Mapping and Valuing Urban Ecosystem Services in the Greater Kuala Lumpur Metropolitan City

Karen Thivya Lourdes

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Abstract

Unprecedented urban growth has placed increasing pressure on cities globally. The intensive land use changes that follow urban growth often result in the degradation of natural ecosystems, with adverse consequences for the wellbeing of urban populations as the potential delivery of ecosystem services diminishes. This thesis: 1) investigated the spatial distribution of urban ecosystem services in Greater Kuala Lumpur, Malaysia, 2) tested the utilisation of two off-the-shelf ecosystem service valuation tools (SolVES and InVEST) in supporting urban planning, and 3) investigated the extent to which urban ecosystem services and urban biodiversity have been considered as part of sustainable development planning in Kuala Lumpur.

Chapter One outlines the aim and scope of the thesis and sets out the research questions addressed in subsequent chapters. It also introduces key concepts and tools used in this thesis.

Chapter Two provides a systematic review on the nature and extent of urban ecosystem services research in Southeast Asia in the last two decades. The chapter showed that while urban ecosystem services research in the region has burgeoned over the last five years, research is unequally distributed across Southeast Asia. The chapter found that research often assessed regulating and cultural urban ecosystem services at a landscape scale, though research on synergistic and tradeoff interactions between services were limited. It showed that research was biased towards more developed cities and countries in the region, which may overlook less-developed nations as well as rural and peri-urban regions and their unique preferences towards urban ecosystem services management. The chapter discusses challenges and considerations for urban ecosystem services research in Southeast Asia, given the region's unique and diverse socioeconomic characteristics, and outlines knowledge gaps addressed in subsequent chapters in this thesis.

Chapter Three provides a novel assessment of the distribution of social values for ecosystem services across the Greater Kuala Lumpur metropolitan area. A public participatory GIS survey and the SolVES tool were used to determine residents' development preferences and perceptions of social values. The chapter reveals that the heterogenous spatial distribution of social values across urban and peri-urban areas was

influenced by residents' development preferences and sociodemographic characteristics. The non-spatial differences in residents' characteristics and development preferences were found to manifest as larger differences in the spatial distribution of social values, leading to conflicts between groups with different development preferences. The work highlights locations where there is potential for land-use conflict with respect to future urban expansion, emphasising the need for further public engagement and the consideration of multiple perspectives in designing cities.

Chapter Four presents a systematic method for integrating the outcomes of a multiple urban ecosystem services assessment to support green infrastructure development across urbanising landscapes. The chapter combines biophysical InVEST ecosystem service models with multicriteria suitability analysis to provide spatially explicit recommendations on targeted areas for five future green infrastructure strategies. The realised distribution of urban ecosystem services was high in semi-natural areas and low in urban areas, highlighting the lack of green infrastructure in dense urban areas. The ecosystem services-based suitability analysis showed that some parts of the study area were suitable for the implementation of more than one type of green infrastructure strategy. The findings suggest that the selection of appropriate green infrastructure strategies must consider the varying degree of urban development in the study area and the implication of these strategies for local communities.

Chapter Five investigates the extent to which ecosystem services and urban biodiversity were considered in sustainable urban development academic and policy literature in Malaysia. The literature review and content analysis indicated that academic literature and policy documents emphasised the aesthetic and cultural aspects of nature in urban design but rarely captured the full suite of ecosystem services found in cities. The chapter also identified several ecological knowledge gaps in academic literature and policy documents and calls for broader ecological perspectives in sustainable urban development research and policy initiatives. Recommendations are made for the adoption of stronger nature-based approaches through the incorporation of ecosystem services in urban planning. The chapter also highlights the need for critical assessments on the effectiveness of sustainable planning policies in the region, to ensure that sustainability initiatives are on track to meet their objectives.

Chapter Six concludes this thesis by synthesising the contributions of the work and highlights challenges for future research in integrating urban ecosystem services to support planning of sustainable and resilient cities.

The concept of urban ecosystem services investigated in this thesis will become increasingly important in planning sustainable cities globally, but more so in the Global South, where cities are growing rapidly and are more vulnerable to the impacts of climate change. The research conducted in this thesis contributes to the limited and exigently needed body of urban ecosystem services knowledge in a tropical Global South city. The novel application of ecosystem service valuation tools and methods demonstrated in this thesis can be adapted for urban areas in Southeast Asia and other Global South regions to support the planning of resilient urban ecosystems.

Preface

The work presented herein was completed as a body of work for this thesis and is substantially my own work. Publications and contributions from others based on the content of this thesis is as follows:

The content in **Chapter 2** was published as:

Lourdes, K.T., Gibbins, C.N., Hamel, P., Sanusi, R., Azhar, B. and Lechner, A. (2021). A Review of Urban Ecosystem Services Research in Southeast Asia. *Land*, 10, 40. https://doi.org/10.3390/land10010040

The content in **Chapter 3** is based on a paper in preparation:

Lourdes, K.T., Gibbins, C.N., Sherrouse, B., Semmens, D., Hamel, P., Sanusi, R., Azhar, B. and Lechner, A. (in preparation). Mapping Social Values for Ecosystem Services to Support Urban Planning in a Rapidly Developing Asian Megacity.

The content in **Chapter 4** was submitted for publication as:

Lourdes, K.T., Hamel, P., Gibbins, C.N., Sanusi, R., Azhar, B. and Lechner, A. (in review) Planning for Green Infrastructure Using Multiple Urban Ecosystem Service Models and Multicriteria Suitability Analysis, *Landscape and Urban Planning*.

The content in **Chapter 5** is based on a paper in preparation:

Lourdes, K.T., Gibbins, C.N., Hamel, P., Sanusi, R., Azhar, B. and Lechner, A. (in preparation). Guiding Sustainable Urban Development In Kuala Lumpur: Shifting The Focus To Ecosystem Services

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Chapter 1 Introduction

1.1 Introduction

Unprecedented urban growth has placed increasing pressure on urban areas globally (Gret-Regamey et al., 2020; Nagendra *et al.,* 2018). Urban ecosystems in the Global South are at greater risk due to the disproportionately higher rates of population growth and urbanisation, particularly in parts of Africa and Asia (United Nations, 2018). The land use changes that take place to cater to the infrastructure demands of urban populations often result in ecosystem degradation and biodiversity loss (Gómez-Baggethun et al., 2013; MEA, 2005), which can be further exacerbated by poor planning (Jones, 2014). Moreover, the range of urban environmental challenges that accompany rapid urbanisation further diminish the potential provision of ecosystem services, adversely affecting the wellbeing of urban populations (Mialhe *et al.*, 2019; Lechner *et al.*, 2020; Estoque *et al.*, 2020; Baker *et al.*, 2021). Hence, over recent years many commentators have called for cities that are liveable, sustainable and resilient, and for the application of ecosystem services in urban planning to support this goal (Díaz et al., 2015; Lafortezza, Chen, van den Bosch, & Randrup, 2018; United Nations, 2015). Additionally, there is renewed emphasis on urban resilience in the post-pandemic era (Asian Development Bank, 2020b; East Asia Forum, 2021), and in light of climate change adaptation and commitments (Chausson et al., 2020; Lafortezza et al., 2018; UNEP, 2021b).

Urban ecosystem services are the benefits derived by humans from ecological infrastructure in or near built environments (Gómez-Baggethun et al., 2013). Ecological infrastructure, such as forests, parks, lakes and wetlands, provide a wide range of urban ecosystem services such as microclimate regulation, wastewater management, mitigation of urban heat islands and floods, and habitats for urban wildlife, as well as recreational opportunities (Irvine *et al.*, 2015; Chaiyarat *et al.*, 2018; Wolff *et al.*, 2018; Bogdan *et al.*, 2019; Sritongchuay *et al.*, 2019; Sanusi and Bidin, 2020). The Economics of Ecosystems and Biodiversity (TEEB) framework for ecosystem services describes four broad ecosystem service categories - provisioning, regulating, supporting and cultural services (Figure 1.1) (TEEB, 2010b). The framework captures both the ecological and biophysical aspects of nature's benefits to humans, as well as the sociocultural aspects of human-nature relationships. As urban ecosystem services support the physical and mental wellbeing of urban populations, maintaining the function of urban ecosystems and ensuring equal access for urban residents is essential for planning (Burkhard & Maes, 2017).

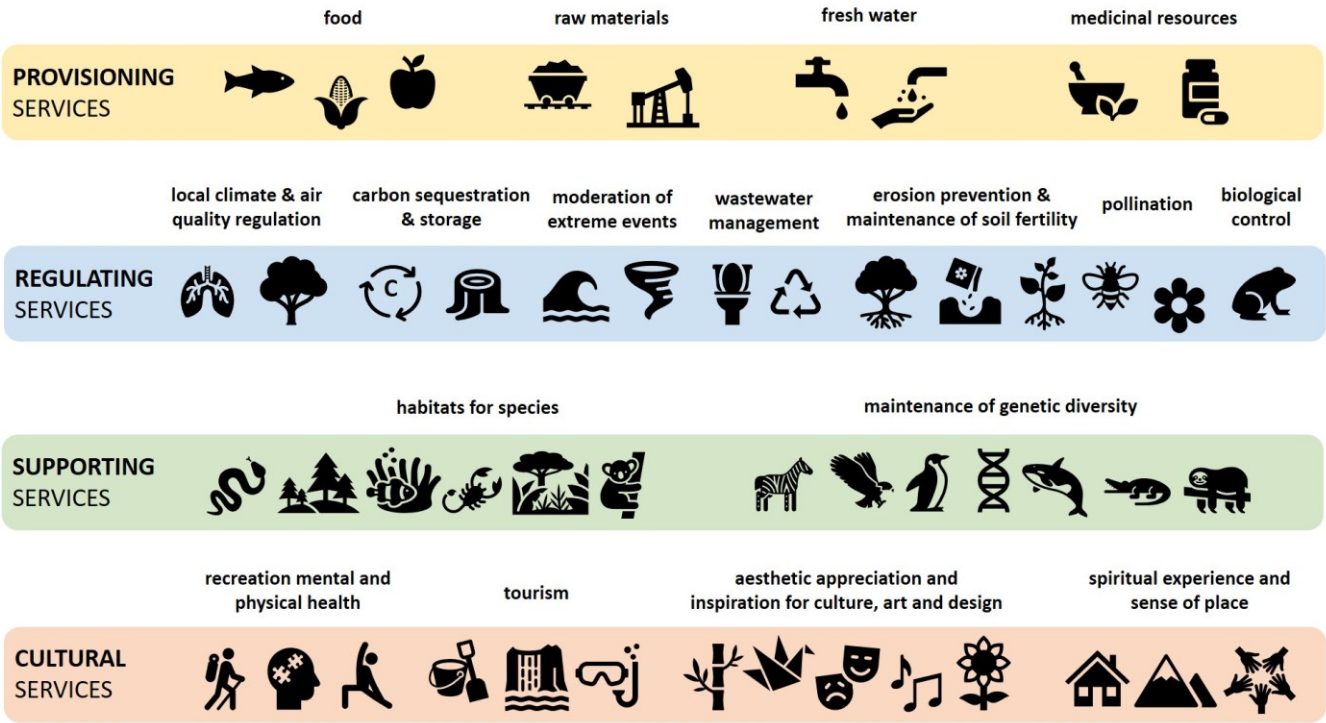

Figure 1.1 The list of ecosystem services relevant to urban areas according to The Economics of Ecosystems and Biodiversity (TEEB) framework. Examples of ecosystem services are presented according to their categories: provisioning, regulating, supporting and cultural services.

The management of ecosystem services and its incorporation in urban planning requires an understanding of the spatial distribution of services and their complex interactions (Dang *et al.*, 2021). Assessments and valuations of urban ecosystem services help characterise and quantify their value to humans. Ecosystem services valuations can be undertaken from various perspectives, where benefits can be quantified economically (e.g., $300 per tonne of timber), biophysically (e.g., 5000 m^3 of water retained per year) or socially (e.g., sense of place and belonging) (Conte, 2013; Costanza *et al.*, 2017; Hamel *et al.*, 2021). Valuations can also be conducted at a range of spatial scales (e.g., site-scale, catchment-scale, city scale), depending on the area under investigation and the purpose of the valuation.

There are various tools available to support the diverse valuation methods of ecosystem services. InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) (Sharp *et al*., 2020) and SolVES (Social Values for Ecosystem Services) (Sherrouse *et al*., 2011) are two such Geographic Information System (GIS)-based tools that respectively employ biophysical and social valuation methods. InVEST comprises a suite of biophysical models, where each model quantifies the provision of a single ecosystem service. The models produce spatially explicit maps determining the distribution of a given ecosystem service based on the environmental characteristics of the study area and related biophysical processes (Hamel *et al.*, 2021). InVEST models require land use and cover data as well as relevant environmental variables as inputs. SolVES, on the other hand, takes into consideration the perception and preferences of stakeholders by quantifying their perceived value for ecosystem services. SolVES derives social value maps indexed on a 10-point scale based on spatial and non-spatial survey responses to questions about social values and development preferences (Sherrouse *et al*., 2014). The social survey is conducted prior to the application of SolVES and is the main source of data input to the tool. Both InVEST and SolVES are considered 'off-the-shelf', as they have a pre-determined structure and so require only the relevant data inputs in order to be applied; both are open source.

Studies have emphasised the need for a pluralistic approach to urban ecosystem services, given the diverse values held by various communities (Pascual *et al*., 2017). While diverse valuations of urban ecosystem services have been widely conducted in the Global North, there remains a pressing need to understand how ecosystem services are provisioned within and around the boundaries of cities in the Global South (Dang *et al*., 2021; Luederitz *et al*., 2015). Tropical cities in the Global South that are rich in biodiversity, such as Greater Kuala Lumpur, are particularly vulnerable to the fragmentation and loss of natural ecosystems due to rapid and poorly controlled urban expansion. Moreover, such rapidly developing regions are often characterised by highly heterogeneous landscapes such as mixed land uses and topographical gradients that shift from urban to peri-urban to rural, which can pose significant challenges when assessing urban ecosystem services in a spatially explicit way (Arifin and Nakagoshi, 2011; Larondelle and Haase, 2013; Sylla *et al.*, 2020). These regions are often data poor and underrepresented in urban ecosystem services research (Karnad & St. Martin, 2020; Lourdes *et al.,* 2021; Perez *et al*., 2017). Therefore, it is especially important to evaluate the extent to which urban biodiversity and ecosystem services are considered in the context of sustainable development in these regions. These findings can be used to improve existing local sustainable development frameworks in order to better support sustainable urban planning.

The research presented in this thesis addresses the knowledge gap on urban ecosystem services research in tropical Global South cities by assessing urban ecosystem services in the Greater Kuala Lumpur metropolitan city, a rapidly developing urban agglomeration in Malaysia. The thesis applies InVEST and SolVES to provide a systematic approach to the assessment of multiple urban ecosystem services to support sustainable urban development. These tools capture distinctly different aspects of nature's benefits to urban populations and support the targets of the Sustainable Development Goals to develop inclusive, resilient and sustainable cities (SDG 11) as well as to restore and maintain ecosystems (SDG 15) (McCartney *et al.*, 2015; United Nations, 2015). The thesis applies InVEST and SolVES in Greater Kuala Lumpur with a view to demonstrate the insights they provide on the value of urban ecosystem services and their utility to support planning decisions. The valuation of urban ecosystem services in this thesis therefore has a two-fold purpose: (i) supporting evidence-based decisions on green infrastructure where it is most needed (Lechner *et al*., 2020), (ii) identify problems and issues with the application of ecosystem service valuations in tropical cities that might require further research.

1.2 Research Aim and Objectives

The aim of this thesis is:

To address the knowledge gap on urban ecosystem services research in tropical Southeast Asian cities by assessing urban ecosystem services in the Greater Kuala Lumpur metropolitan city, a rapidly developing urban agglomeration in Malaysia.

The objectives of this thesis are:

1) to characterise and assess urban ecosystem services in Greater Kuala Lumpur in a spatially explicit manner,

2) to test the utility of existing off-the-shelf ecosystem service valuation tools in supporting urban planning in Greater Kuala Lumpur, and

3) to investigate the extent of ecosystem services and urban biodiversity have been considered as part of sustainable development planning in Greater Kuala Lumpur.

1.3 Research Questions

1. What is the nature and extent of urban ecosystem services research in Southeast Asia?
2. What are the development preferences and perceptions of residents in Greater Kuala Lumpur towards social values for urban ecosystem services?
3. What is the spatial distribution of urban ecosystem services across an urban-peri-urban gradient in Greater Kuala Lumpur?
4. How can urban ecosystem service valuations be utilised to support urban planning?
5. To what extent have local academic and policy literature considered urban biodiversity and ecosystem services in the context of sustainable urban development in Kuala Lumpur?
6. What are the next steps for urban ecosystem service valuations tools to support decision-making and sustainable urban development?

1.4 Thesis Outline

This thesis comprises 6 chapters. The main empirical chapters (Chapters 3 to 5) are written so that they can be read independently as standalone research articles; the literature review (Chapter 2) is also written and presented in the form of a paper. These four chapters have either been accepted, submitted or are in preparation for peer-review publication (see details in title pages of respective chapters). The contents of the chapters remain the same as the published versions except for the formatting, which has been revised to maintain a consistent style throughout this thesis; the references cited have been compiled into a single list at the end of the thesis.

Chapter 2 of this thesis provides a systematic review of urban ecosystem services research in Southeast Asia. As the nature and extent of urban ecosystem services research in Southeast Asia has not been previously investigated, this chapter helps stress the novelty and importance of the research presented in this thesis. The review guides the subsequent chapters by identifying current gaps in knowledge and provides a framework that outlines the next steps for urban ecosystem services research in the region.

Chapters 3 and 4 investigate two different methods of valuing multiple urban ecosystem services in Greater Kuala Lumpur. Chapter 3 quantifies and values urban ecosystem services from a social perspective (i.e., social valuation, SolVES), while chapter 4 quantifies urban ecosystem services biophysically (i.e., biophysical valuation, InVEST).

Chapter 3 investigates the development preferences of residents and social values for ecosystem services associated with the Greater Kuala Lumpur landscape through a public participatory GIS survey. The SolVES tool was used to map and quantify the distribution of various social values for ecosystem services based on the development preferences of residents. This chapter illustrates that the involvement of stakeholders in valuations is key to understanding context-specific demand and the preferences of the people appropriating the services, thus promotes the consideration of alternative planning options.

Chapter 4 investigates the spatial distribution of urban ecosystem services across a rapidly urbanising catchment in the Greater Kuala Lumpur region. This chapter focuses on a systematic approach to facilitate the integration of urban ecosystem services in planning for green infrastructure. InVEST models were used to quantify the biophysical value of six urban ecosystem services and their outputs were used as ecosystem services-based criteria to identify targeted locations for implementing green infrastructure strategies. This chapter illustrates the usefulness of biophysical modelling approaches in capturing the different spatial scales of service supply and demand across a topographically complex landscape.

The final research chapter (#5) investigates how the quantitative research findings in chapters 3 and 4 can be integrated into existing sustainable urban development frameworks in Greater Kuala Lumpur. This chapter explores the current scope of sustainable urban development frameworks in Greater Kuala Lumpur, identifying knowledge gaps in the local academic and policy literature. The chapter highlights the need for greater emphasis on ecosystem services in local sustainable urban development efforts. The chapter provides justifications for this shift in perspective, driven by international frameworks for sustainable urban development and findings from chapters 3 and 4.

Finally, chapter 6 summarises the findings of this thesis and describes potential future directions for the assessment of urban ecosystem services in Greater Kuala Lumpur and more widely in Southeast Asian cities, discussing how these assessments can be supported by off-the-shelf ecosystem service valuation tools such as SolVES and InVEST.

Chapter 2 A Review of Urban Ecosystem Services Research in Southeast Asia

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Lourdes, K.T., Gibbins, C.N., Hamel, P., Sanusi, R., Azhar, B. and Lechner, A. (2021). A Review of Urban Ecosystem Services Research in Southeast Asia. *Land,* 10, 40. https://doi.org/10.3390/land10010040

2.1 Introduction

The global urban population has grown rapidly in the last few decades, with over 70% of the population in the Global North now residing in urban areas (United Nations, 2014). Similar trends are evident in the Global South and while developed regions may be better equipped to manage urban transformations (Nagendra *et al.*, 2018), cities in developing regions such as Southeast Asia face increasing environmental pressures. In 2018, an estimated 320 million people lived in the urban areas of Southeast Asia (49% of the region's total population), and this figure is expected to increase to 66% of the total population by 2050 (United Nations, 2014; Yuen & Kong, 2009). This rapid urbanisation has been accompanied by a range of environmental problems, including the urban heat island effect, floods, poor air quality and noise pollution, all of which directly impact the health of urban residents (Harun *et al.*, 2020; Jacobs & Appleyard, 1987; Jones, 2014; Jusuf *et al.*, 2007; Laeni *et al.*, 2019; Mahmoudi *et al.*, 2015; Morillas *et al.*, 2018; Padawangi & Douglass, 2015). These issues are expected to be further exacerbated by the general vulnerability of the region to climate change impacts (ADB, 2009; Li *et al.*, 2019; Yusuf & Francisco, 2010). Moreover, countries within Southeast Asia have extremely diverse biophysical, cultural, socio-economic and political characteristics (Table 2.1). Levels of urbanisation range from 23% (Cambodia) to 100% (Singapore) and gross national incomes range from the 11th (Singapore) to the 162nd (Myanmar) rank globally. Efforts to mitigate urban environmental challenges should take into consideration these characteristics, in so doing provide context-specific solutions (Arfanuzzaman & Dahiya, 2019; Lechner *et al.*, 2020; Savage, 2006).

Table 2.1. Basic statistics that characterise the diverse biophysical, socio-economic and political backgrounds of Southeast Asian countries for the year 2019.

Country	Land Area (km^2) (ASEANStats, 2020)	Population Size (mil) (UNdata, 2020)	Percentage of Urban Population (%) (Asian Development Bank, 2020a)	Average Annual Population Growth Rate (%) * (UNdata, 2020)	Per Capita Gross National Income Ranking (WorldBank, 2020)	CO_2 Emissions (Million Metric Tons) † (Asian Development Bank, 2020a)	Governance (−2.5 to +2.5)	
							Government Effectiveness (WGI, 2020)	Voice and Accountability (WGI, 2020)
Singapore	720	5.80	100.0	0.90	11	37.5	2.22	−0.18
Brunei Darussalam	5765	0.433	77.1	1.06	31	7.6	1.32	−0.95
Malaysia	331,388	31.94	76.2	1.33	69	248.2	1.0	−0.04
Indonesia	1,916,862	270.62	56.0	1.14	118	512.7	0.18	0.16
Thailand	513,140	69.62	53.6	0.31	86	283.7	0.36	−0.83
Philippines	300,000	108.11	47.1	1.41	123	122.2	0.05	0.03
Lao PDR	236,800	7.16	35.6	1.52	139	17.7	−0.78	−1.80
Vietnam	331,230	96.46	35.0	0.98	141	192.6	0.04	−1.38
Timor Leste	14,870	1.29	30.9	1.94	151	0.49	−0.88	0.38
Myanmar	676,576	54.04	30.0	0.64	162	25.2	−1.15	−0.84
Cambodia	181,035	16.48	23.8	1.48	158	9.9	−0.58	−1.20

Notes: * from 2015 to 2020; † for the year 2016.

Planning and designing cities to incorporate blue-green spaces is vital for mitigating socio-environmental problems affecting health and well-being (el-Baghdadi & Desha, 2017; Kabisch *et al.*, 2015; Xue *et al.,* 2017). Urban blue-green spaces promote greater resilience, sustainability and liveability in cities through the pro-vision of services such as shading and cooling, carbon sequestration, stormwater management, noise attenuation, habitat for biodiversity and recreational opportunities (Baharuddin *et al.*, 2017; Cortinovis & Geneletti, 2020; Haase *et al.*, 2014; Kanniah & Siong, 2018; Keeler *et al.*, 2019). These services, termed 'urban ecosystem services' (UES), capture the role of water (blue) (i.e., lakes and wetlands) and vegetation (green) (i.e., parks and urban forests) in or near the built environment at different spatial scales (streets, buildings, cities, regions) (Bolund & Hunhammar, 1999; Braat & de Groot, 2012; Gómez-Baggethun & Barton, 2013). Generated through the functions and processes of blue-green structures, UES can alleviate the environmental pressures of urbanisation and enhance the wellbeing of urban residents (Burls, 2007; Cilliers, 2010; Gascon *et al*., 2016; Müller-Riemenschneider *et al*., 2018).

The complex pathways through which UES are delivered can be analysed by the relationships between (i) structures (e.g., mangrove forests), (ii) their biophysical processes and functions (e.g., wave attenuation), and (iii) the derived services that deliver goods and benefits to humans (e.g., coastal flood protection) (Potschin & Haines-Young, 2011). The interactions between these different components can be illustrated through frameworks such as the cascade model, which acts as a communication tool between experts and local stakeholders to help support UES assessments for urban planning (Luederitz *et al*., 2015). Moreover, incorporating UES into urban planning requires an understanding of the various interactions between services, which are linked to one another as they stem from the same structures and functions of a particular ecosystem (de Groot *et al.*, 2002; Martínez *et al.*, 2013). These interactions include synergies and tradeoffs, described respectively as positive-positive or positive-negative relationships between two or more services (Bennett *et al.,* 2009; La Notte *et al*., 2017).

Research on UES can also be undertaken from various perspectives, given the inter-disciplinary nature of the concept. The field has gained prominence for its ability to integrate natural and social sciences, communicating the dependence of society on ecological structures (Martínez *et al*., 2013). A wide range of methods have been used to characterise UES and assess their value to humans. These methods range from biophysical modelling to social surveys applied at various scales (e.g., landscape scale, site-based scale), with benefits valued biophysically (e.g., tonnes of carbon sequestered per year), economically (e.g., $500 per hectare per year) and socio-culturally (e.g., sense of place) (Conte, 2013; Costanza *et al*., 2017; Gómez-Baggethun & Barton, 2013). UES hold diverse values to various communities and the valuation of UES is necessary to understand local demands or benefits (Keeler *et al*., 2019; Pascual *et al.*, 2017). Valuations should be supported by the involvement of stakeholders to further deepen the understanding of local UES needs, while promoting the consideration of alternative management options (Brown *et al.*, 2016; Zoderer *et al.*, 2019).

Previous reviews of global UES research by Haase et al. (2014) and Luederitz et al. (2015) highlight that research has mostly been undertaken in Europe and North America, with research in Asia dominated by China. Although these reviews have explored the scope and nature of research on a global scale, they lack the finer resolution needed to understand patterns and traits of research in any one region. Despite the rapid economic growth and urbanisation in Southeast Asian countries, UES research across this region has not been reviewed. Hence, a systematic review of UES is timely, to assess the nature and extent of research on UES in Southeast Asia.

This review covers the last 20 years, the period within which the global UES literature has burgeoned. Inspired by Luederitz et al. (2015), we address four specific research questions: (1) How is UES research distributed across Southeast Asia and at what scale(s) are UES analysed? (2) Does UES research focus on single or multiple services and what type of blue-green structure are assessed? (3) Which components of the 'cascade' are assessed, and how are the interactions between UES conceptualised and stakeholders involved? (4) What research perspectives, and data collection and analytical methods are used to assess UES? Upon reviewing the current state of research in the region, we discuss the challenges and considerations for integrating UES research given the unique context of Southeast Asia. We conclude our review with recommendations for UES research in order to support planning in the region.

2.2 Methods

The search string composed terms that expressed the geographical area of interest ('Southeast Asia' and all the countries within the region), the topic of interest ('ecosystem service', its alternative term 'natural capital' and, to capture studies that did not explicitly refer to these two phrases, we included the keywords 'human', 'environment' and 'benefit') as well as terms that further specified the subtopic of interest (i.e., the urban environment). The search was applied to publication Titles, Abstracts and Keywords in the Scopus and Web of Science database as shown below:

(TITLE-ABS-KEY ((“Southeast Asia” OR “South East Asia” OR “Indonesia” OR “Vietnam” OR “Thailand” OR “Malaysia” OR “Singapore” OR “Philippines” OR “Cambodia” OR “Laos” OR “Myanmar” OR “Brunei” OR “Timor-Leste”))) AND (TITLE-ABS-KEY ((“ecosystem service*” OR “natural capital” OR (“human” AND “environment” AND “benefit*”)))) AND (TITLE-ABS-KEY (“urban” OR “city” OR “cities”))

The initial search return was refined to include only journal articles, book chapters and conference papers (see Appendix A for complete search string). This search returned a total of 255 unique articles published in the English language. The abstracts of the returned articles were screened manually to include publications within the scope of this review based on the following guiding criteria:

- Studies conducted in urban or peri-urban areas in Southeast Asian countries.
- Focuses on ecosystem services or benefits provided to an urban population.
- Explicitly includes the phrase 'ecosystem services' or 'natural capital', otherwise

describes the link between the environment and the benefits provided to urban populations.

The final list comprised 149 empirical articles, assessing one or more ecosystem services in urban Southeast Asia (see Table S1 in Appendix B). Studies that investigated multiple urban areas within and outside of Southeast Asia were included in the review, if at least one study site was located within Southeast Asia. Each article was classified to identify information relevant to the four research questions, as described in the sections which follow. Refer to Table S2 in Appendix C for further details on definitions and classification protocol.

(1) How is UES research distributed across Southeast Asia and at what scale(s) have they been analysed?

Following the TEEB classification for ecosystem services (TEEB, 2010b), we classified the eco-system services studied into four main categories: (i) provisioning, (ii) regulating, (iii) supporting and (iv) cultural. These four categories will be hereafter referred to as 'ecosystem service domains'. We chose the TEEB classification of ecosystem services over the two other common approaches to classifying ecosystem services—the Millennium Ecosystem Assessment (MEA) and Common International Classification of Ecosystem Services (CICES). TEEB is well-known in the context of environmental economics and provides a robust framework for applications in urban planning and policies (TEEB, 2011). Moreover, the TEEB framework emphasises the need for valuing ecosystem services such that the wide range of benefits of ecosystems and biodiversity is recognised by decision-makers (TEEB, 2014). We also recorded the location (e.g., city and country) of studies and quantified the number of times ecosystem service domains were assessed for each country. To analyse the scale of UES assessment, we recorded the population size and area of study sites, scale of assessment as well as distinguished between 'urban' and/or 'peri-urban' areas.

(2) Does UES research focus on single or multiple services and what type of blue-green structure have been assessed?

We recorded the ecosystem services assessed as one of the 17 ecosystem services de-fined by the TEEB framework (TEEB, 2010b). As studies can mention more ecosystem services than those that were empirically assessed, we only classified ecosystem services that were explicitly investigated. We evaluated the number of services assessed in each study and whether the services belonged to the same ecosystem service domain. The ecological structures that provide the investigated ecosystem service(s) were classified as either vegetative (green) or water (blue) structures. We identified 12 categories of blue-green structures, comprising four blue structures (coastal lands, wetlands, rivers, lakes) and eight green structures (urban forests, parks, street greenery, gardens, rooftops, green walls, cultivated lands and grasslands; refer to Table S3 in Appendix D for detailed definitions of blue-green structures).

(3) Which components of the 'cascade' have been assessed, how are the interactions between UES conceptualised, and stakeholders involved?

The components of ecosystem service 'cascade' were assessed according to structure, function, services, and each linkage between structure-function-services (Figure 2.1). We described studies as either reviewing one of these six components, all of the six components or none, if studies did not assess any of the components in depth. We recorded the explicit assessment of synergies and tradeoffs in studies as well as the involvement of stakeholders in supporting UES assessments. The latter was defined as the feedback or involvement of external parties, aside from the researcher, in assessing UES. Studies involving surveys and interviews were considered to have involved stakeholders.

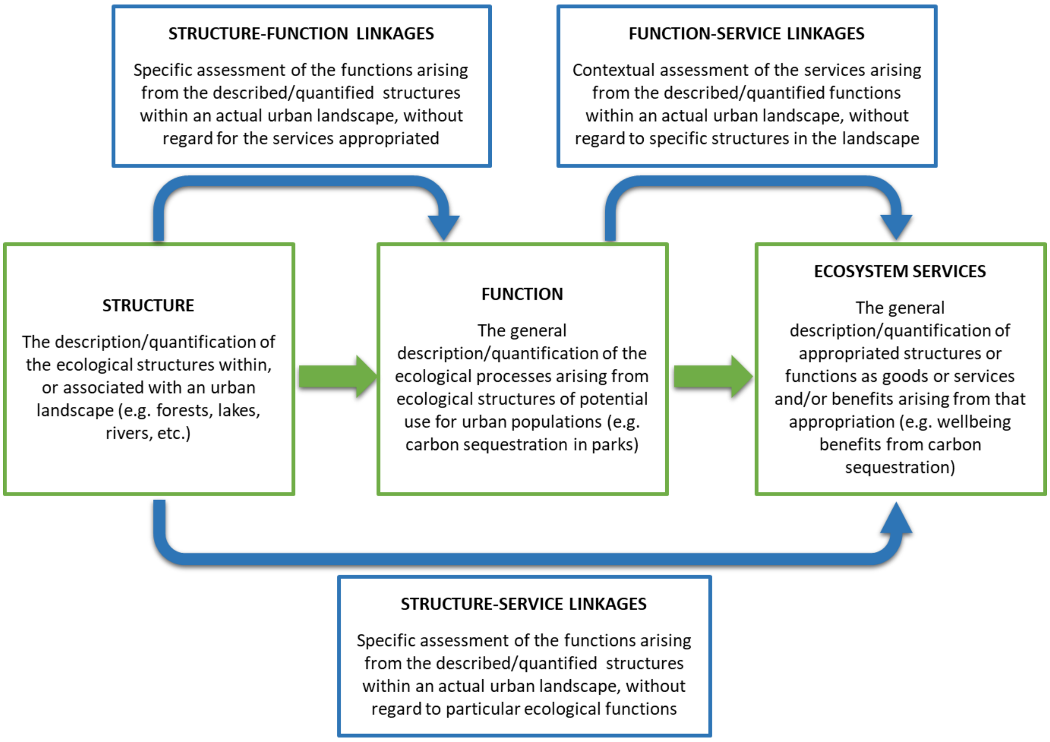


Figure 2.1 The components and definitions of the cascade model used to classify UES studies (Luederitz *et al.*, 2015).

(4) What research perspectives, and data collection and analytical methods are used to assess UES?

We assigned each study one of the following six research perspectives: (i) ecology, (ii) social, (iii) planning, (iv) governance, (v) economic and (vi) methods (Luederitz et al., 2015). The definitions for this classification are available in Table S2 in Appendix C. Although a single study can be undertaken with more than one perspective, we classified each study by its most dominant research perspective.

Data collection methods were classified into four categories: (i) 'field-based empirical', (ii) 'biophysical modelling' which is sub-divided into 'process/mechanistic modelling' and 'land cover proxy' (e.g., remote sensing of land cover), and (iii) 'social surveys' and (iv) case studies. We also recorded the type of data collected (i.e., 'quantitative', 'qualitative', or 'both') and the temporal focus of the study. Studies were also reviewed for the valuation of UES and where valuations were conducted, we distinguished between 'monetary valuation' (i.e., economic) and/or 'non-monetary valuation' (i.e., social or biophysical).

2.3 Results

2.3.1 Distribution and Scale of UES Assessment across Southeast Asia

Of the 149 studies reviewed in Southeast Asia, 29% were conducted in Singapore (n = 44), followed by 22% in Indonesia (n = 33). There were 24 studies in Thailand, 23 in Malaysia, 18 in Philippines and 13 in Vietnam. Cambodia (n = 5), Myanmar (n = 4), Laos (n = 1) and Timor Leste (n = 1) had very few studies, while no published studies from Brunei were returned in the search (Figure 2.2). About 64% of studies had authors with their primary research institution in Southeast Asia (n = 95), with 59% of studies conducted in the country where their primary research institution was located. As for studies with authors' primary research institutions located outside of Southeast Asia, 16% of authors were based in Europe (n = 24), 11% in other parts of Asia (n = 17) (mainly East Asia), 5% in North America (n = 8) and 3% in Australia (n = 5). Note the possibility of some bias in this analysis due to the inclusion of only studies published in English.

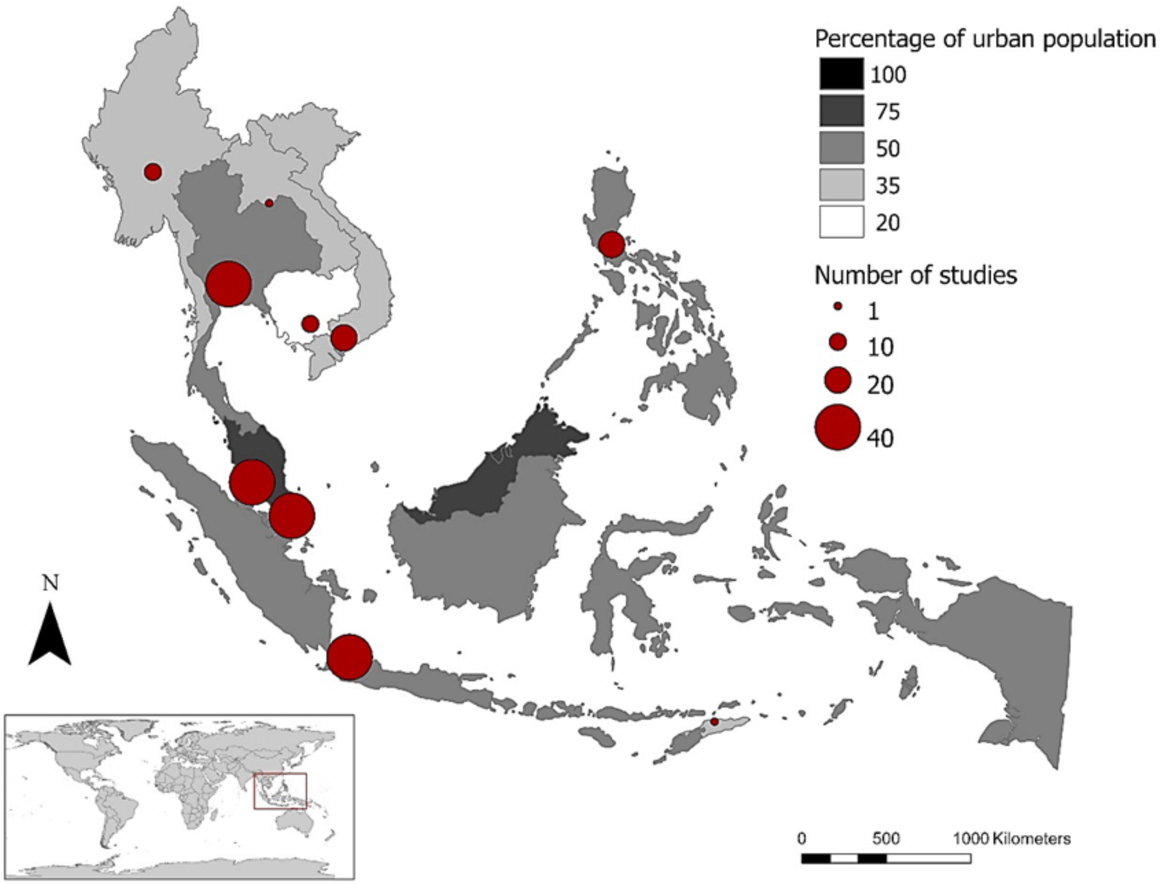


Figure 2.2 Number of UES studies in Southeast Asia and percentage of urban population in each country. Not visible in the map is the percentage of urban population in Singapore, which is 100%. No studies from Brunei were reviewed.

77% of studies are concentrated in four cities; the city-state of Singapore was most frequently studied (n = 44), followed by the metropolitan capital cities of Bangkok in Thailand (n = 13), Jakarta in Indonesia (n = 12) and Kuala Lumpur in Malaysia (n = 8). In terms of the type of urban area assessed, 76% of studies were conducted in fully urban areas (n = 113), 15% in peri-urban areas (n = 23) and 8% of studies spanned both urban and peri-urban areas (n = 13). Around 43% of studies were conducted at a 'single-city scale' (n = 64), followed by 32% at the 'sites within cities' scale (n = 48) (Figure 2.3). Only 17% of studies assessed multiple cities (n = 26) and 7% of studies were conducted at scales larger than cities (i.e., regional or continental scales) (n = 11). Study area sizes varied markedly, extending from a few square kilometres to tens of millions of square kilometres. Similarly, population sizes within the study areas differed greatly from 750 (Botoc village, Philippines) to 9.6 million (Jakarta metropolitan).

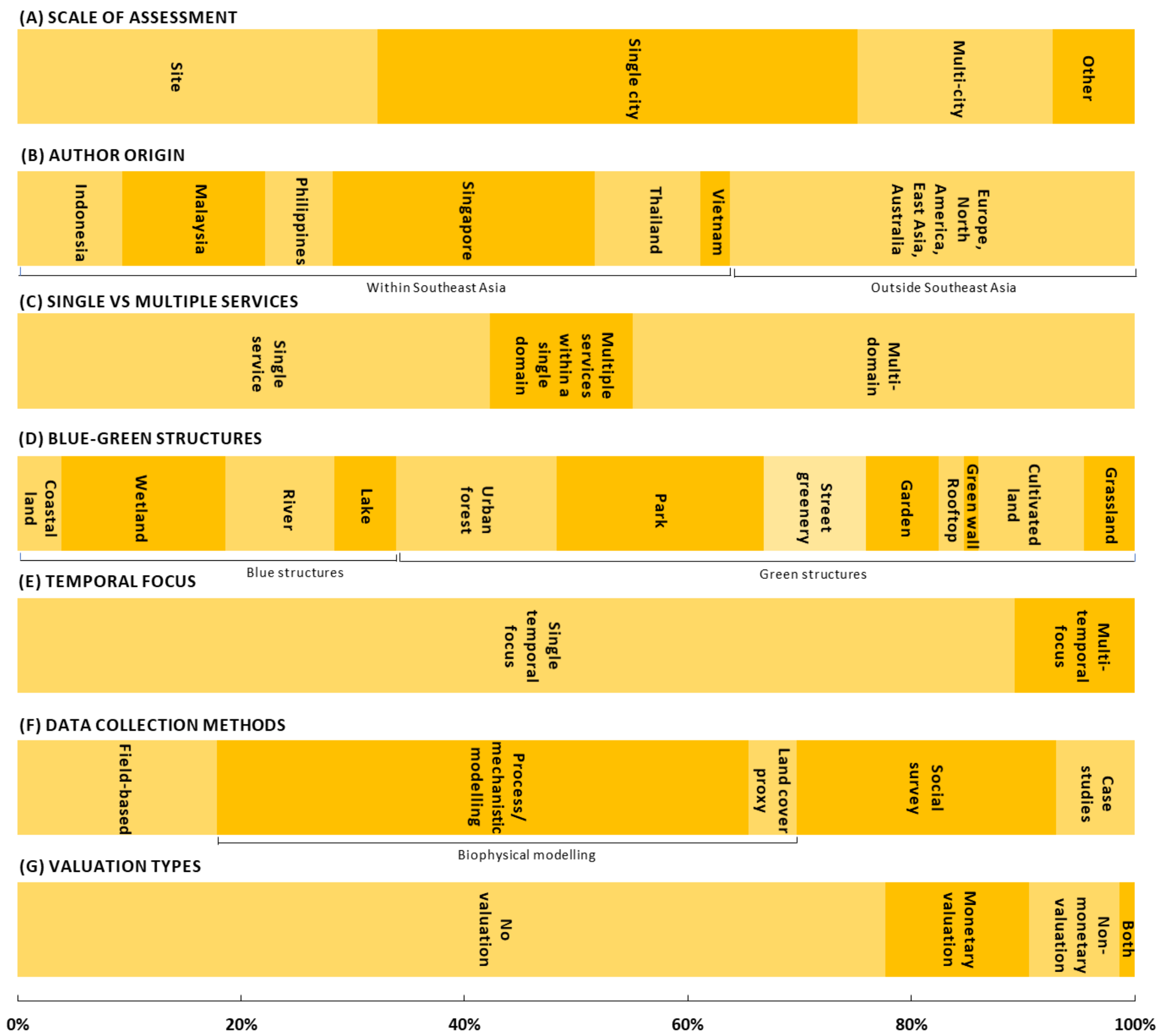


Figure 2.3 The general characteristics of UES research. (A) The various scales at which UES were assessed; (B) The per-centage of studies conducted by authors based in and outside of Southeast Asia (denoted by the country in which the primary institution of the first author is located); (C) The assessment of UES within and/or across domains; (D) The types blue-green structures assessed; (E) The temporal focus of the study where 'single temporal focus' represents studies that examined UES at one point/period in time and 'multitemporal' represents studies that compared UES across time; (F) The methods of data collection and analysis of UES; and (G) The types of UES valuations conducted by studies.

2.3.2 Services and Blue-Green Structures Assessed

Of the four domains, regulating (36%) and cultural (26%) services were most assessed. Most countries had studies encompassing services across all four domains; exceptions were Laos and Timor Leste (Figure 2.4a). Studies comprised all 17 ecosystem services across all domains, with the 'recreation and mental and physical health' as the most frequently studied service (n = 54), followed by the 'moderation of extreme events' service (n = 51). The 'medicinal resources' and 'biological control' services were least assessed, with only 5 and 4 studies respectively (Table 2.2). Most studies took a multi-domain approach (n = 67) by investigating ecosystem services across multiple domains. Around 42% of studies assessed a single ecosystem service (n = 63), while 13% studied multiple services from a single domain (n = 19).

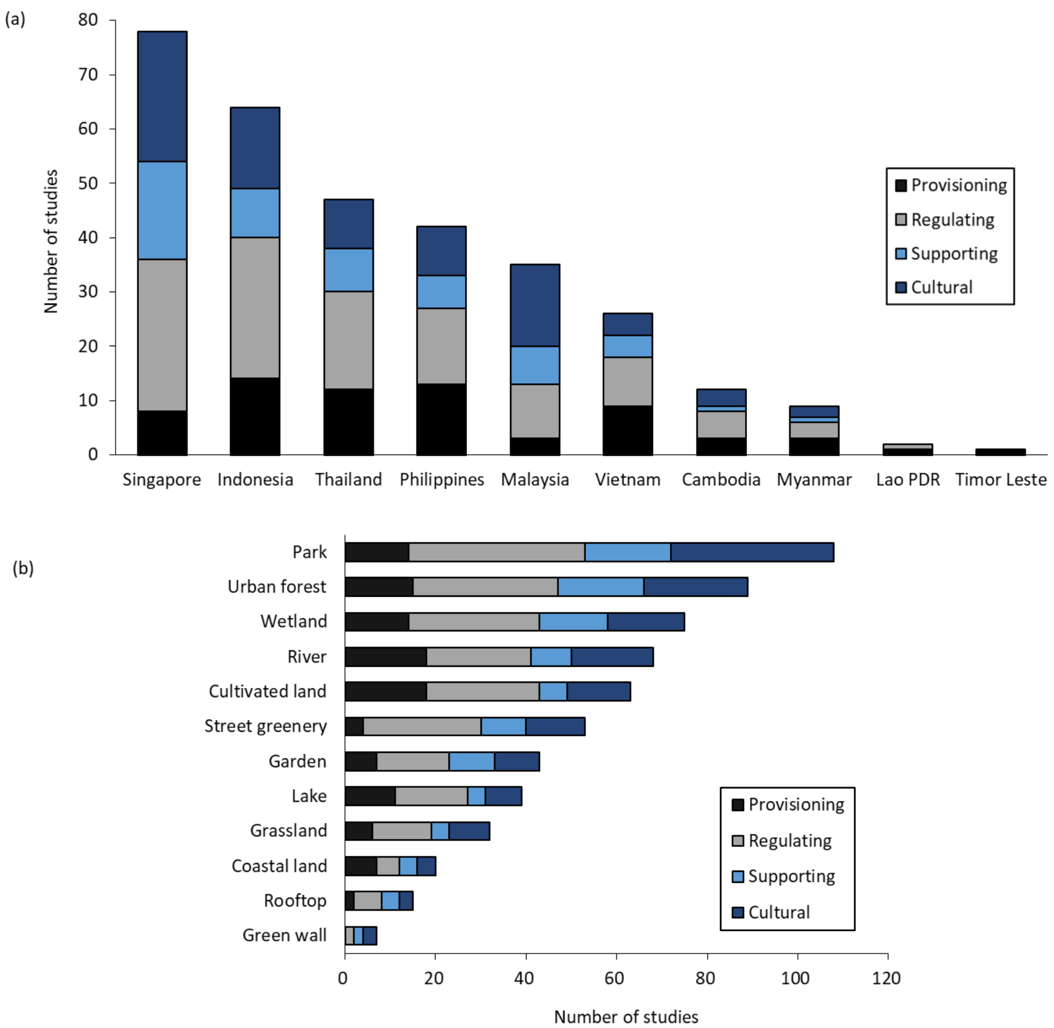


Figure 2.4 Ecosystem service domains assessed according to (a) countries and, (b) blue-green structures.

Table 2.2 The number of studies that assessed each ecosystem service according to the TEEB classification system (TEEB, 2010b). Note that some studies assessed multiple ecosystem services; thus, the total number of ecosystem services assessed is greater than the 149 publications reviewed.

Domain	Ecosystem Service	Number of Studies
Provisioning	Food	40
	Raw materials	29
	Fresh water	18
	Medicinal resources	4
Regulating	Local climate and air quality	44
	Carbon sequestration and storage	27
	Moderation of extreme events	51
	Wastewater treatment	11
	Erosion prevention and maintenance of soil fertility	15
	Pollination	9
	Biological control	5
Supporting	Habitats for species	43
	Maintenance of genetic diversity	8
Cultural	Recreation and mental and physical health	54
	Tourism	19
	Aesthetic appreciation and inspiration for culture, art and design	44
	Spiritual experience and sense of place	25

60% of studies assessed a single blue-green structure (n = 90) while the remaining studies assessed two or more structures; the maximum was seven structures (n = 2) (Figure 2.4b). Of the 12 blue-green structures, parks were most frequently studied (n = 57), followed by wetlands (n = 45) and urban forests (n = 44) (note: values differ from the number of times each structure was studied under ecosystem service domains, see Figure 2.4b). All 12 structures were studied across the four ecosystem services domains except for green walls, which were not studied for provisioning services. Rivers, urban forests and cultivated lands were most commonly studied for provisioning services, while street greenery and wetlands were commonly studied for regulating services. Parks were almost equally studied for regulating (n = 39) and cultural services (n = 36), although studies of cultural services predominantly assessed parks in comparison to all other structures (23%).

2.3.3 Components of the 'Cascade' and Stakeholder Involvement

Only 2% of studies (n = 3) did not assess any component of the cascade in depth. These studies were mainly on the management of ecosystem services using frameworks that did not focus on any specific component of the cascade (e.g., Pierce *et al.*, (2020); Warner *et al*. (2019). Conversely, 16% of studies (n = 24) assessed all three components (Table 2.3). For instance, Remondi *et al.* (2016) simulated changes to land use surrounding rivers in Jakarta under different urbanisation scenarios. The study modelled the capacity of the river (structure) to retain water (function), in providing fresh water and flood protection services to the local population (services and benefits). The most studied component was the structure-function linkage (26% of studies; n = 38), while the function component was least assessed, with only 4% of studies (n = 6). Only 4% (n = 6) of the 149 studies had explicitly investigated ecosystem service interactions such as synergies and tradeoffs. The majority of the studies (56%) did not involve stakeholders either through surveys, interviews or expert input. Of those that did, most assessed cultural services (n = 46). Links between UES and climate change were only assessed by 3% of studies (n = 5).

Table 2.3 Distribution of the number of studies assessing various components of the ecosystem services cascade.

Cascade Component	**Number of Studies**
Structure	11
Structure-function	38
Function	6
Function-benefit	14
Benefit	29
Structure-benefit	24
All	24
None	3

2.3.4 Research Perspectives and Methods of UES Assessment

The number of studies in the region has increased across all ecosystem service do-mains (Figure 2.5a), particularly over the last decade; the review only yielded three studies prior to 2011 (Figure 2.5b), with more than 89% being published post-2014 (n = 133). The highest annual number of studies was in the year 2018, although bearing mind that for 2020 the review only included studies published between January and August, this year also saw a relatively high number of papers published.

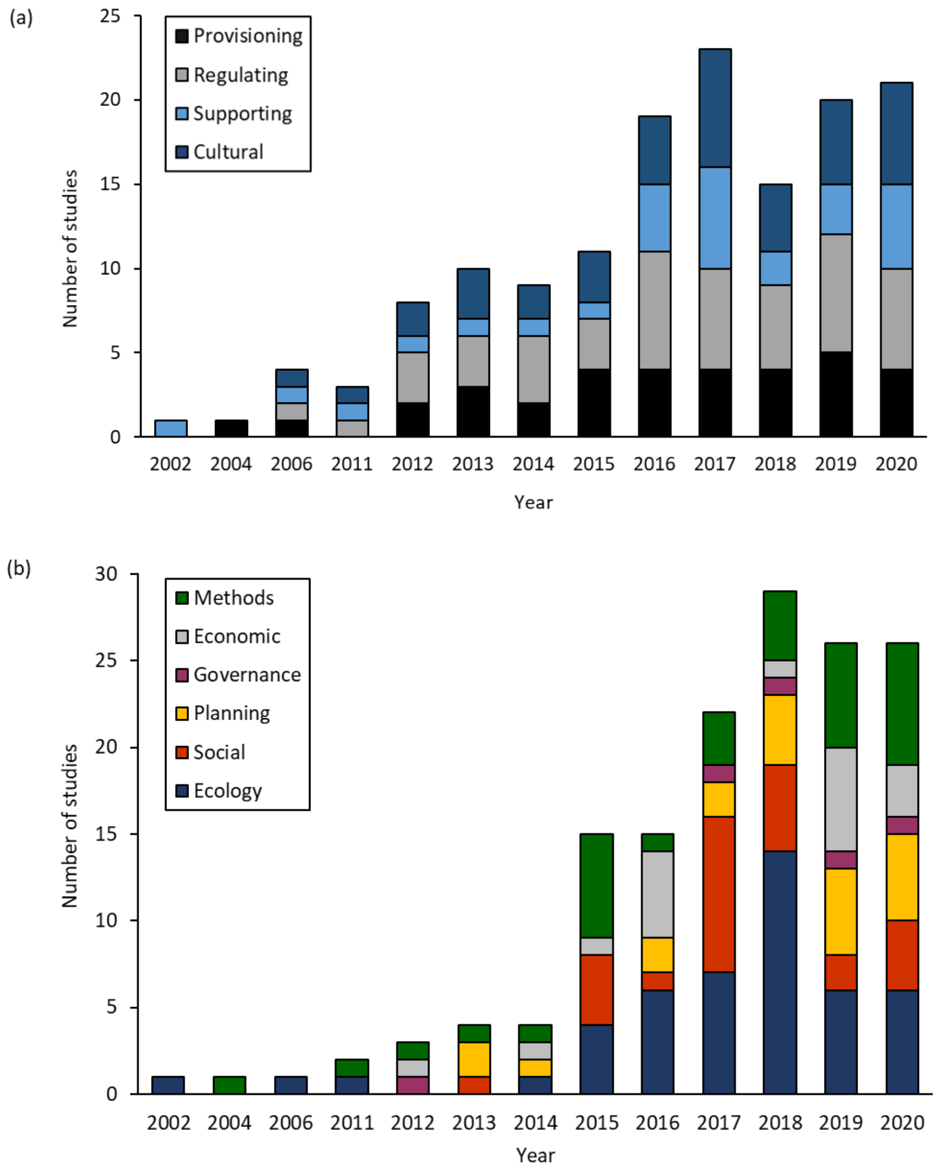


Figure 2.5 The (a) ecosystem service domains and (b) research perspectives, undertaken by studies over time. Note: A study may have assessed more than one ecosystem service domain but only one research perspective. Hence, Figure 2.5b represents the actual number of studies reviewed over time.

Only papers published between 2018 and 2020 encompass all six research perspectives. Of the 149 studies, 32% were dominated by an ecological perspective (n = 47), while studies undertaken with a governance perspective were least common (3%; n = 5). Since 2013, more studies have been undertaken with social and planning perspectives, while governance-based research has received more attention since 2017. Studies with an ecological perspective were conducted in all countries except Timor

Leste, which had the least number of studies in the region (Figure 2.6a). Singapore, Indonesia, Thailand and Vietnam had studies comprising all six perspectives. About 34% (n = 15) of the 44 studies conducted in Singapore had an ecological perspective, while only 5% (n = 2) had an economic perspective and one study had a governance perspective. There were no studies with an economic or governance perspective in Malaysia, although the social perspective comprised 43% (n = 10) of studies in this country.

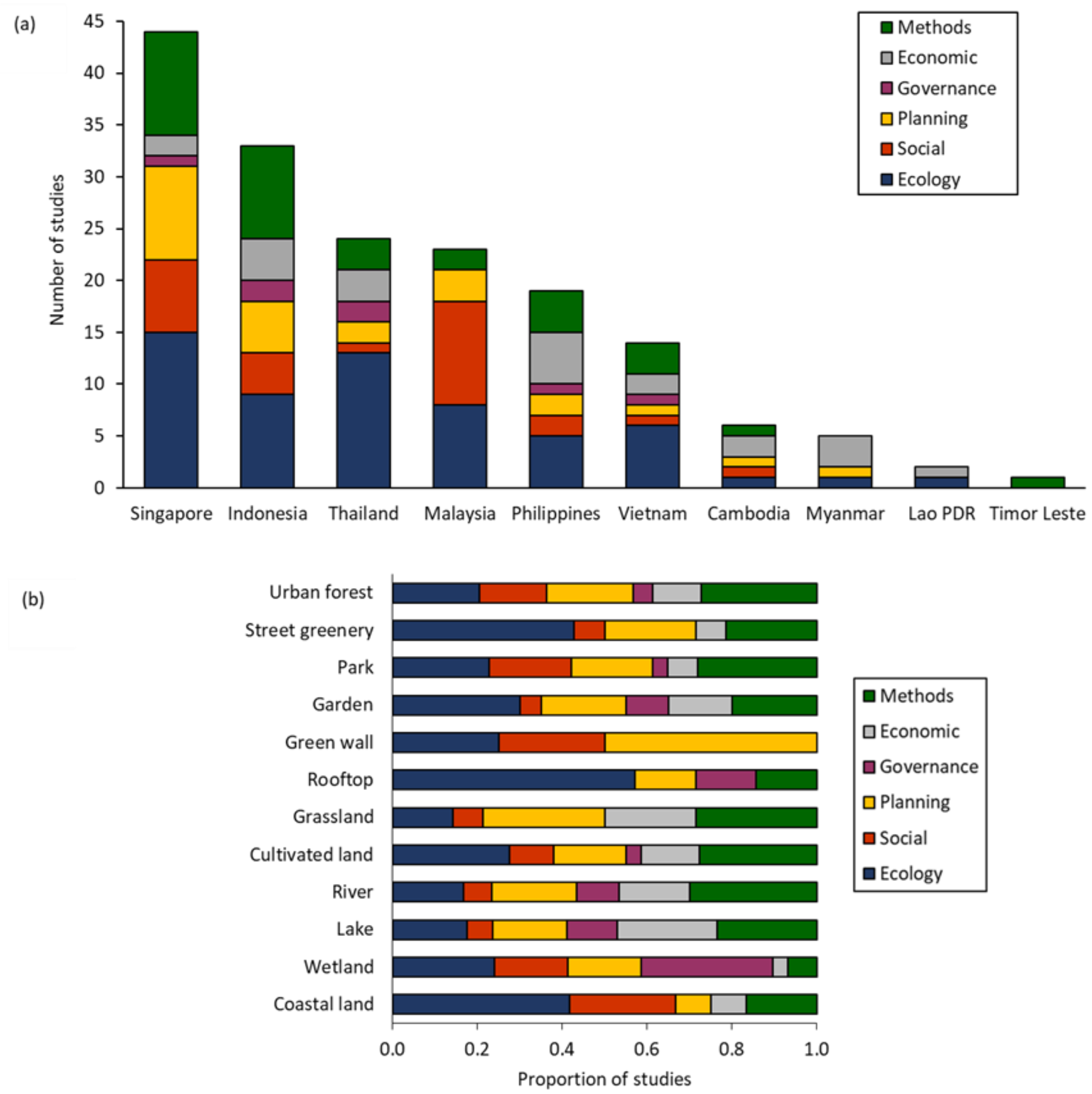


Figure 2.6 Research perspectives undertaken by studies across (a) countries and (b) blue-green structures.

Street greenery, gardens and rooftops were mainly studied from an ecological perspective, while parks, urban forests and rivers were predominantly assessed from a methods perspective (Figure 2.6b). Wetlands were most studied under the governance perspective (n = 9) and two of four studies of green walls had a planning perspective. Cultivated lands were equally studied using methods and ecological perspectives.

Over 89% of studies (n = 133) examined UES in a single time period or duration, with only 16 studies comparing services over two or more points in time. With respect to the type of data collected, 65% of studies (n = 97) collected only quantitative data, while only 5% of studies (n = 8) examined qualitative data. The remaining 44 studies examined both qualitative and quantitative data. Process and/or mechanistic models were the most utilised method of data collection and analysis in the region, comprising 88 studies (note: studies can utilise more than one method). Social surveys were the next most common method (n = 43), followed by field sampling (n = 33). 13 studies used case studies to assess UES and 8 studies used landcover proxies. Only 23% (n = 34) of studies conducted valuations, of which over half were monetary (n = 19). Two studies conducted both monetary and non-monetary valuations, while the remaining studies (n = 12) conducted non-monetary valuations.

2.4 Discussion

2.4.1 Current State of Research

Our review found that the there was a growing body of research on UES in the Southeast Asia, particularly in the last five years. The research was biased towards more developed countries, in particular the city-state of Singapore, where about one third (29%) of published research was conducted. Previous reviews have also found that UES research tends to focus on highly developed and urbanised countries (Haase *et al*., 2014; Luederitz *et al*., 2015). It is also apparent that little research has been conducted in less developed countries such as Myanmar, Cambodia and Laos. While most papers were authored by researchers based in Southeast Asia, there were no clear differences between the research foci of authors based in Southeast Asia and those based outside of the region.

Studies in Southeast Asia provided sufficient contextual information in their assessment, contrary to the findings of Luederitz et al. (2015) in their global review. Studies provided detailed descriptions of the boundary of respective the study areas, population size, location of ecological structures and type of structures studied. Of the four ecosystem service domains, in Southeast Asia, regulating and cultural services were predominantly assessed (62% of all studies). The two most commonly assessed services were recreation, mental and physical health (n = 54) and moderation of extreme events services (n = 51). Parks were the most assessed blue-green structure, while there were few studies focused on coastal areas (n = 12), rooftops (n = 7) and green walls (n = 4).

Over half the studies examined multiple ecosystem services, within and across do-mains, and mostly at a landscape scale (i.e., city scale or larger). Studies also assessed multiple components of the cascade, although there is room for a more holistic research approach, as interactions, such as synergies and tradeoffs between services were rarely examined (4%). There was also a lack of studies with a multitemporal focus (11%). Process/mechanistic modelling was the dominant method of UES assessment (Achmad *et al.*, 2020; Nguyen *et al.*, 2019; Srichaichana *et al.*, 2019), although valuations of services were lacking.

Stakeholder involvement was higher in studies that examined regulating and cultural services. Many studies that involved stakeholders also had social or planning research perspectives suggesting a strong applied focus on managing UES. There were few studies with a dominant governance perspective and this finding is not unique to Southeast Asia, as global reviews by Haase et al. (2014) and Luederitz et al. (2015) also report the lack of governance discourse on UES research. While the nature of UES research within the region may have some commonalities with its global counterpart, we highlight aspects of research that are specific to Southeast Asia, discussing considerations and opportunities for integrating UES in the region below.

2.4.2 Specificity of Research in Southeast Asia

The transferability of research may be limited due to the diverse characteristics of Southeast Asian countries—in particular economic power and government effectiveness (see Table 2.1 and Figure 2.2) (Lechner *et al*., 2020). Furthermore, even within countries there can be diversity in values. There is diversity in environmental conditions as well as the nature of urbanisation and cultural perspectives and values. For example, Hassan et al. (2019) highlighted substantial differences in wetland management preferences between urban and rural areas in Malaysia. While, in Singapore, contrary to popular assumptions around the desire for natural green spaces, some urban residents do not favour high conservation value vegetation and unmanaged secondary forests due to perceived wildlife threats and poor aesthetics (Belcher & Chisholm, 2018; Richards *et al*., 2020). If regional uniformity is assumed in how services are perceived and valued, the specific preferences and/or needs of minority groups may be overlooked when managing UES.

Considering that countries in Southeast Asia are renowned agro-industrial producers and exporters (Kontgis *et al.*, 2019), provisioning services and services from agricultural landscapes (e.g., oil palm) were fairly understudied in the region. Although it is generally expected that highly urbanised areas are less likely to include productive areas, agricultural landscapes can be commonly found within the urban matrix of Southeast Asia (Budidarsono *et al.*, 2013; Shevade & Loboda, 2019). While this adds to the uniqueness of urban-scapes in the region, the interactions between provisioning services and other service types, as well as implications for different stakeholders is yet to be fully understood.

Much remains to be learnt about biodiversity and UES in Southeast Asia. As Mammides et al. (2016) reported, despite most of the world's biodiversity being concentrated in the tropics and the imminent threats it faces, research on tropical conservation is largely underrepresented. In our review, the initial search string, which contained only UES related terms, returned only 48 relevant publications. It was only through expanding our search string with more general keywords that we were able to increase the number of publications. Like most other Global South regions, the underrepresentation of research could be attributed to Southeast Asia being data poor

(Karnad & Martin, 2020; Perez *et al.*, 2017), which was noted in a number of studies (Belcher & Chisholm, 2018; Estoque & Murayama, 2016; Estoque & Murayama, 2012).

Limitations in the quality, availability and access to data pose major challenges to UES research in the region. Databases and organisations that collect and provide open-access regional environmental data are few to none, compared to those in North America or Europe (e.g., United States Geological Survey, European Soil Data Centre, National Biodiversity Network, Biodiversity Information System for Europe, European Environment Agency). This was reported in several studies such as Balmford et al. (2016) who used global environmental data in their assessment of road networks in the Greater Mekong subregion, as finer scale, regional data was not available. Estoque et al. (2012) also utilised global ecosystem service values reported by Costanza et al. (1997) due to the limited availability of local data in Baguio, Philippines. Estoque et al. (2020) highlighted the need for available and accessible city-scale data across Philippines for conducting heat vulnerability assessments, while Belcher and Chisholm et al. (2018) reported that in Singapore LULC data is not publicly available. This limitation significantly affects research outputs as collection and generation of high-resolution regional data requires important human and time resources.

2.5 Conclusions: Research Needs to Move Forward

As Southeast Asian cities grow and the population density in urban areas rise, demand for ecosystem services will become increasing important (Wangai *et al.*, 2016). The recognised im-portance of UES is also seen with the increased number of UES assessments in the region over the last decade (Figure 5b). Increasing urbanisation and urban sprawls in Southeast Asia often result in the loss of natural ecosystems due to the infrastructure demands of growing urban populations (Lechner *et al.*, 2020). Conserving nature and supporting the provision of UES is often more cost effective and practical than restoring degraded ecosystems (Holl & Howarth, 2000; Loomis *et al.*, 2000), so a worthwhile objective for cities in the region is avoiding the loss of natural ecosystems through the consideration of UES in planning.

The prevalence of certain services within UES research suggests some UES are considered to be more important than others, from a research perspective, in the Southeast Asian context. For instance, the preservation of cultural services such as recreation ser-vices (n = 54) and aesthetic appreciation (n = 44), which are strongly associated with green spaces (Braat & de Groot, 2012; Liu *et al.*, 2020), may be of high interest to urban residents, as these areas are being rapidly lost to high density development patterns, characteristic of urbanisation in Southeast Asian cities (Friess *et al.*, 2016; Thiagarajah *et al.*, 2015). Similarly, climate regulating services (n = 44) appear to be valued for their role in reducing urban heat island effects, which is a common issue in the region's densely urbanised tropical cities, with high average temperatures (Buyadi *et al.*, 2014; Gunawardena *et al.*, 2017; Heng & Chow, 2019; Richards & Edwards, 2017). These UES, which have been the focus of research, may be valued for their direct contribution to the wellbeing of urban populations and liveability of cities (Beck, 2009; Braat & de Groot, 2012; Yap & Thuzar, 2012).

Recent research on the nexus between urban challenges, UES and Nature-based Solutions (Almenar *et al.*, 2021; Lafortezza *et al.*, 2018; Lechner *et al.*, 2020), highlights the role of UES in improving the liveability, resilience and sustainability of cities (Savage, 2006; United Nations, 2015). However, the future availability of UES is determined by land use decisions made in urban planning (Geneletti *et al.*, 2020), which need to be supported by exhaustive assessments of UES. Thus, we highlight the following research areas, based on our review, that need further attention in order for UES research to wholly support land use planning and decision-making in the region (Figure 2.7).

Figure 2.7 A diagram summarising the needs of UES research in Southeast Asia to support planning.

i) Geographically representative assessments

UES research is biased towards specific countries, regions and cities (Figure 2.2; Figure 2.4a). Aside from socioeconomic characteristics (Table 2.1), there are major biophysical differences between locations with maritime, continental and island climates in the region. This means that research conducted in Singapore may not necessarily be applicable in Cambodia or Myanmar. UES research needs to be context specific in order to purposefully address local needs. We therefore stress the need for a diverse range of UES assessments in countries that have very low representation of research such as Myanmar (n = 9), Laos (n = 1), Timor-Leste (n = 1) and Brunei (n = 0). The focus of assessments should also expand from megacities to secondary cities that are underrepresented (77% of studies concentrated on only four megacities—Singapore, Bangkok, Jakarta and Kuala Lumpur).

ii) Assessments on peri-urban areas and synergies and tradeoffs

As cities expand, peri-urban areas experience rapid land use change. However, only 15% of assessments examined peri-urban areas, consistent with Richards et al. (2019) and Wangai et al. (2016) that highlight peri-urban areas as being understudied globally. We encourage UES research in peri-urban areas, as these areas are where the intensity of development is the greatest and UES are being lost or degraded, and therefore where planning is mostly urgently needed.

It is especially important to investigate the synergies and tradeoffs of UES in urban and peri-urban areas so the consequence of planning decisions can be considered systematically (Holt *et al.,* 2015; Mokondoko *et al.*, 2018). Although 58% of studies in the region assessed multiple ecosystem ser-vices, only 4% dealt with synergies and tradeoffs. A clear understanding of the complex interactions between UES, as well as UES and land use management, is particularly important in rapidly developing peri-urban areas.

We also highlight the need for synergy and tradeoffs assessments between urbanisation and provisioning services. The spatial expansion of cities has negative impacts on urban/peri-urban agriculture (Artmann & Sartison, 2018), which is commonplace in Southeast Asia (Arif *et al., 2*008; Shevade & Loboda, 2019). Given the importance of agricultural production to local livelihood in the region (Helen & Gasparatos, 2020), the sustainability and multifunctional capacity of urban agricultural landscapes needs to be better understood (Aerts *et al.*, 2016; Dressler *et al.*, 2017). Careful management of land use as peri-urban areas develop can yield more sustainable UES provision, than attempts to retrofit restoration efforts in the future.

iii) Assessments on coastal areas

Many of Southeast Asia's densely populated cities are located along the coastlines (e.g., Greater Jakarta, Singapore, Ho Chi Minh, Bangkok, Manila), yet few studies examined UES in coastal areas. Coastal cities are particularly vulnerable to coastal and riverine floods, coastal erosion, storm surges, monsoons and tsunamis (Eckstein *et al.,* 2020; Hallegatte *et al.*, 2013), all of which bring adverse health risks to the urban population (Arifin & Nakagoshi, 2011; Wells *et al.*, 2016). Moreover, many of these extreme events are expected to increase in frequency in Southeast Asia because of climate change effects (Eckstein *et al.*, 2020; Yusuf & Francisco, 2010). Thus, we bring to attention the exigency of assessments of coastal structures as a Nature-based Solution in coastal cities. Research should also focus on opportunities to support the resilience of urban communities through the sustainable provision of UES (Uy & Shaw, 2013).

iv) Multi-temporal, climate-sensitive and scenario-based assessments

Few studies (11%) have conducted temporal assessments of UES, which are key to understanding changes in service provision and demand (Matthews *et al.*, 2017). This is challenging in practice as there is limited information on how UES change over time and/or under different future scenarios (Mora *et al.*, 2017; Remondi *et al.*, 2016). Moreover, Southeast Asian cities are seen to be highly vulnerable to climate change effects (Lechner et al., 2020; McDougall *et al.*, 2019; Willemen, 2020), yet few studies have examined the link between UES and climate resilience (n = 5). Assessments of changes in UES can be used to identify areas vulnerable to weather-related disaster risks and/or support decisions on appropriate land use management strategies (Yusuf & Francisco, 2010). Our review highlights a pressing need for multitemporal and/or scenario-based research on the resilience of UES provision. Research should also address the increased risk of diseases in tropical ecosystems due to the effects of climate change (Bowen & Ebi, 2017; Saulnier *et al.*, 2017), as well as the consequent impacts to UES, particularly provisioning services (Bito-onon, 2020; van Noordwijk *et al.*, 2016).

v) Diverse valuations and increased stakeholder involvement

Literature supporting the valuation of ecosystem services is abundant (Gómez-Baggethun & Barton, 2013; Hermes *et al.*, 2018; Keeler *et al.*, 2019; Sun *et al.*, 2019), with recent research emphasising diverse perspectives in valuations through value pluralism (Pascual *et al.*, 2017). However, our review found that only 23% of studies in the region conducted valuations. Valuations support decision-making by providing explicit quantification of UES demand, which can be in monetary or non-monetary terms (Conte, 2013). The involvement of stakeholders (44%) in UES assessments can support valuations by identifying con-text-specific demands and preferences of the people appropriating the services (Luederitz *et al*., 2015; Pascual *et al.*, 2017).

In line with TEEB and the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) (Díaz *et al*., 2018; Pascual *et al*., 2017; TEEB, 2010a), we urge research to incorporate diverse valuations, monetary and non-monetary, as well as increase stakeholder involvement in UES assessments. Although contentious (Heikkinen *et al.*, 2019), the comprehensive representation of UES through valuations has been proven to be effective in influencing decision-makers towards planning agendas (Kenter *et al.*, 2011). This is because valuations can be used as a tool to demonstrate the cost of restoring ecosystems or the critical importance of alternative land use options objectively to decision-makers (Brown *et al.*, 2014; Griffin *et al*., 2015; Rambonilaza & Neang, 2018). As the invisibility of nature in economic choices often drives its depletion (TEEB, 2011), valuation of UES can encourage more transparent assessments of tradeoffs to support the planning of sustainable cities.

Chapter 3 Mapping Social Values for Ecosystem Services to Support Urban Planning in a Rapidly Developing Asian Megacity

Prepared as: Lourdes, K.T., Gibbins, C.N., Sherrouse, B., Semmens, D., Hamel, P., Sanusi, R., Azhar, B. and Lechner, A. (in preparation). Mapping Social Values for Ecosystem Services to Support Urban Planning in a Rapidly Developing Asian Megacity.

3.1 Introduction

Urbanisation has been a primary cause for land use and cover change globally, often placing considerable pressure on ecosystem services (Ferreira *et al*., 2019; Romero-Duque *et al*., 2020). Ecosystem services are at greater risk in the Global South due to unprecedented population growth, rapid urbanisation and urban sprawl in these regions, which are often exacerbated by poor planning (Jones, 2014; Nagendra *et al*., 2018). In 2016, twenty-four of the world's thirty-one megacities were located in the Global South and a further ten megacities were expected to be added to the list in the next 15 years (United Nations, 2016). The intensive land use changes that take place as landscapes undergo urban expansion often result in the degradation of natural ecosystems, adversely affecting the delivery of ecosystem services and consequently the wellbeing of urban populations (Lechner *et al*., 2020; Lourdes *et al*., 2021; MEA, 2005).

Rapid and unplanned development can also diminish the social values associated with urban landscapes. The concept of social values for ecosystem services, previously referred to as 'landscape values', reflects the categories of provisioning, regulating, supporting and cultural ecosystem services that measure the composition and configuration of human perceptions of the landscape (Brown *et al*., 2020). The typology of social values for ecosystem services reflects the importance people, as individuals or as a group, assign to both the material and immaterial qualities of places (Scholte *et al*., 2015). Therefore, the importance of social values is relative to an individual/group and can be influenced by a number of factors such as context (e.g. socioeconomic, environmental and cultural context) and people's perception of the place/object being valued (United Nations, 2019a). Though social value information is critical to supporting ecosystem services-based approaches to land use management, quantitative, social value information are often not included in existing ecosystem service valuations, unlike biophysical and economic values (Sherrouse *et al.,* 2014). The lack of consideration for social value information is compounded by the association of social values with cultural ecosystem services, where the latter itself is inadequately integrated within the ecosystem service framework (Daniel *et al*., 2012).

GIS-based methodologies have been commonly applied to capture the spatial distribution of social values for ecosystem services (Sherrouse *et al*., 2011; Brown *et al*., 2016; Fagerholm *et al*., 2016; Hewitt *et al*., 2020). Often operationalised through a combination of traditional questionnaires with a mapping component, public participatory GIS (PPGIS) can generate spatial information on location-specific values, perceptions and preferences for future development (Brown *et al.*, 2020). In recent years, various map-based tools and platforms have been developed to facilitate public participation (Garcia-Martin *et al*., 2017; Lamoureux & Fast, 2019), allowing PPGIS surveys to be conducted in digital formats. Data gathered through PPGIS can be analysed with spatial modelling tools such as SolVES (*Social Values for Ecosystem Services*) (Sherrouse *et al*., 2011), to quantify relationships between perceived social values for ecosystem services and underlying environmental characteristics (Sherrouse & Semmens, 2015). Previous studies have employed PPGIS methods to analyse tradeoffs in land use change scenarios (Sherrouse *et al*., 2017), evaluate mismatches between supply and demand for ecosystem services (Meng *et al*., 2020) as well as to assess the perceptions of different stakeholder groups towards social values (Brown *et al*., 2016; Shoyama & Yamagata, 2016; van Riper *et al*., 2020).

Given that social values for ecosystem services are subjective values driven by individual perceptions, similarities and differences in where values manifest are inherent among individuals of a population. Conflicts could arise when individuals or stakeholder groups have different interests, development preferences or associate different social values in the same location (Brown *et al*., 2020). Studies involving spatial compatibility and conflict analysis have differentiated stakeholder groups by their value orientation (Brown *et al*., 2016), sociodemographic characteristics (Zhang *et al*., 2020), knowledge level (van Riper *et al*., 2020; 2017), and development preferences (Sherrouse *et al.,* 2014; Lechner *et al.,* 2020). These stakeholder groups can be identified prior to conducting PPGIS surveys or *ex post facto* using non-spatial responses collected during the survey (Brown *et al.*, 2016).

Social valuations in the past have often focused on natural ecosystems and landscapes (i.e., forests, mountains) (Bagstad *et al*., 2016; Bogdan *et al*., 2019; Johnson *et al*., 2019; Sherrouse *et al*., 2014), while few studies have assessed social values for ecosystem services in urban landscapes. Given the highly heterogenous and complex nature of cities, social values for ecosystem services are likely to be associated with both natural infrastructure (e.g., trees, lakes) and grey infrastructure (i.e., built features such as museums and commercial areas). As such, the spatial distribution of social values for ecosystem services are likely to be influenced by a range of physical, sociocultural and demographic factors. For example, the development preferences of urban residents could influence the types of social values and the places in which they manifest, especially in urban areas of the Global South, where landscapes are more prone to undergoing rapid changes (Lechner *et al*., 2020; Lourdes *et al*., 2021). While the current literature reflects the high priority of conservation and urban green space planning in the Global North (Stålhammar, 2021), similar studies in urbanising Global South cities are limited and existing studies suggest that preferences towards green spaces are generally positive but vary with the local context (i.e., green spaces are favoured for their ecological and recreational benefits but some studies show concerns around safety and noise pollution from park visitors) (Kasim *et al*., 2016; Shirazi and Kazmi, 2016; Zhang *et al.,* 2021).

This study aims to investigate the social values for ecosystem services associated with Greater Kuala Lumpur, Malaysia, a rapidly urbanising metropolitan city in Southeast Asia. As urban development expands outwards from the capital city, Kuala Lumpur, the current trend of high-intensity development is spreading towards the peri-urban, outer bounds of the metropolitan city. These changes can have negative implications on the liveability of residential areas as well as the quality of life and wellbeing of urban residents. Due to the nature of urban planning in Malaysia, members of the public are rarely involved in the planning process and their perception towards urban development often goes unheard (Lechner *et al*., 2020). To date, the social values residents associate with the Greater Kuala Lumpur landscape and their views on the rapid urbanisation taking place in the metropolitan area have not been investigated. To bridge this gap, we conduct a PPGIS survey to explore the social values for ecosystem services and development preferences of residents in Greater Kuala Lumpur. We explore the factors that influence the development preferences of residents and map the spatial distribution of social values for groups with different development preferences, identifying areas of spatial agreement and conflict between groups. Finally, we discuss our findings with respect to urban expansion in Greater Kuala Lumpur, highlighting the importance of varying stakeholder perspectives in social valuations to support sustainable urban planning in rapidly developing cities.

3.2. Methods

3.2.1 Study area

The study was conducted in the Greater Kuala Lumpur metropolitan region (area = 2793 km^2), Malaysia, which comprises the federal district of Kuala Lumpur and the surrounding six contiguous districts (Petaling, Hulu Langat, Klang, Putrajaya, Sepang and Gombak) (Figure 3.1). The Greater Kuala Lumpur metropolitan region, here after referred to as GKL, has been defined as the National Key Economic Area (NKEA) which contributes to over 30% of the nation's Gross National Income (PWC, 2017). Over 7.9 million of Malaysia's 32 million residents (25%), reside in GKL (UN, 2020), making it the most urbanised and densely populated region in the country (2708 people per km^2). Kuala Lumpur is the most urbanised district in GKL, with a population density of 7366 people per km^2. The degree of urban development in the other six districts vary but are lower in comparison to Kuala Lumpur (for reference, Petaling and Gombak have population densities of 3400 people per km^2 and 970 people per km^2, respectively) (Department of Statistics Malaysia, 2018).

GKL contains a landscape mosaic that is predominantly built, but includes other land uses such as agriculture (mainly oil palm and rubber), forest reserves, and wetlands. Notable natural features across the landscape include the Hulu Gombak and Hulu Langat forest reserves located at the north and northeastern boundaries, the Ayer

Hitam forest reserve located southwest of Kuala Lumpur and the Putrajaya wetlands park located in Putrajaya (Figure 3.1).

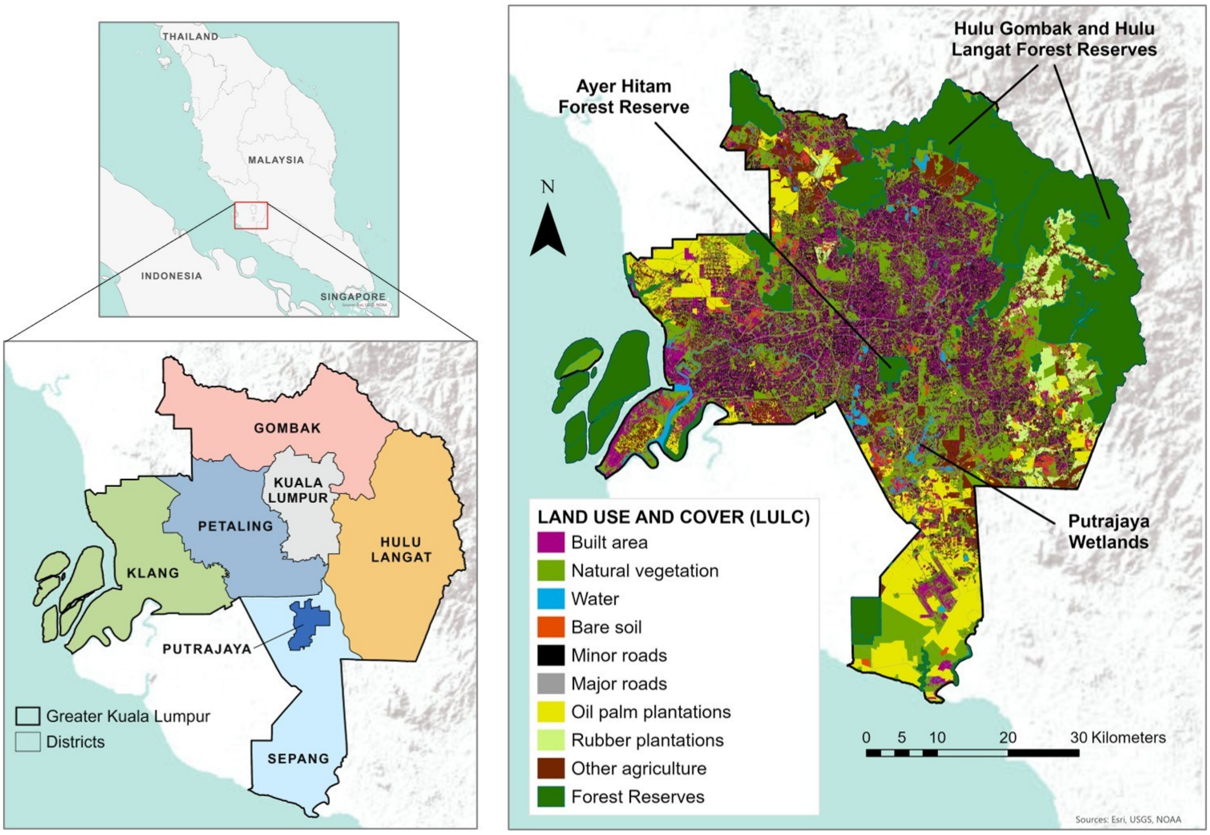


Figure 3.1 The location of the study area, the Greater Kuala Lumpur metropolitan region (top left), and the seven districts in study area (bottom left). The land use and cover of the study area (right) with labels marking key natural features such as forest reserves and wetlands (map produced by Karen Thivya Lourdes, data sourced from Danneck et al. (in review)).

3.2.2. Overview

In this study, we applied the Social Values for Ecosystem Services (SolVES - https://www.usgs.gov/centers/gecsc/science/social-values-ecosystem-services-solves; (Sherrouse *et al.*, 2022; 2011) tool to explore residents' perception of social values for ecosystem services in an urban setting and preferences towards development in GKL. We conducted a social survey using public participatory GIS (PPGIS) to map social values across GKL and clustered the respondents into groups based on their development preferences. We then derived maps illustrating the spatial distribution of different social values for each group and identified areas of spatial agreement and conflict between the groups.

3.2.3 Survey administration and design

We conducted an online PPGIS survey between May and July of 2021 in GKL to investigate the development preferences of residents and the social values associated with their neighbourhood area. The online survey was developed in Maptionnaire (https://maptionnaire.com) and disseminated in two languages (English and Bahasa Malaysia). The survey adhered to the guidelines of the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia and received ethical approval (Ethical ID: KTL050421).

We carried out a pilot study with 24 respondents, obtaining their feedback on the design, structure and understanding of the survey. We made minor changes where appropriate based on the feedback before finalising the survey. The finalised survey was distributed through convenience and snowball sampling by three enumerators, who were trained by the same researcher to ensure consistency in sampling (Fagerholm *et al*., 2020). The online survey was open to all residents of GKL aged 18 and above, with only one response collected from each household to ensure random spatial distribution. Upon completing the survey, respondents were given the option to participate in a lucky draw to win food vouchers. Of the 2388 surveys distributed, 595 responses were returned (25% response rate). However, only 494 responses were complete and used in this study.

The survey contained four sections. The first section inquired about the respondents' characteristics such as their length of residence in their neighbourhood, familiarity with the neighbourhood and opinions on public involvement in local planning as well as environmental management.

In the second section, the respondents were asked to map their social values. Respondents were first asked to identify their district of residence and mark their location of residence on the map. Then, the respondents were asked to allocate RM1000 (USD 241) to preserve 10 social values in their neighbourhood in a hypothetical scenario. The typology of social values was originally developed by Rolston & Coufal (1991) as forest values typology and validated by Brown & Reed (2000). The typology used in this study was developed based on more recent iterations of the typology (Brown et al., 2015; Garcia-Martin et al., 2017), with minor modifications to best reflect the context of GKL (Table 3.1). For example, we replaced 'life-sustaining' value previously used in forests for 'local norm and sense of belonging' value to capture preferences for places associated with the urban Malaysian lifestyle such as watching sporting events at hawker stalls and strolling shopping malls. Moreover, due to the diverse aspects of Malaysia's culture and the different meanings 'cultural value' could have in the region, we differentiated between cultural values associated with the local lifestyle ('local norm and sense of belonging'), religion ('religious and spiritual') and tradition ('heritage and historic'). The respondents were informed that the allocation of money was part of a hypothetical scenario to explore the respondent's relationship with their neighbourhood and were asked to only allocate money to the social values that were most important to them. For the social values that the respondents chose to preserve (i.e., allocate money to), respondents were asked to map the locations that represent these social values in their neighbourhood. Given the scale of the study area, the questions were based on the respondent's neighbourhood as familiarity with the landscape was needed to map social values for ecosystem services (assigned values) (Alessa *et al.*, 2008; Scholte *et al.*, 2015; Van Berkel & Verburg, 2014). In mapping the locations that represent their values, respondents could zoom in and out of their neighbourhood as well as toggle between OpenStreetMap (default) and Mapbox Street maps to aid visualisation (Mapbox Street, 2021; OpenStreetMap, 2021). A clear boundary of the study area was provided to ensure that respondents marked locations within GKL. Respondents could mark up to four locations for each social value that they chose to preserve, resulting in a maximum of 40 mapped points per respondent (no minimum number of points required) (Lechner *et al.*, 2020). Respondents were requested to complete the mapping exercise for their survey response to be considered a 'valid response'.

Table 3.1 List of social values and definitions

Social values	**Definition (as presented in the survey)**	**References**
Aesthetic	I value these places because they have attractive or pleasing landscapes	(Brown *et al.*, 2015)
Economic	I value these places because they provide opportunities for tourism, produce agricultural products or support local businesses	(Brown & Reed, 2000)
Existence	I value these places just for their existence, regardless of benefits to me or others	(Garcia-Martin *et al.*, 2017)
Heritage and history	I value these places for their history and/or because they provide opportunities to express and appreciate culture or cultural practices such as art, music, history and indigenous traditions	(Brown *et al.*, 2015)
Habitat and biodiversity	I value these places for the plants, animals, wildlife or ecosystem	(Garcia-Martin *et al.*, 2017)
Local norm and sense of belonging	I value these places because they embody the local lifestyle, creating a sense of place, community and belonging	(Ramm, 2018)
Recreation	I value these places because they provide outdoor recreation opportunities	(Brown & Reed, 2000)
Religious and spiritual	I value these places because they have religious and/or spiritual meaning	(Brown & Reed, 2000; Brown *et al.*, 2015)
Social interaction	I value these places because they provide opportunities to interact with family, neighbours, friends and other people	(Brown *et al.*, 2012)
Therapeutic	I value these places because they support mental and/or physical wellbeing	(Brown & Reed, 2000)

In the third section, respondents were asked about 14 development preferences in their neighbourhood using a 5-point Likert scale (Strongly Favour to Strongly Oppose). These development preferences included green developments (e.g., neighbourhood parks, recreational forests, community gardens/orchards) and grey developments (e.g., high rise commercial/residential buildings, highways and road developments, shopping malls, train stations). All 14 development preferences are listed in Figure 3.2.

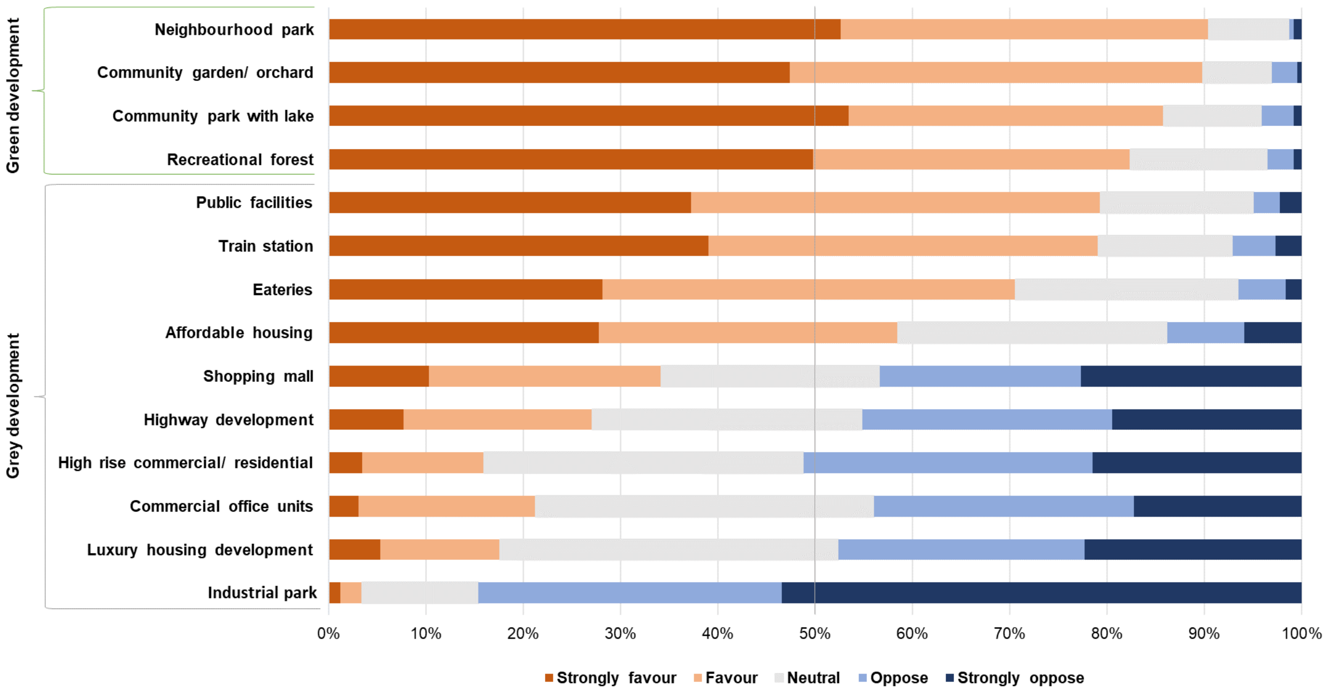


Figure 3.2 The preferences of respondents towards 14 potential development preferences. The first four development preferences (i.e., neighbourhood park, community garden/ orchard, community park with lake, recreational forest) were considered green developments as they represent green spaces, while all other development preferences were considered grey developments due to their built nature.

The final section inquired about the respondents' background. The first three sections of our survey follow the design of Clement (2006), based on methods by (Brown *et al.*, 2002). The final section gathers demographic information following the design of a local PPGIS study by Lechner et al. (2020). The spatial and nonspatial responses from the second and third sections of the survey served as the main data inputs for the SolVES analysis. A copy of the survey is available in Appendix E.

3.2.4 Clustering respondents by development preference

Following Lechner et al. (2020), we conducted a principal component analysis (PCA) to group the respondents based on their shared development preferences (third section of the survey). First, the reliability of all 14 development preferences (Likert scale values of respondents' development preference) was checked using Cronbach's α, where $\alpha \geq 0.6$ was regarded as sufficient. We conducted a PCA on the 14 development preferences with an oblique rotation method, treating each development preference as a variable. Factor scores for each resulting component were calculated using the Regression method. Based on principal components 1 and 2, two distinct groups were identified in the population. We used the factor scores of the first two components of the PCA as inputs for the K-means cluster analysis to group the respondents into two separate groups representing subsets of the population with shared development preferences. We assessed the mean differences in factor scores between the two groups using independent samples t-test. We also examined the average differences in Likert scores for each development preference between the two groups using a Mann-Whitney U test. To compare the sociodemographic characteristics of the two groups, we applied a Chi-squared test and Mann-Whitney U test.

We also examined the distance between each respondents' mapped location of residence and the city centre for the two groups. The coordinates for the city centre, identified as a location in Petaling Street (which is considered the first main town in Kuala Lumpur) were obtained from Chan and Vu (2017). We calculated the residence-to-city-centre (point to point) distance for each respondent using ArcGIS Pro version 2.7 (ESRI, 2020a). Then, we conducted a Student's T-Test to compare the mean distances for the members of the two groups. All statistical analyses were conducted with SPSS version 28.

3.2.5 Spatial distribution and importance of social values

We applied Social Values for Ecosystem Services (SolVES) version 3.0 to explore the spatial distribution of respondents' perception of social values in GKL (Sherrouse *et al.,* 2011). SolVES is an open-access GIS application for mapping, quantifying and assessing the social values for ecosystem services. The tool derives social value maps with a 10-point value index based on spatial and nonspatial survey responses on social value and development preference.

SolVES first calculated the average nearest neighbour statistics for the mapped points to evaluate the relative dispersion, clustering and randomness of the points associated with each social value (Sherrouse *et al*., 2014). Then, using the maximum-entropy approach (Maxent model, Phillips *et al*., 2006), weighting of social values (hypothetical allocation of money across value types), and the environmental data provided, SolVES generated social values maps with a value index ranging from 0 to 10. We used the following ten environmental variables, which were uniformly processed as raster data with a resolution of 10m: Elevation, population count, NDVI, land use and cover, distance to large water bodies, distance to medium natural vegetation, distance to large natural vegetation, distance to agricultural land, distance to built area (all impervious surfaces), and distance to train stations (Table 3.2). We tested for spatial correlation between all environmental variables using the Species Distribution Model toolbox version 2.4 (Brown *et al*., 2017). We maintained all ten variables in our SolVES model to represent the heterogeneous landscape of GKL, given that the variables showed weak spatial correlation (Table 3.3). We standardised the extent (based on the elevation raster) and cell size (10m) of all the environmental variables before loading the layers into the SolVES geodatabase. We used a pixel size of 90 m for the model, based on the density of the mapped point locations, calculated using the following equation:

$$p \leq \frac{h_{ij}}{2} \qquad (1)$$

where h_{ij} is the mean nearest neighbour distance between point pairs (Hengl, 2006). Maxent was applied to each development-preference group, generating 10 social-value maps and associated environmental metrics for each group. Area Under the Curve

(AUC) statistics were calculated by Maxent for the training and test data, which respectively indicates the goodness of fit of the models to the study area and each model's potential predictive capability.

Table 3.2 List of environmental variables used in SolVES, their description and source.

Variable	Description	Source
Elevation	Digital Elevation Model	SRTM Global (https://earthexplorer.usgs.gov/)
Population count	Population count per grid	WorldPop Population Count (constrained) (https://www.worldpop.org/)
NDVI	Average NDVI in a 500m radius around the centre of a 10m pixel derived using a moving window	Multidate cloud-free Sentenel 2 mosaic 10m (https://sentinel.esa.int/)
LULC	9 class categorical land use and cover data: built area, water, natural vegetation, bare soil, minor roads, major roads, oil palm, rubber and other agriculture	Danneck et al. (in review)
Dist. to water	Distance to water bodies with area > 0.1 ha	Derived from the LULC using Euclidean distance
Dist. to large veg	Distance to natural vegetation with area ≥ 10 ha	Derived from the LULC layer using Euclidean distance
Dist. to med veg	Distance to natural vegetation with 0.1 ha < area ≤ 10 ha	Derived from the LULC layer using Euclidean distance
Dist. to agriculture	Distance to all agricultural land (i.e., oil palm, rubber and other agriculture)	Derived from the LULC layer using Euclidean distance
Dist. to built area	Distance to built area (impervious surfaces)	Derived from the LULC layer using Euclidean distance
Dist. to train station	Distance to train stations in GKL	Derived using Euclidean distance from digitised points

Table 3.3 Spatial correlation between environmental variables conducted using the correlation and summary statistics tool.

Variables	Elevation	Population count	NDVI	Dis. to water	Dis. to large veg	Dis. to med veg	Dis. to agriculture	Dis. to built area	Dis. to train station
Elevation	1.000								
Population count	-0.107	1.000							
NDVI	0.419	-0.367	1.000						
Dis. to water	0.084	-0.042	0.162	1.000					
Dis. to large veg	-0.290	-0.034	-0.275	0.167	1.000				
Dis. to med veg	0.136	-0.531	0.255	0.113	0.065	1.000			
Dis. to agriculture	0.084	0.085	-0.180	0.000	0.034	0.147	1.000		
Dis. to built area	-0.237	-0.275	-0.024	0.150	0.429	0.320	0.272	1.000	
Dis. to train station	0.017	-0.124	0.061	0.015	-0.008	0.060	-0.014	0.038	1.000

3.2.6 Spatial agreement and conflict between groups

We identified the social values with the highest importance based on the maximum value index (i.e., the social values with the highest maximum index value) for the two development preference groups identified from the PCA. We then assessed areas of spatial agreement and conflict between the two groups for each social value (Lechner *et al.*, 2020). Areas of spatial agreement between the two groups were calculated using Equation (2):

$$Magnitude\ of\ spatial\ agreement = G_{max} - (|G_1 - G_2|) \quad (2)$$

where G_1 is the pixel value of a selected social value from Group 1, G_2 is the corresponding pixel value for the same social value from Group 2 and G_{max} is the maximum value attained by the social value on the value index across Group 1 and Group 2. Pixels with larger values indicate a higher magnitude of spatial agreement between the two groups for the corresponding social value, while pixels with smaller values represent areas of spatial conflict. To determine the magnitude of conflict by group, we use Equation 3:

$$Magnitude\ of\ spatial\ conflict = G_1 - G_2 \quad (3)$$

where G_1 is the pixel value of a selected social value from Group 1 and G_2 is the corresponding pixel value for the same social value from Group 2. Positive values on this scale indicate that the pixel is more important to respondents in Group 1, while negative values indicate that the pixel is more important to respondents in Group 2. The analysis for spatial agreement and conflict was conducted at the same 90m resolution as the social-value maps. All spatial processing and analysis were performed on ArcGIS Pro version 2.7 (ESRI, 2020a).

3.3 Results

3.3.1 Sociodemographic characteristics and development preferences of all respondents

The ages of the 494 respondents ranged between 18 to 75 years old, although most respondents were less than 30 years old (62% aged between 18 and 29). We received more responses from female respondents than male (63% and 37% respectively), comprising various ethnic backgrounds: Chinese (45%), Malay (31%), Indian (17%) and other ethnicities (7%). Most respondents had received tertiary education (62% have a Bachelor's degree and a further 16% have a Master's degree or higher). Only 2% of respondents (n=12) had no formal education or were educated to up to a primary level; these respondents were 55 years of age or older. 50% of respondents worked in the private sector, 21% were students, 10% were self-employed, 6% worked in the public sector, 5% were retired, and the remaining respondents were either homemakers, unemployed or did not provide a response. The respondents had a wide range of monthly incomes (from less than RM1000 to more than RM15000). The median monthly income of respondents was between RM1000 and RM3000, while 24% of respondents had no monthly income. A majority of the respondents lived in the Petaling (31%), Hulu Langat (27%) and Kuala Lumpur (25%) districts. 6% and 7% of respondents lived respectively in the Gombak and Klang districts while the remaining 5% of respondents lived in Sepang and Putrajaya (Table 3.4). As for respondents' self-described perspective on the environment and economy (survey question 6), 75.9% believed that both the environment and economy should be prioritised equally, 23.1% believed the highest priority should be given to the environment despite negative economic consequences and 1% believed that economic benefits should be prioritised despite negative environment consequences.

Table 3.4 Sociodemographic characteristics of all respondents.

Characteristic	Description
Gender	Male 36.6%; Female 63.4%
Age	Mean 31.92; SD 13.23
Ethnicity	Malay 31.2%; Chinese 45.3% Indian 16.8%; Other 6.7%
Highest Education	No formal education 0.4%; Primary 2.0%; Lower secondary 0.8%; Upper secondary 4.3%; Diploma 9.5%; Graduate 62.3% Postgraduate 16.4%; Other 4.3%
Employment Status	Unemployed 3.8%; Student 21.3%; Self-employed 9.1%; Homemaker 4.0%; Public sector 5.9%; Private sector 50.4%; Retired 5.3%; No response 002%
Monthly Income	No income 24.5%; < RM1k 6.5%; RM1k to RM3k 22.1%; RM3k to RM5k 23.1%; RM5k to RM7k 10.5%; RM7k to RM10k 6.1%; RM10k to RM15k 4.3%; > RM15k 3.0%
Self-described perspective	Prioritise the economy 1.0%; Prioritise the environment 23.1%; Prioritise both the economy and environment equally 75.9%
Residence by district	Petaling 31.0%; Hulu Langat 27.1%; Kuala Lumpur 24.5%; Gombak 6.7%; Klang 6.1%; Sepang 3.6%; Putrajaya 1.0%

The development preferences of all respondents is summarised in Figure 3.2. Over 50% of residents strongly favoured ‘neighbourhood park’ and ‘community garden/orchard’. Over 80% of residents generally favoured (‘strongly favour’ and ‘favour’) all four green developments. ‘Public facilities’, ‘train station’, ‘eateries’ and ‘affordable housing’ were generally favoured (‘strongly favour’ and ‘favour’) by over 50% of residents, with ‘public facilities’ and ‘train station’ being the most favoured grey developments. Residents had relatively neutral preferences towards ‘highway development’ and ‘shopping mall’, while ‘commercial office units’ and ‘luxury housing development’ were opposed more than favoured. ‘High rise commercial/ residential’ and ‘industrial park’ were the only two grey developments that were generally opposed (‘strongly oppose’ and ‘oppose’) by over 50% of residents. ‘Industrial park’ was the least favoured and most strongly opposed development with over 85% of residents generally opposing ‘industrial park’.

3.3.2 Identification of clusters based on development preferences

All 14 development preferences were used in the PCA to group the respondents. The alpha coefficient of all 14 development preferences was greater than 0.70, indicating acceptable levels of internal consistency. The first two components of the PCA explained 43% of the variance in development preferences and represented the following perspectives: (1) favouring grey development and (2) favouring green development. The mean differences in factor scores for both components were statistically significant for the two groups (Table 3.5).

Table 3.5 Mean differences in factor score by component and group identified by the cluster analysis calculated using independent samples t-test.

Component	**Group 1: Favour-balanced-development** Mean (SD)	**Group 2: Oppose-grey-development** Mean (SD)	**t**	**p-value**
Favouring grey development	0.78 (0.62)	-0.82 (0.58)	29.75	< 0.001
Favouring green development	-0.14 (1.03)	0.15 (0.94)	-3.22	0.001
Number of respondents	253	241		

The K-means cluster analysis based on the factor scores of these two components divided the respondents into two groups based on their development preferences. The first group was ‘favour grey and green development’ (hereafter ‘favour-balanced-development’), and the second, ‘favour green development and oppose grey development’ (hereafter ‘oppose-grey-development’). The favour-balanced-development group comprised 253 respondents (51%) who favoured all green developments (average Likert value > 3.9) and favoured some grey developments such as public facilities, train stations and eateries. This group was neutral towards all other grey developments (average Likert value > 2.9 and < 4), opposing only industrial park developments (average Likert value < 2). The oppose-grey-development group included 241 respondents (49%) who favoured all green developments, but generally opposed grey developments. Members of this group were neutral towards several grey developments such as public facilities, train stations, eateries and affordable housing, but (strongly) opposed all other grey developments.

The two groups showed significant differences in terms of their average Likert scores for each development preference (Table 3.6). The average Likert scores for all development preferences were significantly different between the two groups ($p < 0.01$), except for 'neighbourhood parks', 'affordable housing' and 'public facilities'. While both groups favoured green developments, the oppose-grey-development group had a higher average Likert score (i.e., greater preference) for green developments (4.42) than the favour-balanced-development group (4.27). In contrast, the favour-balanced-development group had a higher average Likert score for grey developments (3.47) than the oppose-grey-development group (2.62).

Table 3.6 Differences in development preferences between the two groups by average Likert score. The p-value denoting the statistical significance of these difference was derived using the Mann-Whitney U test. The average Likert score provided in bold summarises the development preferences of the two groups by green and grey development types. (n.s. = not significant)

Development type	**Development preference**	**Group 1: Favour-balanced-development** Average	**Group 2: Oppose-grey-development** Average	**p-value**
Green	Neighbourhood Park	4.38	4.44	0.503 (n.s.)
	Community Garden	4.24	4.44	< 0.01
	Community Park Lake	4.40	4.29	0.404 (n.s.)
	Recreational Forest	4.08	4.49	< 0.001
	Average Score	**4.27**	**4.42**	
Grey	Public Facilities	4.25	3.93	< 0.001
	Train Station	4.27	3.89	< 0.001
	Eateries	4.31	3.48	< 0.001
	Affordable Housing	3.76	3.56	0.155 (n.s.)
	Shopping Mall	3.60	1.93	< 0.001
	Highway	3.22	2.16	< 0.001
	High Rise	3.00	1.90	< 0.001
	Commercial Office	3.16	2.07	< 0.001
	Luxury Housing	3.23	1.80	< 0.001
	Industrial Park	1.87	1.45	< 0.001
	Average Score	**3.47**	**2.62**	

3.3.3 Sociodemographic characteristics of the two groups

In comparing the sociodemographic characteristics of the two groups, we found significant differences for several characteristics (Table 3.7). The two groups differ significantly ($p < 0.05$) in terms of their self-described perspective on prioritising the environment and/or the economy (survey question 6). Most members in the favour-balanced-development group (86%) place equal priority on the economy and environment, while only 16% prioritise the environment over the economy. A larger proportion of members in the oppose-grey-development group prioritise the environment over the economy (31%), while the remaining 69% prioritise the economy and environment equally.

The characteristics of two groups were also significantly different in terms of ethnicity, employment and education. A majority of the members of the favour-balanced-development group had a Chinese ethnic background, while the oppose-grey-development group mainly comprised members of Malay, Indian and other ethnicities. 55% of members in the favour-balanced-development group work in the private sector, which is significantly more people than in the oppose-grey-development group ($p < 0.05$). Members of the oppose-grey-development group also rank higher in terms of education than members of the favour-balanced-development group (Mann-Whitney U test: $p < 0.05$). There was no significant difference between the groups in terms of gender, age or monthly income.

There was also a significant difference in the districts in which members of the two groups resided. More members of the favour-balanced-development group lived in the Hulu Langat and Klang districts ($p < 0.05$), while members of the oppose-grey-development group largely lived in the Kuala Lumpur district. The Student's T-Test comparing the mean distances of residence-to-city-centre for the two groups revealed that members of the oppose-grey-development group reside significantly closer to the city centre compared to members of the favour-balanced-development group ($p < 0.01$).

Table 3.7 Sociodemographic characteristics of respondents by group. For each characteristic, the percentage of respondents within each group is reported based on the Chi-squared test followed by the p-value. Additionally, for age group, education, and income, the mean rank and p-values are reported based on the Mann-Whitney U test. (n.s. = not significant)

Characteristic	Group 1: Favour-balanced-development	Group 2: Oppose-grey - development	Statistical significance of p-value
	Percentage within group (Chi-squared Test)		
Self-described perspective			
Prioritise the economy	1.6%	0.4%	n.s.
Prioritise the environment	15.8%	30.6%	< 0.05
Prioritise both equally	82.6%	68.9%	< 0.05
Gender			
Male	39.5%	33.6%	n.s.
Female	60.5%	66.4%	n.s.
Age			
No response	2.4%	1.7%	n.s.
18-29	63.2%	60.6%	n.s.
30-39	13.4%	17.8%	n.s.
40-49	5.1%	6.2%	n.s.
50-59	10.7%	11.2%	n.s.
> 60	5.1%	2.5%	n.s.
Ethnicity			
Malay	26.9%	35.7%	< 0.05
Chinese	57.3%	32.8%	< 0.05
Indian	11.5%	22.4%	< 0.05
Other	4.3%	9.1%	< 0.05
Highest Education			
No formal education	0.4%	0.4%	n.s.
Primary	3.6%	0.4%	< 0.05
Lower secondary	0.8%	0.8%	n.s.
Upper secondary	4.0%	4.6%	n.s.
Diploma	11.1%	7.9%	n.s.
Graduate	60.5%	62.7%	n.s.
Postgraduate	13.4%	19.7%	n.s.
Other	1.2%	0.4%	n.s.
Employment status			
Unemployed	2.0%	5.8%	< 0.05
Student	20.2%	22.4%	n.s.
Self-employed	7.9%	10.4%	n.s.
Homemaker	3.2%	5.0%	n.s.
Public sector	5.5%	6.2%	n.s.
Private sector	54.9%	45.6%	< 0.05

Retired	6.3%	4.1%	n.s.
Monthly income			
No income	21.7%	27.4%	n.s.
< RM1k	6.3%	6.6%	n.s.
RM1k to RM3k	22.9%	21.2%	n.s.
RM3k to RM5k	25.3%	20.7%	n.s.
RM5k to RM7k	11.1%	10.0%	n.s.
RM7k to RM10k	5.9%	6.2%	n.s.
RM10k to RM15k	4.0%	4.6%	n.s.
> RM15k	2.8%	3.3%	n.s.
Residence by district			
Petaling	27.7%	34.4%	n.s.
Hulu Langat	32.0%	22.0%	< 0.05
Kuala Lumpur	19.4%	29.9%	< 0.05
Gombak	6.7%	6.6%	n.s.
Klang	8.3%	3.7%	< 0.05
Sepang	4.3%	2.9%	n.s.
Putrajaya	1.6%	0.4%	n.s.
	Mean rank (Mann-Whitney U Test)		
Education	235.03	260.59	< 0.05
Age Group	244.96	250.17	0.641 (n.s.)
Income	253.31	241.40	0.344 (n.s.)

3.3.4 Distribution and importance of social values

The nearest neighbour statistics for all social values across both groups is shown in Table 3.8. The degree of clustering for all social values across both groups were statistically significant ($p < 0.01$). The social value with the highest maximum value index for the favour-balanced-development group was economic value (Max VI = 10), followed by the heritage and historic value (Max VI = 9). In contrast, the oppose-grey-development group placed equally high importance on economic, heritage and historic, and recreation values, which all achieved a Max VI of 9. The social value ranked least important was therapeutic value, which had the lowest Max VI across both groups (Max VI = 5).

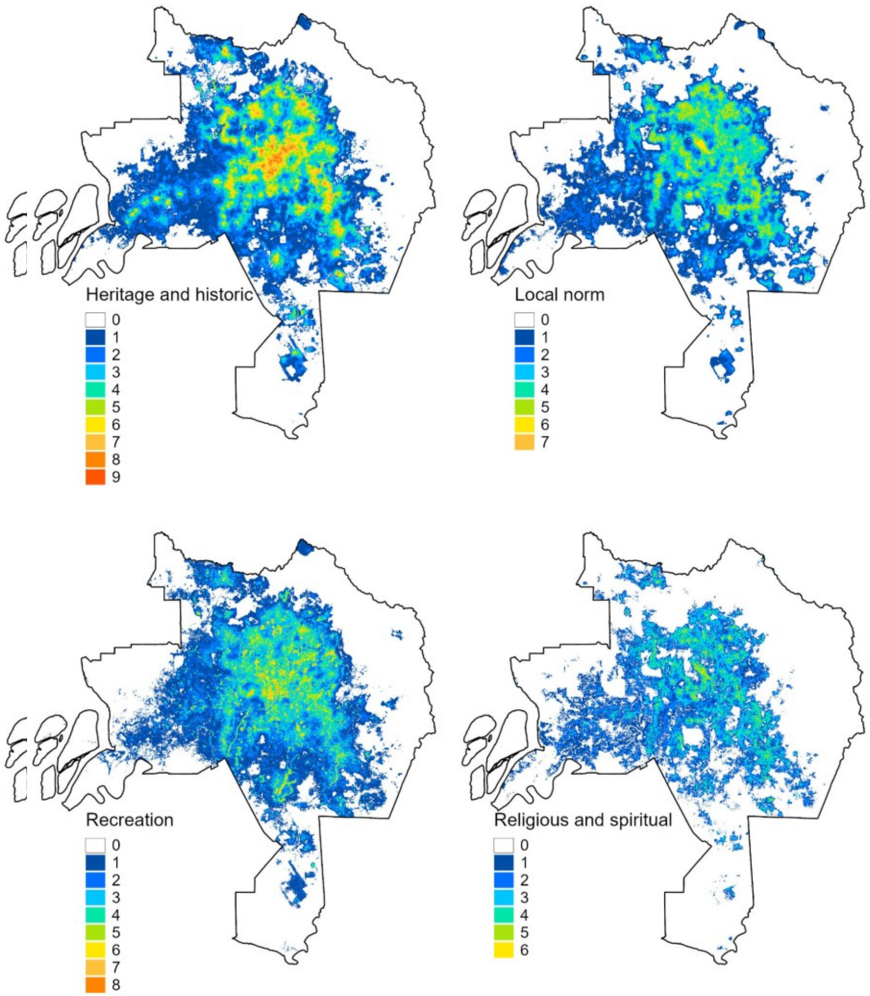
Table 3.8 The nearest neighbour index for social values across groups. N represents the number of points marked by respondents, the R value represents the degree of clustering of points (R value < 1 clustering patterns; R value = 1 random patterns; R value > 1 no clustering), the Z score represents the number of standard deviation from the mean of each R value and Max VI represents the maximum value achieved on the value index. ** P < 0.01

Social value	**Group 1: Favour-balanced-development**				**Group 2: Oppose-grey-development**			
	N	R value	Z score	Max VI	N	R value	Z score	Max VI
Aesthetic	210	0.584	-11.529**	8	231	0.511	-14.224**	7
Economic	224	0.482	-14.838**	10	232	0.505	-14.421**	9
Existence	162	0.547	-11.036**	6	175	0.520	-12.158**	5
Habitat and biodiversity	159	0.678	-7.758**	5	211	0.588	-11.448**	6
Heritage and historic	124	0.554	-9.496**	9	123	0.440	-11.879**	9
Local norm and sense of belonging	163	0.530	-11.485**	7	179	0.475	-13.438**	7
Recreation	182	0.488	-13.223**	8	233	0.482	-15.130**	9
Religious and spiritual	134	0.444	-12.303**	6	140	0.407	-13.421**	6
Social interaction	161	0.504	-12.041**	6	199	0.433	-15.315**	7
Therapeutic	126	0.563	-9.389**	5	146	0.578	-9.755**	5

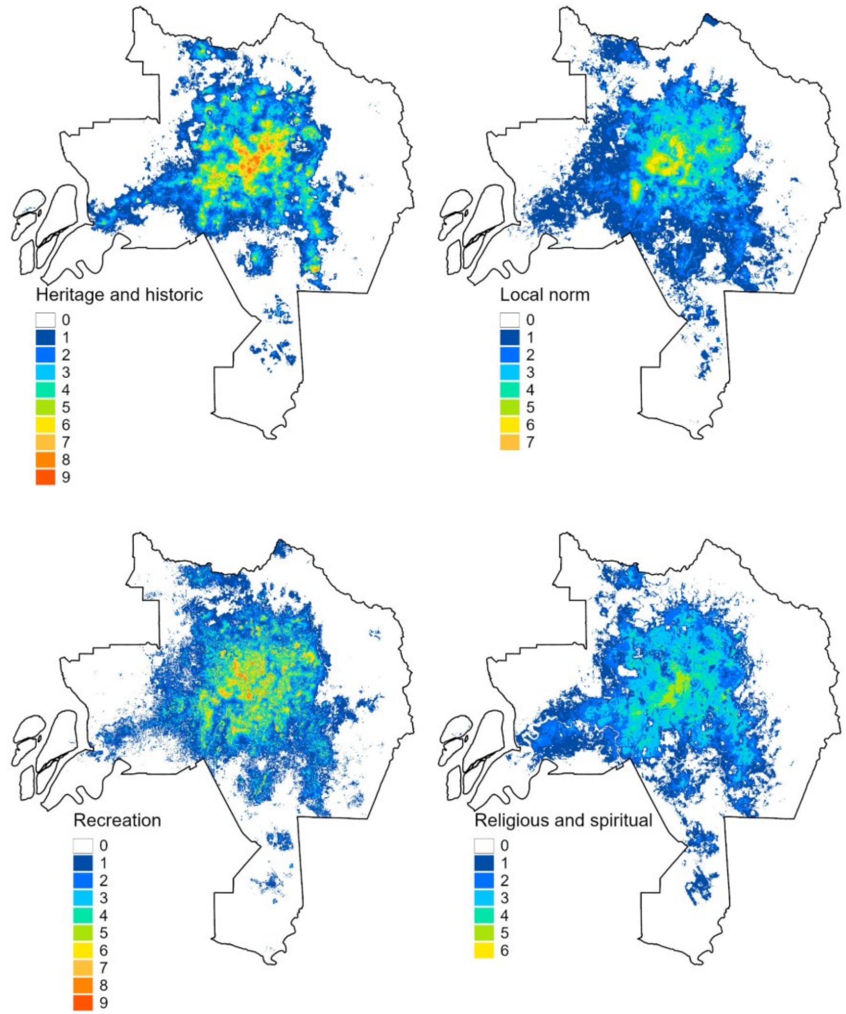
The spatial distribution of the 10 social values for both groups is shown in Figure 3.3. The distribution of social values was generally concentrated in the centre of GKL for both groups, although the extent of value distribution and intensity varied with the type of social value. Given the spatial heterogeneity of the GKL landscape, values were concentrated in different locations for each social value, presenting similarities and differences in between the two groups. Economic value, which had the highest Max VI for both groups, was concentrated in the urban areas of the Petaling and Kuala Lumpur districts. Areas of high economic value spread out from the urban centre into peri-urban towns for the favour-balanced-development group, while for the oppose-grey-development group areas of high economic value was concentrated in existing urban centres. For the oppose-grey-development group, green spaces such as parks and areas peripheral to forest reserves also had high economic value, in contrast to the favour-balanced-development group which associated economic value with built areas. Similar patterns in distribution were observed for heritage and historic, local norm and sense of belonging and social interaction values.

We also examined the area under the curve (AUC) statistics and the relative contribution of the environmental variables in modelling the spatial distribution of each social value (Table 3.9). For both groups, all models showed high goodness-of-fit with training AUC values > 0.87. The models also had useful potential predictive capabilities with test AUC values > 0.82. Of the ten environmental variables, factors associated with density of urban areas such as population count, distance from train station and distance to agriculture, contributed the most to the spatial distribution of social values for both groups. These contributions were followed by physical factors such as elevation and NDVI. The directional relationships between environmental variables and the value index score varied with the type of social value but were relatively similar across the two groups. Generally, the value-index score for social values increased as distance to agriculture and distance to large vegetation increased, and decreased as distance to built area, distance to train stations and distance to water bodies increased.

FAVOUR-BALANCED-DEVELOPMENT



OPPOSE-GREY-DEVELOPMENT



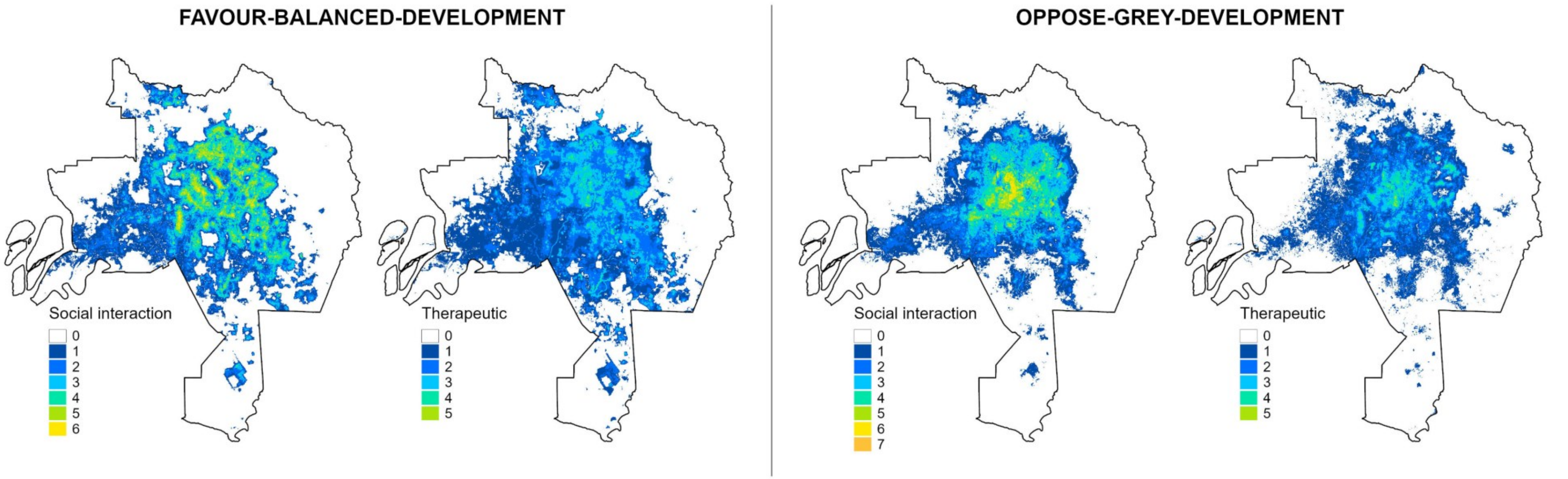


Figure 3.3 The spatial distribution of the 10 social values for each group: (1) favour-balanced-development and, (2) oppose-grey-development. The AUC values and the percent contribution of environmental variables for each model is listed in Table 3.9. The legend values from 0 to 10 represent the intensity of the corresponding social values perceived by respondents.

Table 3.9 The number of samples, AUC values and percent contribution of environmental variables to the Maxent model. The percent contribution of an environmental variable to the modelling of a social value is represented through a blue-white-red gradient, where values in blue represent lower percent contributions and values in red represent higher contributions.

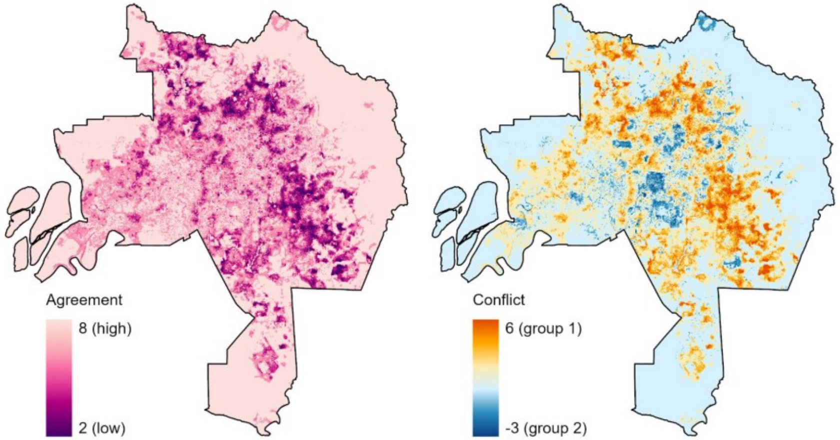
Group	Social value	No of training samples	Training AUC	No of test samples	Test AUC	Percent contribution									
						Elevation	Population count	NDVI	LULC	Dist. to water	Dist. to large veg	Dist. to med veg	Dist. to agriculture	Dist. to built area	Dist. to train station
Favour-balanced-development	Aesthetic	158	0.872	52	0.818	12.9	20.4	8.3	1.3	10.1	2	2.3	10.1	0.2	32.4
	Economic	168	0.9	56	0.916	5	44.2	15.6	6.9	0.5	6.6	5.5	9.5	0.6	5.6
	Existence	122	0.88	40	0.891	9	51.4	6.2	1	1.6	1.4	3.7	14.7	0.6	10.4
	Habitat and biodiversity	120	0.877	39	0.833	16.3	1.3	2.2	5.9	12.6	7.6	4	14	2.5	33.6
	Heritage and historic	93	0.903	31	0.86	5.4	26.8	2.8	0.5	0.8	0.9	6.1	11.6	0	45.1
	Local norm and sense of belonging	122	0.903	40	0.896	10	62.6	6.9	0.4	1.1	3.9	1.6	8.3	0.1	5.1
	Recreation	137	0.899	45	0.886	11.8	14.1	2.8	2.6	18.1	1.1	6	7.2	0.1	36.2
	Religious and spiritual	101	0.932	33	0.894	5.1	66.1	1.2	0.3	2.1	9.4	6.1	4.5	0	5.3
	Social interaction	121	0.904	40	0.881	6.9	56.5	10.7	2.9	2.7	3.3	2.2	8.7	0	6
	Therapeutic	95	0.879	31	0.861	15.6	29.9	10.1	0.7	10.8	0.7	0.7	16.3	0.2	14.9
Oppose-grey-development	Aesthetic	173	0.9	57	0.895	6	1	4	6.9	12.2	0.4	1.8	21.2	0.7	45.7
	Economic	174	0.9	58	0.895	2.8	38.4	3.3	4.6	0.5	3.1	5.4	16.7	0	25.3
	Existence	132	0.899	43	0.874	10.1	16.5	3	1.4	2.8	4.7	2.8	21.7	0.9	36.1
	Habitat and biodiversity	159	0.9	52	0.897	11.8	0.9	3.6	9.7	4.9	1.5	1.1	24.8	7.8	33.9
	Heritage and historic	93	0.935	30	0.871	3.9	2	1.5	0.6	1.7	1.3	0.2	25.5	2.4	60.8
	Local norm and sense of belonging	135	0.917	44	0.889	11.2	40.8	0.5	0.2	2.2	2.2	0.7	22.5	0.1	19.7
	Recreation	175	0.922	58	0.863	9.6	1.1	3.4	12.5	2.4	0.6	1.8	24.8	3.1	40.5
	Religious and spiritual	105	0.905	35	0.927	5.3	51.1	1.7	0.7	0.9	4	0.2	16.2	0.4	19.5
	Social interaction	150	0.92	49	0.874	5.4	43.1	0.2	2	0.3	0.8	0.9	22	0	25.2
	Therapeutic	110	0.915	36	0.866	7.8	2.2	4	2.2	4.9	4.2	2.2	30	0.1	42.4

3.3.5 Spatial agreement and conflict between groups

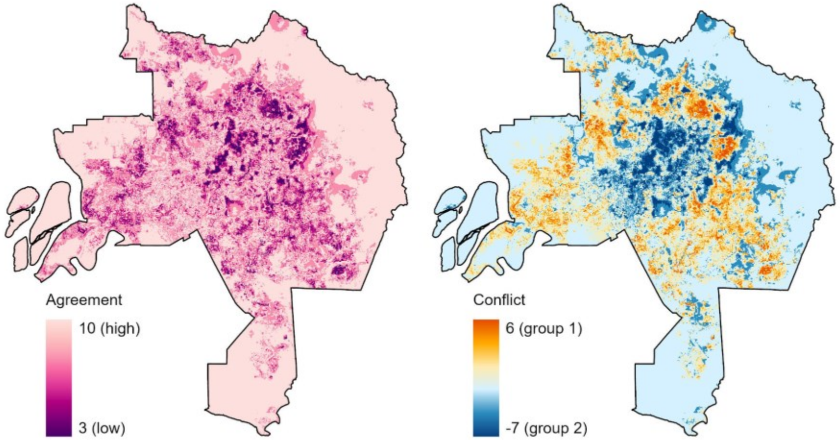
Maps illustrating areas of spatial agreement and conflict for each social value between the two groups are shown in Figure 3.4. Generally, areas within Kuala Lumpur city centre showed spatial agreement for economic value, while universities and heritage sites showed spatial agreement for heritage and historic value. We observed that for economic, recreation and local norm and sense of belonging values, developing areas (peri-urban areas adjacent to urban centres) are highly valued by the favour-balanced-development group, while the oppose-grey-development group valued existing urban centres. However, given the spatial heterogeneity of the landscape, these patterns were challenging to discern at a metropolitan city scale. Thus, we zoomed into areas where spatial conflict between groups was highest to identify meaningful patterns.

Patterns in spatial conflicts become more apparent through close-up images (Figure 3.5). In Figure 3.5a, we observe that the oppose-grey-development group perceive economic value to be higher in commercial area A and the Hulu Langat forest reserve area C (likely linked to tourism), while the favour-balanced-development group perceive economic value to be higher in B, a rapidly urbanising area located adjacent to the Kuala Lumpur. As for existence value, the oppose-grey-development group highly values the Hulu Langat forest reserve area D, conflicting with the favour-balanced-development group who perceive existence value to be high in the densely built Ampang Jaya area (E). Similar observations are made with respect to heritage and historic value (Figure 3.5c); the Bukit Kiara forest (F) is strongly valued by the oppose-grey-development group, while the favour-balanced-development group more strongly values the commercial area adjacent to the forest (G). The same is observed for the Ayer Hitam forest reserve H, where the forest area is valued by the oppose-grey-development group, while the built area surrounding the forest is valued by the favour-balanced-development group. While the favour-balanced-development group tend to value built areas over green spaces, this group is observed to value water bodies more strongly for recreation value than the oppose-grey-development group, as seen with the Putrajaya wetlands park (I) (Figure 3.5d).

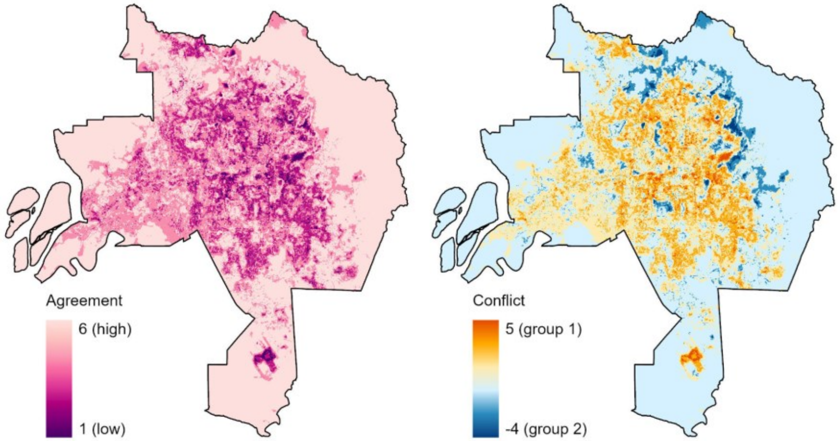
AESTHETIC



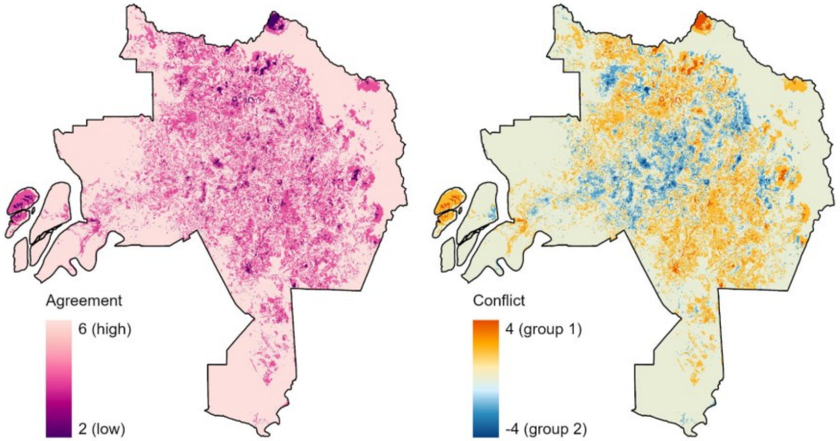
ECONOMIC

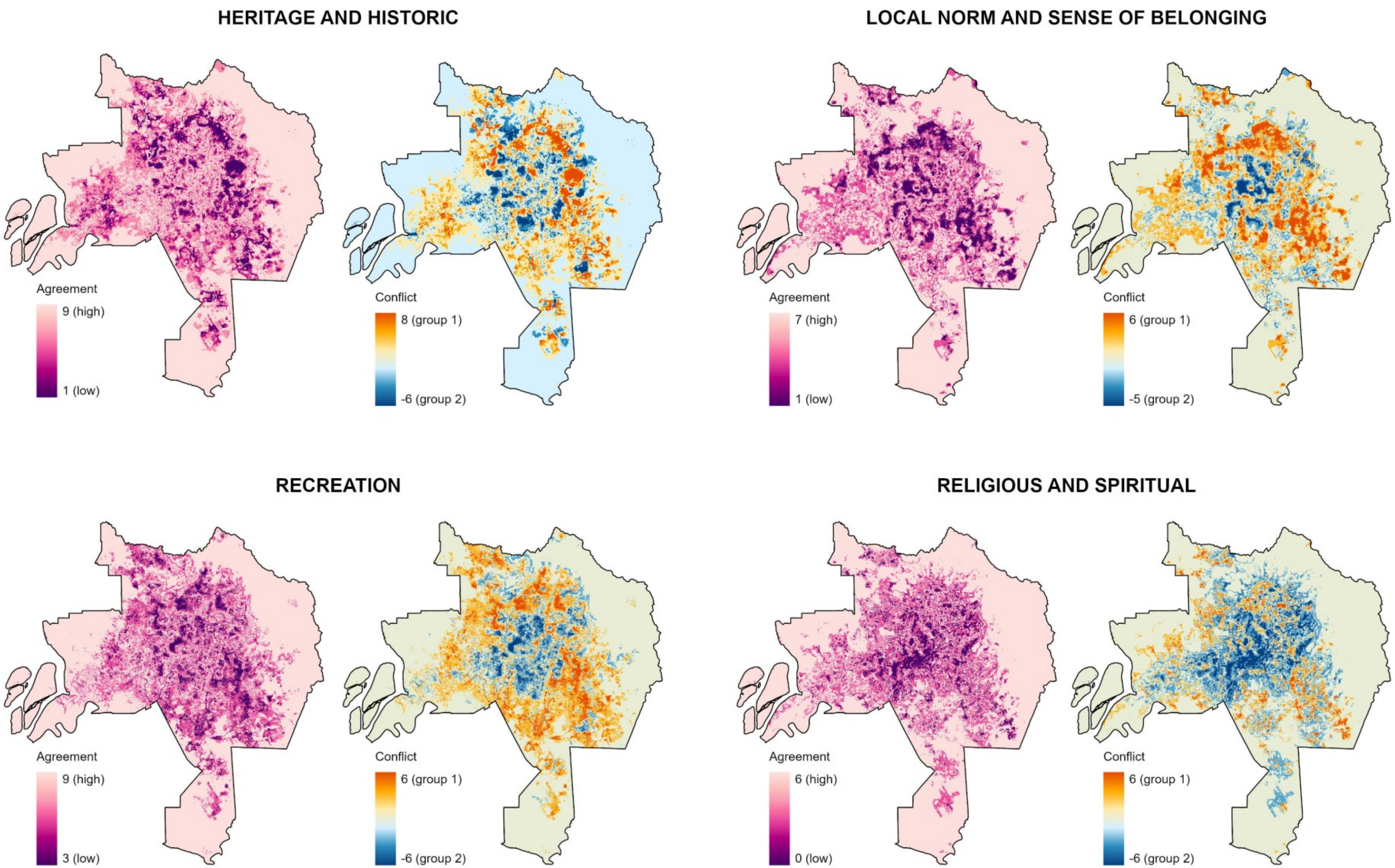


EXISTENCE



HABITAT AND BIODIVERSITY




HERITAGE AND HISTORIC
Agreement
9 (high)
1 (low)
Conflict
8 (group 1)
-6 (group 2)
LOCAL NORM AND SENSE OF BELONGING
Agreement
7 (high)
1 (low)
Conflict
6 (group 1)
-5 (group 2)
RECREATION
Agreement
9 (high)
3 (low)
Conflict
6 (group 1)
-6 (group 2)
RELIGIOUS AND SPIRITUAL
Agreement
6 (high)
0 (low)
Conflict
6 (group 1)
-6 (group 2)

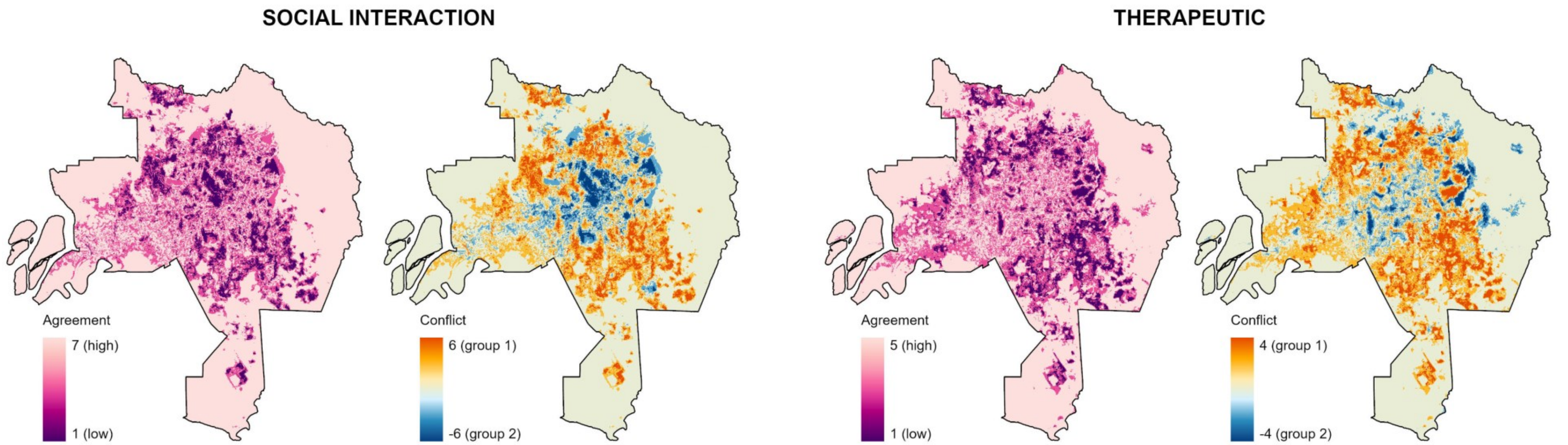


Figure 3.4 Spatial agreement and conflict maps for all social values. For the agreement map, higher pixel values indicate stronger agreement between the two groups, while lower values indicate conflict. The conflict maps illustrate the areas that are more strongly valued by the favour-balanced-development group (group 1: positive values in orange) and the oppose-grey-development group (group 2: negative values in blue), for each social value.

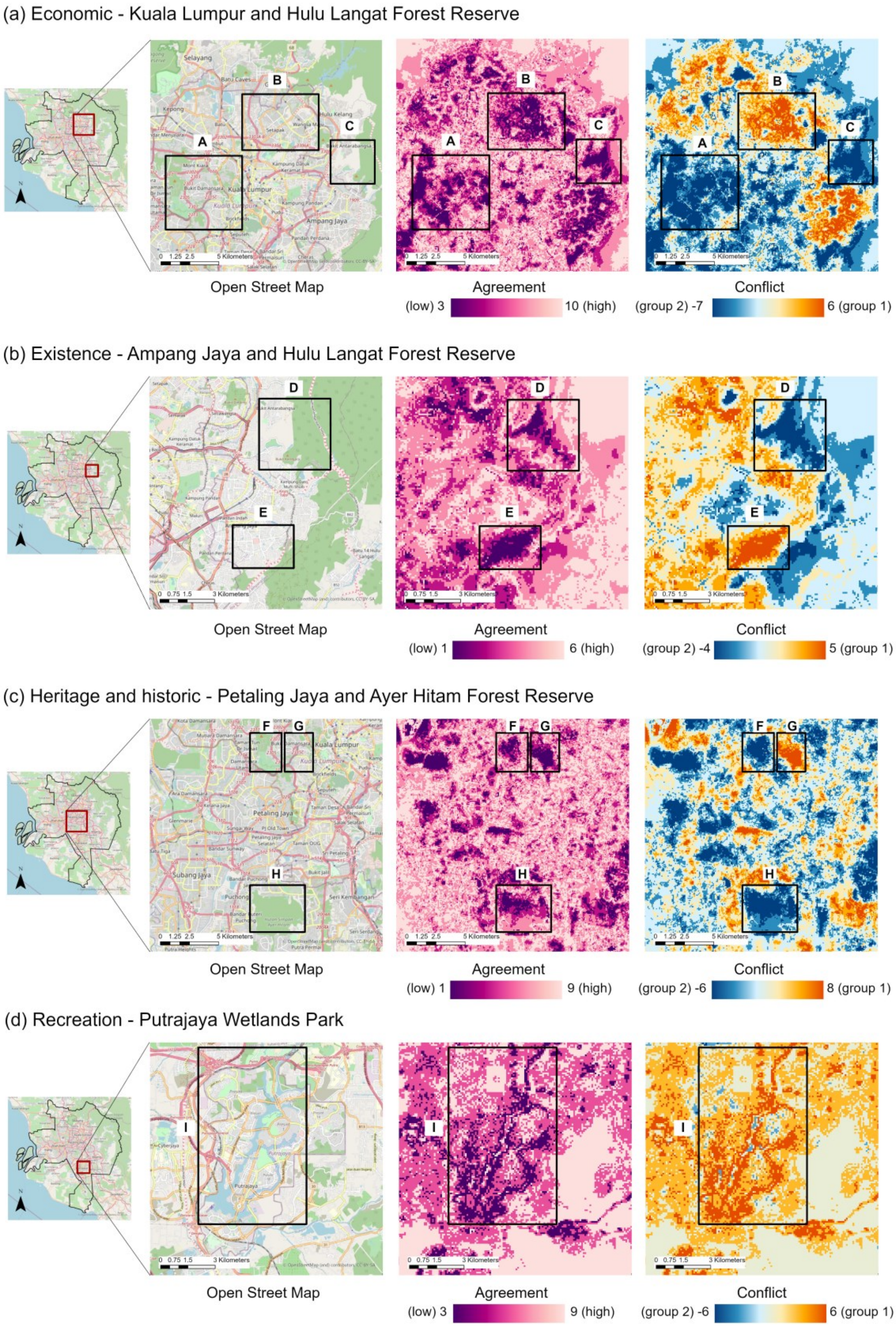


Figure 3.5 Close-up images of areas of high spatial agreement and conflict between the two groups for (a) economic, (b) existence, (c) heritage and historic and (d) recreation values. The image on the left illustrates the close-up location on the Open Street Map (map used by respondents to map social values), followed by the corresponding

agreement and conflict maps for the close-up location. References are made to areas of interest, where conflicts between the two groups is highest (labelled A to I).

3.4. Discussion

3.4.1 Development preferences of residents in rapidly a developing city

This study conducted a novel assessment of development preferences and social values for ecosystem services in a rapidly developing metropolitan city. While social valuations in urban ecosystems are limited, previous studies on the development preferences of residents in the Global South generally observe different patterns to the Global North (Rigolon *et al.*, 2018; Watson, 2009). A study by Diko and Hollstein (2021) showed that urban green spaces, while positively viewed, are not a priority to the residents of the rapidly urbanising metropolitan of Kumasi, Ghana. The study posits that the low preference for urban green spaces is indicative of residents' priorities to meet their survival needs over a desire for urban green spaces. However, our findings revealed that residents of GKL strongly favour green developments (i.e., green spaces), suggesting that the preferences of GKL residents lie between those of Ghana and a Global North city. This is supported by the results of the cluster analysis where one group of residents favour balanced development (i.e., residents in GKL favour both urban expansion and green space development as opposed to favouring only urban expansion as seen in Ghana or only green space development as seen in the Global North). The favourable preference towards green developments, which contrasts the preferences of Kumasi residents, could be influenced by two factors: i) Malaysia's ranking on the 'developing to developed nation' spectrum, and ii) the location of study within Malaysia. Firstly, while Malaysia is categorised as a 'developing nation', it is closer to achieving a 'developed nation' status as an upper-middle income country (World Bank, 2021). For comparison, Malaysia ranked 62nd out of 189 countries in 2019 Human Development Index while Ghana ranked 138th for the same year, demonstrating the possible disparities in development priorities (United Nations, 2021). The second factor is the location of sampling; GKL is the largest and most urbanised region in Malaysia with the highest population of the districts sampled. The general favourability of residents towards green developments could be a result of living in dense urban environments that could be perceived to lack green spaces (Boulton *et al.*, 2018).

While the respondent groups shared the same preference for green developments, they had diverging preferences towards grey developments in the metropolitan area. Our post-hoc analysis identified various sociodemographic characteristics that could have influenced the difference in development preference, such as place of residence, level of education and environmental perspectives (Table 3.7). We found that respondents with higher education levels and environmental perspectives that prioritised conservation ($p < 0.05$) more strongly favoured green developments and opposed grey developments (oppose-grey-development group), similar to the findings of Fagerholm et al. (2020), Lechner et al. (2020), and Yen et al. (2016). In contrast, respondents who favoured both green and grey developments largely worked in the private sector and prioritised economic and environmental benefits equally (favour-balanced-development group). Another significant influence is the location of residence of group members. We found that members of the oppose-grey-development group resided in dense urban areas, closer to the city centre, while members of the favour-balanced-development group resided in peri-urban areas which are farther from the city centre ($p < 0.01$). This finding is not unusual as other local and global studies have indicated that preferences between urban and peri-urban residents can differ (Hassan *et al.*, 2019; Lapointe *et al.*, 2019; Stålhammar, 2021), presenting differences in development preferences in urban-rural gradients of varying spatial scales of (e.g., within a metropolitan city, city-town, town-rural area).

3.4.2 Spatial conflicts in social values between groups

The wide range of social values associated with GKL had varying importance and conflicting spatial distribution between the two groups. Economic value was the single-most important to the favour balanced developed group, and while the oppose-grey-development group also placed high importance on economic value, two other cultural values (i.e., recreation and heritage and historic values) were given equal importance (Figure 3.3). It is not surprising that residents of a rapidly developing country placed high importance in economic value (e.g., Jiao *et al.*, 2020). However, it is interesting to note that some residents valued cultural ecosystem services (i.e., recreation, heritage and historic values) as highly as they would economic value.

It is clear that differing development preferences can lead to conflicts in land use planning, given the spatial conflicts in the distribution of social values. The two groups showed some agreement in the terms of where social values were associated (i.e., places of high historic and cultural significance such as heritage sites were associated with heritage and historic value, commercial and urban centres were associated with economic value) (Figure 3.4). However, the spatial conflicts between the two groups were more pronounced, both in terms of the places and the intensity to which social values were associated. The dissonance between the two groups was most striking in the social values associated with the density of built areas; the favour-balanced-development group associated a larger number of social values (i.e., aesthetics, economic, existence, local norm and sense of belonging, social interaction) with less dense, peri-urban areas while the oppose-grey-development group associated a fewer number of social values with built areas (i.e., economic, heritage and historic, social interaction) but these social values were perceived to be distributed in dense urban centres (as opposed to peri-urban areas). Such spatial conflicts could result in tradeoffs between social values, where actions to promote one social value could negatively impact the other (Sherrouse et al., 2017). Hence, examinations of spatial conflicts should include the assessment of inter-value conflicts and associated tradeoffs.

The spatial agreement and conflict analysis allows differences within the GKL community to be identified, including the intensity and direction of location-specific conflict. Moreover, identifying location-specific agreement and conflict through the segmentation of respondents by development preferences provides an added layer of nuance in the theory and practice of mapping land use development preferences (Lechner *et al.*, 2020). Our study shows that differences in the perceived distribution of social values are the manifestation of differences in non-spatial sociodemographic characteristics and development preferences. The application of spatial agreement and conflict analysis based on the two groups of respondents creates room for negotiating land use and planning strategies in ways that could not be previously achieved (Brown & Raymond, 2014; Brown *et al.*, 2017; Plieninger *et al.*, 2018). For example, through the analysis we are able to suggest that the conflicts identified be mitigated by applying different planning objectives in different parts of the metropolitan, clearly prioritising green development in the city centre and both green and grey development in peri-urban areas. The significance of spatial agreement and conflict analysis in land use planning conflict resolution is further addressed in Lechner et al. (2020).

3.4.3 Social values for sustainable cities

The inclusion of social values for ecosystem services has been emphasised in recent sustainable development guidelines (Díaz *et al.*, 2015; TEEB, 2014), demanding that the plurality of values are taken into account in planning for liveable cities (Raymond *et al.*, 2019). This study has contributed to the growing body of knowledge on the development preferences and social values for ecosystem services in Global South cities (Arku & Marais, 2021; Nagendra *et al.*, 2018). The use of public participatory tools and methods in this study also encourages the involvement of urban populations in guiding the design of sustainable cities, in line with the Sustainable Development Goal 11 (United Nations, 2015). Our study also emphasises the importance of considering various perspectives in planning for context-specific liveable, sustainable and resilient cities. Ecosystem services are valued diversely by various communities and the social valuation of ecosystem services is needed to capture local demands and perceived benefits (Lourdes *et al.*, 2021). Involving members of the public in social valuations deepens the understanding of social values for local needs (Keeler *et al.*, 2019; Sandifer *et al.*, 2015). Furthermore, our study is novel in that it recognises that the GKL population is not homogenous and different segments of the population have varying preferences and values for ecosystem services influenced by a number of sociodemographic characteristics.

We advocate for more green developments in urban centres given that residents in these areas prioritise recreation and cultural values in green spaces and strongly oppose further grey developments. This will require green spaces to be retrofitted as green roofs and walls, as opposed to parks or urban forests given the limited availability of vacant land in GKL. For peri-urban areas, we recommend that both green and grey developments be prioritised, noting that cultural (e.g., heritage and historic, local norm and sense of belonging, social interaction) and recreation value (also a cultural ecosystem service) are also associated with built areas, and not only with blue-green spaces (i.e., wetlands, forests, parks), as conventionally expected (Mohd Fauzi & Abd Ghafar, 2020; Uy & Shaw, 2013). We also propose that water-based features such as lakes and ponds (i.e., blue spaces) be incorporated into existing or future recreational spaces as a large proportion of the respondents (members of the favour-balanced-development group) strongly associated recreation value with blue spaces (Figure 5d). It is also well-established that blue spaces provide a range of ecosystem services especially important for GKL such as mitigating flooding and the urban heat island effect, in addition to recreational opportunities (Gascon *et al.*, 2015; Majizat *et al.*, 2016; Tan & Jim, 2017). These recommendations are particularly relevant to a post-COVID-19 world, where greater emphasis is being placed on creating resilient and liveable spaces in cities by improving human-environment relationships (Asian Development Bank, 2020b; Stockholm Environment Institute, 2020; United Nations, 2020).

3.4.4 Limitations of this study

There are several limitations that should be noted when interpreting the findings of this study. We received low responses rates from respondents in peripheral districts of GKL (Gombak, Klang, Sepang, Putrajaya only represent 21% of total respondents) and as such the development preferences of respondents may not be representative of all GKL residents. Of the four districts with lower respondent representation, we note that Putrajaya is most organised as a township, with greater opportunities to enjoy sizeable green spaces, in comparison to Klang and Gombak which are less organised and likely to have fewer green spaces. The unique characteristics of districts are likely to influence the development preferences of residents and could have resulted in variations in the survey outcomes, and subsequently our empirical findings. In addition, we acknowledge that while our typology of social values was comprehensive and tailored for GKL, it can be further improved. Given that this is the first assessment of social values in a dense urban Global South landscape, future studies can build on our typology of values, omitting social values that were of less importance or significance to residents and perhaps adding others. We also note here that areas of high elevation (e.g., parts of the Hulu Langat forest reserve) were not captured in our SolVES analysis, as the urban population in GKL is concentrated in low-elevation areas and respondents were asked specifically about the neighbourhoods in which they reside. Nevertheless, the training and test AUC values of all models were above acceptable levels for the study area, as well as for value transfer (Sherrouse & Semmens, 2014).

3.5. Conclusions

This study provides a novel assessment of social values for ecosystem services and the application of SolVES at the scale of a major metropolitan area. We investigated the development preferences of residents of a rapidly urbanising metropolitan area and analysed the perceived importance and spatial distribution of social values across groups with different development preferences. We also mapped areas of spatial agreement and conflict between these groups. Our assessment revealed two groups of respondents with different development preferences; a favour-balanced-development group (favour both green and grey developments) and an oppose-grey-development group (favour green developments but strongly oppose grey developments). The two groups differed in their sociodemographic characteristics, the importance they place on different social values and the places they associated with those social values. The outcomes of spatial agreement and conflict analysis with respect to future urban expansion in GKL show locations where there is potential for land-use conflict. These findings support the inclusion of socioecological aspects in urban landscape management emphasising the need for public engagement and the consideration of multiple perspectives in designing sustainable, liveable and resilient cities, especially in rapidly urbanising cities in the Global South.

Chapter 4 Planning for Green Infrastructure Using Multiple Urban Ecosystem Service Models and Spatial Multicriteria Analysis

Submitted as: Lourdes, K.T., Hamel, P., Gibbins, C.N., Sanusi, R., Azhar, B. and Lechner, A. (in review) Planning for Green Infrastructure Using Multiple Urban Ecosystem Service Models and Multicriteria Suitability Analysis, *Landscape and Urban Planning*.

This work was presented at the following conferences:

- Ecocity World Summit 2021 [Oral presentation]. Mapping and Modelling Multiple Ecosystem Services to Support Planning in Peri-Urban Areas, 22nd – 24th February 2022.
- Innovate4Cities 2021 [Oral presentation]. Planning for Green Infrastructure Using Multiple Urban Ecosystem Service Models. 11th – 15th October 2021.
- ESRI User Conference 2021 [Virtual Map/ Poster]. Planning for Greener Suburbs Using Multiple Ecosystems Service Modelling, 12th – 15th July 2021. Won 3rd place in the ArcGIS Analytical Methods and Results category.

4.1 Introduction

Unprecedented urban growth has placed increasing pressure on ecosystem services in towns and cities (Nagendra et al., 2018; Romero-Duque et al., 2020). As urban areas expand, especially peri-urban ones, they undergo intensive land use change due to the infrastructure needs of growing urban populations. Such rapid urbanisation and urban sprawl are often accompanied by a range of socio-environmental issues, which can be exacerbated by poor planning (Jones, 2014; Palanivel, 2017; United Nations, 2018). These land use changes often result in the degradation or loss of natural ecosystems which, in turn, undermines ecosystem service provision and affects the wellbeing of urban populations (Lechner et al., 2020; MEA, 2005).

Urban Ecosystem Services (UES) are those ecosystem services in urban and peri-urban areas provided by green (and blue) infrastructure (GI) such as forests, wetlands, parks, lakes, street greenery and green roofs (Gómez-Baggethun et al., 2013; Tan et al., 2020). We use the term 'urban ecosystem services' to mean ecosystem services provided in urban or peri-urban areas (Tan et al., 2020), which is also the most common interpretation (Luederitz et al., 2015). These UES range from heat mitigation, stormwater retention, carbon sequestration, opportunities for recreation, aesthetic value and habitats for urban biodiversity, all of which enrich the quality of life in urban environments (Elmqvist et al., 2015; Goddard et al., 2010; Konijnendijk et al., 2013; Parker & Simpson, 2018). As demands for liveable, sustainable and resilient cities rise (United Nations, 2015), the role of GI in alleviating the environmental repercussions of urbanisation, in addition to the pressures of climate change, becomes increasingly important (Lafortezza et al., 2018; Lechner et al., 2020; Sanusi and Bidin, 2020). Increasing use and recognition of the UES concept highlights the dependence of urban populations on GI (Tan et al., 2020) and emphasises the need to better manage and protect GI, which is often more cost-effective than restoring degraded ecosystems.

Mapping and modelling of multiple ecosystem services are useful for capturing landscape-scale information on the distribution of UES and their interactions in a spatially explicit manner (Maes et al., 2012). Various models have been used to value the supply and demand for ecosystem services, although quantitative biophysical, empirical and geographic information system (GIS)-based models are most common (Haase et al., 2014; Hamel et al., 2021). Multiple UES are often modelled at large spatial scales (i.e. city scale or larger) (Nikodinoska et al., 2018), in order to capture hotspots of UES across the landscape as well as synergies and tradeoffs between them (Nelson et al., 2009). Hotspots and coldspots respectively refer to areas with high and low amounts of an ecosystem service and can be determined using various techniques such as Getis-Ord Gi* (Schröter & Remme, 2016). In addition to mapping the spatial distribution of UES, assessments of synergies and tradeoffs can be used to examine the interactions between two or more UES; interactions are typically described as being either positive-positive (synergy) or positive-negative (tradeoff) (Mouchet et al., 2014).

UES mapping has also been integrated with multicriteria analysis (MCA) to more explicitly link the spatial patterns of multiple UES and help identify suitable locations for specific land use management activities (Cortinovis et al., 2021; Saarikoski et al., 2015). MCA consists of structured methods that formalise the decision-making process needed to address a defined problem (Langemeyer et al., 2016). Application of MCA to the assessment of ecosystem services has long been advocated (Koschke et al., 2012). Studies have used MCA in ecosystem service-based decision-making through scenario analysis (Kremer et al., 2016; Vollmer et al., 2016), prioritising land use tradeoffs (Martínez-López et al., 2019; Meerow, 2019) and integrating stakeholder preferences (Griffin et al., 2015; Zoderer et al., 2019). Multicriteria suitability analysis is used to identify the suitability of a site for a given purpose or use, based on defined constraints and criteria (Gelan, 2021; Li et al., 2021). In conjunction with UES assessments, this approach can be used to identify suitable areas for new urban parks or green roofs (Cortinovis & Geneletti, 2018; Langemeyer et al., 2020). Past studies using spatial multicriteria suitability analysis have applied land cover proxy-based ecosystem service models, but this approach has not been applied in tandem with multiple, biophysical UES models to plan GI.

There are numerous studies modelling and mapping UES, but complex assessments of UES often fall short of effectively communicating outcomes in a manner that is relevant to urban planning or lack elements that are crucial for supporting decision-making. One element frequently lacking is consideration of whether the UES being assessed is ‘potential’ or ‘realised’. Potential service is the service value irrespective of use by people (i.e., it represents the supply of the service), while the realised service value accounts for use by beneficiaries (i.e., it is a function of service supply and demand) (Turner et al., 2012). While modelling the potential distribution of UES solely identifies areas of high UES supply, modelling of realised UES illustrates the benefits of UES more clearly to decision-makers and so is of greater value for planning (Aziz & Van Cappellen, 2019). Cortinovis and Geneletti (2019) have taken this further by conceptualising UES as service providing units, service benefitting areas and interlinking variables which occur at various spatial scales (Fisher et al., 2009; Syrbe & Walz, 2012).

The aims of this study are (i) to characterise the spatial distribution of multiple UES in a rapidly urbanising landscape, and (ii) develop a systematic approach to integrate UES within GI planning by combining biophysical modelling with multicriteria suitability analysis. We applied InVEST (INtegrated Valuation of Ecosystem Services and Tradeoffs), a widely used ecosystem services modelling tool (Hamel et al., 2021; Sharp et al., 2020), together with readily available GIS tools, to assess six realised UES (heat mitigation, runoff retention, sediment retention, scenic quality, urban recreation and agricultural production) in a rapidly developing, peri-urban catchment in Greater Kuala Lumpur, Malaysia. We analysed hotspots, identified synergies and tradeoffs between UES, and examined the cooccurrence and overlap of hotspots between multiple UES. We then undertook a spatial multicriteria suitability analysis to identify opportunities for GI strategies to improve the provision of UES (conservation of headwater areas, reforestation for biodiversity, development and conservation of urban parks and greening of built infrastructure (impervious surfaces)). This novel approach combines multiple UES models with multicriteria suitability analysis to support ecosystem service-based decision-making.

4.2 Methods

4.2.1 Study Area

The Langat catchment is located along the southern metropolitan boundary of Greater Kuala Lumpur, Malaysia's capital city (Figure 4.1). The Langat is the most urbanised river basin in Malaysia and a major source of water for the 7.9 million residents of Greater Kuala Lumpur (Memarian et al., 2014; United Nations, 2019). We selected two upper sub-catchments in the Langat, hereafter referred to collectively as the 'Upper Langat'. These two sub-catchments, the Semenyih and mainstem Langat rivers, provide examples of the UES and urban development pressures that are common to urban development in the Global South, especially in larger growing cities in Southeast Asia. While the focus of the study was on UESs, we had to include non-urban areas to allow us to model catchment scale hydrological processes and evaluate the downstream benefits of hydrological UES. However, as our focus was on UES within urban and peri-urban parts of the Upper Langat, we do not assess non-UES provided by other parts of the catchment such as non-timber products provided by forested headwater areas. We included only the upper catchment to avoid the complexities associated with hydrological modelling of the large, man-made and intensively managed Putrajaya wetlands located further down in the catchment, as well as the extensive tidal influence in the lower section of the river.

The Upper Langat study area (spanning 1022 km2) has distinct topographic contrasts, with a mountainous area located in the northeastern region and plains in the southwestern region. The eastern area is also densely forested (denoted by C in Figure 1). Urban development is most intense in the west (denoted by A in Figure 1), expanding southeast with major townships such as Kajang, Bangi and Nilai. Previous studies of the Upper Langat highlight problematic trends in river discharge and fine sediment loads due to poorly planned development (Memarian et al., 2012, 2014; Muhamad et al., 2015). Rapid development in peri-urban areas such as Semenyih and Beranang often involves clearance of secondary forests and agricultural land (denoted by B in Figure 1). The continued expansion of urban areas in the Upper Langat threatens the provision of UES to the local population, which could potentially result in intense urban heat island effects, reduced water quality, increased risk of urban floods, loss of recreational spaces and adverse impacts on biodiversity. These issues are addressed by UES modelling presented in this paper.

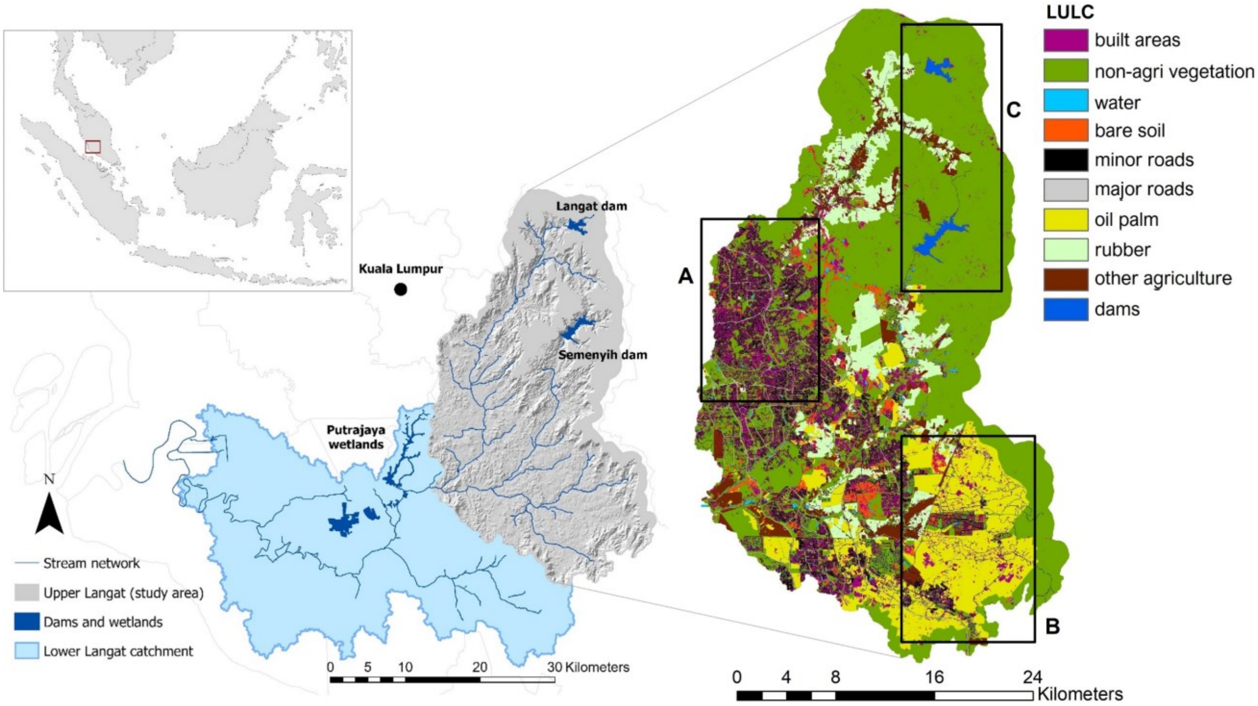


Figure 4.1 The location and land use and cover (LULC) characteristics of the Upper Langat catchment. Vegetated areas in the catchment have been divided into agricultural vegetation (i.e., oil palm, rubber and other agriculture) and 'non-agricultural vegetation' (includes forests, parks, street greenery and vacant vegetated land). Areas of interest within the Upper Langat catchment are : A - dense built areas, B – agricultural areas, and C – forest reserve.

4.2.2 Overview of Analyses

Figure 4.2 summarises the steps taken to model the six UES and the subsequent data processing and analyses. The UES modelled in this study are heat mitigation (HM), runoff retention (RR), sediment retention (SR), scenic quality (SQ), urban recreation (REC) and agricultural production (AP) (i.e., urban farming). Of these six, the RR, SR, SQ, REC and AP UES models estimated the realised distribution of UES by default. The choice of UES to focus on was based on expert knowledge and literature, as well as the availability of data and models. The HM model estimates potential service distribution, so additional steps were undertaken to model the realised service provision (detailed in sections 4.2.3). The realised UES were normalised prior to spatial analyses (see 4.2.4).

The outcomes of the analyses were used as ecosystem service criteria in a spatial multicriteria suitability analysis to identify suitable locations for five GI strategies: conservation of headwater areas, reforestation for biodiversity, development of new urban parks, conservation of existing urban parks and the greening of built infrastructure. The remainder of the methods section provides further details of the UES models (section 4.2.3), the conceptual framework used to capture realised UES (section 4.2.4), data sources and inputs (section 4.2.5), spatial analyses undertaken (section 4.2.6) and the multicriteria suitability analysis (section 4.2.7).

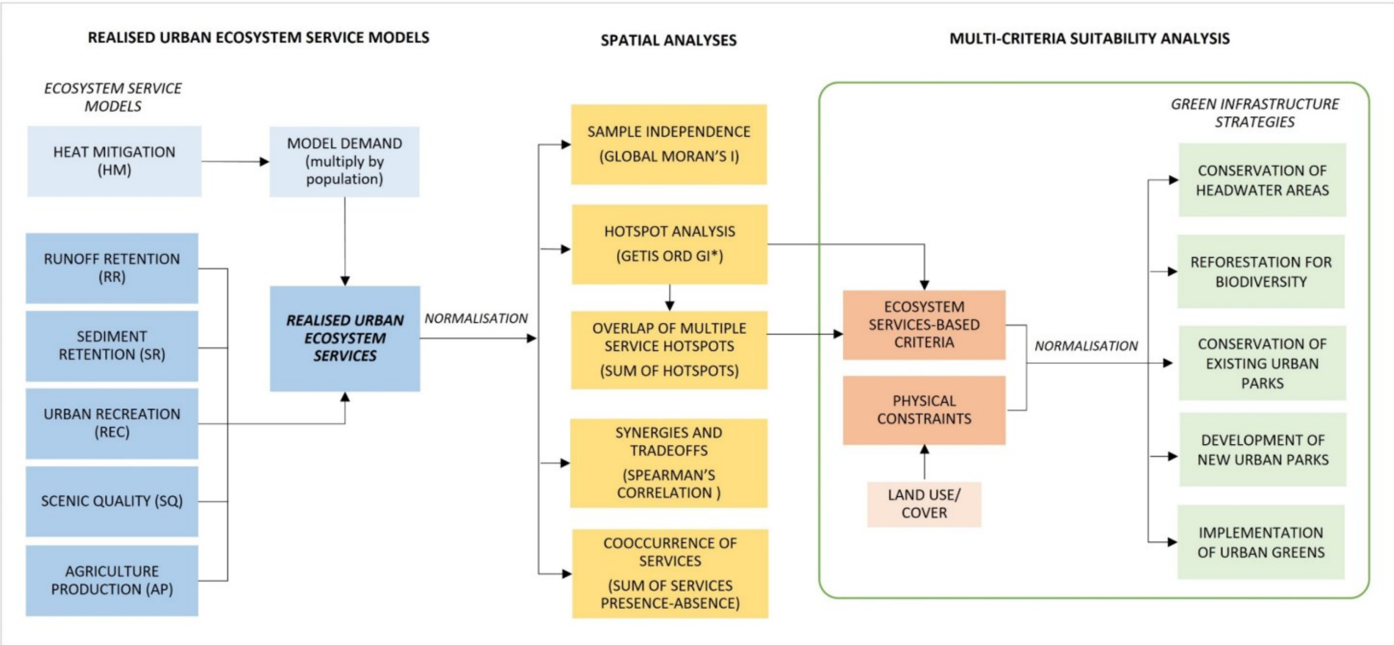


Figure 4.2 Flow chart of the methods applied in this study, outlining the steps taken to model the six realised urban ecosystem services, data processing and analyses conducted. The outcomes of the analyses were used as ecosystem services criteria in the multicriteria suitability analysis for five green infrastructure strategies.

4.2.3 Urban Ecosystem Service Models

Developed by the Natural Capital Project, the InVEST suite of models quantifies and maps the distribution of ecosystem services using spatial and environmental variables (Sharp et al., 2020). InVEST is best suited for analysing multiple UES as it is designed to inform decision-makers about natural resource management or urban GI planning (Hamel et al., 2021). We used InVEST version 3.8.7 (Sharp et al., 2020) to model HM, RR, SR, REC and AP. We used a bespoke model to capture SQ using the Observer Points tool on ArcGIS Pro, building on previous tools which use viewshed analyses. A summary of each UES model is provided in the sections below, while more detailed descriptions of how the models work are given in Appendix F.

4.2.3.1 Heat Mitigation (HM)

Urban green spaces have strong cooling capacities which mitigate urban heat island effects. The cooling effect of green spaces is a function of their size, with larger green spaces having stronger cooling effects (Richards et al., 2020; Zardo et al., 2017). The HM model calculates the cooling capacity of green spaces based on distance, evapotranspiration, shade and albedo and estimates the heat mitigation index by taking into consideration the cooling effect of large green spaces (Sharp et al., 2020).

4.2.3.2 Runoff Retention (RR)

Increased surface runoff retention by green spaces can prevent flooding, reducing threats to human life and damage to infrastructure in urban areas. The RR model uses the Curve Number method to calculate runoff production and flood attenuation based on a specified design storm (USDA, 2004) and estimates stormwater runoff retained in a catchment.

4.2.3.3 Sediment Retention (SR)

Major changes in the export of sediment from a catchment due to land use conversion can affect soil fertility, water quality, downstream irrigation and in-stream biodiversity (Jones et al., 2012; Taylor & Owens, 2009). The SR model estimates the amount of annual soil loss per pixel based on the revised universal soil loss equation (RUSLE1), then calculates the per pixel sediment retention of the land cover relative to bare soil (Sharp et al., 2020).

4.2.3.4 Scenic Quality (SQ)

Urban green spaces provide scenic and aesthetic qualities which may be compromised by urban development. Assuming that all vegetation increases scenic quality, our bespoke SQ model evaluates the percentage of population benefitting from scenic views of vegetation (agricultural and non-agricultural) based on sampled observer points (ESRI, 2020a). The model uses a digital surface model to capture possible visual obstructions resulting from the built environment.

4.2.3.5 Urban Recreation (REC)

Urban green spaces provide important recreational and wellbeing benefits to residents. The REC model quantifies access to nature as the difference between green space supply and demand per pixel, which is used as a proxy for daily recreation. Demand for green spaces is based on the distance of urban populations to green spaces (Liu et al., 2020; 2022). We set this to 2000 m, meaning that we are only considering daily recreation in proximity to residents' homes. The supply-demand balance represents the per pixel surplus or deficit of recreation service, expressed in m2 per capita.

4.2.3.6 Agriculture Production (AP)

Conversion of land in peri-urban areas impacts agricultural production services, and consequently local livelihoods. The AP model quantifies the 95th percentile of agricultural production service of oil palm and rubber (the predominant agricultural land use in the Upper Langat), in tons per pixel per year, based on observed production yields, precipitation and temperature (Sharp et al., 2020).

4.2.4 Realised Ecosystem Service Conceptual Model

The realised distribution of an ecosystem service is a subset of the potential supply that is enjoyed by beneficiaries. Thus, the realised distribution of a service is a function of potential supply of, and demand for, that service. We modelled the realised distribution of the six target UES based on the spatial relation between the service providing unit (SPU), service benefitting area (SBA) and the potential scale of SBA for each service (Cortinovis & Geneletti, 2019), as illustrated by Figure 3. For UES that have potential

SBA that spans the entire upper Langat study area (i.e. RR, SR and AP), we considered the modelled UES to be a realised service. For HM, we used population distribution as a proxy for demand (Burkhard et al., 2014). We multiplied the output from the HM model by population, changing the units to 'heat mitigation index multiplied by population in a given pixel'. By multiplying the potential service maps by population distribution, areas with high potential service and high population were translated into areas of high realised service; conversely, areas with high potential service but low population became areas with low realised service. We did not apply this method for the SQ and REC models, as the respective models take into consideration both supply and demand in its evaluation. Further details of each UES model are provided in Appendix F.

Figure 4.3 The links between potential service benefitting area (horizontal axis) and the spatial relation between service providing units (SPU) and service benefitting areas (SBA) (vertical axis) for the six modelled UES in the Upper Langat study area. The spatial relations between SPU and SBA can take four forms, as illustrated from top to bottom on the vertical axis: in-situ, omnidirectional, directional upstream-downstream and directional buffer. Figure adapted from Cortinovis and Geneletti (2019).

4.2.5 Data Sources and Inputs

We selected input parameter values using spatial data as close as possible to 2018 (when this study commenced), using the LULC as our reference layer. Given limitations in data availability and accessibility in the study area, models were parameterised based on best available data and local literature. When data for the study area were unavailable, we used data from Putrajaya, the nearest city within the Langat catchment. Underpinning the analysis for all of the UES modelled was a 10 m LULC layer composed of ten classes - built up areas, major roads, minor roads, non-agricultural vegetation (includes open spaces, urban forests, parks, street greenery, vacant vegetated land), bare soil, water, dams, oil palm, rubber and other agricultural land use (Danneck et al., in review). The LULC had an overall accuracy of 89.4% and the individual accuracy of classes ranged from 78.6% for agricultural classes and 100% for major and minor roads. We also used a 15 m Digital Terrain Model (DTM) and Digital Surface Model (DSM) obtained from the Department of Survey and Mapping Malaysia (JUPEM). The model inputs were resampled to 10 m and aligned to the original LULC layer. All data were resampled using the appropriate resampling methods (categorical: nearest; continuous: bilinear). We delineated the Upper Langat catchment boundary using the ArcSWAT extension in ESRI ArcMap 10.5 (ESRI, 2020b). The complete list of data sources and input parameters for each model is available in Appendix G. We used a 100m population count layer (number of people per pixel) to transform the heat mitigation and scenic quality model outputs as realised UES. The population data was obtained from WorldPop for 2018 and mapped using random forest-based dasymetric redistribution (Lloyd et al., 2019; WorldPop, 2020).

4.2.6 Spatial Analysis

4.2.6.1 Normalisation and sample independence

The model outputs were normalised (values between 0 and 1) using the following equation:

$$X'_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} \qquad (1)$$

where X'_{ij} is the normalised service, X_{ij} is the raw realised UES model output and X_{min} and X_{max} are respectively the minimum and maximum values of X_{ij}.

We used the Global Moran's I in ArcGIS Pro (ESRI, 2020a) to characterise the spatial autocorrelation of ecosystem services. The spatial processing, analysis and visualisation of maps was conducted using ArcGIS Pro.

4.2.6.2 Hotspot analysis

We used the Getis-Ord Gi* statistic to quantify hotspots and coldspots, which respectively represent significant clustered areas of high and low service provision. We used the Gi* statistic over the top 10% of pixels method because the Gi* statistic reports hotspots/coldspots at a neighbourhood scale (Getis & Ord, 1992), as opposed to the top 10 % method which operates at a global scale. This means that hotspots/coldspots are determined by comparing the magnitude of service provision of a pixel relative to neighbouring pixels, capturing areas of high/low service provision with greater granularity than if hotspots/coldspots were defined as the absolute percentage of pixels with the highest/lowest service provision across the study area (i.e., top/bottom 10% of pixels). The Gi* statistic distinguishes between hotspots and coldspots with varying significance of clustering (Li et al., 2017), so is useful for our purpose.

We applied the fixed distance method for the hotspot analysis, where the distance band was determined by the minimum Euclidean distance required for each pixel to have at least one neighbouring pixel (ESRI, 2021). The hotspot analysis was run at 100 m resolution, since the finest resolution of population data available for the study area was 100 m; this is also a more useful scale for characterising ecosystem services from the perspective of planning as it removes the fine-scale "salt and pepper" effects (ambiguous areas where pixels have a mix of high and low values) which were observed at 10 m. All subsequent analyses were also carried out at 100m resolution.

4.2.6.3 Overlap of multiple service hotspots

We summed the individual hotspot maps from the Getis-Ord Gi* analysis to derive the overlap of hotspots and coldspots for multiple UES (Falinski, 2016). We applied this analysis to visualise areas with synergistic interactions, as these areas have high or low values respectively across multiple UES. Hence, we did not differentiate the statistical confidence levels for multiple UES hotspots and coldspots.

4.2.6.4 Synergies and tradeoffs

We used Spearman's rank correlation coefficient to identify pixel-scale synergies and tradeoffs between pairs of UES. The strength of correlation between UES is expressed by the Spearman's correlation coefficient, rs (high values indicate stronger correlations) and significance is taken as $p < 0.05$. The direction of correlation, positive and negative, indicates synergy or tradeoff between ecosystem services. We performed the pairwise correlation test using the 'Raster' package in R version 4.02 (R Core Team, 2020).

4.2.6.5 Cooccurrence of services

The cooccurrence of UES was quantified by applying a median threshold to each service, where values above the median value denote the presence of an ecosystem service and values below the median denote absence (Bai et al., 2011; Pan et al., 2020). These binary layers were summed to derive the cooccurrence of UES, which is the number of UES present in a given pixel.

4.2.7 Multicriteria Suitability Analysis

The results of the ecosystem service modelling were used to conduct a multicriteria suitability analysis. The objective of this part of the work was to identify suitable locations for (a) conservation of headwater areas, (b) reforestation for biodiversity, (c) conservation of existing urban parks, (d) development of new urban parks and (e) greening of built infrastructure (impervious surfaces). These five GI strategies were selected based on the common existing green space types found in the study area. We selected GI strategies that were most relevant in providing the six modelled UES. Figure 4.4 provides an overview of the steps taken to derive the suitability maps.

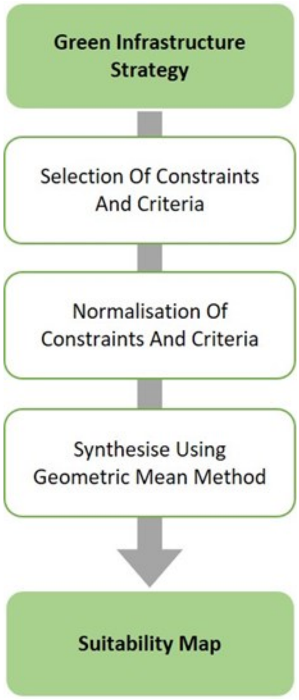


Figure 4.4 Overview of steps taken to derive suitability maps for each green infrastructure strategy.

Green spaces in the Upper Langat include recreational forests (including parts of forest reserves with public access) and urban parks of different sizes (extending from small neighbourhood parks to larger community parks). As such, we selected 'reforestation for biodiversity', 'conservation of existing urban parks' and the 'development of new urban parks' as GI strategies. For urban parks, we differentiate between existing urban parks that should be prioritised for conservation and areas that are most suitable for the development of new urban parks. We included the 'conservation of headwater areas' as a GI strategy to promote the conservation of soil and hydrological ecosystem services. In order to increase green cover on smaller scale impervious surfaces, we included the 'greening of built infrastructure'. Examples of this include, but are not limited to, green roofs, street trees, green walls and gardens. This GI strategy is particularly relevant in dense urban areas where vacant space for large GI strategies is limited. Further justification for the choice of each GI strategy is provided Table 4.1.

We used physical constraints and ecosystem services-based criteria to produce suitability maps for each GI strategy (Table 4.1). We selected physical constraints based on land use/cover (includes distance to a land use/cover) to determine where a specific GI strategy could be implemented. The physical constraints delineate strict area boundaries within which a GI strategy could be implemented. Areas outside the physical constraint were considered unsuitable for GI strategy implementation. Based on the types of UES that could be provided by the GI strategy, we used the hotspot maps derived in sections 4.2.6.2 and 4.2.6.3 as ecosystem services-based criteria. As the 'reforestation for biodiversity', 'conservation of headwater areas' and 'greening of built infrastructure' strategies have the potential to provide all six modelled UES, we used the 'overlap of hotspots' (sum of the six UES hotspots maps in section 4.2.6.3) as the criterion for these GI strategies. For the 'conservation of existing urban parks' and 'development of new urban parks', where the agricultural production UES was not considered to be a feasible outcome, we used the individual UES hotspot maps for the other five UES modelled (hotspot maps from section 4.2.6.2). Though the overlap of hotspots and cooccurrence of UES maps show similar patterns (i.e., overlap hotspots coincided with areas of high UES cooccurrence and vice versa), we selected the 'overlap of hotspots' map (rather than the 'cooccurrence of UES' map) as the criterion for the suitability analysis. This is because the 'overlap of hotspots' map captures the magnitude of a pixel's service provision relative to its neighbouring pixels, unlike the cooccurrence map which simply denotes the sum of UES presence/absence.

Table 4.1 Constraints and criteria used to derive the suitability maps of the five green infrastructure strategies.

GREEN INFRASTRUCTURE (GI) STRATEGY	PHYSICAL CONSTRAINTS	ECOSYSTEM SERVICES-BASED CRITERIA (Sign)	JUSTIFICATION
1. Conservation of **headwater areas**	Vegetation, rubber, oil palm, other agriculture, bare soil	Overlap of hotspots (+)	**Constraint**: Conservation of terrestrial headwater areas should include all non-built land cover (UNDP, 2017). These include regions being developed or managed for agriculture and plantations, urban and semi-urban development and production forests. **Criteria:** Areas with hotspots of greater number of services considered more suitable for conservation. All ES given equal importance.
2. **Reforestation** for biodiversity	Non-forest, non-agricultural vegetation Area threshold (≥ 10 ha)	Overlap of hotspots (+)	**Constraints:** Reforestation of large, vegetated areas as forests, excluding areas officially recognised as forests or forest reserves, to improve biodiversity in urban areas (Tee *et al.*, 2018). Minimum threshold area of 10 hectares applied in selecting large, vegetated areas. **Criteria:** Areas with hotspots of greater number of services considered more suitable for conservation. All ES given equal importance with the objective of converting non-forest vegetation into multifunctional forests which can be used as productive areas (agriculture) and/or recreational forests.
3. Conservation of existing **urban parks**	Existing parks	Heat mitigation hotspots (+) Urban recreation hotspots (+) Sediment retention hotspots (+) Runoff retention hotspots (+) Scenic quality hotspots (+)	**Constraint**: Layer of all existing parks to avoid selection of vegetated areas that are not parks (e.g., forests or marginal green spaces). **Criteria:** Selection of regulating and cultural UES provided by parks. Positive direction of criteria denotes areas with higher service provision as more suitable – conservation efforts should prioritise existing parks where UES provision is higher. Urban agriculture production was excluded as it is not provided by urban parks in the catchment.

<table>
<tr><td rowspan="5">4. Development of new urban parks</td><td rowspan="3">Non-forest reserve vegetation, bare soil, oil palm, rubber, other agriculture</td><td>Heat mitigation hotspots (-)</td><td rowspan="5">Constraints: Selection of vegetated areas suitable areas for new urban park development, excluding forest and forest reserve areas. Bare soil and productive areas have the potential to be developed for built infrastructure and therefore potentially suitable for development as urban parks. Maximum threshold distance of 500m applied as parks should be located within walking distance of built areas (residential or commercial).

Criteria: Selection of regulating and cultural UES provided by parks. Negative direction of criteria denotes areas with lower service provision will be more suitable – new parks should be developed where UES provision is lower to improve service provision. Urban agriculture production was excluded as it is not provided by urban parks in the catchment.</td></tr>
<tr><td>Urban recreation hotspots (-)</td></tr>
<tr><td>Sediment retention hotspots (-)</td></tr>
<tr><td rowspan="2">500m distance threshold from built areas</td><td>Runoff retention hotspots (-)</td></tr>
<tr><td>Scenic quality hotspots (-)</td></tr>
<tr><td>5. Greening of built infrastructure (impervious surfaces) - through the implementation of gardens, green walls and roofs, etc..</td><td>Built area</td><td>Overlap of hotspots (-)</td><td>Constraint: Selection of all buildings as suitable for the greening of built infrastructure. Negative direction of criteria captures areas with lower UES provision as more suitable for greening of built infrastructure.

Criteria: Greening of built infrastructure has the potential to provide all six UES, particularly green roofs. All UES are therefore given equal importance.</td></tr>
</table>

To indicate suitability, each criterion was assigned a positive (+) or negative (-) sign. A positive sign was assigned to areas where GI strategies need to protect existing high service provision. Conversely, a negative sign was assigned to areas which had low service provision and therefore could benefit from conversion to GI. The 'conservation of headwater areas', 'reforestation for biodiversity' and 'conservation of existing parks' would be prioritised for areas of high realised service provision, while the 'development of new urban parks' and 'greening of built infrastructure' strategies would be prioritised for areas of low realised service provision. All criteria were normalised from 0 to 1 using equation (1) (for criterion assigned a positive direction) and equation (2) (for criterion assigned a negative direction) (Wang et al., 2017).

$$X'_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}} \qquad (2)$$

where X'_{ij} represents the normalised value of the jth criteria in cell *i*, X_{ij} is the value of the *jth* criteria in cell *i*, while X_{min} and X_{max} respectively represent the minimum and maximum value of the *jth* criteria.

Finally, the physical constraints and ecosystem services-based criterion/criteria for each GI strategy were synthesised using the geometric mean (Equation 3) to produce suitability maps (Li et al., 2021).

$$Suitability_{x_y} = \sqrt[n]{\prod_{i=1}^{n} a_i} \qquad (3)$$

where $Suitability_{xy}$ represents the average suitability of pixel *y* for GI strategy *x*, with the value between 0 and 1. n is the number of criteria to average and ai is the *ith* criteria (normalised to values between 0 and 1).

4.3. Results

4.3.1 Spatial Distribution of Services

The spatial distribution of the six realised UES and the corresponding hotspots and coldspots are illustrated in Figure 4.5. All UES exhibited positive spatial autocorrelation ($p < 0.01$) and the hotspots and coldspots of UES showed significant clustering. In dense urban areas (A in Figure 4.5), we found hotspots for HM and coldspots for RR and REC. Hotspots for SQ were scattered across high elevation areas of the catchment, while small patches of hotspots for REC were scattered in semi-natural areas (C in Figure 4.5). Hotspots for RR and SR were widespread in C, while hotspots for AP were largely located in the agricultural areas (B in Figure 4.5).

The provision of each realised UES was quantified for the Upper Langat catchment. The catchment was estimated to retain 73.5 million m3 of stormwater runoff per storm event and 420 million tons of sediment (compared to bare soil) per year for the population within the catchment. The production yield of oil palm and rubber were estimated respectively at 267,184 tons and 13,446 tons per year for the population within the catchment. Of the total population in the catchment, an estimated mean of 1.25% benefit from scenic views, though the intensity of service varies across the catchment (SD = 6.65). The urban recreation service was found to be at a mean deficit of 143 m2 per capita per 100 m by 100 m area (the target was 20 m2 per capita). The heat mitigation index had a mean value of 5.6 per population in a given pixel and a high standard deviation (SD = 9.25), indicating much variability.

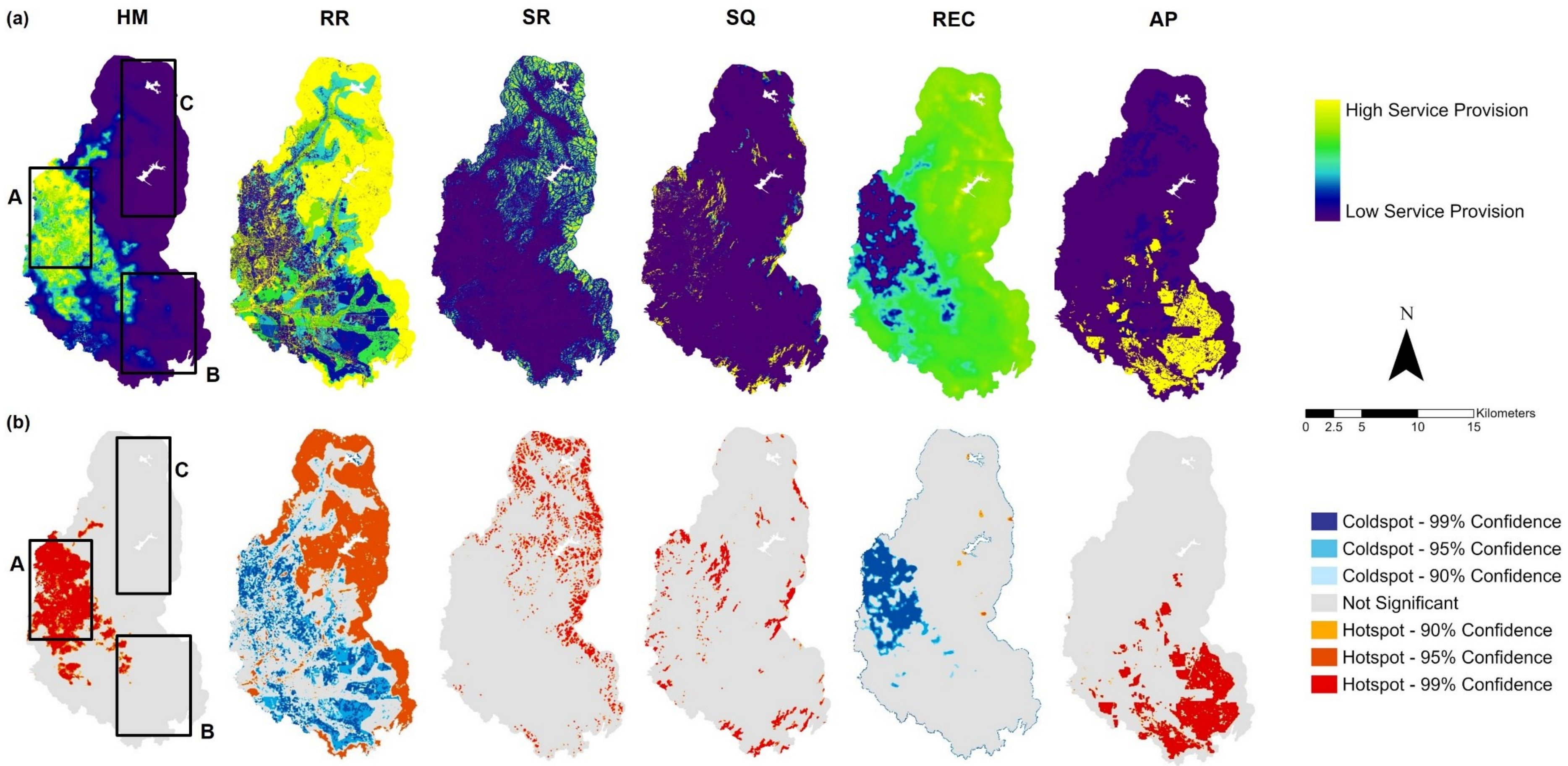


Figure 4.5 The spatial distribution of the (a) six realised urban ecosystem services: heat mitigation (HM), runoff retention (RR), sediment retention (SR), scenic quality (SQ), urban recreation (REC) and agricultural production (AP) after rescaling (values between 0 and 1); and (b) the corresponding hotspots and coldspots of service distribution (based on the Getis-Ord Gi* statistic) for the services in (a). Areas of interest: A - dense built area, B – agricultural areas, and C – forest reserve.

4.3.2 Synergies and Tradeoffs

The pixel-scale correlation between UES is shown in Figure 4.5. All pairwise correlations, except for the correlation between REC and AP, showed significant synergies and tradeoffs ($p < 0.01$). Strong synergies were observed between RR and SR (0.67), while strong tradeoffs were found between HM and REC (-0.88) as well as HM and RR (-0.60). REC displayed strong synergy with both RR (0.60) and SR (0.64), while RR showed weak tradeoffs with AP (-0.28). SQ and SR displayed a weak synergy (0.11).

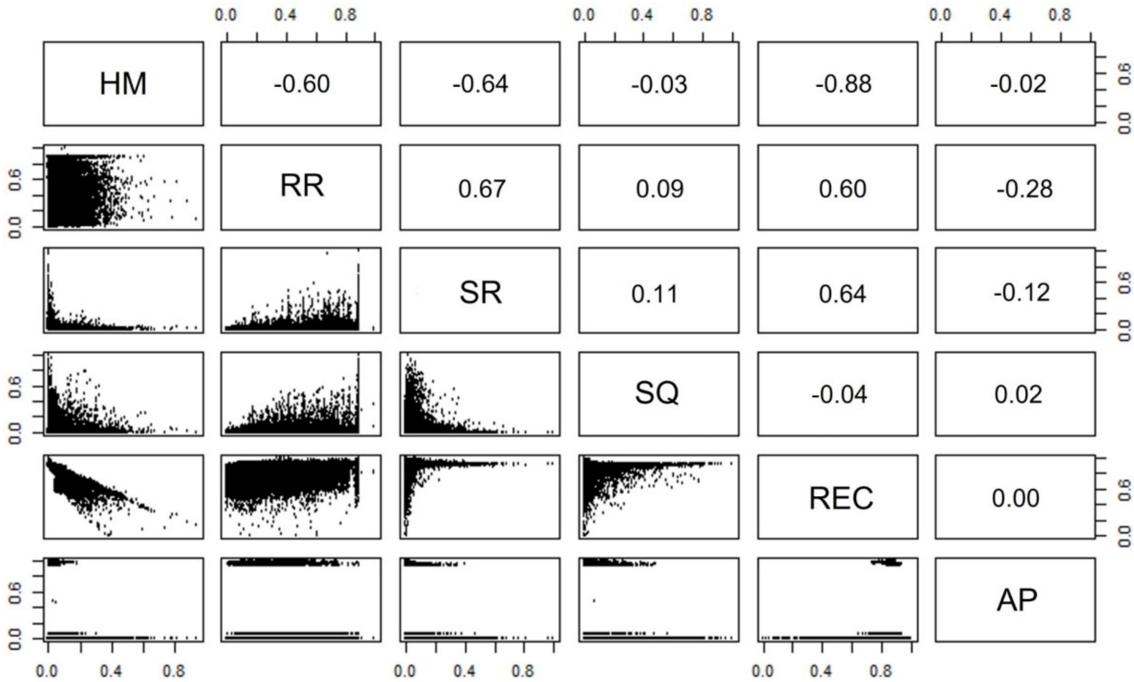


Figure 4.6 Pixel-scale pairwise correlation between realised urban ecosystem services using Spearman's correlation coefficients for heat mitigation (HM), runoff retention (RR), sediment retention (SR), scenic quality (SQ), urban recreation (REC) and agricultural production (AP). We conducted the analysis using the modelled distribution of realised UES, standardised to values between 0 to 1. All correlations were significant at $p = 0.01$, except for the correlation between REC and AP, which was not significant ($p > 0.1$).

4.3.3 Overlap of Service Hotspots and Cooccurrence

Maps illustrating areas of overlap of multiple service hotspots and cooccurrence are shown in Figure 4.7. The overlap was highest in the catchment headwaters. Dense urban area (A) consisted largely of coldspots for multiple services, while hotspots for multiple services were scattered across the catchment though were most concentrated in forested area (C). Most parts of the catchment had only one UES per pixel, though the edges of dense urban areas had between four to five UES per pixel. There were few to no cooccurring UES (between zero and one service per pixel) in agricultural area (B), while forested areas had between two to four UES per pixel.

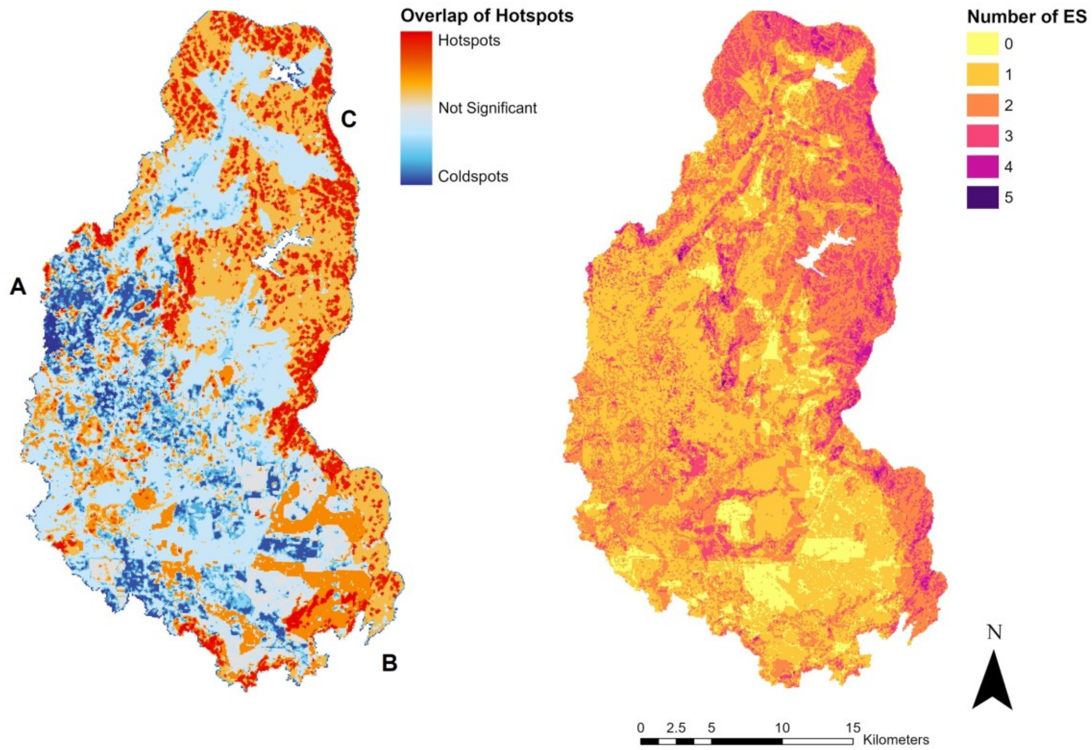


Figure 4.7 (a) The overlap of hotspots and coldspots for multiple urban ecosystem services (by summing the six individual urban ecosystem service hotspot maps); and (b) the cooccurrence of UES (the number of urban ecosystem services per pixel). Areas of interest: A - dense built area, B – agricultural areas, and C – forest reserve.

4.3.4 Multicriteria Suitability Analysis

Figure 4.8 shows the suitability maps for the headwater conservation GI strategy. This suitability map was first derived as 100m by 100m pixels (Figure 4.8a), and then aggregrated by subcatchment (Figure 4.8b). Figure 4.9 shows the suitability map five GI strategies in the Upper Langat catchment. The results suggest that the two most northeastern subcatchments were most suitable for headwater conservation. Areas adjacent to existing forest reserves in the center of the catchment were most suitable for reforestation efforts, while the southern parts of the catchment (B in Figure 4.9) appear most suitable for the development of new urban parks. The dense urban areas (A in Figure 4.9) were most suitable for the conservation of existing urban parks and greening of built infrastructure. Some parts of the catchment were suitable for the implementation of more than one type of GI, indicated by the overlap between suitable areas for reforestation and development of new urban parks in the center of the study area, adjacent to existing forest reserves. Areas in the northeast (C in Figure 4.9) were generally not identified for GI strategies, as these areas were far from residents and/or already forested.

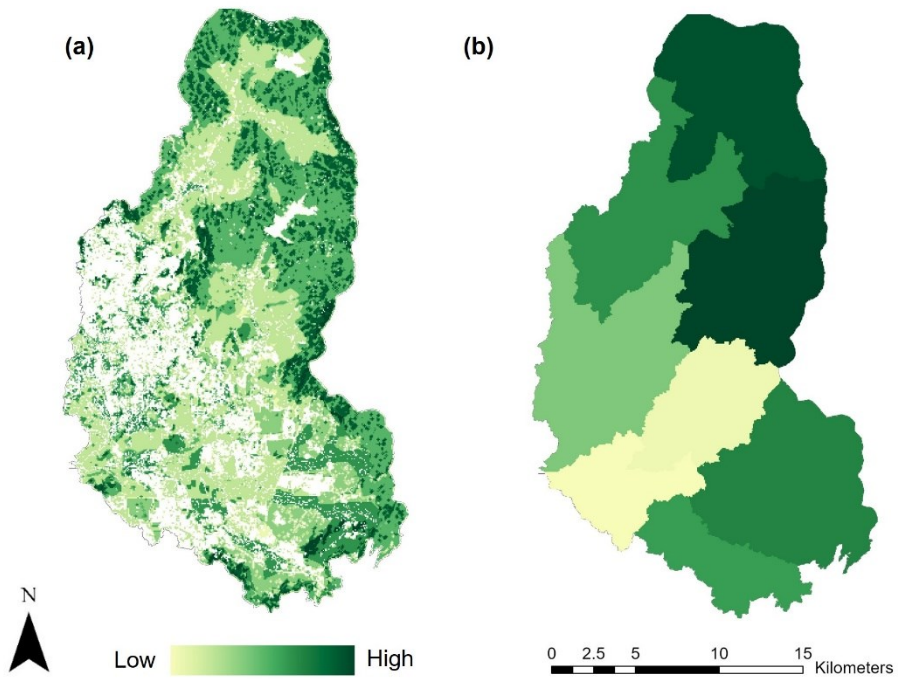


Figure 4.8 Suitability map for the conservation of headwater areas (a) in 100m by 100m pixels, and (b) aggregated by mean suitability per subcatchment.

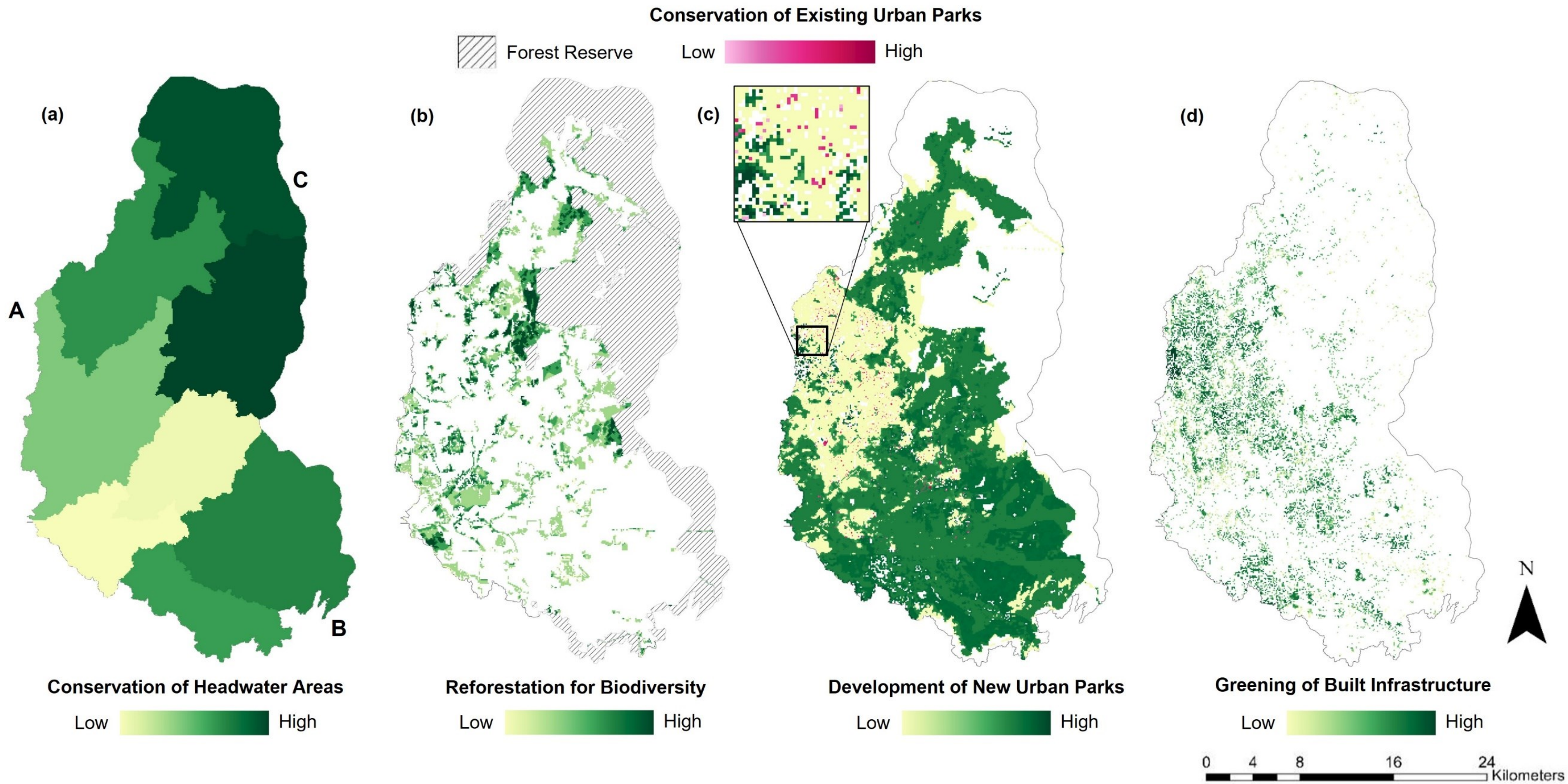


Figure 4.9 Suitability maps for the implementation of five green infrastructure: (a) conservation of headwater areas, (b) reforestation, (c) conservation of existing urban parks and development of new urban parks and (d) greening of built infrastructure. 'High' and 'low' on the legend bars indicate the magnitude of suitability (i.e., high and low suitability respectively). Areas of interest: A - dense built area, B – agricultural areas, and C – forest reserve. Note: The suitability maps for the 'conservation of existing urban parks' and 'development of new urban parks' were derived individually and visualised in a single map.

4.4. Discussion

4.4.1 Identifying Areas for Green Infrastructure in Heterogenous, Multifunctional Urban Landscapes

Assessments of UES tend to describe the spatial distribution of UES, but often fall short of providing specific recommendations to planners (Longato et al., 2021). Spatial multicriteria suitability analysis has been widely applied outside of the ecosystem services field to support planning (Wang et al., 2017; Li et al., 2021), but our approach of integrating this method with multiple UES assessment derived from biophysical models, may be more useful to planners in undertaking ecosystem services-based planning. Our case study in the Upper Langat catchment illustrates the usefulness of such assessment in multifunctional (peri-)urban areas, where the modelling approach needs to address the spatial heterogeneity associated with a gradient in urban development, from urban, peri-urban to rural/natural areas across a topographically complex landscape (hills to the northeast and flatter plains further west). Characterising UES in such a location can be challenging due to the different spatial scales of service supply and demand as well as the GI strategy requirements that need deliberation. The methods applied in this case study are especially useful for supporting the management of other, similarly heterogenous landscapes, which are likely to become more common as urbanisation in the developing countries of the Global South continues to accelerate (Nagendra et al., 2018).

In the Upper Langat catchment, the overlap of coldspots seen in area A (Figure 4.7b) indicate a lack of service provision in densely populated areas and is likely driven by the lack of GI. Identifying existing GI, including greenfields at the peripheries and within the urban matrix, before they are lost to development is key for management in these areas (Lechner et al., 2020). The high provision of multiple UES in the semi-natural areas (C) (i.e., overlap of hotspots and high cooccurrence of UES) was expected given the dense vegetation of the forest reserve here. We note that the scale of the SBA of an UES plays a key role in its realised spatial distribution. The high provision of HM in A is only utilised by people nearby (smaller scale of SBA; see Figure 4.3), while the high provision of UES in C (RR and SR) benefit people throughout the catchment; thus, it is evident that the benefits of these UES are realised at different scales, which in turn influences the collective realised distribution of multiple UES (Cortinovis & Geneletti, 2019).

The spatial relationships between SPUs and SBAs and the definition of demand pose a challenge in capturing and conceptualising realised UES. The realised value of an UES often increases the more it is in demand or utilised, even if its supply decreases (Dworczyk & Burkhard, 2021). For example, the potential SQ service in a town may decrease due to urban expansion resulting in a less visually-appealing landscape, but realised SQ service may increase as the total number of beneficiaries in the town increase (Jones et al., 2016). In addition, in some cases, such as the REC service, realised UES is degraded as population increases (urban nature per capita decreases) whereas in other cases, such as HM, realised value increases (more people benefit from heat mitigation). Hence, some synergies and tradeoffs appear counterintuitive, such as HM which is inversely correlated with REC. This is due to the definition of demand (number of people benefiting, in the case of HM, or meeting a per capita policy standard, in the case of REC). This influences how population distribution was used to model realised UES, where HM was multiplied by population while in the REC model, population was the denominator. Nonetheless, we believe the concept of realised UES still has utility, especially in high population urban ecosystems where it is important to distribute UES in response population needs.

Some parts of the study area were suitable for the implementation of more than one type of GI and, as such, selecting the appropriate GI strategy must consider the varying degree of urban development in the area and the implication of these strategies for local communities (Figure 4.10). The development or conservation of urban parks and the greening of built infrastructure should be targeted in dense urban areas (A1 in Figure 4.10) where these strategies benefit a large urban population (Elmqvist et al., 2015). The greening of built infrastructure is especially suitable in dense urban areas where GI strategies are likely to be developed in the future but vacant land for greening is limited (Rigolon et al., 2018). For greening areas in B1 in Figure 4.10, we recommend the development of new urban parks as other GI strategies are less suitable. The most appropriate greening efforts in C1 in Figure 4.10 may be headwater conservation and reforestation, as it would preserve the naturalness of the forest reserve and livelihood of the indigenous people known to reside there (built areas in C1 Figure 4.10). While some of these recommendations are driven by spatial constraints (e.g., development of urban parks is limited to places outside forests or protected areas), they allow us to understand tradeoffs between UES at the fringe of existing urban areas at a finer scale.

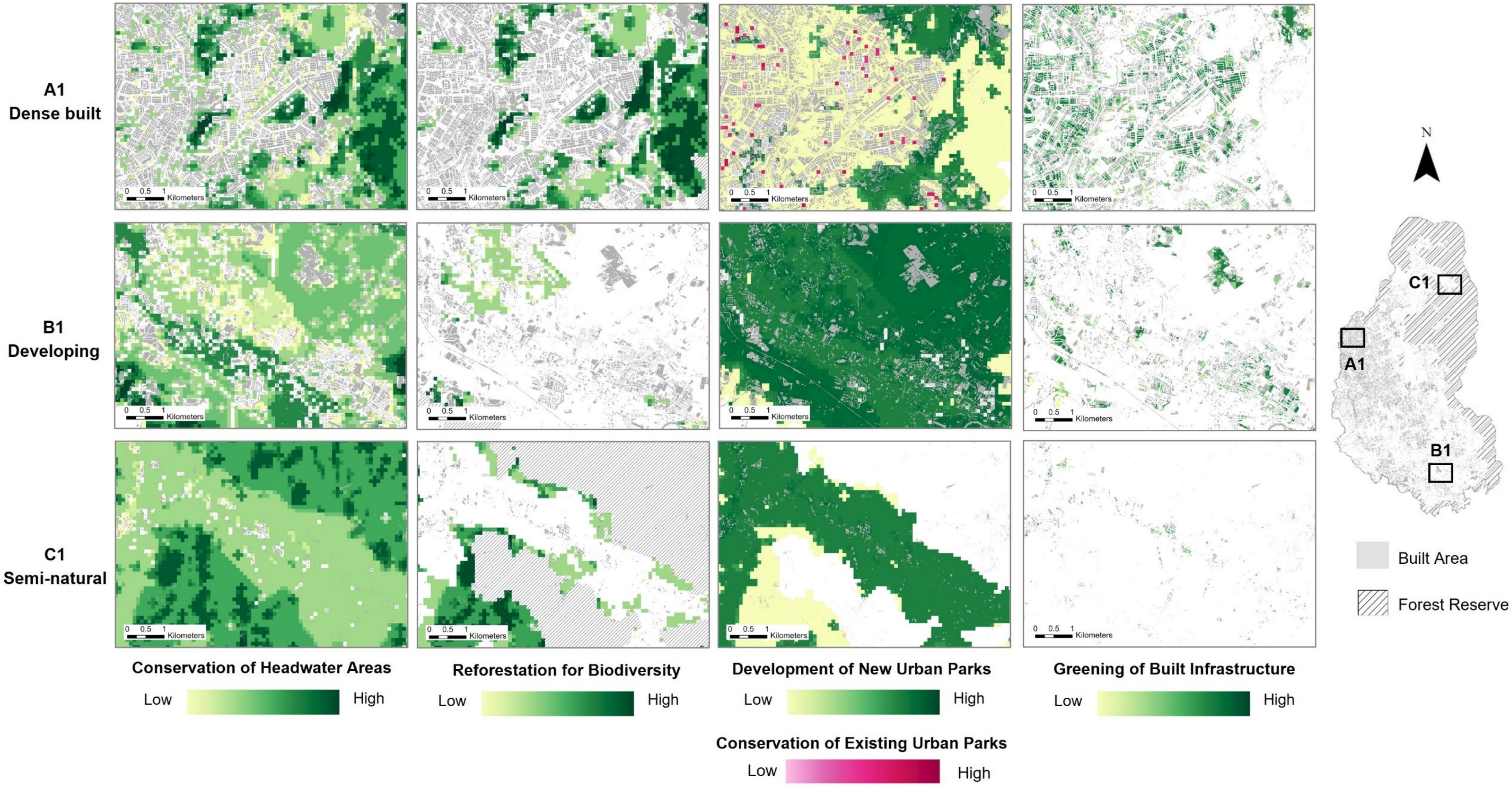


Figure 4.10 Selected images comparing the suitability of five green infrastructure types for areas with varying degree of urban development: dense built areas (A1), developing areas (B1) and semi-natural areas (C1).

4.4.2 Considerations for GIS Modelling of Multiple UES to Support Planning

In this section, we highlight several considerations in adapting our approach for use in other urban landscapes. In assessing multiple UES, the choice of hotspots analysis will determine the pixel-scale suitability of each GI strategy as selected individual or sum of service hotspots are used as ecosystem service-based criteria in the multicriteria suitability analysis. We applied a local hotspot analysis (Getis-Ord Gi*) as it provides a means of capture clusters of hotspots which are higher or lower than neighbouring areas (Schröter & Remme, 2016). This was especially important for SR and REC, which would have been lost in a global hotspots analysis (e.g. top 10% of pixel values) (Figure 4.5). We also normalised UES values to allow for relative comparisons, as the UES had different minimum and maximum values which were not equivalent (i.e., it is physically impossible or unlikely for some UES to have a zero value such as HM) (Maes et al., 2012). We acknowledge that the interpretation of UES values will be impacted by the Getis-Ord Gi* hotspot analysis and normalisation. However, it is also important to note that comparisons between UES values are complicated by the complex non-linear relationships between UES and values (Guswa et al., 2014).

Additional considerations when selecting ecosystem services-based criteria and physical constraints include relevant economic, structural and institutional factors (Langemeyer et al., 2020) and limitations associated with data and models (Bayani & Barthélemy, 2016). While these factors have not been considered in our study, they are highly likely to influence the implementation of GI strategies. The criteria in this study were assigned equal weights; however, in other cases it may be preferable to assign different weights to criteria to reflect preferences for specific UES (Martínez-López et al., 2019). It is also worth noting that the selection of GI strategies in our study was constrained by the precision of the modelling (i.e., GIS input data) and scale of our study (i.e., 100 m pixel size) (Guswa et al., 2014). As such, we could not make recommendations for specific types of GI measures, such as bioswales versus street trees, especially within the urban matrix. However, given the important role that large, vegetated patches have in providing ecosystem services in tropical cities due to the considerable number of remnant natural areas remaining (e.g., urban forests, parks, trees on vacant but vegetated land), these larger urban green spaces are likely to be the most ubiquitous GI measure for UES provision. Such larger patches are well captured at a 10m resolution through the 'non-agricultural vegetation' class in the LULC (Figure 1, Appendix G). Furthermore, due to cost and technical challenges, the application of more highly engineered GI measures like bioswales is still quite rare. Finally, our mapping should be considered as a first step in supporting decision-making by identifying the general locations where GI strategies should be targeted. Subsequent fieldwork and local community engagement is needed to evaluate and choose the most appropriate local measures.

Our study represents a rare application of the scenic quality model to urban environments. Nevertheless, we acknowledge the uncertainties introduced by our model parameters (see Appendix G), which were derived from regional or global literature due to data limitations in the region and modelling realised UES based on population sizes (Dang et al., 2021). We also acknowledge the limitations presented by non-calibrated ecosystem service models. These drawbacks can be addressed through additional field-based data collection to calibrate parameters and validate model estimations. Also, due to the complexity of certain ecosystem services and a lack of data over larges extents, some models, in particular, recreational services (REC) may lack precision, and indeed only represent a realised UES through a proxy. However, most of the models parameterised in this study are novel to the region, so our work contributes to the limited but growing body of UES knowledge in tropical Southeast Asia (Lourdes et al., 2021), and demonstrates that such an approach could be used in other data poor urban regions in the Global South.

4.5 Conclusions

This study provides a rare application of a systematic method for integrating the outcomes of multiple UES assessments to support GI planning in rapidly developing multifunctional urban areas. The novel approach combines biophysical ecosystem service models with multicriteria suitability analysis to first characterise the spatial distribution of multiple UES, then identify areas where GI should be targeted. The results of our realised UES assessment highlight hotspots and coldspots as well as synergies and tradeoffs for the provision of multiple UES, accounting for the complex spatial characteristics of UES supply and demand in the rapidly changing tropical study catchment. The suitability maps were derived using ecosystem services-based criteria to provide spatially explicit recommendations on locations for GI conservation or development, addressing the gap between UES assessments and its application in urban planning. This overall approach is especially useful for characterising UES in rapidly urbanising and spatially heterogeneous urban landscapes such as those in the Global South, but it can also be adopted to support sustainable land use management in urban areas globally.

Chapter 5 Guiding Sustainable Urban Development In Kuala Lumpur: Shifting The Focus To Ecosystem Services

Prepared as: Lourdes, K.T., Gibbins, C.N., Hamel, P., Sanusi, R., Azhar, B. and Lechner, A. (in preparation). Guiding Sustainable Urban Development In Kuala Lumpur: Shifting The Focus To Ecosystem Services

5.1 Introduction

Southeast Asia has been urbanising rapidly over recent decades. In 2018, 49% of the region's population lived in urban areas but this figure is expected to reach 66% by 2050 (United Nations, 2018). Kuala Lumpur, once a renowned mining town and now the capital city of Malaysia, is one of the most economically prosperous cities in the Southeast Asia, with a population of 1.79 million (based on the 2017 census). Rapid development and increasing urban populations have led to the formation of an urban agglomeration beyond Kuala Lumpur city, known as Greater Kuala Lumpur. This region is expected to have a population of 10 million by 2030 (Department of Statistics Malaysia, 2019). Increasing population pressure on the urban system and a lack of careful planning have led to various environmental and socioeconomic problems in the region, including traffic congestion, urban heat island effects, flash floods and poor air and water quality (Leh *et al*., 2014; Ooi, 2009).

Several strategies have been developed to rectify these urban challenges and advance Malaysia as a 'garden nation', with attempts to position Kuala Lumpur as a highly liveable and vibrant green capital (National Landscape Department Ministry of Housing and Local Government, 2011). Increasing the cover and quality of green spaces (also referred to as 'green infrastructure' or 'green networks') has been a key element of Malaysia's agenda of building sustainable and resilient cities. Green spaces have been recognised globally as providing ecosystem services. These services represent the benefits provided to humans by healthy and functioning ecosystems (Daily *et al*., 1997), including microclimate regulation, stormwater management and noise attenuation (Bolund & Hunhammar, 1999; Costanza *et al*., 1997; Morillas *et al*., 2018; Sheikhi *et al*., 2015). Green spaces are also frequently linked to concepts such as 'Nature-based

Solutions' (NBS), which refer to the use of nature to tackle socio-environmental challenges such as climate change and food security. NBS are often used in the urban context to support the development of self-sustaining urban ecosystems (Almenar *et al*., 2021). Concepts of ecosystem services and NBS can be applied in sustainable development frameworks and policy initiatives to guide urban planning and design (Langemeyer *et al*., 2020; Vignoli *et al.*, 2021).

Despite their potential value, literature on urban ecosystem services and the general application of nature-based solutions in Southeast Asia remains limited in comparison to the global literature (Lechner *et al.,* 2020; Lourdes *et al.,* 2021). Lechner et al. (2020) highlight that of 520 publications on 'Nature-based Solutions', only 16 were from Southeast Asia, with most of these published in the last 3 years. Similarly, Lourdes et al. (2021) reports that Southeast Asian cities are often underrepresented in the global literature on urban ecosystem services, with most research undertaken in Europe and North America. There are also disparities within the region, with research dominated by work on the city-state of Singapore (44 out of 149 papers reviewed by Lourdes et al., 2021); only 8 papers found through this systematic review concerned Kuala Lumpur city. While more research on the application of NBS or urban ecosystem services is needed in Kuala Lumpur (see Lourdes et al., in review), urban green spaces in Malaysia have been recognised as improving social cohesion in neighbourhoods (Bajunid & Nawawi, 2012; Kadir & Othman, 2012), wellbeing (Mokhtar *et al.,* 2018; Nath *et al.*, 2018), and increasing property values and eco-tourism prospects (Belcher & Chisholm, 2018; Dreyer *et al.,* 2018; Konijnendijk *et al.*, 2013; Young, 2010). Studies have also investigated how green spaces can improve urban resilience to climate (Kamarulzaman *et al.*, 2014; Sanusi & Bidin, 2020) and support sustainable urban development (Ahmad & Simis, 2017; Darkhani *et al.*, 2019).

In Malaysia, several indicators have been developed as tools to track sustainable development efforts at different jurisdictional levels (i.e., municipal, city and national) (DBKL, 2004; Department of Town and Country Planning, 2019; Ministry of Energy Green Technology and Water, 2017). National policies on sustainable development such as the Malaysian Urban Rural National Indicators Network 2.0 (MURNINets 2.0) (Department of Town and Country Planning, 2019), and Low Carbon Cities Framework (Ministry of Energy Green Technology and Water, 2017), guide city and municipal level policies on planning sustainable cities. While these indicators track various aspects of sustainable development, there is a need to evaluate the extent to which ecological requirements are included in sustainable development policy initiatives. Ecological infrastructure such as green and blue spaces plays a major role in supporting the overarching goal of advancing Malaysia as a 'garden nation' with increased urban liveability, notably in its capital city. Moreover, by understanding the extent and ways in which ecological elements are incorporated in sustainable development policy initiatives, gaps in current knowledge can be identified and addressed. Local academic literature can play a key role in bridging these gaps, particularly in sharing current ideas between disciplines and providing evidence-based guidance for policy initiatives, so a review of this literature is timely.

This study aims to investigate the extent to which urban biodiversity and ecosystem services are considered explicitly as part of sustainable development planning in Greater Kuala Lumpur. We first review academic literature to assess the topics and ecological features studied, among other elements, to assess the extent of ecological research undertaken with respect to sustainable development in Kuala Lumpur. Then, using content analysis, we examine how ecological considerations are addressed in key sustainable development policies in Kuala Lumpur. We compare these findings with other city and national level policies in Malaysia. Finally, we discuss how urban biodiversity and ecosystem services have been considered in sustainable development, identifying important next steps through ecosystem services valuation. As part of this discussion, we provide recommendations guided by international frameworks on sustainable development, advancing current perspectives and efforts to build a more sustainable, liveable and resilient Kuala Lumpur.

5.2 Academic Literature Review and Content Analysis of Policy Documents

We reviewed a subset of published literature, focusing on local and internationally published works on Kuala Lumpur over the last 10 years. A keyword search was conducted on Scopus with the following search string ("Malaysia" AND ("urban" OR "city") AND ("ecology" OR "greenspace" OR "green space" OR "nature" OR "liveability" OR "wellbeing") OR ("sustainab*" OR "resilien*") to confirm that key literature in this field was not overlooked. We reviewed a total of 52 publications (journal articles and conference papers) which comprised empirical studies and reviews on a range of topics linked to sustainable urban development (the list of the 52 articles reviewed is available in Appendix F). The publications were classified according to the topics listed in Table 5.1. Each article was classified under a single topic or a maximum of two topics. In addition, we reviewed the articles for the main ecological feature assessed, scale of assessment, data collection and analysis methods, and the type of data collected to gain insights on research perspectives and potential knowledge gaps. The details of how each of these categories are defined and classified are listed in Table 5.2.

Table 5.1 The list of topics used to classify papers and the description of the topics.

Topic	**Description**
Biophysical functions of UGS	Studies on the ecological functions of green spaces such as microclimate regulation, stormwater retention
Habitat and biodiversity	Studies on habitat quality and urban flora or fauna
Physical and mental wellbeing	Studies on physical and mental wellbeing linked to urban green spaces
Social wellbeing	Studies linking UGS with social cohesion or opportunities for social activities
Public perception and use of UGS	Studies on preferences and perceptions towards green spaces, including preferred attributes of UGS
Planning and policies	Studies assessing the quality or quantity of UGS in KL, including tools to support urban green space planning
UGS for tourism and education	Studies on tourism and/or education linked to green spaces
Sustainable and smart cities	Studies on sustainable and smart city developments which include concepts such as biophilic urbanism, water-sensitive urban designs and green architecture

Table 5.2 Review categories, definition and classification method.

Category	Definition	Classification
Ecological feature assessed	Summarizing the ecological features that were assessed by the study. Classified based on explicit mention of the (main) ecological feature assessed in the study.	1 for green spaces (general vegetated areas or water bodies) 2 for green walls 3 for green roofs 4 for urban forests 5 for urban parks 6 for street trees 7 for no specific feature (i.e., none were mentioned)
Scale of assessment	Scale at which the assessment was conducted. Distinction between a site, a single city, studies across multiple cities, a region/state or at national-scale	1 for a single site (e.g., a park in KL) 2 for a single-city (e.g., KL city) 3 for multiple cities 4 for region or state-scale (e.g., Greater KL metropolitan region) 5 for national scale (i.e., Malaysia) 6 for other
Data collection method	The method(s) of data collection and analysis applied in the article. Distinguished between field sampling, GIS/process/mechanistic modelling, survey/interview, review or multiple methods.	1 for field sampling 2 for GIS/process/mechanistic modelling 3 for survey/interview 4 for review (includes content analysis and case studies) 5 multiple methods (i.e., use of one or more of the above methods)
Type of data gathered	The type of data gathered within the study. Distinction between qualitative and quantitative data.	1 for quantitative 2 for qualitative 3 for mixed methods

Next, we used content analysis to examine how and whether Malaysian sustainable urban planning and development policy documents have tackled ecological considerations. First, we examined the proportion of ecology-linked initiatives across overall policy initiatives. Then, we reviewed policy documents for any text that indicated the presence of ecological considerations in urban planning. The text was read with particular attention to how terms such as 'ecology' or 'ecological', 'ecosystem', 'ecosystem service', 'green space(s)', 'green network(s)', 'biodiversity', 'conservation', 'sustainability', 'biophilic urbanism', 'water sensitive urban design' and 'nature-based solution' were used, to examine the nature and extent of ecological consideration. Finally, we explored how well the policy documents made provisions for ecological attributes that can be considered key to sustainable development. Following the method of Danjaji & Ariffin (2017), we scored the comprehensiveness of each policy document in tackling ecological attributes linked to blue and green spaces. We used the classification of ecological attributes devised by Danjaji and Ariffin (2017); the four ecological attributes can be summarised as ‘open space’, ‘natural space’, ‘corridors’ and ‘conservation’. The attributes were weighted equally and received a score between one to three points. The scoring was based on the adequacy of the section(s) on the ecological attributes in dealing with the objectives of the policy with respect to ecological function. A ‘good’ score was assigned three points, an ‘average’ score was assigned two points and documents with ‘limited’ coverage on the ecological attribute were assigned one point. A score of zero was assigned if there was no mention of the ecological attribute in the policy document. Each ecological attribute had a maximum score of three points and so each policy document could receive a maximum score of 12.

We studied policy documents at city (i.e., federal territory) and national levels (Figure 5.1). We first reviewed three major policies in Federal Territory of Kuala Lumpur: the (i) 2020 Kuala Lumpur Structure Plan (DBKL, 2004), (ii) the Kuala Lumpur Structure Plan 2040 draft (DBKL, 2020), and the (iii) 2020 Kuala Lumpur City Plan (DBKL, 2008). Then, we compared our findings to two policies in the Federal Territory of Putrajaya: the (i) 2025 Putrajaya Structure Plan (Perbadanan Putrajaya, 2014), and the (ii) 2021-2025 Putrajaya Strategic Plan (Perbadanan Putrajaya, 2021). We selected the Federal Territory of Putrajaya, which is the administrative centre of Malaysia, as Putrajaya is renown as a ‘green city’ and recognised nationally for its policies in urban and environmental management (Azmi, 2020). These finding are then related to two national level policies which guide urban sustainability in Malaysia: (i) MURNINets 2.0 (Malaysia Urban-Rural Network Indicators 2.0) (Department of Town and Country Planning, 2019), and the (ii) Low Carbon Cities Framework (Ministry of Energy Green Technology and Water, 2017). The content analysis was largely performed in English, but where an English version of the policy was not available, the content analysis was performed on the Malay version.

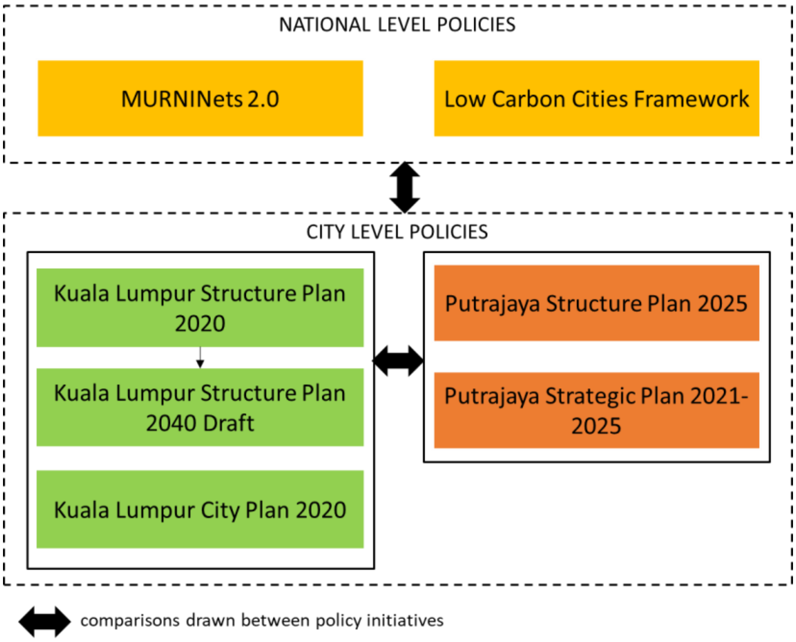


Figure 5.1 An overview of the policies analysed in this study and the comparisons drawn.

5.3. Sustainable Urban Development in the Academic Literature

Academic literature on sustainable development in Kuala Lumpur spanned a broad range of topics (Figure 5.2). The predominant topic (including both primary and secondary) was 'planning and policies' which was addressed by 27 out of 52 articles (51%). The articles on this topic often applied remote sensing and GIS-based methods (e.g., Chan and Vu, 2017; Rasli, Kanniah and Ho, 2019), as well as providing tools and frameworks that support green space planning (e.g., Malek and Nashar, 2018; Arof *et al.*, 2020). While 19 out of these 27 articles (70%) only addressed the topic of 'planning and policies', several also addressed concomitant topics such as 'public perceptions and use of UGS' or 'habitat and biodiversity.' For example, Nath and Magendran (2021) investigated current management of urban parks as well as public uses and willingness to pay for conservation.

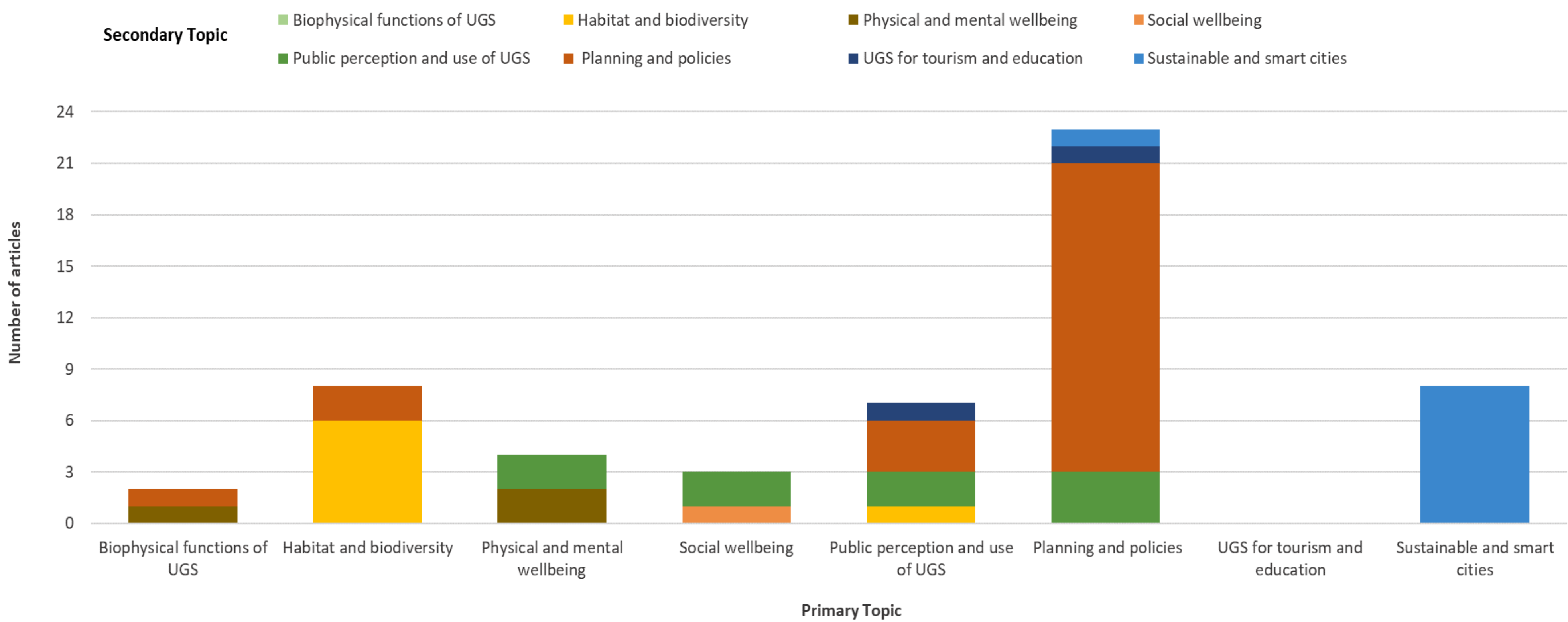


Figure 5.2 A summary of the topics covered by the articles reviewed. Some articles were classified under more than one topic with a maximum of two topics. The horizontal axis represents the primary topic covered in the article and the legend colours represent the secondary topic of the articles. Articles classified under only one topic will be represented by the same topic under both the primary and secondary topic labels. Note: No articles covered 'UGS for tourism and education' as a primary topic.

‘Public perception and use of UGS’ was the second most prevalent topic (including both primary and secondary topics) (21% of articles) followed by ‘sustainable and smart cities’ (17% of articles). Articles focusing on ‘public perception and use of UGS’ include investigations on the uses and constraints of green outdoor environments at workplaces. 81% of articles on ‘public perception and use of UGS’ (9 out of 11 articles) cover a secondary topic; these secondary topics included ‘physical and mental wellbeing’, ‘social wellbeing’ and ‘planning and policies’. Articles that addressed the topic of ‘sustainable and smart cities’ explored the adoption of the biophilic cities concept in Kuala Lumpur (see Arof *et al.*, 2020a; Arof *et al.*, 2020b), opportunities for smart technology in urban water management (see Beecham and Fallahzadeh, 2011) and assessed the impact of urban transportation on local sustainable development agendas (see Bonasif, 2017).

Of the topics that addressed aspects of the ecological and social benefits derived from nature, ‘habitat and biodiversity’ and ‘physical and mental wellbeing’ were most commonly covered, with 8 (15%) and 5 (10%) articles respectively. Articles on the topic of ‘habitat and biodiversity’ commonly evaluated the diversity of fauna in urban parks (see Karuppannan *et al.*, 2014; Aida *et al.*, 2016; Baharuddin *et al.*, 2017) as well as assessing networks of ecological connectivity and forest fragmentation in Kuala Lumpur (see Nor *et al.*, 2017; Tee *et al.*, 2018). Topics that had the least number of articles (3 articles or less) were ‘social wellbeing’, ‘biophysical functions of UGS’ and ‘UGS for tourism and education’, which are also topics linked to the ecological and social benefits of nature. Two out of the three articles covering the topic of ‘social wellbeing’ also addressed the topic of ‘public perception and use of UGS’. Articles focused on ‘social wellbeing’ assessed preferences and perceived benefits of green spaces in neighbourhoods in relation to social cohesion (see Bajunid and Nawawi, 2012; Sreetheran, 2017), as well as perceived disservices such as fear of crime (see Sreetheran and van den Bosh, 2015).

The two articles that addressed the topic of ‘biophysical function’ assessed elements of microclimate regulation and urban heat island mitigation (see Kamarulzaman *et al.*, 2014; Aflaki *et al.*, 2017). However, there were no articles of other biophysical functions such as flood risk mitigation, stormwater retention, carbon storage or the prevention of soil erosion or landslides (Azis & Zulkifli, 2021; Kok et al., 2015). This absence is notable, given the wet tropical climate of the city. The topic of 'UGS for tourism and education' was covered by two articles as secondary topics, which investigated the perception of urban forest visitors to environmental education (see Dreyer *et al*., 2018) and opportunities for eco-tourism through the use of walking trails in Kuala Lumpur (see Wan Omar *et al*., 2012).

A range of ecological features were assessed in the articles using diverse data collection and analysis methods (Figure 5.3). 'Green spaces' were commonly assessed (18 out of the 52 articles (35%)), while 'green walls' were the least assessed (2 articles; 4%). Articles that assessed 'green spaces' most frequently used 'GIS/process/mechanistic modelling', followed by 'review' methods for data collection and analysis. 'Urban parks' were the second most common (14 articles; 27%) ecological feature assessed, with articles largely applying 'survey/interview' methods, followed by 'field sampling'. Eight articles did not assess any specific ecological feature; these articles most frequently addressed the topic of 'sustainable and smart cities', which usually does not focus on a specific ecological feature. These articles often used 'review' methods for data collection and analysis, though some articles applied a combination of methods in their assessment.

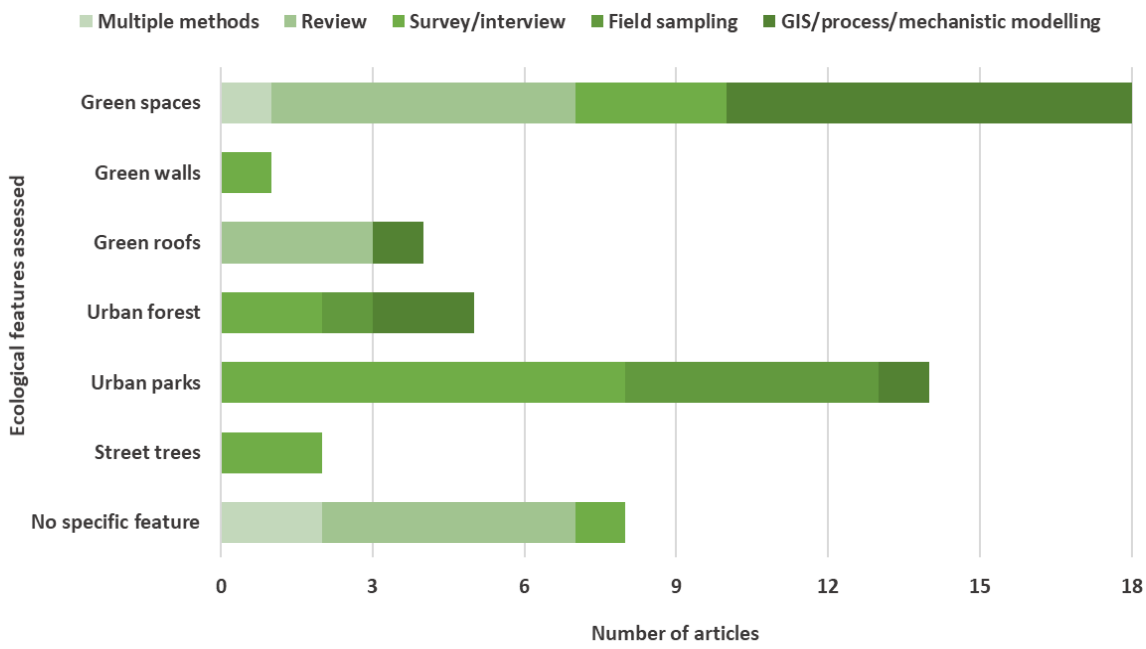


Figure 5.3 The data collection and analysis methods applied across the ecological features assessed.

Figure 5.4 contrasts the approaches used for data collection and analysis across the various scales of study. The most common scale of assessment was the 'single-city' scale (35%), with 18 out of 52 articles focused on sustainable development topics within Kuala Lumpur city. Studies conducted at this scale most frequently used 'survey/interview' methods for data collection and analysis, followed by 'GIS/process/mechanistic modelling' and 'field sampling'. Other common scales of assessment include 'national'- and 'regional' -scales, which were used in 13 (25%) and 9 (17%) of the studies respectively. Studies conducted at 'national' scales more commonly used 'review' methods for data collection and analysis, while studies conducted at 'regional' scales utilised a variety of methods, even combining one or more methods. The least common scales of assessment were 'site' and 'multi-city' scale, with 3 articles each (comprising a total of 10% of all articles). Articles that conducted assessments at these scales often applied 'survey/interview' data collection methods; the 'survey/interview' method was the most frequently applied data collection method across all 52 articles (see Sreetheran and van den Bosh, 2015; Dreyer *et al.*, 2018). The type of data collected across the 52 articles was predominantly quantitative (30 out of 52 articles) (Figure 5.5). A total of 17 articles collected solely qualitative data, while the remaining 5 articles collected both quantitative and qualitative data. Studies conducted at large scales such as 'national' and 'other' tended to utilise solely qualitative data over quantitative or mixed methods.

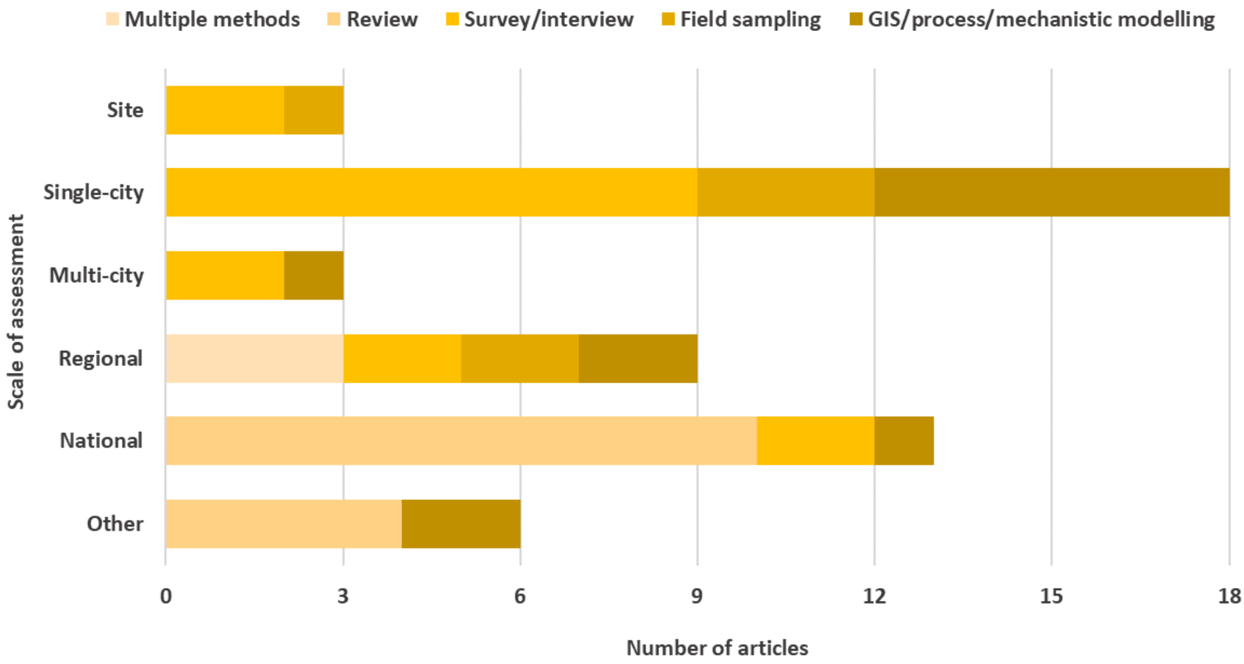


Figure 5.4 The types of data collection and analysis methods undertaken in the articles across the scales of assessment.

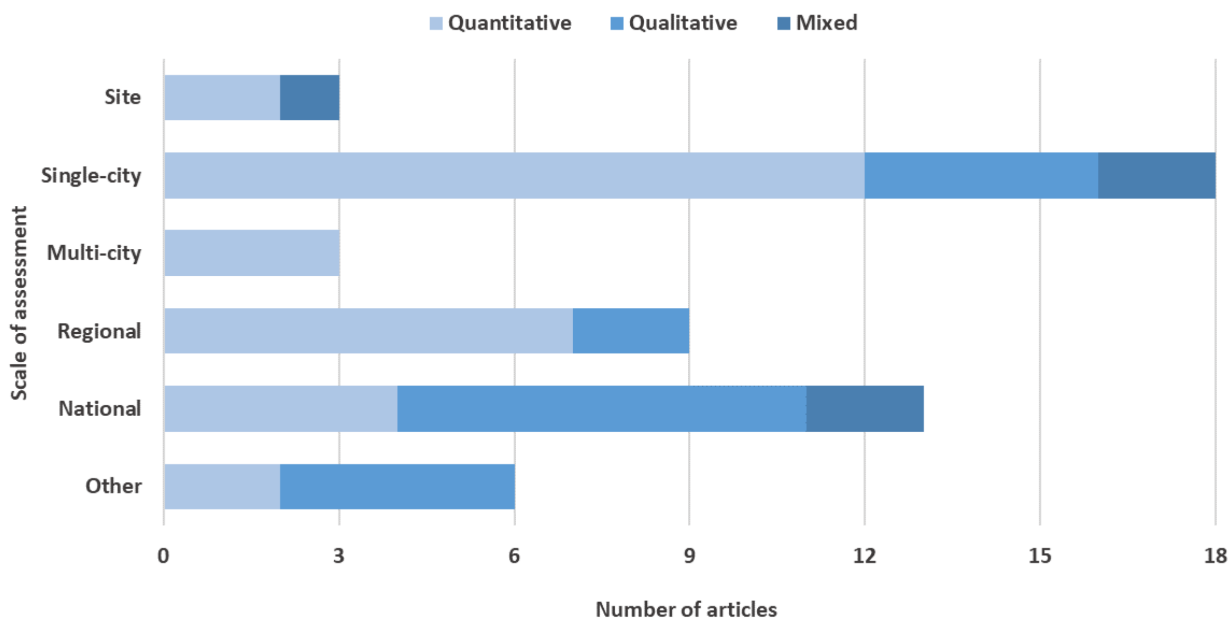


Figure 5.5 The type of data collected in the articles across the different the scales of assessment.

Based on our review, the ecological features assessed in the academic literature are skewed towards 'green spaces' and 'urban parks', with 32 out of 52 articles (62%) assessing one of these features. We note that smaller scale ecological features such as street trees, gardens, bioswales and green walls were rarely assessed in the articles. Blue spaces (i.e., water bodies such as wetlands, ponds, lakes) were rarely mentioned or assessed in the articles, even though such ecological features can support sustainable urban development goals and improve urban wellbeing through the provision of urban ecosystem services (Chen *et al*., 2019; Merriman *et al*., 2017; Seifollahi-Aghmiuni *et al*., 2019). Smaller scale ecological features and blue spaces are elements that should therefore be addressed by future studies on sustainable urban development.

The insights on the scale of assessment and data collection methods indicate that academic literature on sustainable urban development comprise both studies specific to the context of Kuala Lumpur (i.e., single-city scale assessments), and studies that can be broadly applied to cities beyond Kuala Lumpur (i.e., regional and national -scale assessments). These insights also indicate that studies conducted at spatial scales larger than regional scale tended to used 'review' methods which largely rely on secondary data. As such, we highlight the scope for large-scale studies on sustainable development based on new primary data, for which regional/national-scale surveys and/or GIS-based methods and tools can be employed.

5.4 Policies On Sustainable Urban Development

The objectives and number of initiatives linked to ecological considerations in the seven policy documents reviewed are summarised in Table 5.3. Of the five city-level and two national-level policies, the 2021-2025 Putrajaya Strategic Plan had the highest percentage of ecologically relevant policy initiatives (20% of total initiatives). The 2020 Kuala Lumpur City Plan had the second highest percentage (17%) followed by the 2040 Kuala Lumpur Structure Plan Draft (14%). The national-level policy documents have a moderate to low proportion of initiatives with ecological consideration, though this is likely due to the policies having fewer number of initiatives (policy documents with fewer total number of initiatives such as 2025 Putrajaya Structure Plan, MURNINets 2.0 and Low Carbon Cities Framework, have fewer initiatives linked to ecological considerations).

The number of times terms linked to ecological initiatives appeared in the policy documents is provided in Table 5.4. Across all seven policy documents, the terms 'sustainability' was most frequently recorded (a total of 218 mentions), followed by 'biodiversity' (154 mentions) and 'conservation' (112 mentions). The term 'nature-based solution' was not recorded in any of the policy documents, though some policy documents strongly reflected nature-based solution approaches in their initiatives. For instance, the 2020 Kuala Lumpur City Plan promotes nature-based approaches to addressing urban environmental challenges with initiatives such as 'protecting vegetation along river corridors for river water quality improvement' and 'retaining green spaces to improve air quality'. The terms 'biophilic urbanism' and 'water sensitive urban design' were only used in the 2040 Kuala Lumpur Structure Plan Draft, where nature-based approaches were encouraged in building sustainable and resilient cities. These nature-based concepts were not present in the preceding 2020 Kuala Lumpur Structure Plan. The 2040 Kuala Lumpur Structure Plan Draft also contains the only mention of the term 'ecosystem services' across all policy documents. While there are references to ecosystem services in the 2020 Kuala Lumpur City Plan, it is notable that the document contained no explicit mention of 'ecosystem services' and only one mention each for the terms 'ecology' and 'ecosystem'.

Table 5.3 A summary of the policy documents reviewed: the objectives, planning level (city or national), total number of initiatives in the document and the number of initiatives linked to ecological considerations (also shown in percentage).

Policy	**2020 KL Structure Plan**	**2040 KL Structure Plan Draft**	**2020 KL City Plan**	**2025 Putrajaya Structure Plan**	**2021-2025 Putrajaya Strategic Plan**	**MURNINets 2.0**	**Low Carbon Cities Framework**
Objective	Contains the vision, goals, policies and proposals to guide the development of Kuala Lumpur over the next 20 years (2001 to 2020).	Contains the vision, goals, policies and proposals to guide the development of Kuala Lumpur over the next 20 years (2021 to 2040).	Sets out a 12-year plan on what must happen to achieve the vision for Kuala Lumpur City in 2020	Sets the key directions for sustainable growth by outlining policies and initiatives that will guide strategies and decisions for the city's planning and development implementation for the next 13 years	Outlines the planning policies, strategies and next steps of the administrative management, Putrajaya Corporation, for the next 5 years	A guide for local and state authorities as well as other relevant agencies to measure and monitor the achievements and progress of urban areas towards sustainable development	Provides a framework and tool for implementing strategic and policy development on sustainability within the Malaysian context; with specific focus on tracking carbon emissions at city levels.
Planning level	City	City	City	City	City	National	National
Total number of initiatives	190	71	64	32	104	39	41
Number of initiatives linked to ecological considerations	17	10	11	2	21	3	5
(Percentage of total number of initiatives)	(9%)	(14%)	(17%)	(6%)	(20%)	(8%)	(12%)

Table 5.4 The number of times terms linked to ecological initiatives were recorded in the policy documents.

	Policy document	2020 KL Structure Plan	2040 KL Structure Plan Draft	2020 KL City Plan	2025 Putrajaya Structure Plan	2021-2025 Putrajaya Strategic Plan	MURNINets 2.0	Low Carbon Cities Framework
No. of mentions for ecology-linked terminology	*Ecology/ ecological*	3	20	1	7	0	1	30
	Ecosystem	0	18	1	1	1	1	4
	Ecosystem services	0	1	0	0	0	0	0
	Green space(s)	2	9	22	10	0	3	6
	Green network(s)	29	18	4	3	0	0	0
	Biodiversity	2	49	6	85	4	0	8
	Conservation	29	22	52	1	0	6	2
	Sustainability	3	25	19	14	11	132	14
	Biophilic urbanism	0	1	0	0	0	0	0
	Water sensitive urban design	0	4	0	0	0	0	0
	Nature-based solution	0	0	0	0	0	0	0

The scores assigned to each policy document for their comprehensiveness in tackling the listed ecological attributes is provided in Table 5.5. The 2040 Kuala Lumpur Structure Plan Draft scored the highest, receiving an average score of 3 and the total maximum score of 12 points. In this document, all four ecological attributes were tackled to achieve their desired objective (i.e., thorough explanations for each section was provided, with clear purposes and actions to implement the relevant initiative). The 2040 Kuala Lumpur Structure Plan Draft places a strong emphasis on the ecological function of urban ecosystems. Initiatives in this document address the integration of nature in urban development, encourage effective green governance and promote enhanced resilience against natural disasters and climate change. Examples of ecological initiatives under these themes are 'connecting the green area and blue corridor as urban ecological nodes', 'enhancing efficiency of sustainable water management and supply' and 'establishing a public trust fund for parks and green areas'. The 2040 Kuala Lumpur Structure Plan Draft is also the only document to receive a maximum score of '3' for the 'corridors' ecological attribute. Most policy documents received a score of '1' or '0' for this attribute because the relevant initiatives either provided limited coverage or did not address it at all. For example, the 2020 Kuala Lumpur City Plan received maximum scores for all ecological attributes except 'corridors' because the relevant initiatives place emphasis the amenity and design value of the river corridors, with little focus on its ecological function.

Table 5.5 The comprehensiveness of policy documents in dealing with the ecological attributes. The documents were scored based on how well the section(s) on the ecological attributes in the document tackle the desired objective (3 = 'good'; 2 = 'average'; 1 = 'limited'; 0 = 'not mentioned').

Ecological attributes	**KL Structure Plan 2020**	**KL Structure Plan 2040**	**KL City Plan 2020**	**Putrajaya Structure Plan 2025**	**Putrajaya Strategic Plan 2021-2025**	**MURNI-Nets 2.0**	**Low Carbon Cities Framework**
open space, urban parks, residential green spaces, gardens	3	3	3	2	2	2	3
natural areas, protected areas, natural forests and wetlands	3	3	3	3	3	1	2
corridors, streams, ridges, valleys, upland forests, water trails, green belts, rooftop gardens	1	3	2	2	1	0	1
conservation of biodiversity/ flora and fauna	2	3	3	3	3	1	1
Average score	**2.25**	**3**	**2.75**	**2.5**	**2.25**	**1**	**1.75**

All other city-level policies received relatively high to moderate scores averaging between 2.25 and 2.75 points (Table 5.5). The 2020 Kuala Lumpur Structure Plan, in comparison to the 2040 Kuala Lumpur Structure Plan Draft, did not place sufficient emphasis on the ecological function of urban ecosystems. Hence, a score of '2' was assigned to the 'corridors' and 'conservation' ecological attributes respectively. All five city-level policies received maximum scores for the 'natural areas' ecological attribute and most received maximum scores for the 'open space' and 'conservation' attributes. These scores suggest that more emphasis/attention is placed on some ecological attributes than others in city-level sustainable development initiatives. The low scores received by the 'corridors' attribute in contrast to the other three ecological attributes suggests that more attention needs to be paid to ecological features linked to connectivity (e.g., corridors, streams, upland forests, water trails, green belts) at a city-level. We note here of other more recently published city-level frameworks such as the

Kuala Lumpur Low Carbon Society Blueprint 2030, that have a dedicated section on improving ecological connectivity in Kuala Lumpur through green and blue networks. This document was not included in the content analysis as it was not one of the most used city-level indicators and focuses largely on strategies to reduce Kuala Lumpur's greenhouse gas emissions by 70% by 2030. Nonetheless, the aforementioned section in this document provides examples of ecology-centred indicators that can be applied to management of blue-green spaces in cities.

National-level policies received lower average scores compared to city-level ones. MURNINets 2.0 received the lowest average score across all policy documents with an average score of 1. As the national guide for sustainable development indicators, MURNINets 2.0 covers a broad range of sustainable development initiatives. However, only three initiatives have ecological links (Table 5.3), so most of the ecological attributes assessed were either not tackled in great detail or not addressed at all (e.g., 'corridor' ecological attribute). Some initiatives were also somewhat abstract or incongruous such as 'percentage of applications for the gazettement of open spaces' as an indicator for 'urban development', as the indicator is not an accurate or relevant measure for the monitoring urban development. 'Percentage of gazetted open spaces (to total land use)' or 'population density' would be more useful as indicators of 'urban development'. The lack of clarity in tackling the initiatives contributed to the low scores. It is likely that the indicators were developed for a high-level coarse overview and were limited to data available, given the scale at which they are implemented (i.e., national-level); hence, indicators at a city level are more specific (i.e., higher scores in tackling ecological attributes).

The outcomes of the content analysis provide insights into how the different policy initiatives address the ecological aspect of sustainable development. Yet, this content analysis is limited in its scope of exploring the extent and nature of ecological considerations in policy documents. Though sustainable development initiatives in Putrajaya are better known for integrating strong nature-based approaches in urban planning, especially in the management of the Putrajaya wetlands, the 2025 Putrajaya Structure Plan had the lowest percentage of initiatives linked to ecological considerations (6%) (Table 5.3). The lack of focus on the ecological initiatives in the document could be attributed to the wide range of existing ecology-based practices in Putrajaya that extend from the reuse of lake water and grey water from sewerage plants for irrigation, to the conservation of over 900 species of fauna and the allocation of nearly 40% of land cover as green spaces. Initiatives outlined in the Putrajaya Structure Plan 2025, go beyond ecological considerations, which are reported in the document to be integrated in current practice. The plan instead focuses on initiatives that promote green technology, communities, infrastructure and economies. We discuss the need for assessments of the success rates of such sustainable development initiatives in Section 5.5.

It is important to note that the outcomes of the analyses presented in above are to some extent subjective and should be interpreted cautiously. For instance, a simple count of the number of times terms linked to ecological considerations are used in a document is not itself indicative of weaker/stronger ecological consideration. Nevertheless, the ecological terminologies recorded in this exercise are widely used in international sustainable development frameworks and the absence or scarcity of key terminologies such as 'ecology', 'ecosystem', 'ecosystem services' and 'nature-based solution' suggest that there are gaps in ecological considerations in local policy documents. Therefore, while the results of this content analysis have its limitations, the knowledge gaps identified can be used to expand the scope of ecological consideration in sustainable development policy initiatives; this is the focus of the following section.

5.5 Shifting The Focus To Ecosystem Services

While the policy initiatives, especially those at a city-level, emphasised the ecological benefits of green infrastructure, a broader perspective towards building ecologically resilient and sustainable urban systems could be adopted. The current initiatives implicitly adopt a 'biophilic cities' perspective, a concept that stems from the field of urban design and architecture that places nature at the centre of city planning and design (McDonald & Beatley, 2021; Russo & Cirella, 2017). The biophilic cities perspective focuses on the amenity and cultural ecosystem services provided by urban nature (i.e., aesthetic value, human-nature connection, recreational, physical and mental wellbeing), but does not capture the full-suite of ecosystem services that could be derived in cities. For example, the 2020 Kuala Lumpur Structure Plan, 2020 Kuala Lumpur City Plan and MURNINets 2.0 tend to address the same few ecosystem services, which are microclimate and air regulation, stormwater retention and recreation. A host of other ecological, social and economic benefits provided by nature should be included in these policies; for example, inclusion of wastewater management, soil retention, food production through urban farms, freshwater provision for domestic use and ecotourism all warrant consideration.

5.5.1 Case Studies from Abroad

5.5.1.1 Belgium: Nature Value Explorer

Land conversion, for urban, agricultural, industrial and infrastructure expansion, was the main cause for biodiversity loss in Belgium, much like in Kuala Lumpur (UNEP, 2022). The urban nature of the Brussels-Capital region further placed high recreation pressure on green spaces. Coupled with concerns on the impacts of climate change and fuelled by the 2020 Aichi Targets, the Belgium Ecosystem Services (BEES) Community was launched in 2012 to develop the ecosystem services concept, tools and practices within policy and management, business and society as a whole (UNEP, 2022). Among the outcomes of BEES, which aims to connect research, policy and practice on ecosystem services, is the 'Nature Value Explorer' web tool (Nature Value Explorer, 2022). The open-access tool serves as a method for valuing ecosystem services and mapping its socioeconomic importance to support planners, land managers and policy makers in taking more balanced policy and investment decisions (IPBES, 2022; Liekens et al., 2013). The Nature Value Explorer combines spatially sensitive and site-specific information to identify the value of ecosystem services in day-to-day decision making through a cost-benefit analysis. The tool was developed to estimate the impact of land use and cover change on ecosystem services, though it does not provide detailed spatially explicit ecosystem service quantifications or mapping. Instead, the tool identifies service providing units (SPU) for various ecosystem services within the Classification of Ecosystem Services (CICES) framework (Liekens et al., 2013). With the aim to support both specialist and non-specialist users, the tool also allows an option for the monetary valuation of regulating ecosystem services based on avoided abatement cost, damage costs and hedonic pricing and allows choice experiments to estimate the user's willingness to pay for cultural ecosystem services (IPBES, 2022).

The Nature Value Explorer started as a valuation tool for the cost-benefit analysis of large infrastructure projects in the Flanders region of Belgium (Liekens et al., 2013). Since then, the tool has been applied for policy appraisals on transportation infrastructure decisions linked to effective flood management plans and to support the development of green built areas. The tool has also been used to demonstrate the value of nature, motivate investments in ecosystem restoration and support payments for ecosystem services. Note that while the tool was developed as one of the first steps in addressing Belgium's biodiversity loss, the overarching biodiversity recovery plan involved numerous policy strategies and government authorities at the local, regional and national levels (Bauler & Pipart, 2013). The status of biodiversity and environment indicators in Belgium are published annually as part of this ongoing journey to restore national biodiversity and ecosystem services provision. New policies, such as the 2020 National Biodiversity Strategy, continue to further develop and evaluate the effectiveness of current measures towards achieving this goal (UNEP, 2022).

5.5.1.2 United Kingdom: National Ecosystem Approach Toolkit

Ecosystem services in the UK are managed nationally to provide a desired level of benefits and a key part of this is the UK National Ecosystem Assessment (UKNEA) (POST Report 378, 2011). In 2011, the first UKNEA was conducted, involving various government, academic, non-governmental organisations, and private institutes, to develop an evidence base for ecosystem services provision at the national level (UNEP-WCMC, 2011; POST Report 377, 2011). Subsequently, the UKNEA Follow-On was published in 2014, with the National Ecosystem Approach Toolkit (NEAT) as an output of the research (Scott et al., 2014). The NEAT framework, which is illustrated as a tree, outlines guidance for selecting and using tools within the toolkit that have been adapted to incorporate the ecosystem approach (NEAT, 2022). These tools often follow the decision-making/policy cycle of identify, survey, assess, plan, deliver and evaluate (Scott et al., 2014). Examples of tools within NEAT include cost-benefit analysis tools, ecosystem mapping and valuation tools such as InVEST, ARIES and LUCI as well as futures tools that allow scenario modelling (Bateman et al., 2014). NEAT provides diverse recommendations for ecosystem service valuations, not all of which involve a specific ecosystem service valuation application (e.g., web-based tool), as non-monetary valuations such as public engagement and participatory mapping are also encouraged (NEAT, 2013). Though there have been no further UKNEA Follow-Ons since, the provision of ecosystem services continues to be monitored and valued at a national level and more specifically in urban ecosystems (Office for National Statistics, 2019).

5.5.1.3 Singapore: City Biodiversity Index

Singapore's status as a global lead in ecosystem and biodiversity management is often compared to Kuala Lumpur's efforts to achieve the same. The River of Life project, which entails the cleaning and beautification of the Klang river segment in Kuala Lumpur, is reminiscent of the cleaning of the Singapore river in 1960s. The difference being that the leaders of Singapore envisioned a sustainable city with long-term planning and effective implementation (Tan et al., 2021). While the River of Life project focuses on a deep cleansing of the river largely to attract tourists, the clean-up of the Singapore river involved the relocation of farms, factories and street-food stalls that were polluting the river (UNEP, 2018). Over a 10-year period, the Singaporean authorities addressed the socio-environmental issues linked to the river at the root cause, taking a systems-thinking approach, planning long-term and ensuring effective implementation. The shift in mindset from prioritizing 'economic benefit over the environment' to making 'pragmatic policy decisions based on scientific evidence and economic principles' is believed to be the key to Singapore's success (UNEP, 2018). Over three decades, Singapore has established agencies such as the National Parks Board and incorporated nature in their planning and policy decisions (Friess, 2017).

Ecosystem services research in Singapore is well-established and has further supported efforts to safeguard the city-state's biodiversity (see Chapter 2; Tan et al., 2020), through comprehensive tools such as the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index) (Chan et al., 2021). The City Biodiversity Index is a self-assessment tool for cities to benchmark and monitor their progress on biodiversity conservation. Developed through global research but aimed at local action, the tool embodies the ecosystem approach in addressing the system as whole with ecosystem service valuations being a component. The self-assessment comprises two parts: 1) the profile of the city which provides background information and 2) 28 indicators which measure the city's native biodiversity, ecosystem services provision and governance and management of biodiversity (Chan et al., 2021). Applications of the City Biodiversity Index find that the assessment promotes capacity building and acts as a guidance for conservation with the quantitative scoring setting clear conservation priorities (CBD, 2022). Another key aspect to Singapore's success in biodiversity and ecosystem services management, that can be applied in Kuala Lumpur, is the gradual shift in public mindset through public engagement. Youth engagement is a key components of Singapore's agenda such that values linked to appreciation for nature and environmental conservation are prioritised for generations to come (UNEP, 2018).

5.5.2 Recommendations for Kuala Lumpur

We propose that sustainable development policy initiatives in Kuala Lumpur adopt a stronger nature-based solution perspective, in addition to the existing biophilic cities approach. To support this shift in perspective, we include a list of recommended indicators to support ecological consideration in sustainable development initiatives (Table 5.6). These ecological indicators stem from international academic literature and sustainable development frameworks which can be considered as best practice guides. The recommended indicators address detailed ecological initiatives that have been divided into six categories of ecological considerations and are intended to be used alongside existing ecological initiatives covered in the policies. Note that many of the recommended indicators link to and overlap with ecosystem services. For example, the indicators in the 'urban climate' and 'hydrological conservation' categories measure regulating urban ecosystem services such as heat mitigation, microclimate regulation and stormwater retention. The indicators in 'biodiversity' and 'water quality' categories are linked to supporting ecosystem services such as habitats for biodiversity and aquatic habitat quality and also pollination services. The inclusion of ecological indicators can act as a benchmark for assessing the effectiveness of environmental projects that are intended to have positive ecological benefits. Examples include River of Life project and the integrated management of Putrajaya wetlands, where explicit tracking measures and further research is needed to evaluate the impacts of such projects on the local ecosystem.

Table 5.6 Ecological indicators recommended for tracking the progress of sustainable urban development in Kuala Lumpur.

Category	Indicator	Indicator measurement	Reference
Air quality	Pollution concentration	Concentration of sulphur dioxide (SO2), nitrogen dioxide (NO2), particulate matter (PM10) and ozone (O3)	Urban China Initiative (2010)
	Pollution levels	Number of times that the limit of pollutants the SO2, NO2, PM2.5, PM10 and O3 is exceeded	Michalina *et al.* (2021)
Water quality	Stormwater pollution	Concentration of pollutants in stormwater runoff, including chemical composition and pH	Didzaroglu (2015)
	River and wetland water quality index	Biological oxygen demand, chemical oxygen demand, dissolved oxygen concentrations and pH levels	Shathy and Reza (2016)
Urban climate	Urban heat island	Urban heat island (difference in urban and rural air temperatures)	Shathy and Reza (2016)
	Surface temperature	Surface temperature map	Shathy and Reza (2016)
	Climate regulation by trees	Percentage of tree canopy cover over total land area	Cities Biodiversity Index (2021)
Hydrological conservation	Regulation of water quantity	Percentage of permeable surface areas (includes parks, vegetated areas, and pervious roadsides but excludes water bodies) over total land area	Cities Biodiversity Index (2021)
	Surface runoff	Susceptibility maps for surface runoff generation, transfer and accumulation (to identify flood prone areas and areas needing more green cover)	Lagadec *et al.* (2016)
Land use	Urban density	Number of people per square kilometer of urban area	Urban China Initiative (2010)
	Built area	Percentage of built area (including impervious surface) in relation to total land area	Michalina *et al.* (2021)
	Green space	Percentage of vegetated land, forests and parks in relation to total land area	Michalina *et al.* (2021)
	Waterways	Percentage of wetlands, rivers, streams and lakes in relation to total land area	Michalina *et al.* (2021)
Biodiversity	Ecological connectivity	Effective mesh size for the city area	Cities Biodiversity Index (2021)
	Habitat restoration	Proportion of habitat restored (to good ecological function) compared to baseline area of original habitat degraded	Cities Biodiversity Index (2021)
	Native biodiversity	Percentage of the number of native bird species in built up areas relative to the total number of native bird species	Cities Biodiversity Index (2021)
	Protected natural areas	Percentage of protected natural areas over total land area	Cities Biodiversity Index (2021)
	Invasive Species	Percentage of invasive species over total species present in the area	Cities Biodiversity Index (2021)

Adopting an ecosystem services approach in planning would better reflect the wider benefits of nature in cities, going beyond 'environmental benefits' to capture ecological, social and economic benefits (Figure 5.6). International policies on sustainable development reforms, such as those by the United Nations Environment Programme (UNEP) and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), have emphasised the importance of understanding the provision of biodiversity in cities through ecosystem services (Pascual *et al*., 2017). As such, we recommend that policy initiatives at regional and national levels conduct ecosystem services valuations to support the tracking of sustainability initiatives. Ecosystem service valuations can evaluate the diverse benefits of nature by considering economic (i.e., monetary), biophysical (i.e., volume of stormwater retained) and/or social (i.e., importance to people) values (Conte, 2013; Kenter *et al*., 2011). These valuations are often spatially explicit and so can be used to model changes in current versus future ecosystem service supply/demand across various scenarios, such as climate change impacts and land use changes as Greater Kuala Lumpur undergoes urban expansion (Kontgis *et al.*, 2019; Kremer *et al*., 2016; Wells *et al.*, 2016). Such work would be of great significance, given recent extreme flooding, with loss of life and property (BBC News, 2021; Reuters, 2022). Moreover, ecosystem services and its valuation have been included as a core component of the City Biodiversity Index, an internationally applied self-assessment tool for cities (Chan *et al.*, 2021). Incorporating ecosystem services valuations in urban planning would support the strategic management of natural and ecological resources and better align sustainable development initiatives in Kuala Lumpur and Malaysia with international standards. Organizations currently advocating for more streamlined sustainability agendas in Kuala Lumpur, and generally Malaysia, include the United Nations Habitat and Urbanice Malaysia.

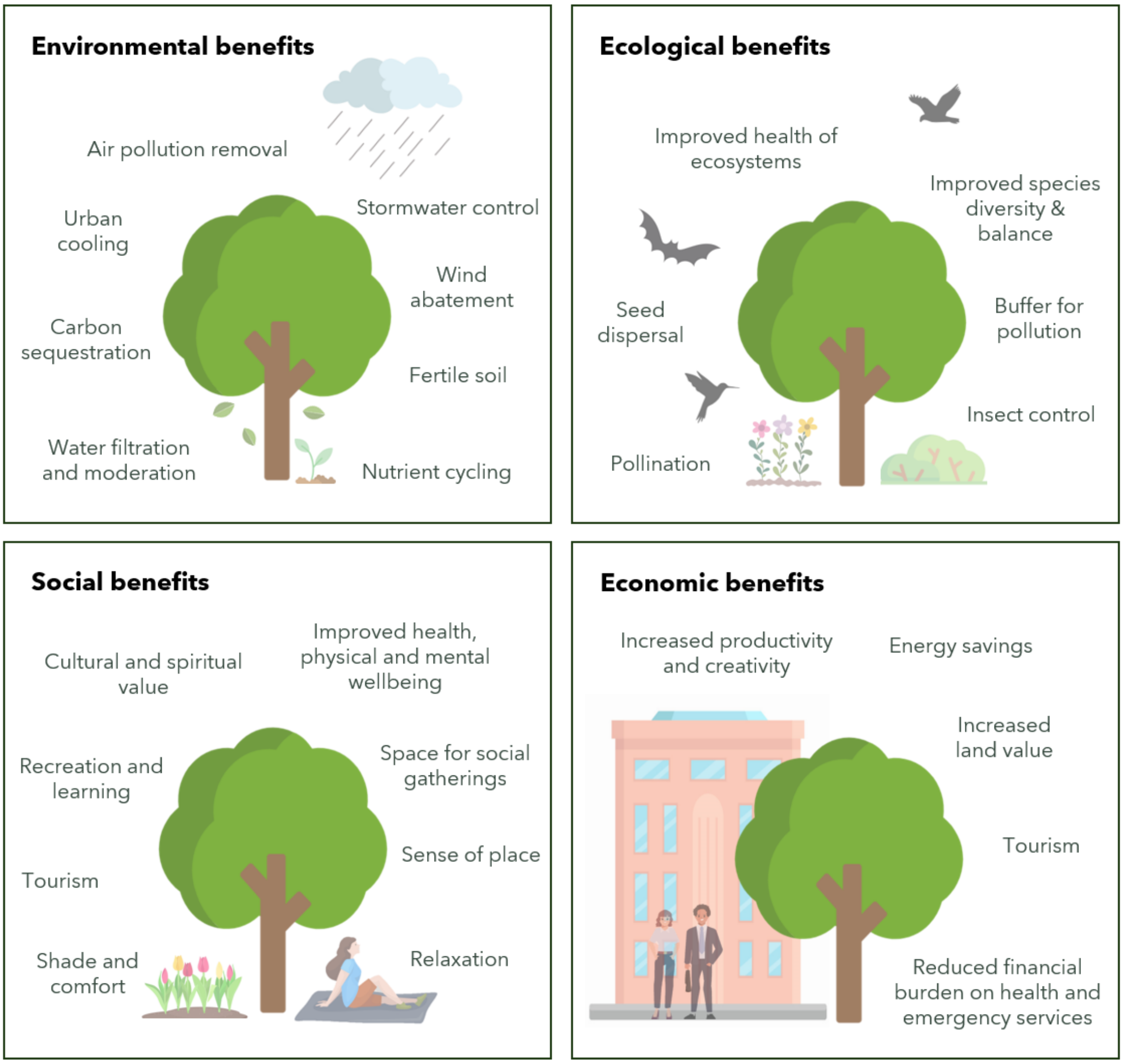


Figure 5.6 The diverse ecosystem services provided by urban biodiversity in cities. Adapted from the Nature in the City Strategy (City of Melbourne, 2017).

Despite the clear benefits, the shift to more ecology-centred land management practices is likely to be challenging given the complex historic, social and political context of Malaysia. Though green spaces were generally positively perceived by the residents of Kuala Lumpur, who possess a strong sense of appreciation for nature (Nath & Magendran, 2021; Malek and Nashar, 2018a), the management of green spaces (especially urban parks) in Malaysia according to the "beautiful garden nation" agenda, is at variance with less intensively managed and ecologically functional landscapes (Ibrahim *et al.*, 2020). A study revealed that while urban park managers appreciated having wilder and denser vegetation (as opposed to a more manicured park landscape), this would likely result in complaints from residents as it conflicts with residents' expectations for a clean and tidy park (Ibrahim *et al.*, 2020). Similar divergences on preferences for cultural ecosystem services in Greater Kuala Lumpur have been revealed in Lourdes et al. (in preparation) (see Chapter 3). Such challenges are to be expected due to differences in social perceptions and preferences within the community, though this transition can be supported through education and awareness on human-nature relationships (Vining *et al.*, 2008; Yen *et al.*, 2016).

As next steps, we recommend that the ecological knowledge gaps identified in this study are addressed through research to support the adoption of stronger nature-based perspectives in sustainable urban development policy initiatives. This includes research on the role of blue spaces, ecological corridors and small-scale ecological features such as bioswales, on which there is currently limited research. We call for more research on urban ecosystem services and valuations to guide sustainable land use planning in Kuala Lumpur. We posit that the research conducted in the previous chapters of this thesis provides context and support for the integration of ecosystem services valuation in urban planning. The research and ecosystem service valuation tools applied in chapters 3 and 4 can be utilised to support planning within the Greater Kuala Lumpur region and can act as a guide for the application of ecosystem service valuation tools in other urban areas in Malaysia. While part of the methods applied in this chapter link to the systematic literature review conducted in Chapter 2, this chapter narrows down from a regional scale (Southeast Asia) to a city scale (Kuala Lumpur) and goes beyond a literature review to identify specific gaps and provide recommendations for integrating ecosystem services in Kuala Lumpur's design and planning. For example, we highlight the need for studies assessing the effectiveness of sustainable urban development initiatives in Kuala Lumpur. These assessments are key to ensuring that implemented sustainability initiatives are on track to meet their objectives, identifying areas for adaptive management where initiatives are not achieving the desired goal and promote the scaling up of successful initiatives (Dizdaroglu, 2017). These recommendations are in line with advancing sustainable urban development initiatives in Kuala Lumpur, and building liveable, resilient and sustainable cities.

Chapter 6 Synthesis

6.1 Summary

This thesis investigated various aspects of urban ecosystem services provision in the Greater Kuala Lumpur region. The concept of urban ecosystem services has been recognised for supporting sustainable urban planning. However, research on urban ecosystem services is underrepresented in Global South regions such as Southeast Asia, though it is well-studied in the Global North (Chapter 2). To address the research gap on urban ecosystem services, this thesis characterised the diverse values of urban ecosystem services in Greater Kuala Lumpur (Chapters 3 and 4) and demonstrated the potential for ecosystem service valuations to support planning in rapidly developing Global South regions (Chapter 3, 4 and 5). It is argued in Chapter 5 that greater ecological consideration is needed in sustainable urban development policies in Kuala Lumpur, and that this can be addressed by adopting stronger nature-based perspectives.

This concluding chapter discusses the contributions of this thesis and potential challenges in integrating urban ecosystem services and off-the-shelf valuation tools to support the development of sustainable and resilient cities. Section 6.2 provides answers to the research questions that were set out in Chapter 1. Section 6.3 links the research conducted in this thesis to components of the cascade model and discusses the wider implications for the management of urban ecosystem services. Section 6.4 outlines the challenges to designing sustainable and liveable cities that have become evident as a result of the research conducted for this thesis and sets out some next steps that will move the field forward. Section 6.5 concludes this chapter with some final remarks on this thesis and hope for the urban ecosystem services field with respect to building more sustainable and resilient cities in the Global South.

6.2 Research Questions

6.2.1 What is the nature and extent of urban ecosystem services research in Southeast Asia?

Chapter 2 presented a systematic review and analysis of the scope of urban ecosystem services (UES) research in Southeast Asia. The review showed a growing body of research on urban ecosystem services in the region over the last five years, though highlighted the geographic distribution of research remains unequal. Research was biased towards more developed countries, particularly Singapore where one-third of all UES research in the region had been conducted; less-developed countries within Southeast Asia were least studied. Such a bias towards developed regions had also been found in previous global literature reviews (see Haase *et al.*, 2014; Luederitz *et al.*, 2015).

The review found that most studies assessed multiple ecosystem services, largely at the landscape-scale (city scale or larger). While studies assessed multiple components of the ecosystem service cascade, interactions between services such as synergies and tradeoffs, were rarely examined. There were also a limited number of studies that assessed how urban ecosystem services provision have changed over time (i.e., multitemporal studies) Much remains to be learnt about urban ecosystem services in Southeast Asia, and like most other Global South regions, this stems from the lack of data in the region. Moreover, Chapter 2 argued that the diverse socioeconomic characteristics of Southeast Asian countries are likely to limit the transferability of research within the region due to the context-specific nature of ecosystem services valuation. As such, more geographically representative and context-specific urban ecosystem services research is needed within Southeast Asia to purposefully address local needs.

6.2.2 What are the development preferences and perceptions of residents in Greater Kuala Lumpur towards social values for urban ecosystem services?

Chapter 3 demonstrated that the social values assigned to ecosystem services by the residents of Greater Kuala Lumpur are not homogenous. This chapter revealed two groups of respondents with different development preferences: a favour-balanced-development group (favour both green and grey developments) and an oppose-grey-development group (favour green developments but strongly oppose grey developments). There were similarities in the social values that were most important to the two groups, yet the degree of importance and the locations associated with these social values varied between the groups. These differences were likely shaped by the residents' development preferences and their sociodemographic characteristics, demonstrating the diversity and complexity in social preferences and perceptions towards the values assigned to ecosystem services. Hence, recommendations were made to prioritise more green developments in urban centres given that residents in these areas place greater importance on recreation and cultural values in green spaces and strongly oppose further grey developments. For peri-urban areas, both green and grey developments were recommended as priority, noting that cultural and recreation values in these areas were associated with both blue-green spaces and built areas.

6.2.3 What is the spatial distribution of urban ecosystem services across an urban-peri-urban gradient in Greater Kuala Lumpur?

Chapter 4 demonstrated that urban ecosystem services are spatially heterogenous in their distribution across the rapidly urbanising Upper Langat catchment. In comparing the urban, agricultural (peri-urban) and semi-natural areas within the catchment, realised service provision was generally lower in urban areas but higher in semi-natural areas. The high provision and intensity of multiple services in semi-natural areas was an expected result of the dense vegetation of the forest reserve. In contrast, urban areas had lower service provision because the supply of urban ecosystem services was insufficient to meet the needs of the urban population. In agricultural areas, there were low provisions of some services (i.e., runoff retention) but high provision of others (i.e., agricultural production).

The work conducted in chapter 3 also showed similar heterogeneous patterns, except in the distribution of social values for ecosystem services and development preferences across urban-peri-urban gradients in Greater Kuala Lumpur. The favour-balanced-development group associated a larger number of social values with peri-urban areas while the oppose-grey-development group associated fewer number of social values with built areas, but these social values were largely concentrated in dense urban centres.

6.2.4. How can urban ecosystem service valuations be utilised to support urban planning?

From a social perspective, chapter 3 demonstrated that residents' perceived distribution of social values for ecosystem services were not homogenous across Greater Kuala Lumpur and were influenced by a number of sociodemographic characteristics. The chapter showed that the non-spatial differences in development preferences of residents manifests as larger differences in the spatial distribution of social values, leading to conflicts between groups of different development preferences. By recognising that the population of Greater Kuala Lumpur is not homogenous in its development preferences and its valuation of ecosystem services, the chapter highlighted that there is room for negotiating and optimising land use planning strategies through public engagement. Moreover, the chapter suggested that the spatial conflicts identified can be mitigated by applying different planning objectives in different parts of the metropolitan area. As such, land use planning in Greater Kuala Lumpur cannot take a one-size-fits-all approach but instead must consider the spatially complex nature of ecosystem services provision and how it is valued by residents.

Work detailed in Chapter 4 also helped address this question. Chapter 4 quantified the provision of multiple ecosystem services in biophysical terms, providing tangible, quantitative figures that represent the benefits provided by nature in Greater Kuala Lumpur. In addition, this chapter provides spatially explicit recommendations on targeted areas for future green infrastructure development, bridging the gap between ecosystem services assessments and its application in land use planning. The methods applied in this study are especially useful for characterising UES in rapidly urbanising landscapes and can be operationalised to support sustainable land use management.

6.2.5 To what extent have local academic and policy literatures considered urban biodiversity and ecosystem services in the context of sustainable urban development in Kuala Lumpur?

Chapter 5 provided a review of the academic literature and policies initiatives that, to varying degrees, concern urban biodiversity and ecosystem services related to sustainable urban development specifically in Malaysia. It found that urban ecosystem services are rarely considered in an explicit manner in academic literature and sustainable urban development policies in Kuala Lumpur. Local academic literature addressed a range of topics and ecological features with respect to sustainable urban development, yet few studies assessed blue spaces or the small-scale ecological features which are important for the provision of urban ecosystem services. Similarly, sustainable urban development policies place more emphasis on including nature as part of the urban design for aesthetic and cultural reasons but do not capture the full-suite of ecosystem services that could be derived in cities. The chapter calls for greater research on urban ecosystem services and the incorporation of ecosystem services valuation in planning to better reflect the wider benefits of nature in cities and to align sustainable development initiatives in Kuala Lumpur with international standards.

6.2.6 What are the next steps for urban ecosystem service valuations tools to support decision-making and sustainable urban development?

Chapters 3 and 4 respectively used off-the-shelf ecosystem service valuation tools to value biophysical and social urban ecosystem services in parts of Greater Kuala Lumpur. These tools, due to their ready-to-use and transferrable nature, can act as a stepping-stone, particularly in data poor regions, for characterising and valuing ecosystem services. Chapter 5 proposes that the valuation of urban ecosystem services should be incorporated into sustainable development policies in Kuala Lumpur and, by extension, Greater Kuala Lumpur. There are various ways of conducting valuations of urban ecosystem services and the off-the-shelf valuation tools used in the thesis can be a direct and accessible option for conducting such assessments. While this thesis applied SolVES and InVEST to support urban planning in Greater Kuala Lumpur, the methods applied in this thesis could be conducted with other ecosystem service valuation tools such as ARIES (Artificial Intelligence for Environment and Sustainability), ESTIMAP (Ecosystem Services Mapping Tool), Co$ting Nature, i-Tree and Tessa, among many others. Off-the-shelf valuation tools have been widely used globally to support ecosystem service assessments at various scales. A key next step for mainstreaming the application of ecosystem service valuation tools in Greater Kuala Lumpur and Malaysia, requires a wider adoption of such tools in local research and urban planning.

6.3 Integration and Wider Implications

The research conducted in this thesis has examined various components in the pathway of urban ecosystem services delivery. These components and interactions between components can be illustrated through the ecosystem service cascade model reviewed in Chapter 2 (Figure 6.1) (Braat & de Groot, 2012). Chapter 3 examines the socio-cultural components of 'service', 'benefits' and 'value' by assessing residents' willingness to conserve and prioritisation of social values of ecosystem services. The chapter elucidated that there are similarities and differences in the value residents of urban and peri-urban areas place on ecosystem services, which were found to be shaped by their development preferences and sociodemographic characteristics. These complex interactions between residents' perception and attached social value are represented by the 'feedback between value perception and use of ecosystem services' component. The recommendations made in this chapter to retrofit and conserve blue-green spaces in Greater Kuala Lumpur also extend to the 'management/restoration' component.

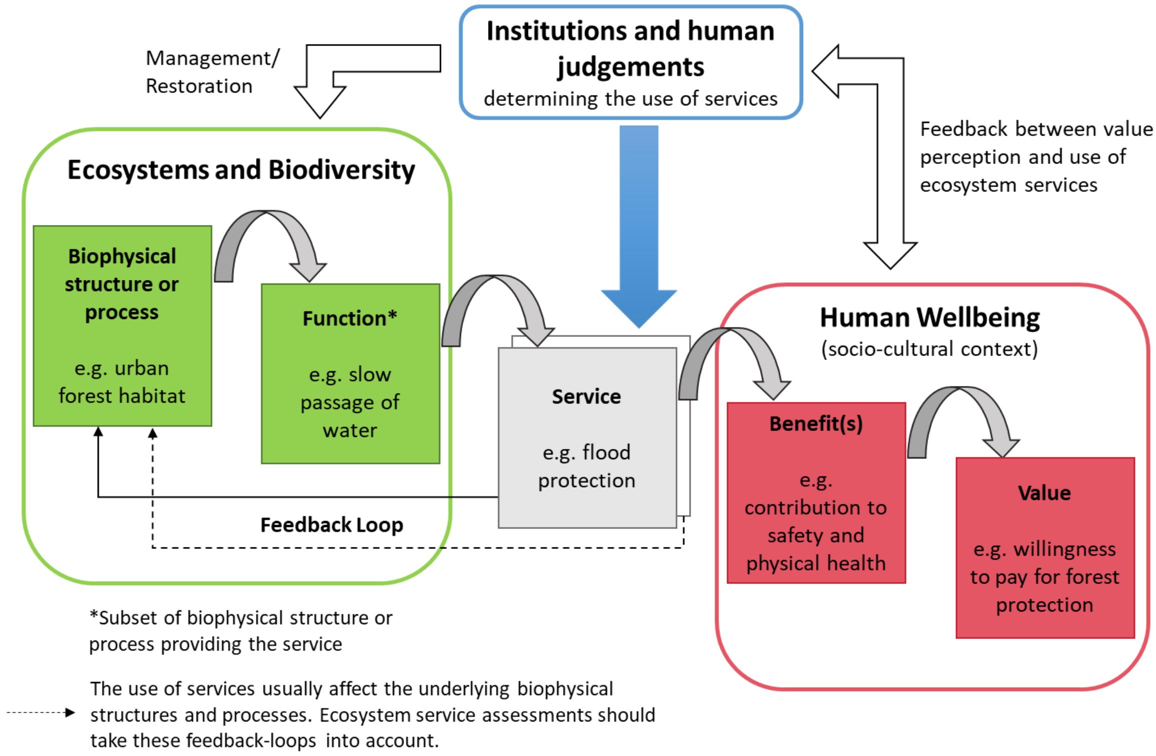


Figure 6.1 The ecosystem service cascade model illustrates the complex interactions between components through which urban ecosystem services are delivered. Adapted from Braat & de Groot (2012).

Chapter 4 examines the 'biophysical structure/process', 'function' and 'service' components through the biophysical valuation of six urban ecosystem services. The 'feedback loop' and 'management/restoration' components are represented by the outcomes of the multicriteria suitability analysis, which provides ecosystem services-based recommendations for what type of green infrastructure and where they should be implemented within the study area. As the research conducted in this chapter is a first-step in supporting ecosystem services-based planning, the recommendations to conduct community engagement and fieldwork in selecting appropriate local measures additionally engages the 'institutions and human judgement determining use of services' component.

Chapter 5 investigates the 'institutions and human judgement determining the use of services' component and its impact on all other components in the cascade by examining how urban biodiversity and ecosystem services have been considered in sustainable urban development policies. Additional emphasis was given to the 'biophysical structure/process', 'service' and 'benefits' components in this chapter through the recommendation for broader ecological perspectives in sustainable urban development research and policy initiatives. By examining the various components of the ecosystem service cascade model, the research conducted in this thesis has endeavoured to holistically assess the ecological properties, functions and elements of human-wellbeing involved in the pathway of urban ecosystem services provision (La Notte et al., 2017; Potschin & Haines-Young, 2016). Moreover, the cascade model is universally accepted as a theoretical framework for assessing ecosystem services and promotes the practical application of the assessment results (Vasenev et al., 2018). In aligning with the cascade model, the findings of this thesis are supported by a strong theoretical foundation and has the potential for broad practical applications in the field.

The wider implications of the research conducted in this thesis is demonstrated by several key outcomes. The application of SolVES and InVEST in chapters 3 and 4 which are novel to the region, provide insights on the use of valuation tools with respect to land use planning, encouraging wider adoption of the tools. Moreover, the spatial agreement and conflict and multicriteria suitability analysis applied in tandem with the valuation tools, in Chapters 3 and 4 respectively, act as a blue-print for the systematic application of ecosystem services valuations tools to support nature-based urban planning in urbanising areas globally. The work done in Chapter 5 highlights the need for further research that critically examines the effectiveness of implemented sustainable urban development initiatives, which is currently lacking, especially in developing regions (Dizdaroglu, 2017). The ecological knowledge gaps identified in existing sustainable development policy initiatives as well as the recommendations provided in this research, may also be relevant to other cities in Malaysia and Southeast Asia. As such, the work implicitly encourages similar critical evaluations of policy initiatives to be conducted in the region in an effort to forward sustainability agendas.

6.4 Challenges and next steps towards ecosystem services-based planning

The research conducted in this thesis revealed several challenges in characterising urban ecosystem services that should be addressed by future research.

i. Primary data for urban ecosystem services model calibration, validation and sensitivity testing

The InVEST ecosystem service models utilised secondary data from academic literature due to data limitations in the study area. Though data that most closely reflects the biophysical characteristics of the study area were used as inputs in the models, the use of global datasets with low spatial resolutions and potential inaccuracies in the representation of the study area may result in uncertainties in the model estimates (Bagstad et al., 2016; Redhead et al., 2018). The lack of primary data also limits the scope for empirical model validation and sensitivity analyses, which is key to determining the degree of uncertainty in the model estimations (Hamel & Bryant, 2017). Scarcity in the measurements of uncertainty has been reported to be a key obstacle for the successful implementation of ecosystem services assessments in decision-making (Maes et al., 2012; Seppelt et al., 2011). While the need for ecosystem service models is driven by the lack of relevant empirical data in many parts of the world (Crossman et al., 2013), utilising field-based data in ecosystem service models would allow: 1) the models to be parameterised to the conditions specific to the study area, 2) the empirical validation of potential modelling uncertainties, and 3) broader ecological knowledge gaps to be addressed given the general lack and inaccessibility to environmental data in Malaysia, as in other developing nations (Lourdes et al., 2021; Perez et al., 2017).

ii. Increased stakeholder involvement in urban ecosystem services assessments and beyond

Stakeholder perspectives on biodiversity conservation and management actions can be invaluable, both in research and in decision-making. The involvement of stakeholders can reveal context-specific demands and preferences in ecosystem services assessments (Pascual et al., 2017; TEEB, 2010b), and can improve the credibility of ecosystem services assessments to influence decision-making (Dang et al., 2021). Stakeholder feedback can also be used to verify ecosystem service assessments (Brown et al., 2016b; De Leon & Kim, 2017). Though stakeholders opinions should not be limited to inputs during ecosystem services valuations, as stakeholders should be involved throughout the decision-making process. The ecosystem service valuations conducted in this thesis can be seen as first step to supporting decision-making, where subsequent stakeholder engagement and fieldwork is needed to support the most appropriate local measures. Evidence suggests that stakeholder involvement can improve the quality of environmental decisions made (Reed, 2008). Moreover, aligning with stakeholder viewpoints and values can lead to long-term effectiveness in the implementation of sustainability initiatives due to increased willingness to comply with regulations, or willingness to monitor one another where enforcement is lacking (Velde et al., 2019).

iii. Opportunities to implement urban ecosystem service assessments in city planning and measure the effectiveness of sustainable development policy initiatives

Urban ecosystem services were formally incorporated into Singapore's national planning in the 1960s and now Singapore is leading case study for urban biodiversity, sustainability and resilience (Friess, 2017; UNEP, 2021a). Research on urban ecosystem services needs to be applied in city planning if the ecosystem services approach is to be a useful tool in advancing sustainability goals. Promoting scientific knowledge on urban ecosystem services especially through science-policy frameworks can help mainstream the concept, increasing the likelihood of its implementation in planning (Dang et al., 2021; FAO, 2016). While the implementation of urban ecosystem service assessments can be used to support sustainable urban development initiatives, it can also be used to measure the effectiveness of the ecological aspect of sustainability (Chan et al., 2021). Assessments of sustainable urban development initiatives are necessary to monitor the implementation of policies and the provide feedback needed to achieve the desired policy objectives (Dizdaroglu, 2017). Future research can employ various methods to measure the effectiveness of sustainable urban development policies, which are especially needed in Greater Kuala Lumpur), and once policies are found to be successful, they can be scaled up to meet more ambitious sustainability targets (Jacob et al., 2019).

6.5 Final remarks

The incorporation of ecosystem services in urban design and planning will become increasingly important as cities wrestle against the effects of urbanisation and climate change. While this is true for urban areas globally, tropical and urbanising Global South regions, such as Greater Kuala Lumpur, are disproportionately affected by urbanisation and climate change impacts and yet are understudied with respect to ecosystem services. This thesis has demonstrated opportunities and challenges in utilising ecosystem service valuation tools to support planning in a tropical Global South city. The first main contribution of this thesis is the novel spatial characterisation of urban ecosystem services for supporting sustainable land use planning in the Greater Kuala Lumpur metropolitan region. Additionally, the off-the-shelf ecosystem service valuation tools and methods applied in this thesis contributes to the limited but growing body of urban ecosystem services knowledge in the region, which can be adapted for urban areas in Southeast Asia and other Global South regions. Finally, the challenges faced in this thesis have been outlined for the benefit of future research. It is hoped that with increased understanding of urban ecosystem services in the region and the adoption of the concept in land use planning, Greater Kuala Lumpur and cities alike in the Global South become truly sustainable and resilient urban ecosystems.

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Zhang, W., Yu, Y., Wu, X., Pereira, P., & Lucas Borja, M. E. (2020). Integrating preferences and social values for ecosystem services in local ecological management: A framework applied in Xiaojiang Basin Yunnan province, China. *Land Use Policy*, *91*, 104339. https://doi.org/10.1016/J.LANDUSEPOL.2019.104339

Zoderer, B. M., Tasser, E., Carver, S., & Tappeiner, U. (2019). An integrated method for the mapping of landscape preferences at the regional scale. *Ecological Indicators*, *106*. https://doi.org/10.1016/j.ecolind.2019.05.061

Appendix A – Chapter 2 Search Strings

Search string for Scopus database = 200 hits

(TITLE-ABS-KEY (("Southeast Asia" OR "South East Asia" OR "Indonesia" OR "Vietnam" OR "Thailand" OR "Malaysia" OR "Singapore" OR "Philippines" OR "Cambodia" OR "Laos" OR "Myanmar" OR "Brunei" OR "Timor-Leste"))) AND (TITLE-ABS-KEY (("ecosystem service*" OR "natural capital" OR ("human" AND "environment" AND "benefit*")))) AND (TITLE-ABS-KEY ("urban" OR "city" OR "cities")) AND (EXCLUDE (PUBYEAR , 1994) OR EXCLUDE (PUBYEAR , 1991) OR EXCLUDE (PUBYEAR , 1990) OR EXCLUDE (PUBYEAR , 1983) OR EXCLUDE (PUBYEAR , 1975) OR EXCLUDE (PUBYEAR , 1971)) AND (EXCLUDE (DOCTYPE , "re") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "cr") OR EXCLUDE (DOCTYPE , "er")) AND (EXCLUDE (LANGUAGE , "Chinese") OR EXCLUDE (LANGUAGE , "French"))

Search string for Web of Science database = 143 hits

TS=(("Southeast Asia" OR "South East Asia" OR "Indonesia" OR "Vietnam" OR "Thailand" OR "Malaysia" OR "Singapore" OR "Philippines" OR "Cambodia" OR "Laos" OR "Myanmar" OR "Brunei" OR "Timor-Leste") AND ("ecosystem service*" OR "natural capital" OR ("human" AND "environment" AND "benefit*")) AND ("urban" OR "city" OR "cities"))

Refined by: [excluding] DOCUMENT TYPES: (REVIEW OR CORRECTION) AND LANGUAGES: (ENGLISH)

Search conducted on 2.8.2020 on both databases.

Appendix B – Chapter 2 Table S1

Table S1: Bibliography of the 149 studies analysed in this review.

Author(s)	Year	Title	Source
Abdullah, R., Kanniah, K. D., & Ho, C. S.	2018	Identification of suitable trees for urban parks and roadsides in Iskandar Malaysia.	Chemical Engineering Transactions, 63, 385–390. https://doi.org/10.3303/CET1863065
Abino, A. C., Castillo, J. A. A., & Lee, Y. J.	2014	Assessment of species diversity, biomass and carbon sequestration potential of a natural mangrove stand in Samar, the Philippines.	Forest Science and Technology, 10(1), 2–8. https://doi.org/10.1080/21580103.2013.814593
Achmad, A., Ramli, I., & Irwansyah, M.	2020	The impacts of land use and cover changes on ecosystem services value in urban highland areas.	IOP Conference Series: Earth and Environmental Science, 447(1). https://doi.org/10.1088/1755-1315/447/1/012047
Achmad, Ashfa, Irwansyah, M., Nizamuddin, N., & Ramli, I.	2019	Land Use and Cover Changes and Their Implications on Local Climate in Sabang City, Weh Island, Indonesia.	Journal of Urban Planning and Development, 145(4), 1–7. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000536
Adnan, N.	2018	Mapping recreation of FRIM via social media	ASM Science Journal, 11(Special Issue 3), 168–171.
Afriyanie, D., Julian, M. M., Riqqi, A., Akbar, R., Suroso, D. S. A., & Kustiwan, I.	2020	Re-framing urban green spaces planning for flood protection through socio-ecological resilience in Bandung City, Indonesia.	Cities, 101(10), 102710. https://doi.org/10.1016/j.cities.2020.102710
Ahmad, C. B., Abdullah, J., Jaafar, J., & Anuar, A. N. A.	2017	Spatial Adaptation of Protected Area Buffer Zones in Urban Setting: Impact on human and conservation agenda.	Environment-Behaviour Proceedings Journal, 2(5), 65. https://doi.org/10.21834/e-bpj.v2i5.683
Ajrina, H., & Kustiwan, I. (2019).	2019	From green open space to green infrastructure: The potential of green open space optimization towards sustainable cities in Bekasi City & Regency, Indonesia.	IOP Conference Series: Earth and Environmental Science, 399(1). https://doi.org/10.1088/1755-1315/399/1/012130

Alves, A., Gómez, J. P., Vojinovic, Z., Sánchez, A., & Weesakul, S.	2018	Combining co-benefits and stakeholders perceptions into green infrastructure selection for flood risk reduction.	Environments - MDPI, 5(2), 1–23. https://doi.org/10.3390/environments5020029
Ancog, R., & Ruzol, C.	2015	Urbanization adjacent to a wetland of international importance: The case of Olango Island Wildlife Sanctuary, Metro Cebu, Philippines.	Habitat International, 49, 325–332. https://doi.org/10.1016/j.habitatint.2015.06.007
Arifin, H. S., & Nakagoshi, N.	2011	Landscape ecology and urban biodiversity in tropical Indonesian cities	Landscape and Ecological Engineering, 7(1), 33–43. https://doi.org/10.1007/s11355-010-0145-9
Baharuddin, Z. M., Rusli, N., Ramli, L., Othman, R., & Yaman, M.	2017	The diversity of birds and frogs species at perdana botanical lake Garden, Kuala Lumpur, Malaysia.	Advanced Science Letters, 23(7), 6256–6260. https://doi.org/10.1166/asl.2017.9247
Balmford, A., Chen, H., Phalan, B., Wang, M., O'Connell, C., Tayleur, C., & Xu, J.	2016	Getting Road Expansion on the Right Track: A Framework for Smart Infrastructure Planning in the Mekong.	PLoS Biology, 14(12). https://doi.org/10.1371/journal.pbio.2000266
Barau, A. S.	2015	Perceptions and contributions of households towards sustainable urban green infrastructure in Malaysia.	Habitat International, 47, 285–297. https://doi.org/10.1016/j.habitatint.2015.02.003
Belcher, R.N., & Chisholm, R. A.	2018	Tropical Vegetation and Residential Property Value: A Hedonic Pricing Analysis in Singapore.	Ecological Economics, 149, 149–159. https://doi.org/10.1016/j.ecolecon.2018.03.012
Belcher, Richard N., Sadanandan, K. R., Goh, E. R., Chan, J. Y., Menz, S., & Schroepfer, T.	2019	Vegetation on and around large-scale buildings positively influences native tropical bird abundance and bird species richness.	Urban Ecosystems, 22(2), 213–225. https://doi.org/10.1007/s11252-018-0808-0
Benzeev, R., Hutchinson, N., & Friess, D. A.	2017	Quantifying fisheries ecosystem services of mangroves and tropical artificial urban shorelines.	Hydrobiologia, 803(1), 225–237. https://doi.org/10.1007/s10750-017-3299-8

Bito-onon, J. B.	2020	Climate risk vulnerability assessment: Basis for decision making support for the agriculture sector in the province of Iloilo	International Journal of Innovation, Creativity and Change, 13(3), 186–202.
Bouma, G. A., & Kobryn, H. T.	2004	Change in vegetation cover in East Timor, 1989-1999.	Natural Resources Forum, 28(1), 1–12. https://doi.org/10.1111/j.0165-0203.2004.00067.x
Brown, A., Dayal, A., & Rumbaitis Del Rio, C.	2012	From practice to theory: emerging lessons from Asia for building urban climate change resilience.	Environment and Urbanization, 24(2), 531–556. https://doi.org/10.1177/0956247812456490
Brown, G., & Hausner, V. H.	2017	An empirical analysis of cultural ecosystem values in coastal landscapes.	Ocean and Coastal Management, 142, 49–60. https://doi.org/10.1016/j.ocecoaman.2017.03.019
Bueno, E. A., Ancog, R., Obalan, E., Cero, A. D., Simon, A. N., Malvecino-Macalintal, M. R., Bactong Jr, M., Lunar, J., Buena, G.R. and Sugui, L.	2016	Measuring Households' Willingness to Pay for Water Quality Restoration of a Natural Urban Lake in the Philippines.	Environmental Processes, 3(4), 875–894. https://doi.org/10.1007/s40710-016-0169-8
Chakraborty, T., & Lee, X.	2019	A simplified urban-extent algorithm to characterize surface urban heat islands on a global scale and examine vegetation control on their spatiotemporal variability.	International Journal of Applied Earth Observation and Geoinformation, 74, 269–280. https://doi.org/10.1016/j.jag.2018.09.015
Chan, A. A. Q., Aziz, S. A., Clare, E. L., & Coleman, J. L.	2020	Diet, ecological role and potential ecosystem services of the fruit bat, Cynopterus brachyotis, in a tropical city.	Urban Ecosystems, (Corlett 1992). https://doi.org/10.1007/s11252-020-01034-x
Danielaini, T. T., Maheshwari, B., & Hagare, D.	2018	Defining rural–urban interfaces for understanding ecohydrological processes in West Java, Indonesia: Part II. Its application to quantify rural–urban interface ecohydrology.	Ecohydrology and Hydrobiology, 18(1), 37–51. https://doi.org/10.1016/j.ecohyd.2017.11.007

Danielaini, T., Maheshwari, B., & Hagare, D.	2019	Qualitative and quantitative analysis of perceived liveability in the context of socio-ecohydrology: evidence from the urban and peri-urban Cirebon-Indonesia.	Journal of Environmental Planning and Management, 62(12), 2026–2054. https://doi.org/10.1080/09640568.2018.1524576
De Leon, R. C., & Kim, S. M.	2017	Stakeholder perceptions and governance challenges in urban protected area management: The case of the Las Piñas – Parañaque Critical Habitat and Ecotourism Area, Philippines.	Land Use Policy, 63, 470–480. https://doi.org/10.1016/J.LANDUSEPOL.2017.02.011
Drillet, Z., Fung, T. K., Leong, R. A. T., Sachidhanandam, U., Edwards, P., & Richards, D.	2020	Urban vegetation types are not perceived equally in providing ecosystem services and disservices.	Sustainability (Switzerland), 12(5). https://doi.org/10.3390/su12052076
Edwards, P.	2019	The role of ecosystem services in making cities sustainable.	In SpringerBriefs in Architectural Design and Technology. https://doi.org/10.1007/978-981-13-0713-3_16
el-Baghdadi, O., & Desha, C.	2017	Conceptualising a biophilic services model for urban areas.	Urban Forestry and Urban Greening, 27, 399–408. https://doi.org/10.1016/j.ufug.2016.10.016
Elliott, S., Chairuangsri, S., Shannon, D., Nippanon, P., & Amphon, R.	2018	Developing forest restoration approaches for northern Thailand	Natural History Bulletin of the Siam Society, 63(1), 11–26.
Estoque, R.C., & Murayama, Y.	2016	Quantifying landscape pattern and ecosystem service value changes in four rapidly urbanizing hill stations of Southeast Asia.	Landscape Ecology, 31(7), 1481–1507. https://doi.org/10.1007/s10980-016-0341-6
Estoque, R.C., & Murayama, Y.	2012	Examining the potential impact of land use/cover changes on the ecosystem services of Baguio city, the Philippines: A scenario-based analysis.	Applied Geography, 35(1–2), 316–326. https://doi.org/10.1016/j.apgeog.2012.08.006

Estoque, R.C., & Murayama, Y.	2013	Landscape pattern and ecosystem service value changes: Implications for environmental sustainability planning for the rapidly urbanizing summer capital of the Philippines.	Landscape and Urban Planning, 116, 60–72. https://doi.org/10.1016/j.landurbplan.2013.04.008
Estoque, R. C., Murayama, Y., & Myint, S. W.	2017	Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia.	Science of the Total Environment, 577, 349–359. https://doi.org/10.1016/j.scitotenv.2016.10.195
Estoque, R. C., Ooba, M., Seposo, X. T., Togawa, T., Hijioka, Y., Takahashi, K., & Nakamura, S.	2020	Heat health risk assessment in Philippine cities using remotely sensed data and social-ecological indicators.	Nature Communications, 11(1), 1–12. https://doi.org/10.1038/s41467-020-15218-8
Fauzi, M. A. Abd Ghafar, A.	2020	Cultural Practices Generated by Structural Biodiversity of Two Urban Forests in Johor Bahru, Malaysia	International Journal of Built Environment and Sustainability, 7(2), 15-23, https:// 10.11113/ijbes.v7.n2.402
Fitri, M., Triyadi, S., & Harun, I. B.	2017	A topology of residents' based on preferences for sustainable riparian settlement in Palembang, Indonesia	MATEC Web of Conferences, 101. https://doi.org/10.1051/matecconf/201710105025
Friess, D. A.	2017	Singapore as a long-term case study for tropical urban ecosystem services.	Urban Ecosystems, 20(2), 277–291. https://doi.org/10.1007/s11252-016-0592-7
Friess, D. A., Richards, D. R., & Phang, V. X. H.	2016	Mangrove forests store high densities of carbon across the tropical urban landscape of Singapore.	Urban Ecosystems, 19(2), 795–810. https://doi.org/10.1007/s11252-015-0511-3
Ghosh, S., Scharenbroch, B. C., & Ow, L. F.	2016	Soil organic carbon distribution in roadside soils of Singapore.	Chemosphere, 165, 163–172. https://doi.org/10.1016/j.chemosphere.2016.09.028
Ghosh, S., Deb, S., Ow, L. F., Deb, D., & Yusof, M. L.	2019	Soil characteristics in an exhumed cemetery land in Central Singapore.	Environmental Monitoring and Assessment, 191(3). https://doi.org/10.1007/s10661-019-7291-9

Gret-Regamey, A., Galleguillos-Torres, M., Dissegna, A., & Weibel, B.	2020	How urban densification influences ecosystem services - A comparison between a temperate and a tropical city.	Environmental Research Letters, 15(7). https://doi.org/10.1088/1748-9326/ab7acf
Gunawan, H., Sugiarti, Rianti, A., & Sihombing, V. S.	2016	Diversity of faunal communities in the Biodiversity Park of Ciherang, Bogor, West Java, Indonesia.	Biodiversitas, 17(2), 479–486. https://doi.org/10.13057/biodiv/d170212
Gunnell, K., Mulligan, M., Francis, R. A., & Hole, D. G.	2019	Evaluating natural infrastructure for flood management within the watersheds of selected global cities.	Science of the Total Environment, 670, 411–424. https://doi.org/10.1016/j.scitotenv.2019.03.212
Hails, C. J., & Kavanagh, M.	2013	Bring back the birds! Planning for trees and other plants to support southeast Asian wildlife in urban areas.	Raffles Bulletin of Zoology, (SUPPL. 29), 243–258.
Hamid, A. R. & Tan. P. Y.	2017	Urban Ecological Networks for Biodiversity Conservation in Cities	Greening Cities: Forms and Functions, Advances in 21st Century Human Settlements, doi 10.1007/978-981-10-4113-6_12 251
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Z., Gurr, G. M., Lundgren, J. G., Burra, D. D., Palao, L. K., Hyman, G., Graziosi, I., Le, V. X., Cock, M. J. W., Tscharntke, T., Wratten, S. D., Nguyen, L. V., You, M., Lu, Y., Ketelaar, J. W., Goergen, G., & Neuenschwander, P.			
Yen, Y., Wang, Z., Shi, Y., & Soeung, B.	2016	An assessment of the knowledge and demand of young residents regarding the ecological services of urban green spaces in Phnom Penh, Cambodia.	Sustainability (Switzerland), 8(6). https://doi.org/10.3390/su8060523
Yotapakdee, T., Asanok, L., Kamyo, T., Norsangsri, M., Karnasuta, N., Navakam, S., & Kaewborisut, C.	2019	Benefits and value of big trees in urban area: A study in bang kachao green space, Thailand.	Environment and Natural Resources Journal, 17(1), 33–43. https://doi.org/10.32526/ennrj.17.1.2019.04
Yu, K.	2020	Work with and by Nature: The Essence of Territorial Spatial Planning and Ecological Restoration.	Landscape Architecture Frontiers, 8(1), 4-9. https://doi. org/10.15302/J-LAF-1-010006
Yuniastuti, E., & Hasibuan, H. S.	2019	Green Open Space, Towards A Child-Friendly City (A Case Study in Lembah Gurame Park, Depok City, Jakarta Greater Area, Indonesia)	IOP Conference Series: Earth and Environmental Science, 328(1). https://doi.org/10.1088/1755-1315/328/1/012016
Zhang, L., & Tan, P. Y.	2019	Associations between urban green spaces and health are dependent on the analytical scale and how urban green spaces are measured.	International Journal of Environmental Research and Public Health, 16(4). https://doi.org/10.3390/ijerph16040578

Appendix C – Chapter 2 Table S2

Table S2: Review categories, description and classification method.

Research Question	Category	Description	Classification
(1) How is UES research distributed across Southeast Asia and at what scale(s) have they been analysed?	Origin of Author	The country of the first author's research institution	Text
	Country	Name of country in which the study was conducted	Text
	City	Name of city in which the study was conducted	Text
	City area	Urban or peri urban	1 for urban; 2 for peri/sub-urban; 3 for both
	City area size	City area size mentioned in the study.	Text
	Population	Population size mentioned in the study.	Text
	Scale of assessment	Scale at which the assessment was conducted. Distinction between a site within a city, city-scale or multi-city scale	1 for a site within/ near a city; 2 for a single city; 3 for multi-city; 4 for other
(2) Does UES research focus on single or multiple services and what type of blue-green structure have been assessed?	Domain classification	Ecosystem services assessed were assigned to one of the domains - provisioning, regulating, supporting and cultural based on the TEEB classification	Text
	Ecosystem service classification	Ecosystem services assessed were listed based on the TEEB classification	Text
	Single vs multiple service	The number of ecosystem services assessed within and across the four ecosystem service categories (referred to as 'domain') – provisioning, regulating, supporting and cultural	1 for single service; 2 for multiple services within a single domain; 3 for multiple services from different domains

	Blue-green structure assessed	Summarizing the ecological structures that provide a service that was analysed by the case study. Refer to the Table S3 for definitions.	Text
(3) Which components of the 'cascade' have been assessed, how are the interactions between UES conceptualised and stakeholders engaged?	Cascade stages	Following the definition provided by Luederitz et al. (2015). Refer to Figure 2.1.	1 for structure; 2 for structure-function; 3 for function; 4 for function-benefits; 5 for benefits; 6 for structure-benefits 7 for all components
	Interactions between services	Explicit assessment of synergies, tradeoffs or flows. Identified through phrases such as "tradeoffs in service provision"	1 if yes; 0 if no
	Stakeholder involvement	Did the assessment involve stakeholders? Interviews were classified as a form of stakeholder involvement.	1 if yes; 0 if no
	Links to climate change	Did the assessment explicitly examine links between ecosystem services and climate change? E.g. changes to ecosystem service(s) distribution due to climate change impacts	1 if yes; 0 if no
(4) What research perspectives, and data collection and analytical methods are used to assess UES?	Research Perspective: Ecology	Articles undertaken from an ecology perspective. Includes studies of urban ecosystem services and interactions, types of interactions between urban and other ecosystems, pressures of urbanisation on ecosystem services, urban ecosystem health, ecology and conservation. (See for example: Abino et al., 2014; Ghosh et	1 if yes; 0 if no

		al., 2016; Tor-ngern & Puangchit, 2018)	
	Research Perspective: Social	Articles undertaken from a sociological, anthropological, health or philosophical perspective. Includes articles that deal with social behaviour, norms and perceptions of ecosystem services. (See Hassan et al., 2019; Quiros et al., 2018; Richards et al., 2020)	1 if yes; 0 if no
	Research Perspective: Planning	Articles that follow an architectural perspective in analysing and planning urban area. Includes studies that focus on urban form and planning issues. (See for example: Gret-Regamey et al., 2020; Mialhe et al., 2019; Ongsomwang et al., 2019)	1 if yes; 0 if no
	Research Perspective: Governance	Articles that refer to the governance or management of ecosystems through institutional and organisational structures, policy instruments relevant to urban ecosystem services. Focus of articles is on explaining how decisions are made and what mechanisms or tools might improve the decision-making process. (See for example: Brown et al., 2012; Pierce et al., 2020; Warner et al., 2019)	1 if yes; 0 if no
	Research Perspective: Economic	Articles that focus on the valuation of ecosystem services. Consists mainly of economic assessments and valuation studies. Includes studies with a strong focus on non-monetary valuation (e.g. social valuation) of urban	1 if yes; 0 if no

		ecosystem services. (See Belcher & Chisholm, 2018; Chakraborty & Lee, 2019; Ureta et al., 2014)	
	Research Perspective: Methods	Articles that focus on the development or specification of methods, tools or guidelines for assessing (or managing) urban ecosystem services. Includes frameworks or methods for analysis and modelling ecosystem services (e.g urban assessment frameworks or spatial models). (See Bito-onon, 2020; Song et al., 2020; Danielaini et al., 2019).	1 if yes; 0 if no
	Temporal study focus	Classification of articles that investigate either one point or period of time or compare data from different points in time.	1 if one point in time or a period of time was analysed; 2. if two or more points in time were compared
	Data collection and analysis method	The method(s) of data collection and analysis applied in the article. Distinguished between field-based, process/mechanistic modelling, landcover proxy, social survey and case studies. The use of multiple methods in an article was recorded.	1 for field-based; 2 for mechanistic/ process models; 3 for land cover proxy; 4 for social surveys; 5 case studies
	Data gathered	The type of data gathered within the study. Distinction between qualitative and quantitative data.	1 for quantitative; 2 for qualitative; 3 for both
	Valuation of Services	We distinguish between no valuation, monetary valuation and non-monetary valuation. Economic valuation includes methods associated to monetary valuation, such as: hedonic pricing, contingent	0 for no valuation; 1 for monetary valuation; 2 for non-monetary valuation

		valuation or replacement cost valuation. Non-monetary valuation includes methods, which are ascribing value to a service -e.g. by ranking them, without assigning a monetary value to it. Studies that ascribed social values or quantified biophysical values of services were classified under non-monetary valuations.	3 for both monetary and non-monetary valuations
	Method of Valuation	The valuation method used in the assessment	Text

Appendix D – Chapter 2 Table S3

Table S3: Ecological structures and definitions.

Ecological structure	Definition
Street greenery	"…vegetation that is integrated within the built environment, such as roadside trees ("street trees"), can provide valuable ecosystem services" (D.R. Richards & Edwards, 2017). Street greenery refers to ecological components that line city roads. Typical ecological street components include trees, green strips, and green pavements, as well as flowerbeds.
Parks	Urban parks are city "feature[s that] serve many functions as providers of passive and active recreation, environmental benefits, and wildlife habitat" (Solecki & Welch, 1995, p. 95). Parks can be found at the urban fringe or at central locations and include a vast amount of different characteristics such as playgrounds and -fields, camping areas, botanical gardens, and green and blue infrastructure (Cranz, 1982).
Gardens	Urban gardens are "private [owned or rented] spaces adjacent to or surrounding dwellings, which may variously comprise lawns, ornamental and vegetable plots, ponds, paths, patios, and temporary buildings such as sheds and greenhouses", forming a "complex and heterogeneous mosaic" in urban landscapes (Cameron et al., 2012; Loram, Tratalos, Warren, & Gaston, 2007, p. 602).
Green walls	"Vertical greenery is greenery where plants can be grown on, up or against internal or external walls of buildings or as freestanding structures" (Mansor, Zakariya, Harun, & Bakar, 2017)
Rooftops	Green or living roofs consist of a growing medium and vegetation layer, over engineered roof membranes, and can be divided into 'intensive' and 'extensive' types depending on depth of substrate, vegetation type, and primary purpose (Oberndorfer et al., 2007, p. 824).
Grassland	"Urban grasslands are ecosystems dominated by turf-forming" (Groffman, 2013) native and non-native species. Grasslands can be managed or unmanaged but mostly share characteristics of unmown, ungrazed, unirrigated, open land patches (Groffman, 2013; Hinners, Kearns, & Wessman, 2012)
Cultivated land	Urban cultivated land refers to professional farming activities in urban and peri-urban areas (Mougeot, 2000) as well as residents

	engaged with farming activities in allotment gardens (J. . Sharp & Smith, 2003). (2014), Opitz et al. (2016), Specht et al. (2013) and Ayambire et al. “The Food and Agricultural Organization (2003) defines urban agriculture as any production in the home or plots in an urban area” (Azunre et al., 2019).
Urban forests	A forest is an area of land greater than 0.5 ha dominated by trees higher than 5 meters (FAO, 2000). Conceptually, we may think of the urban forest either as a forest within the city or a forest upon which a city relies. To some, urban forests are the aggregation of woody parts, a collection of isolated trees within the urban landscape (Carlisle, Pevzner, & Piana, 2014).
Coastal land	Coastal areas are “part of the land adjoining or near the sea” (Oxford Dictionaries, n.d.). Cities in coastal zones are very vulnerable socio-ecological systems that are pressured by increasing damages of natural disasters which also results from the insufficient placement of ecological infrastructure (Costanza & Farley, 2007).
Lakes	A lake is a “relatively large [temporary] body of slowly moving or standing water that occupies an inland basin of appreciable size” (Lane, 2013). Urban lakes can be natural (referred to as ‘indigenous blue infrastructure’ (Deak & Bucht, 2011)) but are often artificially created.
Rivers	Rivers are “natural watercourses, flowing over the surface in extended hollow formations [and are] critical components of the hydrological cycle, acting as drainage channels for surface water” (Hebert, 2013)
Wetlands	Wetlands are areas that are “inundated or saturated by surface water or groundwater with vegetation adapted for life under those soil conditions” (State of Florida, 2011). Urban wetlands include natural or artificial constructed forms and often function as a buffer for city contaminated runoff (Gilbert, Fulthorpe, & Kirkwood, 2012). Mangrove forests are included in this classification.

Appendix E – Chapter 3 Survey Questionnaire

MERITS OF MY NEIGHBOURHOOD:
SIGNIFICANT PLACES, VALUES AND DEVELOPMENT PREFERENCES

As a resident of Greater Kuala Lumpur, you have a chance to share where and why places in your neighbourhood have special meaning to you. Your opinions and preferences are key to planning for liveable neighbourhoods in Greater Kuala Lumpur.

This survey includes questions about:

1. Your neighbourhood
2. The values you associate with your neighbourhood and where those values are represented
3. The types of development plans you think are appropriate or inappropriate for your neighbourhood
4. Your background

The survey takes an average of 15 minutes to complete. All residents of Greater Kuala Lumpur aged 18 and above are welcome to complete this survey. Greater Kuala Lumpur is composed of the following districts: Kuala Lumpur, Petaling, Hulu Langat, Gombak, Klang, Putrajaya and Sepang.

Participation in this survey is voluntary. You can opt out of this survey at any point in time without having to provide a reason. All your responses will be kept confidential and will not contain information that will personally identify you. We thank you in advance for your time and effort!

This survey is part of a PhD research under the School of Environmental and Geographical Sciences at the University of Nottingham Malaysia.

Ethics and Consent To Participate

This study complies with the requirements of the Ethics Committee of the Faculty of Science and Engineering of the University of Nottingham Malaysia Campus.

Please read the following to learn more about this study and how we protect your privacy:

https://d24tbo0jkzipyh.cloudfront.net/uploads/assets/8jie9cme4cmk.url.pdf

https://d24tbo0jkzipyh.cloudfront.net/uploads/assets/6bro6yhz8lns.url.pdf

Voluntary Participation Consent

- ○ I confirmed that I am 18 years old and above.
- ○ I have read the study and understood its purpose. I am satisfied with the explanation and am willing to participate in this study. I understand that I am free to withdraw at any time.

If you require more information about the study, please contact:

Karen Lourdes (researcher) at hgxkl1@nottingham.edu.my

Dr Alex Lechner (supervisor) at alechner@lincoln.ac.uk

Section A - Your Neighbourhood

This section is about your neighbourhood.
Your neighbourhood is the area surrounding your place of residence.
Please answer the following questions based on the area you consider to be your neighbourhood.

1. **Where do you live?**
- o In a city – good access to public amenities, presence of high rise buildings
- o In a town – limited access to public amenities, few high rise buildings
- o Not in a city or town – poor access to public amenities, isolated, rural or undeveloped areas

** 'Public amenities' refers to shopping malls and public transportation services, in particular railway services such as MRT, LRT and KTM stations.*

2. **Please specify the name of your residential area or building - e.g. name of 'taman' or apartment.**

   (open answer)

We do not need your address; however, we need to know your general area of residence. All your responses will be kept confidential and will not contain information that will personally identify you.

3. **How long have you lived in this area/ building?**
- o < 6 months
- o 6 months – 2 years
- o 2 – 5 years
- o 5 – 10 years
- o 10 – 20 years
- o > 20 years

4. **How well do you know your neighbourhood and the places in it (e.g. nearest shops, parks, petrol station)?**
- o Very well
- o Somewhat well
- o Average
- o Not really
- o Not at all

5. **Is it important to consider the public's values and preferences in urban planning?**
- o Very important
- o Somewhat important
- o Neutral
- o Not really
- o Not at all

6. **Which of the following statements do you most agree with?**
- o Highest priority should be given to maintaining natural environmental conditions even if there may be negative economic consequences.
- o Environmental and economic factors should be given equal priority.
- o Highest priority should be given to economic considerations even if there may be negative environmental consequences.

Section B – Values Associated With Your Neighbourhood

7. **Imagine that you could "spend" RM 1000 to preserve the existing values of your neighbourhood. Of the 10 values listed below, please allocate the RM1000 to the values that are most important to you in your neighbourhood.**

(This is a hypothetical scenario. Reference to money is NOT made to actual money, your own, the local council's or the university's).

INSTRUCTIONS

1\. For values you allocate money to, **mark on the map** the locations of places in your neighbourhood that represent that value.

2\. You only need to allocate the RM 1000 to **values important to you**. However, if you feel that all ten values are important to you, you can choose to allocate money to all ten values.

3\. The **total** spending must equal to RM 1000.

Click here for instructions on marking locations on the map

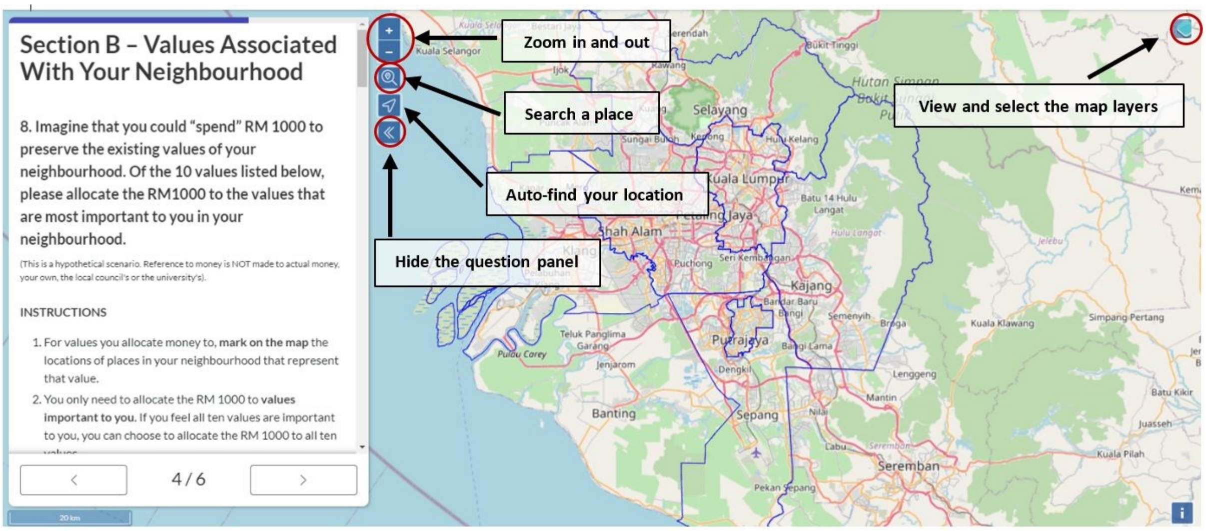
Click here for instructions on marking locations on the map

NAVIGATE THE MAP

Left-click the map and drag to move. Scroll forward to zoom in and scroll back to zoom out.

You can also use the '+' and '-' buttons on the left side of the page to zoom in and out of the map.

Use the 'search address' button on the left side of the page to find a place.



8A. Which district and area do you live in?

list of districts and areas in Greater KL – total of 61 areas

8B. Please mark the location of your home on the map. This location should indicate the area you live in.

Mark the location of your home

(We are interested in the relationship between your place of residence and the values you associate with your neighbourhood. We do not need your address; however, we need to know your general area of residence. All your responses will be kept confidential and will not contain information that will personally identify you.)

Aesthetic – I value these places because they have attractive or pleasing landscapes

How much would you spend on this value?

Mark on the map places with 'AESTHETIC VALUE' in your neighbourhood

Economic – I value these places because they provide opportunities for tourism, produce agricultural products or support local businesses

How much would you spend on this value?

Mark on the map places with 'ECONOMIC VALUE' in your neighbourhood

Existence - I value these places just for their existence, regardless of benefits to me or others

How much would you spend on this value?

Mark on the map places with 'EXISTENCE VALUE' in your neighbourhood

Heritage and history – I value these places for their history and/or because they provide opportunities to express and appreciate culture or cultural practices such as art, music, history and indigenous traditions

How much would you spend on this value?

Mark on the map places with 'HERITAGE AND HISTORIC' in your neighbourhood

Habitat and biodiversity - I value these places for the plants, animals, wildlife or ecosystem

How much would you spend on this value?

Mark on the map places with 'HABITAT AND BIODIVERSITY VALUE' in your neighbourhood

Local norm and sense of belonging - I value these places because they embody the local lifestyle, creating a sense of place, community and belonging

How much would you spend on this value?

Mark on the map places with 'LOCAL NORM AND SENSE OF BELONGING' in your neighbourhood

Recreation - I value these places because they provide outdoor recreation opportunities

How much would you spend on this value?

Mark on the map places with 'RECREATION VALUE' in your neighbourhood

Religious and spiritual - I value these places because they have religious and/or spiritual meaning

How much would you spend on this value?

Mark on the map places with 'RELIGOUS AND SPIRITUAL VALUE' in your neighbourhood

Social interaction - I value these places because they provide opportunities to interact with family, neighbours, friends and other people

How much would you spend on this value?

Mark on the map places with 'SOCIAL INTERACTION VALUE' in your neighbourhood

Therapeutic - I value these places because they support mental and/or physical wellbeing

How much would you spend on this value?

Mark on the map places with 'THERAPEUTIC VALUE' in your neighbourhood

Please check that you successfully completed this section:

- [ ] I have allocated a total of RM1000 to values important to me.

- [ ] For each value I have allocated money to, I have marked places in my neighbourhood that represent these values on the map.

**When marking places for each value – the following reminders will pop-up:

You may mark up to four places in your neighbourhood that represent this value.

Remember: You only need to mark places for values that you have allocated money to!

Section C - Preference Towards Urban Development Plans

There are many possible urban development plans that could affect your neighbourhood and the values you associate with it.

In this section, you will state your preferences towards different development plans in your neighbourhood.

Mark one preference for each item.

9. Do you favour or oppose the following new developments taking place in your neighbourhood?

	Strongly Favour	Favour	Neutral	Oppose	Strongly Oppose
Neighbourhood park i.e. small recreational park)					
Highway and road development					
Community garden/orchard					
Train station (e.g. MRT, LRT, KTM)					
Luxury housing development					
High rise commercial/residential building					
Community park with lake (i.e. large park with open space and facilities for recreational activities)					
Recreational forest					
Public facilities (e.g. school, hospital, sports facility)					
Shopping mall					
Affordable housing development					
Commercial office units					
Eateries (e.g. mamak stall or cafe)					
Industrial parks or factories					

<u>Section D – Your Background</u>

Please provide the following information about yourself to help us process this survey. Your information will be used only for the purpose of this study and will be kept strictly confidential.

10. Gender

- Male
- Female

11. Age

(open answer)

12. Ethnicity

- Malay
- Chinese
- Indian
- Other

If other, please specify:

(open answer)

13. Highest formal education

- No formal education
- Primary (UPSR)
- Lower secondary (PMR)
- Upper secondary (SPM)
- Pre-university (STPM/ Matriculation/ A-Level)
- Certificate/ Diploma
- Bachelor's degree
- Postgraduate (Masters/ PhD)
- Other

If other, please specify:

(open answer)

14. Employment status

- Unemployed
- Student
- Homemaker
- Public sector
- Private sector

- Self-employed
- Retired/ Pensioner

15. What is your monthly income?

- No income
- < RM 1000
- RM 1000 – RM 3000
- RM 3000 – RM 5000
- RM 5000 – RM 7 000
- RM 7000 – RM 10 000
- RM 10 000 – RM 15 000
- > RM 15 000

16. If you would like to share your thoughts or opinions about urban development and planning in your neighbourhood, please comment below.

(open answer)

--- End of survey ---

APPENDIX F – DESCRIPTION OF URBAN ECOSYSTEM SERVICE MODELS

Full descriptions of each model can be found in the User's guide (InVEST v3.8, Sharp et al. 2020), except for urban recreation (Liu et al., 2020) and scenic quality (ArcGIS Pro Spatial Analyst Tool, ESRI, 2020).

1. Heat Mitigation

We applied the InVEST Urban Cooling Model to model heat mitigation services. This model derives the per pixel index of heat mitigation (HM) service as a function of the cooling capacity of each pixel and its distance to large, vegetated areas. The model calculates the cooling capacity index of each pixel based on shade, albedo and evapotranspiration. The cooling effect of large green spaces (over 2 ha) on surrounding areas is accounted for by the heat mitigation index, which is function of distance to large green spaces. HM is equal to cooling capacity if the pixel is unaffected by large green spaces, otherwise it is equal to a distance-weighted average of the cooling capacity values between the large green space and the pixel of interest. To achieve this, the model calculates the amount of green areas within a search distance (d_{cool}) around each pixel (GA_i), and the cooling capacity of each park (CC_{park_i}):

$$GA_i = cell_{area} \cdot \sum_{j \in d\ radius\ from\ i} g_j$$

$$CC_{park_i} = \sum_{j \in d\ radius\ from\ i} g_j \cdot CC_j \cdot e^{\left(\frac{-d_{(i,j)}}{d_{cool}}\right)}$$

where $cell_{area}$ is the area of a cell in ha; g_j is 1 if pixel j is a greenspace, 0 otherwise; and $d(i,j)$ is the distance between pixel i and j.

The cooling effect of large greenspaces is expressed as the HM index (Figure F.1a), which is calculated as:

$$HM_i = \begin{cases} CC_i \\ CC_{park_i} \end{cases} if\ CC_i \geq CC_{park_i}\ or\ GA_i < 2ha$$

$$HM_i = \begin{Bmatrix} CC_i\ if\ CC_i \geq CC_{park_i}\ or\ GA_i < 2ha \\ CC_{park_i} \qquad otherwise \end{Bmatrix}$$

We modelled realised heat mitigation (HM_r) services, a product of the HM index and population count to capture the amount of heat mitigation service reaching beneficiaries (Figure F.1b).

$$HM_r = HM_i \cdot population$$

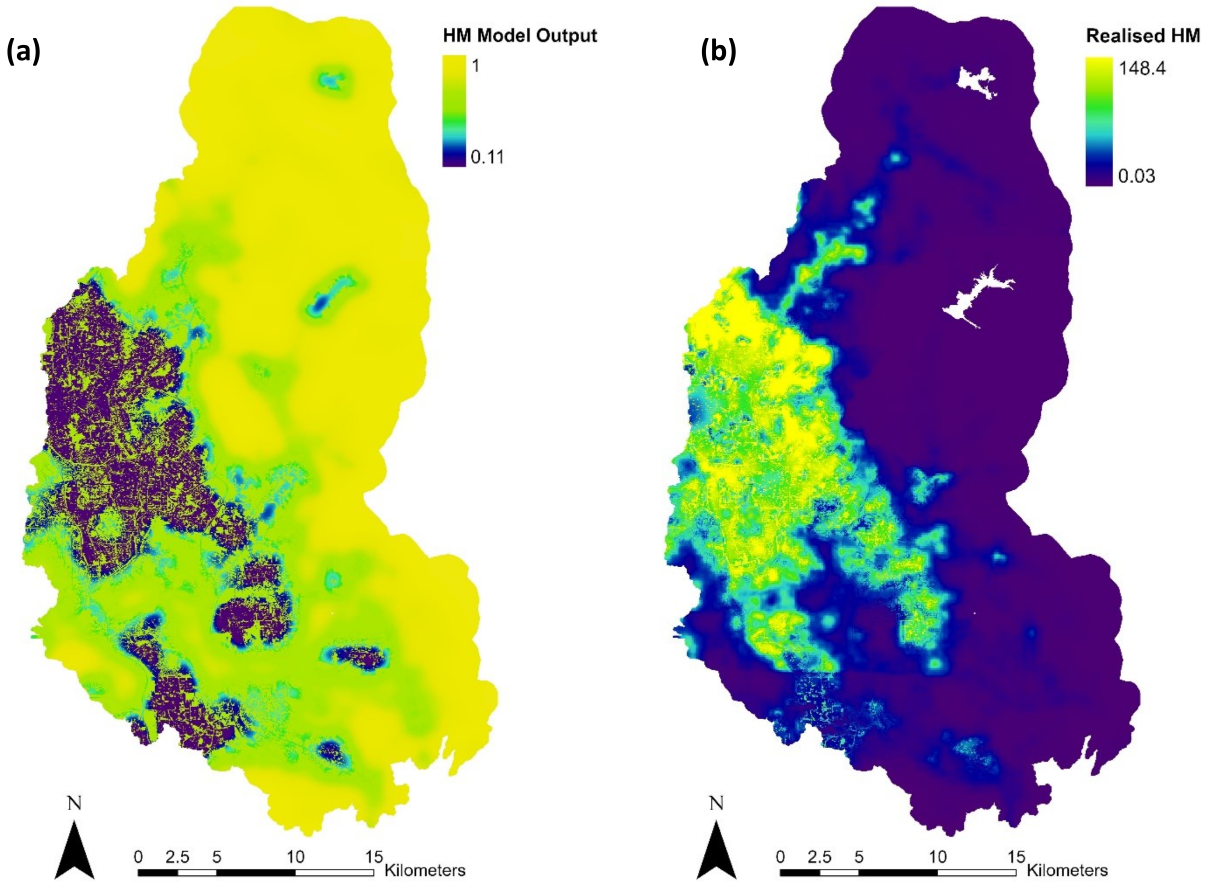


Figure F.1 (a) The heat mitigation model output (potential heat mitigation service) as an index (not absolute values), and (b) the realised heat mitigation service obtained by multiplying the model output with population distribution.

We calibrated the 'UHI_{max}' parameter against 2018 land surface temperature derived from Landsat 8 (Benali *et al.*, 2012). We used land surface temperature to calibrate the model as there is no readily available air temperature data in this region (Vancutsem *et al.*, 2010).

2. Runoff Retention

To model runoff retention services, we applied the InVEST Urban Flood Risk Mitigation model. This model estimates per pixel runoff production as a function of land use type and soil characteristics using the Curve Number method for a specified design storm (USDA, 2004). For each pixel in the Upper Langat catchment, the model estimates runoff (Q) in mm using the Curve Number method as follows:

$$Q_{p,i} = \begin{Bmatrix} \dfrac{(P - \lambda S_{max,i})^2}{P + (1-\lambda)S_{max,i}} & if\ P > \lambda \cdot S_{max,i} \\ 0 & otherwise \end{Bmatrix}$$

where P is the depth of rainfall in mm; $S_{max,i}$ is the potential retention in mm; and $\lambda \cdot S_{max,i}$ is the rainfall depth needed to initiate runoff, also known as initial abstraction ($\lambda = 0.2$).

The depth of rainfall (P) is calculated in a two-step process. First the IDF relationship equation is used to calculate rainfall intensity (i):

$$Rainfall\ intensity, i = \frac{\lambda T^{\kappa}}{(d + \theta)^{\eta}}$$

where λ, κ, η and θ are parameters are IDF parameters specific to the site, T is the average recurrence interval and d is the duration of rainfall. We followed the 'Design Rainfall' chapter of the Urban Stormwater Management Manual (Department of Irrigation and Drainage Malaysia, 2010) in designing the storm as observed data in the study area was limited. The depth of rainfall was calculated based on a hypothetical storm with a 24-hour duration, d, and average recurrence interval (ARI), T = 2 years using the Intensity-Duration-Frequency (IDF) relationship equation. We chose the IDF relationship method because the parameters for this equation, which are site specific, were readily available for a gauging station in the study area (SK Sungai Lui station - ID: 3118102).

Next, the rainfall intensity is converted to rainfall depth (mm) by multiplying rainfall intensity by the duration of rainfall, d:

$$Rainfall\ depth\ (mm) = i \cdot d$$

S_{max}, calculated in mm, is a function of the empirical Curve Number (CN):

$$S_{max,i} = \frac{25400}{CN_i} - 254$$

Runoff retention per pixel (R_i) is calculated as:

$$R_i = 1 - \frac{Q_{p,i}}{P}$$

We map and analyse the runoff retention in m^3 per pixel ($R\_m^3{}_i$) in the Upper Langat catchment, calculated as:

$$R\_m^3{}_i = R_i \cdot P \cdot pixel.area \cdot 10^{-3}$$

Given that runoff retention service has a wider spatial reach in benefitting users (e.g. downstream users benefit from upstream runoff retention), we consider the modelled runoff retention to be a realised service (Figure F.2).

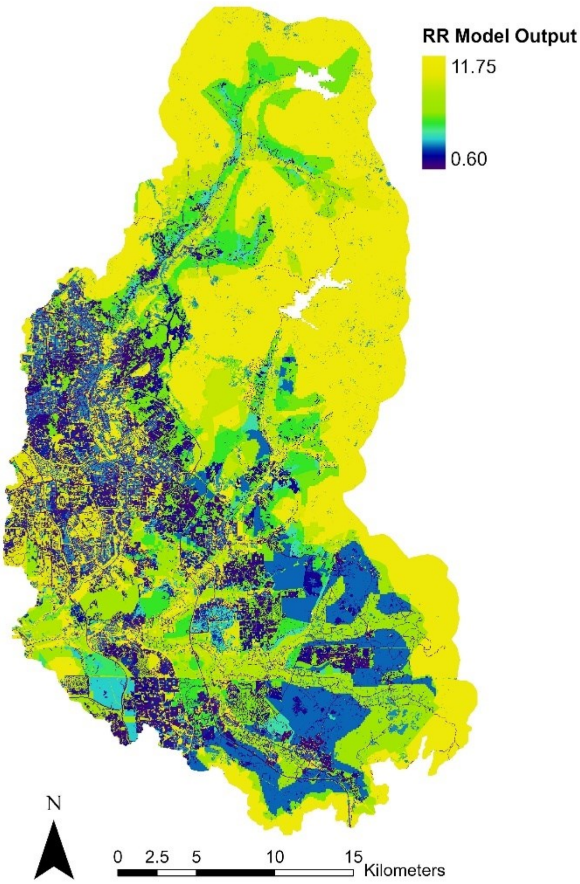


Figure F.2 The runoff retention model output illustrating the realised runoff retention service provided in m^3 per pixel.

We attempted to validate the predicted runoff retention services using the discharge values quantified by the model. However, the temporal resolution of the discharge data obtained (mean discharge values per day) was not comparable to the model output (mean discharge per catchment per event). As manually collecting discharge data for the catchment was beyond the scope of this research, we were unable to validate this model.

3. Sediment Retention

We applied the InVEST Sediment Delivery Ratio model to evaluate sediment retention services. This model estimates the amount of annual soil loss per pixel based on the revised universal soil loss (RUSLE1) equation. Based on this, the model calculates the per pixel sediment delivery ratio (*SDR*), sediment export (*E*) and sediment retention (R_i) in the Upper Langat.

The amount of soil loss per pixel is given by:

$$usle_i = R_i \times K_i \times LS_i \times C_i \times P_i$$

where R_i is rainfall erosivity, K_i is soil erodibility, LS_i is the slope length-gradient factor, C_i is the crop management factor and P_i is a support practice factor. *SDR* is a function of *IC,* the connectivity index of each pixel describing the hydrological linkages between sediment sources and sinks in the catchment. *IC* is a function of the upslope area of each pixel (D_{up}) and the flow path between the pixel and the nearest stream (D_{dn}):

$$IC = log_{10} \frac{D_{up}}{D_{dn}}$$

And the SDR is derived as follows:

$$SDR_i = \frac{SDR_{max}}{1 + \exp\left(\frac{IC_0 - IC_i}{k}\right)}$$

where SDR_{max} is the maximum theoretical SDR – set to an average value of 0.8; and *IC* and *k* are calibration parameters that define the shape of the SDR-IC relationship. See (Sharp *et al.*, 2020) for further details.

Sediment export is the amount of sediment eroded from a pixel that actually reaches the stream. Sediment export, calculated in tons per year, from a given pixel *i* is:

$$E_i = usle_i \times SDR_i$$

Conversely, the amount of sediment that is deposited on the landscape (and does not reach the stream) is given by:

$$E'_i = usle_i(1 - SDR_i)$$

Due to the nature of the SDR calculation, the flow of E'_i downstream can be modelled independently of the flow of E_i by fulfilling two assumptions captured in the following equation (see Sharp et al., 2020 for detailed explanation):

$$dR_i = \frac{\sum k\epsilon_{\{directly\ downstream\ from\ i\}}\ SDR_k \cdot p(i,j) - SDR_i}{1.0 - SDR_i}$$

where d in dR_i indicates the delta difference and $p_{(i,j)}$ is the proportion of flow from pixel i to j. This notation invokes the intuition of a derivative of R_i. This includes artificial drainage connections to the stream (e.g., roads, stormwater pipes, etc.). The flow routing will stop at these "artificially connected" pixels, before reaching the stream network, and the corresponding sediment exported is assumed to reach the catchment outlet.

To define the amount of sediment flux that is retained on any pixel in the flowpath, R_i, the model uses dR_i as a weighted flow of upstream flux, given as follows:

$$R_i = dR_i \cdot \left(\sum_{j\epsilon\ \{pixels\ that\ drain\ to\ i\}} F_j p(i,j) + E'_i \right)$$

Where F_j is the flux of sediment export that does not reach the stream, defined as:

$$F_i = (1 - dR_i) \cdot \left(\sum_{j\epsilon\ \{pixels\ that\ drain\ to\ i\}} F_j p(i,j) + E'_i \right)$$

We used R_i to express sediment retention services provided by the landscape. Sediment retention is expressed in tons per pixel, relative to all land use classes in the catchment being converted to bare soil (Figure F.3). Similar to the runoff retention service, we consider the modelled sediment retention service to be a realised service due to its large service benefitting area.

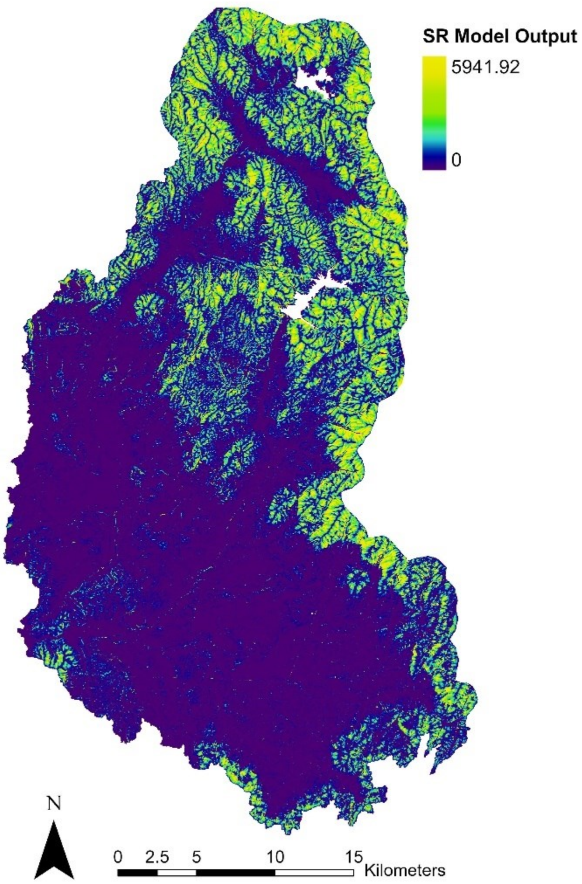


Figure F.3 The sediment retention model output visualising the realised sediment retention services in tons per pixel, relative to all land use classes being converted to bare soil.

4. Scenic Quality

To model scenic quality services, we applied the Observer Points Spatial Analyst tool in ArcGIS Pro version 2.5.0 (ESRI, 2020). This tool conducts a viewshed analysis by identifying raster surface locations visible to specified observer points. The visibility of each cell center to the observer is computed by comparing the altitude angle to the cell center with the altitude angle to the local horizon. The local horizon is determined by considering the intervening terrain between the point of observation (observer) and the current cell center. If the cell center lies above the local horizon, the cell is considered visible to the observer. We used a digital surface model (DSM) where elevation input was required in order to capture potential visual obstructions by the built environment. The output of the Observer Point tool provides the cells visible to each observer and the number of observers that can view a given cell. Further details on the Observer Point tool can be found here: https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/observer-points.htm

We used point features of population (observers) to represent the beneficiaries of scenic quality service. We classified a 2018 population density raster from WorldPop (WorldPop, 2018), into five equal interval classes and extracted these classes as polygons. These five classes represent the five population density groups in the upper Langat (i.e., most dense to least dense). We delineated 10 random feature points within each population class, using the 'Create Random Points' tool, to represent a total of 50 (10 x 5) sample of observer points which reflect the population distribution in the study area (Figure F.4). We executed the Observer Point tool five times (once for each population class) using the respective delineated points as the 'observer' input in the Observer Point tool. Then, we computed a weighted overlay of the five Observer Point tool outputs. Weights for each population class was derived based on the percentage of total population density residing within the class:

$$Weight_x = \frac{Population\ density_x}{Total\ population\ density\ in\ study\ area} \times 100\%$$

where $Weight_x$ is the weight assigned to population class x, and $Population\ density_x$ is the mean population density of the pixels in class x. The output of the weighted overlay denoted the percentage of total population density that benefitted from scenic views across all land cover types.

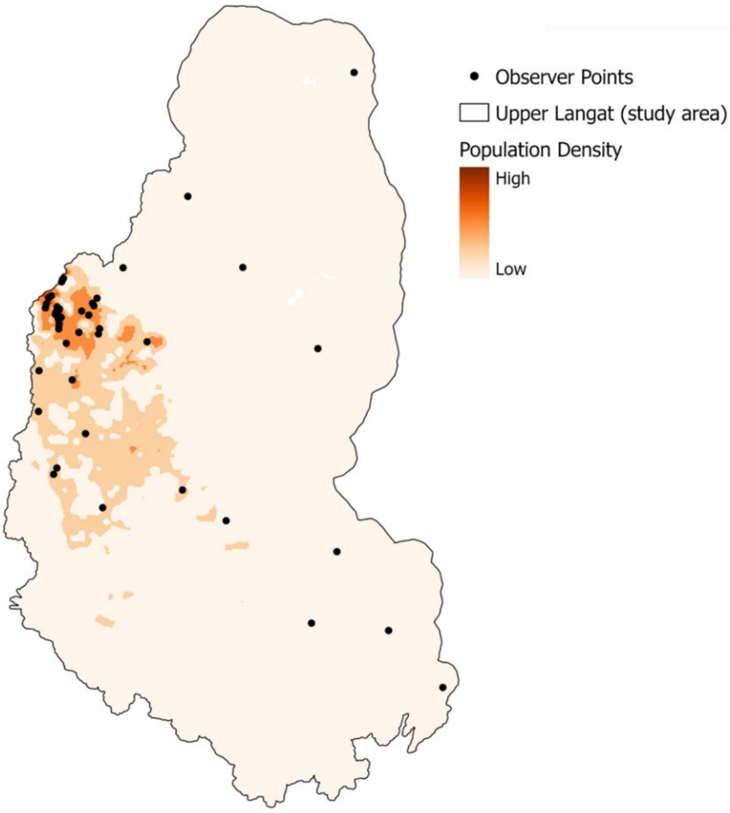


Figure F.4 The 50 sample observer points delineated based on population density in the upper Langat.

To capture scenic views of vegetation, we extracted all vegetative classes from the LULC (i.e., natural vegetation, oil palm, rubber and other agriculture). We assumed that vegetation of any kind provided better scenic quality in comparison to a total absence of vegetation. We reclassified the extracted raster classes to represent pixels with vegetation as '1' and pixels with no vegetation as '0'. We overlayed the weighted overlay output with the vegetation raster to quantify realised scenic quality as the percentage of population density benefitting from scenic views in a given pixel. The scenic quality service modelled is a realised service as both supply (vegetated areas) and demand (visibility to observer) is considered (Figure F.5).

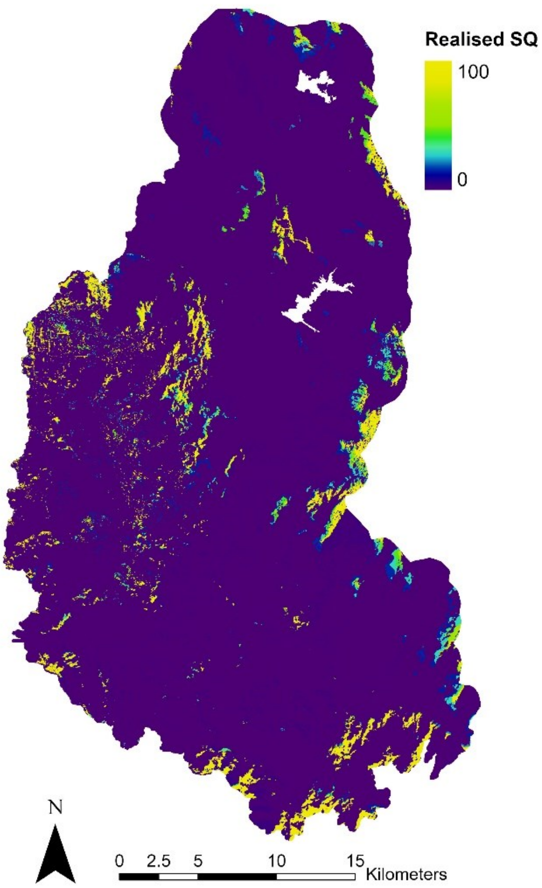


Figure F.5 The realised scenic quality service illustrating the percentage of population density benefitting from scenic views in a given pixel.

5. Urban Recreation

To model urban recreation services, we applied the InVEST Nature Access model (beta version) as described by Liu et al. (2022). This model quantifies the supply, demand and supply-demand balance per pixel of recreation services based on the distance of urban populations to green spaces (Liu *et al.*, 2020; 2022). As such, it represents "daily recreation" in green spaces near residents' homes (as opposed to green spaces that are visited less often due to their distance). To calculate the supply of green spaces, the model quantifies the green space to population ratio (R_j) for each green area pixel j. This is achieved by dividing the green area in pixel j (S_j) by population (p_k) within the search radius, with the decay function, $f(d_{jk})$, representing the decline in visitation with distance:

$$R_j = \frac{GA_j}{\sum_{k \in \{d_{kj} \leq d_0\}} p_k \cdot f(d_{kj})}$$

Where d_{kj} is the Euclidean distance between pixel j and population pixel k. There are five options for the decay function: Gaussian, Dichotomy, Power function, Kernel density function and Poisson. Then, the model sums all R_j values from green space pixels within the search radius. The supply of green space per pixel ($supply_i$), in m^2 per capita, as:

$$supply_i = \sum_{j \in \{d_{ij} \leq d_0\}} R_j \cdot f(d_{ij})$$

where i is any pixel in the study area, d_0 is the search radius and d_{ij} is the Euclidean distance between pixel i and j.

The demand of green space, defined as the amount of green space per capita within proximity, is determined by distance (d_0 in meters) and amount of green space ($demand_{cap}$ in m^2 per capita per pixel). We applied the local policy target per capita for Greater Kuala Lumpur (Federal Department of Town and Country Planning, 2006), for a common driving range to urban parks based on local literature (Nor Akmar, 2012) to determine the demand for green spaces. The balance between supply and demand of green spaces per pixel was quantified by calculating the difference between supply and demand, per capita.

$$balance_{cap,i} = supply_i - demand_{cap}$$

The balance of supply-demand per pixel population ($balance_i$) is calculated by multiplying $balance_{cap,i}$ with the population at pixel i (p_i) (Figure F.6). This represents the surplus or deficit of recreation services in pixel i in the Upper Langat, that is the "realised" recreation service (m^2 per capita):

$$balance_i = balance_{cap,i} \cdot p_i$$

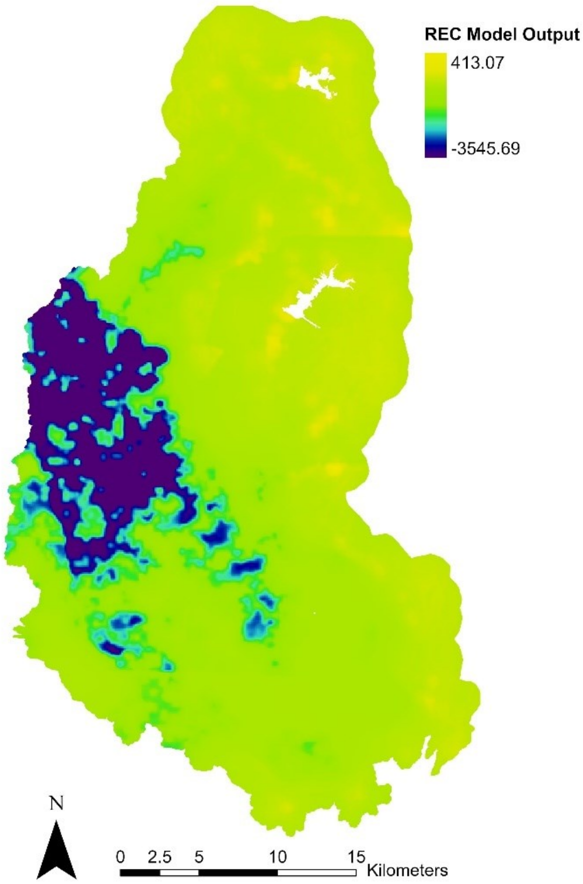


Figure F.6 The modelled realised recreation service illustrating the surplus or deficit of recreation area m^2 per capita.

While the model captures both the supply and demand of nature access, modelling true recreation service (i.e., people conducting recreational activity in green spaces) was not possible within the scope of our desktop modelling exercise. Modelling the recreation service supply and demand is complex and requires local data on people's preferences and values, typically obtained through surveys (Liu et al. 2022). Therefore, our study uses access to nature as a proxy for urban recreation. Similar limitations are observed in other recreation models (e.g., ESTIMAP; see Suárez *et al.* (2020)). We refer to Jones *et al.* (2016) and Dworczyk and Burkhard (2021) for further discussions on the spatial relationships between SPUs and SBAs as well as the challenges of modelling demand for realised ecosystem services.

6. Agriculture Production

We applied the InVEST Crop Production model to evaluate agriculture production services. This model estimates the crop yield for a specific crop based on climate, land cover and observed crop yield information. The observed yield information is derived from sub-national and United Nation's Food and Agriculture Organisation datasets for 175 crops globally (Sharp *et al.*, 2020). We modelled the yield of oil palm and rubber in tons per pixel per year for the Upper Langat catchment. We map and analyse agricultural production services as the 95th percentile of total crop yield of oil palm and rubber (in tons per pixel) (Figure F.7). As the beneficiaries of agricultural production services are not limited by spatial factors, we consider the modelled agriculture production service to be a realised service.

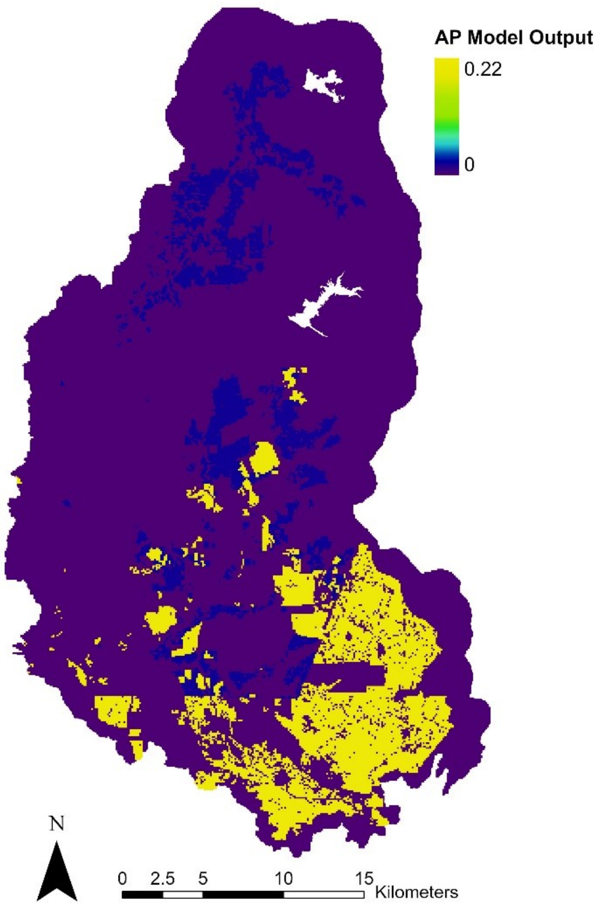


Figure F.7 The model output for agricultural production illustrating the 95th percentile yield of total crop production (oil palm and rubber) in tons per pixel.

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APPENDIX G – URBAN ECOSYSTEM SERVICE MODEL PARAMETERS

Table B.1 Model parameters, sources and confidence in estimation

InVEST Model /Tool Name (Urban ecosystem service modelled)	Parameters	Input	Source	Confidence Level
1. InVEST - Urban Cooling Model (Heat Mitigation)	LULC raster	LULC raster	Manually digitised	High
	Reference evapotranspiration raster	Global ET0 1970-2001	(Trabucco and Zomer, 2018)	Low
	Area of interest	Catchment boundary	Delineated from DTM	High
	UHImax	7	Data sourced from https://yceo.yale.edu/research/global-surface-uhi-explorer, cited as (Chakraborty and Lee, 2019) and LST validation (Landsat data sourced from Earth Explorer (https://earthexplorer.usgs.gov/), LST layer manually derived).	Medium
	Baseline air temperature	26	Weather report and LST calibration	Medium
	Maximum air temperature blending distance	500m	(Sharp *et al.*, 2020)	Medium
	Green area maximum cooling distance	500m	(Buyadi, Wan Mohd and Misni, 2014)	High
	Biophysical table (based on LULC)	See Table B.2	(Allen *et al.*, 1998; Carr, 2011; Stewart and Oke, 2012; Wang *et al.*, 2019)	Medium
2. InVEST - Urban Flood Risk Mitigation (Runoff Retention)	LULC raster	LULC raster	Manually digitised	High
	Hydrological soil groups raster	Soil group raster	(USDA, 1986)	Medium
	Watershed shapefile	Catchment boundary	Delineated from DTM	High
	Built infrastructure shapefile	Built infrastructure footprint	Urban class from LULC	High
	Depth of rainfall	117.465	(Drainage and Irrigation Department Malaysia, 2015)	High
	Biophysical table (based on LULC)	See Table B.3	(USDA, 1986)	Medium

InVEST Model /Tool Name (Urban ecosystem service modelled)	Parameters	Input	Source	Confidence Level
3. InVEST -Sediment Delivery Ratio (Sediment Retention)	DEM	DTM	JUPEM and SRTM	High
	Shade	0.6	(Sharp *et al.*, 2020)	Medium
	Albedo	0.6	(Sharp *et al.*, 2020)	Medium
	Evapotranspiration	0.2	(Sharp *et al.*, 2020)	Medium
	Watershed shapefile	Catchment boundary	Delineated from DTM	High
	Drainage raster	Road network extracted from LULC	Road classes from LULC	High
	Rainfall erosivity index (R) raster	Global rainfall erosivity raster	(Panagos *et al.*, 2017)	Low
	Soil erodibility (K) raster	Soil erodibility raster	(USDA, 1986; Yusof *et al.*, 2011)	Medium
	Biophysical table (based on LULC)	See Table B.4	(USDA, 1986; Department of Irrigation and Drainage Malaysia, 2010; Rizeei *et al.*, 2016)	Medium
	Threshold flow accumulation	800	Derived from sensitivity analysis and validation	High
	Kb	2	Expert opinion	High
	IC0	0.5	Expert opinion	High
	SDRmax	0.8	(Sharp *et al.*, 2020)	Medium
4. InVEST –Nature Access (Urban Recreation)	LULC Map with greenspace indicated	Recreational green space extracted from LULC	Vegetation class from LULC	High
	Area of interest	Catchment boundary	Delineated from DTM	Medium
	Population	UN population 2018 adjusted	(WorldPop, 2020)	High
	Decay function	Dichotomy	(Sharp *et al.*, 2020)	High
	Search radius	2000m	(Nor Akmar, 2012)	Medium
	Greenspace demand	20m2	(Federal Department of Town and Country Planning, 2006)	High
5. InVEST - Crop Production (Agriculture Production)	LULC raster	LULC raster	Manually digitised	High
6. ArcGIS Pro - Observer Points Tool Spatial Analyst, (Scenic Quality)	Input raster	DSM	JUPEM and SRTM	High
	Input point observer features	Sampled population (observer) points	Manually delineated based on population density	Medium
	Z factor	1	Default value	High

Table B.2 Biophysical table for the heat mitigation model.

lulc_class	lucode	shade	Kc	albedo	green_area
impervious	1	0	0	0.14	0
non ag veg	2	1	0.9	0.2	1
water	3	0	0	0.08	0
bare soil	4	0	0.3	0.18	0
minor roads	5	0	0	0.08	0
major roads	6	0	0	0.08	0
oil palm	7	1	0.9	0.157	1
rubber	8	1	0.9	0.157	1
other ag	9	1	0.9	0.157	1
dams	10	0	0	0.08	0

Table B.3 Biophysical table for the runoff retention model.

lulc_class	lucode	CN_A	CN_B	CN_C	CN_D
impervious	1	89	92	94	95
non ag veg	2	30	55	70	77
water	3	1	1	1	1
bare soil	4	77	86	91	94
minor roads	5	98	98	98	98
major roads	6	98	98	98	98
oil palm	7	71	80	87	90
rubber	8	61	70	77	80
other ag	9	64	75	82	85
dams	10	1	1	1	1

Table B.4 Biophysical table for the sediment retention model.

lulc_class	lucode	usle_c	usle_p
urban	1	0.15	1
non ag veg	2	0.03	0.1
water	3	0	0.5
bare soil	4	1	1
minor roads	5	0.01	1
major roads	6	0.01	1
oil palm	7	0.2	0.5
rubber	8	0.2	0.4
other ag	9	0.38	0.4
dams	10	0	0.5

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Appendix H – Chapter 5 List of Articles Reviewed

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