (Paule-Mercado et al., 2017, Zhou, 2014). Presently, these urban water-related concerns are amplifying due to the collective impacts of climate change and unsuitable urban planning policies globally (Marlow et al., 2013, Nguyen et al., 2019). Confronted with these challenges, modern cities have veered towards sustainability. Subsequently, there is an apparent rise in the implementation of intelligent stormwater management systems and resilience design approaches, which are vital for adapting to climate change.

Hence, sustainable stormwater management approaches are being utilised as a practically feasible solution to resolve these issues (Lashford et al., 2019). Some famous examples of these practices include Low Impact Development (LID) in the United States (Ahiablame et al., 2012a, Liu et al., 2016, USEPA., 2000, Zhou, 2014, Pyke et al., 2011); Sustainable Urban Drainage System (SUDS) in the United Kingdom (Hoang and Fenner, 2016), and Water Sensitive Urban Design (WSUD) in Australia (Chui et al., 2016, Mao et al., 2017, Li et al., 2018b). These concepts and practices are aimed at the maximal reintroduction of stormwater into the natural water cycle and are important criteria for ecologically suitable and sustainable stormwater planning and management methods for any given region or site.

In developing countries like China, rapid urbanization has led to more conspicuous natural resource and environmental issues, mostly connected with the water ecology crisis (Chan et al., 2018). A context-tailored solution is crucial in order to adapt established effective stormwater management practices for resolving local issues. The launch of the Sponge City Program (SCP) in 2013 was with this specific goal (Xu, 2015, Xie, 2016) and the Sponge City Development Technical Guide (SCDTG) was issued in October 2015. The general Office of the State Council issued 'Guiding Opinions on Promoting Building of Sponge Cities', and allocated tasks to drive the construction of sponge cities. A selection of thirty cities as the first group of pilot cities was done between 2015 and 2016, including: Baicheng, Zhenjiang, Jiaxing, Chizhou, Xiamen, Ningbo, etc. (Nguyen et al., 2019). Currently, these pilot cases are in progress and China is dynamically moving towards developing numerous sponge construction projects (Jiang et al., 2018). As a result, sponge city is listed as a national strategic level project, and an important theme nationally and internationally (Jiang et al., 2018, Nguyen et al., 2019, Sun et al., 2020).

1.2 The Significance of Multi-objective Green Infrastructures for Sponge City Program and Resilient City Development

1.2.1 The 'resilience' connotations and its scope within this research

Climate variations and hydrological inconsistencies are challenging various municipalities to re-examine the design and construction of their basic infrastructures. Green Infrastructure (GI) can be used to alleviate the environmental impacts of cities, help in adapting to environmental variability and enhance city resilience.

In terms of city resilience, this has a broader meaning and has been interpreted in multiple ways. Hence, for better understanding the relationship between GI, SCP and resilient city development, this thesis will start with a brief illustration of the meanings of 'Resilience' and define the scope of resilience in this research. 'Resilience' comes from the Latin word 'resilio' (Klein et al., 2003). There are still numerous controversies about the origin of this concept: some scholars think that it originated from ecology, while others believe that its origin is from physics (Manyena, 2006). From 1960s to 1970s, while the ecologist, Holling, whilst studying the population relations and ecological stability theory of predators and preys, was the first one to bring the concept of resilience to ecology (Holling, 1961, May, 1972). Since then, the whole idea of resilience has been widely associated in many fields, for instance, ecology, social ecology, and water ecosystem; in addition, its connotation has also achieved a lot of progress. Holling (Holling, 1973) defined resilience as the capability of a system to maintain its state after having interference. He argued that resilience determines the maintenance of various relations within a system; and resilience is the measurement of system ability of bearing various interferences and remaining stable.

This concept evolved into 'ecological resilience' later.

The concept of resilience in the field of social science is an extension of resilience in the field of ecology in natural sciences. Resilience alliance define resilience as the amount of interferences that could be absorbed by system before the system moves to other states with different structures, different functional properties, and different ecosystem services provided for human (Resilience Alliance, 2007). Adger believes that social resilience refers to the ability of communities or groups to cope with outside pressures from society, economics, politics and environmental changes (Adger, 2000, Adger et al., 2005). Afterwards, in social ecology, definitions of resilience center on the idea that systems are in flux and that to survive, systems adapt or transform to accommodate shocks or changes in variables (Friedland and Gall, 2012).

Additionally, some scholars define resilience using perspectives and theories which incorporated both the ecological and social aspects (Qiu, 2018). The system's resilience mainly involves consideration of three aspects: the amount of interference that the system can bear, the recovery speed of system after been disturbed, and system's abilities of self-organization, learning and adaptation (Carpenter and Gunderson, 2001, Cai et al., 2012). Moreover, this system resilience theory discussed the importance of persistence through continuous development, innovation, and better-adapted configurations from both ecological and social aspects (Qiu, 2018, Matthews et al., 2014). This concept is valuable for the current transitional period in china.

Therefore, this thesis favors the definition of resilience in the system resilience perspective and theory. Hence, both the ecological and social resilience which are the important aspects of the system resilience, are integrated in the research scope. The research goal is to develop a functional system to reinforce the role of GI design methods, principle, and strategies utilized in SCP for supporting overall system resilience. Additionally, this research is supported by considering social-economic factors and relevant policy discussions required for creating strategies aimed at strengthening social resilience while the ecological and technical considerations were explored for supporting ecological resilience reinforcing strategies.

1.2.2 The Multifunction GI and Its Multiple Scales

1.2.2.1 Brief Introduction of GI Connotation with the Multiple Scales and the Scope in this Research

GI is widely used as an innovative approach for the management of stormwater in order to tackle urban hydrology and water related issues (Qiao et al., 2018, Gogate et al., 2017, Jiang et al., 2018, Nguyen et al., 2019). GI has been adopted as a crucial measure in various well-established strategies for stormwater management practices, such as BMPs and LID in the U.S. (Ahiablame et al., 2012a, Liu et al., 2016, USEPA., 2000, Zhou, 2014, Pyke et al., 2011), SUDS in the UK (Hoang and Fenner, 2016), and WSUD in Australia (Wong, 2006). The successful implementation of these innovative solutions have been observed in many places, and the main model is centralized around the use of green infrastructures, such as bioretention cells, vegetative swale, wetlands, etc. (Ahiablame et al., 2012a, Law et al., 2017, Ferguson et al., 2013a, Ferguson et al., 2013b). Many studies have shown that GI facilities can be utilised for the effective control of the quantity and quality of surface runoff from rainfall (Bedan and Clausen, 2009, Demuzere et al., 2014, Xu and Guo, 2017, Luan et al., 2019). Thus, China's Sponge city programme (SCP) was initiated with a similar objective by learning from, adopting and adapting good practices used globally.

The definition of GI is quite extensive as it typically refers to multi-scale and interconnected networks of greenways, wetlands, waterways, urban agriculture, vegetated landscapes, and/or green roofs, designed to function inside and around cities, which are deliberately planned and implemented to provide ecological, social, and economic benefits. (Bendict and McMahon, 2006, Kambites and Owen, 2006, Tzoulas et al., 2007, Wright, 2011). In addition, there is a further increase in the appeal of GIs as its approaches have been termed as Nature-based Solutions (NBS) (Song et al., 2019, Jim, 2015). Likewise, the US Environmental Protection Agency (EPA) describes GI as an economical, resilient approach for dealing with stormwater that benefits the community and specific sites (neighbourhood and/or street) (EPA, 2000).

Whilst emphasizing the significance of GI's application in stormwater management, a concept labelled as 'Green Stormwater Infrastructure (GSI)' must also be highlighted (Lucas and Sample, 2015, Luan et al., 2017, Tao et al., 2017). These GSI measures (shown in Figure1- 2) mainly consist of: Bio-Retention Cells (BC),Bio-Swales (BS), Green Roofs (GR), Permeable Pavements (PP), Green Parking, etc. (EPA, 2017).

Broadly, GI can also be defined as a multi-objective and multi-scale interconnected systems of urban green space and nature (such as flowerbeds, forests, trees, court yards, grasslands, parks and wetlands) utilized for the conservation of the ecological values and functions for the benefit of the population (Benedict and McMahon, 2002, Mell, 2013). Therefore, waterbodies are usually planned or considered within the GI system and some researches prefer to use the term Blue and Green infrastructure (BGI) to describe the entire network (Ghofrani et al., 2017, Evans et al., 2019, Deely et al., 2020).

This thesis will refer to such facilities as GI, mainly because it is the most widely used term in both academic research and government policies.

GI can be designed in a relatively large scale, for example it can be a park area for a neighbourhood, for example the Luming park (shown as Figure 1.5), a famous resilient park design located in Zhejiang province in China and designed by professor Yu and his team (Turenscape, 2015); or a green belt along a waterbody, like the BIG U proposal (shown as Figure 1.6) developed to protect lower Manhattan from floodwater, storms, and other impacts of a changing climate in collaboration with New York City (BIG Architects, 2016). Furthermore, GI designs can be significantly larger in scale, for example; a network system with intensified connection and functionality for a region or a small watershed area of a city, such as the Canway Urban Watershed Framework Plan (shown as Figure 1.7) which is one part in a multipronged initiative by the United States Environmental Protection Agency (EPA) and the Arkansas Natural Resources Commission to mitigate severe urban water management problems in the Little Creek Palarm Creek (LC-PC) sub-watershed incorporating the City of Conway, Arkansas (Wang, 2016). GI can also be used to form a network for a town and a city scale, for example, a city scale GI model conceived as the macro-scale part of Taizhou planning which received the 2005 ASLA honour awards for remarkable analysis and planning (Yu et al., 2005b, Yu, 2011). In Taizhou planning (Yu, 2011), three scales of interrelated GI planning method was put forward, which will be further illustrated in the methodology and the discussion chapters.

In short, the scales and scope of GI (including GSI) in this thesis can be summarised with three key points. Firstly, GSI is imbedded as a part of GI, mainly attributed to the site scale (neighbourhood and/or sub-neighbourhood) sustainable stormwater management. The framework of typical site scale GSI technical tools and the main functions of the tools are shown in Figure 1.4. Secondly, the scope of this multi-objective and multi-spatial research incorporates an investigation of the broad use of GI (including GSI) for SCP planning and constructions. Thirdly, the three-scales of GI are considered in this research for more systematic planning method. These three scales are consistent with the three major scales of overall urban and rural spatial planning system for a specific region, city or town. Moreover, this scaled organisation system of GI planning corresponds with China's current urban and rural planning system. The three major scales include:

(1) the micro-scale consists of sub-neighborhood units which usually are units of the neighborhood scale corresponding

to the micro-scale detailed constructional planning of the urban planning system in China;

(2) meso-scale consist of a neighborhood scale or a small region of the city/town corresponding to the meso-scale detailed regulatory planning of the urban planning system in China;

(3) macro-scale can be a small watershed, a town or a city scale planning corresponding macro-scale master planning of the urban planning system in China;

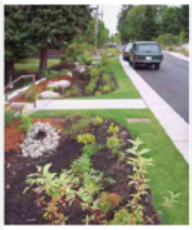
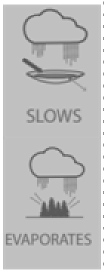
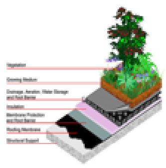
Typical GI (GSI) tools	Description	Main Functions	How it usually used in Design	Figure
Bioretention	Bioretention areas function as soil and plant-based filtration devices that remove pollutants through a variety of physical, biological, and chemical treatment processes. This can help to reduction of pollutant loads to receiving waters and increase infiltration for achieving stormwater regulatory goals.		Bioretention can be uesd in a line on the side of the street or form a rain park for a site, providing for a more aesthetically pleasing site. Bioretention can also be designed with different underground structures and thickness for different level of regulation functions.	
Bio-Swales (Vegetated Swales)	Vegetated swales are open, shallow channels with low-lying vegetation covering the side slopes and bottom that collect and slowly convey stormwater runoff to a downstream stormwater storm drain system, or receiving water.		Vegetated swales provide pollutant removal through settling and filtration in the vegetation (usually grasses) lining the channels, provide the opportunity for stormwater runoff volume reduction through infiltration and evapotranspiration,and reduce the flow velocity of the site.	
Permeable Pavers	Alternative paving materials can be used to locally infiltrate rainwater and reduce the runoff leaving a site. This can help to decrease downstream flooding, provide for groundwater recharge and facilitate pollutant removal.		Permeable Pavers uesd as alternative paving materials for the site as most of the 'paving over' in developed areas is due to common roads and parking lots, which play a major role in transporting increased stormwater runoff and contaminant loads to receiving waters.	
Green Roofs	Green roofs, also known as vegetated roof covers, eco-roofs or nature roofs, are multi-beneficial structural components that help to mitigate the effects of urbanization on water quality by filtering, absorbing or detaining rainfall		They are constructed of a lightweight soil media, underlain by a drainage layer, and a high quality impermeable membrane that protects the building structure.	

Figure 1.4 Framework of typical site scale green infrastructure (GI) technical tools and the main functions of the tools

Figure 1.5 The GI landscape design of Quzhou Luming Park in Zhejiang province China (Turenscape, 2015)

Figure 1.6 The big U GI design forming a green belt for serval blocks of Lower Manhattan of the city of New York (BIG Architects, 2016)

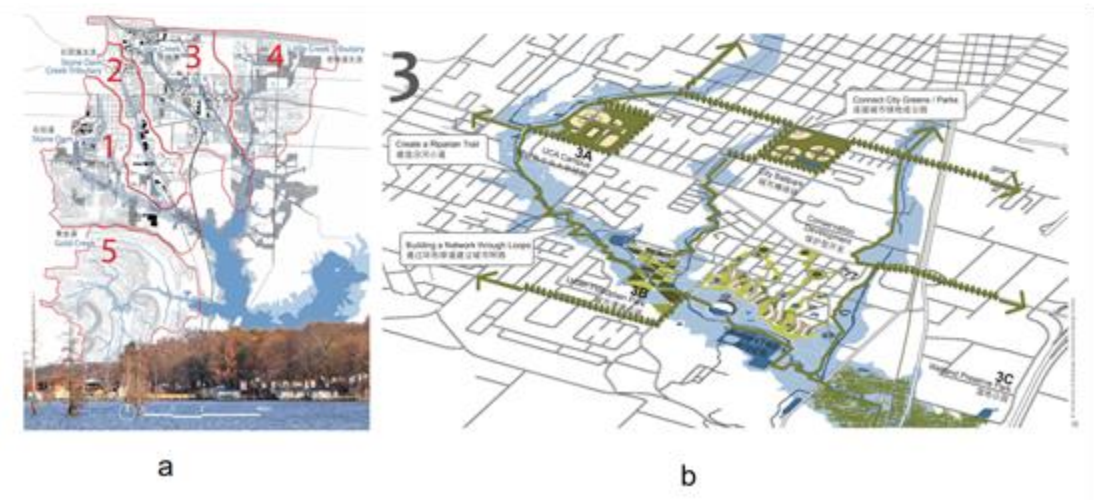


Figure 1.7 The Urban Watershed GI Framework Plan for Conway, U.S forming a network plan of a watershed scale (a is the location of the watershed, b is the GI network planning) (Wang, 2016)

1.2.2.2 The Multi-functionality of GI

GI can be used to reduce the impact of flooding events, for example, floodplains or wetlands can be restored at strategic sites that will store excess water. This is an adaptive solution to prevent flood and enhance water resilient capacity of cities or towns. Although traditional grey infrastructure such as removable flood-barriers or waterproof walls could be also constructed to cope with flooding, the use of GI solutions, such as restored floodplains and wetland parks, deliver multiple additional ecosystem services that is unavailable with traditional grey infrastructures. Services such as water purification, air quality improvement, increase in biodiversity and enriched scenic value. Moreover, these benefits also extend to promoting healthier lifestyles that lead to improved wellbeing, growth of green economy and enhanced city resilience (UK Green Building Council, 2015).

In fact, GI is recognized as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecological services " (European Comission, 2010). These multiple functional capability of GI are acknowledged in academic researches as a range of ecological services (ESs) (Díaz et al., 2015, Pascual et al., 2017). Zhang and Ramírez (2019) provided a relatively comprehensive summary of the multiple functions of GI in terms of the descriptions of ESs, which were grouped into four main categories: providing services, regulating services, habitat services and cultural services (shown as the Appendix 1.1 Table A.1.1, the first column lists 32 sub-categories of ESs).

Moreover, the multiple benefits of GI can also be embedded into the three-pillar framework of environmental, economic, and social sustainability (Sachs, 2012, White, 2013, Dos Santos et al., 2019). Additionally, there is a growing consensus that GI can provide exciting opportunities for the delivery of significant environmental, social, and economic benefits as summarised by (Li et al., 2020a). It is evident that these benefits can be exploited for promoting healthier lifestyles that lead to improved wellbeing, green economy development and ecological resilience in addition to the regular ESs such as improving biodiversity, flood protection, water purification, as well as air quality improvement etc.

In terms of SCP development, classifying the multiple benefits into the three-pillar concept framework of environmental, economic, and social sustainability will aid the promotion of the implementation of GI schemes. This indicates that the maximization of only ecological benefits in the GI planning process is not enough. Hence, it should be taken into consideration that there are myriad of social and economic factors acting as barriers and drivers to GI design and implementation. Additionally, some economical and the social-cultural factors that are closely linked with the transitional development trends and needs in a given location should be stressed and should be taken into consideration early during the planning stage. Furthermore, a comprehensive performance evaluation system needed to be developed for SCP, serving as an assessment tool to support the robust decision making (which will be further reviewed in the Chapter 3). This is of great importance to ensure the application of GI delivers on the enhancement of resilience and sustainability, especially in the application of sponge City in the transitional period towards 2030s and even 2050s. The research significance will be further illustrated in the subsequent section 1.2.3 with a summary of the relationship between GI, SCP and RCD.

1.2.3 The Research Significance and Relationship between GI, SCP and RCD

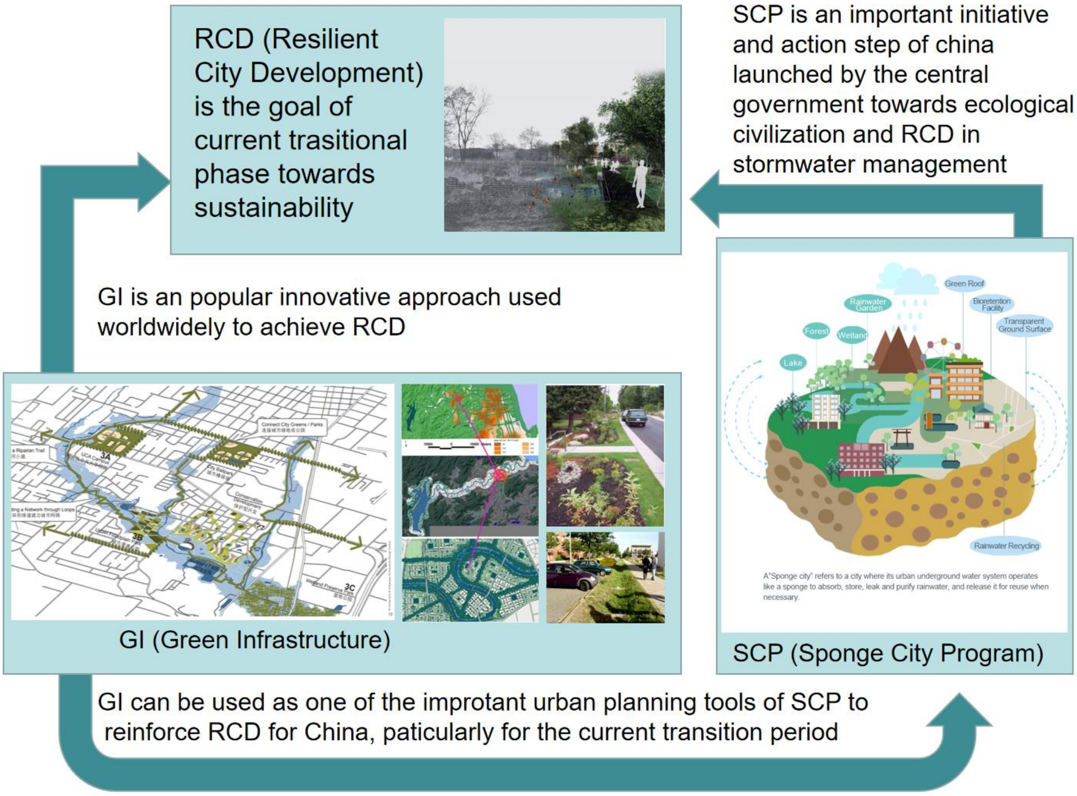


Figure 1.8 The relationship of Sponge City Program (SCP), Green Infrastructure (GI) and Resilient City Development (RCD)

Considering the impact of population growth, global warming, mass migration, and global economy, the 21st century is characterised by unique and fundamental changes and varied evolution. Therefore, the threshold into a new ecological era, the Anthropocene, has been crossed such that the impact of human activities are recognized as a geological force (Benedict and McMahon, 2002, Tzoulas et al., 2007, Aronson et al., 2014). Hence, for the sustainability and resilience of the world in this 'century of the cities', innovative urban ecosystems will play a fundamental role, and cities/and towns must be incorporated as a vital part of the solution.

This is particularly of importance due to the forecast that 90% of population in developed countries will be living in urban areas by 2050 in comparison to the currently estimated 50% of the global population inhabiting urban locations (Beery et al., 2017). As illustrated previously, excessive urban runoff caused by increased urbanization has changed the natural water process, thus, bringing about negative impacts including urban flooding, water shortage, water pollution, and other water related ecological environment problems. These negative impacts as well as the challenges posed by climate change upsurges interest in resilient city development, especially for China which has been undergoing four decades of rapid urbanization (McDonnell and MacGregor-Fors, 2016).

GI is utilised as an effective tool to enhance the resilience of cities to cope with the growing urban challenges globally (Gómez-Baggethun et al., 2013, Lafortezza et al., 2017, Badiu et al., 2019, Niţă et al., 2017, Elmqvist et al., 2003). Additionally, It is well kownledged that GI can deliver a wide range of ESs for cities and people, and thus applied as a popular innovative approach worldwide for this purpose (Vallecillo et al., 2018, Pauleit et al., 2019, Majekodunmi et al., 2020, Miller and Montalto, 2019, Ghofrani et al., 2017, Evans et al., 2019).Moreover, GI has been adopted in China as the one of the main approches in building SCP which is an important initiative launched by the central government towards ecological civilization and resilient city development in stormwater management (Demuzere et al., 2014, Lovell and Taylor, 2013, Grant et al., 2013, Foster et al., 2011, Gaffin et al., 2012, Kim and Kim, 2017, Schifman et al., 2017, Simić et al., 2017, Pauleit et al., 2019).

In short, RCD (Resilient City Development) is the goal of current transitional phase towards sustainability and GI can be used as one of the important urban planning approaches of SCP to reinforce RCD for China (as shown in Figure 1.6). In addition to a well-designed planning model, GI offers a crucial functional system for the interconnection social and ecological infrastructure networks within a city for enhancing resilience.

1.3 Sponge City Frontiers with Green Infrastructure Design and Assessment Trends and Needs in China

After almost four decades of rapid urbanization and economic growth, China's populations demand for better quality of life is evolving (Jia, 2018, Fang, 2019). This is mostly due to the severe threats posed by urbanisation to natural area and biodiversity preservation. Within the last two decades, a systemic increase in the ecological stress induced by urbanization has been recurring, particularly in the metropolitan area in South-East coastal area in China. These ecological stress are not limited to the water crisis, but also associated to bigger concerns such as habitat degradation, wetland reduction, and biodiversity reduction (Fang, 2019, EconomicDaily, 2019).

Nevertheless, in recent years, the growth of urbanization in these cities in China have begun to decelerate and crucial factors such as ecological environment protection and ecological restoration have been attached to urban construction (Guan et al., 2019). The 'double repair' initiative, which refers to 'urban ecological restoration' and 'urban environment improvement', was put forward after china's 2015 central government urbanization conference. This initiative is another national level strategy, following SCP, for adapting to the new era of ecological civilized construction and high- quality development. Both the 'double repair' and SCP are the important steps taken by the Chinese government, towards high-quality urban construction (Yi, 2019, Xu et al., 2019). Moreover, this transition to urban development is multi-faceted and the scheme aims at an inclusive sustainable development of the environment, economy and society (Jiang et al., 2018, Liu et al., 2019). Thus, the construction of a human-centred, healthy city and high-quality built environment for improving human wellbeing are emphasized, as well as with ecological sustainability.

The reliance of human wellbeing on various ecosystem services (ESs) provided by GI systems in cities facing numerous environmental, economic, and social challenges have been recognized by international researchers (Zhang et al., 2020, Wang et al., 2017, Venkataramanan et al., 2019, Hunter et al., 2015, Jeanjean et al., 2016, Sadler et al., 2010, Payne and Barker, 2015, Jerome et al., 2019, Frumkin et al., 2017, Alcamo, 2003). Hence, efforts to redirect such cities towards improved resilience, sustainability, as well as higher quality of living with enhanced human health and wellbeing represents an immense improvement with this transition process (Reid et al., 2005, Kumar, 2010, Benayas et al., 2009, Vallecillo et al., 2018, Venkataramanan et al., 2019). Within this context, more resilient and humanized delivery frameworks of GI still need to be improved in terms of enhancing ecological and social resilience to shocks and disruption as varied as natural disasters, food shortages, in addition to severe stress and anxiety of the citizens.

Subsequent to its identification as one of the main strategies for attaining sustainability and resilience, (Demuzere et al., 2014, Grant et al., 2013, Schifman et al., 2017, Simić et al., 2017, Pauleit et al., 2019), GI has gained tremendous interests in the sponge restoration programs and was implemented at a national level as the main tool in building sponge cities (Yin et al., 2020, Luan et al., 2019). Yu (2015c) highlighted that GI is a holistic stormwater management strategy with water management at its core and provides comprehensive and systematic solutions to the ecological restoration. Some of their GI projects, such as Taizhou EI planning, Quzhou Luming Park, Yongning River Park and Qinhuangdao Red Ribbon Park(Wang and Banzhaf, 2018, Yu, 2015a), have won design awards form American Society of Landscape Architects.

Even with good examples of clear and evidence-based GI designs and guidance to highlight the ways in which GI delivers a good ecosystem service, there are still significant uncertainties amongst experts about the design, delivery, and evaluation of a GI plan for China's transitional development period. During this transition period, it is of great importance that GI design and evaluation should not only emphasize the sustainability of the natural environment and ecological resilience, but also improve the level of humanized design and social resilience, because GI itself not only benefits nature but also the people. Therefore, with regards to 'multi-functional' planning with more resilience and sustainability incorporated, the holistic GI planning and assessment model should be improved. This would require improvements of the strategic framework design with special identification methods for supporting, planning and comprehensive evaluation methods to aid decision-making.

1.4 Research Objectives, Research Questions and Research Frame

1.4.1 Research Objectives

Within the context of high-quality transitional development towards reinforced resilience and sustainability, it is of great importance that GI design and evaluation must improve the level of humanized design and social resilience. This must be done to achieve a better and a healthier living space that is ecologically resilient in coping with the impact of natural disasters and promote the sustainability of the natural environment

Hence, the major objective of this study is developing a novel strategic model that will guide the GI planning for China's Sponge City Program (SCP) towards reinforced resilience and sustainable outcomes. This involves the systematic exploration of GI planning strategies, design pathways and comprehensive evaluation methods for the three-scale integrated planning process. Thereby, the key focus is development of GI planning and assessment strategies for the multi-objective ecological restoration of waterfront areas in big cities with the potential for benefitting from the SCP scheme. This could be associated with occupancy of key ecological land by urban constructions, thus causing a series of problems that needs to be addressed in the SCP to achieve high-quality living environment.

Based on a large number of literature review, field research and interviews (details are shown in the chapters 2 and 3 in the international and national literature review and the preliminary research detailed in chapter 4), it was determined that two key aspects must be addressed with further research for improving the overall of high-quality GI planning and assessment model.

1. First, in terms of the macro-scale, there are only few studies on how to define and develop a multi-benefit framework to focus on the goal of more resilience and sustainability, as well as the enhancements of human health and wellbeing during the GI spatial planning and land use management strategies; and
2. Secondly, in terms of the meso-and micro- scale research, there is a lack of comprehensive and quantitative evaluation system. This evaluation system is defined as the sustainability key performance indicator frame work (KPIF) with a set of key performance indicators (KPIs), which would be helpful in optimizing GI design scheme and selecting the optimal solutions with by comparing multi-benefits trade-offs in order to assist with decision making.

These aspects are the main research gaps in this field that needs to be strengthened.

In response to these, three sub objectives are set in this study (see Figure 1.9). The sub target one is proposing a basic framework model to improve multifunctional GI spatial network identification at macro scale with strategies for developing integrated GI spaces for high-quality transition with reinforced resilience, functionality, and connectivity. Thus, utilising the integrated GI system aids in improving the ecological resilience of the whole watershed, responding to challenges with more rapid and smooth adaptation. In addition to these, it enhances the social resilience through using the green spaces to relieve the severe stress and anxiety of the citizens, and improves human health and wellbeing by fostering valuable experiencing activities while preserving local natural and cultural landscape heritage.

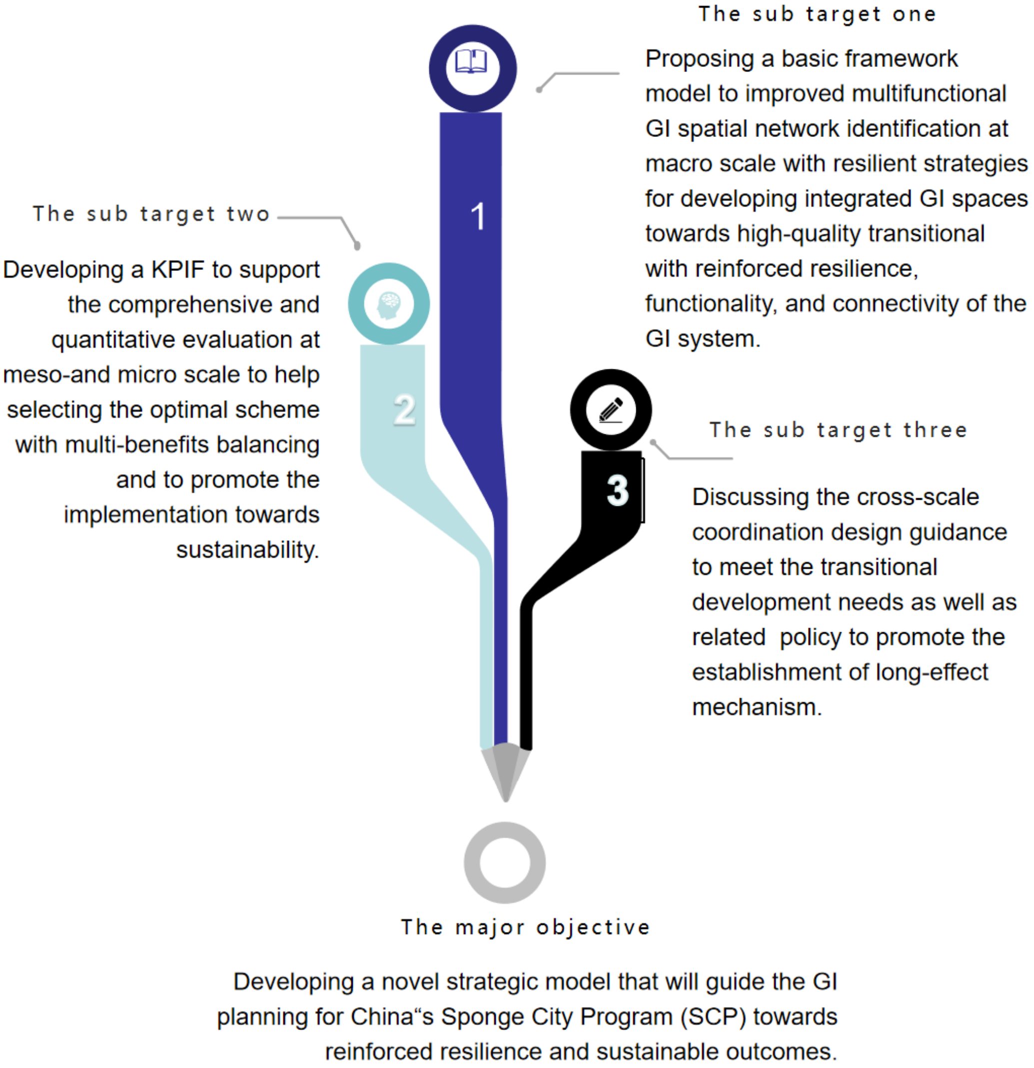


Figure 1.9 Research objectives

The sub target two involves developing a KPIF to support the comprehensive and quantitative evaluation at meso-and micro scale to aid in the selection of optimal schemes based on multi-benefits comparison and to promote the implementation towards sustainability. This can provide targeted regulatory controls for each meso-scale node that containing a series of micro-scale sponge cell. Thus, help in building the polycentricism of the system which is one of the important factors that can support the tight feedback loops and improve the function of the GI landscape systems (Qiu, 2018, Bajc and Stokman, 2018).

Admittedly, it is acknowledged that GI can provide a wide range of ESs and there is a growing consensus that GI can provide exciting opportunities for the delivery of significant environmental, social, and economic benefits. However, there are myriad of barriers that the process of implementing a GI might face from the designs stage to the construction of the GI, including economic factors such as lack of funding, insufficient technical design strategies and guidance, as well as the corresponding planning system and policy defects, etc. Especially for Chinese cities, the concept of GI is relatively new, many urban and rural planners are unfamiliar with the design methods as well as the barriers they may face during the stage of planning and implementation of GI project. Therefore, certain consideration in the early design stage is on how to develop a set of indicators, and thus to build a comprehensive evaluation framework to optimise GI scheme and/or select most suitable scheme.

Move over, the evaluation framework should consist of a set of key sustainability indicators from three major detentions: environmental, economic, and social sustainability which is commonly linked to the so-called triple bottom line (TBL) of economic-social-environmental balance (Sachs, 2012, White, 2013, Dos Santos et al., 2019).The evaluation system based on the framework of the three pillars of sustainable development can be adopted for GI implementation.

Additionally, in order to promoting the implementation of GI planning for SCP, some economic and technological factors should not be ignored and must be taken into consideration during the evaluation part of the GI planning stage. In addition, the cultural elements of ESs can be incorporated into the social-cultural assessment dimension; and some important factors linked with the humanized design and promotion of human health and well-being can be included in the social dimension, which are of great importance of promoting resilient cities and sustainable development（further illustrations of the importance are presented in the GI design trends and needs that has illustrated in the section 1.3）.

The third sub target involves discussing the cross-scale coordination design guidance to meet the high-quality transitional development needs as well as relevant policies to promote the establishment of long-effect mechanism. The GI delivery model would need to be a multi-scale correlation system integrating the macro-scale GI spatial network identification strategy and KPIF for the meso-and micro scale SCP assessment. This means that the multi-scale correlation system includes the top-level design and strategy of macro-scale, the multi-scheme design to generate multiple alternative future scenarios at meso- and micro-scale, as well as at the methods of evaluating, comparing, and optimizing the benefits of various design alternatives to support GI decision making.

This needs to be integrated within key steps of analysis and evaluation of the whole GI planning process, as well as to be taken into consideration as a strategy to improve the implementation of GI schemes by linking the GI planning to the whole spatial planning and management system. As GI planning is currently an independent planning, which does not belong to the current spatial planning system of China (official planning generally issued by the urban planning bureau of local municipal government). As a result, GI designs usually serve specific project as an additional consideration or special design feature of a certain site/region because it is not a compulsory planning element. This highlights GI as an unessential planning aspect during the decision making of most urban construction with the exception of SCP pilot areas or when projects with similar development goals are required by the local government (show as Figure 1.10).

In addition, most of GI planning for SCP are designed for the neighbourhood or sub-neighbourhood site scales due to the current scales of most of the SCP pilot projects, thus, not forming a network for a larger scale. These practices are usually closely related to the meso-and micro-scale spatial planning and thus these smaller scales planning is significant for the SCP construction, especially for the current period. Additionally, there is few planning implemented in a macro-scale, for a town or a city. However, a cross-scale integrated planning that linked to the whole planning system is of great importance for sustainable development, this mainly due to the larger scale GI implementation has a positive correlation to the enhancement of the connection and the functionality of the whole GI system (will be further illustrated and discussed in the section 7.4 of Chapter 7).

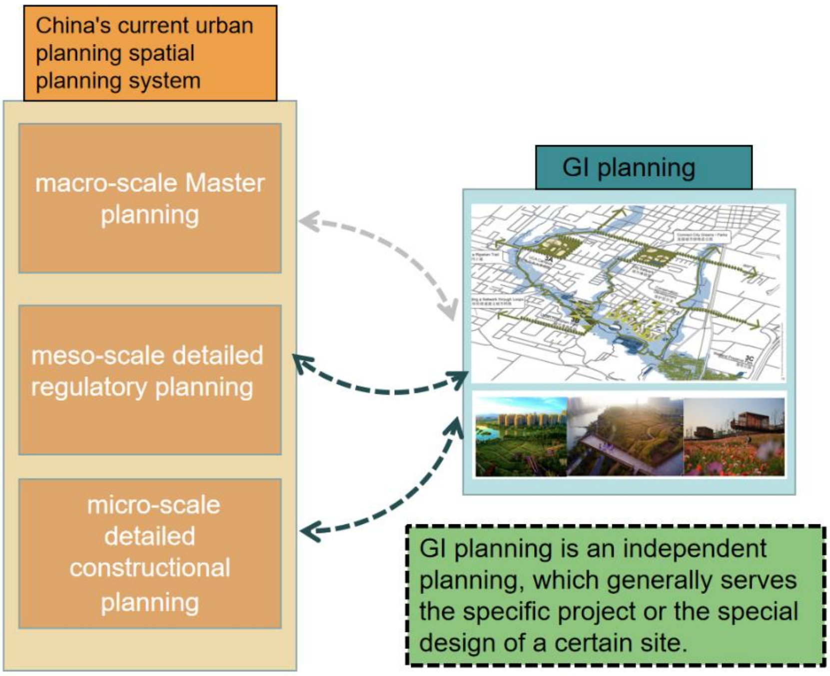


Figure 1.10 GI Planning position and its relationship with current spatial planning system of China

This research selects the Siming Lake watershed of Liangnong of Ningbo as a case study area, which is a typical representative case of the ‘Jiang Nan water net City/Town’. Cities in the southern region of Yangtze Creek Delta with developed water network of river bends, dispersed lakes, and abundant waterfront, known as ‘Jiang Nan water net areas’, represent an ideal natural water resilient ‘sponge’ landscape. However, due to the rapid economic development and urbanization, the water resilient landscape formed in these regions have been destroyed to different extent, among which Siming Lake watershed Area in Ningbo is a typical example.

After rapid urbanization development, the traditional sponge landscape pattern of this area has drastically changed. The study area has been severely intruded by human activities, and some parts of the natural waterfront landscapes are covered and replaced by various artificial landscape and built-up area, mainly small factories. In addition, the Siming Lake waterfront area is an important ecological sponge node and an attractive locality, which not only faces water environment problems such as water quality degradation, but also faces serious ecological crisis such as wetland reduction, habitat degradation and the damage of the related ecological cultural and wellbeing services. In the process of building sponge cities, it is crucial to restore the water resilient landscape pattern and the landscape ecology at the water source (the upper stream area) within the city.

With transitional development towards reinforced resilience and sustainability being the required outcome, the need for improving the GI design and assessment model and development of a comprehensive quantitative evaluation system linked with the model is crucial. Furthermore, the multi-scale functionality of the GI requires a strategic multi-spatial design model with an interrelated tactic for supporting cross-scale coordination. This cross-scale coordination is important as the meso- and micro- scale are detailed design stages in the framework, well arranged under the top-level macro-scale of the GI network, which is guided by the holistic objectives and strategies.

In summary, this area will be considered as a cross-scale case study, and systematically explored for developing a comprehensive GI planning and assessment model for achieving more resilient and sustainable outcomes, especially for SCP of the Jiangnan water net area. This model embodies multi-dimensional improvement in resilience and sustainability strategies with improved human wellbeing. Thus, an overall exploration of solutions for addressing these two research gaps were carried out in this research with two main focus. The first focus in the macro scale is the proposing an improved multifunctional GI spatial network identification model to enhance both ecological and social resilience by integrating water resilient landscape pattern, rebuilding of biodiversity, heritage protection and recreation for improving human health and wellbeing. Another focus is to develop a key performance indicator framework (KPIF) which incorporates key performance indicators (KPIs) and develops multiple scenarios for the meso- and micro- scale. Finally, the related design guidance and policy to supporting the transitional planning with Siming case study will be discussed and recommended subsequently for promoting the establishment of long-effect mechanism and improving the implementation possibility.

1.4.2 Research Questions

Considering the research objectives and research gaps summarized in the previous section, four main research questions are developed:

1. How to develop the GI planning and assessment with BSPF model for SCP especially for Jiangnan water net area of China towards reinforced resilience and sustainability?

   This model needs to be a multi-objective strategic framework towards enhanced resilience and sustainability that can better meet the transitional trends and needs. Additionally, this model also needs to be a multi-scale integrated model, so that the requirements of the three scales of designs are satisfied and the three-scales are interlinked in a holistic coordination system.

2. How to build a multi-objective spatial GI network for resilient and sustainable transitional development in the macro-scale?

   This network must incorporate strategic point identification capabilities to meet the transitional requirements. Additionally, the transitional requirements must include both ecological and social resilience to attain enhanced environmental and human wellbeing.

3. How to develop a comprehensive and targeted KPIF for the meso- and micro scales?

   This KPIF will consists of a set of key indicators focused on sustainability which will basically be categorized based on the fundamental framework of the three pillars of sustainable development (economy, environment and social). Also, this KPIF can be linked with the GI planning and assessment model to support the quantitative evaluation of multiple GI scenarios designed at meso- and micro- scale; and

4. What are the cross-scale integrated planning guidance and policy recommendations for management and implementation?

   The planning guidance and policy recommendations will be proffered based on the developed model and implementation outcome using the Siming Lake watershed case study.

1.5 The Research Scope and Research Frame

1.5.1 Research Scope

As it was illustrated in the section 1.4.1, the main purpose of this paper is to explore the delivery of high-quality GI to cope with the main challenges of the holistic natural water resilient landscape pattern by restoring and repairing the multi-functional waterfront sponge node in the SCP in Jiangnan area. Hence, the research scope is the high-quality GI planning and assessment strategies and pathways for the SCP towards more resilient and sustainable planning, especial for the upper areas of the cities in the south of the Yangtze River, which usually called "Jiangnan water town".

The study aims at developing a comprehensive GI planning and assessment model with multi-scale integrated planning considerations. This urban planning and landscape design approach requires management of the relationship between people and land, exploration of balanced urban development solutions for guiding sustainable policies and strategies while accounting for the challenges of the contemporary society. Waterfront is a significant element of GI as it integrates a water resilient space with significant ecological section of biodiversity, and a relaxation spot for humans to experience nature. In view of the multi-disciplinary requirements of this transformative era, this research adopts comprehensive perspectives for developing more resilient GI model for Jiangnan Water network area.

1.5.2 Research Hypothesis

For the macro-scale, by using Siming Lake as case study with GIS support, this study aims at the identification of a multi-functional GI network with the ideal water resilient landscape as the core. In addition, this exploration focusses on the GI network identification tactics for designing more resilient cities with emphasis on human health and wellbeing enhancement simultaneously. The GI network identification is based on key landscape ecological process analysis used for identifying key elements of the network as strategic positions.

This is based on landscape ecological planning methods: landscape security patterns (SPs) theory and ecological infrastructure network planning methods developed by professor Kongjian Yu (Yu, 1995a, Yu, 1995b, Yu, 1996, Yu et al., 2005b, Yu, 2015c). According to the SPs theory, not all points (locations) or portions of the landscape are equally important in terms of their influences on different ecological processes. Some positions and portions are more important than others, and some are strategically critical in affecting certain processes. It is hypothesized that some potential spatial patterns exist which are composed of strategic portions and positions that have critical significance on the security of an ecological process, and these potential patterns called security patterns (SPs).

On this basis, for the meso-and micro scale, these important elements of the network would be targeted as the foremost point of solution implementation in the ecological repairing process of the whole watershed. Therefore, the development of a comprehensive evaluation KPIF to support and optimise planning decision is of great importance at these scales. This KPIF should not only enables assessment and design of alternative futures, but also enables the quantitative and more comprehensive evaluation of the multiple GI design scenarios of SCP with practically balanced multi-benefits for attaining sustainability.

Additionally, with the use of the developed KPIF for the Siming Lake case which is a typical example of the Jiangnan water net area, the comparative evaluation and optimization are carried out to support the GI planning and implementation strategies, as well as policy recommendations for the key sponge node. Additionally, the KPIF can be used as the evaluation framework to optimize the design schemes for the Jiangnan water net area of China, and also serve as a reference for quantitatively evaluating similar or sponge-related projects in other regions in China. This KPIF can also serve as a comparative case study and provide useful reference for the GI development abroad.

1.5.3 Major Methods

This research focuses on the gaps of GI design and assessment for SCP by incorporating multi-scale comprehensive review and in-depth quantitative explorations with GIS mapping, SWMM simulation and experts' interviews. The exploration involves multi-disciplinary perspectives from both natural and social science. Natural Science's SWMM modelling was utilised for the simulation analysis of hydrological effects while field investigation and GIS spatial mapping analysis, interview and AHP evaluation methods was adopted from social science.

The relevance of this research is not only limited to finding solutions to the environmental resilience or exploring how to cope and/or deal with uncertain environmental challenges posed by climate change. It also encompasses the social resilience which addresses how to better serve people by planning for people and nature's co-existence within the built environment for improving human health and wellbeing. The discipline of the urban planning and landscape design requires management of the relationship between people and land, thus, exploration of balanced urban development solutions for guiding sustainable policies and strategies while accounting for the challenges of the contemporary society. Waterfront areas are significant elements of GI network as they integrate a water resilient space with significant ecological function of biodiversity, and a relaxation venue for experiencing nature for humans.

In view of the multi-disciplinary requirements of this transformative era, this research adopts comprehensive perspectives for developing more resilient multifunctional GI model for the SCP of Jiangnan Water network area.

1.5.4 Research Frame and Chapter Organization

This research is divided into two stages: preliminary research and in-depth research (Figure 1.11). In addition, the overall research is carried out at three scales: macro-, meso- and micro-scale for each stage.

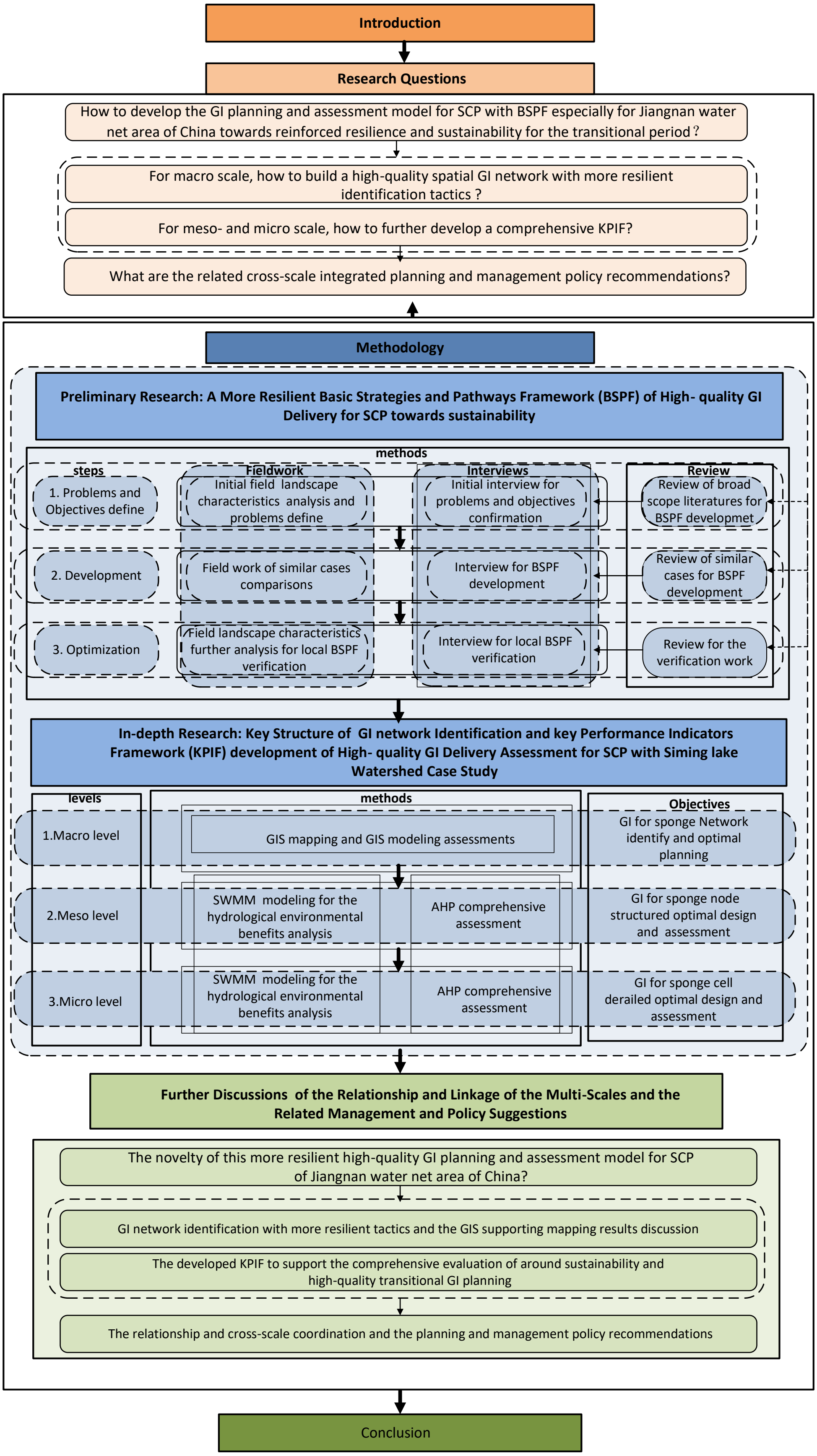


Figure 1.11 Research frame with overall research flow and main methods

In the preliminary research stage, this study mainly adopts the use of research methods such as literature review, field study, case review and interview for developing a more resilient Basic Strategies and Pathways Framework (BSPF) model of a high-quality GI delivery model for SCP. In addition, the basic GI planning strategies for the three scales and the cross-scale interlink planning, such as the network mapping strategies at macro scale and the multiple design scenarios with the integrated more resilient design pathways at meso- and micro- scale are proposed using Siming Lake as a case study.

During the in-depth research stage, this study aims at establishing a high-quality multi-functional GI spatial network at the macro-scale, with the model applied to Siming Lake. Landscape ecology-based landscape security patterns (SPs) method and GIS mapping analysis are used for the identification of key structure of the multifunctional GI network (Yu et al., 2005b, Yu, 1995b, Yu, 1995a, Yu, 2011). At the meso- and micro- scale, a comprehensive evaluation system, defined as Key performance indicator framework (KPIF) was developed for the evaluation of GI for SCP transitional development. The designed GI scenarios are comprehensively evaluated using this KPIF, based on Stormwater Management Model (SWMM) and Analytic Hierarchy Process (AHP) methods.

The thesis is structured in eight chapters. To begin with, Chapter 1 is the introductory chapter, which includes the background review for topic selection and significance, research objectives and questions, scope and frame. Subsequently, Chapters 2 and 3 are the literature review chapters, which consists of the review of international and national concepts, practices and researches, research progress and gaps. Next, Chapter 4 illustrates the methodology utilised in this research while Chapter 5 describes the preliminary research findings. In Chapter 5, a general Basic Strategies and Pathways Framework (BSPF) model for Jiangnan Water Area towards high-quality GI delivery is proposed (in response to question number 1 and number 4, see Table 1.1), and the preliminary landscape characteristic investigation and analysis was performed with the Siming Lake case study. Afterwards, Chapter 6 explains the analysis and findings of the in-depth research of the more resilient GI network. This chapter includes the SPs identification at macro-scale(in response to question number 2, see Table 1.1); the results from the developed KPIF (in response to question number 3, see Table 1.1), and the comprehensive evaluation of the multiple scenarios of the key node at meso scale and the key unit at micro scale, using the BSPF model and the KPIF with the Siming Lake case study. Consequently, Chapter 7 is focused on the discussion of the relationship and linkage of the multi-scales, the related management and policy suggestions (in response to question number 4, see Table 1.1), as well as the novelty and application of the developed BSPF model with the KPIF, in conjunction with the further discussion and analysis of the Siming Lake watershed case study. Finally, Chapter 8 is the concluding chapter, which provides a summary of the research findings, proffering of policy recommendations, limitations, and future directions.

Table 1.1 The Questions, methods, and the related Chapter organization of the main results and further discussions

Questions	Methods	Chapter organization of the main results and further discussions
Q1: How to develop the GI planning and assessment with BSPF model for SCP especially for Jiangnan water net area of China towards reinforced resilience and sustainability?	field study, literature review, and interview	Chapter 5 and chapter 7
Q2: How to build a multi-objective spatial GI network for resilient and sustainable transitional development in the macro-scale?	GIS mapping and analysis	Chapter 6 and chapter 7
Q3: How to develop a comprehensive and targeted KPIF for the meso- and micro scales?	SWMM and AHP	Chapter 6 and chapter 7
Q4. What are the cross-scale integrated planning guidance and policy recommendations for management and implementation?	field study, literature review, and interview	Chapter 5 and chapter 7

Chapter 2 Literature Review: International Concepts and Practices of Sustainable Stormwater Management and Resilient City

2.1 Introduction of the chapter

In response to the rapid urbanisation globally and the impact of urban stormwater on urban water cycle and ecosystems, the management of urban stormwater has changed drastically over the past decades. More recently, urban planning initiatives are shifting from the use of short-term unsustainable approaches for tackling issues such as flooding and restoring the natural water-cycle process, to an approach where multiple objectives drive the design and decision-making process with innovative concepts and practices (Fratini et al., 2012, Wong, 2006).

Such innovative concepts consists of Best Management Practices (BMPs) initiated in the 1970s (Roesner et al., 1991, National Cooperative Highway Research Program et al., 2006), the Low Impact Developments (LIDs) in the USA (Ahiablame et al., 2012a, Liu et al., 2016, USEPA., 2000, Zhou, 2014, Pyke et al., 2011) as well as the Water Sensitive Urban Design (WSUD) in Australia (Mouritz et al., 2006, Wong, 2006). These concepts and practices in the urban stormwater management field evolved in a rather informal manner, mainly driven by local and regional perspectives, understandings, and context(Chang et al., 2018). This has resulted in the use of different terms for defining similar concepts in different regions globally, thus leading to an extent of overlaps and confusion(Chang et al., 2018). Consequently, this chapter reviews these innovative concepts and practices by tracing their development history, main principles, benefits, and influences. Afterwards, the subtle differences and the commonalities in the tools and principles, as well as their influences on SCP are summarized.

2.2 Best Management Practice Development in the USA

2.2.1 The Definition of BMP

Best Management Practice (BMP) is said to be a specific practice or various practices that are considered to be the most practical and effective (with all economical, technological, and institutional considerations satisfied) means of discouraging or minimising the pollution produced from non-point sources to amounts that are well-matched with water quality goals (Roesner et al., 1991, National Cooperative Highway Research Program et al., 2006). The selection of BMP is always determined through comprehensive problem assessment, evaluation of alternate practices, and engaging suitable public stakeholders carried out by either the state or a designated area-wide planning agency.

2.2.2 Inception of BMP

In comparison to other countries, Americans were quite early in deliberations about water and stormwater management. The need for implementing better land management practices was stated in an article by (Craddock and Hursh, 1949), as a means of repairing the soil structure and enhancing plant cover as required for preserving land and water conditions in order to meet all current and impending needs of usable water. The proposed land management practices were early precursors of BMP and in 1972, the Federal Water Pollution Control Act Amendments incorporated the separation of different pollution sources and implemented the dependence on BMPs for non-point pollution sources.

Similar regulations for the control of point sources of pollution were imposed in the 1977 and 1983 amendments of the Clean Water Act (CWA), which led to a significant decrease in point source pollution. Subsequently, the main cause of impaired water quality were nonpoint source (NPS) pollution as detailed in 1984 USEPA (United States Environment Protection Agency) to the Congress (Consortium, 2003). In 1988, USEPA identified runoff of stormwater as one of the major cause of urban water quality concerns in rivers and lakes (Novotny and Olem, 1994). These developments made the optimal control of stormwater a necessity (Roesner et al., 1991). BMPs proposed were mostly control methods used to delay, retain, and absorb contaminants generated by NPS associated surface runoff (Mandelker, 1989). Hence, the determining factor of a suitable BMP must include a balance of climate, geographic, and financial considerations.

2.2.3 Benefits of BMP

After four decades, BMP has evolved from better land use practices and are now widely accepted as the most appropriate method of controlling non-point sources of water pollution. BMPs can be regarded as a platform that provides an equilibrium between the conception of control measures for NPS and the practical viability of those measures (Schueler, 1987). BMPs are quite different in comparison to traditional rainwater treatment systems. In the latter system, rainwater is rapidly drained into pipe networks and conveyed into nearby water body. In contrast, BMPs involve the collection, temporary storage and guiding of rainwater for soil and downstream rainwater facilities penetration at an intended design conditions for reducing runoff and pollutants as well as controlling the flow rate

(Middlesex University, 2003). Differences are depicted in Table 2.1.

Table 2.1 Comparison between traditional rainwater pipe network and BMPs (Consortium, 2003)

	Traditional rainwater treatment system	BMPs
Construction cost	Almost no difference, but BMPs have multiple functions which may reduce the total cost	
Operation and maintenance cost	Clear	Unclear for some types
Site flood control	Yes	Yes
Erosion and flood control at lower reaches	No	Yes
Potential of water resources recycling	NA	Available
Potential of recharging underground water	NA	Available
Potential of pollutants removal	Low	High
Provide liveable environment	No	Yes
Education function	NA	Available
Area occupied	Unclear	Based on BMPs types
Service life	Established	Unclear for some types
Design standard	Established	Unclear for some types

BMPs can be classified as structural or non-structural controls. As indicated in the name, physical structures for the collection and treatment of surface runoffs is required in structural BMPs (Roesner and Matthews, 1990). In contrast, non-structural BMPs integrates extensive planning and design, and can be escalated to be policies which incorporates several practices of environmental and economic benefits (National Cooperative Highway Research Program et al., 2006). Non-structural BMPs require activities such as engagement and educating of the public, regulatory tools such as control of chemical usage on vegetation or zoning restrictions for controlling population densities. Table 2.2 respectively summarizes key types of the non-structural BMPs and the structural BMPs.

Table 2.2 Comparison of non-structural BMPs and structural BMPs (Consortium, 2003)

Non-structural BMPs	Type	Structural BMPs	Type
Protect sensitive resources	● Protect/recover/improve waterfront natural environment ● During general planning and design of stormwater management, protect/ utilize circulation of natural materials ● Protect sensitive resources	Permeable BMPs measures	● Pervious pavement with permeable bed ● Infiltration pool ● Subsurface permeable bed ● Infiltration channel ● Rainwater garden ● Infiltration pit/catch pit ● Filtration bed ● Grassy hollows ● Vegetation filtration belt ● Infiltration narrow puddle
Clustered development	● Cluster buildings in a small area as much as possible ● Smart growth		

Non-structural BMPs	Type	Structural BMPs	Type
Reduce disturbance	• Reduce areas impacted by urban development • Reduce soil density in disturbed areas • Restore vegetation in disturbed areas and use native species	BMPs measures with flow/peak flow reduction	• Green roof • Capture and re-utilize runoff
Reduce impervious areas	• Reduce impervious area of streets • Reduce impervious area of parking lots	BMPs measures with control of runoff water quality/peak flow	• Wetland • Wet Swale/detention pond • Dry Swale extending the detention time • Water filtration and water conservancy driven facilities
Pollution Source control	• Street cleaning		
Education and public participation	• Newspaper, handout, etc. • Participate in land utilization planning and management • Stormwater management explanation system • Integrated noxious and hazardous substances management	Restorative BMPs measures	• Waterfront buffer zones restoration • Landscape recovery • Soil remediation • Flood plain restoration

2.3 Low Impact Development in the USA

2.3.1 Definition of LID

Low Impact Development (LID) is a relatively new stormwater management concept based on BMPs (Prince George’s County, 1999).

According to USEPA, Maryland's Department of Environmental Resources has developed numerous tools and applicable practices for attaining affordable and effective environmental designs (United States Environmental Protection Agency, 2000). LID's approach involves the utilisation of a "design with nature approach" for cost minimization (Barlow et al., 1977). The 'Impact' represented in the name 'LID' signifies adoption of practices with implicitly lower deterrent effect to the environment in comparison to conventional systems.

2.3.2 Background and Principles of LID

LID designs tend to simulate the natural hydrology of a location via distributed micro-scale control methods for accomplishing pre-development water conditions (Coffman, 2002, HUD(U.S. Department of Housing and Urban Development), 2003, Davis, 2005). Natural hydrology can be defined as the attainment of a location's runoff, penetration, evaporation and transpiration capacities before urban development by utilising a well-designed hydrologic landscape (United States Environmental Protection Agency, 2000). Hence, LID was specifically developed for achieving natural hydrology through strategic site layout designs and integrated control measures. This objective was targeted to reduce and negate the deterrent effects of urban development and on natural hydrological processes while restoring the site vitality and ecological functions of the site (Torno, 1984). This was useful in directing focus on urban water quality issues and the influence of stormwater runoff.

LIDs adopted site design practices that enables the storing, permeating, evaporating and detaining of surface runoff to improve site hydrology by ensuring adequate groundwater replenishment and minimising off-site runoff. Due to the high sensitivity of hydrology to all aspects of site developments, LID control measures focused specifically on on-site hydrology rather than the large communal or post-catchment solutions practiced previously. This was due to the ineffectiveness of such post-catchment methods in achieving hydrographic repair of the catchment basin (Fletcher et al., 2015). Extracts from (PGCo (Prince Georg'sh County), 1999, DoD (Department of Defense), 2004) indicates that the following practices should be integrated in any LID design:

- Incorporation of stormwater management techniques during preliminary site planning stage;
- The management of stormwater is done in close proximity to the source by using distributed micro-scale practices.
- Stimulation of environmentally sensitive schemes that

improves natural hydrological functions and landscape;

- Emphasis on preventive measures rather than corrective or mitigation actions;
- Inexpensive life cycle cost of the stormwater infrastructures; and
- Engagement and empowerment of the local community and general public by raising awareness on environmental protection.

2.3.3 Benefits and Influences of LID

As a novel and sustainable management strategy for stormwater, LID aims to develop functional hydrological landscape for both new and renovation projects. LID implements regular and strategic controls during the course of the urban landscape. This differentiates its approaches from the traditional structural methods which only implements control measures during or at the end of the conduit networks. The comparison of methods by which traditional and LID management systems influence the on- and off-site hydrological conditions is summarized in Table 2.3 (Prince George’s County, 1999).

Table 2.3 Comparison of conventional and LID stormwater management technologies (Cheng et al., 2003)

Hydrologic Parameter	Conventional	LID
	Onsite	
Water-resistant Soil Cover	Promoted for attaining effective drainage	Reduced to minimize impacts of impermeable surfaces
Natural Vegetation Cover	Minimised for effectual site drainage	Maximized to maintain predevelopment hydrology
Duration of Concentration	Shorter time due to improved drainage efficiency	Period increased to simulate pre- urbanised conditions
Runoff Volume	Negligible control is implemented and overall runoff volume is maximal	Regulated to simulate conditions before development
Peak Discharge	Controlled to simulate pre-development storm design (2 year)	Regulated to simulate expected occurrence before development.
Runoff frequency	Maximised, particularly in minor, recurrent storms	Regulated to simulate expected occurrence before development.

Hydrologic Parameter	Conventional	LID

Runoff duration	Maximised for all storms due to lack of volume control	Regulated to simulate expected occurrence before development.
Rainfall Capture, Penetration, Depression and Storage	Considerable decrease in all elements	Controlled to mimic conditions before urban development
Groundwater Recharge	Decrease in groundwater recharge	Controlled to mimic conditions before urban development
	Offsite	
Water Quality	Decreased pollutants but restrictive control during storm events with lower design discharge	Reduced pollutants with full control during storm events with lower design discharge
Receiving Streams	Various deposition and conduit erosion issues results in reduction in base flow and other ecological impacts.	Stream ecology preserved to conditions before site development
Downstream Flooding	An after-effect of the peak discharge control includes escalation of downstream floods	Regulated to simulate expected occurrence before site development

By 1998, LID was commonly utilised in practice and a guidebook for municipal Low Impact Development design was created and distributed nationally to increase its adoption (Coffman, 2000). Due to various inputs and interpretation from the design community, LID designs drifted off its primary objective to encompass all stormwater treatments between late 1990s and early 2000s (Davis et al., 2011, DeBusk et al., 2010, Dietz, 2007, Shuster et al., 2008). In order to re-establish, meet and sustain its 'natural hydrology restoration' purpose, US researcher published a detailed instruction and design manual for both new and renovation urban projects. Afterwards, utilisation of LID was codified in a legal bill and considered a regulatory framework all over North America (Toronto Region Conservation Authority, 2010, United States of America, 2007). Hence, making LID a typical, although not prevalent, management method for stormwater in Canada and United States of America with some municipalities using both the older BMP manuals and a recent LID guidebook (Ontario Ministry of Environment, 1991). This could be in order to optimise the design of both communal and on-site stormwater management for retaining natural hydrology.

LID was developed in the US to address the weakness of treating stormwater using traditional pipeline system. After almost five decades, they have been successful in formulating a relatively complete management system. Thus, some LID concepts and techniques have been successfully adopted by European and Asian countries for concepts and technology diffusion. Consequently, there were minor variations during the evolution of the concept in other countries such as emphasis on ecological pollution mitigation rather than flow management in New Zealand (Marjorie, 2011). As a result, modified programs such as Low Impact Urban Design and Development, or LIUDD were developed (Eason et al., 2006).

In 1971, US EPA also developed Stormwater Management Model (SWMM) as an assessment tool for the development and control of urban drainage systems (Deng et al., 2019). Some commercial models such as DAnCE4Water, Info-Works, and Mike-Urban were built on this concept with LID evaluation modules included. Interestingly, the lack of reference to 'hydra' or 'water' in the label 'LID' might have considerably enabled its application in other disciplines – including economics, planning, social science and agriculture – and its ease of adaptation to local practices globally.

2.4 Sustainable Urban Drainage System (SUDS) in the UK

2.4.1 Definition of SUDS

According to Keeley (2011), Sustainable Urban Drainage Systems (SUDS) has been in use in the U.K since the 1990s for alleviating problems associated with stormwater. SUDS integrates water management services, technologies and practices aimed at channelling surface water in a way that mimics the natural water cycle. This may include physical infrastructures used for the reception of runoff. Treatment of surface water involves settling of residues, percolation, absorption and decomposition of organic materials in very close proximity to where the rain falls with the possibility of improving permeation and/or tempering of stormwater flow (Li et al., 2019a).

2.4.2 Background and Principles of SUDS

Stormwater management measures in Britain gained momentum in early 1990’s when the “Scope for Control of Urban Runoff” guiding principle were published. This manual provides guidance on variety of control measures of practical viability (CIRIA, 2001). Afterwards, the uptake of these practices increased rapidly in Scotland compared to England and Wales due to regulatory drive for implementation by the Scottish Environmental Protection Agency (SEPA). The objective of SUDS was established as sustainable drainage triangle which involves a balance of quality, quantity and amenity using variety of techniques for stormwater management (D'Arcy, 1998). Numerous strategies are utilised in SUDS for delivering reduction, permeation, flow control and water treatment using natural landscapes, artificial devices, or a both (Stephenson, 2015).

In 2000, key guidance manuals with comparable but distinct design for Scotland, Northern Ireland, England and Wales were published (CIRIA, 2000). The formalisation of the term 'SUDS' was established in this guidance manual which provides detailed assistance on its practices and execution in Britain. Sometimes, SUDS is also referred to as sustainable drainage systems in order to encompass both urban and rural sites.

2.4.3 Benefits and Influences of SUDS

SUDS aims to provide a sustainable solution for draining surface water using design/planning methods and technologies. Similar to LID, SUDS strategy involves the planning and design of surface water in close proximity to the point of rainfall by simulating the natural process and pre-development conditions of the site. This is structured as an array of devices/infrastructure and practices that can be combined effectively to create a management train.

The use of SUDS in new urban development projects have been obligatory in Scotland since 2003 as SEPA promotes its use for maintaining water quality (WEWS, 2003, SEPA, 2010, Duffey et al., 2013). In contrast, the SUDS implemented in England and Wales are more tailored for volume control rather than the control of quality control (Defra, 2011). Regardless, the required water quality standards must be complied with by the use of suitable elements of a water treatment plan.

2.5 Water Sensitive Urban Design (WSUD) in Australia

2.5.1 The Definition of WSUD

The use of Water Sensitive Urban Design (WSUD) began in Australia in the 1990s as a method of urban planning and design for reducing deterrent effects of urban development on hydrology and the environment (Ashley et al., 2013). The management of stormwater is contained as a section within WSUD for flow management, flood control, and enhancement of water quality. In addition, it enables water harvesting for augmenting mains supply of water.

2.5.2 Background and Principles of WSUD

During the early 1990s, WSUD explores models and practices (both structural and non-structural) for urban water management. The development of WSUD was a measure taken to meet up with international standards with regards to land and water management. In the course of Australia's settlement era, sustaining good environmental conditions of the catchment site was not a major consideration during the construction of water, sewage and stormwater infrastructure settlement. However, with rapidly increasing inhabitants, the ecological footprint of development activities became serve on hydrological resources. This established the primary need for restoration and expansion of its deteriorating infrastructures to meet growing demands in urban regions became vital. More importantly, the need for the repair of ecological values by implementing approaches to improve, sustain and/or protect the hydrological reserves and catchments was recognised. The industry-wide support for the WSUD scheme was attained at a conference in Melbourne in 2000.

The principles of WSUD could be utilised for the design of a single building unit or multiple buildings within a cluster. The anticipated result of the WSUD schemes include (Whelans et al., 1994):

- Sustenance of appropriate water balance by ensuring suitable aquifer levels, inhibiting flood-related impairment and averting erosion of waterways and banks;
- Preservation and potential improvement of water quality by reducing overall water pollutants (from stormwater, waste water and sewage), minimising the transfer of such pollutants to receiving water bodies and mitigating the impacts of pollutants;
- Promotion of water conservation practices by minimising water

demands, reducing reliance on imported water supply and encouraging the re-use of stormwater and recycled waste water; and

- Preservation of ecological and recreational values of hydrological resources and reserves.
- Within these contexts, the main objective of the stormwater management section of WSUD were (CSIRO, 1999):
- Securing and improving the natural water system;
- Integrating stormwater treatment and utilising stormwater in the landscape for visual, functional and aesthetics benefits;
- Maintaining and/or enhancing of water quality;
- Minimising flows and runoffs to increase permeation and localised water retention; and
- Reduction of associated life cycle cost.
- Thus, SUDS compels the amalgamation of land and water use practices and development at every stage of urban planning from the initial concept design.

2.5.3 Benefits and Influences of WSUD

WSUD's application mostly involved stormwater management during the formative years even with its broad definition. This implies the drive of the scheme by the Australian drainage community and its practitioners in the early years. Still, the need to consider the entire water cycle via a comprehensive framework was suggested (Mouritz et al., 2006, Wong, 2006).

More recently, WSUD was described to include all parts of the of urban water cycle management including the management of water supply, sewage and stormwater Mouritz et al. (2006). This changes the planning and design of water infrastructures of municipalities at all scales. In 2004, a working group on urban drainage was formed for integrating urban water management into urban design due to increased uptake of WSUD internationally (Ashley et al., 2013). Furthermore, it allows for engagement with other disciplines such as social scientists, architects, ecologist, and planners. The model utilized in WSUD has also encouraged other related ideas such as climate sensitive urban design (Coutts et al., 2013).

2.6 Green infrastructure (GI) and Resilient City Research Trends and Needs

2.6.1 Definitions of Green Infrastructure (GI)

Green infrastructures are also facilities that are vital to the sustainable continuance and development of any community. Based on the context of usage, GI implies a different meaning to various people as depicted in Table 2.4. Hence, for the transitional period towards reinforced resilience constructions, GI requires multi-objective and multi-spatial considerations.

Table 2.4 Comparison of GI definition

Discipline	Common Definition	Primary function(s)and benefit(s)	Priority Aspect(s)
Land conservation Planning	GI is considered a natural life support system incorporating water management measures and open areas to support the natural ecological cycle and community wellbeing (Mell, 2010).	This connects the planning of land use to biodiversity conservation (Mell, 2010).	Sustainable and effective land usage (Poelmans and Van Rompaey, 2009).
Landscape Architecture	The design of natural features into landscapes for supporting the ecosystem and improving human health(Tzoulas et al., 2007) Provision of natural facilities such as clean air, water, food and relaxation space (Yu, 2007).	This GI approach involves the interpretation of design and plans into physical landscape reality while maintaining ecological and cultural values at various scales (Rouse and Bunster-Ossa, 2013)	Preserving the ecosystem via healthy landscape and water process (Yu, 2007).
Stormwater management	Green stormwater infrastructure (GSI) is a resilient and affordable stormwater management practice with social benefits (United States Environmental Protection Agency, 2000).	GSI utilizes practices and nature components for natural water cycle restoration and improving urban environments (United States Environmental Protection Agency, 2000).	Stormwater management (United States Environmental Protection Agency, 2000).

Discipline	Common Definition	Primary function(s)and benefit(s)	Priority Aspect(s)
Ecological planning	Interconnected systems of green space for the preservation of ecosystem values and functions with improved human welfares (Benedict and McMahon, 2002).	Various ecological services (European Commission, 2013).	Preservation of native species and the ecosystem using practices and facilities to reverse ecological deterioration (European Commission, 2013).

Broadly, GI can be defined as a multi-objective and multi-scale interconnected systems of urban green space and nature (such as flowerbeds, green roofs, forests, trees, court yards, grasslands, parks and wetlands) utilized for the conservation of the ecological values and functions for benefiting to the population (Benedict and McMahon (2002); Mell (2013)). GI frameworks balances out the environmental, economic and social sustainability requirements of urban development projects. GI’s model integrates environmental conservation practices into land and built infrastructure development, making its approaches to open space designs and plans different from traditional practices. According to Weber et al. (2006), GI involves the utilisation of natural features in landscapes for promoting ecosystem values while improving human health and welfare. This makes GI an essential model in the delivery of goods and services (water, food, clean air, and relaxation space) to humans while reverting deterioration in landscapes (Ewers et al., 2009, Lafortezza et al., 2010). The approaches implemented in GI were also adapted from US infrastructure for hydro-geological restoration by simulating management of stormwater.

Nonetheless, the economical and resilient concept recognised for stormwater management practices in GI is labelled ‘Green Stormwater Infrastructure (GSI)’ (Lucas and Sample, 2015, Luan et al., 2017, Tao et al., 2017). Hence, GSI is a subsection of GI utilised for site scale stormwater management for neighbourhoods. GSI involves the management of the effect of wet weather conditions for helping communities. In contrast to traditional water systems with pipeline networks designed to move stormwater away from the built environment, GSI aims to minimise and treat stormwater at its source while simultaneously maximising economic, social and environmental incentives. This water management process adopts the utilization of soil, vegetation, and other elements to restore the natural water cycle for the creation of better urban environment (neighbourhood scale). GSI methods include rain gardens, permeable pavements, land conservation, bio-retention, rain harvesting and green roofs (United States Environmental Protection Agency, 2017).

2.6.2 Conceptual Evolutions and Connotation of GI

GI concept and planning originated from United States in the 1990s and has since grown rapidly even in other European countries. After the Second World War, the United States started their rapid urbanization period which led to a series of urban problems such as the disorderly spread of cities, excessive urban land consumption, and urban ecosystems crisis. In 1990s, the concepts of "smart growth" and "smart protection" was developed for coping with these challenges caused by uncontrolled urban growth (Carlet, 2015, Consoli et al., 2016, White and Boswell, 2007, Margerum and Robinson, 2015, Keeley et al., 2013, Ahiablame et al., 2012b).

In 1999, efforts for identifying and developing concepts of green infrastructures was initiated in the US by the President's Council on Sustainable Development. Later in 2003, another publication highlighted the use of cost-effective GI measures with open space and waterways networks for reshaping urban space and preventing ecological problems for new development projects. The guidelines provided by these papers established natural landscape, vegetation, and open space as a smart growth approach to be adopted by US communities for improving social welfare. This led to the defining of GI as the natural life support system for achieving sustainability in America (Wang and Banzhaf, 2018, The Conservation Fund, 2004).

Frederick Olmsted, a landscape architect believed that a single park, regardless of its design or size, was not suitable to provide natural ecosystem benefits. However, the linkage of multiple parks together and to surrounding nearby neighbourhoods' poses immense benefits to people by promoting pedestrian and cycling trails, and recreation which progressed as greenway movement (Fábos, 2004).

In the EU Green Infrastructure Strategy 2013–2020, GI was defined as a tactical network of natural and semi-natural regions with ecological components designed to provide variety of ecosystem services (European Commission, 2013). Furthermore, different GI tactical designs are adopted after isolating the main areas of improvement which results in multi-spatial and multi-functional measures required for the priority area. The use of this approach in Europe for targeted ecological services have been proposed by the European Environment Agency (European Environment Agency, 2014, Liquete et al., 2015, Vallecillo et al., 2018). This was in line with EU's commission's promotion of Nature-Based-Solutions (NBS) that enables the enhancement of ecology quality and improvement of human health and wellbeing (European Commission, 2015).

As a result, GI is currently considered as an effective and significant practice for improving complex urban ecosystems mainly with the following measures:

- Implementation of green measured for stormwater management;
- Creation of networks of green spaces and parks to improve human wellbeing;
- Conversation of nature to enhance biodiversity and reverse habitat destruction.

2.6.3 Conceptual Evolutions and Connotation of Resilience and Resilient City

2.6.3.1 Conceptual Evolutions of 'Resilience'

'Resilience' comes from the Latin word 'resilio' (Klein et al., 2003). There are still controversies about the origin of this concept as some scholars think it is originated in ecology, while others believe it's origin is from physics (Manyena, 2006). The concept of resilience in ecology was first mentioned during the study of population relations and the ecological stability theory of predators and preys (Holling, 1961, May, 1972). The author defined resilience as the capability of a system to maintain stability after enduring interferences. This concept developed into 'ecological resilience' and is required for maintaining the various relations within a system. Since then, the notion of resilience has been widely used in other fields like social ecology, and water ecosystem for attaining progress.

Resilience has also been defined in terms of the speed of recovery from the system's interference, which further developed as 'engineering resilience' (Fiering, 1982, Hashimoto et al., 1982). Engineering resilience refers to the time needed for equilibrium recovery after a system's disturbance. Ecological resilience refers to the amount of interference that a system can endure before its state changes. Ecological resilience reflects multiple stability state; while the engineering resilience refers to only one steady state. Overall, resilience is related to the state and interference of system.

The concept of resilience in social ecology is an extension of resilience in the field of ecology. Social resilience refers to the ability of communities or groups to cope with outside pressures from society, economics, politics and environmental changes (Adger, 2000, Adger et al., 2005). Resilience is the measure of the interferences that could be tolerated by system before the system moves to other states with different structures, different functional properties, and different ecosystem services for humans (Resilience Alliance, 2007). The three important aspect of resilience in social-ecology are the system's capacity for enduring interference, the post-disturbance recovery speed, and the system's abilities of self-organization, learning and adaptation (Carpenter and Gunderson, 2001, Cai et al., 2012).

2.6.3.2 Connotation of the Resilient City

At the global level, the implementation and testing of various resilience programs is being performed by governmental and non-government agencies in the US as a means of empowering communities to alleviate, defend, react and recover from risks, threats and vulnerabilities (Norris et al., 2008, Cutter et al., 2008).

An example of such programs includes the 100 resilient cities scheme for enhancing resilience to interferences including but not limited to food deficiencies, natural disaster, and prolonged unemployment done by the Rockefeller Foundation (Federal Emergency Management Agency, 2015, United States Department of Health and Human Services, 2009). Another example is the use of social organisations such as American Red Cross for incorporating community resilience and enhancing community engagements in its programs(American Red Cross, 2015). Similarly, a community based initiative to increase public’s awareness and engagement about resilience and its preventive, corrective and protective measures known as Community PrepareAthon (Federal Emergency Management Agency, 2015). Furthermore, there are neighbourhood level programs such as Neighbourhood Empowerment Network (Neighborhood Empowerment Network, 2014, Community and Regional Resilience Institute, 2016).

Therefore, there are two important implications of resilience for resilient cities: (1) the ability to withstand state changes, especially the fast response and recovery after disasters, (2) adaptations and social management capabilities. These are corresponding to the tow concepts of ecological resilience and social resilience (Eisenman et al., 2016, Leykin et al., 2013). Hence, urban resilience depends on the capacity to concurrently sustain societal and environmental values within the urban environment.

2.6.4 The Significance of GI and Resilient City with International Research Trends and Needs

The upsurge of interest in sustainability, resilience and human health and wellbeing practices in urban cities is a response to the various societal, economic and ecological challenges (Wigginton et al., 2016, McDonnell and MacGregor-Fors, 2016). Consequently, green infrastructures are utilised for the instantaneous and long-term solutions to the growing urban challenges globally (Gómez-Baggethun et al., 2013, Lafortezza et al., 2017, Badiu et al., 2019, Niţă et al., 2017, Elmqvist et al., 2003). Therefore, GI offers a crucial model for the interconnection social and ecological infrastructures networks within a city for enhancing social and ecological resilience which enhances human wellbeing and ecology values (McDonnell and MacGregor-Fors, 2016).

Currently, an estimated 50% of the global population live in urban areas with a forecasted increase to 90% for developed countries by 2050 (Beery et al., 2017). The consequence of the migration to urban areas results in a reduction in exposure and interactions of humans with nature and the natural ecosystems (Skår and Krogh, 2009, Elmqvist et al., 2013). This change in techniques of learning and thinking about the natural world is termed as 'extinction of experience' (Nabhan et al., 1993, Pyle, 1993, Thomashow, 2001, Miller, 2005, Krasny, 2015, Soga and Gaston, 2016). As a result, the link between human wellbeing and nature experience and synergies between social, health and nature components are currently acknowledged in the assessment frameworks of the impact of NBS in urban areas (Figure 2.1) (Raymond et al., 2017, Vallecillo et al., 2018, Brink et al., 2016).

This involves enhancements in physical, mental and social welfare as well as positive health habits (Maller et al., 2008, Keniger et al., 2013, Sandifer et al., 2015, Shanahan et al., 2016). This also described by Sandifer et al. (2015) as putting "…human health and well-being at the centre…" thus enabling human-nature interactions and making certain that "people are surrounded by and have access to biologically diverse natural habitats" (Beery et al., 2017).Subsequently, urban cities across the globe are implementing GI practices for its ecological services and value to promoting human wellbeing (Hammer et al., 2011). The multi-functionality of GI is recognized globally in various science and policy platforms.

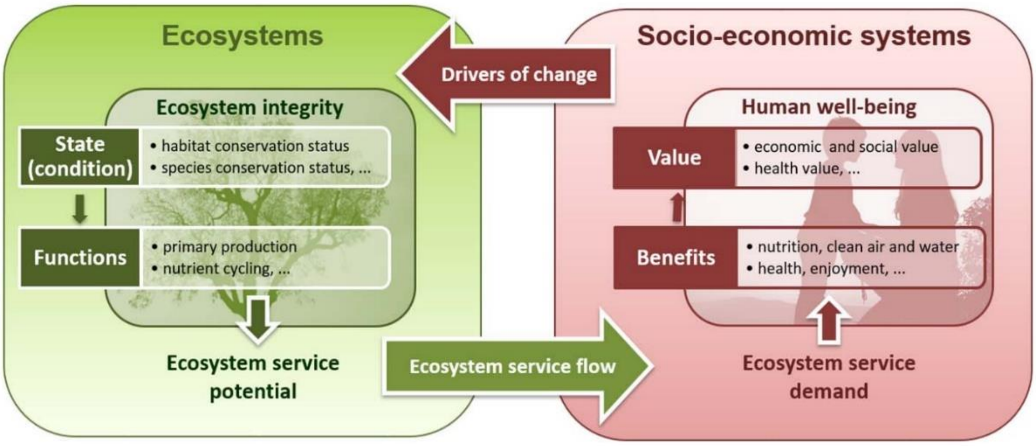


Figure 2.1 Conceptual framework for EU wide ecosystem assessments linking socio-economic systems with ecosystems via ecosystem services and drivers of change (Vallecillo et al., 2018)

Extensive data from research and practice has established the multiple values and benefits to environment, people and society presented by implementation of GI (Demuzere et al., 2014, Lovell and Taylor, 2013, Kim and Kim, 2017, Schifman et al., 2017). Hence, government support for GI is apparent via regulatory guidelines and strategic policies for maximising benefits through quality assurance in design and planning systems. Examples of this includes European countries strategy for protecting biodiversity and enhancing ecological values in policies and UK's incorporation of GI strategies in its national planning policies (Jerome et al., 2019, Davies and Lafortezza, 2017, Albert and Von Haaren, 2017, Sinnett et al., 2018).

GI mapping provides irrefutable and quantitative data that can be used for facilitating the generation of recommendation on assets management strategies for enhancing GI functionality while addressing the needs of residents and ecology (Wang and Banzhaf, 2018). This could also be applied as a valuable policy tool to stimulate sustainability, resilience and smart growth in urban development projects for achieving various objectives and meeting various requirements (Larondelle et al., 2014, European Environment Agency, 2011). The universal approach to GI reflects ecological and societal benefits for inhabitants at localized, regional and urban scales (Naumann et al., 2010, Naumann et al., 2011, Niemelä et al., 2010, Demuzere et al., 2014, Pauleit et al., 2011). Therefore, the development of a comprehensive view is pertinent to investigate the suitable level of decision-making and implementation required at the different scales (local, sub-regional or national) to realise these benefits (Sternlieb et al., 2013, Wyborn and Bixler, 2013). With its versatility, GI can perform multiple functions at multiple scales while remaining aware of the crucial connections and interactions within the system.

Recently, related researches have shown interest in the potential connections between the ecosystem, human health and wellbeing, and experiencing with nature in the GI network (Capaldi et al., 2015, Shanahan et al., 2016). These connection are mainly focussed on the benefits derived from intentionally experiencing nature (Keniger et al., 2013). In support of this, past studies have provided convincing information and opinions about the ecological services, such as natural regulation, natural supporting, cultural services, and wellbeing enhancement derived from experiences in green landscape. However, there are still gaps in literature that requires further research for completing understanding of high-quality GI delivery and comprehensive evaluation approaches (Vallecillo et al., 2018, Kathryn and Marissa, 2015, Pauleit et al., 2019). This involves stressing of GI approaches for in-depth quantitatively evaluation of its multi-functionalities (at meso- and micro-scale) and the identification of key areas and their inter links at the macro-scale with integrated essential landscape ecological processes and local landscape experiencing processes analysis.

2.7 Comparison and the Influence of the International Concepts

2.7.1 Comparison of the International Concepts

Recently, there has been rapid growth in the use of terms such as LID, SUDS, WSUD, BMP and GI. Also, urban stormwater management (USM) and associated literature has experienced growth and implementation of new terminologies for describing the transition to more sustainable practices. In this chapter, the evolution and history of common terms associated with sustainable stormwater management and resilience city construction were reviewed. The development and evolution of these interchangeable terminologies are summarized and shown in Figure 2.2 (Li et al., 2019a).

In order to better understand the development of research trends, the similarities and differences between these concepts are shown in (Table 2.5)(Ding et al., 2019). It was observed that, LID, SUDS, WSUD and SCD are all the methods aimed at sustainable stormwater management with a substantial similarity between the various methods. Although there are slight variations in how these principles are represented based on the context (localised development and/or institutional), the terms are supported by two main underpinning ideologies (Liu and Jensen, 2018). First, the limitation of hydrological alterations and development towards a natural flow regime or specific local ecological objectives for the enhancement of natural water features and natural hydrology. Secondly, maximal reduction of pollutants and overall enhancement of water quality. The noticeable overlap in terms of precision and scope of application illustrates the extent of similarity of the ideologies supporting the different practices.

In contrast, the term GI describes a multi-objective and multi-scale approach, which is broadly utilized for achieving resilient city and all-round sustainability. It is a conceptual methodology to urban design and development at macro-scale by using nature-based solutions and green techniques at meso- and micro-scale (Elmqvist et al., 2003, Niţă et al., 2017, Badiu et al., 2019). Hence, GI planning is not only a sustainable stormwater management tool, but also a multi-objective regulatory tool, which aims to boost human health and wellbeing with social, ecological, and economic benefits, based on the multi-functional use of ecosystems.

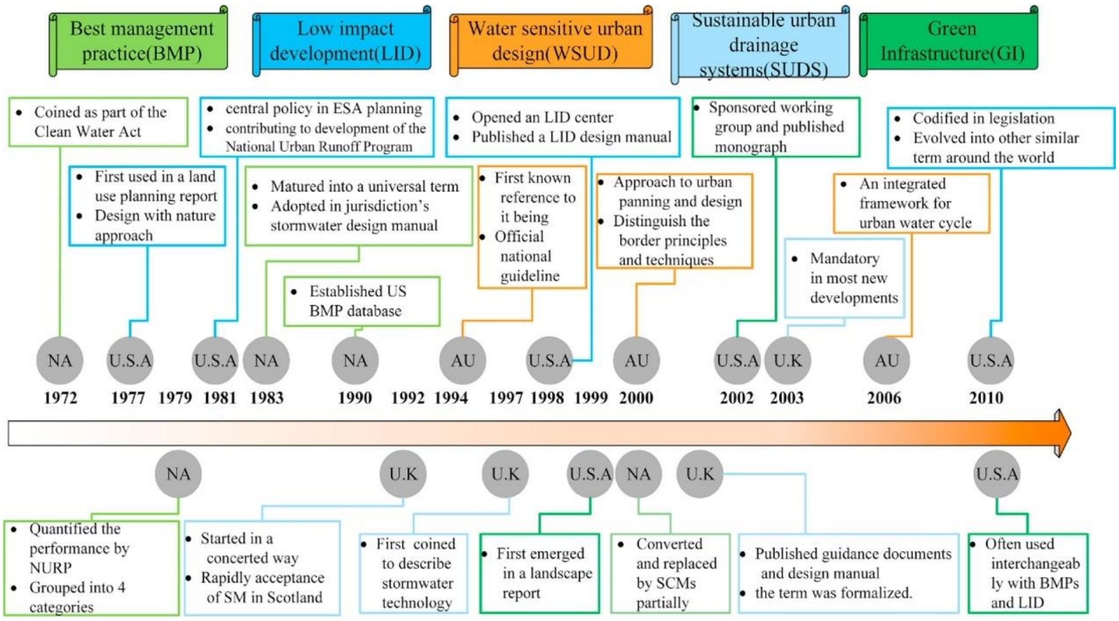


Figure 2.2 Historical roadmap for development and evolution of stormwater management approaches (BMPs, LID, WSUD, SUDS and GI) (Li et al., 2019a) Acronyms: NA (North America); USA (United States of America); UK (United Kingdom); AU (Australia)

Table 2.5 Comparison of the international concepts in terms of the scope, main contents, main characteristic and facilities (Ding et al., 2019)

Concepts	Connotation	Scope	Main contents	Main characteristic	Facilities
Green infrastructure (GI)	A system which incorporates building with nature for developing solutions to urban and climate challenges.	Within and around cities and towns	Adaptation to Climatic variation, sustainable energy production, greater biodiversity, improved air and water quality, healthy soil, enhanced food production, stormwater management and improved human wellbeing through nature leisure activities, and the provision of accommodation	GI aims at maximizing ecological services, biodiversity conservation, and restoration of the water cycle using a network of green spaces with objectives synonymous but much more than stormwater management in LID	Green spaces such as school yards, green walls, green roofs, constructed wetlands, urban forests and low-impact development facilities
Low-impact development (LID)	An ecology-based design and development strategy for managing surface runoff and treatment of stormwater.	Associated with design and planning in the macro-scale for a whole urban region	Application of small-scale hydrological controls to mimic the pre-development conditions by permeation, filtration, delay, storage, and evaporation of runoff in close proximity to its source	LID practices incorporates on-site to stormwater control devices for the restoration of natural hydrologic processes to pre-development conditions	Pervious pavement, green roofs, rain gardens, bio-retention cells, vegetative swales and rain barrels.

Concepts	Connotation	Scope	Main contents	Main characteristic	Facilities
Best management practice (BMP)	Primarily, water pollution control strategies	Mainly specifies distinct engineering practices for urban and rural areas	Main treatment and control tactics for stormwater and wetland management. Also utilised as secondary pollution controls for municipal and industrial waste water control.	All structural and non-structural strategies for decreasing contaminants from stormwater discharge (both on- and off-site strategies)	Filtration, open-channel and infiltration practices, stormwater wetlands, and stormwater ponds.
Sensitive urban drainage system design (SUDS)	SUDS provides an ecologically friendly alternative drainage system for urban surface water.	Urban area	Management of ground water, surface water and flood risk sustainably while conserving the natural cycle and enhancing water quality and ecological comfort.	SUDS requires an innovative, co-operative and aware local communities for partnership.	rainwater retention and seep ponds, constructed wetlands and underground ditches.
Water-sensitive urban design (WSUD)	Theoretical methodology for urban planning and design for reducing the hydrological impacts of urban development on the environment	Both urban and rural area	Incorporation of stormwater treatment, enhancement of water quality, protection of natural water systems, decrease in runoff and peak flows in urban area	Maximisation of aesthetic and leisure service by integrating multiple-use corridors to surface water to improve 'liveability'	Watery landscapes, rainwater collection boxes and green roofs

2.7.2 The Influence and Enlightenment of the International Concepts and Practices

LID, SUDS, and WSUD all utilized GI as a major innovative approach for maximising the design benefits. This was done by integrating adaptive landscape designs and stormwater management systems to provide better amenities for both people and nature. Despite this similarity, there are some subtle differences in the underpinning principles of these tools within their own local development and institutional context(Chen et al., 2021, Chang et al., 2018). Even though these concepts have been tailored to tackle specific issues related to a localised context and development, the approach and experiences from their implementations have a significant influence on the practices for other regions or cities.

In terms of timeline, LID emerged nearly thirty years ago, hence there is sufficient data-driven practices and knowledge on this concept (Eckart et al., 2017). This includes sufficient technical guidance of LID, with various amended versions to accommodate for local requirements in different states. Such states have published their own technical guidance to account for dissimilar climate conditions and different local environment in order to effectively implement LID. In general, LID is argued to be the most influencing sustainable storm-water management concepts with the longest history in comparison to the other concepts such as the SUDS and WUDS (Davis, 2005).In contrast to LID, SCP is relatively a new program which official started in 2013 with a national level technical guide issued in 2014 (MHURD, 2014). Hence, SCP practices is still at the commencement stage with only 30 pilot cities constructions in the first decade. For the less than 10 years of practice, SCP has been referred to as an innovative redesign and application of the LID principles. This is mostly associated with the Sponge city technical guidance having mainly referenced the LID technical guidance because of the vast availability of extensively informed guidelines for local government in the U.S. These guidelines include the detailed reports on technical design, implementation, operation, and maintenance of LID measures due to its three decades of practice.

Following LIDS, SUDS emerged about two decades ago with detailed guidance that incorporates both technical and policy dimensions. For example, major set of guidance documents was published with similar but separate design manuals for Scotland and Northern Ireland, and England and Wales (CIRIA, 2000) with regular updates based on accumulated knowledge and experiences (CIRIA, 2007, Maranges et al., 2020). This implies that although SUDS is far from being widespread within the EU, it is known to be more sustainable by the integration of a range of sustainable technologies and techniques for draining stormwater and surface water(Fletcher et al., 2015). This can still provide useful reference for the SCP development in China.

Finally, WSUD can be described as a widely accepted but partially acted on concept by Australia's federal and state governments. This practice was described as a ‘philosophical approach to urban planning and design that aims to minimize the hydrological impacts of urban development on the surrounding environment’. Hence, it is applied at both federal and the local municipal level by linking its approaches with urban planning frameworks and urban design projects. Consequently, WSUD is an integrated sustainable water management concept that has been interlinked urban planning and urban design. With increasing international business and career opportunities within urban design companies, WSUD approaches have also been integrated into the development of SCP in China. For example, Ningbo Cicheng planning, which was selected as the sponge representative area of the pilot city, was designed by an international team who incorporated WSUDs concepts into its planning 10 years before the emergence of SCP (Xin et al., 2015).

While these international concepts have varying degrees of influences, they all provide beneficial information and guidelines for SCP development due to wealth of knowledge and lesson learnt from decades of practice. Hence, the guidelines for planning, technical design, implementation, operation, and maintenance of these initiatives provided by various national, state, and local agencies will aid in informing the design of an effective GI delivery model for SCP. Additionally, the GI for SCP development trends and requirements will be further reviewed in the subsequent Chapter 3.

Chapter 3 Literature Review: National Concepts and Practices

3.1 Sponge City Program (SCP) in China

3.1.1 The Background of SCP

The significant urban development and expansion resulting from rapid urbanization has brought about various environmental and ecological issues, especially the water ecology crisis (Zhou et al., 2017b, Chen, 2016). In recent years, many large and medium-sized cities in China have suffered heavy rains and frequent waterlogging hazards leading to extensive financial losses and deaths (Zhou et al., 2017b). Data collected from an investigation of 351 Chinese cities by the Ministry of Housing and Urban Rural Development (MHURD) from 2008–2010 revealed that about 217 cities experience urban flooding with the occurrence being more than thrice annually in ~136 cities (Lv and Zhao, 2013). In addition, it was observed that there had been an increase in the number of affected cities since 2008 with at least 37% of the surveyed cities being flooded virtually every year (Lv and Zhao, 2013). More recently, in 2016, About 28 provinces, thousands of districts, and hundreds of cities within the northern and southern part of China were submerged due to severe flooding and waterlogging hazards caused by weeks of heavy rainfall throughout the wet season (Shepard, 2016). Furthermore, it was deduced that about 650 Chinese cities were exposed to frequent floods (Task Force on Urban Flooding Problem and Solution Investigation, 2014). Consequently, urban flooding has become a regular hydro-meteorological occurrence associated with heavy rainfalls, and is of increasing concern due to its potentially diverse damages and societal impacts (Jiang et al., 2018). However, the problems associated with the water ecology of these cities are much more than floods.

The co-existence of water shortages and water security issues is well-known. China has a large amount of freshwater resources, but the water resources allocated per person are extremely insufficient (a quarter of the world's average allocation per capita). This has given China a spot among the thirteen countries with prevalent water resource shortages. Subsequently, the distribution of water resources in China is generally that "the south supplies a larger proportion while the north supplies less". That is, the land area in the north of Yangtze River accounts for almost 64% of China's land area, while the water resources available within this region is only ~19% of the country's requirements (Xia et al., 2011). This depicts an extreme imbalance in the water and land resources as a result of spatial distribution of these resources. In addition, the direct economic losses per year caused by water shortage in China are 350 billion yuan (Hu, 2013). At the same time, human beings unilaterally pursue economic interests, neglect the environmental hazards, and habitually discharge pollutants into the limited water bodies. This results in an increasingly severe water pollution issue in China. In the past two decades of development within China, there have been numerous cases of water pollution in urban cities which has intensified the water shortage concerns. Likewise, the continuous deterioration of the natural environment pose a huge threat to human health, social stability and economic development (Huang et al., 2018a). Thus, there is an imperative need for practical solutions to China’s urban water security concerns.

In addition, China’s traditional city construction model has obvious deficiencies in coping with floods and water security problems. Hence, it is unable to successfully minimize the escalating urban water problems and/or improve the deteriorating water ecology (Jiang et al., 2018). This is mostly due to the ineptitude of the traditional flood control and drainage plan and engineering design, the conventional pipeline-type grey drainage facilities used in old projects, as well as the lack of awareness on appropriate utilization of rainwater resources. China’s conventional pipeline-type drain infrastructure depends on the use of reinforced concrete for creating a protection mode and this reflects the actions of people in overcoming nature during Western industrial period. However, rapid urbanization has resulted in the inability of the outdated drainage facilities to manage the increasingly severe urban rainstorms. This reveals issues such as the low construction standard at the initiation of China’s traditional city drainage system construction, the high reconstruction cost and the inconsideration of pollution and contamination concerns related to sewage and rainwater. All of this results in problems such as waterlogging, pollution and water environment deterioration consecutively (Hong, 2014). From a planning perspective, Chinese cities generally lack special plans for rainstorm control and utilization, which are important aspects in the developments of flood control designs, drainage plans and environmental protection proposals etc. (Che et al., 2013). Therefore, China's conventional drainage model has inadvertently led to the discharge and wastage of large volumes of rainwater resources, posing a sharp contrast to the current water shortage reality in the country. This water-ecology dilemma and the ineffectiveness of construction approach in China's urban regions has constrained economic growth significantly, endangered various species and attracted widespread attention from domestic scholars. Accordingly, the escalating water concerns in China are predominantly intense urban flooding, worsening water resource scarcity and increasing water pollution (Du et al., 2016, Duan et al., 2016, Jiang, 2015). These problems can be attributed to many factors such as climate change, rapid urbanization, and unsustainable urban expansion. Regardless, these factors combined with administrative and management failures are considered the major cause (Jiang et al., 2018).

In view of these factors, China began to reflect on the urban stormwater planning and management model and called for the transformation of ideas of flood control and disaster reduction. This entails the treatment of flood as a resource and turning the waste stream into useful asset and shifting from the traditional single control method to an ecological control method for an integrated management of stormwater. Within the context of China's new urban construction model and the water ecosystem deterioration, Sponge City was developed as an effective way for people and nature to co-exist harmoniously, performing the function of urban water ecology services and guiding sustainable management has been proposed and promoted. Hence, It has become the strategic objective and standards for the governments (both nationwide and provincial) to actualize innovative urban stormwater management (MHURD, 2014).

3.1.2 Connotation of the 'Sponge' Concept

Sponge City program (SCP) was defined in China's Sponge City Development Technical Guide (SCDTG) as a novel sustainable stormwater management strategy for urban areas, denoting a city's capability for absorbing, storing and decontaminating rainwater (like a sponge), filtering the purified rainwater using nature based solutions, then conveying it to urban aquifers, and discharging it for re-usage when required (MHURD, 2014).

The inference of the SCP was to build cities with superior resilience for acclimating to and protecting against various environmental fluctuations and disasters instigated by stormwater issues (MHURD, 2014, Yu et al., 2015). In addition, the main aim of the SCP is to preserve the conditions of hydrological systems of urban catchments such that it remains similar to the conditions before urban development (Nguyen et al., 2020). This viewpoint is similar to some of the urban stormwater management philosophies (i.e., LID, BMP, WSUD, SUDS, etc.) utilized in some industrialized countries.

3.1.3 The Development of SCP

Sponge city, as denoted by its name, refers to the functions of a city in terms of properties of a sponge. The origin and development of the discussion about sponge cities in China are shown in Figure 3.1. This development can be divided into four main phases: concept formation, concept exploration, concept development and concept implementation. According to literatures, the inception of this concept was around 2003. Joint publication by Professor Kongjian Yu and Dihua Li of Peking University titled 'Urban Landscape Innovation: Communication with the Mayors' (Yu and Li, 2003b) was the first to use the concept of "sponge" as a metaphor for the regulation and storage capacity of natural wetlands and rivers in response to the urban drought and flooding disasters. Due to escalating water ecology problems, the exploration of viable solutions required for the sustainable development of urban water systems is being carried out by various researchers(Sun, 2013, Mo and Yu, 2012). In the practice and exploration stage, Professor Kongjian Yu and his team have made outstanding contributions including Tianjin Bridge Park (2008) and Harbin Qunli Yuhong Park (2010) which are some of the many successful examples of stormwater management practices have been implemented (Yu, 2015c). Likewise, Shenzhen was the first to introduce and explore the suitability of applying LID model to its city in 2004. This led to the construction of Guangming New District as a comprehensive demonstration area of national low impact development rainwater (Ding et al., 2012).

The research and development of the theoretical aspects of urban stormwater management in China has been supported by these practices. While learning from the advanced concepts and technologies utilised in foreign countries, various researchers have explored the theories and innovated approaches to adapt such principles for controlling urban stormwater issues in China. They have vigorously promoted the development of SCP in China. In an academic journals by Dong and Han (2011), the concept of constructing an "ecological sponge city" was first proposed during the theoretical study of the practice utilised in Shougang industrial zone reconstruction planning. In addition, many related industry personnel and research scholars have also proposed the construction ideas of the sponge city (Mo and Yu, 2012, Wang et al., 2013, Sun, 2013). As an example, the current project co-ordinator of the comprehensive management office for Jiangbei water system in Changde City, Liu Bo, submitted two proposals and suggestions about the scientific use and management of urban water resources. This was done during the 4th session of the 11th National People's Congress in 2011 and the 1st session of the 12th National People's Congress in 2013 (Liu et al., 2017, Jiang et al., 2018), both of which have suggested "construction of a sponge city".

Chinese government in late 2013 officially declared the launching of the Sponge city program initiative. This was further ascertained by President Xi Jinping's speech at the Central Urbanization Working Conference held in December 2013, which referred to constructing a sponge city with the ability to naturally accumulate, penetrate and get purified. By February 2014, the urban construction department of the Ministry of Housing and Urban-Rural Development (MHURD) specified the sponge city image in its Work Focus. In March 2014, President Xi Jinping proposed that the water control strategies of new era will "take water saving as the priority, keep spatial balance, conduct systematic management and take actions with both hands" during the construction of sponge cities at the 5th meeting of the Central Financial and Economic Leading Group, (Nguyen et al., 2020). In October 2014, MOHUD officially issued the Sponge City Development Technical Guide (SCDTG) (MHURD, 2014). Shortly after, in December 2014, the Ministry of Finance (MOF), MOHUD, and the Ministry of Water Resources (MOWR) issued a joint notification on the launch of Sponge City pilot projects construction supported by Central Finance (CJ [2014] No. 838), and organized the demonstration work of these pilot projects (Jia et al., 2017, MHURD, 2015b).

In October 2015, the ‘Guiding Opinions on Promoting Building of Sponge Cities’ was issued with the allocation of responsibilities for the construction of sponge cities. From 2015 to 2016, 30 Chinese cities were selected for the construction of the sponge pilot projects. Additionally, an annual incentive of 400–600 million RMB was paid annually by the central government to these sponge pilot cities for three years. This gives a total investment estimated to be about 42.3 billion RMB (Jiang et al., 2017). As a result, the concept of “Sponge City” has become a popular topic in China and frontier in the industry in recent years. Furthermore, the attention and promotion by the central government has encouraged the official development of this concept, which is of interest to provincial and municipal governments around the country as well as various personnel in related fields (Jiang et al., 2018, Nguyen et al., 2019). Hence, currently, sponge city as an effective way towards a resilient city, has gained significant interest both nationally and internationally.

To summarize the whole process of SCP, a model of the Sponge City Construction initiative was developed to clearly describe the sponge city development process as shown in Figure 3.1 (Ding et al., 2019). In addition, the execution of SCP strategies would have numerous and varied benefits within the confines of the city. However, there are still several risks and challenges associated with SCP, similar to other urban stormwater management practices globally (Ding et al., 2019).

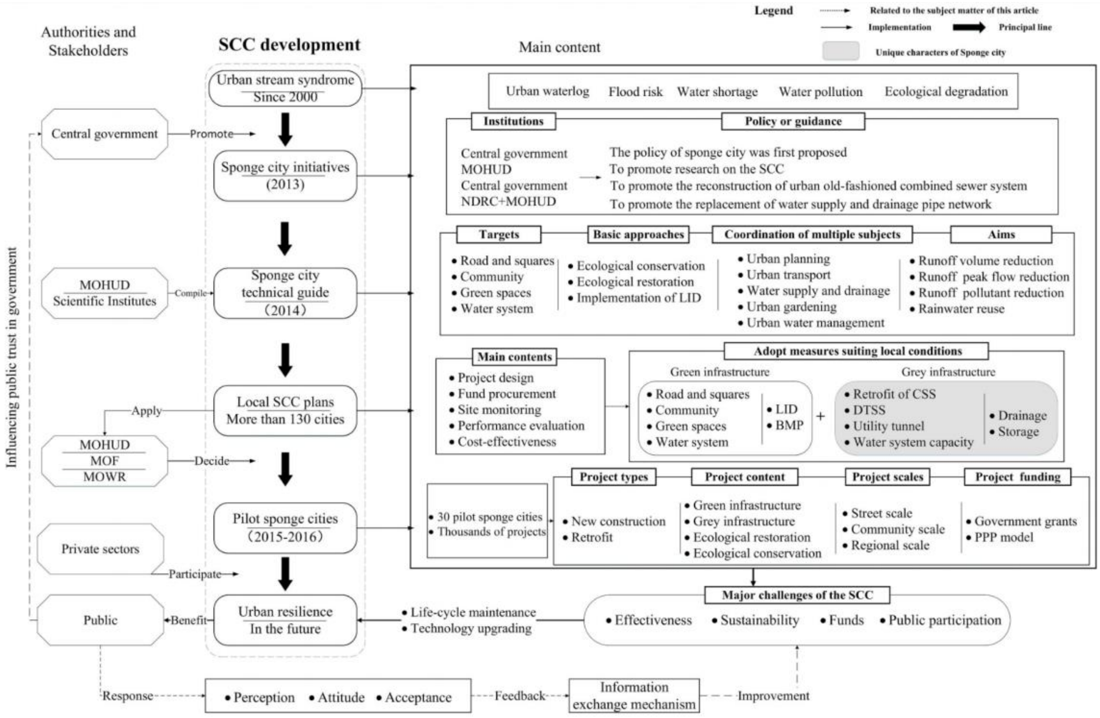


Figure 3.1 Developmental framework of the sponge city construction initiative (Ding et al., 2019)

3.1.4 Comparing SCP with the Other International Practices and Rethinking of SCP

3.1.4.1 Comparing SCP with the other International Practices

The SCP aims to methodically resolve water system issues in urban areas, such as water scarcity, flooding, water contamination, water logging, and ecological restoration. The scope of SCP is mainly focus on urban areas, including old downtown and new urban areas (MHURD, 2014). This is different with GI and WSUD usually incorporating around towns or rural area (Jiang et al., 2018, Ding et al., 2019) (shown in Table 2.5 in the section 2.6.1). As a novel sustainable stormwater management strategy, the connotation of the SCP denoting a city’s capability likes a sponge which absorbing, storing and decontaminating rainwater, filtering the purified rainwater when it rains, then conveying it to urban aquifers, and discharging it for re-usage when required (MHURD, 2014). This is similar to other international urban sustainably water management concepts such as, LID, SUDS and WSUD (Nguyen et al., 2019, Yu, 2015c). The main contents of SCP include utilizing low impact development masseuses, upgrading terminal water treatment technology, and protecting the original ecosystem. Additionally, the main characteristic of the SCP is combination of both natural water system functions and artificial facilities to mimic natural water cycle and improving water quality (MHURD, 2015a).

According to the SCDTG (Sponge City Development Technical Guide) (MHURD, 2014), the main facilities are low impact development facilities, also called GSI (Green Stormwater Management Facilities) such as Rain Gardens (RG), Bio-Swales (BS), Green Roofs (GR), Bio-Retention Cells (BC), Permeable Pavements (PP) etc. This is similar to other low impact development measures used abroad, such as, LID,SUDS and WSUD (Yu, 2015c, MHURD, 2014).

3.1.4.2 Three Key Points of Rethinking of SCP

There are continuous recommendations and reflection from local management practices and researchers from the relevant fields as the process of construction of SCP. The fowling three key points were summarized.

Firstly, single-target technologies which are lacking in integrated values, need to be improved in terms of comprehensive management and corresponding implementation mechanisms. According to Kongjian Yu, 'SCDTG represents the ecological and sustainable stormwater management concept and approaches that have progressed from academic to management practice and achieved implementation within china'. Still, the central government guide of SCD is focussed on stormwater management technology with the site design tools which makes reference to LID (USA), SUDS (UK) and other systems' (Yu, 2015c). China is currently tackling a variety of water-related issues including water contamination, water scarcity, flooding, and loss of marine habitats. Coupled with the water-related issues, rapid urbanization, high population density with high impact development infrastructures in China are increasingly worsening the environment (Yu, 2015c). Therefore, engineering-oriented approach of the SCD are not suitable for solving these problems within Chinese context.

Secondly, the flood resilient/adaptive landscape, which does not reflect the traditional method of stormwater management but embodies the modern landscape ecology, is an essential part of implementation of SCP (Yu and Zhang, 2007b, Yu, 2015c, Wang and Banzhaf, 2018). Due to its vast territory, China has different experience in the application of adaptive stormwater management in different regions. The advanced river network in the east, especially for the Jiangnan water network area known as 'Jiangnan water town' is a typical example of building cities with natural water resilient landscape pattern. Other typical examples of flood adaptive landscape patterns include the pond system in the south, flood water storage system of 'city building in the highland' and 'pond building by excavation' in Huang fan Plain in the north. All these are based on adaption to local environments, natural features, and thousands of years of accumulated local sponge experience. Regrettably, these valuable experiences were lost during urbanization. These flood adaptive landscape patterns, also called water resilient landscape pattern, need to be restored for the construction of Sponge City. Hence, the use of tools such as green infrastructure is an effective and multi-objective tool which can be used for the landscape pattern restoration.

Thirdly, it is important to explore and understand the local environment and landscape characteristics before any large-scale constructions can be started in the pilot cities. From USA's experience, LID system is a bottom-top process developed and continuously refined with experience accumulated over 20 years. As a result, it takes almost 10 years for detailed studies, data collection, design & construction, maintenance & management, and late-stage evaluation for any urban community. This time is required for the preparation and accumulation of knowledge and experience within the local environment. This includes the accumulation of experience in local targeted practice, such as the accumulation of technology suitability experience, landscape pattern research, applicable management tools, systematic management models, and comprehensive assessment tools.

Reflection on these three key points is the foundation of this research concept. The following subsection gives an overview of the research progress of GI for sponge cities at multiple scales.

3.2 Green Infrastructure (GI) for Sponge City Program (SCP) Research Progress

3.2.1 The Main Barriers and Problems of GI Delivery for SCP

As it was mentioned previously in section 1.2 and 2.6, GI has been acknowledged as an innovative approach for achieving RCD (resilient city development) globally. This is done with strategically planned natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ES" (Vallecillo et al., 2018, Basnou et al., 2020, Majekodunmi et al., 2020, Miller and Montalto, 2019). Furthermore, GI has been adopted as an important measure of SCP, hence, widely applied in the sponge cities and projects. Still, there are specific barriers encountered during the GI design, construction and implementation process.

According to literature, there are mainly five categories of barriers listed as the main concerns worldwide by: technical and biophysical

(T&B), institutional and governance (I&G), socio-cultural (SC), knowledge (K), and funding and markets (F&M). These five categories represent the main barrier frameworks with more detailed barriers subcategorised as presented by Deely (Deely et al., 2020) based on his comprehensive review of more than 500 papers. Their research describes the construction of a barrier identification framework and further identified 30 barriers that might potentially affect GI planning, development, and implementation. The summarized framework of global barriers provides useful reference for the application of GI for SCP.

A study by (Dhakal and Chevalier, 2017) conducted a survey of the implementation status and availability the relevant city, state, and federal policies for GI projects in 10 US cities. The result of their study suggests that the most critical barriers are cognitive barriers and socio-institutional path dependencies, while indicating that resource barriers due to lack of financial resources are one of the most well-known barriers. Based on this, it was suggested that adopting policies that focus on awareness, education, and training, as well as coordinating and encouraging innovative funding mechanism would promote the implementation of GI in these US cites. However, the context may not be relevant to barriers faced when GI is applied to SCP. The main concerns in the Chinese context will be discussed below.

In Chinese context, some obstacles are quite evident, and the identification and resolution of such barriers is necessary to improve the implementation of GI for SCP. Recently, a competitive analysis for identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management in China and UK discovered financial, biophysical, and socio-political circumstances for both SUDS and SCP. This research was conducted by semi-structured interviews with a range of professionals with expertise in GI approaches in both the UK and China, and the summarized barriers in both China and UK can provide meaningful reference for future SCP development.

Two key aspects must be taken into consideration for the application of GI in China (Yu, 2015c)(Yin et al., 2020). The first point involves the relative novelty of GI is within china due to the recent emergence of SCP in comparison to mature practices such as LID (Yin et al., 2020). Hence, SCP is still at its early research stage. After the declaration of 'Sponge city' development as the national level strategy, many urban and rural planners are still unfamiliar with the design methods and lack the design experience for delivering a suitable GI project (Yin et al., 2020). At the same time, there is a lack of sufficient guidance for targeted GI planning strategies which is focussed on enhancing resilience for sustainability as required by this transition period(Jiang et al., 2018). Therefore, at this infancy stage of SCP development, a hindrance to effective GI delivery includes the need for developing more GI planning knowledge and design methods in a local context, as well as developing related planning guidance and supporting policy of technical and biophysical dimension. It can be argued that the development of a robust GI scheme is impossible if the planners lack adequate knowledge in relation to GI planning and design for resilience and sustainable planning, and the managers lack of suitable GI evaluation methods with relevant guidance supporting for local regions for the transitional development.

International concepts such as the LID or SUDS, after decades of concept development and practices have more information and knowledge for more comprehensive localised technical guidelines of GI planning, as previously explained in chapter 2 (see section 2.7.2).

The second aspects that needs to be highlighted in terms of sustainable transition development is that there should be a comprehensive evaluation system. This evaluation system can serve as the target assessment framework for sustainability, especially for neighbourhood scale and sub-neighbourhood projects at meso-and micro-scale GI planning for SCP (detailed see review in section 3.2.2).

This is mainly due to the lack of comprehensive and feasible evaluation system for the assessing optimal design at these scales. Additionally, currently, the ongoing sponge pilot projects are mainly of neighbourhood and sub-neighbourhood scales. Therefore, if there is no suitable evaluation system, designers will be lacking a target framework as a defined goal during the design stage, and the local governments would also be lacking an evaluation framework to evaluate and choose the optimal solution. Additionally, the evaluation must incorporate ecological, socio-culture and economic dimensions. Therefore, some factors must be considered in the design stage and design evaluation process to support these transitions. These factors mainly include: the development of GI design with reinforced resilient strategies so as to better respond to climate change; and secondly, taking into account the needs of more humanized design as well as social and cultural benefits concerns. In addition to these, some economic factors should also be considered in the GI design stage in order to improve the possibility of GI implementation.

In short, the main problems hindering the improvement of GI planning and development for SCP, includes the lack of planning methods due to shortage of technical and biography resources and sufficient knowledge database with basic principles and strategies for planners. In addition to this relevant planning guidance and policy innovations are required to support the GI development.

Hence, the solution of these problems will become an important driving force for SCP development towards higher-level sustainability. The following section of the research progress will review focus on the solution to these two major aspects, from the macro scale and meso, micro scale respectively.

3.2.2 Macro-scale Research Review and the Research Gap Define

Presently, there is no agreement in literature on any single ideal GI mapping method that is best for a specific purpose and under specific conditions (Wang and Banzhaf, 2018) (As we have reviewed in the section 2.5.4 of Chapter 2). Several factors must be considered for the selection of appropriate choice of approach and tools, including technical objectives, landscape properties of the site, society background, and the availability of data, resources, and supportive policy.

GIS is the most widely used method for GI mapping globally, and are described as software by combining digital data mapping and analytical techniques that plays a paramount role in spatial planning (Rall et al., 2019, Pauleit et al., 2019). It is widely accepted that GIS mapping provides irrefutable and quantitative data that can be used for facilitating the generation of recommendation on assets management strategies for enhancing GI functionality (Wang and Banzhaf, 2018, Hoerbinger et al., 2018, Jeong et al., 2020)

Moreover, GI assessments conducted by Chinese scholars have provided important data about crucial tools of GI mapping approaches utilised in GIS (Wang and Banzhaf, 2018; Jeong et al., 2020). A prominent and widely used method developed by Professor Yu are Security Patterns (SPs) linked with GIS mapping methods for focused analysis of key landscapes processes (Yu, 1995a, Yu, 1995b, Yu, 1996, Yu et al., 2005b, Yu, 2015c).In order to support the GI planning process, various GI mapping approaches are necessary. In the last decades, the shift from hand-drawing to CAD (Computer Aided Design) to GIS (Geographic Information Systems) has enabled more accurate and convenient quantitative mapping with process analysis. GIS is widely used for GI mapping globally, and it is the most widely used mapping supporting tool of GI and SCP in China(Wang and Banzhaf, 2018). Hence, it is well acknowledged that GIS mapping provides irrefutable and quantitative data that can be used for facilitating the generation of recommendation on assets management strategies for enhancing GI functionality while addressing the needs of residents and ecology.

There are several renowned GI and SCP related planning practices making use of this methodology with the GIS mapping as support in china, such as Taizhou city planning (2005) (Yu et al., 2005b), Beijing's growth planning for ecological infrastructure (EI) in 2011 (Yu et al., 2011), and Liupanshui's urban river system in 2014 (Yu and Turenscape, 2014, Yu, 2014a) etc. These practices were presented by distinguished Chinese academic of high commendations. Yu's ideas of landscape SPs identification for the ecological infrastructure planning supported by GIS was actually conceived as an effective multi-functional GI network identification methods (Ahern, 2007, Wang and Banzhaf, 2018). This method is based on the essential landscape process analysis which supports abiotic, biotic and cultural functions, thereby providing multiple ecosystem services (Yu, 2011).

This SPs linked GI mapping approach utilised GIS was first successfully performed by Turenscape team in Taizhou city, which received the 2005 ASLA Analysis and planning category honour awards (Yu et al., 2005b, Turenscape, 2009). In practice, the application of this approach includes the Taizhou ecological infrastructure planning (2005) which involves individual ecological process analysis, the overlap analysis of these individual ecological SPs, and comprehensive evaluation based on each SPs (Yu et al., 2005b, Yu et al., 2010, Yu, 2014b). The Taizhou Planning is an excellent example that utilised the GIS mapping supporting tools to do the quantity analysis for the GI planning in urban planning practice in China.

Additionally, a multi-functional GI network, defined as ecological infrastructure, was planned for Taizhou to guide, control, and contain the urban spread. This structural landscape network encompasses critical landscape components and spatial configurations of strategic importance for the preservation of the human wellbeing, as well as the natural and cultural landscape. The "flood resilient" landscape restoring concept utilised in Taizhou planning also emphasised the water-network landscape recovery design implemented for the 'Jiangnan water net area' (Ahern, 2007). The Jiangnan water landscape, an effective resilient landscape pattern used for protecting the city for several millenniums, is threatened by utter collapse due to rapid and unsustainable urban development. Before this GI plan was implemented, considerations of activities such as the filling of the wetlands, straightening and channelling of the rivers, destruction of non-protected historical relics/cultural heritages, and the local residents experiences (visual and recreational) were neglected during rapid urbanisation (Turenscape, 2009). Hence, EI planning and the “flood resilient” landscape restoring design tools were integrated in a green landscape waterfront belt for re-establishing the ecological utilities of Jiangnan river systems with this case study.

The Taizhou planning project gave priority to green and blue networks and placed an emphasis on the management of flood risks and the restoration of the ecological services provided by the river system (Yu and Li, 2003a). Kongjian Yu et al. then used the concept of ‘sponge’ landscape to describe the resilience of the natural water system in urban areas, and indicated that ‘the natural wetlands on both sides of the river work as sponges to adjust the river water amount, and ease the drought and flood disasters (Yu and Zhang, 2007a, Yu and Zhang, 2008, Tore and Karsten, 2013, Yu and Chen, 2014). In this sense, the Taizhou planning is a pioneer study of the sponge city that utilised GI which is completed before the SCP was officially launched.

In this Taizhou EI project, the planners substituted the traditionally used infrastructure (artificial gray networks) with natural and novel

GI components, and the overall GI network and corresponding SPs were planned at the macro scale (Wang and Banzhaf, 2018, Yu, 2015c, Yu et al., 2005b). Yu's concept on EI and the related SPs, and its applications are considered a major breakthrough in China's pursuit of enhanced resilience in cities using GI. Evidently, the principles of the EI network and the planning approaches at macro-scale are simply assessment of the suitable methods to achieve multi-functional GI network mapping in China (Yu, 1995b, Yu, 1996, Dan, 2012). This contributes to the global GI mapping methodology by detecting the four structural elements of the GI system with the use of least-distance modelling tools. All of these features provide practical tools and useful information required for GI planning.

However, after four decades of rapid urban development and extensive economic growth, the demand for a sophisticated urban development and enhanced quality of living is evolving (Jia, 2018, Fang, 2019). As a result, the adverse ecological burden from urbanization has progressively increased over the past two decades, especially in the metropolitan area within China's Southeast coastal area. These environmental pressures are not limited to the water ecology crisis, but linked to a greater complications such as decline in wetlands, destruction of natural habitat and loss of biodiversity (Fang, 2019, EconomicDaily, 2019). Hence, urbanization has been demonstrated to be a major threat to the conservation of natural areas, biodiversity, and resources. Nonetheless, a reduction in the rate of urban growth was observed in these Chinese cities recently. This could be associated with the increase in awareness of the importance of ecological environment protection and ecological restoration features in urban construction (Guan et al., 2019). Furthermore, high-grade urbanization transition is a sustainable approach which aims at an extensive economic, environmental and societal development (Jiang, 2018). Therefore, this approach is not limited to environmental sustainability but also promotes superior built environment and human-centred healthy city for enhancing human welfare.

Consequently, in conjunction with the three key points of SCP highlighted in the section 3.1.4, it is important to develop a GI design and assessment model with more resilient and sustainable competences for this transition period. This model needs to be a multi-objective strategic framework, which not only emphasize the sustainability of the natural environment and ecological resilience, but also improves the level of humanized design by enhancing social resilience with considerations of the human health and wellbeing enhancement. This is because the GI interacts and benefits from both nature and people. Additional, in terms of the macro-scale GI network identification and the more resilient landscape designs, there is a need to explore GI network mapping tactics with respect to health and well-being promotion concern for enhancing social resilience during this transitional period. This is inferred from the current GI planning practices and widely applied EI planning methods and recommendations from prominent and renowned researchers in the field.

3.2.3 Meso- and Micro-scale Research Review Research Gap Define

The quantitative valuation of hydrological benefits is an essential requirement for the assessment of pilot cities during the SCD construction. The Sponge City Development Technical Guide presented the intended goals and deliverables in terms of Annual Total Runoff Control rate (ATRCR) for the various regions of the pilot cities. More recently, researchers and the government have started investigating the evaluation of the complete benefits derived from the use of GI in the SCP. In 2018, "Sponge City Construction Performance Evaluation and Assessment Criterion" was updated. In this criterion, the assessment system for the pilot projects were published and the associated indicators were defined, including ATRCR, pollutant reduction rate, and peak runoff of the pilot areas.

The quantitative assessment of hydrological benefits is done globally with the use of various stormwater models such as DAnCE4 Water, InfoWorks, Mike-Urban and SWMM (Nguyen et al., 2020). These tools have been used to assist numerous designers, planners and policymakers, by simulating the process of the urban stormwater runoff process, as well as estimating water quantity and water quality

(Jiang et al., 2018). Furthermore, advancements in software capabilities, expertise and technologies have improved the efficacy and performance of these models in recent years. Most of these models make use of the LID or the site scale GI module (as we have reviewed in section 2.2.3 of Chapter2) which are capable of assessing the hydro-environmental performance of GI plans in meso- and micro-scale projects.

SWMM is one of the most advanced models for hydrodynamic and water quality simulations in sewer systems. It is widely used to evaluate different stormwater control strategies, and provide optimal stormwater control solutions globally, including the SCP evaluation in China (Jang et al., 2007, Kong et al., 2017, Palla et al., 2008, Versini et al., 2015, Zhang et al., 2009, Jin et al., 2010, Xu and Guo, 2017, Moscrip and Montgomery, 1997, Cai et al., 2017, Zhou et al., 2017a, Guan et al., 2015). SWMM was developed mainly for the design and management of urban stormwater by the United States Environmental Protection Agency (USEPA) (Zhu et al., 2019). It is a popular catchment model for estimating the urban water quantity and water quality, as well as simulating the runoff process of urban stormwater. Moreover, SWMM is one of the most preferred models to evaluate the performance of LID practices in stormwater management, where it includes a functionality to analyse the performance of LID practices(Randall et al., 2019). This is mainly due to SWMM version 5.1 being utilised for simulating the hydrological effects with specific LID modules containing commonly used facilities, such as bio-retention areas, swales and permeable pavements, etc. (Rossman, 2010). These facilities are also commonly used in the neighbourhood or sub neighbourhood site scale projects of SCP and SWMM has been widely used for hydrodynamic simulations SCP (Mei et al., 2018).

However, there is currently no official report of a comprehensive and quantitative assessment tool for the site- or neighbourhood- scale projects. Recent studies by Mei et al. (2018) proposed an integrated assessment method of evaluating economic benefits through the application of SWMM for quantitative appraisal of hydrological and environmental benefits. This study provides certain reference value but its evaluations are not suitably comprehensive, and the potential implementation of micro- or neighbourhood- level projects were not incorporated (Mei et al., 2018). Luan et al. (2019), with the City of Zhuhai as their example, carried out a quantitative assessment of hydrological and environmental benefits of single and combined GI strategies based on the application of SWMM. In their research (ibid), with explorations mostly done on site scale, the assessment system still focused on the integrated evaluation of hydrological and economic benefits.

Eventually, Li (2018b) proposed a more thorough assessment system based on AHP for the case study of Guangxi project. This was quite informative for assessments done at the neighbourhood scale.

However, the proposed system requires additional enhancements with respect to its evaluation indicator system for key sustainability dimensions, such as human health and welfare, which are closely related to humanized design. Additionally, some key performance indicators, such as ATRCR, land use efficiency and technical adaptability should have been included in the evaluation system. Therefore, more in-depth research is essential, especially at the neighbourhood scale. Thus, the development of a key performance indicator framework (KPIF) with a set of KPIs, for meso-and micro-scale evaluation would be necessary. This KPIF will primarily support assessment and design of alternative futures and assist in the quantitative and comprehensive evaluation of the multiple GI design scenarios for SCP for maximizing sustainability and multi-benefits.

3.3 Summary

3.3.1 The Barriers and Drivers of the GI for SCP Transitional Development

GI has been widely implemented as a novel stormwater management approach for dealing with hydrological and water system concerns in SCP (Nguyen et al., 2019, Jiang, 2015). This approach is receiving more interest due to its multi-functional services and impacts.

With regard to the transitional development needs, after four decades of swift urban sprawl and economic growth, China is drifting towards a sustainable urban transition, focussed on comprehensive environmental, economic, and social development (as discussed in the section 1.3). During this transition period, great importance is placed on both environmental sustainability and superior built environment with improved human health and welfare, as well as other multi-benefits associated with the sustainability requirements of each project.

In light of this context, GI has been recognised as a fundamental tool and approach for achieving dimensions of sustainability and resilience for this transition. This resulted in a tremendous amount of interests from the sponge restoration programs and It was implemented at a national level as the main tool utilised for designing and constructing sponge cities (Demuzere et al., 2014, Kim and Kim, 2017, Schifman et al., 2017, Simić et al., 2017, Pauleit et al., 2019). Hence, it is of great significance to promote the application of GI in SCP in response to climate change and high-quality urbanization transformation towards sustainable development.

Moreover, SCP is in the infancy stage with only 30 pilot cities in the first 10 years of construction with strategic plans outlined for the next 10 years up to 2030, refining and developing its practise will have a significant influenced on this transitional period. As mentioned in the section 3.2.1, a hindrance to effective GI delivery is the planners lack adequate knowledge in relation to GI planning and design for reinforced resilience and sustainable planning, as well as the lack of suitable GI evaluation methods with relevant guidance supporting for local regions.

There are three main aspects that should be stressed during the transitional development up to 2030s. These include: firstly, to better respond to climate change, taking consideration of the ecological resilience trends and needs by exploring and accumulating more ecological knowledge and related planning methods; secondly, the social and cultural benefits concerns which highly linked with the improving social resilience must be taken into account; and finally, economic factors must be well considered in the GI design stage to improve the possibility of large scale economically viable GI implementation.

Therefore, the application of GI for SCP in China has some associated hindrances, and such barriers are also the drivers for its future development. The typical barriers that need to be prioritised include: lack of planning methods in both technical and biography dimension; deficit in the relevant planning knowledge and strategies of planners, and the lack of structured planning guidance and policy development in the institutional and governance dimension at this stage of SCP. In addition to these, socio-cultural and financial factors also should be taken into consideration at the early design stage and the planning evaluation process. Hence, suitable key sustainability performance indicators should be selected to build the evaluation framework, especially for the meso-and micro-scale GI planning.

3.3.2 Summary of the Gaps

To summarize, two key research gaps were identified based on the literature review. Firstly, in terms of macro-scale, there are only few studies on how to define and develop a multi-benefit framework which focuses on the goal of more resilience and sustainability with human-centred benefits. Hence, it needs to incorporate improvements in ecological resilience for water system related issues, rebuilding of ideal landscape patterns, as well as enhanced human health and wellbeing for social resilience enhancement, in additional to the relevant GI spatial planning and land use management supporting strategies and institutional policy innovation.

Secondly, in terms of the meso-and micro- scale, there is a lack of thorough and quantifiable assessment model with defined sustainability KPIF (key Performance Indicator Framework) and selections of KPIs (key Performance Indicators), for supporting the evaluation of specific GI design schemes and selecting the optimal scheme with multi-benefits trade-offs to assist in decision-making.

Most of these ongoing projects of the pilot cities are required to completed within three years are at the neighbourhood scale, however, the detailed comprehensive evaluation framework with key sustainability indicators are missing. It is argued that without the suitable performance evaluation framework and indicators, both the planner and the government will lack of clear goals, especially for the large scale of ongoing SCPs.

Therefore, these aspects are the main research gaps in this field that needs to be addressed in this research. Additionally, it is necessary to take regards of these two important points of achieving advancement of GI planning and implementation of SCP towards reinforced resilience and around sustainability transitional development.

Chapter 4 Methodology

4.1 Study Area with Multiple Scales

The selected case study region is one of the main water source areas and an ecological blockade of Ningbo city, China. Ningbo is a well-known "Jiangnan water town" in Zhejiang Province. It is also a commercial hub of the south Yangtze River Channel. The city was among the selected pilot cities for the SCP at a national-level and it has a relatively high average annual rainfall volume 1517.1 mm.

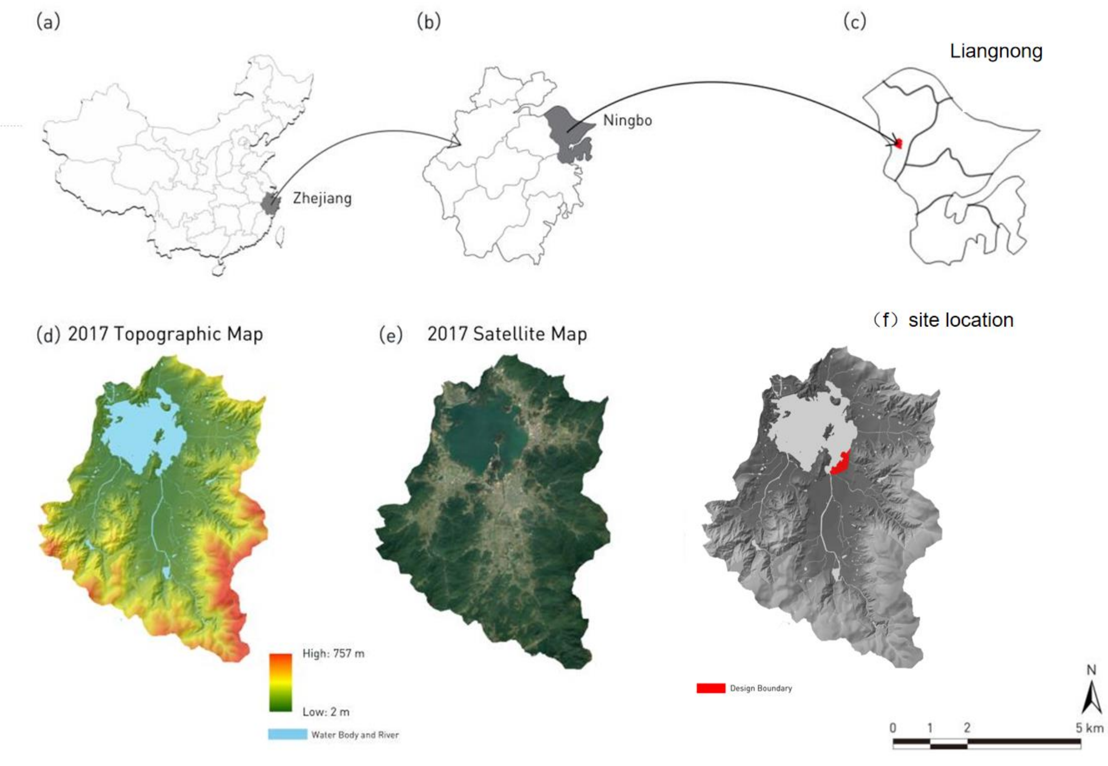


Figure 4.1 The macro scale area location
a, b, c (a is the location of Zhejiang province in China, b is the location of the city Ningbo in Zhejiang province , c is the location of Liangnong Siming Lake Watershed in Ningbo), topographic d, e (d is the GIS topographic mapping result based on the collected elevation information, e is the topographic information based on the satellite image 2017) and the f is the he meso-scale site location

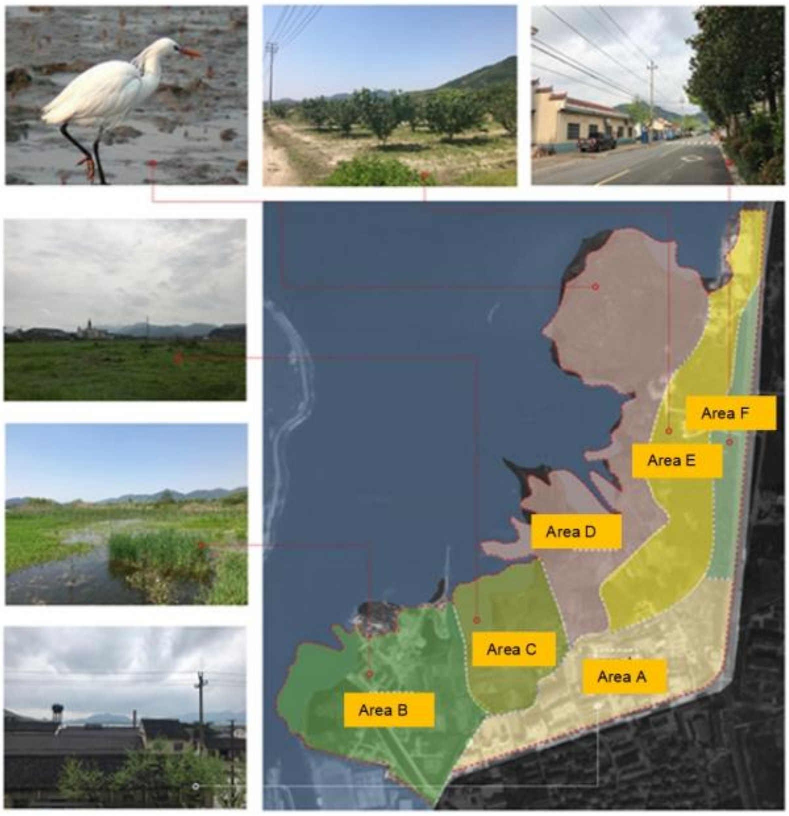


Figure 4.2 The meso-scale site landscape condition and the micro-scale landscape unit areas of the site

The city of Ningbo is surrounded by the Siming Mountains, while the central city is positioned on the Sanjiang Plain. There are three rivers situated in the middle of the city, the Yao River, the Fenghua River, and the Yongjiang River. The Siming lake watershed is one of the important water source areas of in Ningbo and is located in the upstream segment of the Yao River in northern Ningbo.

Additionally, the Siming lake waterfront area is not within the 'sponge' representative area of the pilot city. However, Liangnong Siming lake area is an ecological water town area in northern Ningbo. As one of the important water source areas, it plays an essential part in the maintenance of the water ecology and water security in Ningbo city and such small water town areas are of great significance in sponge city construction.

With its unique and advantageous topography, the whole Siming Lake watershed area (about 9448 hectares, Figure 4.1) is characterized by an exceptional natural landscape making it one of the famous tourist attractions within Ningbo city. Liangnong Siming lake watershed area is famous for its Siming lake water landscape and Siming mountain forest landscape, especially the natural water sceneries, containing views of Siming Lake and Baishuichong Waterfall which are aesthetically attractive.

With the industrial development and urban growth experienced within the past three decades, the natural sponge features and landscape pattern of this region has been significantly altered. The Liangnong Siming lakeside region has been severely disrupted by new buildings development projects. Particularly, the wetland region in close proximity to downtown Liangnong which is mostly occupied by industrial structures. Therefore, this lakeside area, which has been severely degraded by human activities, is the main study area of this research. The study area can be distributed into 6 landscape components (as shown in Figure 4.2, the detailed land use will be illustrated in the preliminary research). The main concerns associated with this study region, which is located exactly next to a protected water source area, is the water contaminations and the obstruction of the tranquil lake view by the industrial buildings of area A (depicted in Figure 4.2).

Siming Lake waterfront area, which is an essential environmental sponge node and sightseeing attraction spot, is presently challenged by both water ecology issues (such as deterioration of water quality) and severe ecological catastrophe (such as decrease in natural wetlands, destruction of habitat and the impairment of the cultural and welfare services provided by the ecosystem). Hence, the landscape and ecological qualities of the scenic area around the lake needs to be improved, as well as the overall Siming Lake watershed (Figure 4.1). This is a typical example of a restoration of sponge landscape pattern for Chinese Jiangnan 'water town' landscape, which embodies the natural and resilient green and blue water landscape pattern (mainly consists of the water systems and the natural waterfront green open areas).

This research is conducted in three levels with three linked research area: (1) macro-scale study with the Siming Lake watershed as the research area , the site location shown in Figure 4.1 ; (2) meso-scale study with focus on the lakeside wetland area as a sponge node (34.19 hectares, the site location shown in Figure 4.1); and (3) micro-scale study with a landscape unit (sponge cell) of the meso-level area specified above as the focus area(6.43 hectares, shown as Area A in Figure4.2).

This research was carried out with a design and assessment integrated model mostly adapted form Carl Steinitz's six-step framework for design (Hollstein, 2019, Steinitz, 1994, Steinitz, 2012). The model utilized in this multi-scale research consists of two main stages (shown as Figure 4.3): (1) The preliminary research executed mainly for basic strategies and pathways Framework (BSPF) development of a GI delivery model (in response to research question number 1 and number 4, see Figure 4.3), the main supporting methods include field study, literature review, and interview; and (2) a comprehensive investigation mainly for the identification of the reinforced resilient GI network with the GIS mapping analysis supporting (in response to research question number 2,see Figure 4.3), and the development of the KPIF using the AHP and SWMM quantitative analysis methods (in response to research question number 3). Furthermore, the assessment of the optimal GI design for SCP are carried out using the KPIF in this stage with Siming lake watershed as case study.

Additional, based on these explorations, some discussions and policy recommendations will be illustrated in the Chapter 7. This further discussion chapter will further clarify the relationship and linkage of the multi-scales, the related planning management and policy suggestions (in response to research question number 4), as well as the novelty and application of the developed BSPF model with the KPIF. This will be done in conjunction with the further discussion and analysis of the Siming Lake watershed case study.

The implementation and assessment of the optimal GI design for SCP will be carried out with Siming lake watershed as case study (as introduced in the introduction Chapter 1, shown as Fig 4.3 with the main methods in the middle column). These methods will be discussed according to the various research stages and scales after spatial data collection and preparing section.

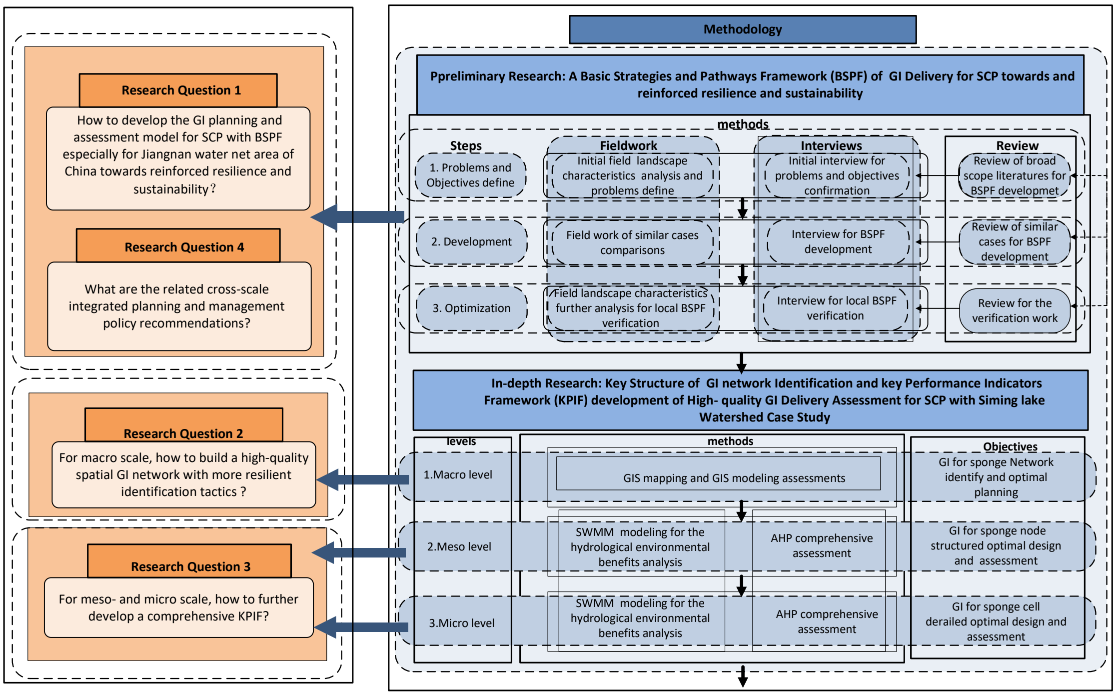


Figure 4.3 The research methods frame of the different research phases in response to the research questions

4.2 Spatial Data Collection and Preparing

The planning and meteorological data in this study were primarily provided by the Ningbo Natural Resources and Planning Agency, the Ningbo Meteorological Agency, and the Ningbo Housing and Urban-Rural Development Agency. A basic topographic map was provided by the city of Ningbo and the Liangnong government, while other required spatial data such as the landscape characteristics and their evaluations were collected from literature and internet sources such as Baidu Map. Furthermore, these data were also validated by field study and interview, which will be collected for further analysis and will be illustrated and in the preliminary research chapter. Other detailed spatial data required for in-depth evaluations, such as detailed spatial distributions of the land-use, terrain, and built information will be prepared by the unmanned aerial vehicle (UAV) surveying and digital mapping. This will be done before the mapping and simulation work using geographical information system (GIS) and Storm Water Management Model (SWMM).

4.3 Methodology of the Multi-scale Preliminary Study

The preliminary research is a systematic study performed with cross-scale examination with the aim of developing a Basic Strategies and Pathways Framework (BSPF) for the GI planning with reinforced resilience. The BSPF will be based on the field studies, interviews, landscape characteristics and evaluation analysis. Within this, a further review based on relevant case study, semi-structured interviews (see Appendix 4.1 Form A.4.1.2) with the targeted experts, and site visits to Siming lake areas and relative cases were conducted.

A three-step process examination is carried out for the preliminary research (shown as Figure 4.4). The first step involves defining the problems and objectives of the Siming Lake watershed case study. This is obtained through an initial field landscape characteristics analysis and interviews mainly from residents. In addition, the landscape characteristics evaluation by a satellite map and the land use change mapping by GIS are carried out in this step. The second step incorporates the BSPF development with literature, interview, and field work. Reviews of similar case studies and interviews from experts are also involved in this step. The final step includes the primary application of the developed BSPF to the Siming Lake watershed case study with concluding the more resident strategies and developing multiple scenarios. Field study and interviews for investigating the landscape characteristics are carried out to support this research.

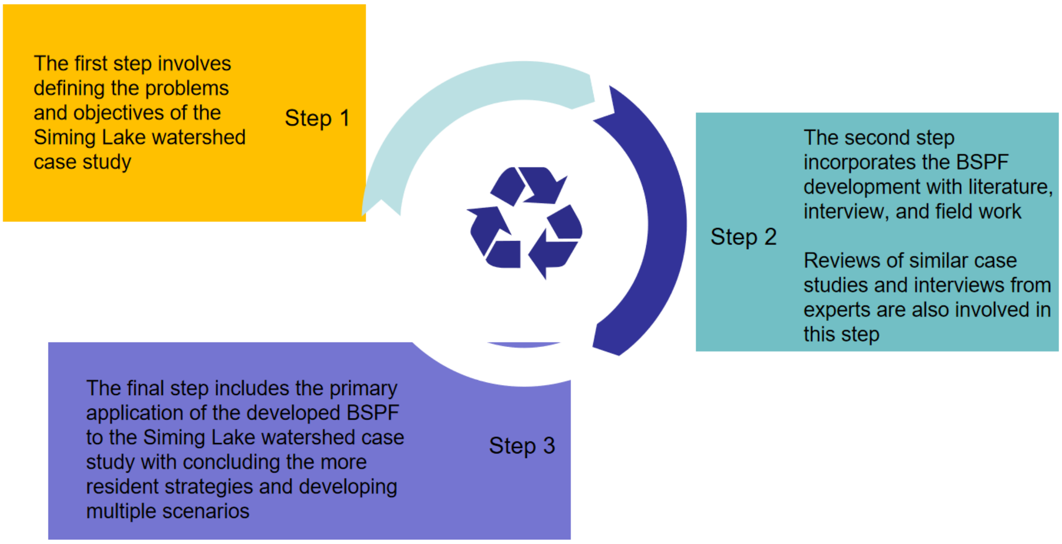


Figure 4.4 The three-step process analysis of the preliminary cross-scale study

Additionally, a cross-scale research is carried out in the three scales with a linked focus area. Hence, the developed BSPF for high-quality

GI delivery for SCP is intended for multi-scale strategies and pathways at the three spatial levels. This BSPF comprises of the construction approaches of the top-level sponge landscape pattern at the macro-scale, the detailed design plans of the neighbourhood-level sponge node at the meso-scale, and the detailed strategies required for the sub-neighbourhood level sponge cell at the micro-scale.

4.4 Methods for Macro-scale In-depth Study

4.4.1 The Landscape Security Patterns Methodology and the Overall Mapping Steps

The GI network identification is based on landscape ecological planning methods: landscape security patterns (SPs) theory and Ecological Infrastructure (EI) planning methods developed by Professor Kongjian Yu (Yu, 1995a, Yu, 1995b, Yu, 1996, Yu et al., 2005b, Yu, 2015c). This mainly involved key landscape process analyses with support from GIS mapping and modelling tools.

According to the SPs theory, not all points (locations) of the landscape are equally important in terms of their influences on the various ecological processes. Some locations are more important than others, and some are strategically critical in affecting certain processes. Therefore, it was hypothesized that some spatial patterns, which are composed of strategic points/positions, exist with critical significance to the security of an ecological process. These spatial patterns are called security patterns (SPs) (Yu, 1995b; Yu, 1995a).The identification of the GI network is based on discerning these SPs using key landscape ecological processes analysis. Hence Furthermore, the strategic points or locations that make up the SPs are identified as key elements of the GI network (Yu, 2015a, Yu, 2011, Yu et al., 2011). In light of these, a detailed landscape pattern identification is carried out through processes analysis of key landscapes and the overlay analysis of essential GI objective layers. All these aspects are significant for the identification of GI spatial network system for the comprehensive macro-scale research.

Hence, the identification of the multi-functional GI spatial network which is done mainly by determining key landscape security patterns (SPs) of the GI objective layers is a six-step process analysis (Figure 4.5). GIS mapping methods are used for mapping different objective layers and the overlay analysis in support of the identification of the key structure such as key nodes, main corridors, as well as the buffer zones and their relationships.

4.4.2 The selection of GIS as the Mapping Supporting Method

Several methods that are widely employed for GI mapping include Morphological Spatial Pattern Analysis (MSPA), Multifunctional Landscape Assessment Tools using specific module of Geographical Information System (GIS) and other environmental characterization analysis methods, using specific modelling tools which are developed mainly based on GIS software Platform (Wang and Banzhaf, 2018, European Environment Agency, 2014). Presently, It is impossible to find agreement in the field on which is the best GI mapping tool for any specific context or optimisation of local conditions (Wang and Banzhaf, 2018). The selection of ideal tools and method involves the consideration of several factors and their implications such as technical objectives, relevant policies, characteristics of the site landscape, availability and accessibility of relevant information and resources and society responses (Schägner et al., 2013, European Environment Agency, 2011). Hence, the most suitable GI mapping methods for a program must be the methods with most suitable purposes, taking into consideration of specific conditions of local characteristics involves of multiple scales.

GIS is widely used for GI mapping globally, and it is the most suitable mapping supporting tool for this study. GI mapping provides irrefutable and quantitative data that can be used for facilitating the generation of recommendation on assets management strategies for enhancing GI functionality while addressing the needs of residents and ecology (Wang and Banzhaf, 2018). This could also be applied as a valuable policy tool to stimulate sustainability, resilience and smart growth in urban development projects for achieving various objectives and meeting various requirements (Larondelle et al., 2014, European Environment Agency, 2011).

To support the GI planning process, various GI mapping approaches are necessary. In the last decades, the shift from hand-drawing to CAD (Computer Aided Design) to GIS (Geographic Information Systems) has enabled more accurate and convenient quantitative mapping with process simulation and analysis. Although there are few new digital planning or smart planning systems that support GI mapping, the GIS platform is still the most widely used system globally.

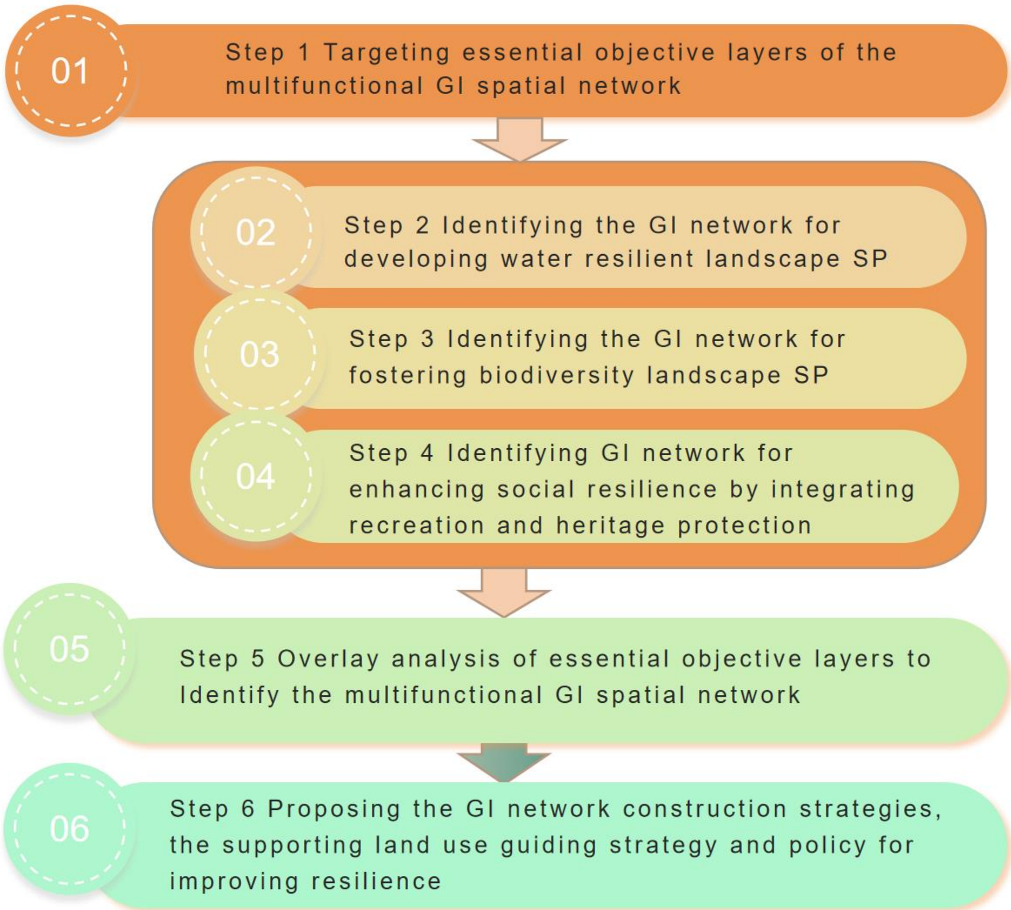


Figure 4.5 The six-step process analysis of the meso-scale study

4.4.3 Six Step Process Analysis and GIS-supported Landscape Pattern Identification

Step 1

The first step involves the definition of the targeted essential objective layers. This is carried out with a focussed process analysis of the multifunctional GI network based on the more resilient BSPF (Basic Strategies and Pathways Framework) for the macro-scale top-level planning. The analysis involves the investigation of the landscape characteristics and the analysis of various landscape restoration strategies. Three essential objective layers are targeted of the more resilient BSPF with the key processes analysis for the enhancement of resilience: (1) The identification of the water security landscape pattern through flood processes analysis for determining the key elements for water resilient landscape pattern and sustainable stormwater management; (2) The identification of the biotic landscape security pattern via landscape processes analysis for ensuring the survival of native species and biodiversity conservation; and (3) The identification of the local landscape recreational network with emphasize of human health and wellbeing promotion linked recreational activities and process of experiencing the landscape analysis, mainly for the vernacular landscape conservation and design a more resilient network space better supporting the human and natural coexist.

Hence, the second till fourth step involves the mapping the three different GI objective layers with their related focus process for the specific landscape security pattern identification.

Step 2

The second step is the identification of the GI network with water resilient landscape SPs (Yu et al., 2005b, Yu, 2011). The Geographic Information System (GIS) runoff analysis was carried out, simulating natural runoff along the terrain in the stagnation of the low-lying point position, to determine potential flood area. Additionally, due to the Siming lake is an important reservoir of the whole Siming lake watershed, playing essential role in flood control process, it needs to be analysed explicitly. According to the flood level information provided in the reservoir management documents by the Liangnong government (mainly including 5-year, 10-year, 20-year, 50-year and 100-year return period), the corresponding water sensitive areas around the lake are identified and mapped by GIS. On this basis, three water resilient landscape security levels (high, middle, and low level) were identified.

Step 3

The third step is the identification of the GI network with biotic landscape SPs. This mainly involves the recognition of the ecological cores, strategic points within the ecological corridors, buffer zones, linkages, and their relationships. The GIS least-distance tools are utilised for supporting the biotic landscape processes analysis which was successfully implemented in the Taizhou EI planning (Wang and Banzhaf, 2018, Turenscape, 2011, Yu et al., 2005b).

In a comparative and spatial sense, there are two kinds of ecological process taking place in the landscape: the vertical and the horizontal (Yu, 1995b). Hence, after the selection of the indicator (targeted) species of a case study area, two kinds of process analysis are required for the identification of GI network: the vertical landscape suitability analysis and horizontal species dispersal and conservation analysis. According to the SPs and Taizhou EI planning methodology, the minimum cumulative resistance (MCR) model is used to simulate the process of species crossing different landscape cover (Yu et al., 2005a). The model is utilised to simulate the horizontal diffusion behaviour mode of targeted species. This is performed with support from the GIS least-distance tool and the generated resistance surface is representative of the accessibility from the source to a certain point in the space. Finally, a comprehensive analysis is carried out base on the vertical landscape suitability analysis and the horizontal diffusion behaviour analysis. Three levels of biotic landscape security patterns (high, middle, and low level) were identified.

Step 4

The fourth step is the identification of the local landscape recreational GI network. This network is identified based on the needs of stressing the health and wellbeing promotional experiences and activities linked strategic points and routes. This mainly includes the identification and mapping of local natural and cultural landscape linked recreational services points and linkage touring routes, especial vernacular water landscape, mountain forest and productive landscape recreational services points and touring routes, which are mostly related to recreational processes that can effectively enhance the human health and wellbeing. GIS basic locational and routes mapping tools are used for supporting this landscape processes analysis (Yu et al., 2005b).

It is needed to point that, in addition to the recreational places and routes that are highly valued, the existing cultural landscape routes (such as the traditional village tourism route and the ancient poetry recreational route), as well as the restored local landscape relics (such as the restored ancient mountain hiking trails and the potential cycling routes along the waterfront areas) are also of great significance.

Step 5

The fifth step is the overlay analysis of essential objective layers to identify the multi-functional spatial network. This step involves the comprehensive overlay analysis of the components from the three objective layers and the identification of the key structure of the multi-functional spatial network. The key structure of the multi-functional spatial network consists of multi-functional key nodes, main corridors, buffer zones and the strategic points. Additionally, this systematic 'layer cake' analysis is performed using the GIS overlay technique tools.

Step 6

The final step is the dissections of the GI network construction strategies, the supporting land use guiding strategy and policy for improving resilience.

It is needed to be mentioned that Similar to the Taizhou EI planning, the high-quality GI network development research for the Siming Lake also highlights the identification of water SPs required for restoring the natural water resilient landscape of the Jiangnan water town (Yu, 2015c, Yu et al., 2005b). This is because Siming lake watershed is a representative of Jiangnan water net town in Zhejiang province. The natural water network is an effective natural water resilient landscape pattern used in safeguarding the cities around the Jiangnan area of china for decades. In addition to the water resilient landscape restoration, the biotic conservation landscape SPs and the cultural landscape conservation layer are also taken into consideration within the multi-functional GI network.

However, for attaining resilience and sustainability for the Siming Lake watershed through high-quality GI delivery, the need for incorporating more social and ecological resilience must be highlighted. Hence, both the spatial network (habitats for biodiversity or ecological systems) and the human-interactions (recreational activities and experience) are valued, especially using the GI network as a ‘physical’ and ‘functional’ connection. This provides an opportunities for the developed GI model to deliver variety of activities, experiences and services within a network of spaces and routes to further improve human health and enhance the wellbeing (Jerome et al., 2019). Therefore, in light of the importance of enhanced social resilience, the specific areas, strategic points (positions), and linkage routes that are related to the promotion of human health and wellbeing are highlighted during the entire network identification strategies for detecting key landscape SPs.

Additionally, the multi-functional GI network identification are based on the overlapping analysis of the essential GI network layers based on the strategic model integrated resilience and sustainability strategies. The development and application of this 'more resilient' Basic Strategies and Pathways Framework (BSPF) for the Jiangnan area in China for delivering a high-quality GI model are illustrated in Chapter 5. The GI network identification with the more resilience landscape security pattern and the related policy discussions will be illustrated in the subsequent Chapter 6 and Chapter 7.

4.5 Methods for Meso- and Micro-scale In-depth Study

4.5.1 Overall Structure

The meso-scale research focuses on a sponge node at Siming Lakeside waterfront area while the micro-scale study concentrates on a specific sponge cell which is a landscape unit of the meso-level area.

The investigation of these two scales involves a unified process model which integrates detailed and interconnected planning for the specific site. This process model is a five-stage integrated design and assessment model:

(1) The first stage comprises of a multi-solution GI scenarios design, which entails the analysis and summary of the findings from the preliminary research;

(2) Afterwards, the second stage encompasses the development of the evaluation KPIF by choosing a set of comprehensive evaluation KPIs, and calculating the weighting of all KPIs based on AHP (Analytic Hierarchy Process);

(3) In the third stage, the hydro-environmental performance of the designed GI scenarios is evaluated based on SWMM, and the values of KPIs for hydro-environmental performance is calculated.

(4) The fourth stage consist of the additional evaluation of the GI scenarios based on experts' remarks, and the calculation of the value of other KPIs considered for the sustainability criteria; and

(5) The final stage involves the scrutiny of the performance of the designed GI scenarios based on AHP, which determines the best performance scenario for decision making. The five –stage process is depicted in Figure 4.6.

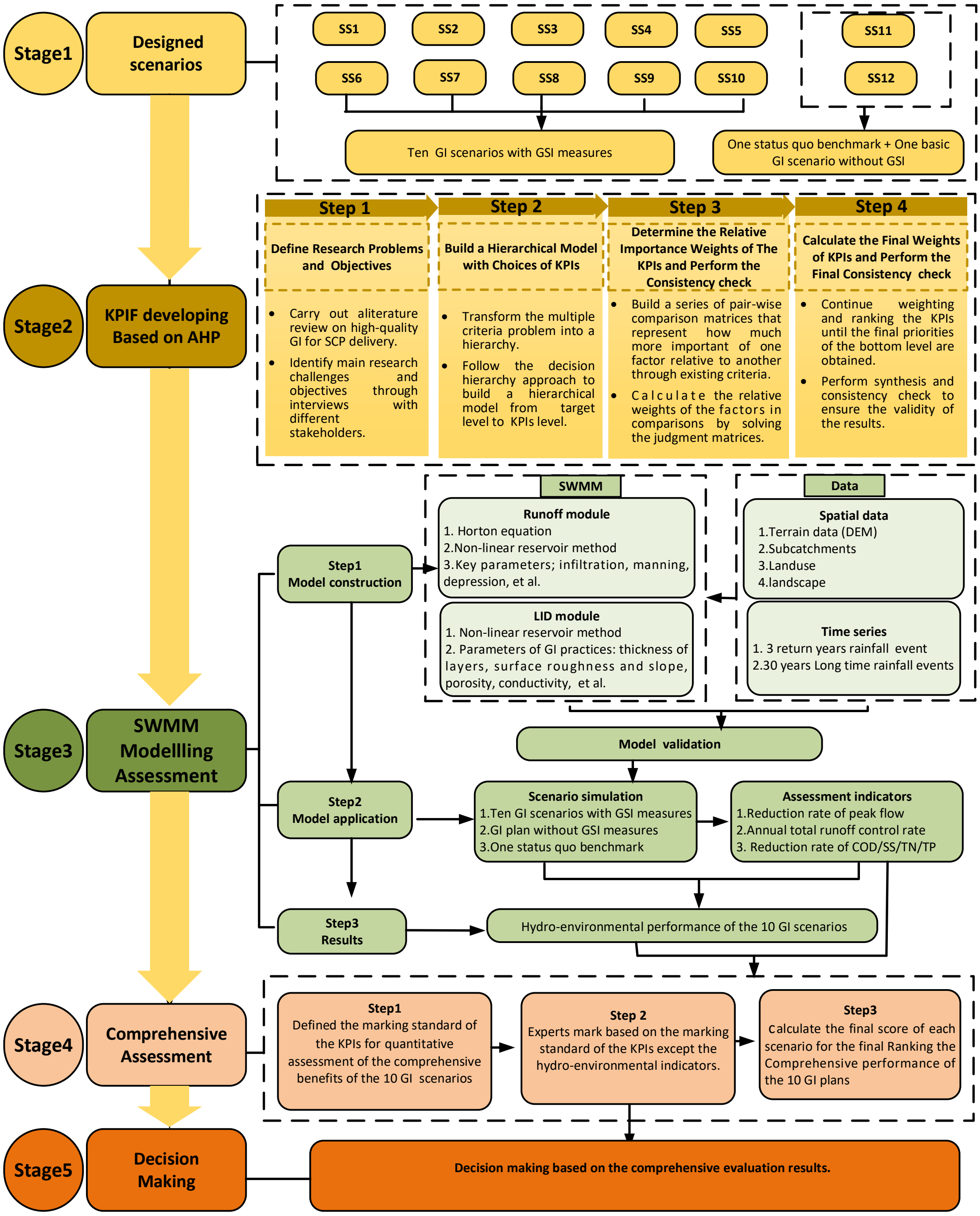


Figure 4.6 Research framework of the meso- and micro study

4.5.2 Analytic Hierarchy Process Methodology and the Selection of KPIs

The analysis and consolidation of multifaceted decision criteria is performed using a well-structured technique called Analytic Hierarchy Process (AHP) (Saaty, 1990). This method is recognised for its meticulousness in the assessment of strengths from qualitative findings, conflicting ideas and favoured inclinations of decision makers (Saaty, 1990, Keeley et al., 2013). Therefore, AHP is considered the most suitable method for ranking relevant indicators in order of significance by the use of a weighting system in an assessment framework (Ameen and Mourshed, 2019). Furthermore, this framework makes use of tiered structure which offers an efficient approach of calibrating numerical values for the quantification of qualitative performance (Ameen and Mourshed, 2019, Ren et al., 2019). In addition, it expedites analysis by breaking down complex assessments into simpler sub-assessments. With AHP, the investigations are conducted at multiple levels, from more general to in depth exploration, and the findings are expressed in a multi-levelled manner. This hierarchical model is commonly made up of 3 levels:

(1) The topmost level is known as the target (goal) level, which indicates the general objective (goals) of the model for determining the rank of indicators based on its weighed significance.

(2) The mid-level is the criterion level, which contains all the benchmarks, sub-criteria and selected indicators that influences the outcome of the process. Here, these components are called the Key Performance Indicators (KPIs) which are utilised for assessing alternate options.

(3) The bottom level which contains the various options (alternatives) to be evaluated is known as the scheme level.

The overall tiered model of the AHP is shown in Figure 4.7 below.

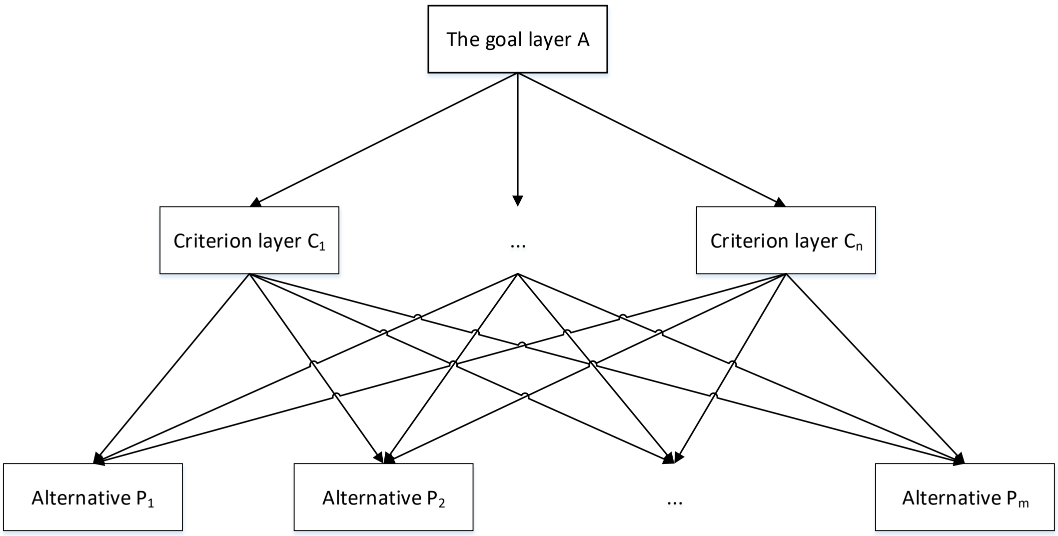


Figure 4.7 The general hierarchical model

As previously mentioned, AHP breaks down complex problems into several levels of manageable sub-assessments and indicators within this model. Hence, with the intrinsic complexity of GI practices required for multi-objective sponge city projects, the developed AHP model would be comprised of numerous social, economic and environmental indicators. The implication of these indicators would vary widely, from negligible impact to great consequence. Therefore, in order to increase the effectiveness and efficiency of this model, the evaluation system is designed to focus primarily on the selected KPIs. Hence, the necessity and significance of the criteria and indicators selection process used in this research must not be underestimated.

Moreover, the summary of the improved efficacy of the AHP model from the implementation of KPI-centred assessment strategy is depicted Figure 4.8 and 4.9. The detailed breakdown of the criterion layer is depicted in Figure 4.9 where the topmost layer represents a specific goal A, the middle criterion level consist of n numbers of criterions denoted as B_1, B_2, ..., and B_n; which are linked to q amounts of sub-criteria designated as C_1, C_2, ..., and C_q, as well as m quantities of KPIs indicated by D_1, D_2,..., and D_m. The components of scheme layer can be seen from Figure 4.6 in which the lowest layer contains X alternate options represented as SS_1, SS_2,...., and SS_X.

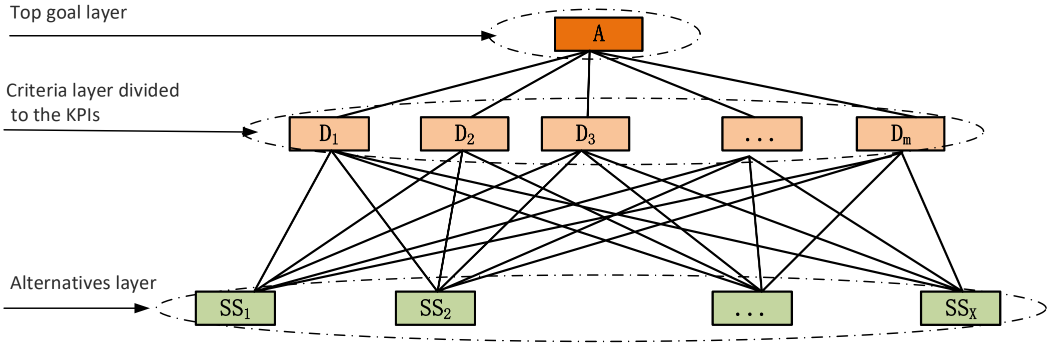


Figure 4.8 The general structure of AHP tiered model with KPIs

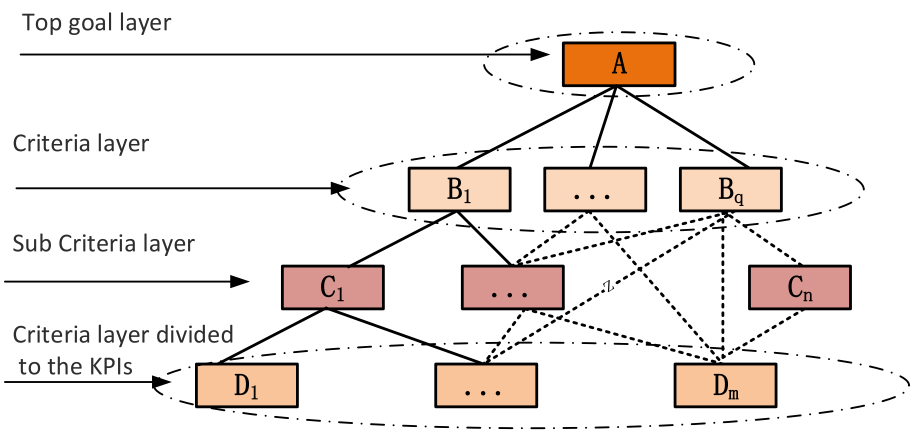


Figure 4.9 General structure of the AHP model utilised in this research

The key performance indicators were carefully chosen based on the appraisal of facts gathered from published documents and literatures, as well as information gathered from expert interviews (Sun et al., 2020). Overall, fifteen local experts and five foreign experts were interviewed to provide insights from their professional knowledge on the setting up of the assessment system. In this research, five experts from 4 main groups were interviewed for this appraisal (see Appendix 4.1 Form A.4.1.3):

(1) Experts from the Liangnong government management office and the Ningbo sponge city construction leading group Office;

(2) Experts from Ningbo Bureau such as the Ningbo Natural Resources and Planning agency and the Ningbo housing and Urban-Rural Development agency;

(3) Experts from local design and construction centres, companies and institutes; and

(4) Experts from the academic sector (mainly universities).

The decision making of the AHP model is dependent on the measured extent of correlation or inter-relationship between these assessment indicators (Dos Santos et al., 2019). The steps involved in the problem resolution stage for determining the optimal process are as follows:

- The problem is defined with main goals emphasized.
- The tiered model is constructed by configuring the decision

layers from the topmost to the bottom level while incorporating KPIs development at the last level.

- The pairwise comparability matrix is developed by for the selection of most crucial factors in view of the specified criteria. This method provides relative weightings of comparable components for sorting out the judgement matrix. It uses the fundamental priorities obtained from the comparison matrix to evaluate the elements of importance in the level directly below. A consistency check is a requisite in this step.
- This weighing and ranking process is repeated continuously until all final priorities of the alternative layer in the lowest level are achieved. Finally, a synthesis and consistency check is carried out to ensure the reliability and repeatability of the result.

Hence, the three steps involved in the Analytic Hierarchy Process can be further explained. Foremost, the main task of the first step is to review the central objectives and define the problem with the aid of information obtained from published literatures and expert interviews. Hence, related literature and existing technical guidance documents of GI for SCP that provides insights on assessment frameworks, criteria, and tools were reviewed to define the research problem, discover comparable works, and to define the scopes and limitations of this research using a context-specific approach. Also, dialogic interviews were conducted with various stakeholders for determining the key challenges and defining the main objectives for GI delivery.

Afterwards, the aim of the second step in the AHP is the transformation of the multi-criterion problem into a hierarchical configuration which is achieved by constructing the decision order from the topmost to the KPIs level, thereby configuring the KPIF. Hence, this research utilises several sets of KPIs for the various identified dimensions during the KPIF construction.

In the third step, pairwise comparison (judgement) matrices are created for determining the comparative significance of the various alternative based on the specified criterion. The measure of each comparison is within a scale of 1–9 as illustrated in Table 4.1. This is gauged based on the professional judgement of experts and government officials (Li et al., 2018a). A consistency check is required for confirming the reliability of the assessment and to ensure that each decision is logical and coherent in order to prevent contradictory results. Even though perfect consistency hardly observed in practice, the decision matrix can be considered sufficiently reliable if its calculated consistency ratio (CR) is less than 0.1.

Table 4.1 Scale of relative importance

Intensity of relative importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between two adjacent judgment values
The reciprocal value	The judgment value of the importance of the element *i* and *j* is r_{ij}, and the reciprocal value is $1/r_{ij}$

CR can be obtained by dividing the consistency index (CI), which is calculated based on the maximum eigenvalue λ_{max} (See Equation 4.1), by the random consistency index (*RI*). Hence, *CR* is depicted in Equation 4.2 with the RI values listed in Table 4.2

$$CI = \frac{\lambda_{max} - n}{n-1}, n = 1,2,\dots,9 \tag{4.1}$$

$$CR = \frac{CI}{RI} \tag{4.2}$$

Table 4.2 The RI values

Elements	1	2	3	4	5	6	7	8	9…
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Lastly, the fourth step of AHP involves the utilisation of the final priority ranking for calculating the ranking weights (hence, the relative significance) of all components in a specified layer to the topmost layer. The weighing of the final priorities of all alternatives are denoted by W_{D1}, W_{D2}, …, W_{Di}, in order to reflect the corresponding criteria layer above (KPI criteria - D_1, D_2….). Still, the final weighing is calculated based on the combination of the ranked weights of all linked criteria layers according to Equation 4.3:

$$W_{D_i} = \sum_{j=1}^{n} W_{C_{ij}} W_j \,, \;\; i = 1,2,\ldots,m \tag{4.3}$$

where W_j is the total ranked weight of each component of the layer C directly above the KPI level; and Wc_{ij} is the ranked weight of the entire layer corresponding to c_j.

The equation for determining the consistency of the final ranking weight is illustrated in Equation 4.4:

$$CR = \frac{\sum_{j=1}^{n} W_j CI(j)}{\sum_{j=1}^{n} W_j RI(j)}, j = 1,2,\ldots,n \tag{4.4}$$

where $CI(j)$ is the consistency index, CI, of the criterion j; and $RI(j)$ is the average random consistency index, RI, of the criterion j.

4.5.3 SWMM Modelling for Hydro-environmental Performance

4.5.3.1 Hydrological Model SWMM and Its Widely Utilisation in the SCP

In this research, SWMM version 5.1 is used for simulating the performance of water quantity and quality control strategies for all previously mentioned scenarios. SWMM was developed mainly for the design and management of urban stormwater by the United States Environmental Protection Agency (USEPA) (Zhu et al., 2019). Hence, it is a popular catchment model for estimating the urban water quantity and water quality, as well as simulating the runoff process of urban stormwater. Therefore, it has been widely used in many countries, including China (Jang et al., 2007, Kong et al., 2017, Palla et al., 2008, Versini et al., 2015, Zhang et al., 2009, Jin et al., 2010, Xu and Guo, 2017, Moscrip and Montgomery, 1997, Cai et al., 2017, Zhou et al., 2017a, Guan et al., 2015). SWMM version 5.1 is utilised for simulating the hydrological effects of low impact development (LID) facilities, such as bio-retention areas and rain gardens (Rossman, 2010).

4.5.3.2 Model Setup

In this study, the research and the land use area of the meso-scale sponge node is shown in Figure 4.10, and the sub-catchments of the sponge node at the micro-scale, denoted as ZHS3 and ZHS4 is shown in Figure 4.11. The Horton equation is used for the estimation of infiltration loses, while the representation of the rainfall and runoff process was based on the water balance approach and Manning's equation (Luan et al., 2019, Horton, 1933). This approach evaluates the efficiency of green stormwater infrastructures and strategies using SWMM-based approach (Luan et al., 2019). In addition, the saturation and exponential functions of this software was utilised for simulating the pollutant build up and wash-off process respectively (Baek et al., 2015).

Hence, according to the Ningbo urban planning and design guideline for Sponge City and in comparison to the monitored data, the event mean concentration(EMC) values used in this study were COD (Typical pollutants reduction rate for chemical oxygen demand) 40 mg/L, TSS (Typical pollutants reduction rate for total suspended solids) 135 mg/L, TN (Typical pollutants reduction rate for total nitrogen) 4.31 mg/L, and TP (Typical pollutants reduction rate for total phosphorus) 0.34 mg/L (Ningbo Municipal Housing and Urban-Rural Development Bureau, 2019). The LID model that contained the bio-retention cell, rain garden, vegetative swale, and permeable pavement was set up based on the published technical guidelines for sponge city design. The specific technical parameters are expressed in Table 4.3 and Table 4.4.

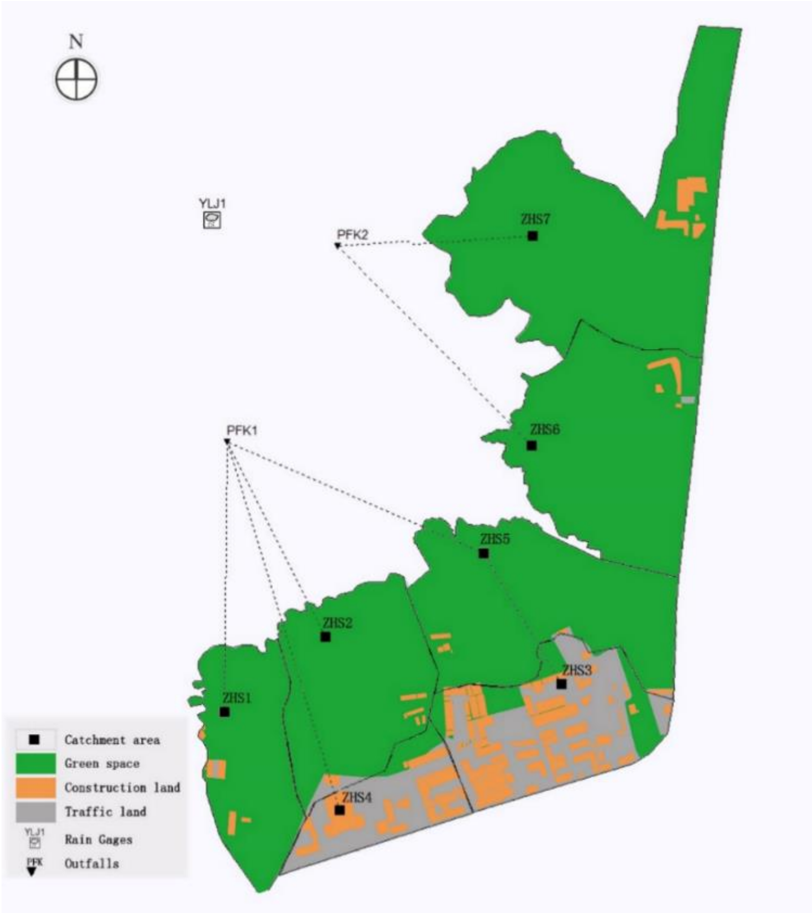


Figure 4.10 The spatial distribution of land use of the sponge node

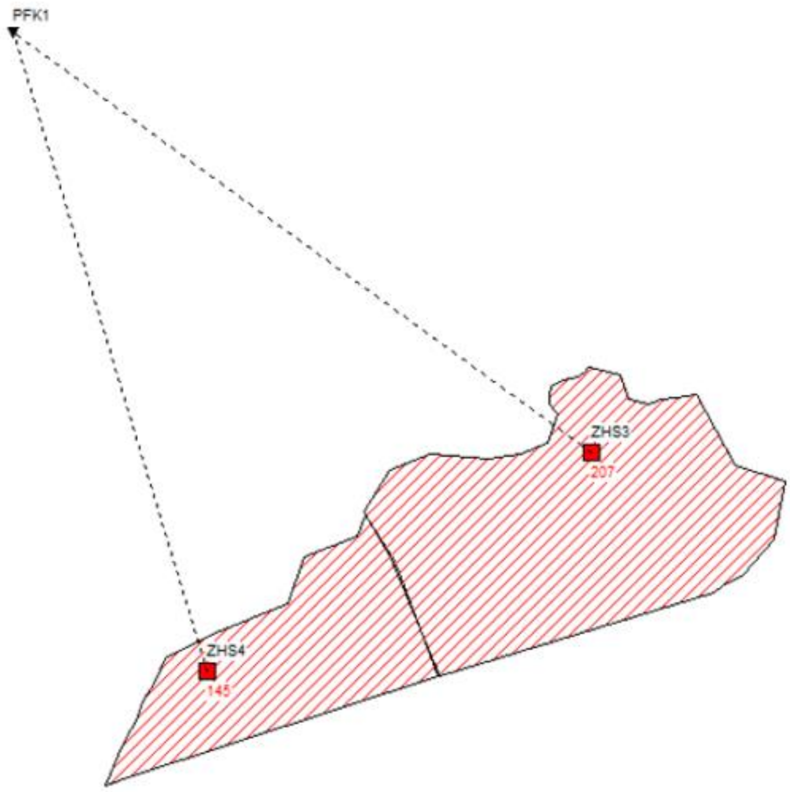


Figure 4.11The research range of micro-scale unit

Table 4.3 Total and impervious areas of sub-catchments

Sub catchments No.	Areas (m^2)	Proportion of impermeable area (%)
ZHS1	$3.22X10^4$	3.00
ZHS2	$4.43X10^4$	1.30
ZHS3	$4.30X10^4$	78.00
ZHS4	$2.13X10^4$	80.00
ZHS5	$5.59X10^4$	0.00
ZHS6	$5.9X10^4$	3.50
ZHS7	$8.62X10^4$	1.90
Total area	$34.19\ X10^4$	16.33

Table 4.4 Design parameters of LID for module GI practices in this study

Layers	Parameters	Units	BC	RG	VS	PP
Surface	Berm Height	mm	150	100	80	5.0
	Vegetation Volume Fraction		0.8	0.8	0.8	0.0
	Surface Roughness	%	0.1	0.1	0.1	0.1
	Surface Slope	%	1.0	1.0	0.5	1.0
Soil	Thickness	mm	500	300	50	--
	Porosity		0.35	0.35	--	--
	Field Capacity		0.12	0.12	--	--
	Wilting Point		0.1	0.1	--	--
	Conductivity	Mm/h	3..0	3.0	3.0	--
	Conductivity slope		10.0	10.0	--	--
	Suction Head	mm	87	80	--	--
Storage	Thickness	mm	650	250	50	200
	Void Ratio		0.75	0.75	0.7 5	0.75
Underdrain	Flow Coefficient		0	--	--	0
	Flow Exponent		0.5	--	--	0.5
	Offset Height	mm	6	--	--	6
pavement	Thickness	mm	--	--	--	100
	Void Ratio		--	--	--	0.15
	Impervious Surface Fraction	%	--	--	--	0
	Permeability	mm/h	--	--	--	100
	Clogging Factor		--	--	--	0

4.5.3.3 Model Calibration

In consideration that the scenarios developed in this research are for future planning, relevant monitoring data are non-existent. Likewise, relevant data for observational comparisons for the Ningbo local pilot project is unavailable. Therefore, the parameters used in this research are adapted from published articles that have previously examined the same region, Shanghai, and Nanjing (Li et al., 2019b), as well as the SWMM user's manual by the US EPA and the sponge city technical manual (Zhu et al., 2019, Xu, 2019, Cai, 2019).

4.5.3.4 Simulated Rainfalls and Standards Settings

In order to attain an accurate and comprehensive evaluation of the hydro-environmental impacts of each scenario as required by the SCDTG, this research utilises a long-duration model of simulation. This simulation model utilises continuous data of daily rainfall in the Ningbo area for a period of 30 years (1981 - 2010) to calculate the total runoff control rate and related pollutant reduction annually.

The primary objective of sponge city construction is to control and store small- and medium-sized rainfall events. Any project with an annual total runoff control rate (ATRCR) of more than 75% is considered suitable for attaining the government's standard. In addition, the simulation of a two-hours rainfall event with return period of 3 years was conducted for each scenario, and the peak flow reduction were compared based on experts' suggestions.

For quantitative measures, the Ningbo rainstorm intensity is calculated using the Equation 4.5 and the Chicago approach is adopted for computing the rainfall data with a return period of 3 years as commonly applied in China (Ningbo Municipal Housing and Urban-Rural Development Bureau, 2019) (Xie et al., 2017).

$$q = \frac{2293.666 \times (1 + 0.698\ lgP)}{(t + 9.77)^{0.723}} \tag{4.5}$$

where q is the rainfall intensity, P is the rainfall data with the designed return period, t is the duration of the rainfall.

4.5.4 Comprehensive Evaluation and Based on AHP

In this research, it is important to moderate the final weight of each KPI. This is done by multiplying the basic value of the KPI obtained from the SWMM assessment and the expert's grades (weighing of final priorities in AHP model). This was applied for the scoring each scenario in order to obtain the final values for each KPI. The calculations are shown in Equation 4.6. These final values (S_i) are then added to calculate the final score of each scenario (SS_k), as shown in Equation 4.7.

$$S_i = P_i W_{Di}\ , \quad i = 1,2, \dots, m \tag{4.6}$$

$$SS_k = \sum_{i=1}^{m} S_i\ , \quad k = 1,2, \dots ,10 \tag{4.7}$$

where S_i is the final value for each KPI, P_i is the basic value of each KPI, and SS_k is the final score of each scenario.

After this comprehensive evaluation, the scenario with the best performance is determined based on the comparison of the value obtained from the quantitative calculations. This is used for decision making, such that the higher the final score, the higher the ranking of the GI scenario. Hence, this evaluation aids in guiding GI implementation at the meso- and micro-scale site for 'more resilient' network models.

The exploration, data analysis, discussion and conclusion from the development of the multiple scenarios for the Jiangnan area (with Siming Lake waterfront area as case study) and its comprehensive quantitative evaluation using AHP (KPIF) are further illustrated in Chapter 5 and 6. This evaluation is important for the development of a holistic BSPF for high-quality GI planning.

4.6 Summary of the Main Methods and Its Limitations

The main objective of this study is the development of novel strategic model that will guide the GI planning for China's SCP to improve ecological and social resilience outcomes for sustainability. This model will be of great importance for China's transitional development. In view of this objective, the research incorporates a multi-scale comprehensive review and quantitative exploration focused on the research gaps. A two stage integrated research was performed : (1)

The preliminary research was carried out for the BSPF development with the field studies, literature review, and interviews used as the main research method (the results and discussions will be illustrated in Chapter 5 and Chapter 7); and (2) a comprehensive investigation mainly for the identification of the functional GI network with the GIS mapping analysis supporting, and the development of the KPIF using the AHP and SWMM methods to maximise resilience and benefits (the main results and discussions are illustrated in Chapter 6 and Chapter 7). Additionally, the assessment of the optimal GI design for SCP are carried out using the KPIF with Siming lake watershed as case study.

The selected research methods, such as the GIS, SWMM, interview and AHP, are all widely used methods for SCP and the GI research globally. However, each method has some limitations as detailed below.

GIS is the most widely used method for GI mapping globally (Jeong et al., 2020, Rall et al., 2019), and it is the most suitable mapping tool for this study. GIS is a software that combines digital data mapping and analytical techniques to provide irrefutable and quantitative data that can be used for enhancing GI functionality (Wang and Banzhaf, 2018, Li et al., 2020b). Although there are few novel digital planning or smart planning systems that support GI, the GIS platform is still the most widely used system globally. With its combination of digital data mapping and analytical techniques, GIS aid in supporting planners and managers to see the city through comprehensive multi-layer overlay that enables making data-driven decisions. GIS deals with this the quantitative analysis using spatial models and statistics which requires detailed data. These data are then stored, processed and visualised as fixed locations in space and time, which is significant for mapping analysis. In the context of this research, the use of GIS mainly relies on the land use data However, the accurate land use data is not easily available in China, which is one of the main limitations of using GIS Mapping. In order to tackle this drawback, a longer duration was assigned for the collection of date for this research by repeated field study and site survey using unmanned aerial vehicle (UAV) in the specified area in order to obtain relatively accurate land use date for mapping preparation.

Similarly, SWMM is one of the most advanced models for hydrodynamic and water quality simulations in sewer systems. It is used to evaluate different stormwater control strategies, and provide optimal stormwater control solutions (Jang et al., 2007, Kong et al., 2017, Palla et al., 2008, Versini et al., 2015, Zhang et al., 2009, Jin et al., 2010, Xu and Guo, 2017, Moscrip and Montgomery, 1997, Cai et al., 2017, Zhou et al., 2017a, Guan et al., 2015). The use of SWMM in SCP projects is associated with its being the preferred models to evaluate the performance of LID practices in stormwater management. This is due to its vast functionality in the analysis of the performance of the general GI facilities. Based on this, SWMM has been considered as the most suitable hydrology performance assessment model for this work. However, the main limitation with its usage also involves the access to land use and long-term rainfall data which is of great significance to the simulation accuracy. The solution to this was a combination of longer data gathering duration obtaining access to the long-term rainfall data of Ningbo city from the local government for retrieving the required dates.

In addition, both AHP and semi-structured interviews was used for collecting samples of experts' opinions. Such explorative interviews for their viewpoints on specific topics is highly influenced by the professional background as well as the numbers of the experts, which is major the limitation for research. Hence, this study aimed at experts from different backgrounds. The interviewees include the urban planning experts of universities and local design institute, as well as the experts in the fields of urban planning and urban construction management who are working for the different governmental departments in China. Additionally, 20 experts from the following four groups participated in the interview due to the limited time and the availability of the experienced and interested experts. The four groups include:(1) experts from the Ningbo Sponge City Construction Leading Group Office; (2) experts form the Ningbo of natural resources and planning Bureau and the Ningbo Housing and Urban-Rural Development Bureau; (3) experts form local design institute; and (4) experts form universities, such as, Peking university, Beijing University of Civil Engineering and Architecture, Zhejiang

University, and Tongji University.

Chapter 5 Preliminary Research - Exploration and Development of the more Resilient BSPF and Multiple Scenarios

5.1 Introduction of the Preliminary Research

The first task in the preliminary study is the clear description of the challenges associated with the Siming Lake case study required for distinct problem definition and the accurate depiction of the requirements for the GI delivery for SCP transitional development. This requires the preliminary exploration of the landscape features of Siming Lake watershed area with an investigation of the landscape characteristics and the landscape evaluation, mainly by obtaining data through GIS land use mapping analysis, field study, academic literature and government planning reviews, and interviews.

In addition, further reviews of related case studies were carried out for the development of the more resilient BSPF (Basic Strategies and Pathways Framework) model for the Jiangnan Water Area on the bases of previous review and illustrations in Chapters 2 - 4. The reviewed cases are mainly focused on the practice-oriented cases that have won American Society of Landscape Architects (ASLA) award. Four cases were reviewed, two international and two local cases. The international cases include the Conway Urban Watershed Framework Plan, a watershed scale case study and 'The BIG U' waterfront area planning while the national cases from the Jiangnan region in China include the Taizhou EI planning and Luming wetland park design.

Hence, drawing from the knowledge obtained from the previous chapters and the experience represented in these case studies, a general BSPF model for achieving high-quality GI delivery for SCP in the Jiangnan Water Area was proposed. The proposed model is a three-scale integrated model with more resilient and sustainable strategies incorporated. This model lays emphasis on reinforced resilience and sustainable planning strategies, especially stressing the human health and welling improvement concern for better people involvement of the high-quality landscape space.

Finally, the application of this general BSPF model generated during the preliminary study was merged with the landscape characteristics, the distinct problem definition and high-quality transitional requirements of Siming Lake for the development of a three-scale integrated strategy with a basic planning scheme and a set of multiple scenarios. This provides the basic strategy framework and groundwork for further landscape characteristics investigation in support of the subsequent in-depth identification of GI spatial network and the multiple scenarios assessment.

5.2 Landscape Characteristics Evaluation and Description of the Main Challenges of the Siming Lake Case Study

5.2.1 Macro Scale Analysis and the Findings

The land use mapping and evaluation was done using GIS based on the satellite maps of the town from 1960s, 2000 and 2017 (with the resolution of 2m) as shown in Figure 5.1. Based on the GIS calculations, the built region in the Siming watershed area increased from 0.61km^2 in 1960s to 4.12 km^2 in 2000 with approximately 575.41% over ~40 years. This developed area further increased to 6.93 km^2 in 2017, up by 68.20%. As the built section increased, the wetland areas gradually reduced from 4.12 km^2 in 1960s to 3.4 km^2 in 2000 (17.48% decrease) and 3.18 km^2 in 2017 with a further 6.47% reduction. Even though the value is estimated due to unavailability of accurate land use data from 1960 – 2017, the downward trend in the wetland area is unambiguous. Furthermore, the trend observed from this data were substantiated from the field study and interviews conducted with the local resident and government officials.

Hence, it is evident that the increasing construction and development activities due to rapid urbanization and the resultant urban expansion have resulted in extensive ecological problems, especially for the estuary of river Daxi, which requires further meso-scale analysis.

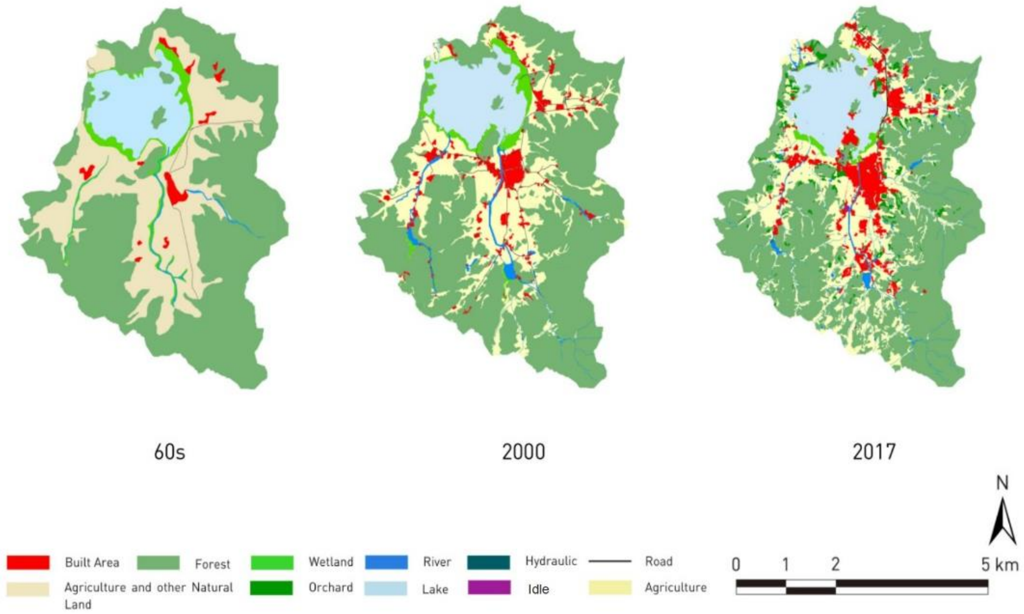


Figure 5.1 The land use mapping results of the town in 1960s, 2000 and 2017

5.2.2 Meso-scale Analysis and the Findings

The comparison of the meso-scale satellite images from 1960s, 2000 and 2017 (Figure 5.2) depicts the apparent landscape pattern transformation of lakeside area (the estuary of river Daxi and the area marked in yellow line shown in the Figure 5.2).

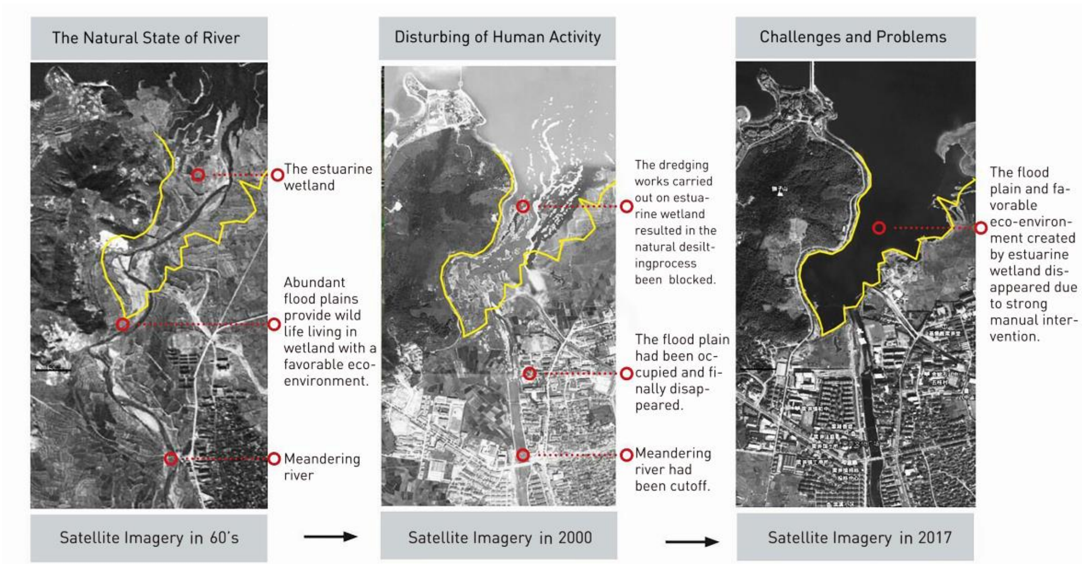


Figure 5.2 Analysis diagram of landscape at Daxi

Taking a closer look at the satellite images, it is quite evident that the river Daxi was in natural landscape form in the 1960s, meandering with abundant flood plains and natural wetland. However, this natural water resilient landscape changed dramatically in the satellite images obtained within the past 20 years. The image from the year 2000 displays straightening and channelizing of the river Daxi with drastic reduction in the number of flood plains as the river straightens. This reveals the deterioration of the ecological system of the watershed due to the artificial straightening and channeling measures. According to the satellite image from 2017, there was an increase in the construction of built area and consistent decrease of wetland such as flood plains with the river straightened. Hence, the ecological system of the whole watershed continually degraded from these artificial flood counter measures. In Particular, the landscape pattern of the estuary of river Daxi depicts transition towards unhealthy conditions between 1960 – 2017 (as shown in the Figure 5.3).

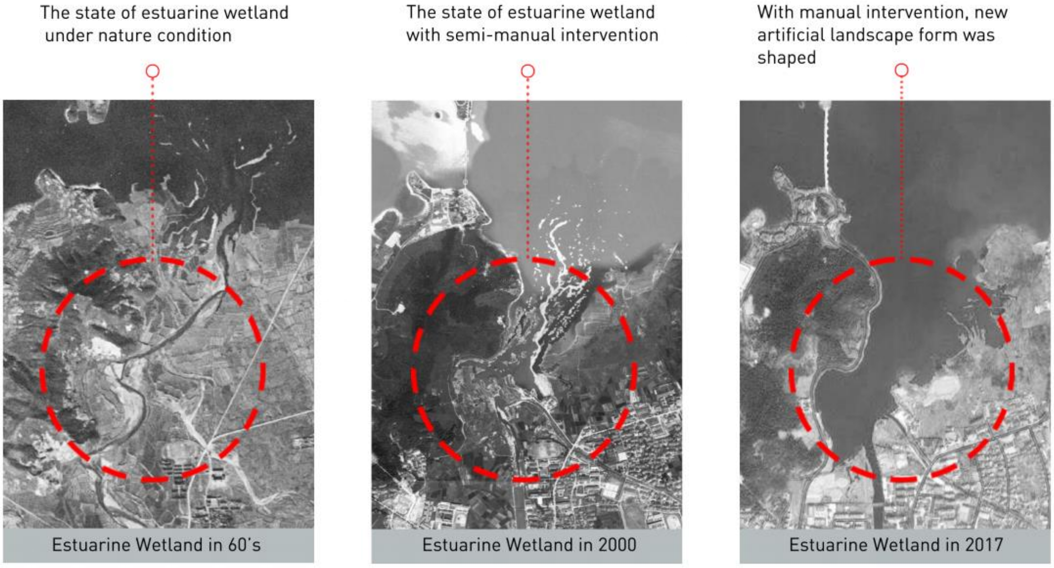


Figure 5.3 Analysis diagram of landscape at Daxi

In summary, the natural landscape pattern of the focus site area in 1960s evolved towards semi-natural landscape pattern due to the implementation of some artificial counter-measures in the year 2000, and finally evolved towards artificial wetland landscape form with traditional concrete flood counter measures (Figure 5.3).

With further evaluation of the focus site's land use pattern, in combination with the field studies and interviews, it was discovered that the degradation of natural wetland is severe due to its diverse land use changes. Within the area, some sites are used as agricultural land, while some areas are used as built area with mainly small factory buildings.

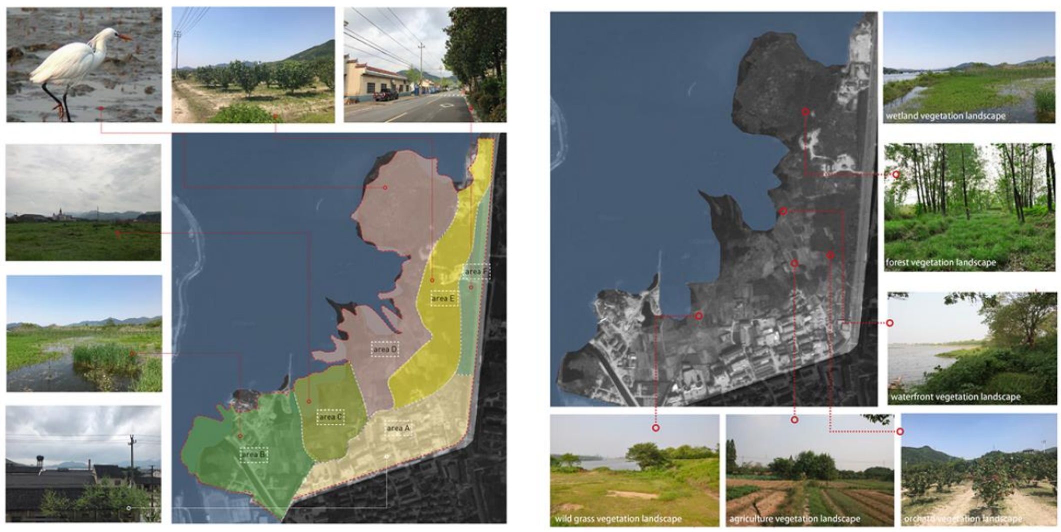


Figure 5.4 Landscape unit of the case study area with depictions of typical landscape and land cover

Hence, the focus area can be segmented into six various landscape units (depicted as Area A – F in the Figure 5.4). The section denoted as Area A is the built-up region with small buildings of diverse usage (residential, commercial and industrial). The Area B represents the artificial wetland landscape created due to the extreme river straightening from constructions. Wetlands with cherry trees were categorized as Area C while Area D primarily consist of natural forests and wetland. Area E signifies regions with some artificial farmlands and Area F are zone with trees beside highways.

The core challenge of this study zone, which is located next to a protected water-source area, is the high degree of contamination and the obstructed sights from industrial buildings located in Area A region (as shown in Figure 5.4 and 5.5).

Figure 5.5 Current land use representations and conditions of buildings located in 'Area A' landscape unit

5.2.3 Micro-scale Analysis and the Findings

Recent depictions of the land use and the current conditions of buildings that are located within area A landscape unit are illustrated in Figure 5.5. It is seen that most buildings in area A consist of small factory workshops used mainly for producing lamps; some public buildings, such as church and offices, and a small number of residential buildings.

5.2.4 Main Challenges of Siming Lake Watershed Case Study

Siming Lake, being the second largest lake in Ningbo, is almost twice the area of West Lake in Hangzhou with beautiful landscape resources. Yet, it is lacking in public accessible waterfront space around the lake and sightseeing corridor of the rivers within the Siming watershed.

This restricts the public's involvement of enjoying the attractive lake view and carry out waterfront fitness and leisure activities.

The Liangnong Siming waterfront area, an ecological barrier of Siming Lake, plays an essential part in the maintenance of the water ecology and water security in Ningbo city. As a consequence of the rapid urban and industrial development, the Liangnong lakeside has been severely affected by urban developmental projects, particularly the wetland area closest to downtown Liangnong of the Daxi watershed. The changes in the landscape pattern is evident from the meso-scale satellite images (Figure 5.3) from 1960s - 2017 which shows the transition from natural to artificial wetland landscape due to severe artificial flood counter-measures. These environmental issues further intensified due to the changes in land use of the waterfront area for industrial buildings, with water quality and ecological deterioration. Hence, the landscape quality of the entire watershed is subpar. Therefore, the ecological repair is not limited to the restoration of the natural water resilient landscape pattern, but also the overall landscape ecological and the revitalization of the waterfront area. A high-quality GI repair program is required for addressing these challenges. Consequently, a preliminary BSPF planning model of the high-quality GI strategy is proposed.

The detailed illustrations of the structure, objectives, and the strategies utilised for this BSPF model is described in this chapter.

5.3 The General Model of the BSPF of GI Planning for SCP with Reinforced Resilient

5.3.1 The Three Scales Systematic Planning Structure Overview

Based on the literature review, it was observed that while most GI projects focus on one specific scale, there were some systematic project designs that includes more scales, such as the Urban Watershed Framework Plan for Conway, which received an award in 2016 from the American Society of Landscape Architects (ASLA) in the Planning and Analysis award category. This framework includes a cross-scale integrated plan, which utilizes green infrastructure for developing a cityscape to aid in management of Conway's water resource concerns, is viewed as a successful example of an effective multi-scale design (Wang, 2016). Thus, the Conway Urban Watershed Framework Plan embodies strategies for different scales, from the street-level to neighborhood-scale stormwater management measures, as well as watershed scale ecological framework.

Similarly, sponge city aims at an ecologically resilient city which requires systematic planning and design at multiple scales. For that reason, the three scales integrated system for GI design proposed by Yu incorporates neighborhood-scale, district-scale and city-scale ecological networks and has been successfully applied in Taizhou EI planning (Yu et al., 2005b, Yu, 1995b, Yu, 1995a, Yu, 2011). This multi-scale design is based on the ecological landscape security patterns (SPs) approach. Hence, the micro- and meso-scale components are the main controlling elements of the macro-scale, such as key nodes, strategic points, and main corridors. Therefore, the structure and scaling of the BSPF for the high-quality GI design should draw on such successful examples.

In practice, the structure of the three-scale integrated GI planning for the development of high-quality GI aimed at attaining sustainability is as follows: the macro-scale is the top planning strategies with basic GI spatial network, the meso-scale are the detailed design stage which contains regulatory design details and strategies, while the micro-scale contains detailed construction design and plans. Additionally, these three-scales integrated GI planning should be designed targeted to linked to the China's official spatial planning system for a specific region, city or town. In China, the official urban and rural spatial planning categories encompass three scales: macro-scale master planning, meso-scale detailed regulatory planning (contains different planning units) and micro-scale detailed constructional planning (for a specific unit within the meso-scale). Hence, the three-scale GI planning should be designed corresponds to the urban and rural spatial planning regulation scale system, serving as the basic strategy and structural guidance of GI planning for SCP (which will be further discussed in the section 7.4 and 7.5 of the Chapter 7 with the relevant policy recommendations).

5.3.2 The Multi-functional Network Basis and the Linked Process Targeting of the BSPF

GI as a multi-objective and multi-benefit solution, can be utilised to reduce the deterrent environmental impacts, assist in adjusting to environmental unpredictability and enhance overall resilience of cities. The overlapping of GI's uses and functions has a big potential for increasing ESs in urban areas(Hölting et al., 2019, Kim, 2019, Meerow and Newell, 2017). In addition, the regulation of hydrological systems, nurture and protection of biodiversity, conservation of local landscape, nature experiences and education are important functions that needs to be integrated into a functional GI system, especially for Jiangnan water net area.

Within the transitional development context, a multi-objective GI network design centred on water resilience and enhanced resilience needs to be developed (Qiu, 2018, Bajc and Stokman, 2018, Gladkikh et al., 2019). This model should incorporate advance resilience strategies that is not limited to improving the ecological resilience such as water resilience, but also with the ability to improve the active usage of these areas for enhancing social resilience. This is done by fostering recreational, aesthetic, and natural education opportunities, as well as supporting programs which enhances physical, spiritual, and/or mental health and wellbeing.

Pertaining to the high-quality GI plans for more resilience, the main objectives at the macro-scale is focussed on the landscape processes for multifunctionality GI network with comprehensive landscape security patterns (SPs). These objectives are mostly adapted from Taizhou EI planning:

- Restoration of water resilient landscape pattern and detailed process analysis of the sustainability and resilience of the stormwater management and water system;
- Conservation of native species and biodiversity with ecological processes analysis of the targeted species; and
- Preservation of vernacular landscapes simultaneously stressing the planning of linked recreational experiences and activities for promoting human health and wellbeing.

5.3.3 Multi-benefits Balancing Assessment Concern for Around Sustainability at Meso- and Micro-scale

The functional objectives of the sponge nodes and the corridors designs at the meso- and micro-scale is based on these three processes analysis-based multifunctionality framework with a range of ecological services (ESs). This planning scale is directly connected with the project construction and requires consideration of the economic efficiency and technical adaptability dimensions. Thus, a set of indicators are linked with the required dimensions and utilised for the comprehensive assessment of the GI's performance. These indicators include a range of ecological services (for instance provisioning, regulating, supporting and cultural services), economic efficiency, technical adaptability, as well as some health and wellbeing indices (Zhang et al., 2020, Rechkemmer and Falkenhayn, 2009).

Additionally, the three triple bottom line (TBL) of economic-social-environmental balance analysis with these indicators' and their rankings are carried out in the in-depth research stage (Sun et al., 2020). This is associated with the different strategies and research focus of each specific scale and the GI planning stage, which are the core components of the BSPF as illustrated in the following sections.

5.3.4 Basic Strategies and Design Pathways of the BSPF Model for High-quality GI Delivery

5.3.4.1 Landscape Security Patterns (SPs) Strategy Supported the Macro-level Planning

The identification of a basic multi-functionality GI landscape spatial network is supported by the landscape security patterns (SPs) strategies. Based on this methodology, not all points (locations) or positions of the landscape are of equal importance in terms of their influence on different ecological processes. Some positions are of great significance and are strategically crucial in influencing certain processes. Therefore, it is hypothesized that some spatial patterns are composed of strategic points or positions that are crucial to the security of an ecological process. These patterns are called security patterns (SPs). Hence, the identification of the macro-scale components of the multi-functional GI landscape pattern is based on the landscape process analysis. In response to the requirements of the high-quality transition, the natural and cultural landscape elements linked with social-cultural activities and recreational experiences are emphasized as a major objective layer of the multi-functional network. This is due to their significance in effectively enhancing human health and wellbeing which promotes resilience.

5.3.4.2 Multiple Scenarios and Comprehensive Assessment Strategies in Support of the Meso- and Micro-scale Planning

Components at the meso- and micro-scale, which are the main controlling elements of the macro-scale network, require more thorough design strategy. The design of these key elements is principally focused on the creation of a green landscape where human and nature can coexist. Therefore, the landscapes need to be multi-functional spaces that enhances both ecological and social resilience. These landscape elements include conservational green nodes, green corridors, and other natural and cultural landscapes strategic points.

Several practices that have been successful utilized in the planning and design of projects globally are well-known and recognized through awards with some of these projects continuing to effective implementation, which provides more insightful recommendations in form of practical case experiences. 'The BIG U' proposal is an interesting GI planning example that won 2016 ASLA Awards by developing a GI model for enhancing the neighborhood's resilience to imminent storm disasters. This design proposal was granted $335 million for the execution of their design in the Lower Manhattan part of New York City. The BIG U strategy involves surrounding the city (Lower Manhattan) with a 10-mile protective system as security against floods and stormwater while concurrently ensuring that the specific needs of the diverse communities are being catered for by provision of public realms.

Similarly, the design of Luming park in Quzhou, in Zhejiang province of China also received the 2016 ASLA Awards. This case is quite pertinent, particularly with its location in the same geographical area with Siming Lake. Hence, some of its experience might be transferable and more significant for the Jiangnan water town area. The awarded proposal explains methods of designing water resilient green landscape with the preservation of the local's landscape assets. Four main design strategies are involved:

(1) The existing variety of landscape and their natural process remain natural dynamic form. Hence, components such as the rock cliffs, the grass covers, rock extensions, the natural drain structure as well as the variations in river water, agricultural fields, and the vegetation around the riverbank stay with maximum preservation.

(2) The "Quilting" of decorative vegetation into the landscape

by the introduction of productive elements such as crops for covering some abandoned or bare sections of the landscape while ensuring the preservation of existing habitats.

(3) The adapting of the water processes and resilience by the addition of green stormwater management infrastructures such as bio-retention areas to the fields and slope regions for capturing and filtering stormwater while preserving the previous drainage system on the site.

(4) The framing of the landscape with a linkage of pathways and structures such as formation of a circular with bridges, pavilions, platforms, boardwalks and viewing towers for enriching visitor's experiences with minimal disturbance to nature while enthralling interactions of varied landscape.

Based on the strategies utilised by the proposals that won the ASLA Awards, it is evident that the design of a multi-functional landscape with enhanced human and nature interaction and co-existence is of great importance. It is also observed that nature-based green solutions and water resilient low impact development measures are the core strategies, as well as the application of the site's sustainable design elements with the guidelines of SITIES (Jia and Guo, 2014). These sustainability elements include the protection and utilisation of the local's natural and cultural landscape, landscape aesthetics and site memory expression, as well as nature experience and leisure activities that enhances human health and well-being. However, the comprehensive quantitative assessment of multiple scenarios and the resilient management approaches are not accounted for in these cases as required in a GI design that facing the high-quality urbanisation transitional trends and needs .

By linking the requirements of the more resilient design and the identified research gaps, a two-stage GI design and assessment integrated process is proposed:

(1) The preliminary stage focuses on the planning strategies and the multiple scenarios development based on the comprehensive investigations carried out at the early research stage. This is performed while focusing on the main restoration objectives and strategies, as well as the more-resilient cross-scale design tactics. Additionally, develop multiple solutions with multiple design scenarios are also required for this stage.

(2) The in-depth stage focuses on the identification of the multi-functional GI network and comprehensive assessment of the multiple design scenarios. Additionally, identification and assessment for the of macro-scale multifunctional GI network via detailed landscape characteristics analysis and landscape pattern assessment with ecological processes and recreational processes analysis. The quantitative evaluation

and multiple scenarios optimization with multi-benefit trade-offs are required for this stage.

5.4 The Application of BSPF Analysis to the Siming Lake Case Study in the Preliminary Research Stage

5.4.1 More Resilient Strategies for Macro-scale High-quality GI Network Identification

For the Siming Lake watershed case study, a high-quality multifunctional GI network needs to be established at the macro-level. This high-quality GI network represent a more resilient landscape pattern that can effectively restore the natural water resilient landscape and regenerate the people and nature coexist waterfront area. This requires not only the restoration of the watershed ecology, but also the enhancement of social resilience by improving human health and welling through various recreational activities utilizing the green spaces (Frumkin et al., 2017, Kim and Miller, 2019, Gladkikh et al., 2019).Hence , this more resilient GI network is a multi-objective model based on overlapping and interactive essential objective layers which are incorporated with proficient identification of key landscape components (such as the key nodes and main corridors) by means of detailed landscape processes analysis.

5.4.1.1 Natural Water Resilient Landscape and Flood Process Analysis for Water Resilient Landscape Network Layer Identification

The restoration to natural water resilient landscape pattern is essential for enhancing stormwater resilience. It is noticed that the reservoirs, lakes, streams, rivers and wetlands in Siming Lake watershed area play an important role in flood control process, and it was described as natural water resilient landscape pattern of the 'Jiangnan water town area'(Yu and Zhang, 2007a, Yu and Zhang, 2008). However, this natural water resilient landscape pattern has deteriorated dramatically in the past 20 years, thereby instigating various problems (analysis in the section 5.1). The usage of green infrastructures for rebuilding the waterfront areas according to the identified flood sensitive areas based on the flood process and the risk level analysis is an effective strategy for restoring the water resilient pattern (Yu, 2015b, Mo and Yu, 2012). The GIS runoff analysis is used for mapping the water sensitive areas based on the flood risk zones and the previous recorded water levels dates. The identification results, the related design guidelines and policy discussions are illustrated in the subsequent chapters.

5.4.1.2 The Biotic Process Analysis for Biodiversity Conservation Landscape Network Layers.

In terms of biotic process analysis, which is relatively more complicated, some spatial strategies such as ensuring the security of habitat cores, buffering, and linking of habitats have proven effective for ecological conservation. However, However, it is not easy to determine how should the landscape be buffered, connected with corridors or additional patches introduced in such a way that they can more effectively influence ecological processes. Hence, the SPs methodology was proposed which emphasize that not all points (locations) or portions of the landscape are equally important in terms of their influences on individual process, whether the landscape is homogeneous or heterogeneous. Additionally, two kinds of ecological processes, the vertical and the horizontal that take place in the landscape are required to be analysis with the targeted indicator species.

The basic principle for targeting indicator species is that targeting species can represent a wild range of habitats. More detailed selection criteria mainly include (Yu and Li, 2003a, Nyerges et al., 2016, Steinitz, 2016b):

- The species' rarity and its current conservation criteria, its threatened status and its conservation practicality based on current planning.
- Regional-scale implementation conditions of current or planned habitat conservation program.
- The evolutionary significance of the species, such as the species in need of huge or a unique type of habitat etc.

Based on the indicator selection principles, three groups of species (birds, amphibians, and mammals) are targeted. The selected groups of indicator species represent habitats of wetlands, streams, lakes, paddy fields and the wooden mountain areas which are the typical landscapes and habitat types of Sliming lake watershed. The groups of indicator species selection and related ecological processes mapping analysis are illustrated in the Chapter 6.

5.4.1.3 Recreational Process Analysis for Vernacular Landscape Recreational Network Identification.

In terms of the landscape process analysis for the conservation of vernacular landscape and enhancement of social resilience, the strategic points and linkage routes that are associated with enriched human experiences with positive influence on health and welling are valued. Presently, there are some existing recreational routes, such as the traditional village tourism route and the ancient poetry recreational route, as well as the ancient mountain hiking trails which requires extensive restoration and/or maintenance. Apart from these, typical source of the local cultural landscapes with positive human health and wellbeing experiences was found from reviews and field study to include:

(1) Productive landscapes such as cherry themed sightseeing and/or fruits picking lots which supports the local-specific tourism industry by attracting tourists from the downtown

regions of the city for the recreational experiences; and

(2) Strategy points linked to natural water landscape experiences, such as the experience along the waterfront areas of Siming Lake and some rivers and streams (McLaughlin, 2013). This includes enjoyment of natural scenery as well as physical and mental relaxation activities linked with such natural landscapes.

Hence, with the vernacular landscape conservation, a more resilient landscape space planning allowing recreational activities will be developed.

5.4.2 More Resilient Strategies for the Meso-and Micro-Scale GI Delivery High-quality

According to the core principles of the BSPF at the meso- and micro-scale, the proposed model should be of multi-functional spaces where human and nature coexist with enhanced ecological and social resilience. This model also requires the application of the sustainable design elements with the guidelines of the SITES. As a result, five detailed design strategies are proposed for the meso- and micro-scale for more resilient GI model.

The first 'more resilient' strategy is to restore lakefront wetland landscape and completely utilize the present riparian sand quarries with minor interference. This strategy is implemented to guide the Liangnong estuary wetland sponge node to gradually recover to its pre-urbanization natural landscape form, while preserving the natural vegetation and micro-terrain, thereby increasing the potential of the diverse habitats to developing with time. Due to the implementation requirements of this strategy, the design period can be divided into short- and long-term design stages.

The second strategy is the water resilient landscape design based on the flood water levels and risk areas. The different landscape units are further divided according to different flood water levels, the micro-terrain and the land use status. The restoring and renewal design for the landscape mainly includes plant configuration, architecture renewal, landscape facilities design, and recreational activities organization. These elements are integrated based on the landscape feature units in order to create a diversified landscape adapted to the flood process. Additionally, the connecting system organized for transport at the site should have negligible interference with the natural ecology and capable of adapting to the flood water risk levels.

The third strategy involves the enhancement of the biodiversity of the area through the preservation and addition of native wetland species. Based on the characteristics of the diverse habitats, a vegetation community with species enrichment design is carried out which focuses on the supplement of aquatic algae, floating and underwater plant species that can improve the water quality. Also, functional vegetation like berry plants for food provision to birds and other animals, and local plants with dynamic seasonal changes are integrated in the design.

The fourth strategy is the development of resilient spaces for dynamic experiences by creating innovative, exciting and hospitable forms of experience for visitors, such as wetland natural education, aesthetic experience, sports and fitness, and other outdoor leisure activities. Hence, ensuring the availability of spaces for developing social programs aimed at improving social resilience is crucial for enhancing stressful urban lifestyle and promoting residents' health and wellbeing.

The fifth 'more resilient' strategy involves the transformative design of the architectural landscape unit with small factory buildings. This is an important landscape unit in the transformation of the meso-scale sponge node as it involves the greatest amount of human activities. Therefore, more detailed planning and design with short-term (5-year planning) and long-term design stages (10-year planning) is required for this unit. This timeframe is a consequence of considering factors such as economic, social and ecological entombment, as well as balancing the construction efficiency with the developmental requirements of different stakeholders etc.

In the five-year construction plan, some buildings with poor structural quality, severe pollution and deterrent impact on the landscape views and/or ventilations will be demolished. During this period, some buildings will be upgraded and replaced, including transforming into creative design studios, shops or other public services. In the 10-year plan, more buildings demolishing work will be carried out due to aging of buildings, with only a portion of the necessary public service facilities retained and transformed to a more natural and ecological waterfront space.

5.4.3 The Multiple GI Design Scenarios of Meso-and Micro Scale for Further Competition Towards Around Sustainability

5.4.3.1 Basic GI Design Scheme of the Meso-and Micro Scale

According to previous analysis, the plan for restoration and transformation into a public waterfront wetland park is divided into two stages. This plan would progressively promote the site’s natural landscape restoration while gradually converting the site into a vibrant and artistic public open space. Hence, the basic planning scheme proposed for the entire ‘sponge node’ park transformation is shown in Figure 5.6 and Figure 5.8. This design utilizes nature-based green measures on the site with negligible interference with the primitive wetland environment for developing more resilient ecological structure.

Figure 5.6 The Basic planning scheme of the meso-scale site

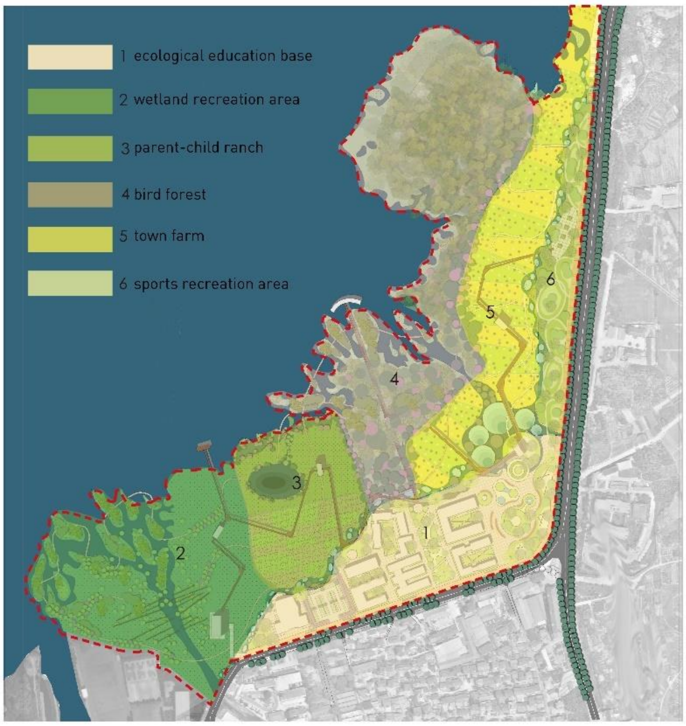


Figure 5.7 The landscape units organization of the basic planning scheme

Figure 5.8 The aerial view of the basic planning scheme

In the basic GI restoration scheme, the landscape was divided according to the current landscape characteristics and varying landscape experience into six landscape units with different themes (shown as Figure 5.7).

- Landscape Unit 1 is the building area for ecological education at the waterfront entrance where some of the building will be demolished, while some will be kept and upgraded in the renewal plan. Hence, the rehabilitated buildings will have new functions such as reception, explanation, exhibition and commerce functions.
- Landscape Unit 2 is the estuary wetland area for restoring the natural dynamic and water resilient estuary landscape design according to its natural process. Here, the identity, function and

structure of the natural environment is preserved. In this way, more resilient landscape function is achieved with better and more effective response to the challenges.

- Landscape Unit 3 and Unit 4 are the waterfront wetland areas with maximum natural vegetation preserving area. Unit3 is mainly vegetated with the native waterfront grass and flowers, in addition to a small cherry planting area, which is an ideal natural experiencing and landscape viewing area for parents and children. Unit 4 is mainly vegetated with trees such as metasequoia and camphor preserved form site the status quo, as well as natural reeds, which is an ideal local bird forest & bird watching area. Both units are incorporated for natural landscape restoration, conservation and protection area for preserving natural vegetation and species.
- Landscape Unit 5 is the wetland flowers area, designed with local wetland flowers and planted in water retention areas for enhancing rainwater retention and management based on current low-lying puddles.
- Landscape Unit 6 is the border belt of the park where local trees and shrubs are planted based on natural vegetation and separated from the adjacent expressway.

The GI basic plan includes an overall landscape restoration plan, which includes the demolition of approximately half of the buildings in the park area and the functional transformations and upgrades of all the buildings within the site area.

5.4.3.2 Design Scenarios of the Meso-scale

Based on the basic planning scheme of the site, ten design scenarios were proposed for the first stage (meso-scale). The scenarios include the application of nature-based green solutions and different combinations of site scale GSI to enhance the water retention and water purification effects.

These GSI measures for stormwater management include the use of rain gardens, Bio-Retention Cells, Permeable Pavements and vegetative swales in the design. Figure 5.9 and 5.10 depicts the ten design scenarios with the main difference being the different combinations of GSI facilities. The alternative designs are identified as Siming Lake design Scenarios 1–10, numbered SS1–SS10. The allocated surface area of each GSI facility in each scenario is shown in Table 5.1.

Table 5.1 Allocated surface areas of each GSI facility in each scenario

Scenario	Bio-retention cell (m^2)	Rain garden (m^2)	Vegetative swale (m^2)	Permeable pavement (m^2)	Total area (m^2)
SS1	24,166	--	--	3615	27,781
SS2	--	24,166	--	3615	27,781
SS3	--	--	24,166	3615	27,781
SS4	22,665	1501	--	3615	27,781
SS5	7741	16,425	--	3615	27,781
SS6	9242	--	14,924	3615	27,781
SS7	7741	--	16,425	3615	27,781
SS8	--	9242	14,924	3615	27,781
SS9	--	1501	22,665	3615	27,781
SS10	7741	1501	14,924	3615	27,781

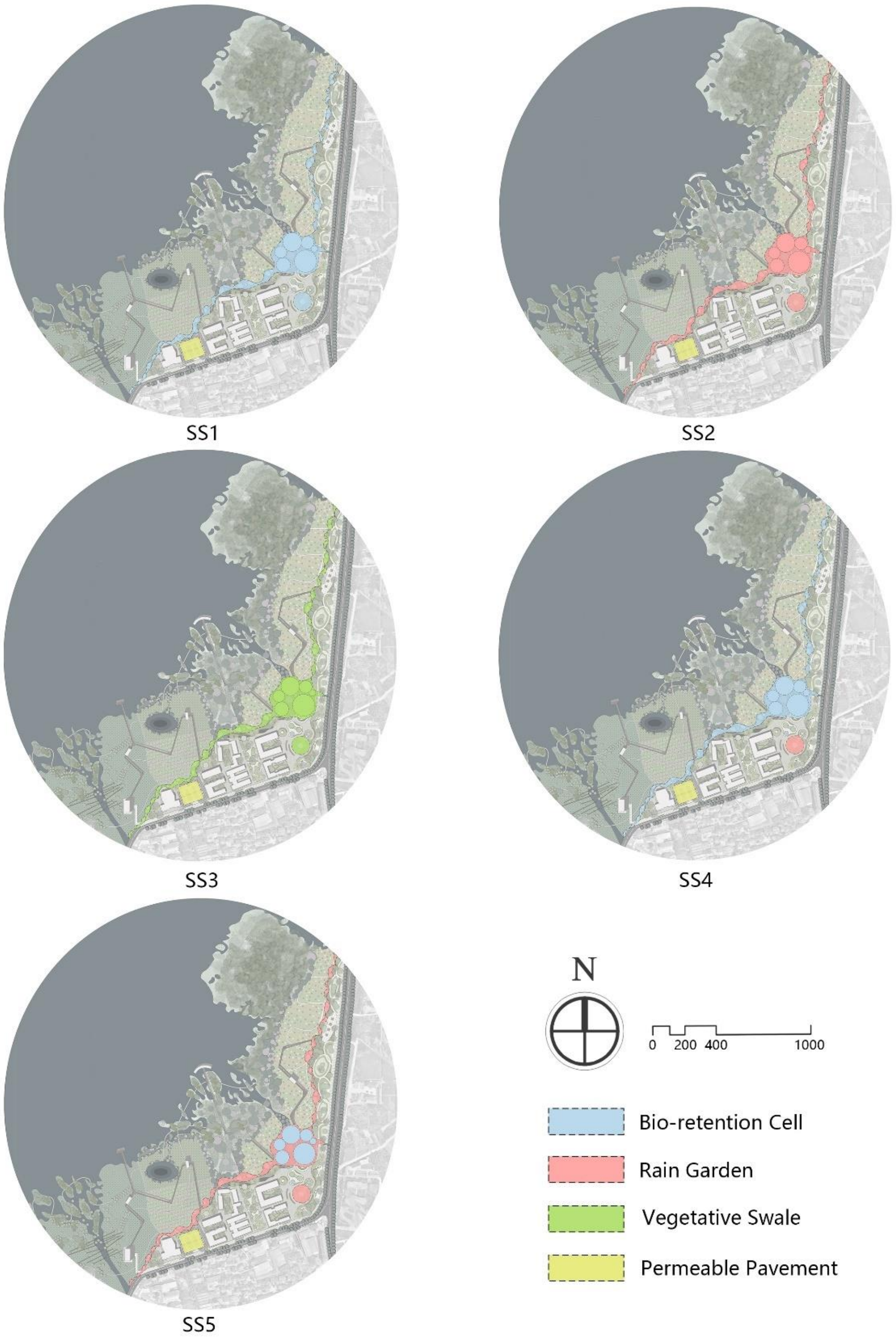


Figure 5.9 The GIS design of cases from SS1 to SS5

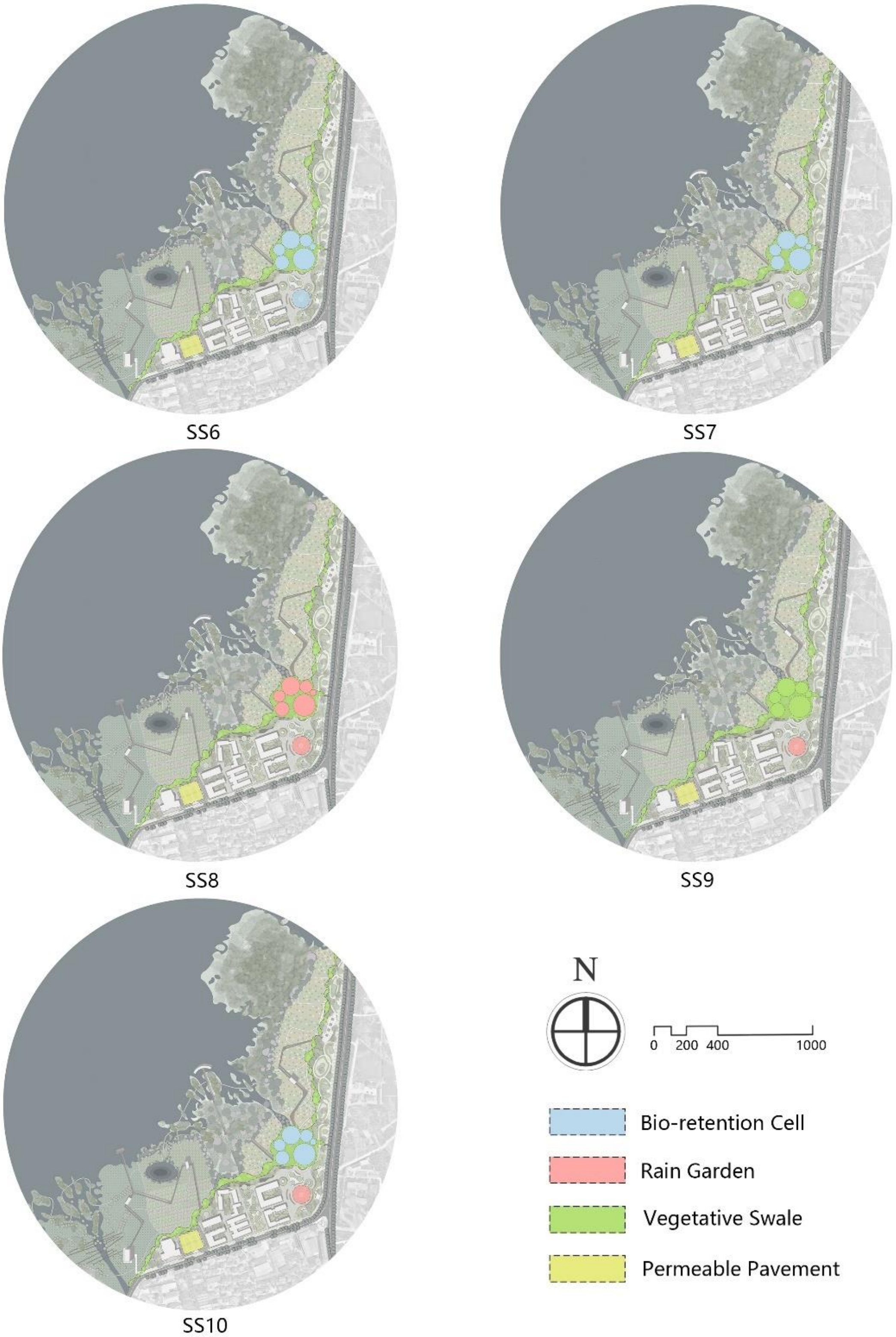


Figure 5.10 The GIS design of cases from SS6 to SS10

Moreover, to further study the role and effect of GSI measures for rainwater management and environmental restoration, the comparison of hydrological effects of GI plans with and without GSI facilities are examined. Hence, the basic GI plan with only the demolition of some buildings and redesign using general green landscape cover without integrating specific GSI facilities was numbered SS11. The status quo, numbered SS12, was used as a benchmark for comparison to the current conditions. The comparison and optimization of these scenarios and analysis of the multi-beneficial trade-offs will be carried out in the in-depth research.

5.4.3.3 Design Scenarios of the Micro-scale

Multiple GI scenarios are also proposed for the renewal of the architectural landscape unit. The basic GI plan involves utilising sustainable design pathways by preserving the memory of the site. Hence, carefully retaining and repurposing the original structures of old buildings or machines, while adding new areas for play, relaxation, and art activities for visitors of all ages.

Beyond these, the assumption that the micro area is designed according to the target of 75% ATRCR（annual total runoff control rate）is recommended in the Sponge City Development Technical Guide (SCDTG) (MHURD, 2014). Thus, it is estimated that about 10800 square meters of GSI facilities are required at the micro scale landscape unit based on the preliminary calculation. The ATRCR is defined in the national SCDTG as the proportion of the total annual rainfall that is locally retained as opposed to discharged. Based on this technical guidance Mainland China is divided into five different zones with different targeted annual rainfall control rates (MHURD, 2014). This ATRCR is one of the main quantifiable objectives of the Sponge Cities initiative set by the Chinese central government. Although, the Siming lake case is not within the demonstrative area of the sponge pilot city, it is also government led project and the same standard is recommended by the local government.

Based on the meso-scale plans, about 5,800 square meters of the GSI facilities have been arranged in the GI design scenarios of the whole meso-scale sponge node area, which can be utilised in this micro scale sub-catchment area. Nevertheless, about 5000 square meters of the GSI facilities are still needed in the building area to fulfil the 75% control rate of ATRCR. Hence, four scenarios (denoted as ZS1 – ZS4) as shown in Figure 5.11-5.14 with different combinations of the GSI facilities are developed, compared and optimized with comprehensive assessment. Details of the allocated GSI measures is seen in Table 5.2

Table 5.2 Allocated surface areas of each GSI facility in each scenario at the micro-scale

Scenario	Bio-retention cell (m^2)	Rain garden (m^2)	Vegetative swale (m^2)	Permeable pavement (m^2)	Total area (m^2)
ZS1	5439	1501	150	3615	10,705
ZS2	3050	4131	150	3615	10,964
ZS3	5439	1501	150	3615	10,705
ZS4	3160	1501	2631+150	3615	11,057

Figure 5.11 The micro-scale design with GSI of scenario 1 (SZ1)

Figure 5.12 The micro-scale design with GSI of scenario 2 (SZ2)

Figure 5.13 The micro-scale design with GSI of scenario 3 (SZ3)

Figure 5.14 The micro-scale design with GSI of scenario 4 (SZ4)

5.5 Summary

A holistic more resilient BSPF model for high-quality GI design of the Jiangnan water network area with reinforced strategies, are proposed in this chapter. This BSPF is a three- scale integrated framework. At macro scale, three essential objectives layers for the identification of multifunctional GI network are targeted as well as more resilient strategies. Additionally, the mapping analysis of key landscape processes was carried out for identifying strategic points and main linkage corridors in the objective layers, which will be further explored and illustrated in subsequent chapters.

At the meso and micro-scale, it is suggested that the core strategies for the more resilient design include:

- The utilisation of nature-based green solutions and integrate more resilient planning and management measures to enhance ecological and social resilience, achieving effectively functional spaces where human and nature can coexist.
- The application of the sustainable 'SITES' design and management pathways to stress humanized designs for human health and wellbeing promotion.
- Develop multiple solutions with multiple design scenarios and improve the comprehensive quantitative assessment of the scenarios to balance the benefits for around sustainability.

With the Siming Lake case study, based on these resilient strategies, a basic GI scheme with multiple scenarios are proposed.

It is found that both the GI planning development and the implementation faced with some difficulties. For example, a very big barrier comes from financial problem in addition to what is the suitable planning and how to assesses different scenarios. These are the factors needed to be taken into consideration at the planning stage. With this consideration, this research started with the exploration of traditional treads and needs towards resilient and sustainability.

Moreover, based on the interview, the government has realized that the Daxi River Estuary Wetland is a very important GI node for SCP. Thus, it has identified as the starting point of the ecological restoration by both the local government and the SCP experts. Actually, a team contained both the local government officers and the planning and construction experts has built to discuss the suitable repair plan, and the author is involved in the team, which the detailed background of this research. Additionally, it is agreed to take into account the needs of social and cultural benefits concern which highly linked with the social resilience improving factors by most of the experts. However, if there is no suitable evaluation system supporting the transitional development towards around sustainability and the competition of the multiple GI scenarios. In this situation, designers are lacking a target framework as a deigned goal at the design stage, and the local governments also are lacking an evaluation framework to evaluate and choose the optimal solution.

Therefore, the evaluation system defined as the sustainability key performance indicator frame work with a set of key performance indicators (KPIs), would be necessary and helpful in optimizing GI design scheme and selecting the optimal solutions with multi-benefits trade-offs to assist in planning decision making. This should be further explored in the in-depth research stage. In addition, a to form the long-term GI planning with supporting policy also need to be further discussed based on this preliminary research of BSPF developing.

Chapter 6 In-depth Research - Analysis and Findings of the Resilient GI Network Identification and Comprehensive Assessment of the Multiple Scenarios

6.1 Introduction of the In-depth Research

The detailed research of the GI network model with enhanced resilience is illustrated in this Chapter. The model is incorporated with SPs identification at the macro-scale and comprehensive evaluation of multiple sponge node scenarios at the meso- and micro- scale. This is further examined by using Sliming lake waterfront area as a case study. This further applicational exploration is based on the development of the holistic BSPF of GI delivery for the Jiangnan area preliminary research in Chapter 5. It is a three-scale integrated exploration, mainly adopting landscape ecology-based landscape SPs with GIS spatial analysis and mapping assistant tools at the macro-scale, and the AHP and SWMM hydro-effects simulation models at the meso-and micro scale. Consequently, this chapter elucidates on the design and analysis of GI network at the three scales and their evaluation.

6.2 Macro Scale Analysis

6.2.1 The Identification Results of the GI Network with Water Resilient Landscape SPs Layer

Due to the methodology utilised for the identification method of water resilient landscape SPs and design strategies of the high-quality GI network in the Siming Lake area (as detailed in Chapter 4 and 5), the GIS runoff analysis and mapping of water-sensitive areas around the lake was conducted. As a result, water resilient landscape SPs with different security levels and the corresponding buffer areas along the water system is identified and proposed as depicted in Figure 6.1 and Figure 6.2.

According to the flood level information obtained from the reservoir management documents and the Liangnong Siming Lake area development planning provided by the Liangnong government, the capacity of the Siming Lake reservoir and the corresponding flooding water level for a wide range of flood return period (5-, 10-, 20-, 50-, 100-, 500- and 1000-year return period) was obtained. Based on this flood-control data, the water sensitive areas around the lake are identified and mapped by GIS as shown in Figure 6.1 and Figure 6.2.

Taking the local conditions, management and construction needs of Siming Lake watershed area into consideration by adopting knowledge from the Taizhou EI scheme, GI conservation networks based on the three levels of water resilient landscape SPs with corresponding water sensitive areas of the lake are identified:

1. The low level of water SP corresponds with the protection of water sensitive areas conforming to a flood sensitive management objective of 20-year return period;

2. The medium level water SP corresponds to the conservation of water sensitive areas round the lake that corresponds to the 50-year return period; and
3. The high level of water SP corresponds to the entire water sensitive area within the influence areas with a range of return period of ≥ 50-year return period, it is recommended to manage at least 50-year to 100-year return period events at this level based on the different waterfront landscape and topography conditions.

Finally, the identified water sensitive areas along the river corridors are examined based on the flood-risk control requirements of Master Plan for Ningbo city and Yuyao district, in conjunction with buffer areas suggestion adapted from Taizhou EI Planning (Yu et al., 2005a). The three levels of water resilient landscape SPs identified are shown in Figure 6.1. The low level safety pattern corresponds to an allocation of 30-50 meters buffer zone as a water sensitive green corridor; the medium level safety pattern corresponds to a 50-80 meters buffer as water sensitive green corridor; while the high level safety pattern corresponds to any protection greater than the 80 meters buffer zone as water sensitive green corridor, and no permanent building is allowed within 80-150 meters width of the water sensitive corridor at this security level.

In addition, based on the interview and the government rainfall information of the reservoirs (Ningbo hydrological station, 2020), the water level of the Siming Lake reservoir reached a record high of 17.59m during Typhoon 'Fitow' event, one of the super Typhoon ever encountered in Siming Lake reservoir at the beginning of October 2013. After this, the City Ningbo was attacked by Typhoon 'Chan-Hom' on July 10, 2015, which was the strongest typhoon ever encountered in Siming Lake reservoir, and the water level of the reservoir reached a record high of 17.70m, close to the risk level of 100-year return period. In fact, during the two attacks of super Typhoon with risk level nearly once in a hundred return years, the Siming Lake has greatly reduced the flooding related losses of the lower reaches and Yuyao urban area of city Ningbo. It obvious that the Siming Lake played remarkable flood resilient role of city Ningbo and has brought significant environmental, social, and economic benefits to the city. Moreover, the further protection the identified water sensitive areas around the lake that required by the water resilient SP, restoring the GI conservation land use areas, can effectively cope with the attack of higher-level flood disastrous challenge. This will make the benefits brought by the lake area to the city to be amplified and further improved.

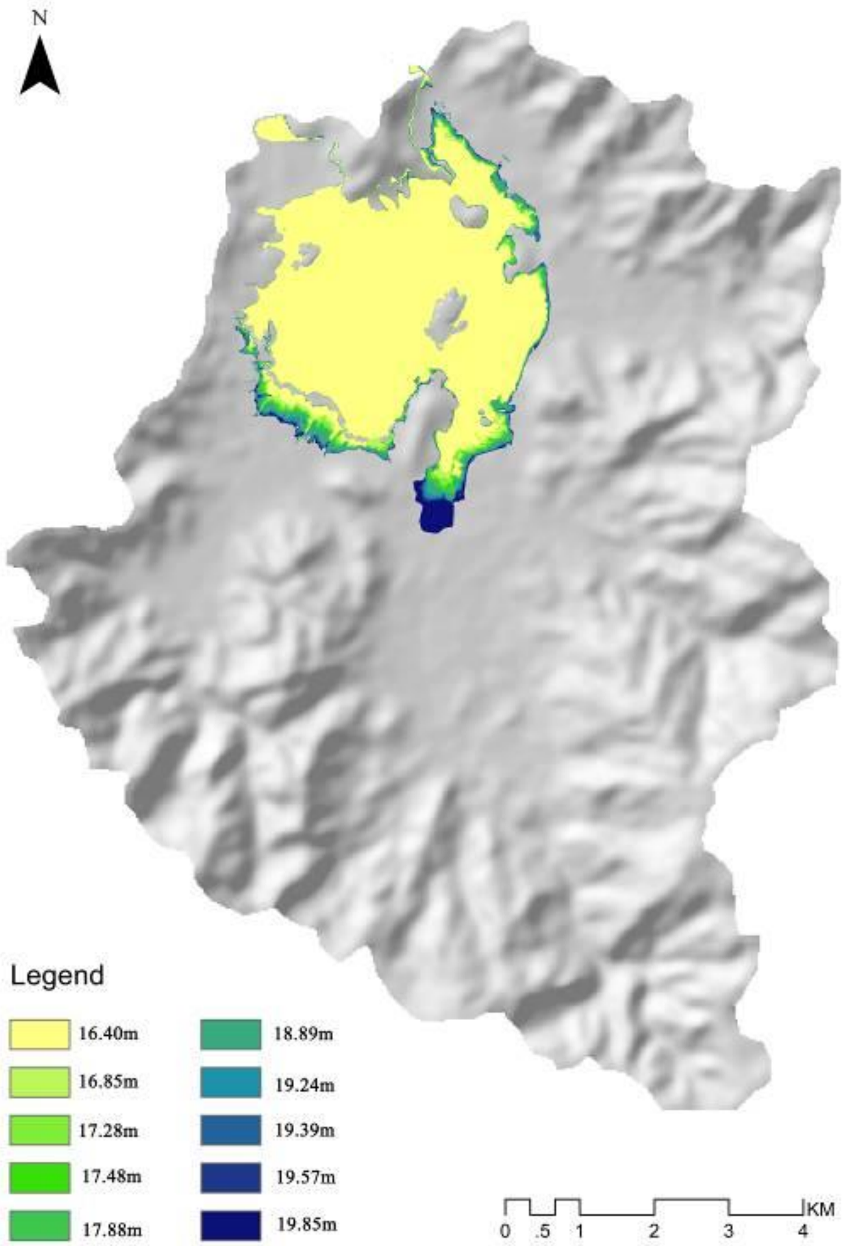


Figure 6.1 Water levels under the different flood return period mapping results (the water levels of the corresponding flood return period are shown in the Appendices Table A-6-1-1)

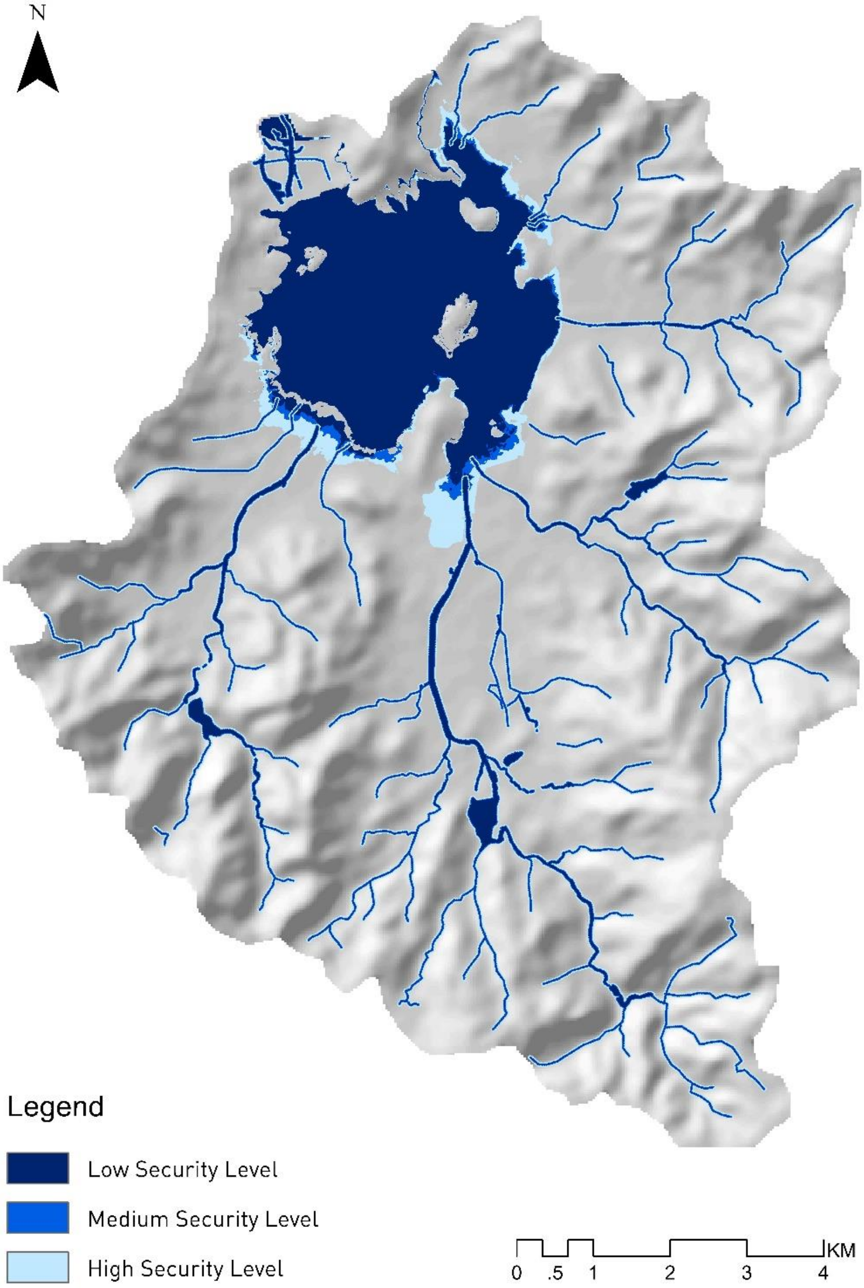


Figure 6.2 GI Conservation network with three levels of water resilient landscape SPs

6.2.3 The Identification Results of the GI Network with Biotic Landscape SPs Layers

6.2.3.1 The Targeted Indicator Species and Their Behaviour and Habitat Analysis

The main objective of the biological SPs is the effective identification of the core conservation areas, buffer areas and the linkage strategies required for the establishment of a protective network that enhances biodiversity.

According to the selection criteria of the indicator species, (summarized in Section 5.3.1), in order to represent a wild range of habitats in this region, three typical groups of indicator species were selected: water birds of Ardeidae family especially Chinese Egret (Lin et al., 2015, Li et al., 2015), forest birds of Phasianidae family especially Syrmaticus ellioti (Yu et al., 2005a, Tao, 2017), amphibians of Salamandridae family especially Cynops orientalis (Wang et al., 2012), and mammals of Viverricula family especially Viverricula indica (Zhong 2001). The main habitats of these selected species include wetlands, rivers/streams, lakes, paddy fields, and forest of the low mountain areas which are typical landscapes of Siming Lake watershed. Therefore, majority of the wildlife habitats in the region is well represented. Therefore, these species are targeted as indicator species for the identification of biological SPs. The habitats and behaviour, as well as the conservation criteria and rarity of these species are described below, and details are summarised in Table 6.1.

The Ardeidae family is one of the most important biological species in wetland ecosystem, and an indicator species for environmental quality assessment. Chinese Egret is a common kind of bird of Ardeidae family in Siming watershed area. This species commonly feed in scattered groups in their habitats (mostly shallow tidal estuaries, mudflats waterfront forest, seashore, lake, river, and swamp, and occasionally visiting fishponds, and paddy-fields). During the daytime, they scatter into small groups and fly from their habitats to their foraging place after daybreak. In the evenings, they flock to the paddy field and hillside trees near their habitat for rest, and then enter the forest together.

Chinese Egret is presently listed in "Vulnerable and decreasing population trends globally" category of the International Union for Conservation of Nature (IUCN) Red List of Species (Red List, 2020). Recently, the greatest threat to this species is habitat loss and degradation due to ecological contaminations and the use of estuarine habitats and unoccupied offshore breeding islands for constructing infrastructures, building industry and as agricultural lands. Additionally, it should be highlighted that wetland is a transitional zone between a terrestrial and aquatic ecosystem. It is recognized as an important ecosystem and GI elements globally for breeding and supporting migration of many rare water birds (Wu et al., 2013). The wetland in Zhejiang Province is an important place for waterfowl to live, sleep and breed. It is also an important transit station and wintering place for migratory birds along the coastal migration route in the Asia Pacific region (Wu et al., 2013). There are abundant species of the waterfowl, mostly rare and endangered, and these species plays a vital role in and ecological and biodiversity protection in China. With the use of a vigorous system to consider opportunities for bird species on the IUCN list that hibernate, migrate or breed in the region, Chinese Egret was chosen as a representative bird to denote the important ecosystem in the region.

Table 6.1 The behaviour and habitat of the indicator species

Category	Species	Behavior	Habitats	The current grade of conservation criteria and rarity
Birds	Chinese Egret of Ardeidae Family (Lin et al., 2015)	Chinese Egrets like to cluster and often act in small groups of 3-5 or more than 10 in shallow water. In the evening, there are dozens, hundreds or even thousands of large groups in the habitat.	Mainly inhabits wetland environment, near waterfront forest, seashore, lake, river, swamp, fishponds and paddy-fields.	Chinese Egret is in the IUCN Red List of Species Threatened under the category of Vulnerable and decreasing population trend globally (Red List, 2020).
	Syrmaticus ellioti of Phasianidae family	This species are fond of clustering and often act in small groups of 3-8. They are mostly active in the middle and low mountain areas. The main activities are in the morning and evening, often eating while roaming, and they perch on trees at night.	Mainly inhabits in broad-leaved forest, mixed forest, coniferous forest, bamboo forest and forest edge shrub zone in low mountains and hills with an altitude of 200-1000m.	Syrmaticus ellioti is in the IUCN Red List of Species Threatened under the category of Near Threatened and decreasing population trend globally (Red List, 2020). Listed as a National first-level protected animals in the China national conservation species list.

Category	Species	Behavior	Habitats	The current grade of conservation criteria and rarity
Amphibians	Cynops orientalis of Salamandridae family	This species inhabits still water areas such as mountain ponds or paddy fields, as well as water areas with slow flow velocity in mountain streams. Their activities include crawling slowly but rarely swimming.	Mainly inhabits pools, ponds, seepages and paddy fields in hilly areas, in both temperate and moist lowland forest and degraded habitats.	Cynops orientalis is in the IUCN Red List of Species threatened under the category of Least Concern (Red List, 2020).
Mammals	Viverricula indica of Viverricula family (Wang et al., 2012)	This species are smart and timid, flexible in action, good at swimming and climbing. They climb trees to prey on birds, squirrels or pick fruits. It has a wide range of activity areas, including forests, fields, marshes, and the edges of streams and ponds.	Mainly inhabits low altitude areas with an altitude of 200-1000m in the tropics and subtropics areas such as low mountain forests, bushland, and riverine habitats.	Viverricula indica is in the IUCN Red List of Species Threatened under the category of Least Concern globally and listed as national second-level protected animals in the China national conservation species list (Zhong 2001, Red List, 2020, Wang et al., 2012).

Syrmaticus ellioti is one of the most treasured species of the Phasianidae family (Peng et al., 2019). It is a special bird in China, which has been catalogued as one of the first-level protected birds of the National protected animals. Hence, Syrmaticus ellioti is an important bird in Siming mountain area of Ningbo. These species reside in habitats of low mountains forests, which is the typical landscape and natural resources in the region.

Cynops orientalis usually inhabits muddy swamps with abundant aquatic plant, still water pond, paddy field and mountain streams (Zhang, 2020). Although this species is categorised as a “Least Concern” species due to its fairly extensive distribution, tolerance to habitat alteration and presumed large population, it is an important representation for habitats of mountain streams, mountain ponds, or paddy fields of the Siming Lake mountain area. In addition, this species preys on aquatic insects and their eggs, larvae, and other small aquatic animal, hence, they contribute to the elimination of some farmland pests and mosquito larvae that endanger human health.

Viverricula indica is a species with a wide range of activity areas related to seasonal changes in its feeding habits, behaviour and ecology (Wang et al., 2012, Song, 2003). It is timid and flexible in action, good at swimming and climbing, and can climb trees to prey on birds, squirrels or pick fruits. The feeding habits of Viverricula indica are varied, mainly animals, such as mice, birds, snakes, frogs, small fish, shrimp, crabs, centipedes, grasshoppers, locusts, etc., supplemented by plant food, such as wild fruits, roots, seeds, etc (Wang et al., 2012). The range of activity is mostly linked with seasonal changes. In autumn, when most fruits are ripe, Viverricula indica often migrates into the forest and consume wild fruits. In winter, it often forages for small animals in the shrubs and fields at forest edge. During summer, there are many amphibian species, hence, most of the Viverricula indicas forage in the stream or pond edge. Therefore, Viverricula indica is selected mainly for its representation of the typical habitats of mountain forests and a wide range of activity areas from forests, to the nearby fields, edges of the streams and ponds in the Siming mountain area (Wang et al., 2012).

6.2.3.2 GI Network Identification with the Biological Process Mapping Analysis of Targeted Species

As it was illustrated in previous chapters, two kinds of process analysis of the indicator species are required: Firstly, the vertical landscape suitability analysis and Secondly, the horizontal dispersal and conservation analysis. Hence, both the landscape suitability of the vertical process and the ease of horizontal activities of the selected indicator species were analysed.

Previous studies (Li, 2018a, Xie et al., 2018, Fuyuki et al., 2014) have shown that some factors have significant impact on the habitat utilization and foraging behaviour of the target species. These factors mainly include disturbance from human activities, unsuitable land covers and distance from the water source. These impacts are more obvious and important for the water birds and amphibians (Peng et al., 2019, Gagné and Fahrig, 2007).

According to the analysis of the habitats and behaviour of the selected indicator species, the habitat suitability of each species was quantitatively evaluated by scoring and weighting influencing factors. The results of their habitat suitability assessment for the four indicator species are shown in Tables 6.2-6.5.

Table 6.2 Suitability evaluation table of Chinese Egret's habitat areas

Evaluation Factor	Category	Grade	Weight
Land Cover	Wetland	10	0.6
	Woodland	9	
	Orchard	7	
	River, lake	6	
	Pond, stream, paddy field	6	
	Agricultural, grassland	5	
	construction land	3	
	Derelict and idle land	2	
	highway	0	
Distance from Water Body (m)	0-30	10	0.4
	30-50	6	
	50-100	2	
	>100	0	

Table 6.3 Suitability evaluation of Syrmaticus Ellioti's habitat areas (Peng et al., 2019)

Evaluation Factor	Category	Grade	Weight
Land Use	Woodland	10	0.6
	Orchard	6	
	Agricultural land	5	
	Paddy field, Wetland	3	
	Derelict and Idle land	2	
	River, lake, Stream	2	
	Construction land	1	
	Highway	0	
Distance from Built Area (m)	>500	10	0.4
	200-500	5	
	<200	1	

Table 6.4 Suitability evaluation of Cynops Orientalis's habitat areas

Evaluation Factor	Category	Grade	Weight
Land Type	Wetland, Pond, Stream, River	10	0.5
	Paddy field	8	
	woodland	4	
	Agricultural land, orchard	4	
	Derelict and Idle land	2	
	Construction land	0	
	Highway	0	
Distance from Water Body (m)	0-60	10	0.5
	60-100	6	
	>100	3	

Table 6.5 Suitability evaluation Viverricula Indica's habitat areas

Evaluation Factor	Category	Grade
Land Use	Woodland	10
	Orchard, Agricultural land	8
	paddy field, wetland	5
	construction land	2
	Derelict and Idle land	2
	Pond, Stream, River	1
	Highway	0

Furthermore, the horizontal diffusion analysis of the indicator species was carried out using GIS least-distance tools. The results of this analysis are represented in Figure 6.3-6.6. Finally, the landscape security pattern of each species is identified with three levels of security - high, medium, and low security as depicted in Figure 6.7-6.10. These three SPs correspond to the following GI spatial network pattern respectively: the low security level GI relates to the protection of GI core area alone, the medium security level GI refers to the protection of GI core area and appropriate buffer areas, while the high security level GI corresponds with the protection of GI core area and appropriate buffer area and peripheral radiation zone.

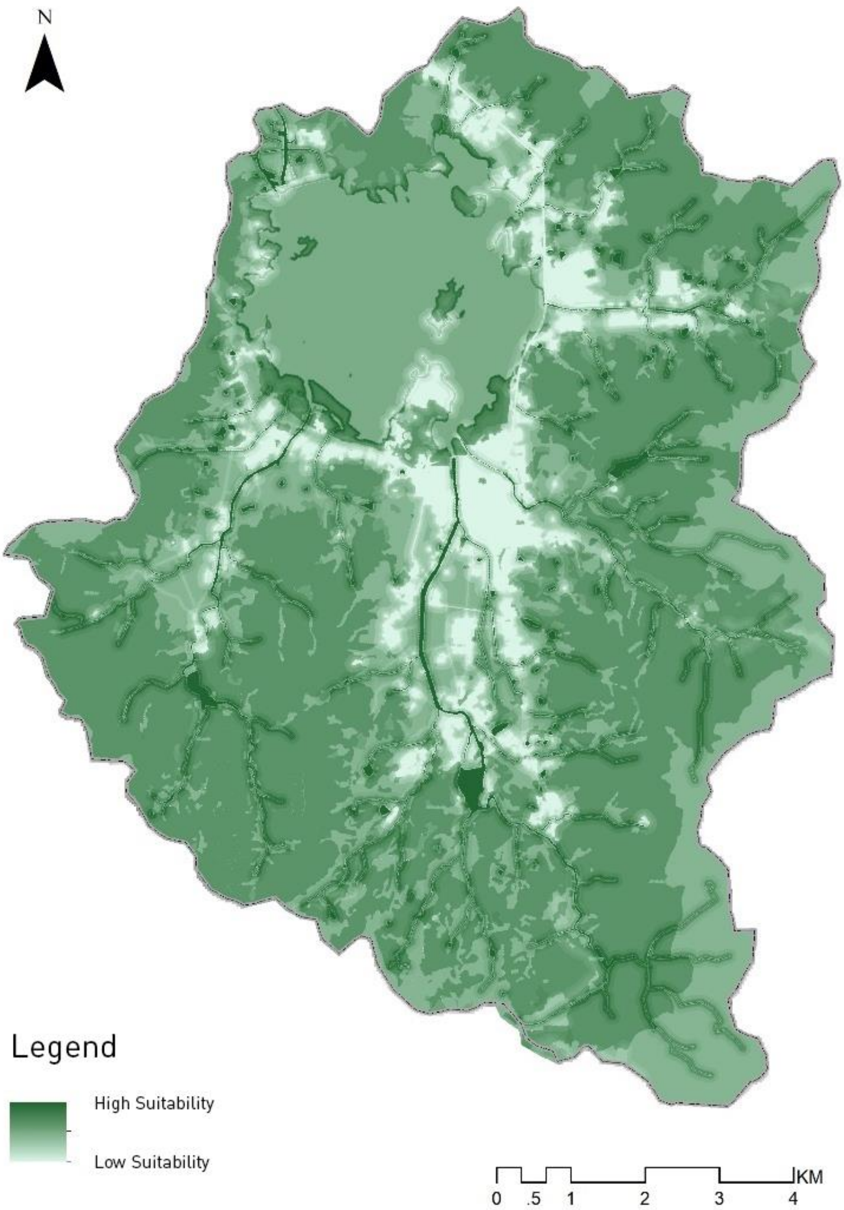


Figure 6.3 Habitat suitability mapping analysis of the Chinese Egret

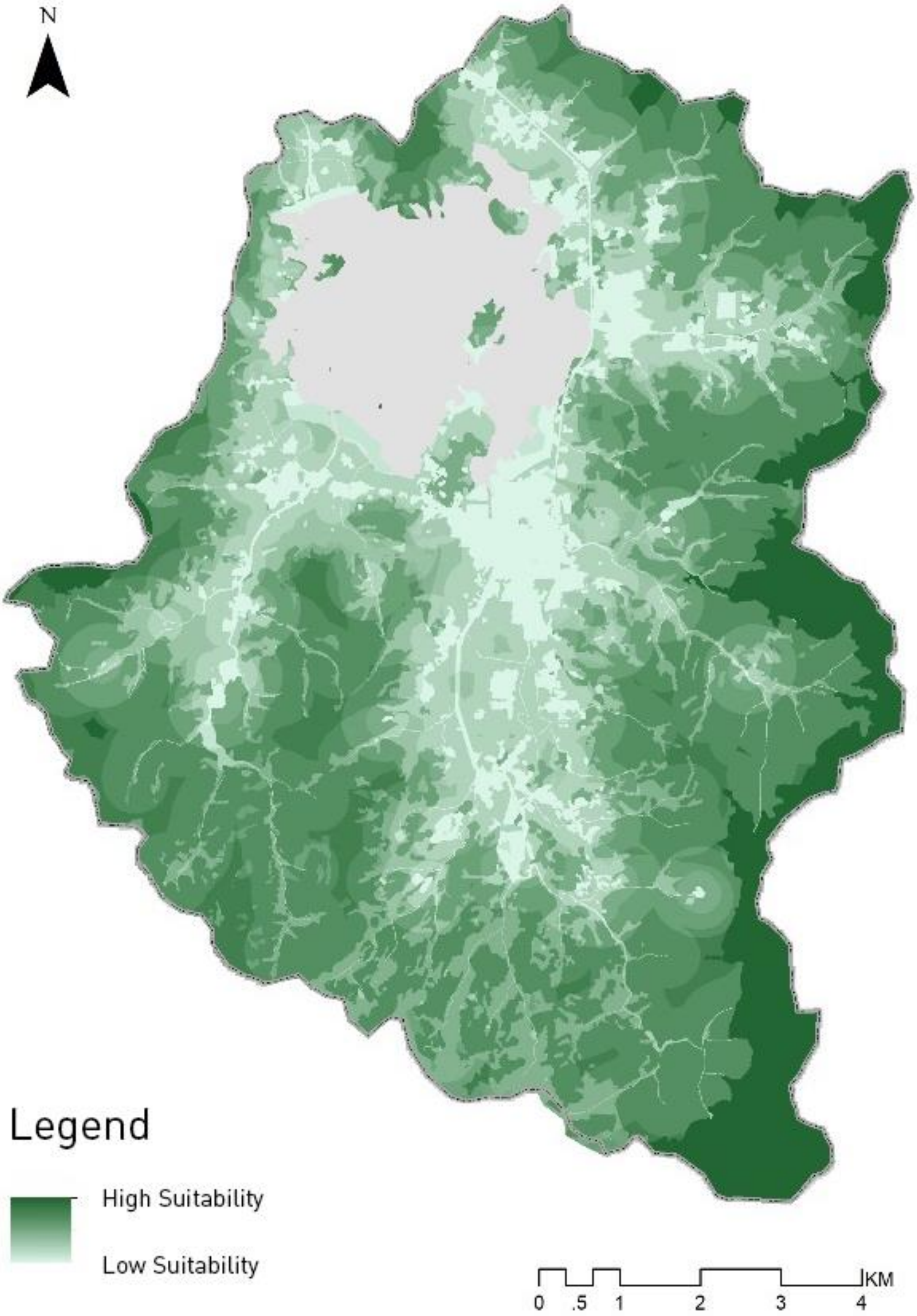


Figure 6.4 Habitat suitability mapping analysis of the Syrmaticus Ellioti

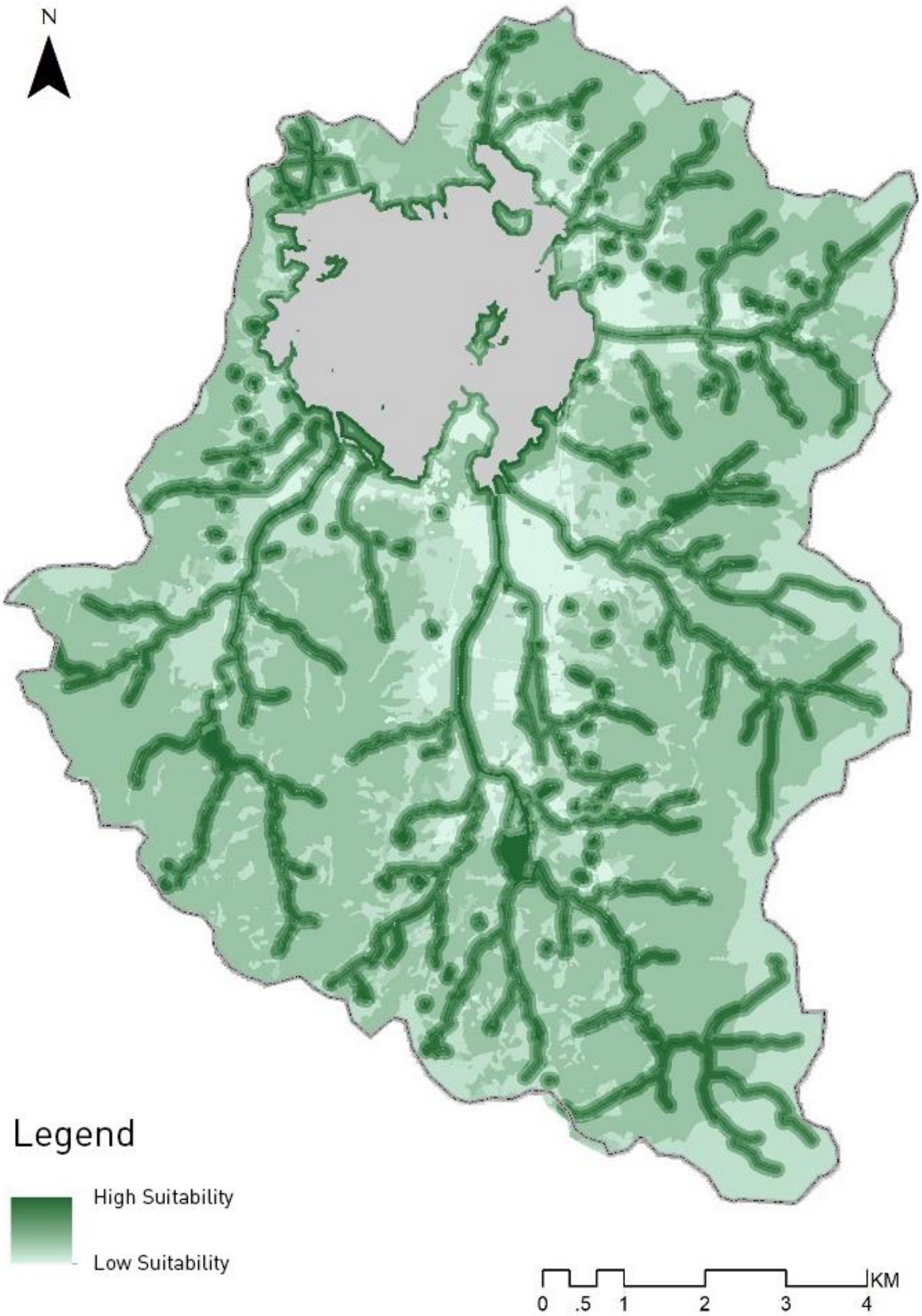


Figure 6.5 Habitat suitability mapping analysis of the Cynops Orientalis

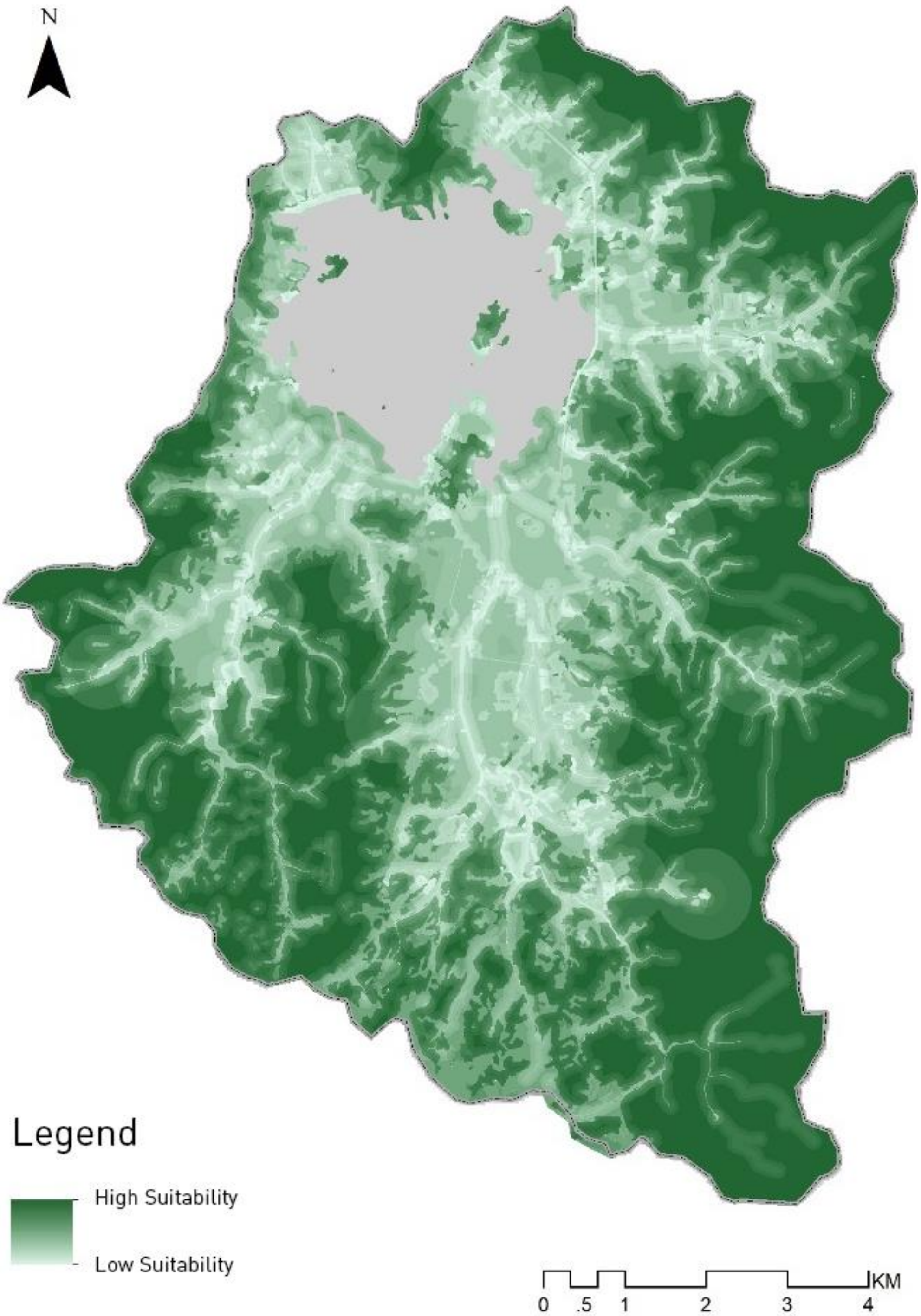


Figure 6.6 Habitat suitability mapping analysis of the Viverricula Indica

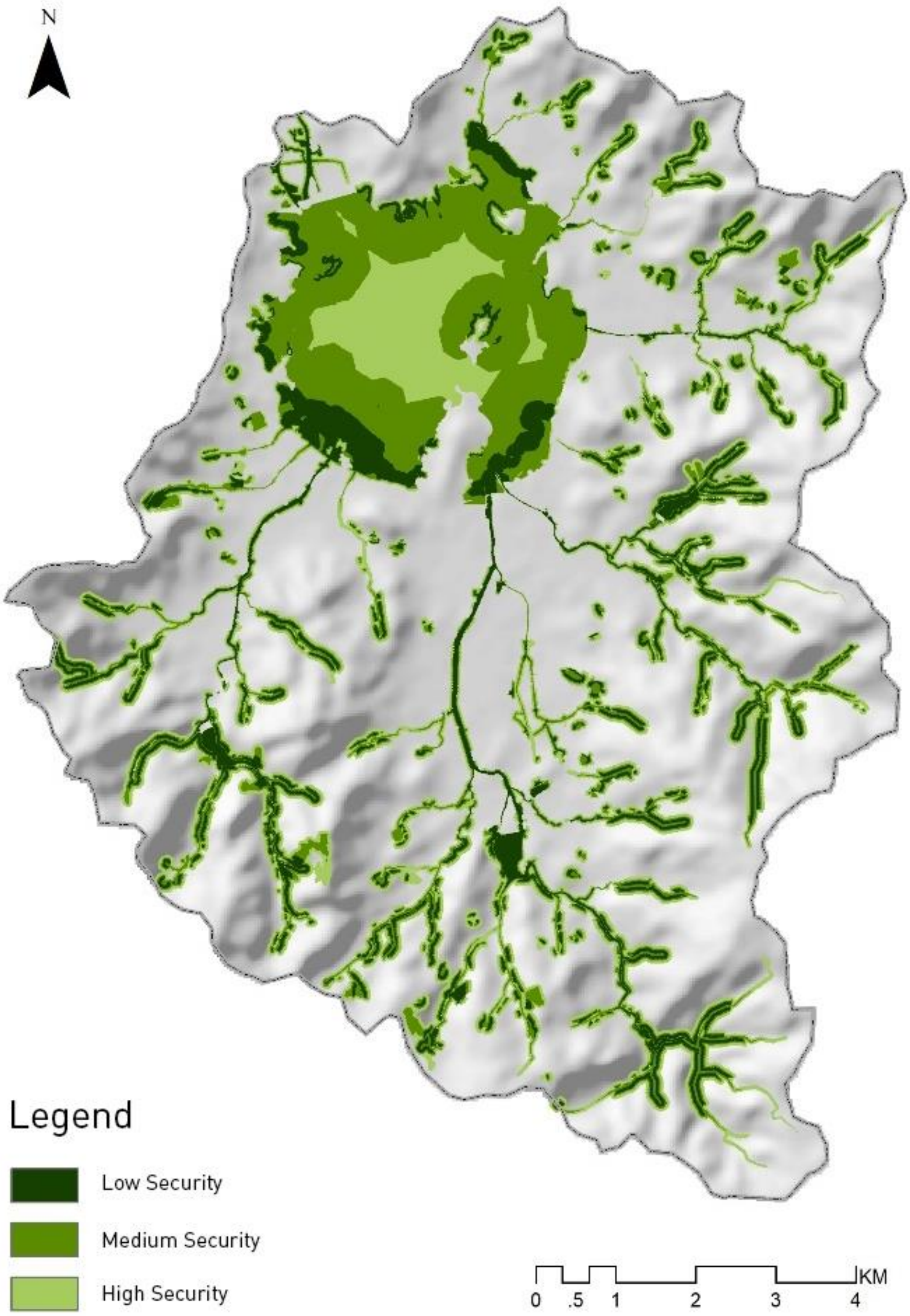


Figure 6.7 GI network conservation area based on three levels of biotic landscape SPs of Chinese Egret

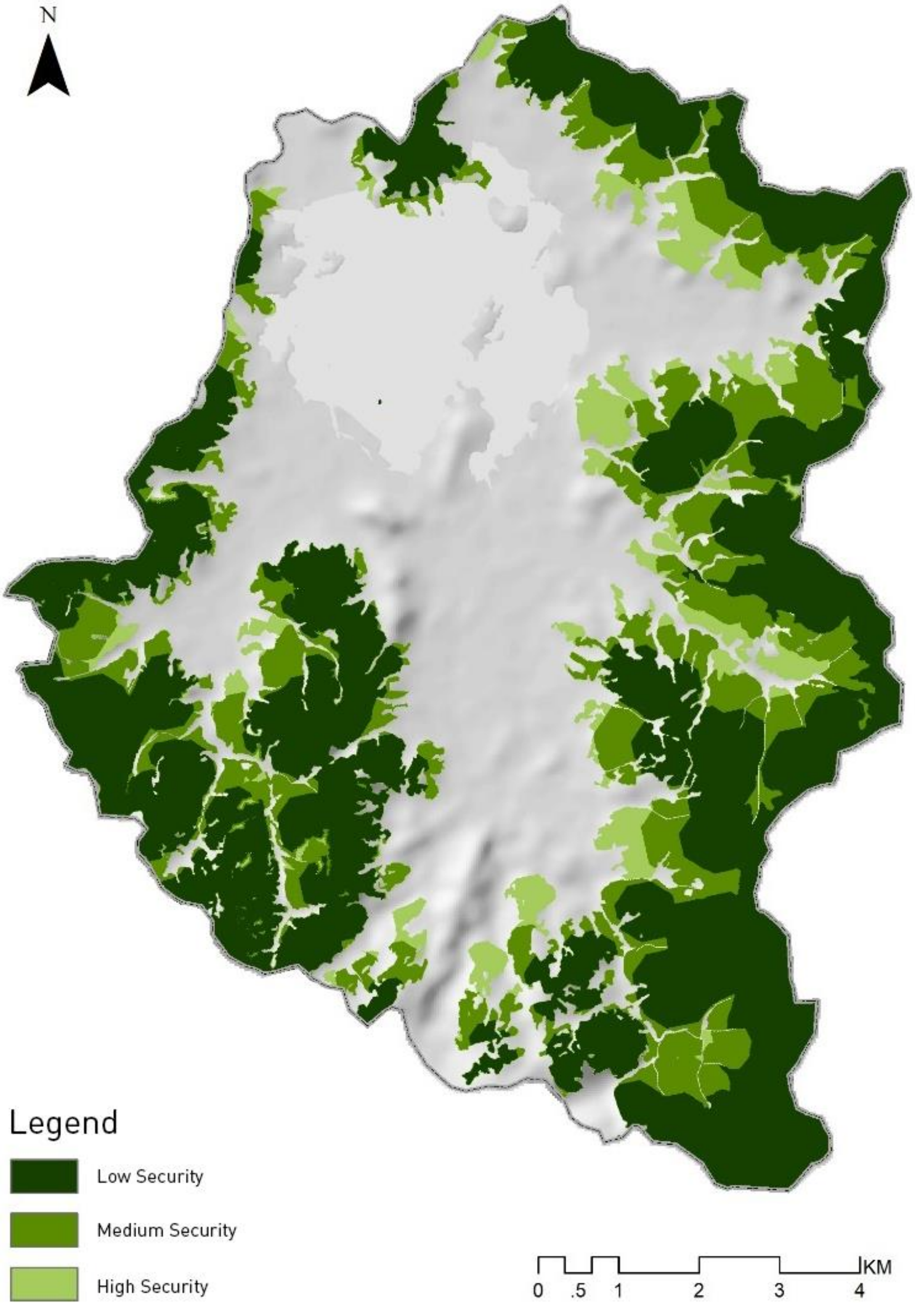


Figure 6.8 GI betwork conservation area based on three levels of biotic landscape SPs of Syrmaticus Ellioti

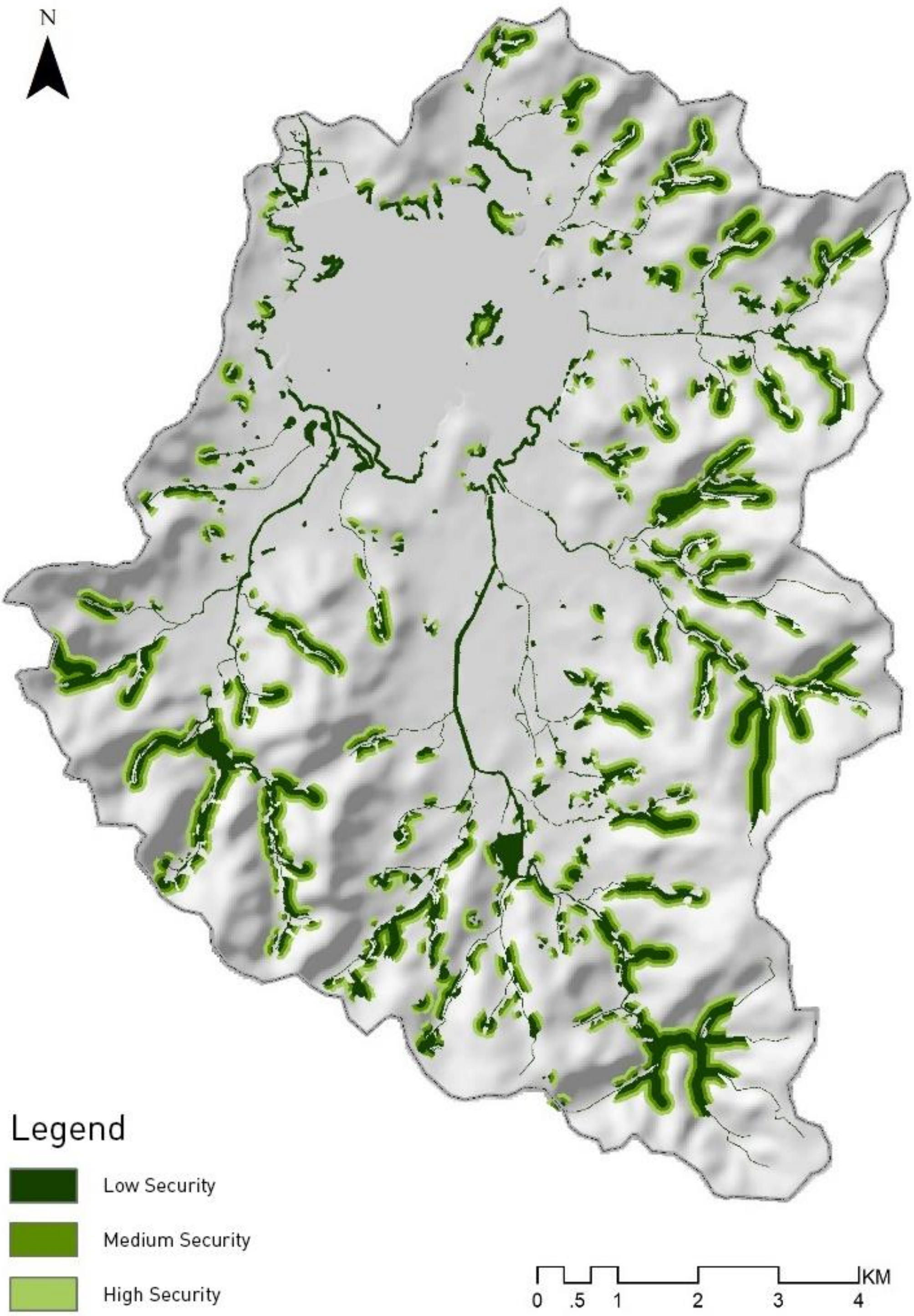


Figure 6.9 GI network conservation area based on three levels of biotic landscape SPs of Cynops Orientalis

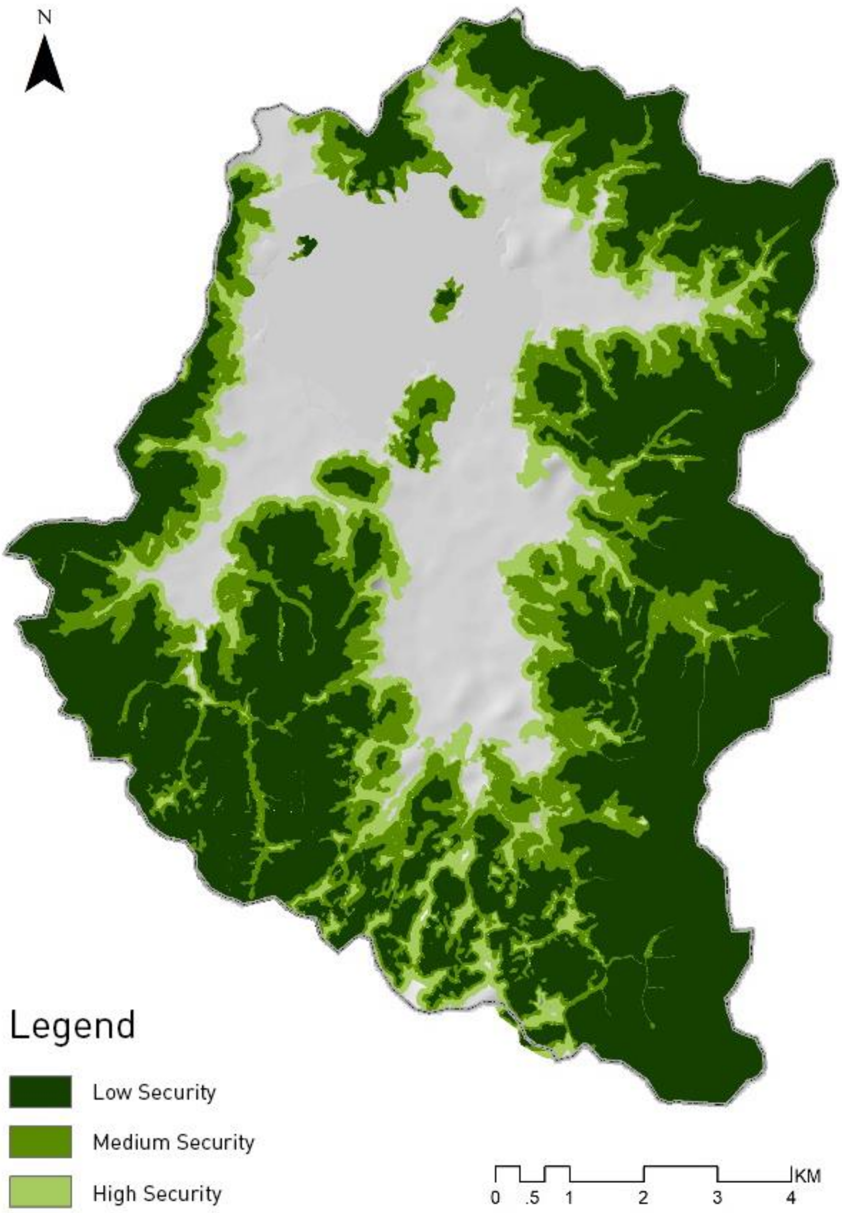


Figure 6.10 GI network conservation area based on three levels of biotic landscape SPs of Viverricula Indica

The suitability assessment and mapping results reflect the habitat and behaviour system of the four indicator species. Consequently, the habitats distribution of Chinese Egret in the Siming Lake watershed is greatly affected by the distribution of water body, mainly in the lake and the around wetlands areas and the stream, paddy field of the nearby mountain forest. Similarly, the habitats of Cynops orientalis is mostly concentrated in paddy field and mountain streams. Correspondingly, the ideal habitats of Syrmaticus ellioti is in the forest of Siming Mountain areas that far from the human settlement areas, while Viverricula indica has a wide range of habitat and activity areas from the forests of Siming mountain, to the nearby fields, edges of the streams and ponds in the Siming maintain area of the region (Wang et al., 2012).

The comparison of the landscape SPs of the indicator species with the land use evaluation mapping results depicted in Figure 5.1-5.3 and Figure 5A-1-3 from Chapter 5 reveals the most severe interference and damage of human construction activities on the Chinese Egret landscape SPs (Figure 6.7) is the loss of wetlands from a spatial perspective. Thus, in order to create opportunities for bird species, represented by the Chinese Egret, to live, sleep and breed in the Siming Lake area, the most important measures are:

- Protecting and restoring the waterfront wetlands, especially the the estuary wetland area of river Daxi, which is the wetland node most affected by human disturbance (the meso-and micro scale research focus area), and
- Protecting the green corridor around the big lake and corridors along the main rivers and the streams to form an integrated linkage system.

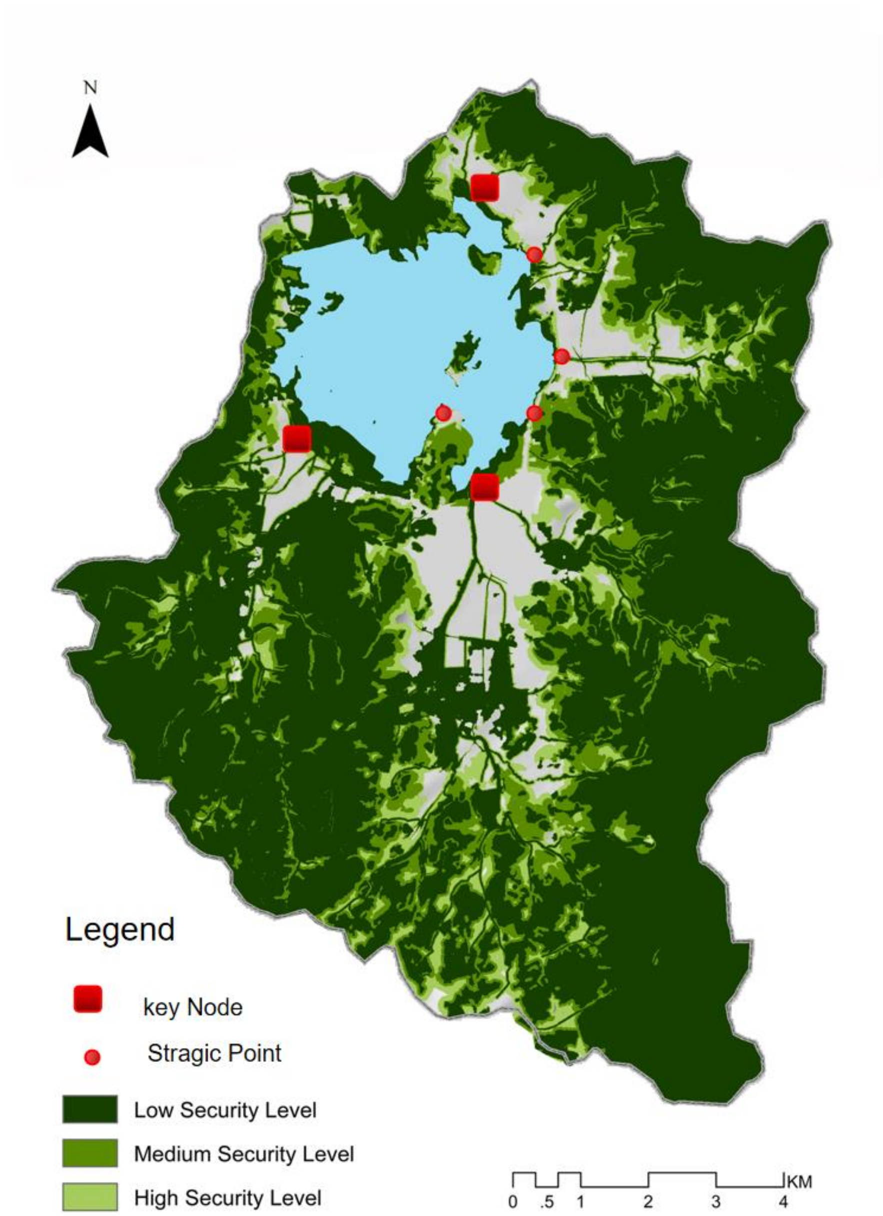


Figure 6.11 GI network conservation area based on three levels of integrated biotic landscape SPs

Additionally, the GI conservational networks based on three levels of biotic landscape SPs with the waterfront buffer areas are proposed for the Chinese Egret indicator species (Yu et al., 2005a). These are low-, medium- and high- level biotic landscape SPs corresponding to the protection of 30 - 50, 50 – 100 and >100 meters buffer zone around the waterfront respectively to act as a green corridor for biological sensitive conservation area. In addition, permanent buildings are not allowed within 100-200 meters radius at the highest security level based on the waterfront landscape and topography conditions.

In terms of the conservation of the amphibian's landscape SPs (Figure 6.4 and 6.8), it is important to restore the green corridors along the streams, which consists of a series of swamps and small wetlands amid the mountain forest areas. The biotic landscape SPs of the amphibian with the Cynops orientalis indicator species is also vulnerable due to reduction of waterfront wetlands from river channelling and straightening, particularly for river Daxi (as analysed in Chapter 5). Hence, the GI conservational networks based on three levels of biotic landscape SPs with the waterfront buffer areas are proposed for the Cynops orientalis indicator species (Yu et al., 2005a). The low-, medium- and high- level biotic landscape security pattern for amphibians corresponds to the protection of 9-20, 20 – 60 and > 60meters waterfront buffer zone respectively as a green corridor for biological sensitive conservation area. Additionally, no permanent building allowed within 60-100 meters area at the highest security level.

Furthermore, the importance of protecting the mountain forest habitat patches from human activities is clearly depicted in Figure 6.8 which shows the landscape SPs of the Syrmaticus ellioti. These rare forest bird species reside in forest areas far away from human settlements. Presently, the safety pattern of these forest bird in the Siming mountain forest area is well maintained since the mountain forest area is relatively far away from the town is mainly mixed forest. Also, the patches throughout the whole watershed are complete and continuous without any evident human interference.

The selected protection of Viverricula indica indicates the representation of a larger range of mountain forest landscape SP. According to the analysis of the landscape SPs of the Siming mountain areas represented by the Viverricula indica, the conservation of the entire forest landscape of Siming Mountain area is required. Hence, the landscape SP of Viverricula indica is maintained at a high level spatially as the surrounding mountains are covered by continuous mixed or bamboo forests that forms a 'big green ring' connected with high habitat patches, as well as some streams, small orchards and a few small fields of cropland patches in the south areas.

Therefore, from a spatial pattern conservation perspective, the biggest challenge is the wetlands destruction, especially the natural landscape of the estuary wetland area of river Daxi), as well as the wetlands loss along the river Daxi due to the river bank solidification and construction cut-offs . Hence, only two kinds of biotic landscape SPs for water birds (Chinese Egret) and amphibian (Cynops orientalis) indicator species are most distressed and vulnerable in the study area.

So, the GI conservational networks with the three levels of biotic landscape SPs with the suggested waterfront buffer areas previously proposed for Chinese Egret and Cynops orientalis will be highly valued for the GI conservational guidance and related policy making. This will provide a significant reference for the multi-objective restoration of waterfront GI network, as a nature-based solution for repairing the wetlands and rebuilding the corridors planning.

In this study, the comprehensive analysis of key structure of GI network the will be identified by multi-functional overlapping analysis with the requirements of the targeted indicated species, the requirements of water resilient SPs (previously analysed in the Section 2.1), as well as the vernacular recreational landscape network with the health and wellbeing enhancement concern. The comprehensive analysis is illustrated after the identification of the vernacular natural and culture landscape recreational network analysis.

6.2.4 The Identification Results of the Local Landscape Recreational Network

The characteristic elements of the Siming Lake watershed are rich and diverse. Apart from the Siming Lake, the natural landscape resources also include Baishuichong waterfall, Donggang Mountain, Honggangjingsong and Shijing Mountain landscape of the Siming mountain area etc. The cultural landscape resources include some famous 'Red revolution' monuments of the New fourth army of the East Zhejiang headquarters and the martyrs in the Siming mountain. Additionally, there are also some traditional buildings and village attractions, such as Wuguilou, Taofen Bookstore, Liangnong Old Street, Yao shan industry site, Sun Zixiu tomb, Baishui palace and Yange ancient path etc. These tourist attractions are summarized in Appendix 6.1 Table A.6.1.2 and mapped in Figure 6.13 according to their spatial location. Moreover, some typical sources of vernacular landscapes in Siming Lake watershed that are associated with enhanced human health and wellbeing are also listed in Appendix 6.1 Table A.6.1.2 and mapped in Figure 6.10. They include high-quality productive landscapes such as cherry themed sights, agriculture and fruits picking lots which promotes local tourism; and strategic points linked with natural water landscape experiences as mentioned in Chapter 5.

Additionally, further assessment of the existing resource points was conducted by investigating their popularity and future tourism plans/suggestions via interviews. The important strategic points with highest popularity and funding supporting plan are summarized in Figure 6.12. Based on the interviews, the strategic points are further categorised into two:

- Existing strategic points with high level of popularity (denoted by purple dots in the Figure 6.12)

- Existing strategic points that government want improving the current landscape quality and will give funding support (denoted by red triangle points in the Figure 6.12).

There are some natural scenery and cultural landscape routes which can be designed for both physical and mental relaxation activities. Seven of such routes were identified, including cycling routes around the lake (marked with purple line in Figure 6.13), hiking and mountain forest landscape route (marked with pink lines in Figure 6.13), ancient trails route (marked with brown lines in Figure 6.13), the 'Red Revolution' memorial tour route (marked with red lines in Figure 6.13),Tang Poetry landscape tour route(marked with blue line in Figure 6.13), traditional architecture and Chinese painting art tour route (denoted by yellow lines in Figure 6.13), fruit picking and health improvement route (denoted by green line in Figure 6.13). The design of these recreational tour routes and the corresponding physical and mental activities are based on the natural and cultural landscape access. These experiences are strongly linked to improving the health and wellbeing of urban residents.

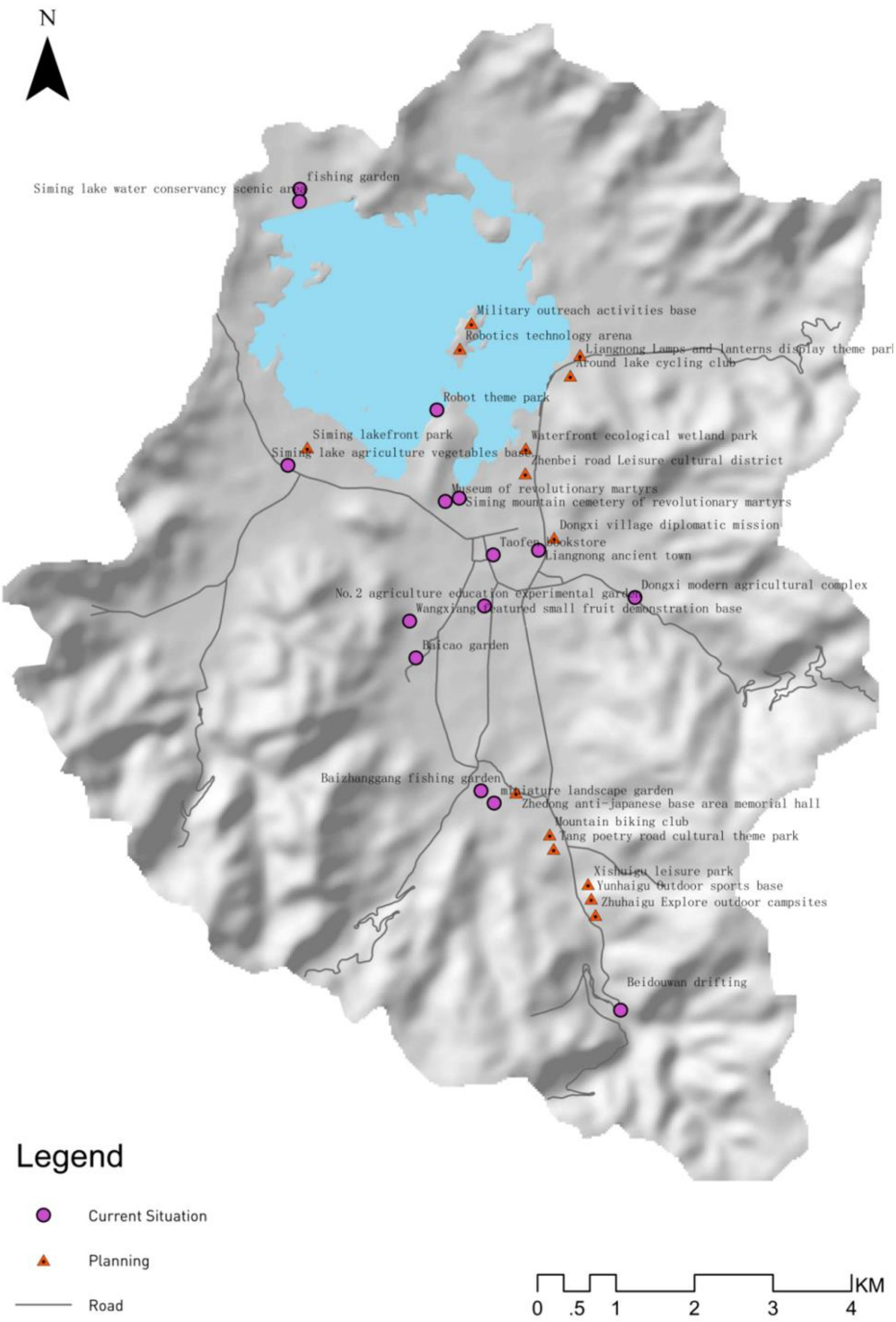


Figure 6.12 Potential vernacular landscape strategic points

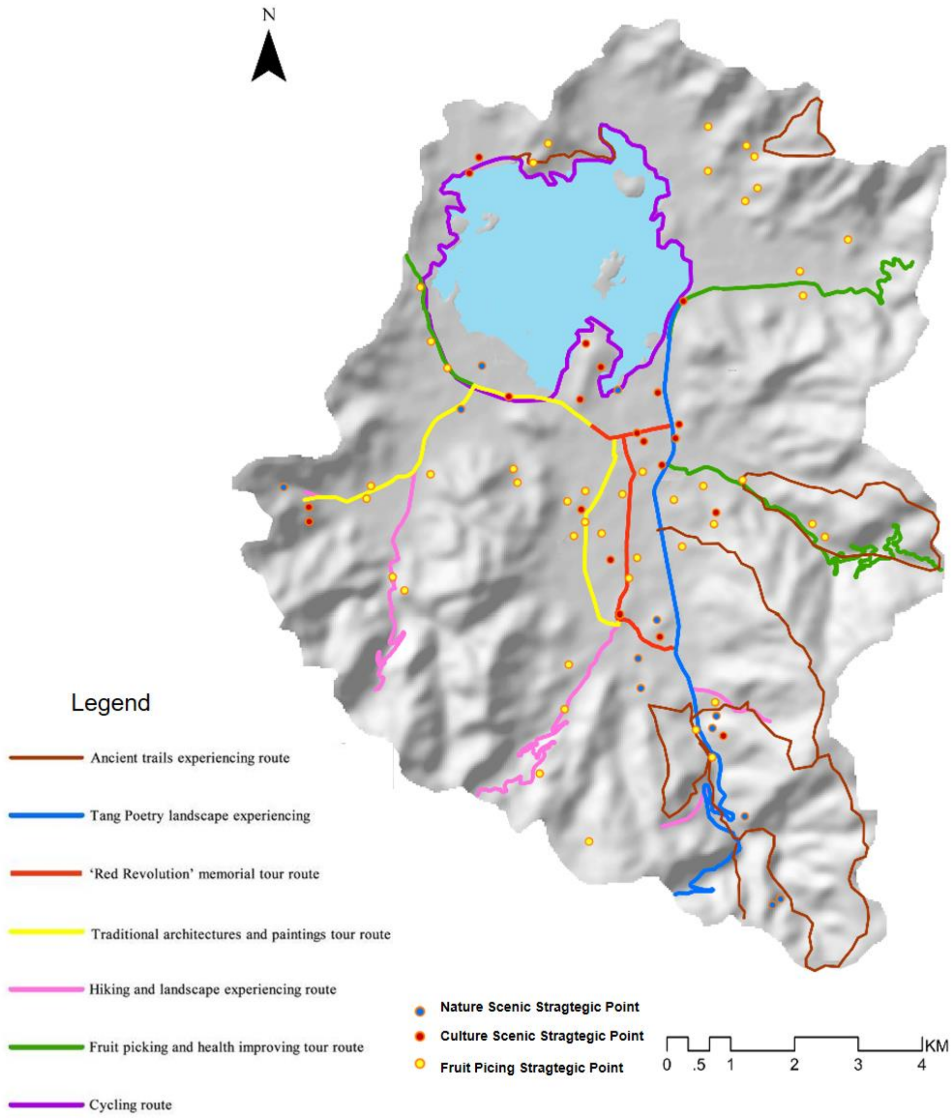


Figure 6.13 The identification of the Vernacular natural scenery and cultural landscape routes for improving health and wellbeing

6.2.4 Overlay Analysis and Comprehensive Identification of the GI Network

The GI comprehensive overlay analysis was carried out based on the specific landscape SPs analysis, including the water resilient landscape SPs, the biotic landscape SPs and the vernacular landscape network (Yu et al., 2005a).. Multi-functional GI networks based on three levels of comprehensive landscape SPs with corresponding waterfront buffer areas of the corridors are proposed (shown as Figure 6.14): the low-, medium- and high-level comprehensive landscape security pattern corresponds to the protection of 30-50, 50 – 100 and >100 meters buffer zone respectively as a green corridor. Additionally, for the high-level GI comprehensive conservation area, no permanent building allowed within 100-200 meters according to the different waterfront landscape and topography conditions.

Moreover, the key structure of the multi-functional GI network based on the comprehensive landscape SPs was identified (Figure 6.15). This mainly consists of the multi-functional strategic nodes, main corridors, and a series of strategic points as shown as Figure 6.16. According to the land use conservation and the water sensitive areas management requirements of Siming Lake watershed area, there are seven strategic nodes around the lake area. This includes three four key nodes, four sub-nodes and a series small node along the main corridors which are proposed as the strategic points of the multi-functional GI network.

The three key strategic nodes are the key ecologic source area (ecological core) of the waterfront area around the big lake with varying degrees of interference, which are requires multi-objective restoration and organic renewal. one node has been partly occupied by small factories, one has been affected by over development of agriculture, and the last one has been mainly influenced by the construction of private houses. Hence, these ecological nodes are also identified as the strategic nodes (important strategic points) of ecological restoration of the waterfront area and the overall macro-scale watershed area. Amongst them the node affected by industry at the estuary area of river Daxi is the most seriously disturbed key node (shown as Figure 6.15) which has received attention form the local government. Hence, the key node with maximum interference was selected as the meso- and micro- scale research focus.

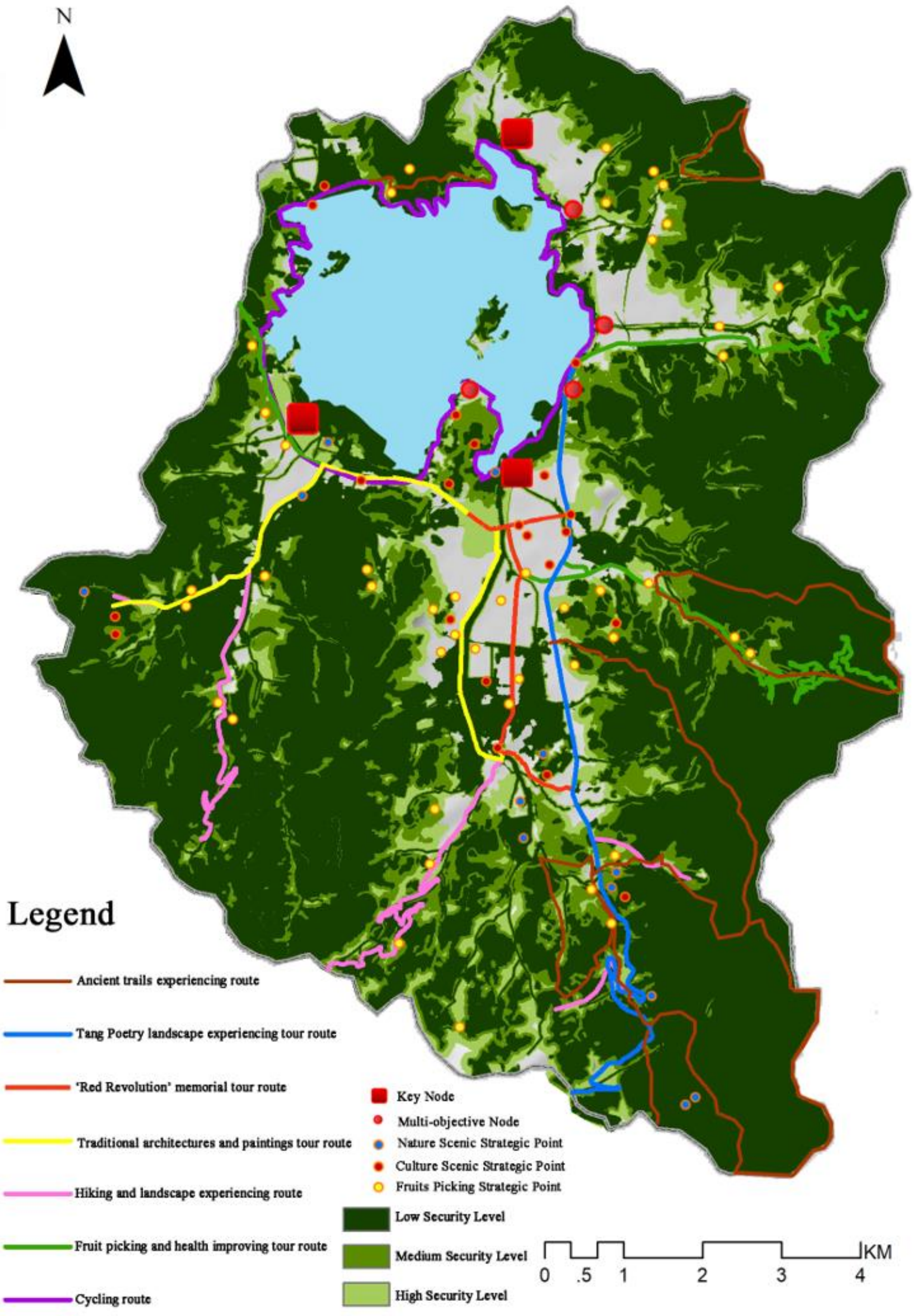


Figure 6.14 The GI network conservation areas with the proposed recreational landscape experience routes and strategic points

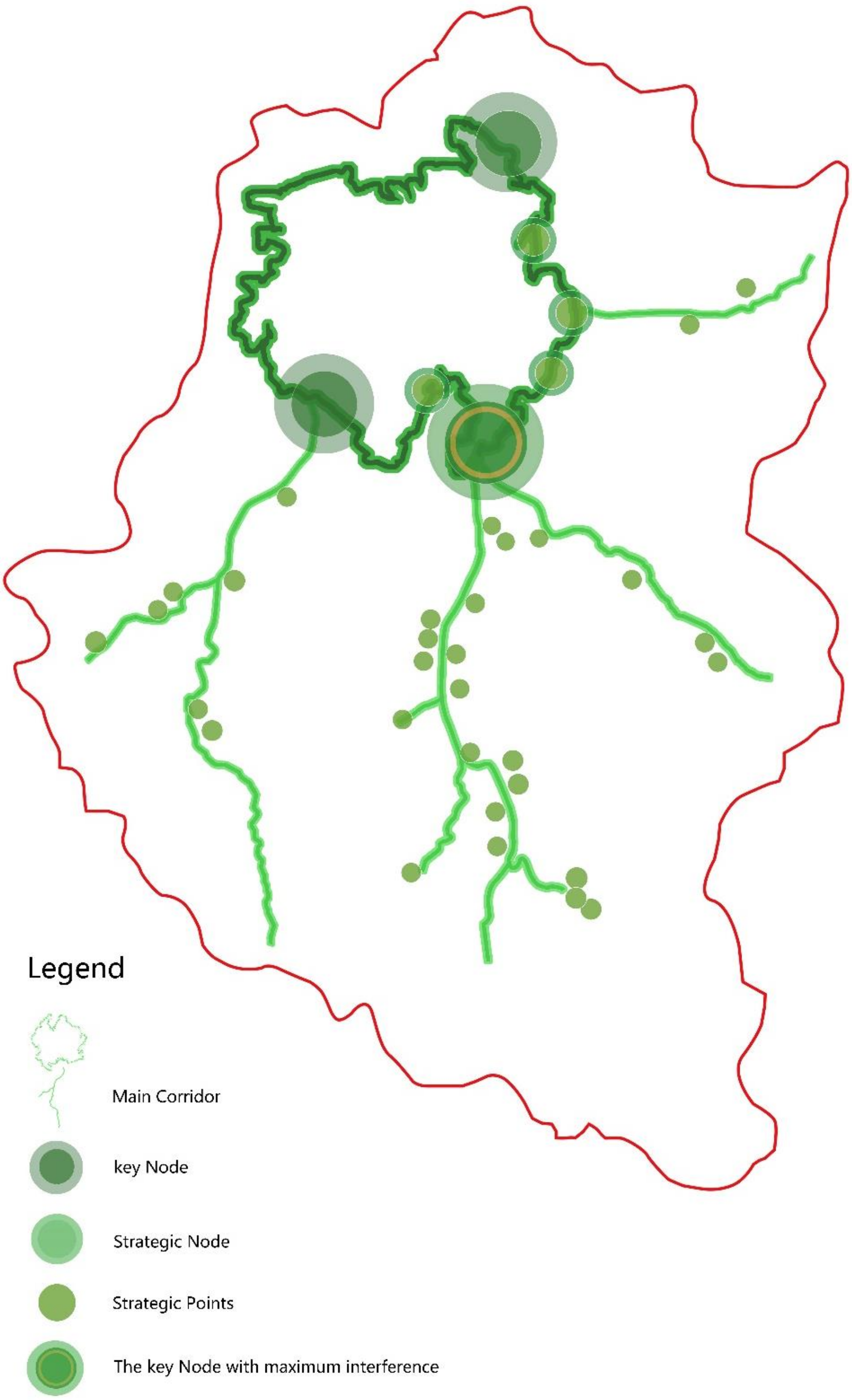


Figure 6.15 The key structure of the multi-functional GI network

6.3 Meso-scale Analysis and the Findings

Combining the implementation requirements of the Ningbo sponge pilot projects (≥75% ATRCR) with the GI design strategies for the water front area restoration (as illustrated in the Section 5.3.3), ten GI alternatives scenarios (with various GSI combinations, numbered SS1–SS10) and one basic GI restoring scheme (general green landscape cover without any GSI facilities, numbered SS11) were proposed. To further examine the performance and effect of the GI designs, the comparison and optimization of these scenarios were carried out using the method detailed in Chapter 4 with results illustrated in the following chapters.

6.3.1 Hierarchical Structure Module and the Selected KPIs

Table 6.6 and Figure 6.16 depicts the hierarchical structure of the evaluation system with the KPIF that was developed. This structure is made of three main levels: the top target level A, the mid- criterion level B, and the sub-criterion level C consisting of the KPIs and the key sustainability indicators. Furthermore, the top level is further divided into three performance benchmarks according to literature and expert interviews: environmental performance, economic and adaptability performance, social-cultural and wellbeing performance.

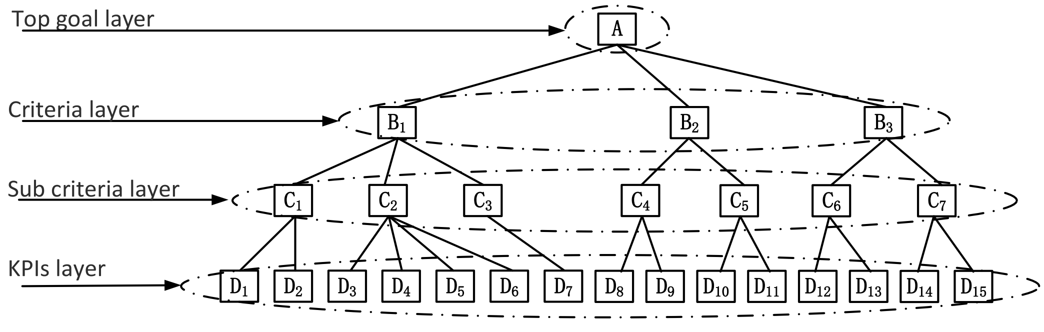


Figure 6.16 Structure of the KPIF for the case study

Table 6.6 Structure of the KPIF with the basic description of the KPIs

Target Hierarchy (A)	Criterion Hierarchy (B)		Indicator Hierarchy (C)	Symbol	Calculating and marking standards for the value of KPIs	References
Comprehensive Assessment	Environmental performance(B1)	Water quantity regulating services (C1)	Annual total runoff control rate (ATRCR)	D1	5: D1＞77% 4: 76%＜D1≤77% 3: 75%≤D1≤76% 2: D1＜75%	MHURD (2015a); MHURD (2019); Ningbo Municipal Housing and Urban-Rural Development Bureau (2019)
			Peak reduction rate	D2	5: D2＞60% 4: 50%＜D2≤60% 3: 40%≤D2≤50% 2: D2＜40%	MHURD (2015a); MHURD (2019); Ningbo Municipal Housing and Urban-Rural Development Bureau (2019)
		Water quality regulating services (C2)	SS reduction rate	D3	5: D3＞45% 4: 44%＜D3≤45% 3: 43%≤D3≤44% 2: D3＜43%	MHURD (2015a); MHURD (2019)
			COD reduction rate	D4	5: D4＞47% 4: 46%＜D4≤47% 3: 45%≤D4≤46% 2: D4＜45%	Ningbo Municipal Housing and Urban-Rural Development Bureau (2019)
			TN reduction rate	D5	5: D5＞45% 4: 44%＜D5≤45% 3: 43%≤D5≤44% 2: D5＜43%	Ningbo Municipal Housing and Urban-Rural Development Bureau (2019)
			TP reduction rate	D6	5: D6＞45% 4: 44%＜D6≤45% 3: 43%≤D6≤44% 2: D6＜43%	Ningbo Municipal Housing and Urban-Rural Development Bureau (2019)

		Habitat supporting services (C3)	Promotion of Biodiversity	D7	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Sadler et al. (2010); Yu (2015c); Hunter et al. (2015); Payne and Barker (2015); European Commission (2016); Pakzad and Osmond (2016b); Jeanjean et al. (2016); Frumkin et al. (2017); Sinnett et al. (2018); Revised National Planning Policy Framework (2018); Jerome et al. (2019); Ministry of Housing Communities and Local Government (2019); Heymans et al. (2019); Charoenkit and Piyathamrongchai (2019); Pauleit et al. (2019)
	Economic and adaptability performance (B2)	Cost saving (C4)	Construction cost saving	D8	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Dhakal and Chevalier (2017); Mei et al. (2018); Luan et al. (2019); Kim (2019); Liang (2018);
			Maintenance cost saving	D9	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Mei et al. (2018); Luan et al. (2019); Pauleit et al. (2019);Bai et al. (2019)
		Efficient adaptability (C5)	Facility adaptability	D10	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Wu et al. (2017); Gordon et al. (2018); Cao et al. (2018); Ye et al. (2018); Huang et al. (2018b)
			Efficient land --use	D11	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Wu et al. (2017); Kim (2019); Mulligan et al. (2019);

	Social-cultural and wellbeing performance (B3)	landscape cultural services (C6)	Promotion of landscape aesthetics and identity	D12	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Yu (2015b); Wang and Banzhaf (2018); Kim (2019); Zhang and Ramírez (2019); Jerome et al. (2019)
			Promotion of educational opportunities	D13	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Ministry of Housing Communities and Local Government (2019), Kim (2019)
		Health and wellbeing supporting Services (C7)	Recreational and wellbeing improvements for all times a year.	D14	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Pakzad and Osmond (2016a); Ministry of Housing Communities and Local Government (2019)
			Recreational and wellbeing improvements for all people	D15	5: Highest level 4: Relatively higher level 3: Medium level 2: Lowest level	Pakzad and Osmond (2016a); Ministry of Housing Communities and Local Government (2019); Ramyar et al. (2019); Garau et al. (2019); Jerome et al. (2019); Kim and Miller (2019); Mulligan et al. (2019)

6.3.1.1 KPIs for the Dimension of Environmental Performance

Sponge city program was initiated as a sustainable water management initiative. Hence, the quality and quantity of water were selected as the main dimensions for evaluating the performance of the stormwater regulating services. It was clearly stated in the *Sponge City Construction Performance Evaluation and Assessment Criterion* (MHURD, 2015a) and the *Sponge City Construction Performance Evaluation and Assessment Criterion* (MHURD, 2019), water quantity and water quality are two significant factors that indicate hydro-environmental benefits (MHURD, 2019). Criteria such as the ATRCR and the pollutant decline rate for total suspended solids (SS) are typical indicators which are highlighted in SCCPEAC 2019. In addition, total nitrogen (TN), chemical oxygen demand (COD), and total phosphorus (TP) are important indicators necessitated in the local urban planning and design guidelines for Sponge City in Ningbo (Ningbo Municipal Housing and Urban-Rural Development Bureau, 2019). Furthermore, the guideline also requires the calculation of the percentage of post-construction peak reductions based on the simulation of the designed return period.

6.3.1.2 KPIs for the Economic and Adaptability Performance Dimension

The main hindrance that has limited the global adoption of GI models are financing restrictions. Securing funds is often the primary concern in executing a GI project (Dhakal and Chevalier, 2017, Keeley et al., 2013, Rowe, 2016, Gordon et al., 2018). Therefore, the cost of construction and maintenance of the GI projects must be minimised to ensure affordability. Also, effective adaptability is crucial for the economic performance according to reviews and interviews, hence benchmarks such as efficacy of land use and adaptability of facility are incorporated as sub-criterions (Wu et al., 2017, Gordon et al., 2018, Kim, 2019, Mulligan et al., 2019). The efficacy of land usage needs to properly considered, particularly in restoration projects with limited land space for the GI facilities. In such restoration projects with space limitations, an efficient facility is required to attain similar water quantity and quality control targets (Wu et al., 2017).

As a result, the assessment system for the economic and adaptability benchmark integrates four main KPIs – land use efficiency, adaptability of the facility, cost saving and efficient adaptability. Therefore, the model must include a smart land-use design with high technical adaptiveness. A GI combination design with a higher economic and adaptability performance means a smarter design with higher technically adaptability and a land use efficiency.

6.3.1.3 KPIs for the Dimension of Social-cultural and Wellbeing Performance

In reference to the social, cultural and welfare dimensions, the selection of indicators include the stimulation of landscape aesthetics and characteristics, promotion of educational avenues, and the enhancement of recreation and wellbeing activities all year round for all age groups (see Table 6.6 and the Figure 6.16). Hence, the ecological service function principally refer to cultural benefits, educational opportunities, aesthetics improvement, and recreational enhancements to the built environment (Cheshmehzangi and Griffiths, 2014). Correspondingly, It is recommended that the enhancement to recreational activities and human wellbeing must be measured based on the recreational activities provision, space abundance, accessible times of the year and the quantifiable human health and welfare improvement (Ramyar et al., 2019, Garau et al., 2019, Jerome et al., 2019, Kim and Miller, 2019, Mulligan et al., 2019). This means that in order to deliver high-quality GI, all people are encouraged to use and enjoy its facilities, especially young children, the old people and the disabled. Additionally, the accessibility to GI at all times of the year should be carefully designed, especially the hot summer days and cold winter day, as well as the raining days, as the case study area is typical for its long raining days, hot summer and cold winter weather characteristics.

6.3.2 Ranking and Weighting Results of the KPIs

Based on the ranking and weighting strategy, the weighted result of the KPIs are presented in Figure 6.17. A consistency check was also applied to the ranking results with a final CR value of 0.0911, which is an indication of the reliability of the results. Furthermore, Figure 6.17 demonstrates the assessment of the followings: the weight of the ATRCR (D1), the promotion of biodiversity (D7), the construction cost-saving (D8), and the level of recreational and wellbeing improvements for all people (D15). These are relatively high among the 15 studied indicators.

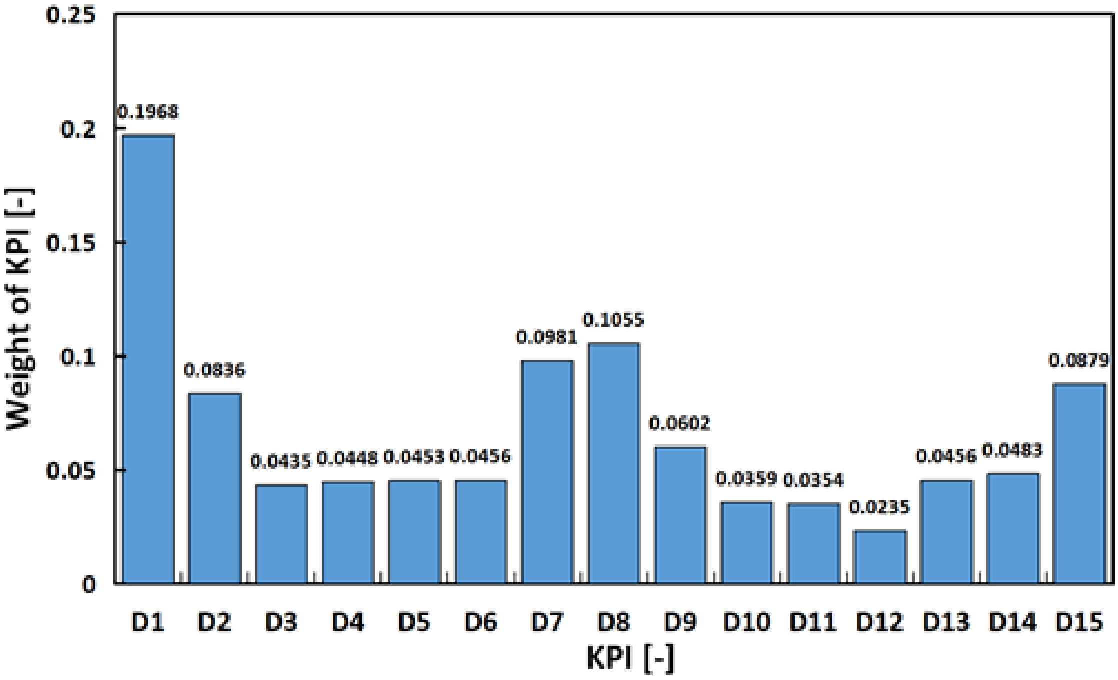


Figure 6.17 Comparison of the weighted results for the key performance indicators

6.3.3 Hydro-environmental Performance of Different Scenarios Based on SWMM Assessment

6.3.3.1 Hydro-environmental Performance Results Base on Long-duration Simulation

Long-term rainfall data of Ningbo City from 1981 to 2010 were used to simulate the ATRCR and pollutant reduction rate of the various scenarios. The results are shown in Table 6.7 and Figure 6.17. Among these, the ATRCR of SS1 (with 87.0% BC + 13.0% PP), SS4 (with 81.6% BC + 5.4% RG + 13.0% PP), and SS10 (with 27.9% BC + 5.4% RG + 53.7% VS + 13.0% PP) was 77.18%, 77.03%, and 77.23%, respectively, which were greater than the alternatives with other GSI facility combinations.

Table 6.7 Results of the hydrological environment simulation based on the long-term rainfall data

Scenario	ATRCR	SS reduction	COD reduction	TN reduction	TP reduction
1	77.18%	45.50%	47.49%	45.42%	45.50%
2	75.29%	43.14%	45.45%	43.04%	43.12%
3	73.75%	42.50%	44.26%	42.68%	42.06%
4	77.03%	45.28%	47.28%	45.19%	45.26%
5	76.55%	44.20%	46.29%	44.11%	44.18%
6	76.57%	44.26%	46.35%	44.17%	44.24%
7	75.90%	42.72%	44.93%	42.62%	42.70%
8	76.11%	42.92%	45.12%	42.82%	42.90%
9	75.85%	42.55%	44.75%	42.45%	42.53%
10	77.23%	44.04%	46.14%	43.95%	44.02%
11	70.39%	40.31%	40.31%	40.20%	40.29%
12	64.98%	35.79%	35.79%	35.67%	35.78%

It can be seen that the first three scenarios with GSI (SS1, SS4, and SS10) show a ~7% points increase in the ATRCR in comparison to SS11 (GI scenario for restoring the green landscape without any GSI facilities) based on the long-term rainfall data. Furthermore, all scenarios had ~ ≥10% point increase in ATRCR in comparison with the current benchmark situation, SS12.

Overall, ten scenarios with the GSI facilities (excluding SS3) reached the 75% ATRCR control standard for the project as a short-term plan implemented in 3–5 years.

The results of pollutant reduction rates are shown in Table 6.7. It was found that SS_1 (with 87.0% BC + 13.0% PP) and SS_4 (with 81.6% BC + 5.4% RG + 13.0% PP) were consistently the best performers, ranking the first and second in the GI scenarios, respectively. While SS3 (with 87.0% VS + 13.0% PP) had the worst performance based on its long-term rainfall data and the GI scenario consistently ranked last.

6.3.3.2 Hydro-environmental Performance Results Base on Short-duration Simulation

The simulation of the hydrological performance of different scenarios was conducted using a two-hour rainfall data of 65.5 mm with a return period of 3 years. The simulation results shown in Table 6.8 show: SS11 is characterised with the lowest peak flow reduction rate, while the SS4 has the highest peak flow reduction rate. In addition, scenarios SS1 - SS10 portrays a relatively strong effect on peak flow reduction which was ~30% higher in comparison to SS11 (without GSI facilities).

Table 6.8 The runoff control data of different scenarios at a return period of 3 years

Scenario	Peak flow rate (m^3/s)
SS1	56.44%
SS2	56.25%
SS3	41.60%
SS4	62.36%
SS5	61.64%
SS6	61.64%
SS7	54.22%
SS8	60.98%
SS9	44.65%
SS10	56.62%
SS11	18.97%

6.3.3.3 Summary of the Hydro-environmental Performance Simulation

In terms of the hydro-environmental performance, the ten combinations remained similar because the alternative scenarios selected in this study were based on different GSI combinations. Also, since the site is located at a wetland park area and adjacent to a natural wetland, the selected GSI facilities have certain effects on the landscape and water storage facilities, such as storage tanks are not included. As the study area is a primary water source area, the Siming Lake reservoir is a large natural storage tank, so artificial storage facilities are not required.

Furthermore, only facilities with high suitability and recommendation by the local sponge design guidance were selected in this study

(Ningbo Municipal Housing and Urban-Rural Development Bureau, 2019). The GSI facilities all have over-ground green vegetation, but their underground structure layers are different in complexity. Therefore, their water storage and pollutant removal capacity are different. The underground structure of the VS facility is relatively simple as it is mainly a water transport facility. Therefore, the pollutant removal ability of scenarios with high % of VS such as SS3 is the weakest. In addition, its water storage capacity is also the lowest among the ten scenarios. In contrast, the underground structure of the BC is the most complex. Hence, GI combinations with high surface area of BC facility like SS1 and SS4 were consistently the best performers for hydro-environmental benefits in terms of both water quantity and quality control. This result is in correlation with the past studies that suggests that BC coupled with PP can decrease the total runoff and peak flow by about 40% (Li, 2017).

Although the accuracy of each GI scenario simulation result is influenced by uncertainties in both the SWMM model settings and the GI parameters, the trends and key insights derived from the comparison of relative results remained unaffected. The study primarily compared the relative differences in the environmental effects of alternative scenarios. Hence, the results of the comparisons are reliable and can be used for further AHP assessments in the final decision-making analysis.

6.3.4 Comprehensive Performance Evaluation Results

Prior to conducting a comprehensive evaluation, the scoring standard was first defined. The specific performance score based on the SWMM and the expert interviews for each value of the KPI was further divided into four grades. The specific scoring standard of these four grades are shown in Table 6.6 (shown in section 6.3.1).

Table 6.9 Basic value of each KPI for the 10 scenarios

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
SS1	0.9840	0.3344	0.2175	0.2240	0.2265	0.2280	0.4905	0.3165	0.1806	0.1795	0.1770	0.1175	0.2280	0.2415	0.4395
SS2	0.5904	0.3344	0.1305	0.1344	0.1359	0.1368	0.3924	0.4220	0.2408	0.1436	0.1416	0.0940	0.1824	0.1932	0.2637
SS3	0.3936	0.2508	0.0870	0.0896	0.0906	0.0912	0.2943	0.5275	0.3010	0.1077	0.0708	0.0705	0.1368	0.1449	0.2637
SS4	0.9840	0.4180	0.2175	0.2240	0.2265	0.2280	0.4905	0.4220	0.2408	0.1436	0.1770	0.1175	0.2280	0.2415	0.4395
SS5	0.7872	0.4180	0.1740	0.1792	0.1812	0.1824	0.4905	0.4220	0.2408	0.1436	0.1770	0.1175	0.2280	0.2415	0.4395
SS6	0.7872	0.4180	0.1740	0.1792	0.1812	0.1824	0.4905	0.4220	0.2408	0.1436	0.1416	0.1175	0.2280	0.2415	0.4395
SS7	0.5904	0.3344	0.0870	0.0896	0.0906	0.0912	0.4905	0.4220	0.2408	0.1077	0.1416	0.0940	0.1824	0.1932	0.3516
SS8	0.7872	0.4180	0.0870	0.1344	0.0906	0.0912	0.4905	0.4220	0.2408	0.1436	0.1416	0.1175	0.2280	0.2415	0.4395
SS9	0.5904	0.2508	0.0870	0.0896	0.0906	0.0912	0.3924	0.4220	0.2408	0.1077	0.1062	0.0705	0.1368	0.1449	0.2637
SS10	0.9840	0.3344	0.1740	0.1792	0.1359	0.1824	0.4905	0.4220	0.2408	0.1436	0.1416	0.1175	0.2280	0.2415	0.4395

Table 6.10 Comprehensive evaluation calculation results of the 10 scenarios

	Environmental performance(B1)	Economic and adaptability performance (B2)	Social-cultural and wellbeing performance (B3)	Comprehensive performance
SS1	2.7049	0.8536	1.0265	4.5850
SS2	1.8548	0.9480	0.7333	3.5361
SS3	1.2971	1.0070	0.6159	2.9200
SS4	2.7885	0.9834	1.0265	4.7984
SS5	2.4125	0.9834	1.0265	4.4224
SS6	2.4125	0.9480	1.0265	4.3870
SS7	1.7737	0.9121	0.8212	3.5070
SS8	2.0989	0.9480	1.0265	4.0734
SS9	1.5920	0.8767	0.6159	3.0846
SS10	2.4804	0.9480	1.0265	4.4549

The performance of the alternate scenarios SS1-SS10 were calculated and ranked based on the scores and weights of the KPIs. The calculation results are summarized in Table 6.9 and Table 6.10. Among others, SS4 had the highest comprehensive benefits. Although, it's ATRCR is slightly lower in comparison to that of SS1, it's economic and adaptability performance exceeded those of SS1. Moreover, the result reveals that the economic and adaptability dimensions of the scenarios were stronger with the substitution of BC with RG in the GSI facility allocation as seen in SS1 (87.0% BC + 13.0% PP) and SS4 (81.6% BC+ 5.4% RG + 13.0% PP). This is attributed to the lower cost of construction and maintenance of RG relative to BC, thereby combining both increases the economic performance.

Scenario SS3 had the lowest comprehensive benefit, although its economy was the best. SS3 (87.0% VS +13.0% PP) had the largest percentage of VS, and similar proportion of PP compared to the other scenarios. In addition, the underground structure of the VS facility is relatively simple; therefore, its construction and maintenance costs are lower than that of BC and RG. However, the environmental, social-cultural and wellbeing benefits of SS3 were lower than other combinations. Combination SS9, ranking second to last, also contained a higher percentage of VS in the GSI facility. The other alternate scenarios are ranked accordingly in decreasing performance order: SS2, SS5, SS6, SS7, and SS8.

6.4 Micro-scale Analysis and the Findings

Four scenarios with different combinations of the GSI facilities were developed in the preliminary research, and detailed assessment analysis is performed. In addition, the developed KPIF is also applied to the evaluation of the micro-scale GI scheme with analysis results illustrated in the following sections.

6.4.1 Hydro-environmental Performance of Different Scenarios Based on SWMM Assessment

At the micro-scale, the long-term rainfall data of Ningbo City from 1981 to 2010 was used to simulate the ATRCR and pollutant reduction rate of all scenarios ZS1 – ZS4 (results shown in Table 6.11 and Table 6.12). Among these, the scenarios ZS1 and ZS3 both demonstrate a relatively better performance, with the ATRCR of 75.77% and 75.96% respectively. Additionally, their performance on the pollutant reduction rates for SS, COD, TN and TP are also higher than that of ZS2 and ZS4.

Table 6.11 Results of the hydrological environment simulation based on the long-term rainfall data at micro-scale

Scenario	ATRCR	SS reduction	COD reduction	TN reduction	TP reduction
1	75.77%	43.71%	43.75%	43.70%	43.62%
2	75.03%	41.06%	41.11%	41.05%	40.97%
3	75.96%	43.61%	43.65%	43.59%	43.52%
4	75.24%	43.49%	43.54%	43.48%	43.41%

Table 6.12 The runoff control data of different scenarios at P=3

	ZS1	ZS2	ZS3	ZS4
Peak flow rate (m3/s)	54.09%	53.12%	54.58%	53.79%

6.4.2 Comprehensive Performance Evaluation Results and Discussions

Based on the results, the hydrological effects of scenario ZS1 and ZS3 are better than scenario ZS3 and ZS4 (shown in Table 6.13). After the comprehensive evaluation with KPIF, scenario ZS3 has the best performance with the maximum comprehensive benefits (shown in Table 6.14).

Table 6.13 Basic value of each KPI for the four scenarios at micro-scale

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
ZS1	0.1491	0.0365	0.0190	0.0196	0.0198	0.0247	0.2943	0.3165	0.1806	0.1077	0.1062	0.0705	0.1368	0.1449	0.2637
ZS2	0.1477	0.0343	0.0179	0.0184	0.0186	0.0242	0.2943	0.3165	0.1806	0.1077	0.1062	0.0705	0.1368	0.1449	0.2637
ZS3	0.1495	0.0365	0.0190	0.0195	0.0197	0.0249	0.2943	0.3165	0.1806	0.1077	0.1062	0.0705	0.1368	0.1449	0.2637
ZS4	0.1481	0.0364	0.0189	0.0195	0.0197	0.0245	0.1962	0.4220	0.2408	0.0718	0.0708	0.0470	0.0912	0.0966	0.1758

Table 6.14 Comprehensive evaluation calculation results of the four scenarios at micro-scale

	Environmental performance	Economic and adaptability performance	Social-cultural and wellbeing performance	Comprehensive performance
ZS1	0.5630	0.7110	0.6159	1.8899
ZS2	0.5553	0.7110	0.6159	1.8822
ZS3	0.5634	0.7110	0.6159	1.8903
ZS4	0.4632	0.8054	0.4106	1.6792

It seems that this slight difference in hydrological performance is most likely due to the impact of micro-terrain changes associated with the distributed GIS facilities configuration on the site. Additionally, this distributed GIS facilities configuration is also linked to its comprehensive performance. Scenario ZS1 and ZS3 have the same types, areas, and proportion of GSI facilities, which are both designed with distributed configuration of GSI facilities within the available space on site according to the local sponge city design guide (Ningbo Municipal Housing and Urban-Rural Development Bureau, 2019). Nonetheless, the GSI facilities of ZS1 and ZS3 are distributed in different sections of the landscape. ZS1 involves dispersing the new facilities near each building group in close proximity to the centre of the designed site. In contrast, the GSI facilities of ZS3 are distributed closer to the periphery of the site, with the water retention green space design at the central axis of the GI design.

ZS2 and ZS4 are alternative designed scenarios which mainly replaces BC with RG or GS at the central axis. However, these scenarios had poor hydrological effect and low comprehensive benefit performance in comparison to ZS1 and ZS3. Also, ZS4 depicts the scenario with the maximum increase in GSI facilities in all four scenarios, but the hydrological and comprehensive benefits remain the lowest.

6.5 Summary

6.5.1 Summary of the Comprehensive Identification and Evaluation Results

For the macro-scale of the research area, the GI comprehensive overlay analysis was carried out based on the above specific landscape SPs and the recreational network analysis. These include the water resilient landscape SPs, the biotic landscape SPs and the vernacular landscape and vernacular landscape recreational network analysis. GI networks based on three levels of comprehensive landscape security pattern with the corresponding waterfront buffer areas of the corridors, the main nodes were identified.

Additionally, the key structure of the GI networks was also examined on this basis. Overall, there are seven main nodes around the lake area, including three key nodes, four sub-nodes and a series small node along the main corridors, which are collectively proposed as the strategic points of the multi-functional GI network. It was found that the key node with the maximum interference was the estuary wetland area of Daxi river, which was selected as the meso-and micro scale research focus area. The discussions of these identification processes, results, and the related policy recommendations are illustrated in the Chapter7.

For the meso-scale evaluation, the results indicated that:

- The water quantity control of the ten scenarios with GSI facilities were significantly better than that of S11, the scenario without any GSI facilities.

- With the exception of SS3, all other scenarios with GSI facilities attained the ATRCR control standard of 75% and an increase of ~7% and >10% in comparison to SS11 and SS12 respectively.
- SS4 (with 81.6% BC+ 5.4% RG + 13.0% PP) and SS1 (with 87.0% BC + 13.0% PP) were consistently the best performers for hydro-environmental benefits in terms of both water quantity and quality control.
- Based on final ranking results, SS4 was recommended to be the scenario with the best comprehensive benefits.
- This best performance scenario was recommended for the short-term GI general plan for the Liangnong Siming wetland construction.

For the micro-scale evaluation, considering the reference target of 75% ATRCR in the sponge City guidelines, four scenarios were developed. The hydrological effects of scenario ZS1 and ZS3 were generally superior to scenario ZS3 and ZS4. After comprehensive evaluation with the developed KPIF, scenario ZS3 represents the scenario with best performance (maximum comprehensive benefits).

Further evaluations and comprehensive analysis of these results and related discussion on the meso- and micro- scale connectivity consideration are discussed in the next chapter. In addition, the planning guidance and policy recommendations based on the multi-scale evaluation results will also be explored and illustrated in the Chapter 7, after a short summary of the main findings of the preliminary research and the in-depth research .

6.5.2 Summary of the Main Findings of the Preliminary Research and the In-depth Research

Table 6.15 Summary of the main findings of the two stage research

Questions	Methods	Outputs
Q1: How to develop the GI planning and assessment with BSPF model for SCP especially for Jiangnan water net area of China towards reinforced resilience and sustainability?	field study, literature review, and interview	A BSPF model was developed as a GI planning and assessment model for SCP to attain reinforced resilience and sustainable development. This would innovatively reshape the overall GI delivery approach by systematically integrating the model with water resilience at its core, ensuring multi-functional and multi-scale coordination, and enhancing multi-dimensional sustainability outcomes (see Chapter 5 for the main results and the further discussion of the application and limitation will be illustrated in Chapter 7)
Q2: How to build a multi-objective spatial GI network for resilient and sustainable transitional development in the macro-scale?	GIS mapping and analysis	Mapping tactics was improved by highlighting the human health and wellbeing promotion linked with experiences within vernacular nature and cultural landscapes/routes and strategic points at the macro scale. This was based on basic process mapping and analysis using GIS (see Chapter 6,section 6.1 and section 6.2 for the main results and the further discussion of the application and limitation will be illustrated in Chapter 7)
Q3: How to develop a comprehensive and targeted KPIF for the meso- and micro scales?	SWMM and AHP	The developed framework further emphasises the impact of appropriate GI planning by refining the impact evaluation process and developing a more comprehensive KPIF that enables the quantitative evaluation of the design alternatives and their impact(see Chapter 6,section 6.3 and section 6.4 for the main results and the further discussion of the application and limitation will be illustrated

Questions	Methods	Outputs
		in Chapter 7)
Q4. What are the cross-scale integrated planning guidance and policy recommendations for management and implementation?	field study, literature review, and interview	The strategies for the three-scale integrated planning guidance was summarized and considered during the design of the model of the BSPF of GI Planning for SCP with Reinforced Resilient (see Chapter 5 section 5.3.1 The Three Scales Systematic Planning Structure Overview) and the suggested planning policy as well as the institutional suggestions will be discussed in the Chapter7

With the main objective of developing a model that will guide the GI planning for China's SCP towards achieving reinforced resilience and sustainable outcomes, this research incorporates a two-stage integrated multi-dimensional exploration in response to the four main research questions (see Table 6.15).

The preliminary study was performed by the reviews of relevant case studies, and the description of the challenges associated of the Jiangnan water net area utilized the Siming Lake case study was mainly by obtaining data through field study, academic literature and relevant planning reports and experts' interview. A general Basic Strategies and Pathways Framework (BSPF) model for Jiangnan Water Area with three-scales of integrated statistics and pathways is proposed (in response to question number 1 and number 4), and the preliminary landscape characteristic investigation and analysis was performed with Siming Lake as case study. The main results of this part of the research are illustrated in Chapter 5 where the developed BSPF model was used as a GI planning and assessment model for

SCP to enhance resilience. This is aimed to nnovatively reshape the overall GI delivery approach by systematically integrating water resilience at its core, ensuring multi-functional and multi-scale coordination, and enhancing multi-dimensional sustainability outcomes

Subsequently, Chapter 6 illustrates the analysis and findings of the in-depth research stage. This includes the SPs identification at macro-scale (in response to question number 2), and the results from the developed KPIF (in response to question number 3). Furthermore, the comprehensive evaluation of the multiple scenarios of the key nodes at the meso-scale and the key units at micro-scale was done using the BSPF model and the KPIF with the Siming Lake as a case study. This stage also considered the three-scale of exploration by mainly adopting ecology-based landscape SPs with GIS spatial analysis and mapping assistant tools at the macro-scale, and the AHP and SWMM hydro-effects simulation models at the meso-and micro scale. Taking account of these factors improved the mapping tactics by highlighting the enhanced human health and wellbeing that can be linked with experience and interactions with vernacular nature and cultural landscapes and/or routes, as well as other strategic points at the macro scale (see section 6.1 and section 6.2 of Chapter 6). Moreover, the developed KPIF framework lay emphasis on the inherent benefits of an impact evaluation during the planning stage by refining the evaluation process and developing a more comprehensive KPIF that enable the quantitative evaluation of the design alternatives in order to measure its effectiveness in achieving the required goals within given constraints (see Chapter 6, Section 6.3 and 6.4 for the main results).

Previously, the basic strategies for the cross-scale integrated planning guidance has been summarized in the general model of the BSPF in chapter 5 and the basic structure of the three-scale integrated planning guidance was summarized in the structural overview of the BSPF (see Chapter 5 section 5.3.1) which led to adoption of the three-scale systematic GI panning structure. It is also crucial that these three-scale integrated GI planning are specifically designed and linked to China's official spatial planning system for a specific region, city or town. Hence, the three-scale of GI planning should be designed to match to the urban and rural spatial planning regulation scale system, serving as a basic strategy and structural guidance of GI planning for SCP. Consequently, Chapter 7 is focused on discussing the relationship and linkage of these three scales, the related planning and management policy recommendations, as well as the further suggestions on the municipal planning and the implementation steps (in response to question number 4, see Table 6.15).

This chapter was incorporated to provide informed answers to some difficult but relevant questions that came up during experts' discussions such as 'which scale of green infrastructure do you think is more important?' and 'how to coordinate these scales with SCP implementation process?'. This could be an indication of deficit in knowledge or experience of experts with regards to GI planning policy and implementation governance. Moreover, most were reluctant to share their planning or management experience and they frequently mentioned that SCP is still on the early stage of practice and the performance of GI should only be reviewed in the long term. As many projects are still in the construction stage and their effect is not evident, an obvious point of uncertainty is whether the current experience and practices should be duplicated, modified or expended. This conflict discourages building further knowledge and experience. Similar responses were obtained for the questions such as 'Do you think GI needs to link with the current official planning system?', 'If there is a need to link with the official planning system and 'what measures or policy suggestions should be taken into consideration?'. Overall, it seems that it is currently too early to summarize or share their experience on governance and policy related issues.

Therefore, Chapter 7 reviews and discusses the policy recommendations based on the developed GI planning model for enhancing resilience and sustainability of the SCP. In addition to this, the novelty, application, and limitation of the developed BSPF model with the KPIF would be further clarified.

Chapter 7 Further Discussions and the Policy Recommendations

7.1 Introduction of the Discussions and Policy Recommendations

According to the needs of the high-quality urbanisation and the more resilient transitional design towards sustainability, aiming at the gaps of the present GI research, this study has carried out a two-stage research with three-scale holistic exploration. Firstly, a preliminary research stage where a more resilient BSPF model for high-quality GI planning and assessment of the SCP was developed, as it was illustrated in the Chapter 5; additionally, the BSPF was subsequently applied to Siming Lake watershed area as a case study to develop the basic strategies of macro scale and multiple planning scenarios of meso- and micro- scale. Secondly, an in-depth research stage for further application of this model with the Siming Lake case study was carried out mainly for the more resilient GI network identification based on the basic strategies of the macro-scale and the comprehensive evaluation of the multiple scenarios of meso- and micro- scale. Additionally, in the in-depth stage, the GI network identification was based on the landscape security pattern theory with key landscape ecological processes assessments. Moreover, a KPIF was proposed for the detailed evaluation of multiple scenarios with results illustrated in Chapter 6. This chapter provides further discussion and analysis of the research results, the model application, and related policy recommendations. The contents of this chapter are categorised divided into the following main aspects:

1. The application, contribution, limitation and future directions of the developed BSPF model and the improved GI evaluation system with KPIF for the meso- and micro-scale SCP;
2. The results of the macro-scale assessment and identified key components of the multi-functional GI network obtained from the application of GIS-supported key landscape process mapping and analysis, as well as the policy recommendations based on these analyses; and
3. The evaluation and optimisation of the multiple meso- and micro- scale scenarios by balancing multiple benefits, the relationship and linkage of the multi scales, and the relevant planning policy recommendations.

7.2 The Novelty of This High-quality GI Planning and Assessment Model for SCP with Reinforced Resilience

7.2.1 The Developed Reinforced Resilient BSPF Model Is a Holistic High-quality GI Planning and Assessment Model for SCP

To fill the research gaps mentioned in the Chapter 1.4.1 (also concluded in the section 3.2 of the Chapter 3 after the literature review), the most notable contribution of the developed BSPF model is use as a holistic high-quality GI planning and assessment model for SCP to attain more resilient and sustainable urban growth. This would innovatively reshape the overall GI delivery approach by systematically integrating the model with water resilience at its core, ensuring multi-functional and multi-scale coordination, and enhancing multi-dimensional sustainability outcomes (in response to research question number 1 in the section 1.4.2 of Chapter 1 and the three key points of rethinking of SCP in the section 3.1.4 of Chapter 3). The BSPF model contains two basic stages: (1) the preliminary stage focussed on the planning strategies and the multiple scenarios development, (2) the in-depth stage focussed on the identification of the multi-functional GI network with the corresponding landscape SPs and comprehensive assessment of the design scenarios.

The multi-scale GI delivery BSPF for SCP was proposed following a design and assessment integrated process model, which mainly adapted from the GI mapping methods of Taizhou EI planning. Taizhou EI planning process followed the Carl Steinitz's six-step framework for the whole Geodesign process (Steinitz and Rogers, 1969, Steinitz, 2016a, Steinitz, 2012, Steinitz, 1994). Geodesign provides an integrative framework for concepts such as overlay of environmental information (Steiner, 2012) morphological measurement (Muller and Flohr, 2016) and landscape evaluation impact analysis to define the main problems which needs to be addressed in the landscape design.

Additionally, Steinitz's method contributions to Geodesign by combining design solutions with impact assessment and using GIS digital technologies to support the overlay analysis of environmental information. Steinitz's 'Geodesign Framework', has a wide impact on landscape planning process. The framework proposed fundamental ideas about Geodesign process modules framework, which combines landscape evaluation with impact assessment module (Hollstein, 2019, Steinitz, 2012, Steinitz, 1990, Yu et al., 2005a). Taizhou EI planning has followed this framework of process models that emphasis impact assessment, design of alternative futures and comparison analysis of the alternatives. This study further develops the planning and assessment framework in two stages containing 14 steps (three-step preliminary research, six-step macro scale in-depth research and five-step meso-and micro scale research). The developed framework further emphasis the impact evaluation before and after planning, by refining the impact evaluation process and developing a more comprehensive KPIF that enable the quantitative evaluation of the design alternatives.

Moreover, the BSPF in this study enabled a reinforced resilient GI network establishment structured based on the water resilient centered three basic-objective layers overlapped and interaction. This in response to research question number 2 illustrated in the section 1.4.2 of Chapter 1. As sustainable urban development is considered a complex problem, Geodesign applies systematic thinking to such problem using a dynamic and collaborative process wherein iteration is necessary to address diverse objectives (Nyerges et al., 2016, Dangermond, 2010). Hence, multi functionality GI network planning was highlighted in this study and it was stressed with multi-discipline more resilient strategies. As illustrated in the section 5.2.2 of Chapter 5, GI model should be incorporate resilience strategies to meet the high-quality transitional development needs. Additionally, through impact simulations informed by geographic contexts with the comprehensive identification of the key structured elements of the GI network, the developed multifunctionality GI network can effectively restore the natural water resilient landscape pattern, while boosting the biodiversity and revitalizing the waterfront area. The detailed GI network identification tactics improving and the GIS supporting mapping results discussion will be further discussed in the section 7.3 of this Chapter.

7.2.2 The Developed KPIF to Support the Comprehensive Evaluation of Around Sustainability and High-Quality Transitional GI Design

In response to the research question number 3 illustrated in the section 1.4.2 of Chapter 1 , a novel multi-objective KPIF with a set of KPIs (including 15 key sustainability indicators) for the neighbourhood scale (meso-and micro level) was proposed, as illustrate it was illustrated in the section 6.3.1 of Chapter 6 (Sun et al., 2020). This KPIF was developed to support the comprehensive evaluation with quantitative assessment methods, which involved collating experts' opinions and communicating with stakeholders from different backgrounds for weighed multi-benefits decision making, particularly for the improved GI planning for SCP at neighbourhood scale.

With the implementation of the enhance GI plan for the Siming Lake waterfront area, the identified sponge node is transformed to a lakeside landscape park where human and nature interaction is enhanced, ecology is preserved for providing valued ecosystem facilities and services to people. These ECS incorporates water management, socio-cultural benefits (development of recreational, aesthetic, and educational avenues), as well as improving the physical, mental and spiritual wellbeing benefits provided to all individuals. Numerous studies have established the importance of integrating high quality GI plans into the built environment due to the immense social and cultural benefits obtained from improving landscape aesthetics, stimulating biodiversity preservation, increasing activities with recreational and mental benefits, supporting human health and wellbeing enhancements, as well as empowering the population with promotional educational opportunities (Hunter et al., 2015, Jeanjean et al., 2016, Sadler et al., 2010, Payne and Barker, 2015, Jerome et al., 2019, Frumkin et al., 2017, Zhang et al., 2020, Venkataramanan et al., 2019).

These facilities are termed as ecological socio-cultural service and health and wellbeing supporting functions and are both represented in the key performance indicators (Yu, 2015c, Revised National Planning Policy Framework, 2018, European Commission, 2016, Davies and Lafortezza, 2017, Albert and Von Haaren, 2017, Sinnett et al., 2018). Hence, the KPIs such as all-year accessible, enhanced recreational and wellbeing amenities for all people, is incorporated in the comprehensive assessment system, serving as the experts' quantitative evaluation basis of the GI alternatives.

7.2.3 The Application and Limitation of the Developed BSPF Model with KPIF

The developed more resilient BSPF model is a holistic high-quality GI planning and assessment model for SCP, especially for the Jiangnan water net area. The model incorporates water resilience at its core, adopts multi-scale management, enhances holistic resilience tactics and enables trades-off multiple benefits. It serves the Geodesign process as a 'more resilient and sustainable design' through refining the impact evaluation process and enhancing impact assessment informed by multi-dimensional requirements. In addition, it must be highlighted that the proposed BSPF model with KPIF will not only help to optimize the design schemes for the Jiangnan area of China, but also quantitatively evaluate similar or sponge-related projects in other regions.

High-quality GI planning for SCP is multi-objective and multi-beneficial approach, hence, requires the active involvement of all pertinent experts, governmental agencies and stakeholders. Moreover, a multi-criteria assessment technique was applied to support decision making for the SCP with assured sustainable development by employing an Analytic Hierarchy Process (AHP) approach (Antunes et al., 2006, Kiker et al., 2005, Diaz-Balteiro et al., 2017, Kumar et al., 2017, Shen and Tzeng, 2018). The AHP is a robust multi-criteria decision-making technique mostly used for evaluating complicated, multifaceted and unstructured problems in various decision-making situations (Saaty, 1990). Therefore, in highly complex schemes such as high-quality GI designs for multi-objective sponge city projects, the AHP approach incorporates various indicators for social, environmental and economic considerations. Nonetheless, the significance of many of these factors may be misplaced in order to achieve the main goal. To clarify the problem and simplify the design implementation process, the KPIs needs to be the central focus of the evaluation system.

Consequently, this study proposed a comprehensive evaluation system with sustainability KPIF of trade-offs for a high-quality multi-objective SCP, particularly at the neighbourhood scale (corresponding to the meso- and micro- site scale of the Siming Lake area). Six KPIs for assessing the performance of quality and quantity of stormwater were chosen, including ATRCR, reduction rate of peak flow, SS, COD, TN and TP which can be calculated from simulations using SWMM or other suitable hydrological software, as illustrated in the section 6.3.3 of Chapter 6. Additionally, there are KPIs representing biodiversity, economic and adaptability performance, and social-cultural and wellbeing performance. These KPIs are incorporated into the comprehensive assessment system as the experts' quantifiable assessment of GI alternatives.

7.3 GI Network Identification Tactics Improving and the GIS Mapping Results Discussion

7.3.1 Improvement of Identification Tactics of GI Networks

This study emphasizes on the analysis of key landscape processes for GI network assessment and identification. This was mainly adapted from Taizhou EI planning with enhanced strategies for achieving the high-quality more-resilient transitional needs for urban development.

To support the GI planning process, various GI mapping approaches are necessary. In the last decades, the shift from hand-drawing to CAD (Computer Aided Design) to GIS (Geographic Information Systems) has enabled more accurate and convenient quantitative mapping with process simulation and analysis. Although there are some new digital planning or smart planning systems that support GI, the GIS platform is still the most widely used system globally. There are two basic concepts for the GIS mapping (Liquete et al., 2015, Meerow and Newell, 2017): the first concept is multi-functionality which supports decision makers pursuing avenues of multiple service provision; and the second theory is based on connectivity analysis which requires the networks identification analysis. This study draws from the Taizhou EI mapping methods which embodies these two basic concepts, and is based on the essential landscape process analysis, making the overall evaluation process more targeted.

As illustrated in the section 5.2.4 and section 5.3.1 of the Chapter 5 ,three basic categories of landscape process are targeted (Wang and Banzhaf, 2018, Turenscape, 2009, Yu et al., 2005b): (1) the abiotic process focussed on the control and management of stormwater with water resilient landscape pattern identification ; (2) the biotic process with main habitat patch and the linking corridor analysis for preservation of native species and biodiversity ; and (3) the cultural and natural landscape recreational process linked recreational potential strategic points and linking routs analysis for social resilience enhancement.

Moreover, based on these three basic process analysis, this study improved the mapping tactics by highlighting the health and wellbeing promotion linked with vernacular nature and culture landscape experiencing routes and strategic points at the macro-scale (Yu et al., 2005b, Turenscape, 2009). This in respond to the SCP Frontiers with high-quality more resilient transitional trends and needs that illustrated in the section 1.3 of the Chapter 1 and the section 2.5 of Chapter 2. Hence, the potential needs of tour routes and strategic points that are strongly linked with health and wellbeing promotion are taking into consideration for the multifunctional GI network. This contributes to the social resilience promotion by utilising the GI model for enhancing the physical and mental health of the inhabitants with nature and cultural experiences or activities, while improving nature's landscape conservation and restoring their ecological functions.

7.3.2 The Water Resilient Centred Multi-objective and More Resilient Network Model with Planning Guidance

7.3.2.1 The Water Resilient Centred Reinforced Resilient Network for Jiangnan Area

Based on the key landscape processes analysis and the improved mapping tactics for the transitional development needs, the water resilient centred, multi-objective and more resilient GI network model was identified for the Jiangnan water net area SCP. The opportunity for increasing ecosystem services in urban areas by integrating hydrological management, biodiversity preservation, vernacular landscape conservation, nature experiences and education into a functional system promotes overlap in the use and functions of various landscape components (Hölting et al., 2019, Kim, 2019, Meerow and Newell, 2017). This can demand reinforced resilient space with multiple functions, such as serving as a flood retention areas temporally, where water recedes later or can coexist with human activity at the same time (Bajc and Stokman, 2018).

Moreover, landscape systems are composed of networks of interacting components in a constant state of changing, open to flows, energy, material, and information, and affected by adjacent and distant circumstances of different levels. Thus, researchers have shown that the multi-functionality and connectivity, and polycentricity of the system can support the tight feedback loops and the information of the landscape systems (Qiu, 2018, Bajc and Stokman, 2018). As a result, the GI system with these characteristics can respond to challenges with more rapid and smooth adaptation, thus can improve the resilience of the region.

In terms of Jiangnan area, the mid-south and lower reaches of the Yangtze River, the water network system is the key skeleton of the whole GI spatial network. Additionally. enhancement of the multi-functionality and connectivity that recognized as significant indices of the landscape function, as well as the polycentricity management are the key points of the network establishment. (Kim, 2019, Meerow and Newell, 2017, Hollstein, 2019). In light of this, the natural connection of the water network system, the connection of the waterfront corridor and the key nodes repairing are the tasks of first importance of the whole multi-objective GI Spatial network rebuilding.

Additionally, this study is based on the landscape SP and Taizhou EI mapping, but not confined to it. This is partly due to taking consideration of the traditional trends and needs, also partly due to the Siming Lake case has its own repetitive characteristics. The repetitive characteristics mainly include its location and its scale compared to Taizhou planning. The Siming Lake watershed is not in the central area of the city Ningbo and it is in the urban edge. This edge as one of the water source areas of the city Ningbo is an important ecological barrier of the entire city. Hence, this study pays more attention to the ecological repairing of the waterfront areas with more resilient strategies, especially for the waterfront areas and the wetland nodes.

Moreover, the multi-objective repairing of waterfront areas is valued. The waterfront areas are linked with natural experiences and fitness activities which can greatly improve the health and wellbeing of city dwellers. Waterfront areas also have strong connection with biodiversity fostering, which is a significant aspect of the protection of the whole ecological environment. Hence, the GI network requires considerations of flood risk with water sensitive levels, as well as security levels of biodiversity. On these bases, it is valued that natural experiences and recreational activities linked recreational points and routs of the GI network planning with more humanised design for social resilient enhancement. This need to be stressed within the planning and assessment framework of the GI system. This embodies the comprehensive identification and restoration of important ecological spaces and connections of the GI network, such as some more resilient multi-objective restoration of key waterfront nodes and corridors.

7.3.2.2 More Water Resilient GI Network and the Planning Guidance for Sliming Lake Area

Considering the unpredictability of the flood challenge with climate change, for some cities, the previous flood peak flow of 100-year return period may be the same as the forecasted peak flow of 10- or 20 -year return period in the near future (Tian and Wang, 2018, Qin, 2014, Liu, 2014, Jiang, 2009). In Ningbo city, it is also found that the frequency of the rainfall increases with the flood peak increased during the rainy season of the past 30 years (Wang, 2019, Qian et al., 2001). Therefore, to achieve more resilient city, a higher level of water resilient SP corresponding conservation spaces for GI is required as long as the conditions permit.

In addition, for the Siming Lake watershed, to better cope with the impact of uncertainty factors associated with weather variability, environmental and social challenges, the use of GI as an important tool for enhancing the resilience of cities and towns needs to be facilitated at a higher level of corresponding comprehensive SP requirement if the conditions permit. Therefore, meeting higher requirements of landscape SP of the corresponding GI conservation area, as permitted by local conditions. Pertaining to Siming Lake case study, it is suggested that the whole watershed should at least control the bottom line of GI land use which corresponds with the low SP. Also, the GI corresponding to higher security level should be achieved for more resilient sustainable development pursers, according to specific land use conditions, as well as taking consideration of the sustainable development needs with the social and economic influencing factors.

Moreover, as it was pointed out the blue-green water network system composed of Jiangnan water area, rivers, lakes, and waterfront is the key skeleton of the whole GI spatial network, and the important waterfront patches are the strategic nodes of the whole GI system (shown as Figure 6.15 of section 6.2.4 of the Chapter 6). The integrity and functional health of the whole system is inseparable from the control of such ecological core of spatial elements as waterfront corridors and network nodes. Actually, the key node of Daxi wetland repairing task has received attention form the local government and the related planning and management work are undergoing.

The multi-objective restoration of the lakeside nodes involves the regeneration of waterfront wetlands, which are a very important links in the whole GI system. For the control of these core spatial elements for more resilience, the consideration of factors such as flood risk, water sensitivity, and biodiversity are important. Also, water sensitivity and ecological sensitivity are interrelated (Lv et al., 2019, Fuyuki et al., 2014, Li, 2018a, Xie et al., 2018). As it was analysis of the in the section 6.2.3 of Chapter 6, researches have shown that some factors have significant impact on the habitat utilization and foraging behaviour of the target species. Among these factors land use suitability distance from the water source ,and the human activity are significant impact factors (Peng et al., 2019, Gagné and Fahrig, 2007), especially for the water birds and amphibians.

For the Siming Lake case study, this was first considered with the establishment of different levels of water sensitive control area corresponding to the water resilient pattern, and then combined with the landscape health and SP level requirements of waterfront environment of selected indicated species. After comprehensive analysis of the requirements, the conservational control guidance with the suggested width of the waterfront buffer areas was proposed.

On these bases, the orderly planning with careful and responsible design of the waterfront space, such as some spaces are left to nature, some are designed with minimize distractions and some spaces are designed to meet the needs of people's sightseeing activities and natural experience. These requires dividing the space to different function unit according to their location and land use condition, as it was designed and summarised in the section 5.3.3 of the Chapter 5.

In addition, there are a series of other sustainable performance indicators such as health promotion for all people, especially the aged people and young children, and economic and land use efficiency factors. Hence, the comprehensive design with the suitable control width of green buffer space can greatly enhance urban resilience and sustainability.

7.3.3 The application Limitation and Future Directions of the GI Network

The more resilient BSPF serves as a supporting tool of GI planning for SCPs in order to achieve high-quality development. After the identification analysis of the essential objective layers and the overlay analysis (show as section 6.2 of Chapter 6), this study proposed three-levels of multi-objective GI networks based on the different level of landscape SPs. These GI networks are identified with water resilient as the core, combined with the consideration of the biodiversity improvement and natural landscape experience activities that linked with the human health and wellbeing promotion. These high-quality GI networks are mainly developed for the Jiangnan water net area, based on field study of the landscape characteristic investigation, academic literature and government planning reviews, and interviews (illustrated as section 5.1 of the Chapter 5).

Additionally, further reviews of related case studies were carried out for the development of the more resilient BSPF model for the Jiangnan Water Area, the reviewed cases are mainly focused on the practice-oriented cases that have won American Society of Landscape Architects (ASLA) award. Four cases were reviewed, two international and two local cases. The international cases include the Conway Urban Watershed Framework Plan, a watershed scale case study and 'The BIG U' waterfront area planning while the national cases from the Jiangnan region in China include the Taizhou EI planning and

Luming wetland park design (shown as section 5.2 of Chapter 5). Hence, the developed multi-objective network mainly based on the investigation and landscape characteristic and its evaluation analysis of the Jiangnan water net area.

The identification results show that for Jiangnan water net area, the water net system and the waterfront spaces are the skeleton of the whole GI network. The water resilient landscape pattern rebuilding is the core and the multi-objective restoration of the waterfront areas is the key task of the high-quality GI network rebuilding of the current SCP. Additionally, the conservation of biodiversity is an essential layer of the entire GI network. Furthermore, the water sensitive areas of the GI network are mainly correlated with landscape processes associated to these wetland habitats (Lin et al., 2015). Subsequent to the analysis, the wetland indicator species linked to the waterfront area are crucial for the final pattern identification for SCP. Amongst the series of targeted indicator species selected in the Siming Lake watershed to represent a wild range of habitats in this region, tow wetland linked species are of significant research value. These species are the water birds represent by Chinese Egret and amphibians represented by Cynops orientalis. They are two representative wetland indicator species, as it was analysed in the section 6.2.3.1 of the Chapter 6. Therefore, based on the landscape SP and the EI planning methodology, they are the targeted as indicator species for the identification of the biological conservation layer of the GI network with the biological process analysis.

Additionally, in order to make GI system more complete, Syrmaticus ellioti and Viverricula indica representing forest birds and mammals are also selected as the target species for their unique range of activity areas (Yu et al., 2005a, Tao, 2017, Zhong 2001).However, more detailed assessment of important landscape patches for biodiversity conservation is still required. This is a limitation of this study at the macro-scale, as this research is manly focussing the GI for SCP. In future research, further landscape investigation and assessment work should be carried out beyond the SCP linked key areas. Additionally, cooperation and collaboration amongst experts from various background is crucial in the GI planning process at macro-scale, for achieve more scientific and larger scale integrated environmental protection in the transitional development period.

7.4 The Relationship and Cross-scale Coordination with the Planning and Management Policy Recordation

7.4.1 The Relationship and Coordination of the Multi Scales

A multi-scale holistic design is essential for reinforced resilient GI delivery for SCP. Carl Steinitz's reasoned that one of the main differentiating features of design is scale, and that the very small and very large scales of space and time should be well represented in landscape design (Steinitz, 2016b). This is in-line with the global trend as GI projects display diversity in terms of scales from the lot or street scale stormwater management measures, to neighbourhood scale measures as well as local and regional scale ecological networks (York and Jacob, 2020, Hansen and Pauleit, 2014, Meerow and Newell, 2017). This also extends to larger scale ecological networks.

Moreover, a national multi-scale GI design applied in Taizhou EI planning in China received the 2005 ASLA honour awards for remarkable analysis and planning. The three scales GI system developed in this research adopts an organization structure similar to that of the GI design scales of the Taizhou EI plan. This was illustrated in the section 5.2.1 of chapter 5 with the macro-scale as the top design with basic framework, while the meso- and micro-scale are the detailed design scale with comprehensive regulatory design for the meso-scale (generally containing different landscape units), and the exhaustive constructional design for the micro-scale (generally for each specific unit within the meso-scale detailed design).

7.4.2 Linking the GI Planning Model to the Overall Urban and Rural Spatial Planning System

Linking the GI Planning Model to the Overall Urban and Rural Spatial Planning System as one of the basic pathways of the constitutional guidance to achieve long effects with improved implementation opportunity and quality. This multi-scale system corresponds to

China's spatial planning system for a specific region, city or town. In China, there are two basic planning categories in the urban and rural planning system: the master planning and the detailed planning. These planning categories encompass three scales: macro-scale master planning, meso-scale detailed regulatory planning (contains different planning units) and micro-scale detailed constructional planning (for a specific unit within the meso-scale). Therefore, it is advised that the multi-scale GI planning system proposed should be further linked to the current urban and rural planning system in order to become part of the spatial planning practice of the system such as being incorporated as a specific type of 'master plan' for the cities or towns. Hence, according to the SP levels and the corresponding land use plans of the GI network in the macro scale, the mandatory measures and related policy should be adopted in the spatial planning system. This includes the GI conservational land use plans and the design guidance for the main corridor and nodes.

7.4.3 Setting the Meso-scale GI Planning and Management as the Key Links of the Management System

Linking of the multi-scale GI system with China's urban and rural planning system is consistent with the 'anti- planning idea' put forward by Kongjian Yu which highlights the importance of GI planning (Yu et al., 2005a, Yu, 2015b). However, in order to enhance the implementation of GI planning, the management of GI at meso-scale should be emphasized by docking the meso-scale GI as the detailed regulatory design of the spatial planning system. This is because the detailed regulatory plans of specific neighbourhoods are more restrictive for management and it serves as a special unit of link up scale and basic management unit of urban management system in China.

Moreover, the developed KPIF with a set of KPIs for the neighbourhood scale can provide targeted regulatory constraints for the meso-scale unit and guide the construction of each unit at the micro-level which belongs to the whole neighbourhood node. The KPIF also allows for certain management flexibility for multi benefits trade-offs which enhances the adaptiveness of the GI model, thereby, easing the implementation of such GI plans. Hence, this adds a dimension of management resilience with operational flexibility to effectively respond to the barriers of implementation, such as funding restrictions and efficient land resources allocation.

7.4.4 GI Planning and Management Guidance with the Coordination of Meso-and Micro-scale

In terms of Liangnong Siming Lake watershed case study, the meso-scale of the GI design is the key linking scale. The coordination between scales are discussed and the related to GI implementation guidance were proposed as follows.

Firstly, the meso scale site (the entire waterfront wetland patch shown as the Figure 4.2 in section 4.1 of the Chapter 4) as an important network node currently receives the most interference and challenges from human construction activities. Consequently, this meso-scale node is the key link and the significant strategic point with priority of restoration implementation in the entire GI network. For the multi-objective restoration of this strategic point, the most important measures of the short-term construction plan are to demolish the buildings in areas with high flood risk and high ecological sensitivity in addition to restore the natural green space while retaining some good quality buildings to integrate with functional transformation during the landscape renewal. These basic measures can improve the ecological services provided by GI landscape by creating a space human-nature co-existence with increased biodiversity, improved human health and wellbeing, as well as enhanced cultural identity of the landscape. Additionally, in light of the sustainable development strategies (shown as the section 5.3.2 of Chapter 5), the coordination and configuration of the landscape functional unit and detailed landscape elements of the meso-scale site is required and should be managed as an integral unit.

Secondly, in order to achieve a certain water quality and quantity standard (75% ARTCR) for the whole meso-scale during the short-term construction plan, the scenario numbered SS4 with high comprehensive benefit is recommended based on the comprehensive evaluation of the multiple scenarios. As the Siming Lake area is not within the Ningbo downtown area, it should be highlighted that this standard is only a reference standard. Additionally, if the same standard of the ARTCR is required in the micro-scale unit, the scenario with the best comprehensive performance can be recommended. However, this would require more investment in GSI facilities, which are generally financed by the public funds from the government.

Hence, it is advised that in the short-term planning of the micro unit, the demolition of old building and the transformation and upgrading of part of the existing building functions are the focus. The demolition of buildings with poor quality should be implemented first while allowing the natural restoration of the green landscape, and then conventional greening measures with relatively low maintenance cost is recommended. For some buildings with good quality, which are not in the high-risk area of flood, the main structure can be preserved, and through reasonable art design, these buildings can be renewable with function replacement and quality improvement. Such measures ensure the maximisation of comprehensive benefit with a higher feasibility of implementation due to affordability. Additionally, no more GSI facilities for the micro-scale are recommended for the short-term planning stage based on the interview, as financial constraint is a major obstacle to the implementation of GI design for the local government. Setting the meso-scale node as the target management unit and taking this whole management unit to meet the SCP requirement, while balancing of environmental benefits, social and economic benefits to promote the GI implementation.

7.5 Further Suggestions on the Municipal Planning and the Implementation Steps of GI

7.5.1 Incorporating GI to the Urban Municipal Planning Process and Further Integrating it the Urban Planning System

To achieve effective long-term effects and enhancing future implementation opportunities, incorporating GI planning to the urban municipal planning process and imbedding the multi-scale considerations into the urban and rural spatial planning system is highly recommended. This is mainly because embedding the GI planning model into the current officially spatial planning system will ensure GI is a compulsory element of planning which is officially required by the urban planning bureau of local municipal government. Thus, it will serve as a requisite consideration during decision making in future constructions for either a single site or larger region development projects. Hence, integrating GI planning into the urban and rural spatial planning system is suggested as one of the basic pathways for improving its uptake and benefits derived via constitutional planning innovation policy.

In addition, the linking of the three-scales of GI planning in the integrated model (as discussed in Section 7.4.2) must be emphasised as an institutional planning policy precaution for local government agencies. Hence, the linking of the GI network planning into the master planning stage as a top planning consideration with specific goals must be enforced. This will enable the GI planning to serve as an official spatial planning regulation guidance for future urban construction development. In urban development projects, setting an official GI plan as a top-level planning guidance at an early planning stage is very crucial. Hence, the GI network planning should be carried out as part of the master planning. This means that the identification and reservation of core functional areas that are required for the GI network will be specified in advance to guide the future developments or at least setting development targets in the official local spatial planning stage. As a result, if the key GI structures (position) are identified and reserved earlier during this phase, such areas will not be used as the construction land in the future development. Furthermore, if the cities already have the key positions of GI already built on during the urban construction process, these areas can be restored gradually with the mapped GI network of the master plan based on the set GI design goals during the spatial planning.

Due to the rapid economic development that occurred during the span of 20-30 years, especially the cities in the southeast coastal areas with rapid economic development, GI planning has not been considered important in many Chinese cities. Therefore, in this transitional development period, GI planning must be incorporated in the urban municipal planning process and linked with multi-scales into the urban and rural spatial planning system as a necessary institutional policy for these cities.

7.5.2 The Two Valued Aspects of Reinforced Resilience

The reinforced resilience GI planning model requires that both the ecological and social resilience are valued as the two important aspects of the system. This indicates that both the ecological and the social-culture development goals are valued for the GI planning (as it mentioned in the section 1.2 and 1.3). The development goal of GI for SCP was to form a functional system in order to enhance the system resilience, and this system should be equipped with improved GI planning methods and strategies (technical and biological dimensions); and more complete guidance and instructional policy (planning knowledge and policy dimensions) (see section 3.2.1 of the Chapter 3).

Therefore, the supporting ecological and technical explorations such as the BSPF developing (main results illustrated in Chapter 5) and the related assessment indicators selected in the KPIF（see Chapter 6）are mainly for reinforcing ecological resilience. Furthermore, the social-economic factors were taken into consideration during the selection of the KPIF（see Chapter 6）and policy discussions and recommendations, which are part of the strategies for enforcing social resilience have been discussed in this chapter（section 7.4.

7.5.3 The Recommended Steps for the Implementation of GI Planning

As highlighted previously, it is necessary to incorporate the three-scale GI planning as an integrated model into the urban planning system in China, with the top-level master planning emphasised in the theoretical planning model. As the multi-functionality, connectivity, and polycentricism of the system can support the tight feedback loops and the information from landscape systems, the GI system with these characteristics can respond to challenges with more rapid and smooth adaptation in order to improve the resilience of the region (Qiu, 2018, Bajc and Stokman, 2018). Therefore, for GI planning, it is ideal to have a macro-scale network planning, serving as the top planning level and should be linked to the master planning of the urban and rural spatial planning system. Thus, a system network plan with multiple functionalities and benefits should be the long-term goal of any city or region at macro-level.

In terms of the implementation practices, while setting a network plan at the early stage is required, the main start point of the GI planning implementation is the meso scale key nodes (strategic positions),which should be set as the short-term goal. Thus, the GI network formation starts from the repair of key nodes, then corridors and then network. For example, in the case of Liangnong Siming lake watershed area of Ningbo as discussed in this thesis, the realization that the Daxi River Estuary Wetland is a very important GI node for SCP. Thus, it was identified as the starting point of the ecological restoration by both the local government and the SCP experts and its restoration became primary focus.

It is evident that both the GI planning and implementation had some limitations during this the case study. For the Siming lake case study, some typical barriers were financial restrictions and approach limitations such as how to develop an optimal planning and how to assesses different GI scenarios. Consequently, this research started with the exploration of traditional trends and needs of resilience and sustainability, and this was then followed by the BSPF and the KPIF to support the planning and assessment of the developed model. As a result, both the short- term GI plan with the sponge node design for the Daxi wetland and the long-term GI network identification method were developed.

The demolition of some existing buildings (as recommended) involved multiple stakeholders, and the corresponding compensation cost of such demolitions are relatively high for the short -term planning, and the rebuilding of other nodes and GI corridor face similar financial difficulties. Hence, it is suggested that the implementation process is done gradually over a longer period of time in order to minimise such incurred financial strain.

In the meso-scale key node, with respect to Daxi estuary node, the current 5-year plan mainly includes these key steps. Firstly, the designation of the meso-scale node as the target management unit for attaining the hydro-effects requirement of the Sponge City (ATRCR ⩾ 75%). Secondly, due to financing constraint being an obstacle to the implementation of GI designs, no more GSI facility is needed at the micro-scale for the short-term GI plan in order to minimise cost. Thirdly, the functional renewal of architectural units, including the demolition of the old building and the transformation of the existing buildings in the micro- scale area, are suggested as the primary task for the restoration of the waterfront sponge node.

The long-term plan which supports the future 10 years implementation mainly includes these key steps. Firstly, due to the aging of existing buildings in Daxi wetland node, when all these buildings gradually became non-functional, these buildings will be demolished, and the natural wetland landscape will be restored for the whole node area. Secondly, the gradual repair of other GI nodes to establish a healthy and complete corridor around the lake. Finally, the repair of connected river corridors is required to form the whole GI network. In addition to this, the life cycle assessment on the ongoing performance of the multi-functional GI is also recommended within the whole GI delivery process.

7.6 Summary

The developed more resilient BSPF model is a holistic high-quality GI planning and assessment model for SCP towards more resilient and sustainable urban development, which followed Steinitz 'Geodesign framework'. This process model was further developed in two phases containing 14 steps (three step preliminary research, six step macro scale research and five step meso- and micro scale research).

As a result, two basic stages were integrated for the development and application of the BSPF model to the Siming Lake watershed. This includes the preliminary stage focused on the planning strategies and the multiple scenarios development, and the in-depth research stage focus on the identification of the multi-functional landscape patterns and the comprehensive assessment of the multiple design scenarios. Hence, this study focuses on the novel development of the multiple scenarios and formulation of a KPIF-based comprehensive evaluation system for the meso- and micro scale of the GI plan. This developed multi-system framework enables the assessment and design of alternative futures and facilitates the quantitative and thorough evaluation of the multiple GI design scenarios at the meso- and micro-scale of SCP for around sustainability with multi-benefits balancing. Hence, this research has innovatively reshaped the GI planning and assessment system with systematic organization of the planning and evaluation processes, as well as the evaluation support

provided by the KPIF tool.

Furthermore, based on the application of the BSPF model and KPIF tool to the Siming Lake watershed case study, a water resilient centred, multi-objective GI network model with more resilience was identified for the entire watershed. Based on this GI network, the planning and management policy and guidance at different scales are discussed. Hence, the linking of GI planning to the urban and rural spatial planning system is recommended, as well as designating the meso-scale plans and guidance as the key link of the management system. Additionally, as multifunctionality and connectivity were highlighted as significant indices of the landscape function. For Jiangnan area, the green and blue water network system with the waterfront conservational buffer areas are the key skeleton of the whole GI spatial network for cities of the Jiangnan water net area. Therefore, the natural connection of the river/lake water network, and the restoration of the waterfront wetland key nodes are the fundamental principle and key tasks of the multi-objective GI spatial network establishment for more resilient water security landscape pattern rebuilding. The waterfront areas as the core spatial elements of the network are linked with biodiversity, which is significant to the ecology. Also, these waterfront areas are also closely associated with the natural experiences and fitness activities that can improve the health and wellbeing of city dwellers. Hence, the developed GI network requires consideration of various encompassing factors such as flood risk and water resilient management, biodiversity and related water sensitive areas and natural recreational experiences from vernacular natural and cultural landscape. These multifunctional overlapping analysis for a holistic, high-quality model with enhanced resilience.

Moreover, in order to better cope with the uncertainties associated with flooding and the climate change, such as flood frequency and peak flow increase, the use of GI for effectively enhancing the resilience of cities and towns requires higher level execution for achieving higher landscape security and safety pattern requirements of the specific local region. Regarding the Siming Lake case study, the entire watershed should at least control the bottom line of GI land use conservation which corresponds to the low security pattern. However, the GI corresponding to higher security level recommendations should be implemented for more resilient sustainable development pursers, as well as satisfying other sustainable development requirements with social, environmental and economic influencing factors.

Finally, the comparison of the different scenarios at meso and micro-scale were carried out based on the comprehensive quantitative evaluation performed with the developed KPIF. The scenario SS4 (with 81.6% BC + 5.4% RG + 13.0% PP) with the best comprehensive benefits was recommended. Additionally, suggestions for GI design and management strategies at meso-and micro-scale for the high-quality transition toward sustainability include:

- Assigning the meso-scale node as the target management unit with consideration of the balanced multi-benefits (hydrological, environmental, economic and social benefits) is recommended with no more GIS facilities for the micro-scale unit at the present stage under the lacking of fund condition.
- With the significance of funding as a hindrance to GI design implementation, the demolition of dangerous old buildings and the transformation and upgrading of existing building functions in the meso- and micro-scale areas are the primary restoration tasks for the current waterfront ecological space.

Chapter 8 Conclusions

8.1 Summary of the Research Significance and the Research Objectives

In recent years, the Sponge City program (SCP), as a sustainable stormwater management approach, has gained prominence as the national strategic program. GI has been adopted as an important measure of SCP. In the construction of sponge cities, a high-quality GI delivery with comprehensive assessments of multi-benefits is required for the transitional development towards sustainability.

As reviewed in the section 2.5 of Chapter 2 and the section 3.2 of the Charter 3, in light of the uncertain impact of factors such as climate change, flood frequency and peak increase, GI is utilised as an effective tool to enhance the resilience of cities and towns. Additionally, it has been adopted globally as a crucial measure in various well-established strategies for stormwater management practices. After recognition as one of main strategies for achieving sustainability and resilience, GI was adopted in China as the main tool in building sponge cities (Demuzere et al., 2014, Lovell and Taylor, 2013, Grant et al., 2013, Foster et al., 2011, Gaffin et al., 2012, Kim and Kim, 2017, Schifman et al., 2017, Simić et al., 2017, Pauleit et al., 2019). This is mainly because GI can help cities and towns enhance their ability to resist and prevent disasters, as well as their ability to recover from the impact of such disasters, better known as the city’s resilience.

Moreover, as reviewed in the literature review chapters, many researchers found that GI has multiple benefits, such as maximizing ecosystem services, restoring watershed, and preserving biodiversity(Emmanuel and Loconsole, 2015, Gill et al., 2007, Matthews et al., 2015). Additionally, GI and its ecosystem services provide an important framework for linking ecological infrastructure to social infrastructure (McDonnell and MacGregor-Fors, 2016). This has the potential to enhance both ecological and social resilience, and ultimately benefit both humans and ecosystems

As illustrated in the section 1.4.1 of chapter 1, the resilience and superior transitional requirements are addressed by further research on improving the cross-scale planning and assessment strategies and methods of the high-quality GI design. This mainly involves two specific aspects based on the literature review, field research and interviews:

1. First, in terms of the macro-scale, there are only few studies on how to define and develop the multi-objective framework to focus on the goal of more resilience for sustainability, as well as the related enhancements of human health and well-being during the GI spatial planning and land use management strategies; and

2. Secondly, in terms of the meso-and micro- scale research, there is a lack of comprehensive and quantitative evaluation system. This evaluation system is defined as the sustainability key performance indicator frame work (KPIF) with a set of key performance indicators (KPIs), which would be helpful in optimizing GI design scheme and selecting the optimal solutions with multi-benefits trade-offs to assist in planning decision making.

These two aspects were the identified as the main research gaps in this field that needs to be strengthened. Thus, with focus on these gaps, a holistic cross-scale exploration was carried out in this research in response to the high-quality traditional trends and needs. A high-quality GI planning and assessment model for attaining multi-dimensional improvement in 'resilience' and 'sustainability' strategies was developed for the Jiangnan water net area. This model provides both ecological resilience enhancing strategies and social resilience enhancing tactics for macro-scale mapping and identification of the GI network with amplifying and synergistic functionality, while integrating comprehensive assessment KPIF to support robust decision-making based on the quantitatively evaluation of multiple scenarios at meso- and micro scale.

8.2 Summary of the Main Findings

8.2.1 The Development of the BSPF Model with the KPIF and Its Application with Siming Lake Case Study

The developed more resilient BSPF model is a high-quality GI planning and assessment model for SCP with more resilient and sustainable strategies, which followed Steinitz 'Geodesign Framework'. This study further develops the process model in two phases containing 14 steps (three-step preliminary research, six-step macro scale in-depth research and five-step meso- and micro scale research). The developed BSPF framework further emphasis the impact evaluation before and after planning, by refining the impact evaluation process and integrating a more comprehensive KPIF that enable the quantitative evaluation of the design alternatives.

Additionally, two basic stages were included for the more resilient BSPF model development and its application to the Siming Lake watershed:

- The preliminary stage which is focused on the planning strategies and the multiple scenarios development; and
- The in-depth research stage focused on the identification of multi-functional landscape pattern and the comprehensive assessment of the multiple design scenarios.

Moreover, this study focuses on the innovative development of the multiple alternative design scenarios and the KPIF-based comprehensive evaluation system of the meso- and micro- scale of the GI model for SCP. With the application of the holistic BSPF model and the KPIF-supported evaluation to the Siming Lake Watershed area, a multi-scale research was executed. The main findings are summarized as follows:

With reference to the macro-scale section of the research, the GI comprehensive overlay analysis was carried out based on the various landscape security patterns (SPs) analysis (including water resilient landscape SPs, biotic landscape conservation SPs and the vernacular landscape conservation network). The water resilient cantered multi-functional GI networks were identified based on the three levels of comprehensive landscape security patterns. The main structure of the GI networks, mostly including the key nodes and corridors with corresponding buffer areas for the waterfront conservation were suggested.

These are collectively proposed as the strategic points of the multi-functional GI network. It was found that the key node with the maximum human interference was the estuary wetland area of Daxi River, which was selected as the meso-and micro scale research focus area.

Regarding the meso-scale comprehensive evaluation of the multiple scenarios, the main results are summarised below:

1. The developed model utilized ten scenarios of the GSI facilities, except for SS3 (with an ATRCR of 73.75, which is slightly lower the project control standard). With this exception, they all attained the ATRCR control standard of 75%, and an increase of approximately or more than 10% in comparison with SS12(status quo benchmark). Additionally, they exhibited an increase of nearly 7% compared to SS11 (basic GI scenario without GSI).

2. SS4 (with 81.6% BC + 5.4% RG + 13.0% PP) and SS1 (with 87.0% BC + 13.0% PP) consistently presented the best performance for hydro-environmental benefits in terms of both water quantity and quality control based on long-term rainfall data.

3. Other benefits were evaluated quantitatively based on interviews for the comparison of comprehensive performance of the ten GI scenarios. It was discovered that the SS4 combination had the best comprehensive benefits in this case study.

4. Hence, SS4, the best performance scenario was recommended for the short-term GI general plan for the Liangnong Siming wetland construction, scheduled to be implemented within 3 – 5 years after further optimisation of the detailed design stage.

Pertaining to the micro-scale evaluation, with the assumption that the micro-area is also designed with a target of 75% annual runoff control rate as recommended in the sponge City guidelines, four scenarios were developed. According to the simulation results, the hydrological effects of scenario ZS1 and ZS3 are generally better than scenario ZS3 and ZS4. Furthermore, the scenario ZS3 was identified as the best performance with the maximum comprehensive benefits after evaluation with the developed KPIF.

8.2.2 The Related Policy and Management Strategies Recommendations

8.2.2.1 Management Policy Recommendations

Firstly, based on these identification and evaluation results, the following strategies and policy recommendations are proposed. From the cross-scale holistic planning perspective, the linkage of the GI plans to the overall urban and rural spatial planning system and allotting the meso-scale as the key links of the management system are suggested. Improving the polycentricity of the whole watershed by management the waterfront important wetland nodes with priority.

For the Siming Lake study, GI design and management coordination strategies at meso- and micro-scale for the high-quality transitional SCP toward sustainability were further discussed and proposed. Three key suggestions were proffered.

1. The designation of the meso-scale node as the target management unit for attaining the hydro-effects requirement

of the Sponge City (ATRCR≥ 75%);

2. Due to financing constraint being an obstacle to the implementation of GI designs, no GIS facility is integrated at the micro-scale for the short-term GI plan in order to minimise cost; and
3. The functional renewal of architectural units, including old building demolition and the transformation and upgrading of existing building functions in the micro- scale area are suggested as the priority task for the restoration of the waterfront sponge node.

8.2.2.2 The Implementation Guidance Recommendations

In terms of the Jiangnan area represented by the Siming Lake case, the water network system is the key skeleton of the whole GI spatial network. The natural connection of the river - lake water network, the connection of the waterfront corridor, as well as the restoration of the waterfront wetland nodes are the core of the whole multi-objective GI Spatial network. Moreover, multi-objective restoration based on more resilient strategies of the waterfront areas are valued with the transitional development trends and needs. The waterfront areas are linked with the biodiversity, which is significant for the entire ecosystem. Additionally, the waterfront areas are also linked with nature experiences and fitness activities, which can greatly improve the health and wellbeing of city dwellers. Hence, the GI network requires essential consideration of flood risk and water sensitivity, as well as biodiversity and natural experience based on the local natural and cultural landscape characteristics.

Moreover, considering the unpredictability of the flood patterns with the climate change, the utilization of GI to enhance the resilience of cities and towns needs to be applied at a higher level, meeting higher landscape security pattern requirements of the corresponding higher level landscape safety pattern of local conditions. For the Siming Lake case study, it was suggested that the whole watershed should at least control the bottom line of GI land use which corresponds to the low security pattern. To better cope with unpredictability of the future with enhanced resilience, the GI model conforming to a higher security level should be implemented for sustainable development purposes according to specific land use conditions, as well as taking consideration of the social and economic influencing factors.

8.3 The Novelty and Main Contributions

The novelty of this research is primarily reflected in its reshaping of the overall sponge project through the development of a high-quality GI planning and assessment model. This model incorporates more resilient and sustainable strategies and provides solutions with multi-dimensional and multi-spatial functionalities. This involves the exploration of the high-quality GI delivery and assessment of key processes, the KPIF development with consideration of human health and wellbeing enhancement, as well as the planning policy and strategies supporting more resilient cities transitional designs.

Furthermore, the developed GI model was examined using multi-disciplinary perspectives from both natural and social science. Natural Science's SWMM modelling was utilised for the simulation analysis of hydrological effects while field investigation and GIS spatial mapping analysis, interview and AHP evaluation methods was adopted from social science. The relevance of this research is not only limited to finding solutions to the environmental resilience or exploring how to cope and/or deal with uncertain challenges and environmental issues posed by climate change. It also encompasses the social resilience, which addresses how to better serve people by designing to enhance people and nature co-existence within the built environment for improving human health and wellbeing. Moreover, the discipline of the urban planning and landscape design requires management of the relationship between people and land, exploration of balanced urban development solutions for guiding sustainable policies and strategies while accounting for the challenges of the contemporary society. Waterfront is a significant element of GI as it integrates a water resilient space with significant ecological section of biodiversity, and a relaxation spot for humans while experiencing nature. In view of the multi-disciplinary requirements of this transformative era, this research adopts comprehensive perspectives for developing more resilient GI model for Jiangnan Water network area.

In addition, the novelty of this research on the macro scale is reflected by the focus on the GI network identification tactics for designing more resilient cities with emphasis on improved human health and wellbeing. The GI network identification is based on SPs with key elements of the network identified via process analysis of key landscape ecological processes.

Furthermore, using Siming Lake as case study, with ideal water resilient landscape as the goal, three-levels of multi-objective and more resilient network with corresponding SPs were also identified. Additionally, the main structure of the GI network was identified, including key nodes, strategic points, and the main corridors. Moreover, this developed multi-objective GI framework is not only for rebuilding the water resilient landscape pattern, but also promoting biodiversity and protecting natural and cultural landscapes. Simultaneously, this model enhances social resilience and improving of the health and well-being of the city's residents. These responds to the high-quality transitional needs of modern cities in China and globally.

Finally, the novelty of this research in the meso- and micro- scale is mainly reflected by the development of a comprehensive and quantitative evaluation system, defined as KPIF. With Liangnong Siming Lake as case study, the developed KPIF incorporates 15 multi-objective KPIs using AHP and SWMM, with three basic criteria: 'Environmental Performance', 'Economic and adaptability performance', and 'Social-cultural Performance and wellbeing Performance'. The KPIF is an evaluation tool which can be directly used for decision-making and comparison between similar designs /plans or programs (Sun et al., 2020). It can also provide a reference not only for the Jiangnan area of China as represented by the case study, but also for the multi-objective evaluation of high-quality SCPs in other regions.

8.4 Limitation of the Research and Future Directions

8.4.1 Limitation of Research and Future Directions

Firstly, the more resilient BSPF is mainly supporting the high-quality GI planning for SCP. As the high-quality GI for 'Sponge city' transitional development requires multi-objective restoration of waterfront areas towards more ecological resilience, biodiversity conservation is an essential layer of the whole GI network (Hölting et al., 2019, Hansen and Pauleit, 2014). Hence, based on the landscape SP methodology and the EI planning methods, in order to represent a wild range of habitats in this region, a series targeted indicator species is selected for the Siming Lake watershed. Among these species, the waterfront area linked wetland indicator species (water birds and amphibians) is more important for the final pattern restoration. The water sensitive areas of the GI network analysis are mainly correlated with these wetland habitats linked landscape processes (Lin et al., 2015).

In this study, based on the landscape SPs theory and Taizhou EI mapping methods, two typical representative species of wetland were targeted as the indicator species to identify the GI conservation areas by analysing their ecological processes linked habitat and behaviour range areas. This provides useful reference for the GI network conservation and guides of the waterfront land use for the multi-objective restoration of the sponge node in the SCP. During the commencement of the ecological repair work of the SCP, the establishment of higher level of lake conservation management as well as implementation areas based on the GI network requirements is suggested.

On this basis, several key wetland nodes implementing the high-quality GI restoring work should be selected for long-term ecological monitoring of wetland nodes. Further assessment of important patches for the biodiversity conservation requires detailed monitoring data. It was observed that in comparison with other lakes that have established national nature conservation zones, Siming Lake area lacks long-term biodiversity monitoring research, as well as the publication of the relevant data. Hence, the normalized tracking and monitoring research on some water birds and amphibians, and relevant biodiversity statistics still need to be stressed in the future after the implementation of key wetland node rebuilding GI.

In future research, further landscape investigation and assessment work will be performed with detailed landscape coverage evaluation and habitat utilization status of more important and valued species. This can also be carried out in the conjunction with more accurate prediction of flood risk changes. Additionally, the collaboration and cooperation with biological experts and hydrogeology experts, as well as communication with experts from various background must be emphasized in the GI planning process at the macro-scale in the future. This kind of multi-disciplinary cooperation is necessary for achieving a more comprehensive and effective multi-functional GI network for SCP in support of sustainable urban development.

Secondly, for the meso-and micro-scale research, for problem clarification and easier implementation, the proposed KPIF of similar SCP must contain a set sustainability KPIs. Theses selected KPIs stands for biodiversity, 'Economic and adaptability performance', and 'Social-cultural Performance and wellbeing Performance', such as improvements of recreational, aesthetic, and natural education opportunities, as well as supporting the spiritual, psychological and mental health and wellbeing benefits.

With regards to the Siming Lake case study, six KPIs for stormwater quantity and quality performance were selected, including ATRCR, SS reduction rate, COD reduction rate, TN reduction rate, TP reduction rate and peak reduction rate, which can be calculated based on the simulations with SWMM or other typical hydrological software. In addition, the value calculation of these non-hydrological environmental KPIs were based on the expert's interviews. This is mainly done for the GI scenarios developed at the design stage, and the evaluation of the multiple scenarios was done at the planning stage. For the comprehensive evaluation of the implemented projects, the KPIs can be calculated in combination with specific monitoring equipment and post-use surveys.

Moreover, with the implementation of this project, the meso-scale wetland park node of Siming Lake waterfront area will be updated within 3-5 years. Therefore, a follow-up research of the post-use evaluation, thus a life cycle evaluation and whole-process tracking can be carried out with the data collection for improvement of the monitoring equipment and user's involvement.

8.4.2 Summary of the Contributions

This study focuses on the more resilient and the sustainable development requirements of a high-quality urban transition. The cross-scale systematic exploration and development of a high-quality GI delivery model for Jiangnan water net area was done with Siming Lake watershed utilised as a case study. This model highlighted a holistic sustainable GI design with comprehensive evaluation strategies of the overall design stage.

Additionally, this model incorporates GI planning strategies for enhanced resilience to mutually benefit nature and people. This exploration emphasizes that multifunctional GI system should not only focus on the sustainability of the ecological resilience, but also improve the level of humanized design and social resilience simultaneously. This research developed design tactics and the evaluation KPIF that focused on achieving nature and people coexisting more resilient space, which are defined as the GI delivery strategies for cities in need of this transitional period.

The development of the BSPF model with the KPIF, as well as its application, evaluation, optimisation, and policy discussions collectively provide useful design and evaluation tools and useful references for similar planning projects for both designers and administrators. Thus, it contributes to promoting the GI planning to achieve high-quality transitional SCP construction with reinforced resilient and sustainable transformation.

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Appendices

Appendix 1.1 List of Main Ecosystem Services and their Related Sub-Categories

Table A.1.1 List of Main Ecosystem Services and their Related Sub-Categories (Zhang and Ramírez, 2019)

Ecosystem services	Definition	Benefits to human welfare and society (examples)	Ecosystem services
Regulating services	The maintenance of essential ecological processes and life support systems, which influence climate, hydrological, and biochemical cycles, earth surface processes, and biological process		
1	Local climate regulation	The influence and regulating of ecosystems on local climatic conditions	Favor local climate, such as alleviating the urban heat island effect
2	Global climate regulation	The impact on global climatic conditions	Control global warming
3	Gas regulation	The effect of ecosystems on bio-geochemical cycles	CO2/O2 balance, ozone layer protection
4	Disturbance prevention	The ability of ecosystems to moderate adverse natural events and environmental disturbances	Flood prevention, storm protection, human and city safety
5	Natural hazard mitigation	The mitigation of natural disasters	Creation of stable life-communities and safe environments for human societies
6	Air quality regulation	The improvement of air quality through ecological processes and components	Access to cleaner air
7	Water regulation	The regulation of	Irrigation and

Ecosystem services	Definition	Benefits to human welfare and society (examples)	Ecosystem services
		runoff and river discharge	drainage maintenance
8	Water purification	The purification and filtering of water	Water security for human, flora, and fauna
9	Groundwater recharge	Underground water supplement	Optimal allocation of water resources
10	Soil retention	The role of vegetation root matrix and soil biota in soil retention	Maintenance of agricultural productivity and prevention of damage due to soil erosion
11	Soil formation	The weathering of rock, accumulation of organic matter	Maintenance of crop productivity and natural productive soils
12	Nutrient regulation	The role of biota in storage and recycling of nutrients	Local plant growth, migration of animals
13	Pollination	The role of biota in the movement of floral gametes	Improvement of biodiversity, protection of certain species
14	Waste treatment/disposal	The dilution, assimilation, and chemical re-composition of certain waste	Pollution control, filtering of dust particles, noise abatement, space for solid waste disposal, effective use of organic wastes
15	Erosion protection	The role of vegetation and biota in erosion protection	Flood, agriculture, and coastal erosion protection
16	Biological control	Population control through trophic-dynamic relations	Control of pests and diseases, reduction of herbivory
17	Disease regulation	The role of biota in disease control	Prevention of the outbreak of diseases
Provisioning services	The provision of natural resources		
18	Food	The conversion of solar energy into wild edible plants and animals	Provision of certain food production for humans (e.g., crops, livestock,

Ecosystem services	Definition	Benefits to human welfare and society (examples)	Ecosystem services
			capture fisheries, fodder)
19	Water	The filtering, retention, and storage of fresh water	Consumptive use (e.g., domestic water, irrigation, industrial use)
20	Raw materials	The conversion of solar energy into biomass	Human construction (i.e., wood and sturdy fibers for building, oils and latex for industrial purposes, and energy resources like fuel-wood and bio-chemicals)
21	Genetic resources	Genetic material and evolution in wild plants and animals	Maintain cultivars productivity, improvement of individual quality and adaptability, such as resistance to pests
22	Medicinal resources	Variety in chemical substances in natural biota	Maintenance of human health, e.g., drugs and pharmaceuticals, animal tests
23	Ornamental resources	Variety use of wild plants and animals for ornamental purposes	Resources for fashion, handicrafts, jewelry, pets, worship, decoration, souvenirs, etc.
Habitat services	The provision of habitats (suitable living spaces) for wild plant and animal species and the maintenance of ecological processes		
24	Habitation	Suitable living spaces for wild plants and animals, and sustainable spaces for human living	Maintenance of biodiversity

Ecosystem services	Definition	Benefits to human welfare and society (examples)	Ecosystem services
25	Nursery	Suitable reproduction habitats	Provision of breeding and nursery areas for commercially harvested species
Cultural services	The provision of opportunities for recreation, cognitive development, relaxation, spiritual reflection, to the benefit of human beings		
26	Identity	The strong feeling of belonging to a particular community	Improve sense of regional, cultural, landscape identity, etc.
27	Aesthetic	Attractive landscape features and views	Satisfy human enjoyment of scenery and aesthetic experience
28	Recreation	Landscapes for (potential) recreation or amusement use	Provision of daily or periodic recreation activities for people
29	Cultural and artistic	Variety in natural and semi-natural features with cultural and artistic value	Nature and cultural landscape as sources of inspiration to promote the development of art and cultural industry (e.g., film, painting, architect, literature, etc.)
30	History and religion	The spiritual and historical value of nature and semi-natural landscapes	Religious purposes and historical values (natural and semi-natural ecosystems and features, and heritages values)

Ecosystem services	Definition	Benefits to human welfare and society (examples)	Ecosystem services
31	Science and education	The scientific and educational value of nature	Natural elements and features provide a range of opportunities for scientific research, excursion, nature study, environmental education
32	Tourism	Variety in nature with (potential) tourism value	Travel to natural ecosystems for eco-tourism

Appendix 4.1 Ethic Form and Questionnaires

Form A.4.1.1 Research Ethics Checklist for Staff and Research Students

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

University of Nottingham Ningbo

Research Ethics Checklist for Staff and Research Students

[strongly informed by the ESRC (2012) Framework for Research Ethics]

A checklist should be completed for every research project or thesis where the research involves the participation of people, the use of secondary datasets or archives relating to people and/or access to field sites or animals. It will be used to identify whether a full application for ethics approval needs to be submitted.

You must not begin data collection or approach potential research participants until you have completed this form, received ethical clearance, and submitted this form for retention with the appropriate administrative staff.

The principal investigator or, where the principal investigator is a student, the supervisor, is responsible for exercising appropriate professional judgement in this review.

Completing the form includes providing brief details about yourself and the research in Sections 1 and 2 and ticking some boxes in Sections 3 and/or 4, 5, 6. **Ticking a shaded box in Sections 3, 4, 5 or 6 requires further action by the researcher**. Two things need to be stressed:

- Ticking one or more shaded boxes does not mean that you cannot conduct your research as currently anticipated; however, it does mean that further questions will need to be asked and addressed, further discussions will need to take place, and alternatives may need to be considered or additional actions undertaken.
- Avoiding the shaded boxes does not mean that ethical considerations can subsequently be 'forgotten'; on the contrary, research ethics - for everyone and in every project – should involve an ongoing process of reflection and debate.

The following checklist is a starting point for an ongoing process of reflection about the ethical issues concerning your study.

SECTION 1: THE RESEARCHER(S)

1.1: Name of principal researcher:Jing Sun

1.2: Status: ☐ Staff

☒ Postgraduate research student

1.3: School/Division: Architecture and Built Environment

1.4: Email address: zx19795@nottingham.edu.cn

1.5: Names of other project members (if applicable):

1.6: Names of Supervisors (if applicable):Ali Cheshmehzangi

	Yes	No
1.7: I have read the University of Nottingham's Code of Research Conduct and Research Ethics (2010) and agree to abide by it: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx	☒	☐
1.8: (If applicable) I have read the University of Nottingham's e-Ethics@Nottingham: Ethical Issues in Digitally Based Research (2012) and agree to abide by it. http://www.nottingham.edu.cn/en/research/documents/e-ethics-at-the-university-of-nottingham.pdf	☒	☐
1.9: When conducting research on people (Section 5) I will prepare both a participant consent form as well as a *participant information sheet.* I am aware that the following templates are available on the Ethics webpage: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx • Participant consent form 1 • Participant Information Sheet English and Chinese	☒	☐

SECTION 2: THE RESEARCH

2.1: **Title of project:**

The Design and Evaluation of Green Infrastructure Models for Sponge City Program transition towards Resilient and Sustainable Construction

2.2: **Research question(s) or aim(s)**

This research is carried out as an exploratory study aimed at improving the quality of green infrastructure planning, in order to promote the resilience and sustainability of green infrastructures for sponge city program (SCP) for the high-quality transitional construction in China. The main research questions posed to experts are:

1. What are the key factors that determines green infrastructures for SCP towards reinforced resilience and sustainable transitional delivery?
2. What are the main criteria for performance evaluations based on their experience and past projects within china?
3. Should health and wellbeing considerations be included in the design and performance evaluation?
4. What are the lessons learned from past projects that might help inform on future improvements in the planning process?
5. Are there other suggested considerations, approach of implementation or policy recommendations that would improve the quality of planning green infrastructure for SCP within China?

2.3: **Summary of method(s) of data collection**

This research is an explorative study with data collection primarily carried out via questionnaire and interviews. The interview approach adopted is semi-structured interviews and in addition further data are collated based on the questionnaires (see the attachment questionnaire). The interviewees are mainly the urban planning experts of universities and local design institute, as well as the experts in the fields of urban planning and urban construction management who are working for the different governmental departments in China.

2.4: **Proposed site(s) of data collection**

The data collection sites will mostly depend on the experts' preference and availability. This could be done either onsite using the meeting rooms in UNNC or offsite, at the expert's place of work. Furthermore, the option of conducting this interview online would also be available for convenience to experts who may be out of Ningbo.

2.5: **How will access to participants and/or sites be gained?**

The participants (experts) would be mainly obtained by mutual referrals. The academic experts are mainly recommended by my research supervisor in UNNC and external researchers of Peking University and Zhejiang University, while the experts from governmental departments are recommended by colleagues and previous contacts from the Ningbo Housing and Urban-Rural Development Bureau.

Additionally, experts from the following four groups will be targeted as participants in the interview: (1) experts from the Ningbo Sponge City Construction Leading Group Office; (2) experts form the Ningbo of natural resources and planning Bureau and the Ningbo Housing and Urban-Rural Development Bureau; (3) experts form local design institute; and (4) experts form universities, such as , Peking university, Beijing University of Civil Engineering and Architecture, Zhejiang University, and Tongji University.

SECTION 3: RESEARCH INVOLVING USE OF SECONDARY DATASETS OR ARCHIVES RELATING TO PEOPLE

If your research involves use of secondary datasets or archives relating to people all questions in Section 3 must be answered. If it does not, please tick the 'not relevant' box and go to Section 4.

NOT RELEVANT	☐

Please answer each question by ticking the appropriate box.

	Yes	No
3.1: Is the risk of disclosure of the identity of individuals low or non-existent in the use of this secondary data or archive?	☒	☐
3.2: Have you complied with the data access requirements of the supplier (where relevant), including any provisions relating to presumed consent and potential risk of disclosure of sensitive information?	☒	☐

SECTION 4: RESEARCH INVOLVING ACCESS TO FIELD SITES AND ANIMALS

If your research involves access to field sites and/or animals all questions in Section 4 must be answered. If it does not, please tick the 'not relevant' box and go to Section 5.

NOT RELEVANT	☐

Please answer each question by ticking the appropriate box.

	Yes	No
4.1: Has access been granted to the site?	☒	☐
4.2: Does the site have an official protective designation of any kind?	☐	☒
If yes, have the user guidelines of the body managing the site a) been accessed?	☐	☐
b) been integrated into the research methodology?	☐	☐

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4.3: Will this research place the site, its associated wildlife and other people using the site at any greater physical risks than are experienced during normal site usage?	☐	☒
4.4: Will this research involve the collection of any materials from the site?	☐	☒
4.5: Will this research expose the researcher(s) to any significant risk of physical or emotional harm?	☐	☒
4.6: Will the research involve vertebrate animals (fish, birds, reptiles, amphibians, mammals) or the common octopus (Octopus vulgaris) in any capacity?	☐	☒
If yes, will the research with vertebrates or octopi involve handling or interfering with the animal in any way or involve any activity that may cause pain, suffering, distress or lasting harm to the animal?	☐	☐

SECTION 5: RESEARCH INVOLVING THE PARTICIPATION OF PEOPLE

If your research involves the participation of people all questions in Section 4 must be answered.

Please answer each question by ticking the appropriate box.

A. General Issues

	Yes	No
5.1: Does the study involve participants age 16 or over who are unable to give informed consent? (e.g. people with cognitive impairment, learning disabilities, mental health conditions, physical or sensory impairments?	☐	☒
5.2: Does the research involve other vulnerable groups such as children (**aged under 16**) or those in unequal relationships with the researcher? (e.g. your own students)	☐	☒
5.3: Will this research require the cooperation of a gatekeeper* for initial access to the groups or individuals to be recruited?	☐	☒
5.4: Will this research involve discussion of sensitive topics (e.g. sexual activity, drug use, physical or mental health)?	☐	☒
5.5: Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?	☐	☒
5.6: Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	☐	☒

5.7: Will this research involve people taking part in the study without their knowledge and consent at the time?	☐	☒
5.8: Does this research involve the internet or other visual/vocal methods where people may be identified?	☐	☒
5.9: Will this research involve access to personal information about identifiable individuals without their knowledge or consent?	☐	☒
5.10: Does the research involve recruiting members of the public as researchers (participant research)?	☐	☒
5.11: Will the research involve administrative or secure data that requires permission from the appropriate authorities before use?	☐	☒
5.12: Is there a possibility that the safety of **the researcher** may be in question?	☐	☒
5.13: Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐	☒

**Gatekeeper- a person who controls or facilitates access to the participants*

B. Before starting data collection

	Yes	No
6.12: My full identity will be revealed to all research participants.	☒	☐
6.13: All participants will be given accurate information about the nature of the research and the purposes to which the data will be put. (*An example of a Participant Information Sheet is available for you to amend and use* at xxxxx) *http://www.nottingham.edu.cn/en/research/documents/participant-information-sheet-in-english-and-chinese.doc*	☒	☐
6.14: All participants will freely consent to take part, and, where appropriate, this will be confirmed by use of a consent form. (An example of a Consent Form is available for you to amend and use at: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx)	☒	☐
6.15: All participants will freely consent to take part, but due to the qualitative nature of the research a formal consent form is either not feasible or is undesirable and alternative means of recording consent are proposed.	☐	☒

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6.16: A signed copy of the consent form or (where appropriate) an alternative record of evidence of consent will be held by the researcher.	☒	☐
6.17: It will be made clear that declining to participate will have no negative consequences for the individual.	☒	☐
6.18: Participants will be asked for permission for quotations (from data) to be used in research outputs where this is intended.	☒	☐
6.19: I will inform participants how long the data collected from them will be kept.	☒	☐
6.20: Incentives (other than basic expenses) will be offered to potential participants as an inducement to participate in the research. (Here any incentives include cash payments and non-cash items such as vouchers and book tokens.)	☐	☒
6.21: For research conducted within, or concerning, organisations (e.g. universities, schools, hospitals, care homes, etc) I will gain authorisation in advance from an appropriate committee or individual.	☒	☐

C. During the process of data collection

	Yes	No
6.25: I will provide participants with my University contact details, and those of my supervisor (*where applicable*) so that they may get in touch about any aspect of the research if they wish to do so.	☒	☐
6.26: Participants will be guaranteed anonymity only insofar as they do not disclose any illegal activities.	☒	☐
6.27: Anonymity will not be guaranteed where there is disclosure or evidence of significant harm, abuse, neglect or danger to participants or to others.	☒	☐
6.28: All participants will be free to withdraw from the study at any time, including withdrawing data following its collection.	☒	☐
6.29: Data collection will take place only in public and/or professional spaces (e.g. in a work setting	☒	☐
6.30: Research participants will be informed when observations and/or recording is taking place.	☒	☐
6.31: Participants will be treated with dignity and respect at all times.	☒	☐

D. After collection of data

	Yes	No
6.32: Where anonymity has been agreed with the participant, data will be anonymised as soon as possible after collection.	☒	☐
6.33: All data collected will be stored in accordance with the requirements of the University's Code of Research Conduct	☒	☐
6.34: Data will only be used for the purposes outlined within the participant information sheet and the agreed terms of consent.	☒	☐
6.35: Details which could identify individual participants will not be disclosed to anyone other than the researcher, their supervisor and (if necessary) the Research Ethics Panel and external examiners without participants' explicit consent.	☒	☐

E. After completion of research

	Yes	No
6.37: Participants will be given the opportunity to know about the overall research findings.	☒	☐
6.38: All hard copies of data collection tools and data which enable the identification of individual participants will be destroyed.	☒	☐

If you have not ticked any shaded boxes, please send the completed and signed form to the School's Research Ethics Officers, with any further required documents, for approval and record-keeping.

If you have ticked *any* shaded boxes **you will need to describe more fully how you plan to deal with the ethical issues raised by your research.** Issues to consider in preparing an ethics review are given below. Please send this completed form to the Research Ethics Officer who will decide whether your project requires further review by the UNNC Research Ethics Sub-Committee and/or whether further information needs to be provided.

Please note that it is your responsibility to follow the University's Research Code of Conduct and any relevant academic or professional guidelines in the conduct of your study. This includes providing appropriate information sheets and consent forms, and ensuring confidentiality in the storage and use of data. For guidance and UK regulations on the latter, please refer to the Data Protection Policy and Guidelines of the University of Nottingham:

Policy - http://www.nottingham.ac.uk/%7Ebrzdpa/local/dp-policy.doc

Guidelines -http://www.nottingham.ac.uk/~brzdpa/local/dp-guidance.doc

Any significant change in the project question(s), design or conduct over the course of the research should be notified to the School Research Ethics Officer and may require a new application for ethical approval.

Signature of Principal Investigator/Researcher: *Jing Sun*

Signature of Supervisor (where appropriate): *Ali Cheshmehzangi*

Date：October 26, 2020

Research Ethics Panel response

☑ the research can go ahead as planned

☐ further information is needed on the research protocol (see details below)

☐ amendments are requested to the research protocol (see details below)

School REO ....

Date 30 Oct 2020

A. LIST OF POINTS TO CONSIDER WHEN SUBMITTING AN ETHICS REVIEW (taken from ESRC (2012) Framework for Research Ethics).

Risks

1. Have you considered risks to:

    the research team?

    the participants? Eg harm, deception, impact of outcomes

    the data collected? Eg storage, considerations of privacy, quality

    the research organisations, project partners and funders involved?

2. Might anyone else be put at risk as a consequence of this research?

3. What might these risks be?

4. How will you protect your data at the research site and away from the research site?

5. How can these risks be addressed?

Details and recruitment of participants

6. What types of people will be recruited? Eg students, children, people with learning disabilities, elderly?

7. How will the competence of participants to give informed consent be determined?

8. How, where, and by whom participants will be identified, approached, and recruited?

9. Will any unequal relationships exist between anyone involved in the recruitment and the potential participants?

10. Are there any benefits to participants?

11. Is there a need for participants to be de-briefed? By whom?

Research information

12. What information will participants be given about the research?

13. Who will benefit from this research?

14. Have you considered anonymity and confidentiality?

15. How will you store your collected data?

16. How will data be disposed of and after how long?

17. Are there any conflicts of interest in undertaking this research? Eg financial reward for outcomes etc.

18. Will you be collecting information through a third party?

Consent

19. Have you considered consent?

20. If using secondary data, does the consent from the primary data cover further analysis?

21. Can participants opt out?

22. Does your information sheet (or equivalent) contain all the information participants need?

23. If your research changes, how will consent be renegotiated?

Ethical procedures

24. Have you considered ethics within your plans for dissemination/impact?

25. Are there any additional issues that need to be considered ? Eg local customs, local 'gatekeepers', political sensitivities

26. Have you considered the time you need to gain ethics approval?

27. How will the ethics aspects of the project be monitored throughout its course?

28. Is there an approved research ethics protocol that would be appropriate to use?

29. How will unforeseen or adverse events in the course of research be managed? Eg do you have procedures to deal with any disclosures from vulnerable participants?

Form A.4.1.2 Interview Questionnaire on Green Infrastructure Planning and Implementation Suggestions for Sponge City Program

Interview Questionnaire on Green Infrastructure Planning and Implementation Suggestions for Sponge City Program

海绵城市建设项目中的绿色基础设施规划实施建议访谈问卷

Dear expert,

To improve the quality of green infrastructure planning, especially to promote the scientific delivery of green infrastructure for sponge city program (SCP) in China, this interview is carried out. And this interview is used to support an academic research of Nottingham University Ningbo China aiming at achieving the goal of resilient and sustainable development for the high-quality transitional construction. Therefore, this interview is conducted mainly for provides reference for the academic research. I will not disclose your personal identity and opinion information without your permission.

Looking forward to your valuable opinions of the topic on green infrastructure development for SCP.

尊敬的专家，您好!

为提升绿色基础规划水平，特别是推动绿色基础实施在中国海绵项目中的科学实施，进而向着更有韧性和可持续发展的目标转型发展，特开展本访谈。本访谈主要为宁波诺丁汉大学建筑与环境系的一项关于绿色基础设施的研究提供参考依据，该研究的主要目标是推动绿色基础设施向着更有韧性和更可持续的方向转型发展。我不会在未经您允许的情况下，公开您的身份和个人观点信息，期待您为绿色基础设施发展规划提出宝贵意见。

1.Are you familiar with green infrastructure? For example, community parks, bio retention design, rainwater gardens, constructed wetlands?

1.您熟悉绿色基础设施吗？比如，社区公园、生物滞留设计、雨水花园、人工湿地？

2.Are you familiar with the concept of sponge city? Do you think there is a difference between sponge city and green infrastructure and what is their relationship?

2. 您熟悉海绵城市概念吗，您觉得海绵城市和绿色基础设施有区别吗，他们是什么关系？

3.What do you think are the main objective functions of an ideal sponge city park design?

3.您觉得一个理想的海绵城市公园设计的主要目标功能应该有哪些？

4. In terms of green infrastructure planning, taking the case of Siming Lake Sponge Park as an example, do you think it should be allowed to have access to the park area to carry out leisure activities, or should it be set as an independent nature reserve area the people are no allowed to go into the site?

4.您觉得绿色基础设施，以四明湖案例中的滨湖海绵公园为例，在设计中是应该考虑承载和设计人们的游览休闲活动，还是应该设立不进入的独立保护区？

5. Do you think that in addition to the requirements of water management, are there other performance evaluation factors should be incorporated into performance evaluation system of the sponge park?

5.您觉得海绵节点公园设计方案评估中，除了水管理方面的要求，还有需要有其他方面的绩效考核因素吗？比如经济方面，或者社会文化方面的绩效考核？

6.Do you think that humanization design and health promotion for people should be included in the evaluation system of green infrastructure projects especially for the neighborhood scale sponge park? If so, what factors should be considered?

6.您觉得应该把人性化和健康促进纳入海绵公园这样的社区尺度的绿色基础设施方案评估体系吗？如果需要，应对主要考虑哪些因子呢？

7.Do you think economic factors should be included in the performance evaluation system of neighborhood scale green infrastructure with the case of Siming Lake Sponge Park? What economic factors do you think should be considered in the design stage?

7.您觉得经济方面的因素是否应该纳入评估体系？您觉得在方案设计阶段就应对考虑到的经济要素有哪些呢？

8.What are the difficulties in promoting the implementation of green infrastructure projects, especially sponge park projects?

8.您觉得目前推动绿色基础设施项目，特别是海绵公园类的项目实施的困难有哪些？

9.If the design of sponge Park involves the demolition of multiple buildings belonging to different stakeholders on the plot, should the government demolish all of these buildings at one time, or should they be demolished by stages in your opinion?

9.您觉得海绵公园设计中如果涉及地块上归属不同利益主体的多个建筑的拆迁，那么政府是应该一次性全部拆除这些建筑，还是需要考虑分期逐步拆除呢？

10. Which scale of green infrastructure do you think is more important? Take Siming Lake watershed in Ningbo as an example, is it a park on a sponge node at a neighborhood scale, or a wider GI network, or a smaller site sub-unit of the node? And how to coordinate these scales with SCP implementation process?

10.您认为绿色基础设施的哪个尺度更重要，以宁波四明湖项目为例，是社区尺度海绵节点上的公园，更小尺度地块，还是更大范围的 GI 网络，这几个尺度的规划应该如何协调？

11.Do you think GI needs to link with the current official planning system? If there is a need to link with the official planning system, what measures or policy suggestions should be taken into consideration?

11.您觉得 GI 需要和当前规划体系对接吗？如果需要对接行政规划体系(官方规划)，GI 在规划体制完善方面应对有什么样的应对措施或者政策建议？

Form A.4.1.3 Research Questionnaire on Evaluation system of High-quality Green Infrastructure for Neighbourhood Scale Sponge City Programmes

Research Questionnaire on Evaluation system of High-quality Green Infrastructure for Neighbourhood Scale Sponge City Programmes

Dear experts,

In order to scientifically evaluate the implementation scheme of high-quality green infrastructure for neighbourhood scale sponge city programmes, this study is carried out. In this study, the analytic hierarchy process (AHP) is used for evaluation. The following is the hierarchy evaluation system (table 2). Please evaluate the relative importance of the paired indicators for different levels refer to table 1.

The survey is conducted for academic research, and the results are only used for data analysis. Your participation is of great significance to our work.

Thank you very much for your support and assistance!

Table 1 Scale of relative importance

Intensity of relative importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between two adjacent judgment values
The reciprocal value	The judgment value of the importance of the element *i* and *j* is r_{ij}, and the reciprocal value is $1/r_{ij}$

Table 2 The hierarchy evaluation system

First Level /Target Hierarchy (A)	Second Level /Criterion Hierarchy (B)		Third level/ Indicator Hierarchy (C)	Symbol	Remarks
Comprehensive Assessment	Environmental performance(B1)	Water quantity regulating services (C1)	Annual total runoff control rate （ATRCR）	D1	The percentage of the accumulated annual rainfall in the site that accounts for the total annual rainfall, which was calculated according to the analysis and calculation of 30 years rainfall statistics
			Peak reduction rate`	D2	The percentage of the peak reduction after construction Calculated based on the simulation of the designed return period
		Water quality regulating services (C2)	SS reduction rate	D3	Typical pollutants reduction rate for total suspended solids (SS)
			COD reduction rate`	D4	Typical pollutants reduction rate for chemical oxygen demand (COD)
			TN reduction rate	D5	Typical pollutants reduction rate for total nitrogen (TN)
			TP reduction rate	D6	Typical pollutants reduction rate for total phosphorus (TP)
		Habitat supporting services （C3）	Promotion of Biodiversity	D7	The level of the enhance of biodiversity, measured by the richness of the species of each design.
	Economic and adaptability performance (B2)	Cost saving	Construction cost saving	D8	The level of GI facilities construction cost saving
			Maintenance cost saving	D9	The level of GI facilities maintenance cost saving
		Benefit efficiency	Facility adaptability	D10	The level of GI measures operation effect according to local soil, plants and horological conditions.
			Efficient land use	D11	The level of efficient land use measured by If the facility needs more land to reach the same water quality or quantity control goal
	Social-cultural and wellbeing performance (B3)	landscape cultural services	Promotion of landscape aesthetics and identity	D12	The level of providing attractive landscape features and views, and contributing to a high-quality built environment with strong felling of belonging to a particular community or space

			Promotion of educational opportunities	D13	The level of providing scientific and aesthetic education activities
		Health and wellbeing supporting services	Recreational and wellbeing improvements for all times a year.	D14	The level of providing recreational activities richness with assessable times of a year
			Recreational and wellbeing improvements for all people	D15	The level of providing recreational activities and space richness, with improvements of health and wellbeing for all people

1. Please evaluate the first level indicators: the relative importance of environmental performance and economic with adaptability performance

Environmental performance a VS Economic performance with adaptability performance																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

2. Please evaluate the first level indicators: the relative importance of environmental performance and social-cultural with wellbeing performance

Environmental performance VS Social-cultural performance with wellbeing performance																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

3. **Please evaluate the first level indicators: the relative importance of social-cultural with wellbeing performance and economic with adaptability performance**

Social-cultural with wellbeing performance VS Economic with adaptability performance																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

4. Please evaluate the second level indicators: the relative importance of water quantity regulation and water quality regulation

Water quantity regulation VS Water quality regulation																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

5. **Please evaluate the second level indicators: the relative importance of water quantity regulation and habitat support**

Water quantity regulation VS Habitat support																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

6. **Please evaluate the second level indicators: the relative importance of the water quality regulation and habitat support**

Water quality regulation VS Habitat support																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

7. **Please evaluate the second level indicator: the relative importance of cost saving and benefit efficiency**

Cost saving VS Benefit efficiency																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

8. **Please evaluate the second level indicators: landscape cultural service function and the relative importance of health and well-being supporting services**

landscape cultural service function VS **health and well-being supporting services**																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

9. **Please evaluate the third level indicators: the relative importance of annual total runoff control rate and peak reduction rate**

annual total runoff control rate VS peak reduction rate																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

10. **Please evaluate the third level indicators: the relative importance of Typical pollutants reduction rate for total suspended solids (SS reduction rate) and Typical pollutants reduction rate for chemical oxygen demand (COD reduction rate`)**

SS reduction rate VS COD reduction rate`																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

11. Please evaluate the third level indicators: the relative importance of typical pollutants reduction rate for total suspended solids (SS reduction rate) and typical pollutants reduction rate for chemical oxygen demand (COD reduction rate)

SS reduction rate VS TN reduction rate																
9:1 ○	8:1 ○	7:1 ○	6:1 ○	5:1 ○	4:1 ○	3:1 ○	2:1 ○	1:1 ○	1:2 ○	1:3 ○	1:4 ○	1:5 ○	1:6 ○	1:7 ○	1:8 ○	1:9 ○

12. Please evaluate the third level indicators: the relative importance of typical pollutants reduction rate for total suspended solids (SS reduction rate) and typical pollutants reduction rate for total phosphorus (TP)

SS reduction rate VS TP reduction rate																
9: 1 ◯	8: 1 ◯	7: 1 ◯	6: 1 ◯	5: 1 ◯	4: 1 ◯	3: 1 ◯	2: 1 ◯	1: 1 ◯	1: 2 ◯	1: 3 ◯	1: 4 ◯	1: 5 ◯	1: 6 ◯	1: 7 ◯	1: 8 ◯	1: 9 ◯

13. Please evaluate the third level indicators: the relative importance of typical pollutants reduction rate for chemical oxygen demand (COD reduction rate) and typical pollutants reduction rate for total nitrogen (TN)

COD reduction rate VS TN reduction rate																
9: 1 ◯	8: 1 ◯	7: 1 ◯	6: 1 ◯	5: 1 ◯	4: 1 ◯	3: 1 ◯	2: 1 ◯	1: 1 ◯	1: 2 ◯	1: 3 ◯	1: 4 ◯	1: 5 ◯	1: 6 ◯	1: 7 ◯	1: 8 ◯	1: 9 ◯

14. Please evaluate the third level indicators: the relative importance of typical pollutants reduction rate for chemical oxygen demand (COD reduction rate) and typical pollutants reduction rate for total phosphorus (TP)

COD reduction rate VS TP reduction rate																
9: 1 ◯	8: 1 ◯	7: 1 ◯	6: 1 ◯	5: 1 ◯	4: 1 ◯	3: 1 ◯	2: 1 ◯	1: 1 ◯	1: 2 ◯	1: 3 ◯	1: 4 ◯	1: 5 ◯	1: 6 ◯	1: 7 ◯	1: 8 ◯	1: 9 ◯

15. Please evaluate the third level indicators: typical pollutants reduction rate for total nitrogen (TN) and typical pollutants reduction rate for total phosphorus (TP)

TP reduction rate VS TN reduction rate																
9: 1 ◯	8: 1 ◯	7: 1 ◯	6: 1 ◯	5: 1 ◯	4: 1 ◯	3: 1 ◯	2: 1 ◯	1: 1 ◯	1: 2 ◯	1: 3 ◯	1: 4 ◯	1: 5 ◯	1: 6 ◯	1: 7 ◯	1: 8 ◯	1: 9 ◯

16. Please evaluate the third level indicators: the relative importance of construction cost saving and maintenance cost saving

construction cost saving VS																
9: 1 ◯	8: 1 ◯	7: 1 ◯	6: 1 ◯	5: 1 ◯	4: 1 ◯	3: 1 ◯	2: 1 ◯	1: 1 ◯	1: 2 ◯	1: 3 ◯	1: 4 ◯	1: 5 ◯	1: 6 ◯	1: 7 ◯	1: 8 ◯	1: 9 ◯

17. Please evaluate the third level indicators: the relative importance of facility adaptability and efficient land use

Facility adaptability VS Efficient land use																
9: 1 ◯	8: 1 ◯	7: 1 ◯	6: 1 ◯	5: 1 ◯	4: 1 ◯	3: 1 ◯	2: 1 ◯	1: 1 ◯	1: 2 ◯	1: 3 ◯	1: 4 ◯	1: 5 ◯	1: 6 ◯	1: 7 ◯	1: 8 ◯	1: 9 ◯

18. Please evaluate the third level indicators: the relative importance of promotion of landscape aesthetics and identity and promotion of educational opportunities

Promotion of landscape aesthetics and identity VS Promotion of educational opportunities																
9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

19 Please evaluate the third level indicators: the relative importance of recreational and wellbeing improvements for all times a year and recreational and wellbeing improvements for all people

Level of recreational and wellbeing improvements for all times a year VS Level of recreational and wellbeing improvements for all people																
9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Many thanks!

Name: Date:

Appendix 5.1 The Slope Map, Gradient Map and Land Use Mapping Results of Year 2017 of the Siming Lake Water Shed Area

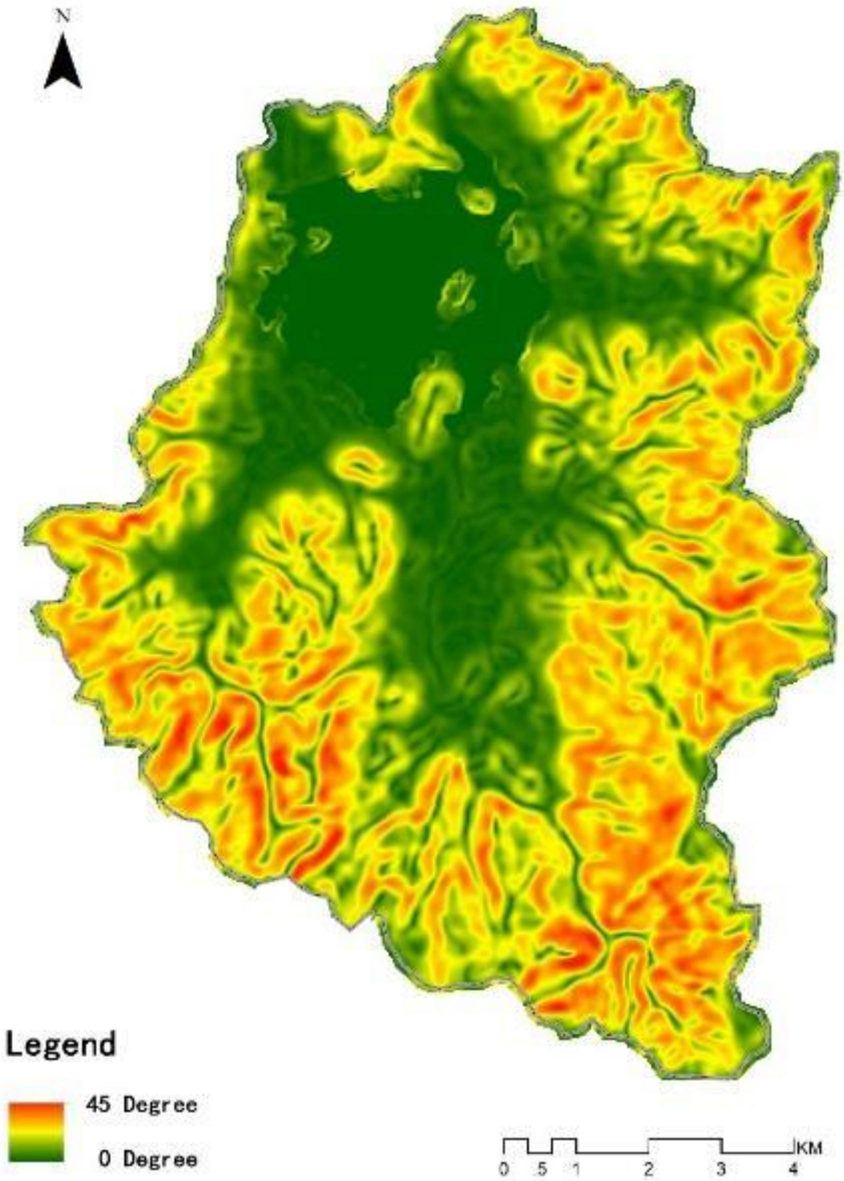

Figure A.5.1.1 The Slope Map of the Siming Lake water shed area

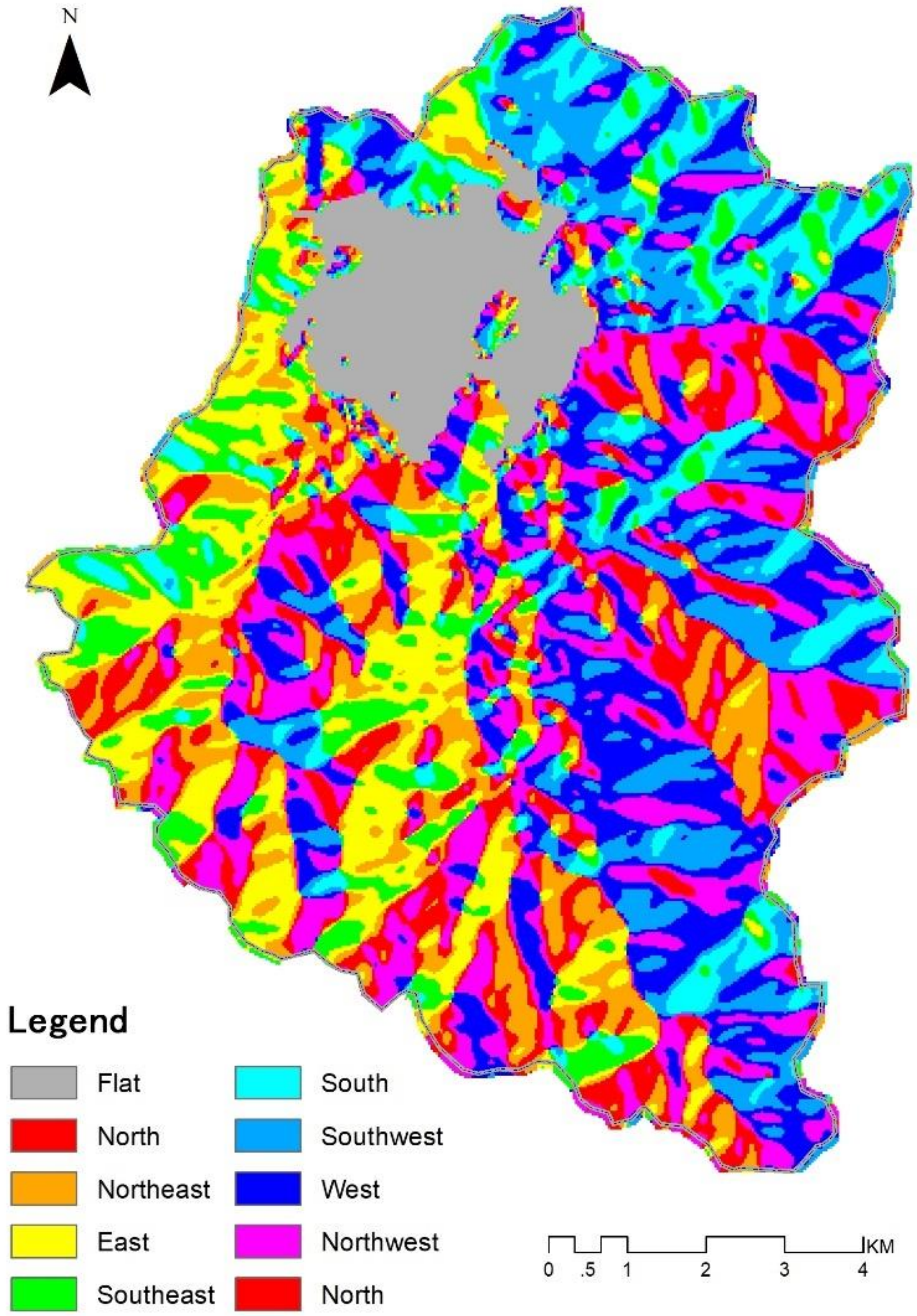

Figure A.5.1.2 The Gradient Map of the Siming Lake water shed area

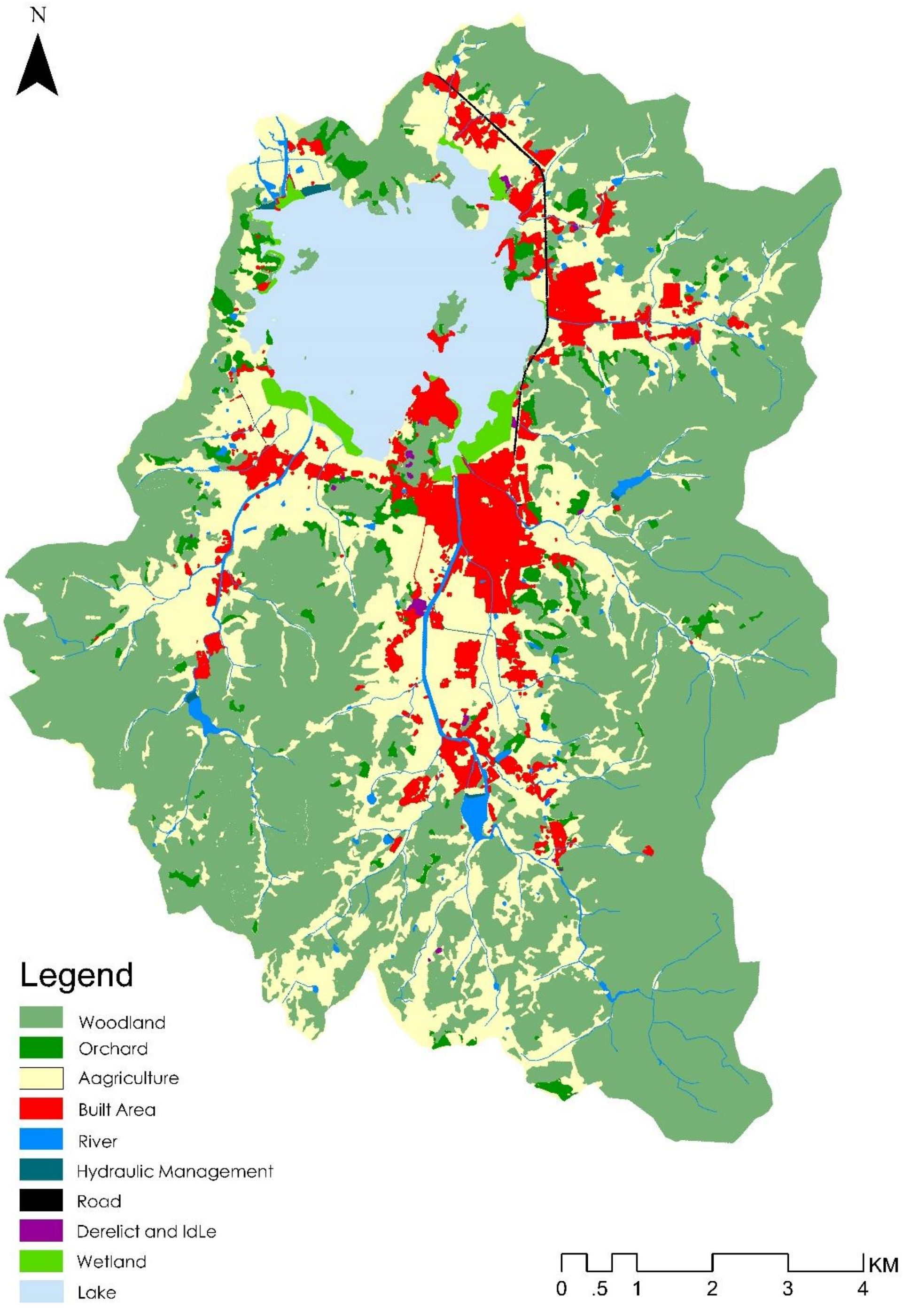

Figure A.5.1.3 The land use mapping results of year 2017

Appendix 6.1 The Water Levels of the Flood Return Period, the List of Vernacular Landscape Resource and Vernacular Landscape Points

Table A.6.1.1 The water levels of the corresponding flood return period

Flood Return Period	5 years	10 years	20 years	50 years	100 years	500 years	1000 years
Maximum Flood Level (m)	16.40	16.85	17.28	17.48	17.88	18.89	19.24

Table A.6.1.2 List of vernacular landscape resource points in the Siming watershed

Number	Name of the recreation resource point
1	Yaoyuan cherry picking farm
2	Peach blossom hill cherry orchard
3	Dongbo villa cherry orchard
4	Qiu jia waxberry base
5	East Lake cherry picking farm
6	Crescent bay cherry base
7	Yuyao city liangnong jia xu orchard
8	Gaonan waxberry base
9	Gaonan cherry base
10	Siming mountain Shanmen
11	lookout pavilion
12	Siming Lake
13	waxberry base of Siming Lake
14	Siming Lake dam foot cherry picking point
15	Siming Lake dam
16	Lake view platform
17	Yuyao city lake west farm
18	Conference center of robotics conference
19	MeiFu thatched cottage
20	Dongming ancient temple
21	Dongshan caves
22	Monument to the revolutionary martyrs in the Siming mountainy
23	The estuarine of Liangnong main river to Siming Lake
24	East zhejiang academy
25	Zhejiang provincial committee of the party school of the Siming mountain branch
26	Zhengmeng street
27	Dongxi village Tianzian picking spot
28	Dongli farm

Number	Name of the recreation resource point
29	The site of the temporary representative meeting of people from all circles of the eastern zhejiang province
30	Wugui building
31	Liangnong ancient town
32	New fourth army east zhejiang general team political department
33	New fourth army east zhejiang headquarters
34	Son ancestral temple
35	Chen hanlin's former residence
36	Xiwei wetland and forest
37	Henglu cherry picking base
38	odern agricultural demonstration base of Siming Lake
39	Hengao main river
40	Jinguoyuan cherry picking base
41	Hexi waxberry base
42	Hexi herry orchard
43	Liangnong Dagao street
44	Yuyao Jinling ecological farm
45	Guanyuan cherry picking spot
46	Houyangao cherry picking spot
47	Dongxi waxberry base
48	Baiyunchan tample
49	Baiyun temple cherry picking spot
50	Liangma village cherry base
51	Liangma waxberry base
52	Strawberry orchard
53	Hexi cherry Liangnong picking spot
54	Wangxiang waxberry base
55	Xianrengu fairy fruit land
56	Yueguogong temple
57	Aaotang cherry picking spot
58	Mengshan ecological farm
59	Laingnong orchard
60	Yuyao city Shanlushibawan orchard
61	Caijia reservoir cherry picking spot
62	Bishui bay cherry base
63	Yaonan Guole farm
64	Lu xun Art Branch school of east Zhejiang college
65	Daxi farm cherry orchard
66	Shanzhai waxberry base
67	Guiyu waxberry base
68	Ganxuan cherry orchard
69	Practice base cherry orchard
70	Hengkantou village
71	Red hills natural scenic

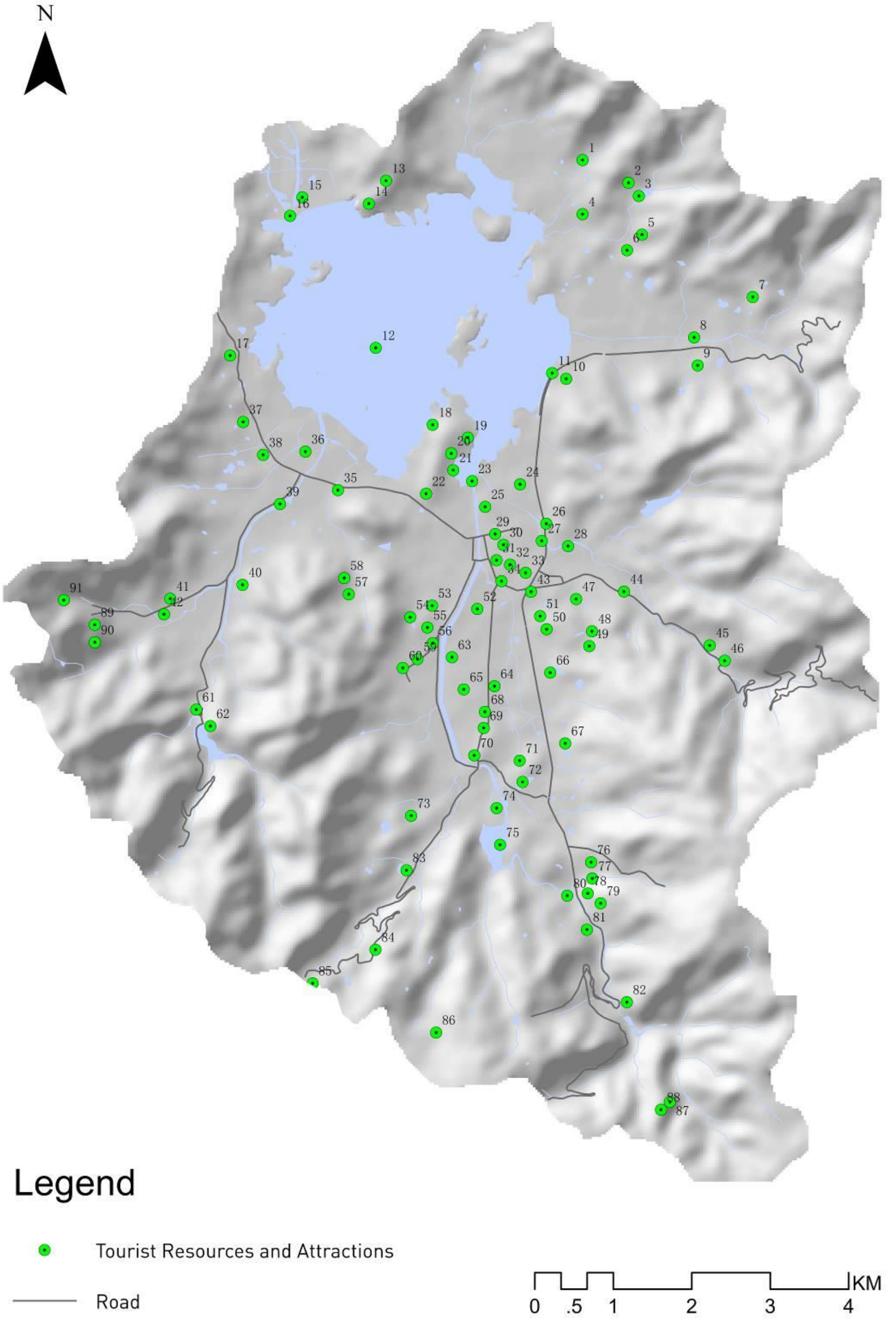

Figure A.6.1.3 Location mapping of the local landscape recreational resource points