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Exploring Urban Spaces across Human-Natural systems

And the Potential to Enhance City Resilience

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Foreword

When we talk about urban space, what could we think about its importance to city development? Basically, space is a physical conception with different ranges from microscale to macroscale, from urban-rural to cities, from cities to nations. For the basic elements of humans and nature, spaces provide various roles in demands, which could be shown as Maslow's hierarchy of needs in 1987 revealing the five layers from physiological needs to self-actualization. With anthropogenic development, urban spaces become a crucial part of human life all over the world; It rapidly changes following the development of economy and society, including the dynamic of technology, governmental decision, population, social media mobility, and others impactors. Urban spaces regularly are defined by the design of urban planning, which could rely on structures of city development and planning goals, for instance, carbon neutrality, resilience city, intercultural diversity, green urban, smart city, etc. During those processes, the emergency of land use changes is the stepping stone for urban spaces planning. Further designing of space elements regulate spatial composition and configuration of grey, green, and blue infrastructures get a form and structure of urban space. The more changes of spatial forms, the more dynamic of urban spaces. In spite of the variety of urban spaces, there are linkages among different spaces that is the function of all urban spaces is to maintain human life in cities. The Resilient City mentions the philosopher Martin Heidegger has revealed there are etymological affinities liking the words of buildings, dwelling, and thinking. Moreover, in the book Transforming Cities said, the ways urban spaces are generated in social relationships, and the ways social relations take distinct spatial forms in cities, are key processes. Under the pandemic of COVID-19, urban spaces among human and nature get alarms.

Conserving nature is getting more and more attention for achieving urban sustainability. It could be seen that building, dwelling, and thinking in cities require connections with nature. Although the coupled human-natural systems have been getting a lot of attention, especially the application in the field of social economy, urban spaces across human-natural systems could get some new insights, which scares attention. Its exploration could have the capacity to understand the potential of resilience to climate change and sustainability of human-natural balance in urban spaces. More importantly, the conception of urban spaces needs to be understood from the perspective of urban ecologists to the implementable knowledge for urban planners and the relative application for decision-makers. Ecological research requires not only to prove urban patch-processes-scale but also to transfer the knowledge which could be applicable to city designers and planners. The integration of landscape ecology, urban planning, and governance brings an insight to probe urban spaces with the method of ecology, remote sensing, and social media data to study the functions of urban spaces under human-natural systems for resilience enhancement.

To reveal urban spaces and their relationship with climate resilience and human demand, this study aims to investigate different urban spaces across human-natural systems and their influence on temperature mitigation and to specially inspect urban green spaces and human demand. Therefore, this thesis totally has eight chapters. Chapter one and two are the introduction and methodology, which demonstrate the relationship among urban spaces, spatial heterogeneity, ecosystem services, human demands, and show several research methods. The Chapter three to seven are the main research part, which include chapter three and four firstly propose the eight-type spaces (ETS), a new category of urban spaces with the integration of land uses and urban functions and model their effects on temperature mitigation; Chapter five specifies urban green spaces planning and its relationship with temperature mitigation in Berlin; Chapter six interacts landscape characteristics with human emotions to maintain human wellbeing; and chapter seven suggests a conception of "city self-learning" to improve city resilience and the conclusion and suggestions in chapter eight.

Overall, engaging a human-natural system into urban spaces with the ETS seems to provide a potential to reform spatial compositions and configurations to mitigate climate change. From the research, the key is to ensure that human systems need more attention on temperature mitigation; in natural systems, urban green space are of significance with the integration of quantity and quality, and human demand to increase urban resilience and promote human emotions. In conclusion, cities need to sustainably support human activities and nature conservation with dynamic urban forms, which could be regulated by city-self comparative to enhance city resilience and satisfy human demand for urban sustainability.

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This thesis was written during my Ph.D. studies at Humboldt-Universität zu Berlin. Over the four and half years under independent research, I get a lot of inspiration from the thought about urban spaces and spatial heterogeneity to think about urban problems and explore their potential for enhancing city resilience. I would like to thank all the education from Bachelor's study at Sichuan Agriculture University, Master's study at University of Chinese Academic of Sciences, Institute of Urban Environment, the time of Ph.D study, those education give me the knowledge structure from ecology tourism, urban ecology to landscape ecology, which combines social science, forestry, tourism, geography, remote sensing, and ecology. The interdisciplinary gives me a lot of basic idea to explore urban spaces. During this stage, I got several chances to join Resilience City, TNOC, and UNCCD to develop an interdisciplinary insight to observe urban spaces and their connections with humans. And the chance of the HU WINS project brought one-year training with mentorship. The department of Geography also provided a lot of help for me in participating in conferences. The lab of landscape ecology provided me with a research atmosphere. I would like to appreciate my supervisor Prof. Dagmar Haase recommend me to follow my thinking; meanwhile, my colleagues gave me help and encouragement in those years, from Jessica Jache, Thilo Wellmann, Manuel Wolff, Salman Qureshi, Peer Von Döhren, Diana Dushkova and from the secretarial assistance of Dagmar Wörister. In particular, I should give a lot of thanks to the China Scholarship Council for financing my three years of Ph.D. studying and the help from the organization of Berlin-Brandenburg Chinese Scholars and German-Sino Environment and Energy Center, and the cooperation with Chen Cheng, Liu Lin, and Xue Bing. Special thanks are given to the reviewers of this thesis and the reviewers from the journals Land, Sustainable Cities and Societies, and Urban Green & Urban Forest.

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23.1. 2022 in Berlin

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Chapter 1: Introduction

Chapter 1. Introduction

Cities are important habitats that support human life and urban ecosystems. As a result of the climate change crisis and coronavirus 2019 (COVID-19) pandemic, increasing attention has been given to urban sustainable development at the global, regional, and local levels. The United Nations 2030 agenda for sustainable development emphasizes 17 sustainable development goals and 169 targets for transforming our world for people, the planet, and prosperity. Making cities inclusive, safe, resilient, and sustainable is crucial. Especially with the development of urbanization, thousands of cities are facing urban heating, urban flooding, biodiversity loss, human health issues, and other environmental problems. Considering these challenges, urban transformation requires that the spatial aspects of urban areas concentrate on functions for ecosystem services and human well-being. City resilience is receiving more attention during the COVID-19 pandemic. Understanding urban space functions and their relationship with human well-being is crucial for increasing spatial multifunction, multi-utilization, and multiple supplies to enhance city resilience in response to climate change and health crises.

1. Urbanization, urban space, and spatial heterogeneity

Urbanization is a manifest process worldwide composed of different models in different areas. The urbanization rate is defined by the urban population, which is the number of people living in urban areas. Global urbanization has increased from 34% in 1960 to 56% in 2020 (The World Bank 2020). Although the overall speed of growth has dramatically decreased, the global trends of urban development present different patterns and scales. Urbanization has several features, including aging population increases in Europe and North America and migration from rural to urban areas in Asia (Haase, Güneralp et al. 2018). Urbanization is driven by the changes in in the relationship between capitalist development and urban space development. It provides the vision for socio-spatial structures for urban forms, such as deconcentrating models (Gottdiener 2010). Several different models partially combine biophilic urbanization with human-natural relationships (Heerwagen 2009), rapid urbanization with rapid economic growth (Monda, Gordon-Larsen et al. 2007, Lin and Ouyang 2014), and suburbanization with the deconcentration of the population to the periphery (Mieszkowski and Mills 1993). With the circles of deconcentration and concentration, urbanization models have primary cities, intermediate-sized cities, and small growth cities (Geyer and Kontuly 1993).

Urbanization has positively impacted economic growth over a long period (Bradshaw 1987), but environmental problems have gradually become prominent in cities. These problems cause humans to rethink how to make urbanization more suitable for life. Urbanization requires innovation and shifts, stimulated by environmental problems, to mitigate ecological and social phenomena. For example, from 1800 to 1850, the growth of slums, pestilence, and overcrowding in British cities led to legislation regarding sanitary and public health (Batchelor 1969). Under the pressure, the concept of the garden city, proposed by Howard, guided updates of urban spaces that included laying out parks and open spaces for public use and creating public urban parks to support recreation and human health in the city of London (Buder 1990). In response to climate change and human health crises, restructuring urban spaces is entering a new era for improving sustainability; it is common sense to consider the importance of urban ecology functions. Urban spaces have always responded to crises with processes for updating cities that benefit the people. With the growth of urban populations and human demands, urban space is a critical issue in the process of urbanization.

When we talk about space as being three-dimensional and relative from its physical perspective, which refers to its size, shape, and position to the other bodies as reference (Dainton 2016). An alternative definition is suggested by Leibniz, stating, “all the material bodies in the universe are differently related to absolute space”, which urban space also dynamically demonstrates. Cities are a product of human activities with spatial-temporal differences depending on anthropogenic design and planning. Dating back to the emergence of early cities in approximately 33500 BC, anthropologists define early cities with as having urban functions and some interactions with sociology; functional definitions vary based on the economic, administrative, and religious perspectives (Fernández-Götz and Krausse 2017). Urban spaces are generally classified into different types for conducting urban functions with biotic and abiotic management and design. For instance, in ancient Greece, urban spaces comprise squares for public entertainment, temples for religion, etc. In addition, urban space bounded by different elevations consists of geometrical characteristics and aesthetic qualities (Krier and Rowe 1979). A narrow view defines urban spaces as encompassing indoor spaces divided into residential, industrial, commercial, and cultural spaces, and outdoor spaces composed of open space, green space, water, agriculture, etc. Cities have gradually developed from urbanization and are characterized by their degree of land exploitation and their model of urban planning. In response to human activities, the evolution of urban spaces in most metropolitan areas changes from monocentric to polycentric under mitigate overcrowding and environmental problems. In the context of climate change, most cities are experiencing urban heat islands attributed to urban space structure and composition (Oke 1982). Normally, land use and land cover (LULC) are heavily utilized to understand urban spaces in ecological analyses. The former is defined as the pattern structure, while the latter is defined as the functions of land (Cadenasso, Pickett et al. 2007). To further strengthen the potential of urban sustainable development, it would be valuable to explore urban spaces and other related aspects. More importantly, understanding and replanning urban spaces constantly empowers city transformations and shifts to face urban challenges. Consistent urban problems that result from global urbanization break basic rules and ask new questions of urban space. Based on the experiences of American cities, Henry Churchill in 1962 proposed that "the city is the people", which means that urban space planning requires that whole communities be combined with architecture when determining the goals of urban planning for citizens (Churchill 1962). Moreover, "Cities for people", proposed by Jan Gehl, provides urban space planning, especially for public spaces and public life, for people to actually use for their lives and work (Gehl 2013). It can be seen that the basic principle of urban spaces is unchangeable for giving people a good life.

Urban is a complex mosaic with different types of spaces. Spatial heterogeneity in cities shows the differential in spatial components of the physical, biological, and social and spatial configuration of the vertical, horizontal, and temporal. Heterogeneity, as a spatial characteristic, can illustrate the influences of patterns on the ecological functions of systems based on landscape ecology theory units (Forman and Godron 1981, Forman 1995). As one of the critical concepts in contemporary ecology, spatial heterogeneity receives much attention regarding urban ecosystems, ecological processes and related functions on human well-being, and it can partly determine the capacity for sustainability (Zhou, Pickett et al. 2017). Primarily, spatial heterogeneity concerns dynamics in different scales, patterns, and processes (Pickett and Cadenasso 1995). The item scale, a crucial concept, seeks to evaluate a range of systems with the multiplicity of grain, extent, lay and ratio (Wu 2004). It can show a degree change at the global-regional-local scale, the macro-micro scale, the urban-suburban–rural scale, etc. Additionally, ecology metric-analysis indicates a whole-part relationship with the level of landscape and class. For example, class levels of land use type have more variable scaling relations than at the landscape level (Wu 2004). The fluxes of materials, energy and organisms at different spatial scales show heterogeneity for producing knowledge and implementation. In total, scale is an essential issue for understanding spatial interaction, providing analysis directions, and guiding level differences.

Pattern describes a form in specific detail. Spatial heterogeneity shows pattern spatial-temporal differences from one place to another and from a certain time to another. Pattern composition and configuration vary significantly and clearly reflect a variety of forms. Spatial composition is represented by the form conditions with a different integration of elements. For example, from a city level, urban patterns can be shown in different land uses, demonstrating the spatial heterogeneity of different geographical positions; moreover, from a neighborhood scale, patterns could consist of green infrastructure, blue infrastructure, and gray infrastructure; in green infrastructure, the distribution of tree species and aging structure could also bring in different patterns. Thus, pattern heterogeneity can be influenced and guided based on the connection and interaction with research questions and chosen scales.

In landscape ecology, processes are influenced by pattern heterogeneity, as shown in Fig. 1-1. The interaction among patterns and processes shows the mechanism of reason and result. The interaction of elements and relative mechanisms on certain processes helps to understand the causes of different processes and to optimize patterns for enhancing their functions. For example, urban heat island (UHI) attributed to land use and land cover being associated with the pattern heterogeneity of temperature and land to determine which pattern of urban form has low temperature and could be used for the construction of cooling cities. Moreover, pattern heterogeneity could affect urban space design and planning.

More importantly, the spatial heterogeneity of human-nature needs more attention in metropolitan areas due to the variety of immigrants who compose a large part of the urban population. Urbanization requires strategies accounting for the processes of society, ecology, and economy. Thus, a comprehensive understanding of the spatial heterogeneity of certain functions and how to design urban space for enhancing ecological functions is needed. For example, climate change calls for the functions of temperature mitigation and adaptation in cities. Meanwhile, spatial heterogeneity in urban systems could help to reconceptualize land classifications (Cadenasso, Pickett et al. 2007). The integration of different urban components, including physical and biological components, has been proposed for developing urban ecology as the first step of urban sustainability (McDonnell, Hahs et al. 2009). Therefore, urban spaces have dynamic characteristics due to the difference in land use and land cover with various spatial components and configurations under different models of urbanization.

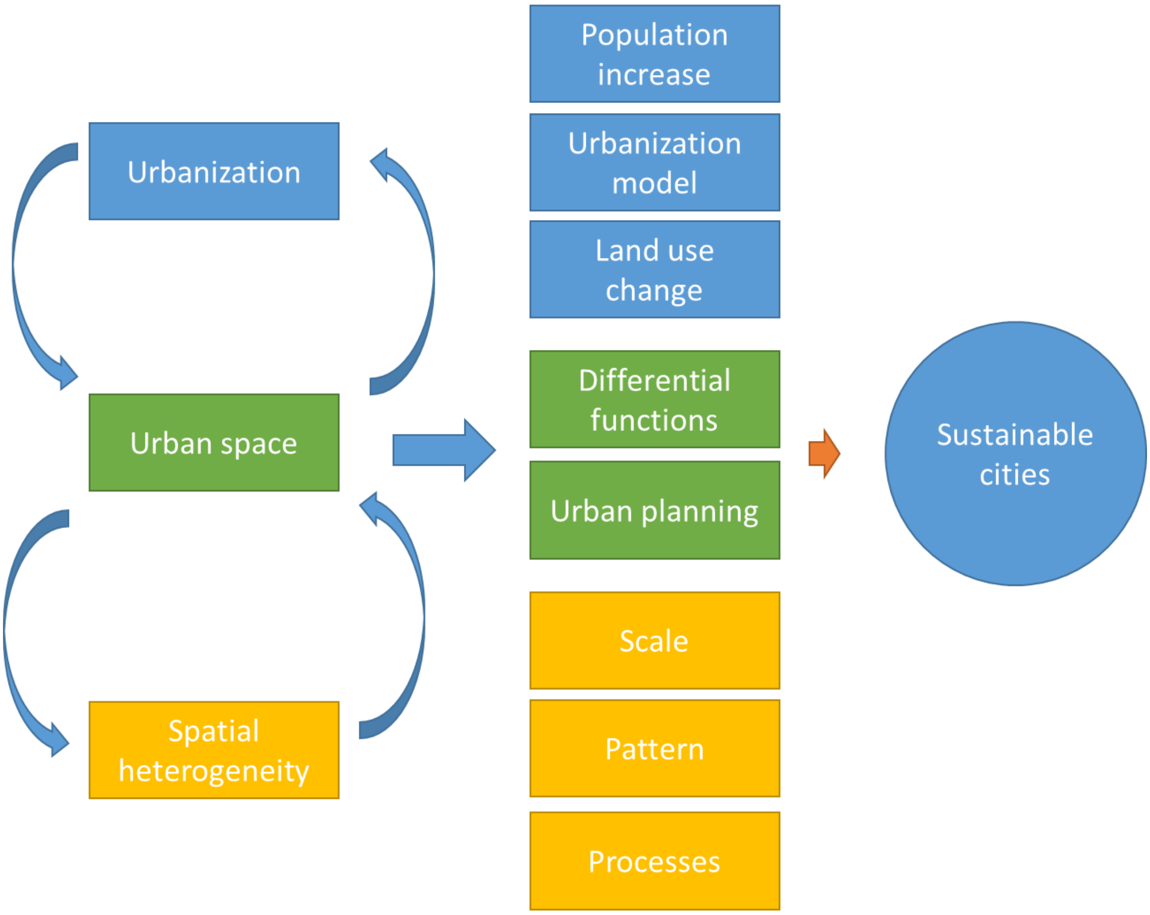

Figure 1-1. The relationship of urbanization, urban space, and spatial heterogeneity

2. Urban human-natural systems, ecosystem services, and human well-being

Urban systems are complex with mosaic patterns, including biotic and abiotic patterns for human activities and nature conservation; the evolution of urban systems chages with a wide range of spatial features. Cities have spatial complexity, organizational complexity, and temporal complexity which refer to the inaction of structures and inside systems (Pickett, Cadenasso et al. 2005). Urban systems can be studied for different purposes depending on the research subjection and aims; factors studies may include soil, water, atmospheric systems, urban forests, and others. Nevertheless, urban systems maintain society, economy, and ecology for human life and activities. Given a city is composed of human and natural systems. The interaction between human and nature typically influences the flows of energy, material and related ecological processes. Human communities are involved in different functional systems with well-developed communication networks; however, the urban ecology of cities is experiencing changes and disturbances during urbanization. The situation of nature influences human life. For example, urban nature functions can offset the impacts of urbanization by purifying air, decreasing noise, mitigating temperature, and enhancing environmental sense. Moreover, they have other functions associated with human mental and physical health, such as asthma, allergies, obesity, and heat disease (Endlicher, Jendritzky et al. 2008, Douglas 2012). The concept of urban ecology evolves in, of, and for cities, responding to the gradual dynamic knowledge of urban ecosystems and reflecting the changes in the sense of nature (Pickett, Cadenasso et al. 2016).

A system that integrates species with the local and nonbiological environment functions to keep life maintenance is defined as an ecosystem (Moll and Petit 1994). Traditional ecology mainly serves urban nature. A system is required to integrate traditional ecology for urbanization (Pickett, Burch et al. 1997). The coupled human and natural systems (CHANS) illustrate the interaction and feedback between humans and nature (Liu, Dietz et al. 2007). The CHANS approach combines ecological and social knowledge into a sophisticated system with a bidirectional model to determine the balance among people and surrounding environment. CHANS addresses central challenges in the 21st century regarding urbanization, land use and agriculture, climate change, sustainability and development, adaptation and resilience, society and culture, governance, general principles and system dynamics, education, science communication, conservation and ecosystem services (Kramer, Hartter et al. 2017). However, CHANS in urban areas needs more attention.

Human motivation impacts human society and communication, which alters natural systems. Human behavior has an influence on ecology (Likens and Cronon 2012); population biota and community affect ecosystems in urban areas, with differences demonstrated on an urban–rural gradient, and these ecosystems depend on management and capital apportionment from anthropogenic sources that are determined by socioeconomic factors (McDonnell and Pickett 1990). From human systems perspective, urban physical forms in size, density, grain, and patterns influence human life (Lynch 1954). For example, building design and residential area planning influence human mobility patterns (Attaianese and Duca 2012). Thus, the physical nature of urban systems is crucial to human lifestyles in cities. Human systems illustrate urban culture and vibrancy in cities with buildings, architecture, and artificial design (Mumford 2016, Chen, Hui et al. 2019). To manage stress, humans need a balance of urban nature and building environments (Beil and Hanes 2013). To fulfill human life, consumption, and life activities, methods that integrate biotic and abiotic are needed in urban space planning. From an urban-natural systems perspective, the primary features are biotic and include forest, agriculture, green spaces, and water, with fewer anthropogenic impacts. Urban nature is also considered to be a natural-based solution that provides ecosystem services. The coupled human-natural systems in cities both directly and indirectly affect human life, as shown in Fig. 1-2.

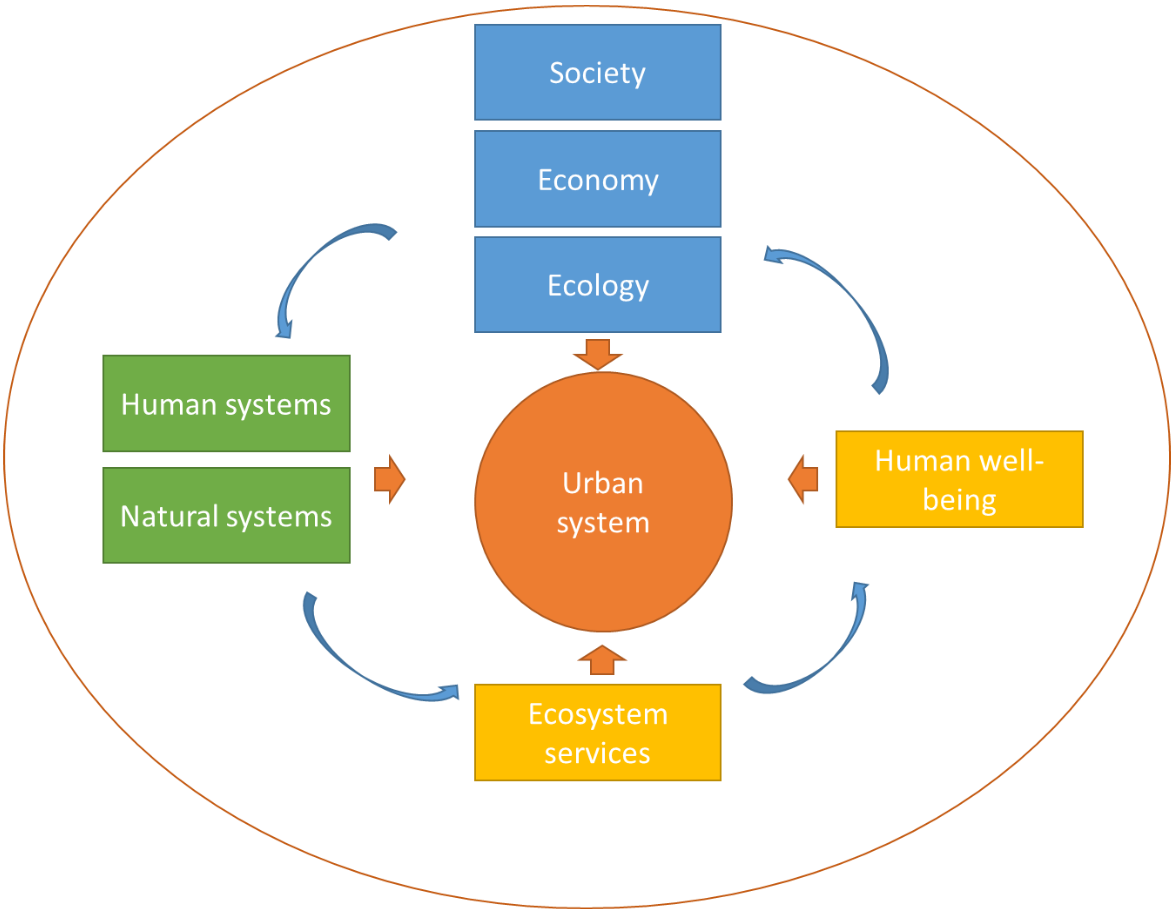

Figure 1-2. Urban human-natural systems, services, and human well-being.

According to the Millennium Ecosystem Assessment, ecosystem services (ESs) consist of supporting services, provisioning services, regulating services, and cultural services to enhance sustainable uses of ecosystems for human well-being (Assessment 2001). Urban ESs display differences from the global, regional, to local scales for safeguarding and sustaining human life (Breuste, Haase et al. 2013). Ecosystem service assessments can identify the spatial structures of systems and demonstrate factors that influence ESs, such as land use analysis and management that highlights climate change (Silvestri, Zaibet et al. 2013). Cities, the main habitat of humans, require more concern for human benefits. In the context of urban systems, human well-being illustrates quality-of-life conditions, which advance from urban spaces and their surrounding environment. These conditions provide guidelines for urban space planning to improve human happiness and satisfy human needs. From human wellbeing perspective, human mental and physical health have certain direct and indirect relationships with the surrounding environment. To deliver multifunctional nature-based solutions, integrating different types of knowledge requires an iterative way of different disciplines with top-down and bottom-up.

3. Natural supply, human demand, and urban space planning

The importance of urban nature and sustainability underscores the need to plan urban space for maintaining ecology and society. The continued imbalance between urban coupled human-nature systems indicates more challenges to human health and urban environment. This unsustainable situation implies a need for integrated solutions that can provide a vision of urban space planning. As urban nature benefits people and provides ecosystem services, the concept of supply and demand is utilized to analyze urban nature and human systems, including the supply and demand of cultural services of urban green infrastructure (Hegetschweiler, de Vries et al. 2017), the supply of and demand for water connected to urban ecosystem management (Chen, Li et al. 2020), the supply and demand for urban green space (Lee and Hong 2013), and quantification of supply and demand of ecosystem services (Baró, Haase et al. 2015, Chen, Jiang et al. 2019), etc. Thus, the analysis of supply and demand has significance in making urban planning more human-centric and natural, as shown in Fig.1-3.

Meanwhile, urban nature contains green and blue infrastructures, such as parks, forests, gardens, lacks, rivers, and others. In terms of cultural ecosystem services (CESs), urban nature has concerned to be vital for sustainable development. According to the 2030 Agenda, fulfilling lives in harmony with nature is essential for sustainable development (Assembly 2015, Colglazier 2015). Recent research has explored that the recreational use of green space increased during the COVID-19 outbreak (Venter, Barton et al. 2020). The benefits of green spaces to human wellbeing are at the center of research regarding the COVID-19 pandemic (Biswas and Sen 2020, Honey-Roses, Anguelovski et al. 2020). Satisfying human seeks to beautify and a healthy life is significant for landscape sustainability (Wu 2013, Ambrey and Fleming 2014, Vogt, Andereck et al. 2020). Urban areas confirmed as the primary human habitats that possess social diversity, especially migrating cities (Polèse, Stren et al. 2000, Zukin, Kasinitz et al. 2015). How to maintain various demands of multicultural communities for greenspaces is also vital for urban equality (Nelson and Ho 2020). It is generally recognized that greenspaces contribute to human wellbeing and sustainability (Bertram and Rehdanz 2015, Jennings, Larson et al. 2016, Kondo, Fluehr et al. 2018). However, relatively little is known about how to use social media data (SMD) to explore human demands across cultures for planning, designing and managing greenspaces to improve their positive outcomes and attractiveness to people.

CESs play an essential role in public life for exercising, taking children out, relaxing, viewing plants and natural landscapes, meeting friends, and other natural exposures. (Coolen and Meesters 2012). Meanwhile, greenspaces also function as tourist destinations, cultural identity locations, and memorials. CESs of greenspaces have association with a wide range of psychological-health benefits, such as improving attention, improving the sense of place, increasing positive emotions, alleviating discomfort and stress, perceiving restrictiveness from nature settings and natural biodiversity (Hartig, Evans et al. 2003, Lafortezza, Carrus et al. 2009, Reis and Roth 2009, Richardson, Pearce et al. 2010, Tamosiunas, Grazuleviciene et al. 2014). Moreover, the benefits of more time spent in greenspaces lead to higher health scores (Van den Berg, van Poppel et al. 2016). Few studies have examined possible negative emotions, such as insecurity and fear of crime in parks (De Donder, Buffel et al. 2013, Sreetheran, Van Den Bosch et al. 2014). Public greenspaces, as integral parts of the human-environment covering many land-uses in cities, are main resources of positive emotions and the sense of identity in urban areas (Barbosa, Tratalos et al. 2007, Coolen and Meesters 2012). The improvement of CESs comes from both people and nature (Milcu, Hanspach et al. 2013). Greenspace design needs to follow city planning and natural guidelines, but more importantly, it needs to reflect the values and preferences of cross-cultural communities (Özgüner 2011, Zhou and Rana 2012, Bell, Phoenix et al. 2014, Ives, Oke et al. 2017).

Considering the functions of CESs, urban spaces need the analyses of supply, demand and trade-offs to match human demands and natural resources. The supply-demand interrelationship provides guidelines for urban space planning. Generally, supply means certain visible goods or invisible services, while demand means the people requiring the goods or services. In economic concepts, the relationship between supply and demand determines price changes and dynamics (Kara 2011). Supply means what is available in markets, while demand emphasizes what customers need. The supply process includes inbound, operation and outbound, while the demand process consists of marketing, sale, and relationship management with customers (Bouchaud, Farmer et al. 2009). In recent years, this concept has received increasing interest and been widely utilized in interdisciplinary research. In tourism, supply-demand is an analytical framework of object and subject (Formica and Uysal 2006). The supply emphasizes that the object provides certain services or production, while the demand emphasizes the needs of the subject during a visit. Tourism supplies include traveling planning, design, cultural products, and tourism infrastructures (Sigala 2008). In tourism, demand requires measuring visitors' comments on goods and services, which have different patterns over time determined by different motivations for visiting tourism destinations (Song, Li et al. 2010). Meanwhile, human demands gradually change with the development of the economy and society. Through the interaction of supply and demand, urban ecology can be better understood from ecological and social perspectives. In urban nature, supply processes mainly identify the functional benefits to cities, including visible physical landscapes and invisible ecological services. The physical landscape is characterized by geometric factors of size, shape, spatial distribution (Dunham and Rieman 1999), and anthropogenic factors of planning conceptions, local cultures, functional design, and others. Moreover, urban nature is composed of different species, structures, and functions influenced by local culture and local climate. For example, if a park is divided into several parts consisting of water, nature conservations, children's playgrounds, and entertainment areas, then each part and region may have different designs. Some research has confirmed that the visual quality of urban nature is important for determining relationships with landscape characteristics (Gungor and Polat 2018). The quantity of urban nature is also identified as a supply feature for the accessibility of urban green space. In addition to these physical aspects, the ecological functions of urban nature contribute to nature supply, which can be quantified, partly including temperature mitigation, air purification, noise reduction, water absorption, and carbon storage. Determining supply can be used to analyze the quality and quantity of urban nature. Urban nature quality provides a foundation for understanding urban nature structure and its relationship with ecological functions, while urban nature quantity defines supply features of spatial distribution and patterns. In total, urban nature provides supplies extending from physical to ecological, from visual to functional, and from quantity to quality, thereby offering a broad range of research topics for integrating urban nature with the supply chain to support improvements and planning guidelines.

Furthermore, demand processes in urban nature could describe people's direct and indirect needs in urban natural environment. Due to the importance of maintaining people's lifestyle in cities, human demand creates requirements for urban nature concerning human health, visual preference, landscape behaviors, and emotional responses. For example, some research has referenced population density to assess urban green spaces with the geographic information system (Lee and Hong 2013), human health to determine urban nature measurements (Shanahan, Lin et al. 2015), human emotions for urban nature to improve environmental settings (Hull IV and Harvey 1989), and landscape behaviors to enhance urban nature functions (Park 1915). Exploring the ways to improve urban nature is vital for matching visitors' interests and preferences. Meanwhile, human demand alters with social background, individual experience and social development. For example, landscape behavior is the experience of human involvement in landscapes, which changes with the surrounding environment and individual situations (Makhzoumi and Pungetti 2003). As one indicator of human demands, human health is affected by urban environment quality, which is determined by the neighborhood socioeconomic status (Van den Bosch and Sang 2017). Moreover, cultural dynamics also affect human demands due to different values regarding urban nature, which potentially include plant symbolism, space utilization, a sense of place, and lifestyles. Under urbanization and globalization, many cities are becoming increasingly international with multicultural societies, while urban migrants and immigrants have cultures distinct from those of natives; these shifts lead to a change in ecosystem capacity and unsustainability (Meyerson, Merino et al. 2007). Thus, human demand for urban nature is a more critical function for migrants and needs more attention. Demand gradually changes with the development and challenges of the economy, society, and ecology, as occurred in response to COVID-19 (Geng, Innes et al. 2021). How to plan the supply of urban nature while integrating multiple demands for it is crucial for urban sustainability.

Urban space planning has a substantial relationship with urban life quality as demonstrated by garden cities, city beautiful movement, urban wildness, and nature-based solutions, all of which indicate the importance of urban nature (Kaplan 1983). Urban nature can, in a short time, improve urban landscapes for human wellbeing, and, depending on design processes and planning principles, contribute to the balance of supply-demand dynamics of urban nature. Understanding human demand and supply-demand interactions in urban space planning can enhance urban visual and ecological quality (Gungor and Polat 2018). The processes contain ecosystems that meet human demands for visual, emotional, healthy, and cultural preferences. In consideration of ecological adaptations and principles, urban space planning needs to give more attention to city sustainability in light of natural supplies and human demands. Moreover, the overlay of supply and demand can be compared to further determine unbalanced conditions where supply and demand are mismatched (Lee and Hong 2013). Consequently, the interrelationship between natural supply and human demand can enhance natural ecological benefits and human well-being during urbanization and urban shifts. To evaluate the potential of the attractiveness of urban nature, urban spaces must connect natural dimensions between ecological functions and human demands. The integration of supply and demand helps with urban planning by prioritizing and ensuring requirements based on visiting preferences, cultural differences, health fulfillment, and supply capacity. Overall, urban space planning combined with nature supply and human demand is crucial for responding to environmental problems in cities, building urban health lifestyles in the era of post-COVID-19, and enhancing urban sustainable development.

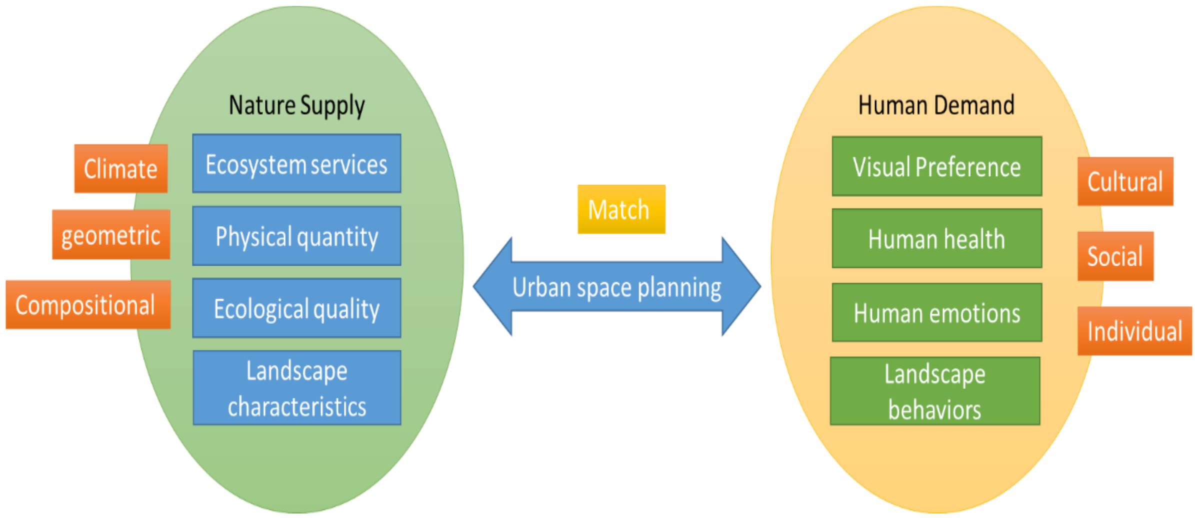

Figure 1-3. The concept workflow of nature supply and human demand.

4. Research scopes

Understanding urban development can help evaluate urbanization's impact on urban space, ecosystem services and human behaviors within a certain period. Urban spaces change spatiotemporally with composition and configuration dynamics, resulting in spatial heterogeneity. Analyzing urban space restrictions and related ecosystem services is necessary to distinguish spatial influences on the ability to mitigate temperature in response to climate change. Given that human demand guides the direction of urban space planning and landscape design, an assessment of human responses can provide integrated social and ecological measurements for landscape design. Meanwhile, the significance of urban land use for improving green space needs to be combined with planning practices in compact cities. This thesis builds upon related research and makes contributions in the following ways:

(1) Determining the classification of urban spaces across human-natural systems

The demand for standardized land use and land cover increases as we seek to assess and manage environmental control and compare different environmental influences (Anderson 1976). Land use classification shows the characteristics of land with strong relations to each other in urban systems. However, most classifications of land use lack the identification of urban functions. Considering the importance of human activities and natural conservation, this study integrates land use and land functions to propose a new classification of urban space across human-natural systems. The eight-type spaces include human systems with H1 residential area, H2 commercial area, H3 public service, H4 open space, and natural systems N5 natural green, N6 farmland, N7 brownfield, and N5 water. To separately discuss urban spaces in human-natural systems, the eight-type spaces are carried out to identify the potential for resilience enhancement.

(2) Exploring spatial variation in the thermal environment in the eight-type spaces

Despite the importance of urban sustainability, not enough studies have been done on spatial heterogeneity for temperature mitigation, especially in human-natural systems. Previous research has confirmed that different urban spaces show temperature differences, especially in green spaces and built-up areas. Exploring temperature mitigation in different land uses is vital for urban planning during the climate change crisis. Due to the effects of evapotranspiration, urban green spaces, green roofs, and urban agriculture contribute to urban temperature mitigation (Qiu, LI et al. 2013). In particular, urban green space is considered an effective way to reduce the urban heat island (UHI) effect, as it can decrease the temperature by approximately 1.1°C in summer months, according to a London case study (Doick, Peace et al. 2014). Meanwhile, increasing city albedo is of significance; for example, urban green roofs and high reflection roofs with gray paint have approximately equal heat fluxes (Takebayashi and Moriyama 2007). Anthropogenic material on cool pavements has high potential for increasing climate resilience (Santamouris 2013, Akbari and Kolokotsa 2016), and reflective pavements have the ability to reduce temperature by approximately 1.5°C (Kyriakodis and Santamouris 2018). Furthermore, water bodies have confirmed the function of temperature mitigation in which lakes have a stronger impact than rivers in Shanghai city when comparing the effect of water cooling islands (Du, Song et al. 2016). Some studies illustrate that water bodies have different influences on temperature mitigation. Spatial composition influences ecosystem services and human wellbeing. Consideration of the spatial composition, normalized difference vegetation index (NDVI), normalized difference building index (NDBI), and normalized difference water index (NDWI) demonstrate the characteristics and pattern differences of urban spaces and analyze the relationship between UHIs and land use/land cover (Chen, Zhao et al. 2006, Ghosh and Das 2018). However, numerous studies have been conducted on temperature mitigation and spatial composition and configuration. Nevertheless, the temperature mitigation ability of different urban spaces has not been studied in relation to coupled human-natural systems. With the application of the eight-type spaces, this study aims to determine the heterogeneity of land surface temperature and related spatial components for enhancing climate resilience.

(3) Improving greenspace with the integration of UGS quality and quantity

UGS plays an important role in moderating environmental problems in urban spaces. To increase city resilience for adapting to climate change and urban capacities for sustainability, UGS improvement has received increasing attention, especially in compact cities with limited land development. Considering the specific function of UGS, this thesis aims to demonstrate how to improve urban green space quality and quantity. The cooling effects of UGS are related to their spatial composition and configuration, and their temperature differential can be used to identify quality. Qualification of temperature in UGS includes land surface temperature (LST) retrieval from satellite data (Weng, Lu et al. 2004, Kalma, McVicar et al. 2008, Li, Tang et al. 2013) and air temperature retrieved through temperature sensors (Doick, Peace et al. 2014, Grilo, Pinho et al. 2020) and weather modeling (Morini, Touchaei et al. 2018, Zhou and Chen 2018). Land surface temperature is a vital parameter for detecting UGS pattern differences. Meanwhile, UGS provides places of entertainment for humans, thus how to increase UGS quantity has attracted much concern in cities, especially compact cities, where there is land competition for economic, ecological, and societal needs (Tian, Jim et al. 2012). Urbanization exacerbates competition between the needs of the urban population and environmental due to the limitation of natural capacity. Thus, clarification of UGS quality and quantity can contribute to land use management and planning practices in cities.

(4) Assessing supply and demand in different types of UGS

Further study on human demand for UGS can improve city resilience. UGS provides cultural ecosystem services that enhance human wellbeing. Human demand is characterized by emotional responses, which can be quantified to determine UGS planning improvements that can satisfy human needs. A variety of human emotions can occur (López-Mosquera and

Sánchez 2011) while visitors have different preferences for UGS landscapes. These landscapes can stimulate different emotional responses for specific areas; for example, larger UGSs can promote more positive emotions (Cameron, Brindley et al. 2020). In different types of green spaces, landscape characteristics with physical and psychological landscapes are dynamic due to differences in planning and design (Hull IV and McCarthy 1988). The design characteristics of greenspaces vary with landscape elements in parks, forests, gardens, and other green spaces (Parker 2001). Based on different landscape characteristics, visitors' responses vary widely depending on their preferences; social media data reflects these emotions. Human emotions in different languages can be captured from social media data and analyzed to compare emotional responses to UGS from the local population with those of the migrant population. Thus, integration of natural supplies and human demands with landscape characteristics and human emotions can determine the relationships and find out how to improve human positive emotions in UGS.

(5) Exploring city resilience with the city self-learning concept

City resilience illustrates system abilities to face change when confronted with environmental problems. Enhancing city resilience requires multiple participants in implementation and includes aspects of urban planning, policy-making (Labaka, Maraña et al. 2019), and stakeholder awareness (Iturriza, Labaka et al. 2020). The health challenges from COVID-19 have inspired people to pay more attention to resilient cities (Scott 2021). Previous research has confirmed the effectiveness of resilience planning to enable facilities to respond to climate problems (Dulal 2017). However, the related concepts still need more attention for a better understanding of resilience mechanisms. Thus, this research aims to propose the concept of city self-learning to enhance city resilience at the local level.

Overall, urban space contributes to climate change and human wellbeing. This thesis aims to evaluate different urban spaces for temperature mitigation, to explore the integration of quality and quantity for improving green spaces, to research greenspace on human emotions with supply and demand and to carry out self-city learning.

Chapter 2: Methodology

Chapter 2. Methodology

Urban space as the basis of urban sustainability comprises an extremely broad analysis of scales and systems. The methods require multiple resources to understand the relationship among human-natural systems**.** An interdisciplinary approach can help urban spatial planning to maintain ecological adaptation under climate change and human demand under urbanization. As many changes occur during urban development, the integration of space management with multiple methods of remote sensing, geographic analysis, landscape ecology, and social media analysis is necessary.

1. Geography information based on remote sensing data

Remote sensing helps to analyze land changes, spatial patterns and ecological processes, support the relationship among patterns and processes, and guide land management and practices. To date, satellites have been launched to characterize terrestrial and ocean systems. There are several remote-sensing programs in the world, mainly including Landsat (Table 2-1), MODIS (Table 2-2), and Sentinel (Table 2-3). Landsat satellites have spectral bands for tracking land surface change and land surface temperature in response to climate change. Moreover, MODIS data are a key instrument for Terra and Aqua satellites. The sentinel program is provided by the European Space Agency. Below is an overview of remote sensing data.

Table 2-1. Landsat satellite program from U.S. Geological Survey.

Program	Launch date	Sensors
Landsat 1	In July 1972	The return beam vidicon and the multispectral scanner system
Landsat 2	In January 1975	The return beam vidicon and the multispectral scanner system
Landsat 3	In March 1978	The return beam vidicon and the multispectral scanner system
Landsat 4	In July 1982	The multispectral scanner and the new thematic mapper
Landsat 5	In March 1984	The multispectral scanner and the new thematic mapper
Landsat 7	In April 1999	The enhanced thematic mapper plus (ETM+)
Landsat 8	In February 2013	The operation land imager and the thermal infrared sensor

*Source from U. S Geographic Survey

Table 2-2. Moderate Resolution Imaging Spectroradiometer (MODIS)

Products	**Contents**
Atmosphere	Aerosol, total precipitable water, cloud product, atmospheric profiles, atmosphere joint, atmosphere gridded product, and cloud mask
Land	Surface reflectance, land surface temperature and emissivity, land cover products, vegetation index, thermal anomalies, fraction of photosynthetically active radiation, evapotranspiration, gross primary productivity, bidirectional reflectance distribution function, vegetation continuous fields, water mask, burned area product
Cryosphere	Snow cover, sea ice and ice surface temperature
Ocean	Sea surface temperature, remote sensing reflectance, diffuses attenuation, particulate organic carbon, particulate inorganic carbon, normalized fluorescence line-height

*Source from the National Aeronautics and Space Administration (NASA)

Table 2-3. Sentinel programs from the European Space Agency

Program	**Launch date**	**Satellite Missions**
Sentinel-1	In April.2014	Monitor land and the ocean
Sentinel-2	In June 2015	Monitor land in vegetation, soil, and coastal area
Sentinel-3	In February 2016	Provide marine observation in sea-surface topography, surface temperature, and color
Sentinel-4	In 2019 and 2027	Monitor the earth's atmosphere
Sentinel-5	In October 2017	Monitor air quality trace gases and aerosols
Sentinel-5P	In October 2017	Perform atmospheric measurements with high resolution
Sentinel-6	In November 2020	Extend the legacy of sea-surface height measurement

*Source from The European Space Agency (ESA)

1.1. Three indices of NDVI, NDBI, and NDWI

To define and characterize the land surface, the three indices of the normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), and normalized difference water index (NDWI) detect the features of land cover (Table 2-4). Remote sensing images partly include Landsat 5, Landsat 7, and Landsat 8 from the U.S. Geological Survey (USGS), and the product of Moderate Resolution Imaging Spectroradiometer (MODIS) from the National Aeronautics and Space Administration (NASA) and Sentinel images with 10 meter resolution from the European Space Agency (ESA). The three indices respectively substitute the percentage of vegetation, building and water (Chen, Zhao et al. 2006, Ettehadi Osgouei, Kaya et al. 2019). In Landsat imagery, NDVI shows the percentage of vegetation calculated from NIR and RED bands; NDBI determines the build-up area monitored with NIR and SWIR bands; NDWI monitors soil moisture and water content in water bodies with NIR and SWIR bands (USGS 2016, USGS 2018). To determine the influence of patterns on ecological processes, the relationship between the three indices and ecological functions has received much attention in the pursuit to understand urban growth.

Table 2-4. Three indices in urban research.

Indices	**Calculation**	**Description**
Normalized difference vegetation index (NDVI)	Red and near-infrared bands	Detecting vegetation coverage and canopy biophysical properties
Normalized difference built-up index (NDBI)	Mid-infrared and near-infrared bands	Detecting Built-up area
Normalized difference water index (NDWI)	Green and near-infrared bands	Detecting hydrology of surface and water body

1.2. Land surface temperature

Land surface temperature (LST) is a crucial land perimeter for describing energy exchange between land and air. It is generally retrieved from thermal infrared data of remote sensing imagery, which includes Landsat TM5, Landsat ETM7, Landsat 8 OLI, and MODIS LST products (Wang and Liang 2009, Neteler 2010, Westermann, Langer et al. 2011), and the advanced spaceborne Thermal Emission and Reflection Radiometer (ASTER) from the Japanese sensor (Liu, Hiyama et al. 2006, Malbéteau, Merlin et al. 2017).

The atmospheric influence on the surface thermal radiation is first estimated. This atmospheric influence is subtracted from the total thermal radiation observed by the satellite sensors to obtain the surface thermal radiation intensity, which is then converted into the corresponding surface temperature. According to Landsat satellite images, land surface temperature is retrieved from the brightness temperature with several methods of correction (USGS 2016, USGS 2018). First, the digital number is converted into spectral radiance and then further calculated into brightness temperature. LST retrieval can be utilized with methods including a mono-window algorithm (Qin, Karnieli et al. 2001, Rongali, Keshari et al. 2018), split-window algorithm (Ulivieri, Castronuovo et al. 1994), radiative transfer equation (USGS 2018) and single-channel algorithm (Jiménez-Muñoz and Sobrino 2003). Land surface temperature is corrected with the NDVI method by emissivity and atmospheric correction.

1.3. Impervious surface percentage (ISP)

Land surfaces have to carry out several perimeters that are highly related to urban human-natural systems. Those systems on land use and ecosystem quality normally could be diminished with impervious surface percentage (Sun, Li et al. 2013). The percentage of impervious surfaces can be calculated from surface area and impervious area using remote sensing satellites (Slonecker, Jennings et al. 2001). Under urbanization, natural dominated surfaces have been replaced by human-made surfaces, for which the impervious surface percentage (ISP) increases. Imperviousness is a crucial indicator responding to land cover changes, which have an influence on urban hydrology and surface temperature. To determine the characteristics for each land use, the ISP can estimate the human-made surface and natural parts,including grasslands, water, and green vegetation. Several studies have confirmed that ISP influences the urban heat environment due to emissivity differences from multiple land reflections (Goward 1981, Zhou and Chen 2018).

2. Methods based on landscape ecology

2.1. Land use and land cover changes

Land use and land cover are altered through anthropogenic processes and are significant to the study of urbanization and climate change assessments. Land use refers to the function of land in human management, such as residential areas, commercial areas, and forests. Land cover provides a definition of elements in the environment, such as buildings and water. An effective method with supervised classification and unsupervised classification can map land use characteristics (Giri 2012). Modeling land use and land cover change (LUCC) demonstrates the driving forces of land use functions from socioeconomic and biophysical perspectives on the functions of land use (Verburg, Kok et al. 2006). In particular, human activities have raised concerns regarding the impact of urbanization. The assessment of ecosystem services analyzed with LUCC demonstrates the interaction between land use and ecological functions and further guides land management (Wang, Dai et al. 2018, Liu, Yang et al. 2021). Previous studies have examined the impact of LUCC on recreation for tourism (Nahuelhual, Carmona et al. 2014), carbon storage (Hernández-Guzmán, Ruiz-Luna et al. 2019), regional temperature (Hale, Gallo et al. 2006, Das and Angadi 2020), urban vegetation net primary productivity (Fu, Lu et al. 2013), and ecosystem service value (ESV) (Wang, Dai et al. 2018). Based on the research described above, land use and land cover change could characterize pattern changes in the processes of urban development.

2.2. Spatial analysis

Spatial analysis can determine the specific implementation of spatial content and its ecological relationships of pattern and processes. Spatial patterns have heterogeneity with scale, construction, and configuration, which are important for comprehending differences in intensity and types of processes (Dale and Fortin 2014). The patterned mosaic can be qualified by analyzing patterns, mapping clusters, measuring geographic distribution, and modeling spatial relationships. Spatial analysis methods can be used to study the interaction of ecology, economy and society that affects the patterns and influences of human activities for sustainable development and human-natural balance. Furthermore, features locations and attribute values with different spatial analyses in ArcGIS are estimated by measuring spatial autocorrelation with Moran’s index (Chen 2013), clustering the degree of value with the Getis-Ord value, and identifying significant hot spots and cold spots with the Getis-Ord GI* statistic (Griffith 1987).

2.3. Landscape metrics

Landscape metrics are adopted to determine the relationship between landscape perception and processes to characterize, evaluate and investigate landscape structure. The definition and choice of metrics can be established with reference frameworks based on landscape patterns and processes (McGarigal 2006). Landscape metrics can be calculated with Fragstats and Patch analysis in GIS. Meanwhile, for ecological functions connections, the patch matric model (PMM) can illustrate landscape heterogeneity and functionality (Lausch, Blaschke et al. 2015), for example, the efficiency of landscape metrics on the impact of urban heat island (Weng, Liu et al. 2007, Liu, Peng et al. 2018). There are metrics quantifying spatial characteristics at three levels of heterogeneity, including the patch level, class level, and landscape level. The pattern aspect contains patch size distribution and density, patch shape complexity, core area, isolation, dispersion, contagion and interspersion, subdivision, and connectivity (McGarigal 2017).

3. Human response based on user-generated geographic information

In urban ecology research, integration with human responses is essential for sustainability to satisfy human demand in urban space design. Humans get entertainment in parks and green spaces within cities, during which dynamic geographic information is generated by social media and mobile devices (Table 2-5). These resources can reflect human activities, emotions, and other responses that provide value and use for several types of data, including public participation, geographic information system, social media, mobile phone operators, and sport tracking (Heikinheimo, Tenkanen et al. 2020). These approaches provide insights on user information, geotags, time-stamps, contents and activities regarding a specific place for monitoring visitors' interactions with the environment (Heikinheimo, Minin et al. 2017).

Table 2-5. The type of user-generated geographic data.

Type	**Description**	**Accessing data**
Social media data	Data from social networking, such as Twitter, Facebook, Instagram, Weibo	Point data including user, post, caption text, emoji, picture, comment text, geotag
Mobile phone operator	Data from mobile operator company	Grid data including number of people, timestamp
Sport tracking	Data from sport tracker	Line data including number of trips and road segments, number of people

*Source from (Heikinheimo, Minin et al. 2017)

3.1. User characteristics

Based on user information and statistics, visitors' characteristics can be acquired with number, age structure, gender distribution, etc. Managing landscape planning is vital understand factors that affect visitors' composition. For example, the number of visitors indicates the degree of popularity of a UGS for attracting people to visit. Basic visitor information shows different social preferences for greenspaces. Meanwhile, the influence of age on recreational preferences of UGSs landscape design reflects the diversity of age-related demands (Arnberger and Eder 2011). The specific greenspace demands of children and the elderly need more consideration and attention in planning. Thus, the combination of human demand with visitor characteristics can promote landscape sustainability to enhance benefits to human wellbeing (Kothencz, Kolcsár et al. 2017).

3.2. Activity analysis

In the context of human health, green space provides multiple sources of entertainment. Human activities in green space vary under different individual motivations and diverse environmental planning. To understand human demands on green spaces, human activities in green space can demonstrate the competing demands of UGS design. Generally, recent surveys have demonstrated that physical activities, such as walking, running, cycling, dancing, assembling, and others, are influenced by individual, cultural and environmental factors (Mytton, Townsend et al. 2012).The association between human activities and the amount and number of UGS has been proven, and humans have a positive relationship with UGS infrastructures, such as water features, parking areas, and walking routes. Human activities can provide planning guidance for UGS by measuring satisfaction through social media data and investigations. Human activity provide convincing evidence for determining human future demands and protecting natural characteristics (Sun and Shao 2020).

3.3. Sentiment analysis

To evaluate human emotions in greenspaces, social media data (SMD) helps to understand human demand. Multidisciplinary methods can combine SMD to qualify and evaluate human responses to green spaces (Plunz, Zhou et al. 2019). In the era of information and communication technology, SMD can be used to determine behaviors (Ilieva and McPhearson

2018) and CESs (Oteros-Rozas, Martín-López et al. 2018). SMD, as a reliable proxy for a survey-derived visitation, can reveal human reactions in greenspaces (Donahue, Keeler et al. 2018, Brindley, Cameron et al. 2019). The real-time messages posted by visitors are aboutl visitors' opinions and current issues, along with their specific sentiment (Ceron, Curini et al. 2014, Lim, Lee et al. 2019). Several studies have used SMD for human health and greenspace usages. For example, in New York, Twitter sentiment as a measure of well-being has compared positive outcomes inside and outside of parks (Plunz, Zhou et al. 2019). Georeferenced Flickr photos and tweets within greenspaces in Sheffield, UK, has been conducted to measure greenspace quality, showing little evidence of an association with the poor health of surrounding residents (Brindley, Cameron et al. 2019). The integration of Tencent density data, park attributes, and surrounding landscape features has revealed the relationship between the number of visitors and park characteristics in Shenzhen, China (Chen, Huang et al. 2018). Geotagged SMD in Beijing quantified the number of visitors in different types of parks (Zhang and Zhou 2018). Meanwhile, Twitter provides tweets in different languages. Some researchers have studied cultural differences within the multilingual web to compare how human behaviors differ across languages. Sentiment analysis guided by user demographics could be an important direction for research (Volkova, Wilson et al. 2013, Barbieri, Ronzano et al. 2016). SMD could visualize human emotions differences for greenspaces based on cultural background. However, little is known about SMD and cross-culture human emotions toward greenspaces.

4. Research framework

As the informed method, this study investigates the submitted research questions in this research with the following methodology.

S1: Urban spatial analysis for mitigating temperature with the eight-type spaces

This research carries out the eight-type spaces for climate change adaptation. Land surface temperature is adopted to assess the effect on temperature mitigation. With hot spot analysis, the composition of different land uses on LST is predominantly used for comparing the relationship with temperature mitigation. The utilization of three indices, NDVI, NDBI, and NDWI, is one of the most important aspects in the analysis of space composition and the effect of temperature mitigation (Fig. 2-1).

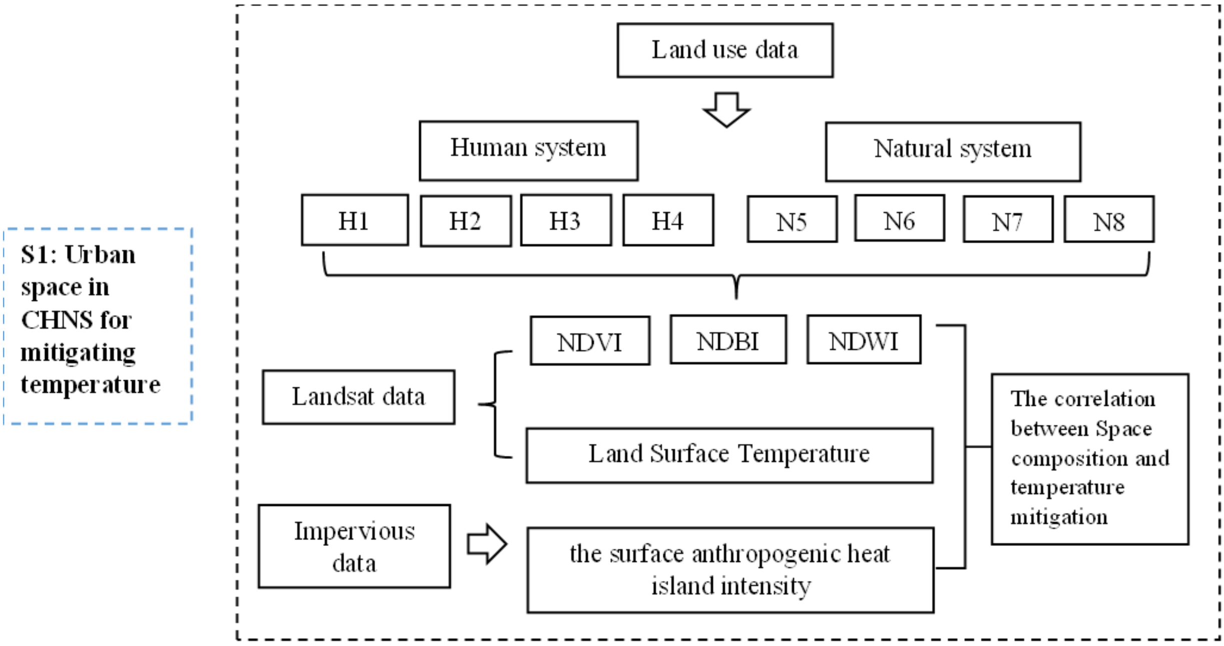

Figure 2-1. The research framework of S1.

S2: Human demand and UGS supply for promoting positive emotions

To illustrate the connection between human emotions and landscape characteristics, this research utilizes sentiment analysis with Twitter content and quantifies the physical and psychological landscape with Google Earth (Fig. 2-2). To detect the relationship among emotions and different types of UGSs, the number and sentiment of tweets are demonstrated in the 26 chosen green spaces. Furthermore, the correlation is demonstrated among landscape characteristics and sentiment for the two main languages of English and German. These methods explore the promotion of positive emotions while determining the specific landscape characteristics, which depend on cross-cultural differences, that can improve the supply.

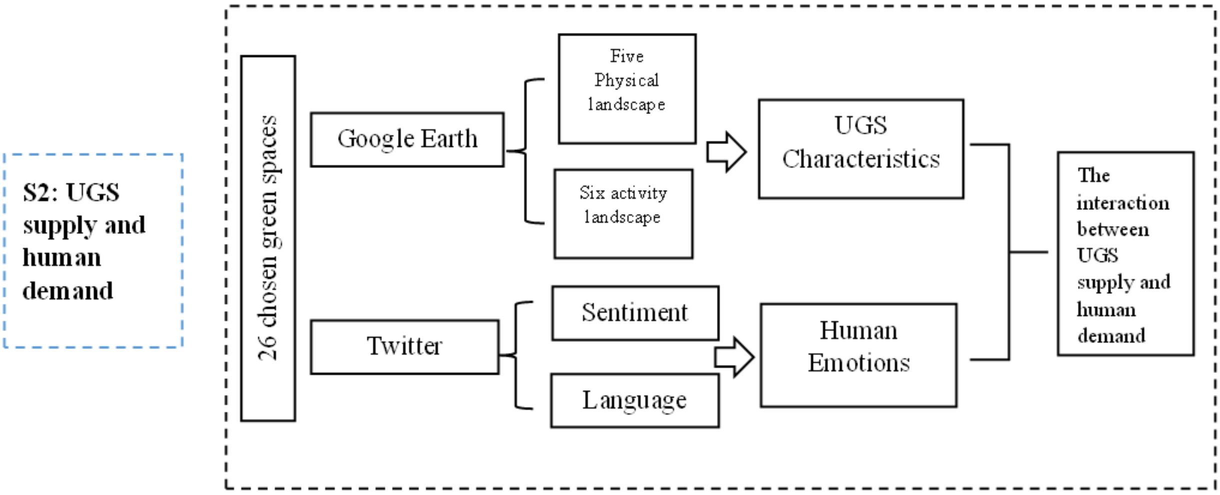

Figure 2-2. The research framework of S2.

S3: The integration of quality and quantity for improving UGS

Improving green spaces in compact cities requires land management and planning practices for USG quantity and quality. The S3 research adopted land use change analysis to determine the flux of decrease and increase areas (Fig. 2-3). The vector of land surface temperature was adopted to demonstrate ecological quality. Meanwhile, landscape metrics have been acquired for three types of UGS according to patch areas of small, medium, and large sizes. Furthermore, the demonstration of UGS planning practices to integrated quality and quantity shows potential for improving UGS in compact cities to enhance city resilience.

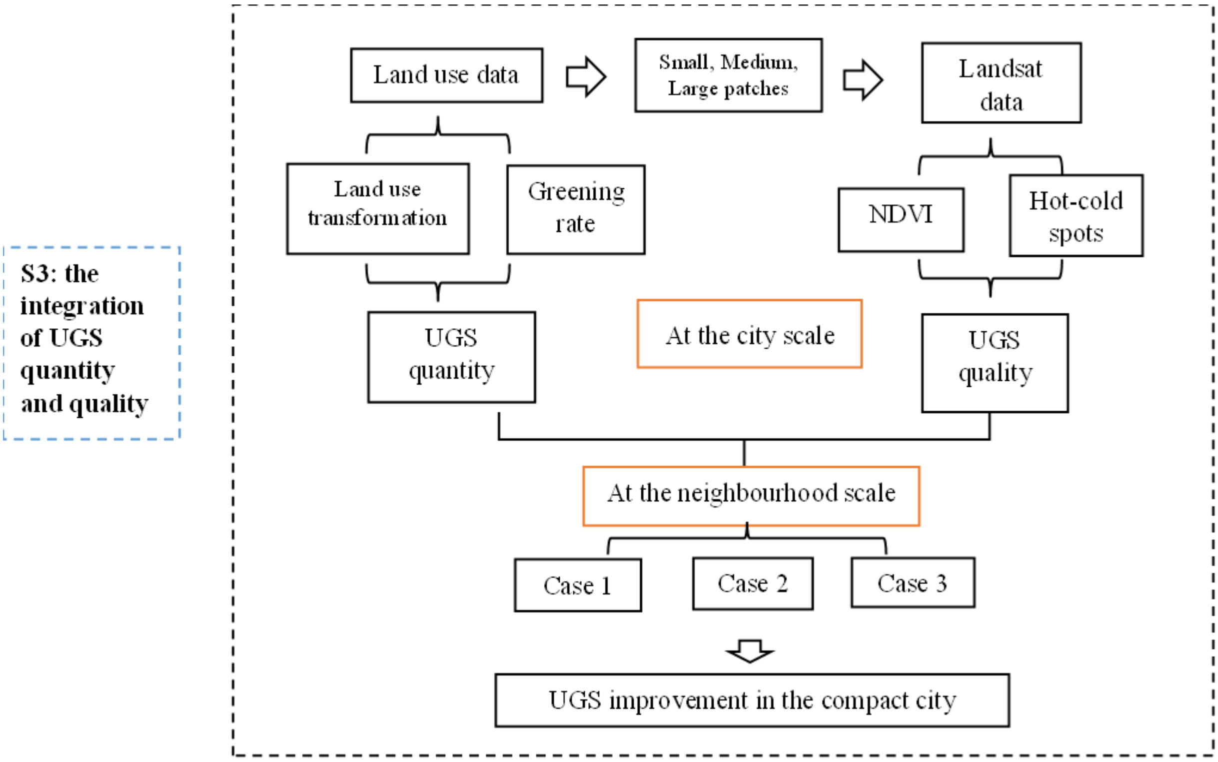

Figure 2-3. The research framework of S3.

S4: The concept of city self-learning for enhancing resilience

A concept of city-self learning with eight-type of land use is one of the major outputs of this work. With a literature review and the above three types of research, this section aims to illustrate spatial heterogeneity and its impact on temperature mitigation and human wellbeing (Fig. 2-4). To increase urban resilience to climate change and promote human health, urban space planning could have substantial potential by implementing the concept of "city self-learning."

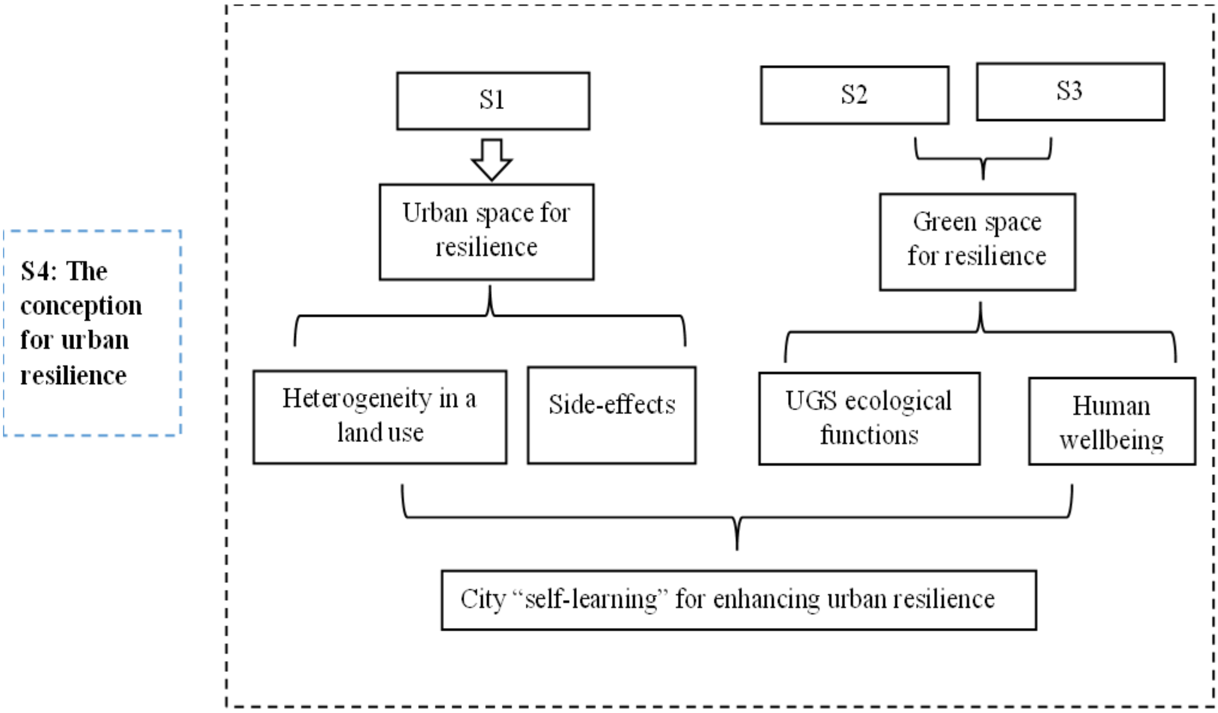

Figure 2-4. The research framework of S4.

In total, according to the workflow with the multiple methods, this project has defined urban space's potential to mitigate temperature. With the largest potential for temperature mitigation, greenspace improvement in compact cities illustrates strategies that combine quantity and quality. Furthermore, to promote human wellbeing, integrating greenspace supply and human demand into human responses demonstrates the correlation of greenspace design with human positive emotions. Combining with the three cases propose a concept for urban planning that increases urban resilience for adapting to climate change and promoting human health.

Chapter 3.

Integrated Land Use and Urban Function Impacts on Land Surface Temperature: Implications on Urban Heat Mitigation in Berlin with Eight-Type Spaces

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Chapter 3. Integrated Land Use and Urban Function Impacts on Land Surface Temperature: Implications on Urban Heat Mitigation in Berlin with Eight-Type Spaces

Abstract

The planning for cooling cities is crucial for sustainable development under the influence of climate change. However, urban warming mitigation across human-natural systems is scarce. This research aims at characterizing land surface temperature with the integration of land uses and land function with the eight-type spaces, including human systems (H1 residential area, H2 commercial area, H3 public service, H4 open space) and natural systems (N5 natural green, N6 farmland, N7 brownfield, N8 water). We seasonally investigated the LST, its correlation with three indices of spatial components. From the results, NDVI had more impact on LST than NDBI in H1, H3, H4, N6, N7, and N8; while NDBI had more influence than NDVI in H2 and N5; The area of Hot and Very hot classes in human systems is higher than in natural systems. It reveals that mitigating temperature across different urban land use types requires different management of green, grey, and blue infrastructures. The eight-type spaces could explain there are different NDVI and NDBI influences on urban temperature. More attention on urban planning is needed on human systems though increasing building height and combining grey infrastructures with green infrastructures and natural systems requiring decreasing impervious spaces for cooling cities.

Keywords: cooling cities, remote sensing, urban planning, green infrastructure, space components;

1. Introduction

Extreme heat is a critically important factor affecting ecosystem services and human wellbeing, in part due to climate change. The Intergovernmental Panel on Climate Change (IPCC) specifically reported global warming of 1.5 °C, suggesting a global response to climate change for sustainable development (IPCC 2016). One of the factors that result in climate change is overexploiting land use for urbanization, which further leads to significant greenhouse gas emissions and changes the interaction between land and atmosphere. Land use is a major anthropogenic activity and has strongly affected earth ecosystems and city resilience (Kalnay and Cai 2003). Due to the imbalance of energy and material in urban land-use planning, the phenomenon of urban heat islands significantly occurs in cities (Tam, Gough et al. 2015). More and more cities are facing the environmental challenges, which takes great risk to human health. Mitigation strategies are crucial for urban sustainability and human wellbeing under climate change (Wu 2014, He, Zhao et al. 2022). Understanding land with sustainable management can help build an effective relationship between humans and nature (Haase 2021).

Land use is a major anthropogenic activity and has strongly affected earth ecosystems and city resilience (Saunders and Becker 2015). Considering the impact of land uses, numerous studies have found that the composition and configuration of urban landscapes alter the local climate with various land use types, which leads to changes in the transactions between land and atmosphere (Foley, DeFries et al. 2005, Zhou, Hu et al. 2022). For determining the influential factors on urban heat, land surface temperature (LST) is an influential index in the identification of urban spaces on different land use types (Weng 2020). Heterogeneity in the LST is a result of the city size (Oke 1973), land use types (Jusuf, Wong et al. 2007), building heights (Alavipanah, Haase et al. 2017), and urban fabric due to the energy exchange between land and atmosphere (Jenerette, Harlan et al. 2016). To date, many researchers have studied the impact of land use on the LST by detecting LST dynamic under the change of land use and land cover (Pal and Ziaul 2017), exploring the relation between LST and land cover metrics (Weng, Liu et al. 2007, Chen, Deng et al. 2022), and modeling local climate zones (LCZs) based on land cover (Cai, Ren et al. 2018). In the exploration of the mechanism of urban heat in different land use types, LST has been confirmed to be positively correlated with impervious surfaces and negatively correlated with vegetation coverages (Li and Zhou 2019). The LCZs is a climate-related classification with ten built types and seven land cover types (Stewart and Oke 2012). Based on remote sensing and geographic information systems, the mapping analysis can determine urban land surface properties and study urban heat indicators (Yang, Ren et al. 2021). Thus, land use is important to research urban heat for temperature mitigation.

Moreover, urban functions are crucial indicators to design landscape and sustain environment. Previous research has used classification combining natural properties with social-economic functions, including residential, commercial, open space, and others in urban regions with the consideration of human activities (Pei, Sobolevsky et al. 2014, Xing and Meng 2018). Due to the different heat production and landscape characteristics, different functional regions have differences in temperature mitigation. For example, in residential regions, different resilience scenarios have illustrated that mitigation facilities of biophilic structures such as cool roofs, green roofs, and white roofs (Carvalho, Martins et al. 2017). Nevertheless, urban agriculture increases evapotranspiration contributing to cooling (Qiu, LI et al. 2013). Decreasing fragmentation of green spaces can mitigate temperature, hence is suggested to be adopted in urban planning (Li, Zhou et al. 2013); in addition, increasing tree canopy and quality of greenery can also enhance resilience to urban heat at the mesoscale and microscale (Breuste, Artmann et al. 2015, Berardi, Jandaghian et al. 2020). Advancing this knowledge is critical for understanding the causes and consequences of the spatial heterogeneity of different functions for temperature mitigation.

However, integrating urban functions and land uses to mitigate urban heat with the human-natural system lacks attention. Previous studies have determined the impact of land use and land cover on LST with different classification, including basic supervised classification into five and six types of land uses and land coves by remote sensing (Grigoraș and Urițescu 2019), and aim-orientation classification, such as five dominant land use types of new residential, old residential, villa, industrial, and institutional land use types, to visualize the impact of urbanization on LST (Li, Bai et al. 2014) and vegetation, artificial features, and cropland (Tran, Pla et al. 2017). Given the city is a complex and multiprocessing integrated system (Haase, Larondelle et al. 2014) that includes human systems and natural systems (Kramer, Hartter et al. 2017). The bidirectional interaction of the coupled human-natural systems (CHNS) with dynamic patches varies at global, regional, and neighborhood scales (Li, Qiu et al. 2017, Wang 2022). Assessing urban ecological processes requires an understanding of how interactions occur in human-natural systems (Alberti and Marzluff 2004). The significance of land use and urban functions can help to understand the mechanism of temperature mitigation.

Thus, mapping different functional land use types across human-natural systems is crucial to determine the compositions and configurations of urban forms for mitigating temperature in urban regions. Concerning the coupled human-nature systems, this study proposed the eight-type spaces (ETS), including four types for human activities in human systems and four types of essential elements in natural systems. This paper aims to identify the different LST patterns in human-natural systems with the eight-type spaces to characterize the influence of spatial components on LST in the eight-type spaces, and to propose suggestions for land use planning to increase urban potential for temperature mitigation. Here, this study proposes the classification of eight-type spaces to represent human activities and essential natural elements to explore the potential of urban heat mitigation and analysis.

2. Materials and methods

2.1. Study area

Berlin (52.52°N, 13.41°E) is the capital city of Germany (Fig.3-1, source from Esri), located in the North European Plain and in a humid continental climate zone according to the Köppen climate classification (Peel, Finlayson et al. 2007). The air temperature typically ranges from -2 °C to 25 °C, with the highest air temperature in July and August. Urban warming is becoming apparently and challenges human wellbeing due to the impact of climate change, land use changes, and anthropogony. Previous studies have confirmed that the urban heat island effect in Berlin is deteriorating (Gabriel and Endlicher 2011, Li, Meier et al. 2018). For instance, the hottest temperature rose to 38 °C in 2019, with risks to public health also gradually appearing (Scherer, Fehrenbach et al. 2013, Schuster, Burkart et al. 2014). The indicators of urban warming include the emission from human behaviors, fossil fuel from factories and traffic to air pollution (Li, Meier et al. 2018), the increasing impervious surface issues in land use (Wang 2022), and other environmental factors. Although Berlin is a mid-high latitude city in Europe, the problem of urban heatwaves has attracted much attention in recent years. With the declaration of a climate emergency, this city could be a suitable example for studying urban forms in the process of a neutral climate city for sustainable development.

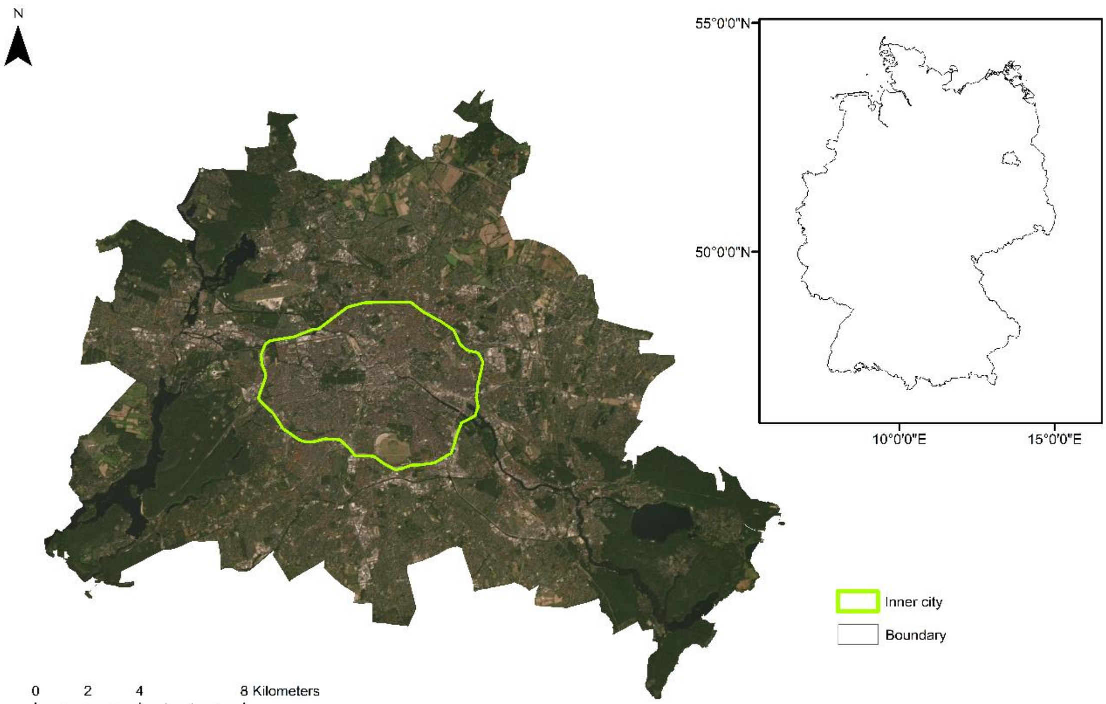


Figure 3-1. Location of the study area.

2.2. Data collection

For the retrieved LST and spectral indices, satellite images acquired on the 11th of April (Landsat 8), 7th of July (Landsat 7), and 3rd of October (Landsat 8) in 2015 downloaded from the US Geological Survey (USGS) Earth Explorer are used for researching the seasonal changes of temperature in the same year for ignorance the impact of land changes. The spatial resolutions of the Landsat 8 (Landsat 7) thermal bands are 100 and 60 meters. Various criteria, including climatic and seasonal conditions, are considered in the selection of the dates of the satellite images. The cloud coverage in the three days was less than 10% and the max air temperature in the three days from April to October was respectively 21 °C, 31 °C, and 20 °C from the world weather online.

2.3. Conceptual design for the eight-type spaces

Urban regions are a combination of human systems and natural systems in providing functions of residence and livelihood to maintain human needs and simultaneously natural conservations. The bi-direction of the human-natural systems helps to explore dynamic spaces reflecting social-ecological interactions. With limited spaces but the high density of dwellers, urban planning for enhancing climate resilience in different land uses is vital in the mitigation of urban heat with accurate planning. The concept of the eight-type spaces (ETS) integrates land uses and land functions covering the needs of human activities and the physical characteristics.

Table 3-1. The protocol of the eight-type spaces (ETS) with the integration of land uses and urban functions across human-natural systems.

Human systems	Definition	Natural systems	Definition
H1. Residential area	Mix of various buildings and attached landscape with a residential function.	***N5. Natural green***	Land use of forests and parks with high vegetation coverage.
H2. Commercial area	Mix of built-up areas with factories, commercial buildings and the attached land with functions of shopping business activities.	***N6. Farmland***	Land use of agriculture with functions of food support or agricultural conservation.
H3. Public service	Mix of land uses in built-up with the functions to provide basic services facilities for medicine, education, cultural, political, public sports activities.	***N7. Brownfield***	Mix land uses as unused land or wasteland.
H4. Open space	Mix of land uses with vegetation but man-made landscape, providing the functions to support entertainment and outdoor activities.	***N8. Water***	Water bodies, including rivers and lakes.

It aims to generalize all different urban land uses into the category. In human systems, land functions mainly serve for human activities. Human activities factored into the basic of life, including living, working, shopping, social and cultural activities, and outdoor activities and entertainment. Considering public daily activities, this category in human systems has four land types, each of which has the land function to satisfy human activities in cities. On the other hand, natural systems in cities are the land types with less impervious surfaces, such as forests and parks, conservations, urban wasteland, agriculture, and waters bodies. Urban natural elements are categized into four types with the concern of natural elements and functions. Therefore, the ETS is defined into human systems with H1 residential area, H2 commercial area, H3 public service, H4 open space, and natural systems with N5 natural green, N6 farmland, N7 brownfield, and N8 water with a protocol in Table.3-1.

2.4. Data analysis

Based on the case study of Berlin, a mid-high latitude city that has been suffering urban heat in recent years, in the first step, we seasonally analyzed the LST of the eight-type spaces and compared the influences of spatial components through the correlation of the LST with the urban biophysical composition. Then, the areas of hotspots and their seasonal variations in different human-natural systems were calculated and compared. Fig.3-2 shows the data processes. Moreover, the study only applied three-month data in 2015 to model the application of the eight spaces for urban temperature study for decreasing the impact of land use change yearly and exploring the impact under temperature increasing and decreasing processes.

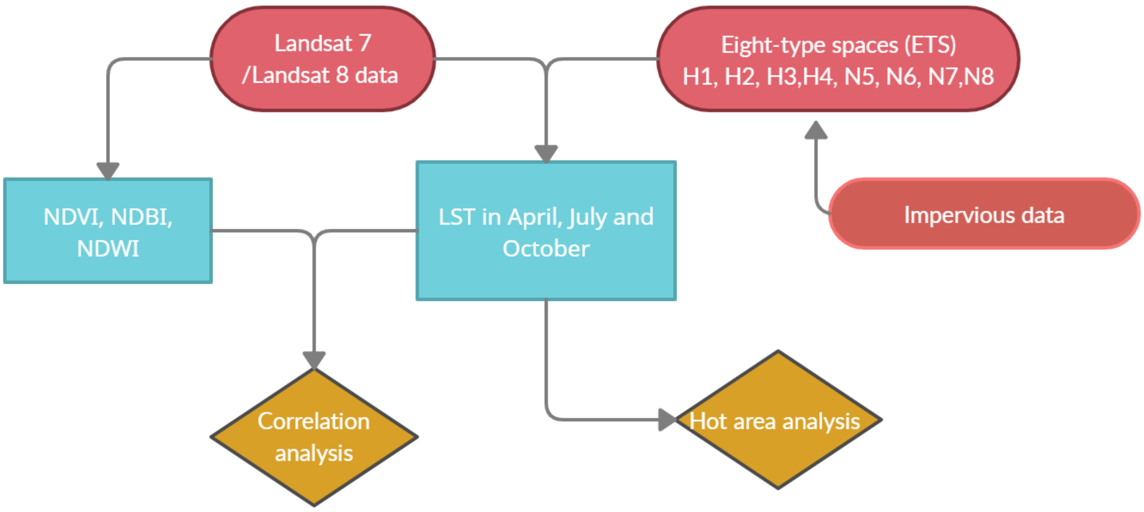


Figure 3-2. The diagram of data processes in the case of Berlin.

2.4.1. The eight-type spaces in the case of Berlin

Here, the contents of ETS are illustrated in Table.3-2 and Fig.3-3, which were reclassified the 2015 Berlin Land use data downloaded from the Berlin Senate Department for the urban environment (Umweltatlas 2015). Additionally, impervious data in 2015 with a 20 m spatial resolution are downloaded from Copernicus (available at https://land.copernicus.eu/).

Table 3-2. The eight land use types and ISP average in the case of Berlin.

H-N	Type	Content	ISP average (%)
Human systems	H1	Residential area: different-types residential buildings	45
	H2	Commercial area: commercial and industrial areas	60
	H3	Public service: culture areas, hospitals, schools, campuses and airports	43
	H4	Open space: squares, children's playgrounds, allotment gardens, cemeteries	35
Natural systems	N5	Natural green: parks and forest	8
	N6	Farmland	6
	N7	Brownfield	16
	N8	Water	0

*ISP, means the impervious surface percentage

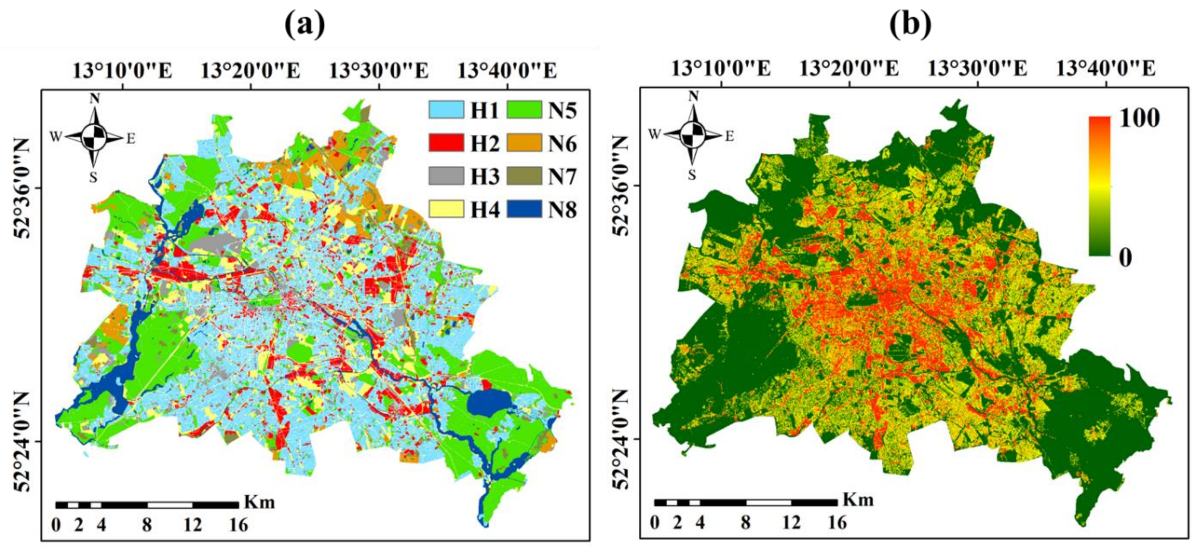


Figure3-3. (a) The eight-type spaces and (b) impervious surface percentage maps of Berlin.

2.4.2. Effect of urban biophysical composition on LST

To characterize the difference in ecological processes to urban heat in each type of land use, we retrieved the LST with satellite images of Landsat (Sobrino, Jiménez-Muñoz et al. 2004). LST was retrieved with TOA Brightness temperature of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Image (OLI) /Thermal Infrared Sensor (TIRS) according to the user handbook of Landsat 7 and Landsat 8 (USGS 2016, USGS 2018). The digital number (DN) value of the pixels from the thermal band images was converted to the spectral radiance and brightness temperature. Then land surface emissivity was calculated based on the method from NDVI. To define the land surface emissivity, NDVIs, for soil, and NDVIv, for vegetation, are assigned values of 0.2 and 0.5, respectively (Jiménez-Muñoz, Sobrino et al. 2014). Finally, LST was estimated.

First, based on Eq. (1), the digital number (DN) value of the pixels from the thermal band images was converted to the spectral radiance at the sensor's aperture ($L\lambda$ in units of Watts/(m^2 sr µm)).

$$TB = \frac{K2}{\ln\left(\frac{K1}{L\lambda} + 1\right)} \tag{1}$$

where TB is the brightness temperature and K1 and K2 are the calibration constants according to the user handbook of Landsat 7 and Landsat 8 (USGS 2016, USGS 2018). Second, the land surface emissivity was calculated based on Eqs. (2) and (3).

$$Pv = ((NDVI - NDVIs)/(NDVIv - NDVIs))^2 \tag{2}$$

$$\varepsilon = 0.004P_V + 0.986 \tag{3}$$

where the NDVI is the normalized difference vegetation index constructed by the red and near infrared bands and Pv refers to fractional vegetation coverage. NDVIs, for soil, and NDVIv, for vegetation, are assigned values of 0.2 and 0.5,respectively .ε refers to the land surface emissivity if 0.2 ≤ NDVI ≤ 0.5; if NDVI < 0, the emissivity is 0.98 (Gillespie, Rokugawa et al. 1998); if 0 ≤NDVI < 0.2, the emissivity is 0.97; and if NDVI > 0.5, the emissivity is 0.99 (Sobrino, Jiménez-Muñoz et al. 2004, Yu, Guo et al. 2014). Finally, the LST was estimated based on Eq. (4).

$$\mathrm{LST} = \frac{TB}{1 + \left(\lambda\, \frac{TB}{\rho}\right) ln\varepsilon} \tag{4}$$

where λ = 11.45 μm for Landsat 7 ETM and λ = 10.8 μm for Landsat 8 TIRIS. From Planck's function, ρ = hc/σ = 14388 μm K.

For modeling the effect of urban biophysical composition on LST, the NDVI, normalized difference built-up index (NDBI), and normalized difference water index (NDWI) are reflected from remote sensing data to characterize the differences of spaces (Weng and Fu 2014). The three indices separately represent the spatial characteristics of green, gray and blue infrastructures in urban biophysical composition. NDVI has been applied as a vegetation index to compare LST patterns and can decrease urban heat islands (Okumus and Terzi 2021). A spatiotemporal comparative study was conducted with the utilization of NDVI and LST to detect the surface ecological conditions of natural and unnatural factors (Qureshi, Shorabeh et al. 2021). NDBI, as the index of the building area, has normally been utilized to detect the impact of urbanization on LST with a long-term analysis (Guha, Govil et al. 2021). NDWI, indicating the index of water bodies, has been used to conduct seasonal analysis with LST on different land types to understand urban planning for cooling cities (Guha, Govil et al. 2020). Thus, the relationships between the LST and NDVI, NDBI and NDWI can effectively monitor the impact of land components.

The spectral indices of the NDVI with NIR and red (Eq. (5)), the NDBI with SWIR and NIR (Eq. (6)), and the NDWI with NIR and SWIR (Eq. (7)) were calculated according to Landsat surface reflectance in the required bands according to the user handbook of Landsat 7 and Landsat 8 (USGS 2016, USGS 2018). Pearson analysis was carried out in IBM SPSS Statistic 22 to quantify the influence of the three indices on LST. We correlated the NDVI, NDBI, and NDWI with the LST of each space in the three months and further compared the seasonal changes of the correlative efficiencies of NDVI r, NDBI r, and NDWI r and determined which index had a strong effect on decreasing temperature in the eight-type spaces.

$$NDVI = \frac{(NIR - RED)}{(NID + RED)} \tag{5}$$

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)} \tag{6}$$

$$NDWI = \frac{(NIR - SWIR)}{(NID + SWIR)} \tag{7}$$

2.4.3. Seasonal variations in hotspot areas in different human-natural systems

To extract hotspot regions, in the first step, classified LST maps from different dates were obtained based on Table.3-3 by mean-standard deviation method (Shirani-Bidabadi, Nasrabadi et al. 2019, Zhang, Zhang et al. 2022). Then, hotspot areas in different human-natural systems and these seasonal variations were calculated.

Table 3-3. Ranges of temperature classified.

Temperature class	Range
Very hot	$\mathrm{LST} > \mathrm{Tmean} + 1.5 \times \mathrm{Tstd}$
Hot	$\mathrm{Tmean} + 0.5 \times \mathrm{Tstd} \le \mathrm{LST} \le \mathrm{Tmean} + 1.5 \times \mathrm{Tstd}$
Medium	$\mathrm{Tmean} - 0.5 \times \mathrm{Tstd} \le \mathrm{LST} \le \mathrm{Tmean} + 0.5 \times \mathrm{Tstd}$
Cold	$\mathrm{Tmean} - 1.5 \times \mathrm{Tstd} \le \mathrm{LST} \le \mathrm{Tmean} - 0.5 \times \mathrm{Tstd}$
Very cold	$\mathrm{LST} < \mathrm{Tmean} - 1.5 \times \mathrm{Tstd}$
Tmean and Tstd are the mean and standard deviation of the LST values for each date.	

3. Results

3.1. LST in the eight-type spaces of human-natural systems

To verify the difference of eight-type spaces and their ecological process, we compared the proportion of each land use and the LST over the three months of 2015 (Figure 4). The percentages of human systems and natural systems were 58.53% and 40.37%, respectively (Table 4). In human systems, the area percentages of each type of land use were H1 residential area 31.09%, H2 commercial area 9.01%, H3 public service 7.31%, and H4 open space 11.42%; in natural systems, the proportions were N5 natural green 25.37%, N6 farmland 4.53%, N7 brownfield 3.39%, and N8 water 6.78%. In terms of land surface temperature, the acquired LST demonstrated that natural systems had lower temperatures than human systems, with temperature differences of approximately 1–2 °C. In general, the dynamics of the LST in land uses followed atmospheric temperature, typically with N5 contributing to the lowest LST and H2 contributing to the highest LST. More importantly, in July, with the highest atmospheric temperature, the LST of H2, N5, and N6 also abruptly changed, and the difference in LST between human-natural systems was more significant than that in April and October (Fig.3-4 and Table.3-4).

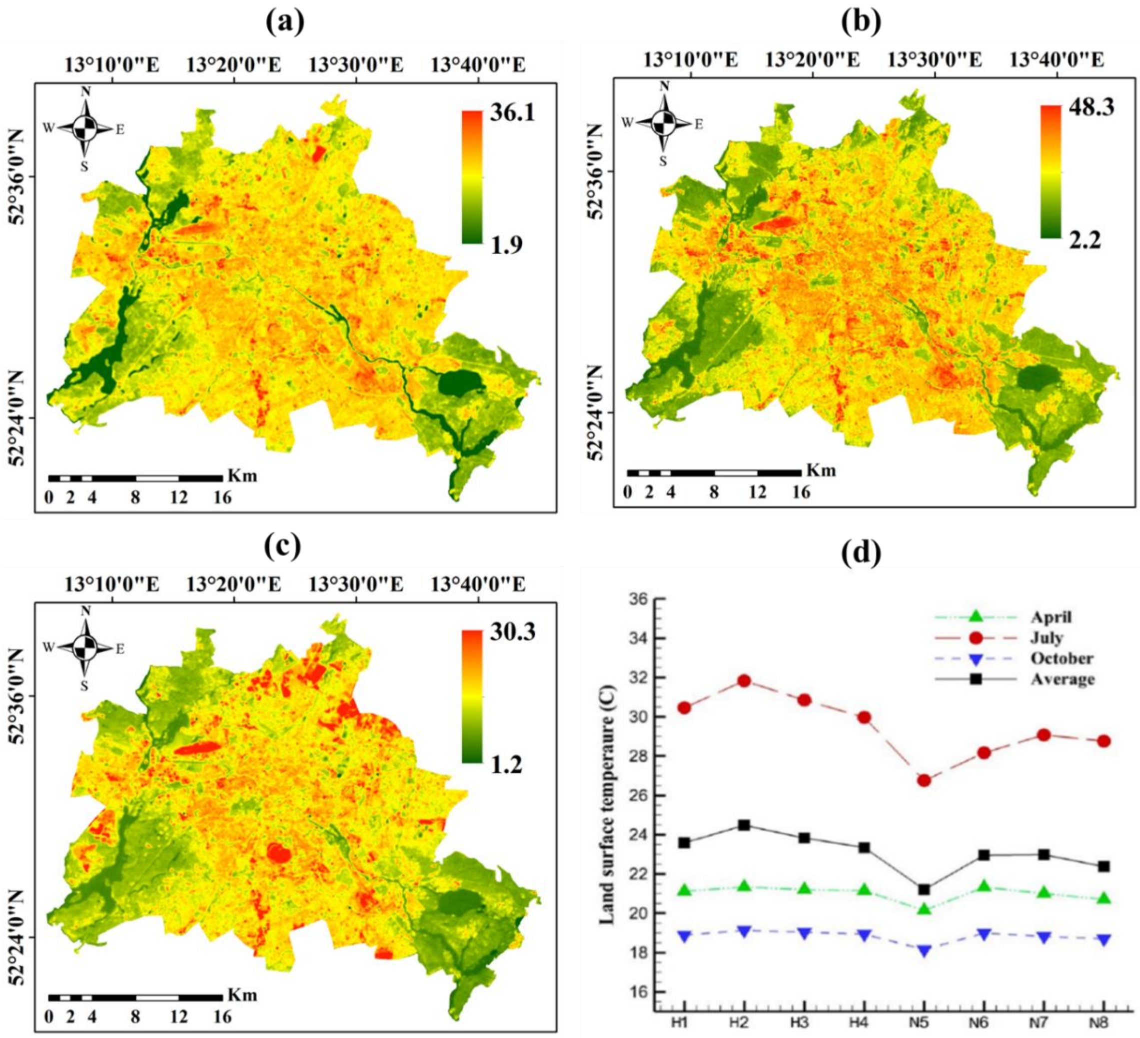


Figure 3-4. LST maps of the 11th of April (a), 7th of July (b), and 3rd of October (c) in 2015 and the mean LST of the eight-type spaces on different dates (°C).

Table 3-4. The proportion of spaces and statistical parameters of LST.

H-N	Land-use type	Proportion %	Min °C	Max °C	Mean °C	SD
Human systems	H1 Residential	31.09	17.11	31.95	23.58	1.52
	H2 Commercial	9.01	17.22	32.04	24.47	1.81
	H3 Public services	7.31	16.72	30.31	23.83	1.83
	H4 Open spaces	11.42	17.07	33.39	23.34	1.87
Natural systems	N5 Natural green	25.67	11.61	30.46	21.21	2.16
	N6 Farmland	4.53	19.15	26.99	22.95	1.35

	N7 Brownfields	3.39	16.97	29.66	22.98	2.01
	N8 Water	6.78	16.71	29.72	22.38	2.34

3.2. The influential spatial components in the eight-type spaces

The LST of the eight-type spaces in the CHNS ultimately had different relationships with the NDVI, NDBI, and NDWI according to comparison of the correlation efficiency on the LST of each space in the three months (Table.3-5 and Fig.3-5). The NDVI had a more considerable impact than NDBI in July on the LST of H1 residential area, H3 public service, H4 open spaces, N6 farmland, N7 brownfield, and N8 water; additionally, the impact of the NDVI and NDBI increased and decreased, respectively, with increasing atmospheric temperature. In contrast, the NDBI had a substantial impact on the LST in N5 natural spaces and H2 commercial areas; significantly, in H2, the NDBI in July had the largest influence, with a correlation efficiency of 0.302 compared with 0.182 in April and 0.202 in October. N5 had the same trend as NDBI, with the largest correlation efficiency of 0.487 in July. In addition, the NDWI had less influence on the LST to different extents in the eight spaces; however, the NDWI in July had a significant positive correlation with the LST of human systems and N8.

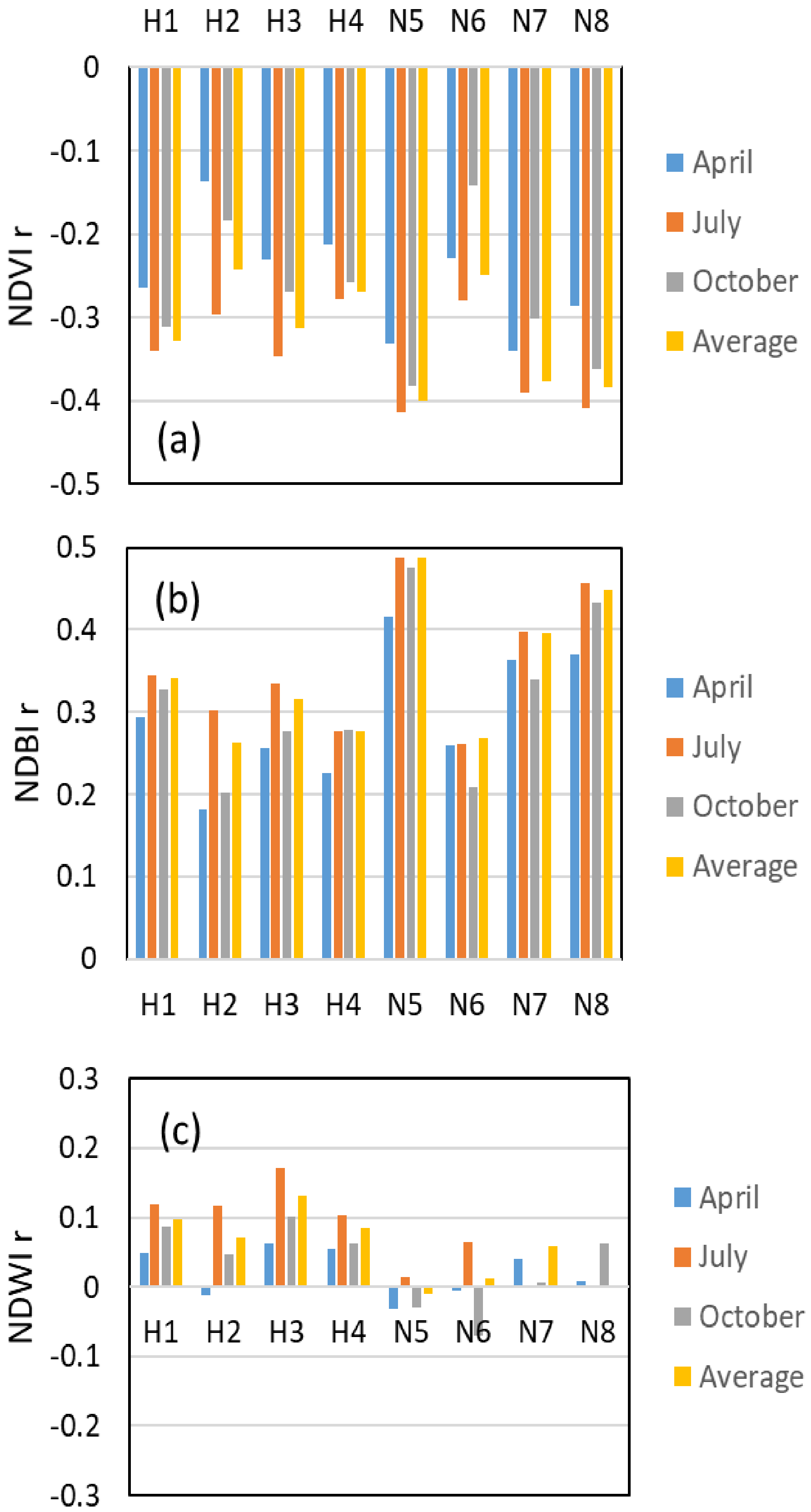


Figure 3-5. The correlation coefficient among LST and NDVI (a), NDBI (b), and NDWI (c).

3.3. Seasonal variations in hotspot areas in different human-natural systems

The temporal and spatial variations in the LST classes in Berlin were heterogeneous (Fig.3-6). In terms of location, most areas with hot and very hot temperature classes were located in the central areas of Berlin. The larges areas of hot and very hot temperature classes occurred in July. The hot class areas for the H1, H2, H3, H4, N5, N6, N7 and N8 classes in April (July, October) were 88.8 (109, 62.4), 36.2 (29.1, 29.3), 21.6 (20.8, 15.9), 33.1 (29.9, 23.1), 15.8 (15.9, 10.8), 8.1 (6.2, 10.1), 7.4 (5.3, 6.1) and 3.2 (3.9, 2.9) km2, respectively. Additionally, the maximum and minimum values of the very hot class area were related to the H2 class in July and N7 class in April, respectively. The areas of hot and very hot classes in human systems were higher than those in natural systems. Moreover, Figure 6 also showed several interesting results of different types. Such as, H1 in July displayed the apparent increase of hot and very hot area, which could be the reason that H1 has diverse composition and patterns, and the temperature could have more impact from surrounding environment. N6 also had significantly increase of very hot area in October, which possibly had an impact from bare land due to agriculture harvesting season. The conditions of different human system classes differed. The natural systems classes exhibited almost the same conditions.

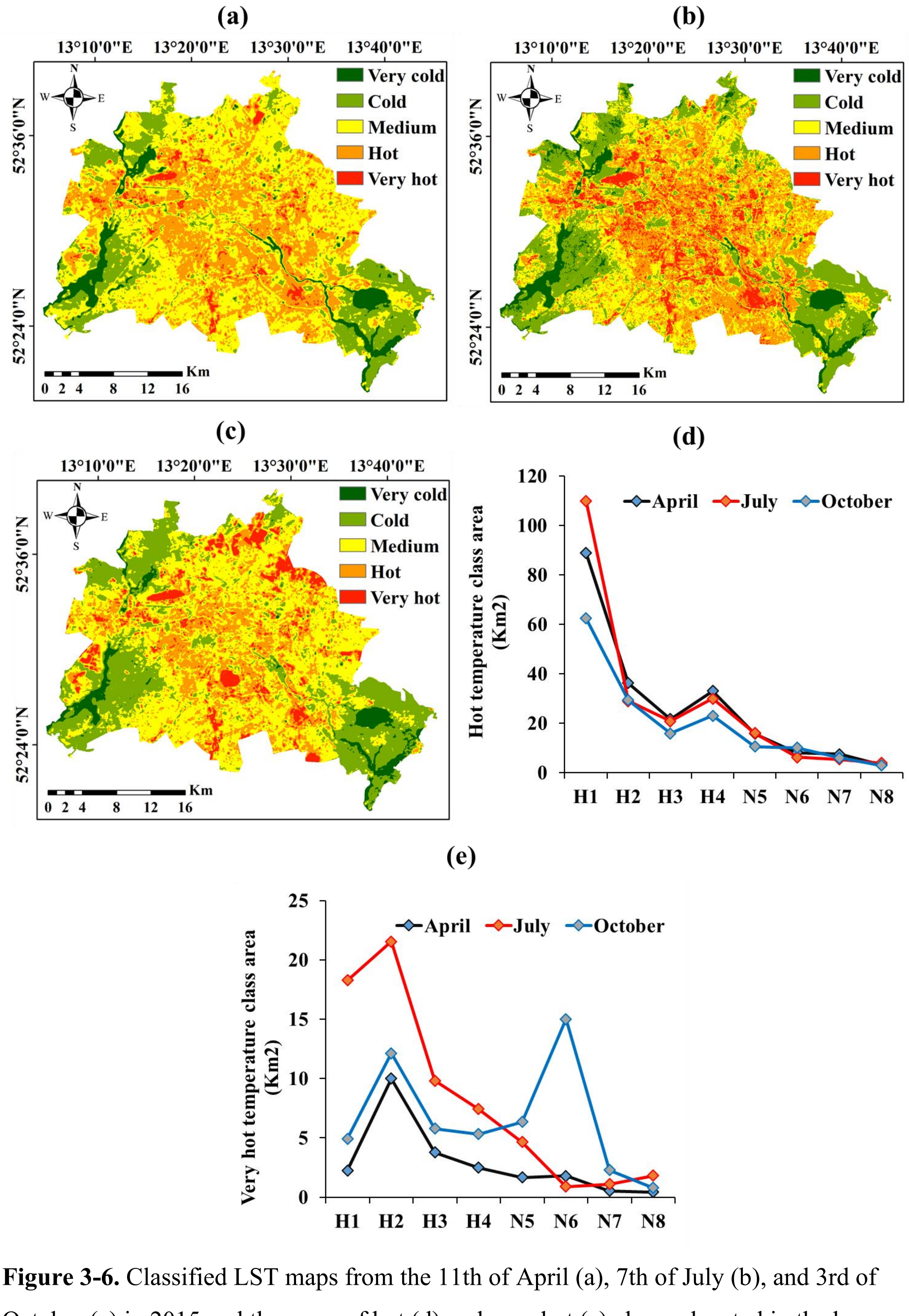


Figure 3-6. Classified LST maps from the 11th of April (a), 7th of July (b), and 3rd of October (c) in 2015 and the areas of hot (d) and very hot (e) classes located in the human-natural systems on different dates (°C).

4. Discussion

4.1. The different LST patterns in human-natural systems

The enhancement of urban ecology has an important potential to balance coupled human-natural systems under abiotic and biotic changes for urban sustainability (Rammig, Bahn et al. 2020). Thus, it is crucial to understand the spatial heterogeneity of coupled human-natural systems and to explore the tolerance alteration in different functional urban land uses in response to climate change with LST as a quantification index. The LST differences between natural-human systems were significantly larger in July at the highest atmospheric temperature. For instance, N5 natural green areas composed of trees provided a source of low temperature, while H2 commercial areas were a source of high temperature. This could be explained by the resilience of biotic and abiotic components in human-natural systems. Due to the differences in ecological processes, natural systems can maintain self-functionality when disturbed by heatwaves compared to human systems. Previous studies have also confirmed the cooling benefits of urban nature during summer heatwaves (Ossola, Jenerette et al. 2021). However, our study emphasizes that urban heat mitigation requires sustainable planning in both human and natural systems. Supposing the ignorance of human systems, more obvious polarization of temperature between human-natural systems is probable, especially in heatwaves. The phenomenon of ignorance of the balance of urban development and the urban natural environment with spatial structures has been proposed (Wang 2009). Therefore, nature-based solutions in human systems are inclusive and appropriate for enhancing urban ecological functions in response to climate change. For instance, grey infrastructure with special planning has also been suggested to mitigate temperature (Qi, He et al. 2019). This study suggests that speeding up the transformation of spaces in human systems could be more important than strengthening natural systems to mitigate temperature and to achieve urban balance in human-natural systems. Transdisciplinary research and coproduction of knowledge regarding the various roles of cities are also needed (Ahlström, Williams et al. 2020, Aminpour, Gray et al. 2020). Nevertheless, the mechanisms for mitigating temperature in human-natural systems should be planned differently with consideration of diverse design concepts, constructions, and functions.

4.2. Characterizing the potential of urban heat mitigation from component indicators

The NDVI, NDBI and NDWI have dynamic influences on the LST differences in the eight-type spaces due to the spatial components of green, grey, and blue infrastructures. Many studies have also confirmed the significant influences of composition on urban heat islands and LST patterns. A negative correlation between the NDVI and LST has been confirmed (Yue, Xu et al. 2007, Guerri, Crisci et al. 2021). In our research, the NDVI in the eight-type spaces also had the most substantial negative effects on the LST in H1 residential areas, H3 public spaces, H4 open spaces, N6 farmland, N7 brownfields, and N8 water. This phenomenon shows that green infrastructure should play an important role in these spaces for urban heat mitigation through the design of more green spaces, even small ones, as green infrastructure can decrease temperature through vegetation evapotranspiration and tree shade (Marando, Salvatori et al. 2019). Previous studies support that residential areas around natural systems obtain cooling benefits, even with small patches of urban vegetation (Ossola, Jenerette et al. 2021). Most of the related studies have generally found that the NDBI has a significant positive correlation/impact with LST. In our research, the positive influences of the NDBI on H2 commercial areas and N5 natural green areas exceeded the negative impact of the NDVI. This could demonstrate that in commercial areas with high-density buildings and natural green spaces, grey infrastructures may have considerable impacts on temperature compared to green infrastructures. Therefore, updating grey infrastructures in these spaces is crucial for decreasing urban temperature. As building height has a negative effect on LST, it has been confirmed that vertical buildings have stronger impacts than building coverage and vegetation coverage in residential neighborhoods (Zheng, Zhou et al. 2019). Therefore, our study suggests that in land use planning, natural green areas should decrease impervious surfaces or use alternative green materials for evitable buildings; in H2 commercial areas such as central business districts and high-technical industry zones, the growth of building height to decrease building coverage has great potential for mitigating temperature. Moreover, from the correlation of the NDWI, the spatial component of blue infrastructure, such as water bodies under heat waves, does not result in significant cooling benefits, which can be explained by the increase in humidity, with lower thermal comfort. Conversely, the existence of water bodies minimizing urban heat has been confirmed through water cooling islands (Steeneveld, Koopmans et al. 2014). Urban planning in coping with global warming requires the consideration of different functional land use types while taking distinctive and effective measurements in the application of green, grey and blue infrastructures to mitigate urban heat.

4.3. The contribution of human-natural system to urban heat mitigation

Urban systems are complex with mosaic patterns, including the biotic and abiotic for human activities and for nature conservation—the evolution of urban systems changes with a wide range of spatial features. The classification of eight-type spaces (ETS) is proposed to emphasize the human-natural systems with the integration of land uses and land functions. In the case study of Berlin, the LST of N2 and H5 had more impact from the NDBI, while the others had more impact from the NDVI. The different influences could support the previous discussion of the fact that in some studies, the NDBI has a greater impact on the LST than the NDVI (Liu and Zhang 2011, Zheng, Zhou et al. 2019), but in others, the NDVI has a more substantial impact than the NDBI (Xiao, Weng et al. 2008). Although the different influences of the NDVI and NDBI on urban LST have been determined from comparisons between the northwestern and southeastern of the city (Jamei, Rajagopalan et al. 2019), the research has lacked discussion on different spaces in human-natural systems. For urban heat mitigation, human activities release heat could be the large cause of urban heat island (Mirzaei and Haghighat 2010), which contribute to the temperature difference among urban area and background non-urban area (Mirzaei 2015). Under the crisis of climate change and COVID-19, taking measures to increase city resilience is addressed in climate adaptation and mitigation (Hurlimann, Moosavi et al. 2021, Pamukcu-Albers, Ugolini et al. 2021).

Approach to mitigation strategies, numerous studies have applied the local climate zones to explore land surface temperature (Stewart, Oke et al. 2014). For instance, urban ventilation correlates with LST based on urban physical characteristics with building density and height (Yang, Jin et al. 2019). The LCZs classifies the differences of climate-relevant surface properties into 17 zones (Bechtel, Alexander et al. 2015, Yang, Ren et al. 2021). Compared with the local climate zone, the eight-type spaces under human-natural systems show the function of land use, while the local climate zones emphasize the different structures of land cover and land uses from the physical characteristics. The LCZs provides a classification for urban temperature studies to fill the gap of popular use of existing urban-rural classification and to sufficiently map a site by urban structure, cover, fabric, etc. (Stewart and Oke 2012). It has much contribution on the heat considering the variety of urban forms, especially in built-up. While the eight-type spaces have a characteristic on urban functions under the human-natural systems, which both composed by green, grey, and blue infrastructures. The ETS across human-natural systems emerge from natural elements and human activities. Urban functions for human activities create diverse landscape with different patterns of spatial compositions. Under the patterns, the variation of building characters, landscape patterns, and anthropogenic heat flux could cause different land surface temperature (Ming, Liu et al. 2022, Zhang, Zhang et al. 2022). For urban temperature studies, the ETS brings a new sight of different treatment to the green, grey, and blue infrastructures in the human-natural systems. That is human systems with different functions can enlarge the potential of temperature mitigation with the consideration of human activities, and natural systems as the most important contribution of urban cooling need more ecological principle. For example, the eight-type spaces can help to build a small form unit to achieve heat balance through the qualification of temperature, then it could maximize city resilience into urban planning, especially in compact cities. We suggest that urban ecologists adopt different urban spaces of human-natural systems to explore the influences of land use change on urban ecology for heat mitigation with functions.

4.4. The potential of the eight-type spaces across human-natural systems

Give a city is integration with human systems needed to fulfill human life, consumption, and activities with biotic and abiotic features and natural system mainly composed by biotic features, such as forest, agriculture, green spaces, and water with fewer anthropogony impacts. Urban nature is also confirmed as natural-based solutions providing ecosystem services. In addition, cities have spatial, organizational, and temporal complexity, which refer to the inaction of structure and inside systems (Pickett, Cadenasso et al. 2005). The interactions between human-natural systems contain the changes of energy, material, and ecological processes. As the urban human-natural systems, urban planning requires to rethink the connection and differences of urban forms and their interaction with urban environment and human wellbeing. More importantly, with the consideration of functions, human systems can regulate human activities with low-energy consumption. For example, building design and planning of residential area has an influence on human mobility patterns (Attaianese and Duca 2012). The ETS could build a linkage among urban planners, designers, governors with ecological researchers. As urban forms have fundamental diversity in urban planning, the eight-type spaces could be used to clear the different key influences in each space for cooling cities with human activities and basic natural functions. Therefore, targeted planning in different spaces according to their characteristics in ecological processes can enhance city resilience to global warming. In further studies, the contents of the eight-type spaces in the local application could be different regarding the divergence of naming land systems (Plumwood 2005) and local existing land classification; relative research on long-term and comparison among cities is also needed to support the eight-type spaces. In our opinion, the results from the case study on the LST and spatial component and influences display the distinctive characteristics of the eight-type spaces, which gives a new perspective about land use for city transformation and sustainable development with the consideration of human-natural systems.

5. Conclusion

This study proposes the eight-type spaces (ETS) include human systems with H1 residential area, H2 commercial area, H3 public services, H4 open spaces, and natural systems with N5 natural green, N6 farmland, N7 brownfield, and N8 water. To determine the contribution to temperature mitigation, firstly, we seasonally compared the land surface temperature (LST) and determined the different influence of land use components, including green, grey and blue infrastructures with the correlation among the LST and normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), and normalized difference water index (NDWI). Secondly, the area of hotspots and their seasonal variations in different human-natural systems have been calculated and compared with each other.

The LST of human-natural systems under high atmospheric temperature in July was more different than in April and October. N5 contributed to the lowest LST, and H2 contributed to the highest LST. The LST of the eight-type spaces in the human-natural systems ultimately had a different relationship with the NDVI, NDBI, and NDWI from the comparison of the correlation efficiency on the LST of each space in the different seasonal conditions. The areas of hot and very hot classes in human systems are higher than those in natural systems. The differences between land use types in human-natural systems are crucial to implementing the spatial components of green, grey, and blue infrastructures to increase the urban potential for temperature mitigation.

Here are suggestions for the potential of temperature mitigation. In commercial and residential areas, increasing building height and combining grey infrastructures with green infrastructures even with small patches is suggested; in open spaces and natural green, decreasing the coverage of grey infrastructures can enhance cooling functions. Our results also demonstrate blue infrastructures may have no effect on mitigating urban heat. Targeted planning in human systems to strengthen urban heat mitigation is crucial for cooling cities with the integration of land uses and urban functions across human-natural systems.

Table 3-4. The correlation coefficients between the LST and NDVI, NDBI, and NDWI.

	Type	April	July	October	Average	Type	April	July	October	Average
NDVI r		-.265**	-.340**	-.311**	-.328**		-.332**	-.413**	-.381**	-.401**
NDBI r	**H1**	.294**	.344**	.328**	.342**	**N5**	.416**	.487**	.475**	.487**
NDWI r		.048**	.120**	.087**	.097**		-0.03	0.014	-0.03	-0.009
NDVI r		-.137**	-.296**	-.183**	-.242**		-.229**	-.279**	-.141**	-.250**
NDBI r	**H2**	.182**	.302**	.202**	.263**	**N6**	.260**	.261**	.209**	.268**
NDWI r		-0.011	.118**	.047*	.071**		-0.005	0.066	-0.07	0.013
NDVI r		-.230**	-.346**	-.269**	-.313**		-.340**	-.390**	-.302**	-.376**
NDBI r	**H3**	.256**	.334**	.276**	.316**	**N7**	.363**	.398**	.340**	.396**
NDWI r		.063**	.172**	.101**	.132**		0.041	.089*	0.007	0.06
NDVI r		-.213**	-.278**	-.257**	-.270**		-.286**	-.409**	-.362**	-.383**
NDBI r	**H4**	.226**	.276**	.278**	.277**	**N8**	.370**	.456**	.433**	.449**
NDWI r		.054**	.104**	.063**	.085**		0.009	.117**	0.062	.078*

Chapter 4.

Exploring the Spatial Heterogeneity of Climate Resilience with ΔLST and temperature-cluster zones in the eight-type spaces

Chapter 4. Exploring the Spatial Heterogeneity of Climate Resilience with ΔLST and temperature-cluster zones in the eight-type spaces

Abstract

Understanding spatial heterogeneity of climate resilience is critical for mitigation strategies with land use management in cities. This study aims to map the spatial heterogeneity of resilience and temperature-cluster zone in eight functional land-use. Under the process of air temperature increase and decrease, ΔLST as the difference among April, July, and October quantify climate resilience in the process of temperature increase and decrease. The temperature-cluster zone is the overlay of temperature value and cold-hot clustering. Here, resilience shows not only the dynamics trends in the CHNS but also the spatial heterogeneity among the eight land-uses. Natural green has the largest resilience, while commercial area has the lowest resilience. Moreover, Open space and brownfields have a large potential for resilience enhancement. The side-effects of patch scale could have impacts on each land-uses spatial heterogeneity. It is crucial to pay more attention to understanding the heterogeneity of different land-uses resilience and their interaction with neighborhood scale for resilience enhancement.

Keywords Spatial heterogeneity; Land use; Land surface temperature; Climate resilience; spatial cluster;

1. Introduction

Urban sustainability remains the highlight of city resilience in response to climate change affecting ecosystem services and human well-being. For achieving the 2030 Agenda, cities are updating for combating climate change of hazards with resilience enhancement. One of climate crises is temperature increasing which is caused by low-quality urban form with less utilities (French, Trundle et al. 2021). It is crucial to understand city resilience for human well-being especially under the environmental warning from the COVID-19 pandemic. Thus, exploring urban space planning is vital to offer strategies in land management.

Resilience, in the originally ecological concept, describes the systematic ability in keeping and retaining their functionality and integrity when disturbed (Holling 1973). From resilience and stability theoretical analysis, it implies a natural or human-made disturbance resulting in the changes and misbalancing system. It depends on the position and quantity of changes with a distinction by the example of raft loaded occupants in several ways taking the raft, the weight, and the occupants as a single system (Ludwig, Walker et al. 1997). Resilience means the ability to adapt to disturbance and environmental changes for self-organize balance. Stronger resilience has also been described as higher stability controlling systems to retrain the same function, structure, and feedback (Walker, Holling et al. 2004). The intensity of resilience reflects the ability to changes the environment (Zaidi and Pelling 2015). Under climate change in particular, climate disturbances have been impacting cities, such as urban flooding, heat wave, drought, etc (Carvalho, Martins et al. 2017, Zhang, Chen et al. 2019, Almeida, Telhado et al. 2020, Kim, Song et al. 2021). Subsequently, improving resilience in urban regions is vital in numerous researches focusing on theories, and indicator approaches, mechanisms, and governances.

Climate resilient city specifically addresses the response in the framework of ecological, social, economic as well as political components with the understanding of processes of change (Adger, Brown et al. 2011, Martinez and Häyrynen 2021). It has been confirmed to require special attention in considering supply and demand of climate resilience implications in addressing poverty and vulnerability (Friend and Moench 2013). Some researchers propose general characteristics of resilience city believed more important than one unique climate impacts (Meerow and Stults 2016). But researchers also propose the different indicators to different cities with uncovering the different kinds of climate resilience indicators in eight Asia cities and offer a framework for developing indicators, including drainage, water supply, public health, flood protection, etc. (Tyler, Nugraha et al. 2016). One of key questions is how to effectively mitigate temperature has been highlighting with resilience enhancement. For quantifying climate resilience with the land-use mechanism, this study uses land surface temperature (LST), which is an influential index (Weng 2020). LST is understood as an essential parameter for identifying the behavior of the earth system (Bojinski, Verstraete et al. 2014). It helps to figure out the relation between different functional land covers and environmental problems (Norton, Coutts et al. 2015, Marando, Salvatori et al. 2019), partly because LST is definitely positive with impervious surface and negative with vegetation cover (Weng, Liu et al. 2007, Liu, Peng et al. 2018, Li and Zhou 2019, Masoudi and Tan 2019). With the base of all systems, land use can directly impact surface albedo and evapotranspiration (Taha 1997). For countering climate change, to calculate the relation among land uses and resilience by remote sensing data for LST is accessible (Weng 2020).

This study aims to explore the heterogeneity of climate resilience in the eight-type spaces. The case study in Berlin has a dynamic urban pattern, which has been developed with its characteristics in the post-war era. In response to heat flow, exploring climate resilience is an important task from Berlin 2030 strategy proposed two-ways on natural and human spaces as development planning for improving urban sustainability (Senate 2015). Considering the relatively less land-use changes in Berlin than in other metropolis cities, this study hypothesis there is no land-use change between April, Jul, and October in 2015 to map temperature changes in the process of air-temperature increase and decrease. With the basic principles of landscape ecology, including scale, process and pattern, this study aims to identify the spatial heterogeneity of climate resilience in the processes of air temperature increase and decrease and map the temperature-cluster zone to define the relation between patch and its surroundings.

2. Methodology

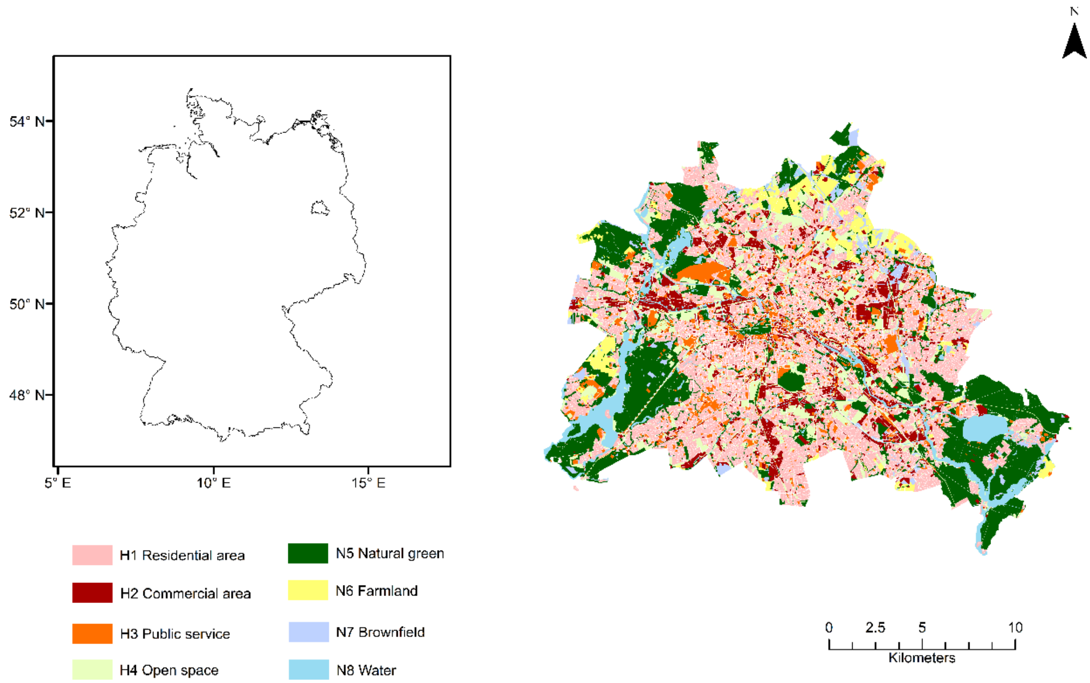


Figure 4-1. Location of Berlin and eight-type spaces.

2.1. The calculation of Δ Land surface temperature

With the eight-type spaces (Fig.4-1), Land surface temperature (LST) was retraveled from Landsat 7 Enhance Thematic Mapper Plus (ETM+) band 6 and Landsat 8 Operational Land Image (OLI) /Thermal Infrared Sensor (TIRS) band 10. The detailed method is based on the chapter3. To qualify climate resilience, ΔLST in the air-temperature increase and decrease was calculated as followed:

$$\Delta LST_{in} = LST_{Jul} - LST_{Apr}$$

$$\Delta LST_{de} = LST_{Jul} - LST_{Oct}$$

Where LST_{Apr}, LST_{Jul} and LST_{Oct} respectively represents LST on April.19th, July.7th and October.3rd. ΔLST_{in} means the temperature difference during the temperature increasing, while ΔLST_{de} means the difference temperature during the process of temperature decreasing.

2.2. Land surface temperature-cluster zones

Temperature-cluster zones (TCZ) show the relation of patch temperature and its surrounding zone of LST. Standard derivation method divided LST into 3 classes, along with low temperature (LT), medium temperature (MT) and high temperature (HT) in Table 4-1. Furthermore, spatial autocorrelation modeled LST cluster zone (Ord and Getis 1995), divided into high Z-scores zone (HZ), not significant zone (MZ) and low Z-score zone (LZ). Overlaid of temperature value and cluster zone identifies into 9 types: HT-HZ (high temperature-high zone), HT-MZ (high temperature-medium zone), HT-LZ(high temperature-low zone), MT-HZ (medium temperature-high zone), MT-MZ (medium temperature-medium zone), MT-LZ (medium temperature-low zone), LT-HZ (low temperature-high zone), LT-MZ (low temperature-medium zone), LT-LZ(low temperature-low zone).

Table 4-1. The classification of temperature value and cluster zone in July.

	Class	**Range**		**Proportion**
Temperature value	LT	LST min ≤ LST< Mean− 2.5σ	17.61 ≤ LST< 22.08	41.79%
		Mean− 2.5 σ≤ LST< Mean− 1.5σ	22.08 ≤ LST< 25.17	
		Mean− 1.5 σ≤ LST< Mean− 0.5σ	25.17 ≤ LST< 28.26	
	MT	Mean− 0.5 σ≤ LST< Mean+ 0.5σ	28.26 ≤ LST<31.35	34.28%
	HT	Mean+ 0.5 σ≤ LST< Mean+ 1.5σ	31.35 ≤ LST<34.44	23.93%
		Mean+ 1.5 σ≤ LST< Mean+ 2.5σ	34.44 ≤ LST<37.53	
		Mean+ 2.5 σ≤ LST≤ LST max	37.53 ≤ LST≤ 44.14	
Cluster Zone	LZ	Cold Spot-99% Confidence Cold Spot-95% Confidence Cold Spot-90% Confidence		40.68%
	MZ	Not Significant		30.96%
	HZ	Hot Spot-99% Confidence		28.35%

Hot Spot-95% Confidence

Hot Spot-90% Confidence

3. Results

3.1. The ΔLST_{in} *in the process of air-temperature increase*

Resilience appears the adjustment and the capacity for being stable under the changes of surrounding. The average of ΔLST_{in} refers to the difference of LST between April and July, during which air temperature increase from 16°C to 26°C. Pearson analysis conducts ΔLST_{in} has significant positive correlation with NDBI, NDWI, and significantly negative with NDVI (Table. 4-2). Especially, higher NDVI results in lower ΔLST_{in} which performs high resilience.

Table 4-2. The Pearson correlation of ΔLST_{in}between April and July in 2015.

ΔLST_{in}	Correlation coefficient	P-value
NDVI	-0.905	<0.005
NDBI	0.841	<0.005
NDWI	0.442	<0.005

ΔLST_{in} classified into 7 levels by standard derivation method identifies the heterogeneity of different landscape resilience (Table. 4-3). Berlin almost occupies more high resilience than low resilience, but the heterogeneity ΔLST_{in} exists across different land uses and within each land use. From the perspective of eight-type spaces, polarization presents in the human systems and natural systems. That is, human systems tend to be high value, while natural system tend to be low value (Fig.4-2). In human systems, the ΔLST_{in} in H1 residential area distributed from the lowest to highest level, with the lowest lying in high dense trees and nearby forest area, the lower lying close to green spaces, the low mainly randomly lying in the western with neighbour green space, the medium accounting the largest lying in whole city, the high located in the city core and the eastern distinct, and the higher close to the commercial area, and the highest without obvious characteristics of surrounding environment (Fig. 4-2). H2 commercial area had low resilience distributing in the high, the higher and the highest ΔLST_{in} lying in core area. H3 and H4 have same characteristics as H1. However, H4 open space has many potential spaces to improve resilience. In the natural systems, N5 is composed by forest and urban parks. The ΔLST_{in} ranged from the lowest to highest with the lowest ΔLST_{in} located in the forest core area, the lower lying in the inner of forest, the low lying in rest forest area and edge of large forest, the medium lying in public parks, the high and the higher mainly lying in the core of city and green space with grass like Templehof Park and Gleisdreieck Park, but only one patch in the highest lying in the inner part of commercial area which is hardly without vegetation covering. N6 farmland distributes from the lowest to the higher which may depend on the growing crop and neighbour environment. N7 wasteland exhibits the distant relation from urban edge to city core. N8 water mainly has effects from the surrounding environment. ΔLST_{in} reflects that high resilience generally tends to be less vulnerable, for example N5 nature green. Moreover, land use in the high, the higher and the highest level of ΔLST_{in} still have the potential to improve landscape composition for mitigating urban land surface temperature.

Table 4-3. The range of ΔLST_{in} between April and July in 2015.

Code	Range		ΔLST (°C)	Proportion of total area (%)
1	Lowest	< -2.5 Std. Dev.	1.22-3.65	0.24
2	Lower	-2.5 - -1.5 Std. Dev.	3.65-5.71	7.47
3	Low	-1.5 - -0.50 Std. Dev.	5.71-7.78	25.38
4	Medium	-0.50 - 0.50 Std. Dev.	7.78-9.84	42.97
5	High	0.50 - 1.5 Std. Dev.	9.84-11.90	21.82
6	Higher	> 1.5 Std. Dev.	11.90-13.96	2.10
7	Highest	> 2.5 Std. Dev.	13.96-14.70	0.02

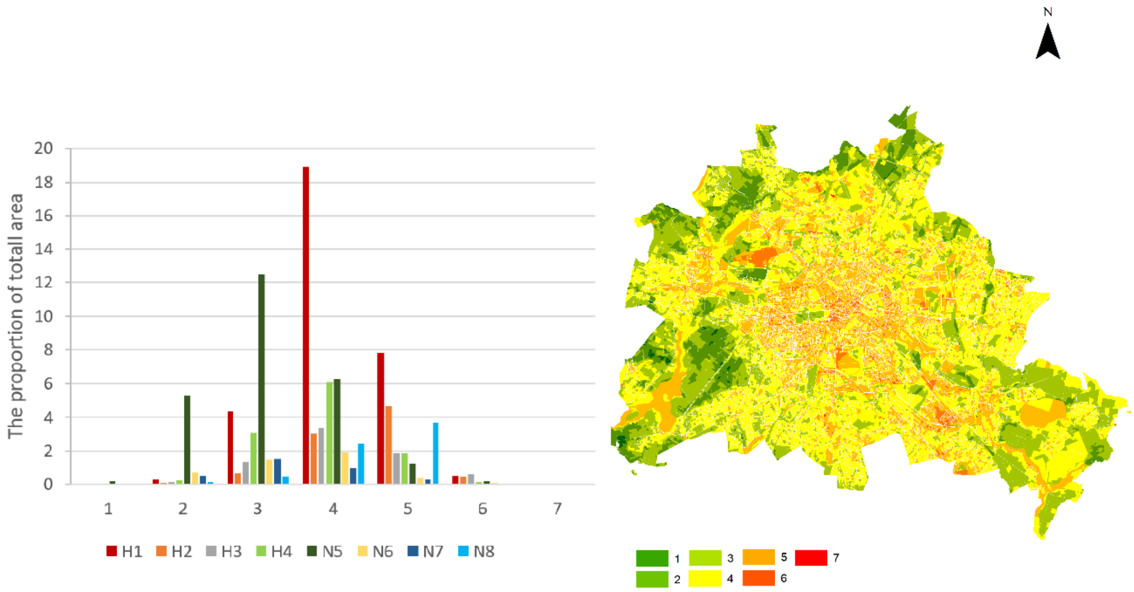


Figure 4-2. The ΔLST between April and July in 2015. The number of 1 to 7 means the level of temperature from the lowest to the highest.

3.2. The ΔLST_{de} in the process of temperature decrease

Pattern changes for adapting the decrease process of air temperature. In order to confirm CHNS under the process of temperature decease. ΔLST_{de} is the LST difference between July and October during which air temperature decrease from 26°C to 18°C. ΔLST_{de} significantly has positive relative with NDBI and NDWI, but negative relative with NDVI from Pearson analysis (Table. 4-4). It conducts that patches with higher NDVI illustrates the lower ΔLST_{de} which means the high resilience. With the 7 types of ΔLST_{de} (Table. 4-5), the proportion of the lowest, the lower and low is also more than the highest, the higher and the high in Berlin.

Table 4-4. The Pearson correlation of ΔLST_{de} between April and July in 2015.

	Correlation coefficient	P-value
NDVI	-0.728	<0.005
NDBI	0.815	<0.005
NDWI	0.145	<0.005

Table 4-5. The range of ΔLST_{de} between April and July in 2015.

Code	Range			Proportion (%)
1	Lowest	< -2.5 Std. Dev.	<5.51	0.87
2	Lower	-2.5 - -1.5 Std. Dev.	5.51-7.66	13.52
3	Low	-1.5 - -0.50 Std. Dev.	7.66-9.82	25.16
4	Medium	-0.50 - 0.50 Std. Dev.	9.82-11.98	36.80
5	High	0.50 - 1.5 Std. Dev.	11.98-14.14	20.98
6	Higher	> 1.5 Std. Dev.	14.14-16.30	2.62
7	Highest	> 2.5 Std. Dev.	>16.30	0.05

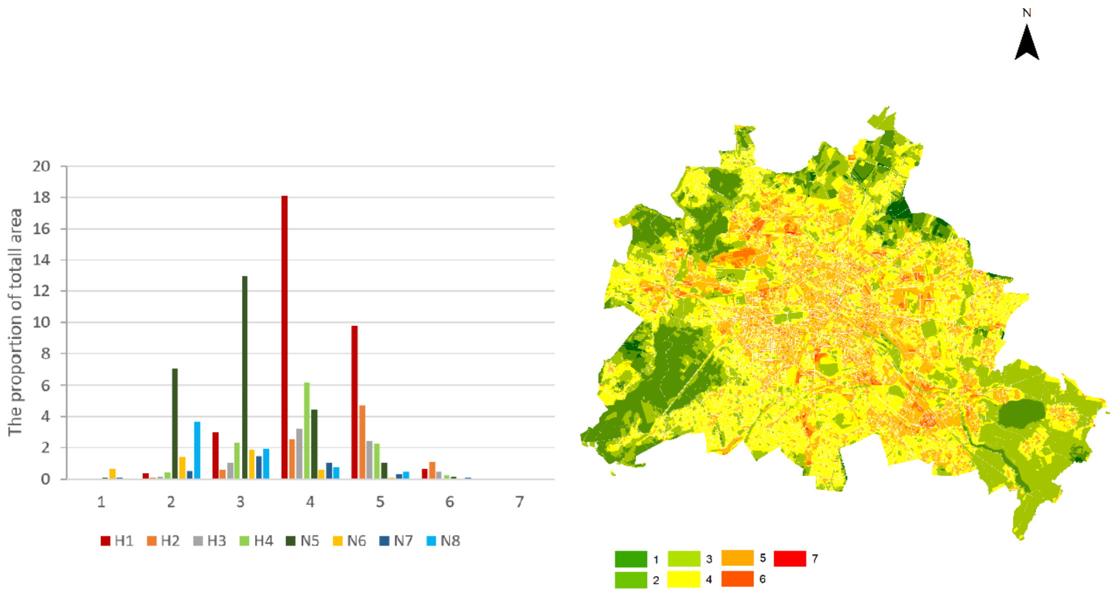
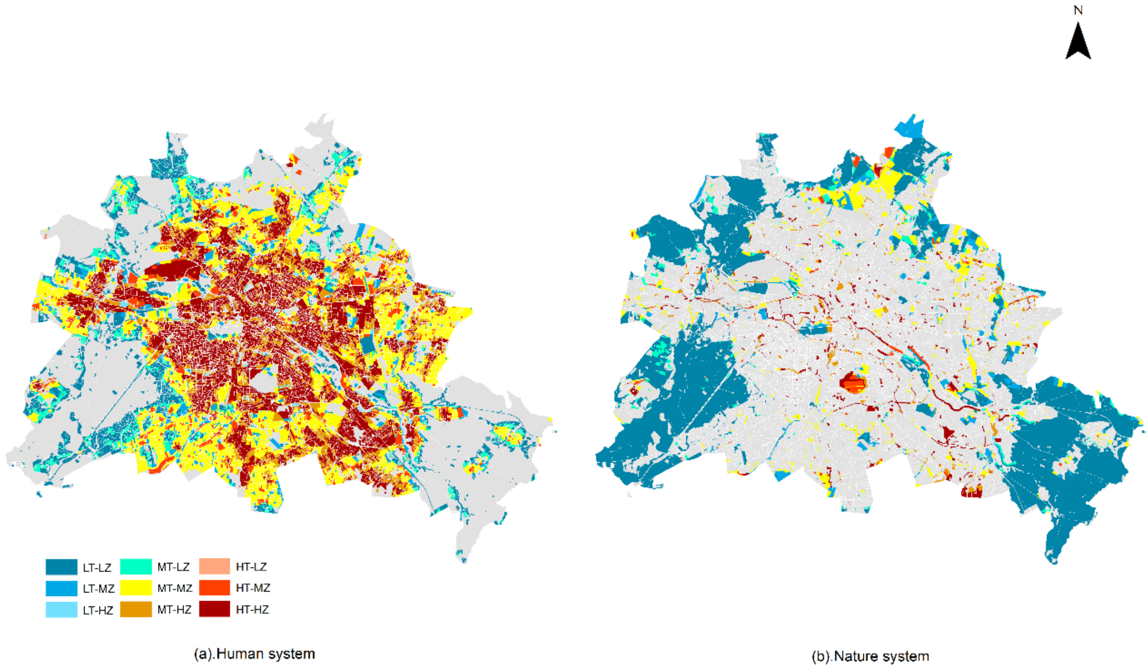


Figure 4-3. The ΔLST_{de} between July and October in 2015. The number of 1 to 7 means the level of temperature from the lowest to the highest.

It is obvious relative among the resilience of different land uses and surrounding environment. From the lowest to the highest ΔLST_{de} , the land use rank of is N6, N5, N7, N8, H4, H3, H1 and H2. From the CHNS perspective, natural systems have lower ΔLST_{de} than human systems (Fig. 4-3). Moreover, the lowest ΔLST_{de} is N6 farmland and its neighbour patches, the lower lying forest area, the low lying in the suburban and nearby forest, the medium which is the largest part of H1 randomly distribute in city, the high close to city core and commercial area, the higher lying inner of commercial, the highest of 12 patches lying in random area without any similar characters. From different land uses, H1 mainly remains in the medium ΔLST_{de} . Moreover, H2 presents that the lowest approaching to farmland, the lower close to water and farmland, the low close to open spaces and parks, the medium area at a little far distance with open spaces, the high area nearby city core, and the highest lying in city core of Berlin. H3 also presents same trends with H1 and H2, with the lowest nearby farmland, the lower close to forest and water, the low close to nature green, the medium as the largest part, the high close to commercial with high impervious area, the higher lying in city core, and the unique highest at the Tempelhof, which certainly relative to the material of building. H4 exhibits the lowest at the farmland area, lower lying nearby forest area and water area in suburban area, the low which is high vegetation covering (which can treat as the city model for high resilience in H4 landscape.) and nearby high dense green space, the medium as the average level of H4, the high mainly along the river area and core city, the higher at the inner core and the highest only 7 patches close to industry areas such as some children playground. Furthermore, in nature system there are more patches in lowest, lower and low of ΔLST_{de}. N5 occupies the lowest nearby farmland, the lower mainly lying in the western forest area close to farmland and water, the low almost containing all of other with high tree dense, the medium which randomly distribute in city, the high approaching to city core, the higher in the inner city and the highest covering less vegetation. N6 is from the lowest to the highest which distributes in the north-eastern, western and southern edge of Berlin. Under this process, N6 displays lower than other land uses which possibly impacted by the crop process. N7 presents that the lowest level nearby farmland, the lower and low lying in the nature green space and nearby green space, the medium mainly lying in the eastern and northern of Berlin, the high lying nearby city core, the higher lying in the inner of core and the highest with high impervious surface. N8, water, one patch of the lowest lying in the rural area, the lower approaching to nature green space and the low to the higher in city core. Hence, Landscape resilience to some extent relies on the surrounding environment.

3.3. The temperature-cluster zones of CHNS in July

The temperature-cluster zones display the pattern of LST value classified by standard derivation and LST cluster zone gained from Hotspot Analysis with Moran's Index 0.633. in Fig. 4-4, the large areas are composed by LT-LZ, MT-MZ and HT-HZ, with proportion of total area 35.69%, 20.98% and 19.35% respectively. Furthermore, LT-LZ is the largest part in Berlin which implies this city have much low value and cold spot of LST. MT-LZ occurs at the edge of human and natural systems, such as the bound of N5 nature green. In Fig. 4-4, the high self-resilience and high surrounding-resilience area is LT-LZ, high self-resilience and low surrounding-resilience is LT-HZ, low self-resilience and high surround-resilience is HT-LZ, low self-resilience and low surround-resilience is HT-HZ. In Human system, apparent gradient exists with the distance from city core. The main TCZ of human consists of HT-HZ 17.58 %, MT-MZ 16.76% and HT-MZ 3.56%. In natural system, TCZ is mainly in LT-LZ 28.24%, MT-MZ 4.22% and LT-MZ 2.66 %, but some natural patch emerges into HT-HZ, for example Tempolhof Park with grass covering. In general, HT and HZ area mainly exists in human system, but LT and LZ are primarily in nature system.



Proportion	H-H	H-M	H-L	M-H	M-M	M-L	L-H	L-M	L-L
Human system	17.58	3.56	0.14	7.54	16.76	3.3	0.38	2.97	7.44
Nature system	1.76	0.82	0.05	0.98	4.22	1.51	0.09	2.66	28.24

Figure 4-4. Spatial distribution of the land surface temperature-cluster zones in July.

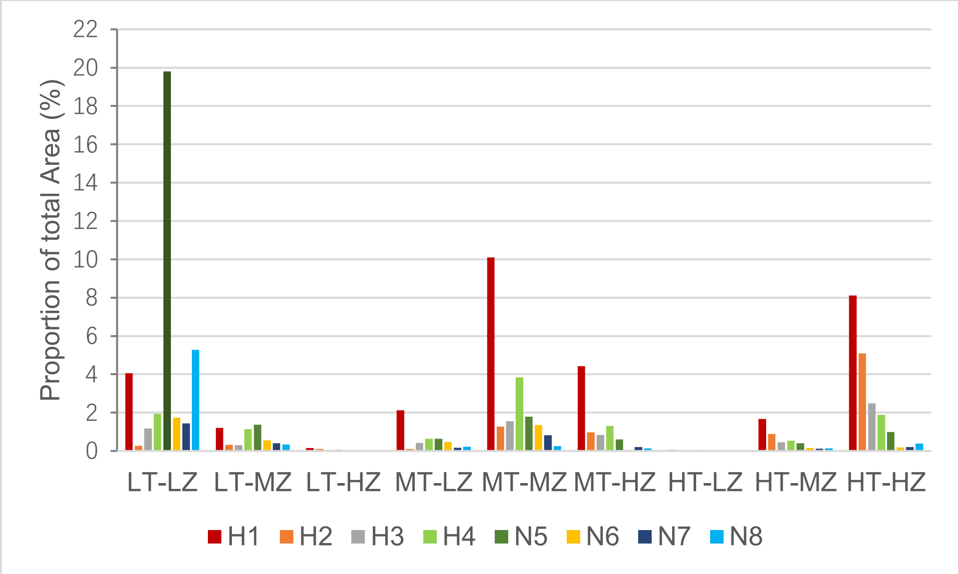


Figure 4-5. The proportion of TCZ in different land use.

From the perspective of different land uses, TCZ are mainly distributed with spatial heterogeneity. H1 varies in all different zones, in which patch in HT possesses high potential to improve (Fig. 4-5). H2 mainly distributes in HT-HZ, HT-MZ, MT-MZ and MT-LZ which means the patch of H2 has ability into optimization case. H3 life infrastructure varies in different parts caused by different pattern. H4 open space also varies in different zones but specially locates in MT-MZ, HT-HZ and LT-LZ. It shows the high potentiality to improve the patch in HT-MZ and MT-LZ. N5 nature green mainly lies in the LT-LZ with potentiality to improve the quality of green spaces in HT-HZ. N6 farmland concentrates in LT-LZ and MT-MZ. Minority of N6 locate in HT which may depend on the vegetation. N7 Westland presents in LT-LZ and MT-MZ reflecting the high eco-quality of Westland. N8 water is mainly in LT-LZ, showing the blue infrastructure is vital to strengthen heat resilience. Some measures can be taken to the high-potential patches gained with TCZ to alleviate urban heat, enhance city resilience and to decrease the eco-gap between human and natural systems.

4. Discussion

Enhancement of city resilience is a significant potential to balance CHNS under abiotic and biotic changes for urban sustainability (Rammig, Bahn et al. 2020). From the results, understanding of spatial heterogeneity of resilience in CHNS is of significance to explore the tolerate alteration in different functional land-use in response to climate change with LST as a quantified index. The present studies indicate that urban resilience is a function of natural habitat and human activities spaces (Alberti and Marzluff 2004, Alberti 2005) and qualities impact of patterns on resilience (Thonicke, Bahn et al. 2020) and present spatial heterogeneity and diversity (Cadenasso, Pickett et al. 2007, Liu, Dietz et al. 2007, Leslie, McCabe et al. 2013). From the general conception, human systems need more resilience than natural systems, while natural systems bring more support to resilience than human systems. In our study, although Berlin occupies more are of high resilience than low resilience, the heterogeneity ΔLST_{in} in the different land uses shows the potential to increase city resilience.

Urban planning for city resilience seems to need convincing in different functions land-uses. From the results, commercial area and natural green are the lowest resilience and highest resilience. Residential area with relatively less vegetation, mainly in the medium resilience but also changes with surrounding settings. In public services, the context are schools, kindergartens, hospitals which need to measures to temperature mitigation for city equality(Williams, Laslett et al. 1962), for the most vulnerable people and societies. Meanwhile, open space, from its spatial heterogeneity, still displays an enormous potential for resilience enhancement. It also has been convinced that managing open space could deliver adaptation options with the access to meeting social and ecological justice from thermal comfort (Wilson, Nicol et al. 2008). Thus, open space should play a vital role in city resilience in human systems for city resilience through improving vegetation coverage, which could mitigate urban heat. From the heterogeneity of natural green, it also shows a large potential to improve resilience in the areas with low resilience because the quality of green infrastructure is vital for ecosystem stability. Farmland in cities may have the possibility of increasing or decreasing resilience depending on the management. In the process of temperature decrease, farmland with low LST changes could be explained by crop maturity, which could increase resilience. Meanwhile, brownfield could be the largest to resilience enhancement in natural systems in the city core. For instance, brownfield redevelopment can affect inner-city micro-climate to cool temperature (Koch, Bilke et al. 2018). Although the response to air-temperature increases also exists in human systems, a large potential for resilience enhancement by optimizing configuration and components.

From the results, in the processes of temperature increase and decrease, resilience qualified as ΔLST, is dynamic in different land use. It is principled that each land-use shows the capacity to be stable as temperature changes to some extent, which the resilience depends on self-composition and the surrounding environment. Our result shows spatial heterogeneity existed in the same land use. For instance, N5 shows the lower resilience in the city core than in forest area, which could be explained by the different compositions. N5 in forest could have more native species and less pattern fragmentation. Previous research has also confirmed the difference in system functions in different compositions in the same land-use that the older, protected old-growth forest has more benefits to carbon storage than the younger and fast-growing forest (Lazdinis, Angelstam et al. 2019). As N5 is the largest resilience of CHNS, how to keep high resilience of forest is crucial in terms of stand structure and species composition, flora age groups (Wang, Dong et al. 2017, Munroe, Crandall et al. 2019).

In addition, the analysis of spatial heterogeneity in the eight land-uses showed the different LST level from the highest to the lowest with some relation with surroundings. It is turned out that the patterns approaching natural green have stronger resilience than that nearby commercial area, as well as natural green approaching to city core also have less resilience than those far from the city core. Interestingly, the distance to the city core has no function to some patches compared to others in the same land-use. As the demonstration of landscape connectivity from Dunning, patches have more substantial impacts on their continuous patches than the distant patches in landscape (Taylor, Fahrig et al. 1993). This study proposes there is a threshold between patch-self resilience and side-effects from neighbor patches. If self-resilience is stronger than side-effects, then the pattern has a low vulnerability and gets low effects from the surrounding; if weaker, it is a high vulnerability and high effects from the surrounding. Therefore, improving system eco-quality in human systems is of significance to explore the side-effects at neighborhood scale.

5. Conclusion

This study demonstrates climate resilience of the coupled human-natural systems with land surface temperature and the spatial heterogeneity of eight land-uses in Berlin under the process of air temperature increase and decrease. The spatial difference of the same land-use possibly depends on side-effects in surrounding patches, which primarily has higher effects on human systems than natural systems. Further research needs to pay more attention to interdisciplinary to develop and implement land-use strategies at city and patch scale for improving city resilience in response to climate chang

Chapter 5.

The Interaction between Human Demand and Urban Greenspace Supply for Promoting Positive Emotions with Sentiment Analysis from Twitter

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Chapter 5. The Interaction between Human Demand and Urban Greenspace Supply for Promoting Positive Emotions with Sentiment Analysis from Twitter

Abstract:

Urban green space (UGS) plays an essential role in providing benefits to human well-being in cities. Understanding how to promote positive emotions is vital for planning and designing a UGS supply that satisfies human demand. However, there is still little knowledge about the impact of the interaction of cross-cultural demands and different supplies on human emotions. This study explored different human emotions about UGS from a cross-linguistics perspective using social media data (SMD). Sentiment analysis was conducted with Twitter data geolocated in 26 UGS in Berlin to acquire sentiment value and tweet number. The sentiments of English and German tweets in four types of UGSs were compared, and the correlations with 11 physical and activity characteristics were identified. The results demonstrate that (1) sentiment value and tweet number were distinctive in the 26 green spaces, showing the dynamic emotions in the different types of UGS; (2) the cross-linguistic demands were different in the comparison of English and German tweets, with the highest sentiment values in gardens and parks, respectively; and (3) the sentiment of the all , English and German tweets was respectively correlated with open space, interesting plants and swimming infrastructures; the activity landscape confirmed the highest contribution to positive emotions even with cross-cultural differences. The results of the study suggest that human emotions can indicate whether the UGS supply meets the human demand and that specific landscape characteristics can enhance human emotions to maintain human demand in cross-cultural background, especially considering the increasing attention to immigrants and natives. Thus, human emotions identify the interaction between UGS supply and human demand based on SMD to improve UGS outcomes for urban sustainability and public well-being.

Keywords: Greenspaces, sentiment analysis, cross-linguistic, landscape characteristics, Twitter

1. Introduction

Urban green space (UGS) is vital for sustainable development and human well-being. From the 2030 Agenda, fulfilling human lives in harmony with nature is essential for urban sustainable development (Assembly 2015, Colglazier 2015). Clearly, human well-being has been receiving more attention in the context of the COVID-19 pandemic (Biswas and Sen 2020). As humans are the center of cities (Churchill 1962), the highest level of Maslow's hierarchy of human needs is to satisfy the inner spirit, for example, through experiences with nature (Maslow and Lewis 1987, McLeod 2007). Several studies have confirmed a wide range of positive outcomes of UGS exploration, such as restoring attention, promoting positive emotions, alleviating discomfort and stress, and perceiving restrictiveness (Lafortezza, Carrus et al. 2009, Richardson, Pearce et al. 2010, Tamosiunas, Grazuleviciene et al. 2014). A few studies have also demonstrated negative outcomes of green spaces, such as lack of safety and fear in UGS (Sreetheran and Van Den Bosch 2014). Due to the importance of human well-being, planning and designing UGSs to promote positive outcomes is crucial for achieving the sustainable development goals (SDGs).

Human emotions respond dynamically to environmental settings, and they can reveal UGS effects on human well-being (Hull IV and Harvey, 1989) with positive, neutral, and negative emotions (Roberts, Sadler et al. 2019). Moreover, human emotions support understanding of people's satisfaction when visiting UGSs. If emotions are more positive, the interaction between green space supply and human demand is appropriate. On the one hand, UGS supply is dynamic depending on landscape characteristics, directly impacting human emotions. It changes with design concepts, local cultures, geographical situations, ecological functions, recreational ideas, etc. (Lengen 2015). To describe the difference in green spaces, landscape quality can be attributed to landscape characteristics, including physical and activity landscapes (Hull IV and McCarthy 1988).

As essential environmental elements, the physical landscape includes the visual perceptions of green spaces (Stedman 2003), such as area, shape, vegetation, water, buildings, and color (Hull IV and Harvey 1989). In addition, the activity landscape describes recreational functions in UGS, such as swimming, dancing, walking, sightseeing, and other entertainments. On the other hand, human demands differ across UGSs, which impacts emotional responses because of society-culture dynamics. In general, people visit green spaces with various demands, such as enjoying the weather, hanging around, breathing fresh air, acquiring restoration, and keeping social bonds (Home, Hunziker et al. 2012). However, people from different cultural backgrounds could have different demands for the green environment according to the impact of culture (Vierikko, Goncalves et al. 2020). As green spaces contribute to mitigating social cohesion, the cultural demands could differ between natives and immigrants. Therefore, UGS planning needs to not only follow urban guidelines but also meet the dynamic demands of citizens regarding UGS supply to promote positive outcomes.

The methods of evaluating human emotions include questionnaires for surveying emotions (Rahnema, Sedaghathoor et al. 2019), experiments measuring psychological variables (Tost, Reichert et al. 2019), and visualizing sentiment with social media data (SMD) (Khan, Chowdhury et al. 2020). In the era of information and communication technology, SMD has been confirmed as a reliable proxy for survey-derived information, which can contribute to human responses to environmental settings (Donahue, Keeler et al. 2018, Oteros-Rozas, Martín-López et al. 2018). Urban sustainability concerns human behavior and values, which are commonly assessed using big data, such as Twitter and Flickr data (Ilieva and McPhearson 2018). To understand urban life quality in urban planning, the integration of urban geography with Facebook APIs and POIs can characterize human activities in the corresponding spatial structures (Chen, Hui et al. 2019). Sentiment analysis can qualify emotions, which could reveal the benefits of green spaces. For example, one study illustrated the positive outcomes of UGS for human health by comparing the sentiments inside and outside of parks (Plunz, Zhou et al. 2019). Several studies have also applied sentiment to classify emotions as positive, neutral, and negative (Khan, Chowdhury et al. 2020) and defined higher sentiment values as more positive emotions (Schwartz, Dodds et al. 2019).

Moreover, sentiment analysis with SMD can reveal the effects of attachments in green spaces (Lim, Lee et al. 2018), assess visitor activity (Brindley, Cameron et al. 2019), and enhance the climate adaptation of UGS (Mabon and Shih 2018). Furthermore, studies have adopted the number of SMDs to characterize human usage with landscape characteristics (Brindley, Cameron et al. 2019). More importantly, SMD in multilinguistic text provides the possibility to compare human emotions in cross-cultural contexts. Thus, research based on SMD can stimulate an understanding of the interaction between UGS supply and human demand in cross-linguistic data by qualifying human emotions and use.

Despite the growing evidence of positive outcomes of green spaces to human emotions, less is known about the interaction between UGS supply and human demand under the influence of different types of UGS and cross-cultural responses in promoting human emotions with SMD. As variations in psycho-emotions appear among individuals in different types of UGSs, including man-made, seminatural, and natural UGSs, this study chose four types of public urban green spaces in Berlin. Considering German as the native language in Berlin, the specific comparison between the German and English tweets reveals different human demands according to the cultural backgrounds of native and immigrants. This research aims to identify the differences of human emotions in different UGSs with sentiment analysis. Furthermore, we compared sentiment differences in German and English tweets to distinguish human demands under different cultures, and analyzed the correlation among positive emotions and landscape characteristics to determine how to promote positive outcomes of UGS.

Set against this background, this study proposes the following three research questions:

1) What differences in human emotions can be identified in the four types of UGSs?

2) What differences in human demand are between English-German linguistic tweets?

3) How can positive emotions from SMD get the interaction for improving the UGS supply to maintain human demand?

2. Method

2.1. Study area

Berlin is shaped and defined by green spaces contributing to a green lifestyle for residents and an attractive destination for international travelers (Kowarik 2019, Vierikko, Paula Gonçalves et al. 2020). Public UGSs consist of parks, forests, gardens, cemeteries, and playgrounds, which account for more than 45% of the total area (Umwelt 2019). According to 2030 Berlin strategies, maintaining multiple functions is vital in green space planning. Moreover, Berlin has a long history as a destination for long-term immigrants and individuals visiting over the summer (Hamann and Karakayali 2016). 2019 Berlin statistics report that the migrants represent approximately 25% of the total population (Statistics Office 2019). In Berlin, the native language is German, which provides the condition to study cross-linguistic tweets in green spaces to explore cross-cultural differences using German and English language tweets.

Thus, we chose Berlin as the case study to evaluate human emotions under a cross-linguistic background with sentiment analysis in the 26 UGSs shown in Fig.5-1 and Table. 5-1.

Table 5-1. All 26 public greenspaces selected.

Type	Code	Name	Area (ha)
Park	P1	Gemeindepark Lankwitz	10.78
	P2	Freizeitpark Marienfelde	36.09
	P3	Weißer See	22.64
	P4	Volkspark Schönholzer Heide	55.81
	P5	Treptower Park	262.07
	P6	Tiergarten	235.34
	P7	Tempelhofer Feld	303.55
	P8	Steinbergpark	30.57
	P9	Bellevuepark	17.67
	P10	Stadtpark Lichtenberg	7.68
	P11	Sportpark Poststadion	13.16
	P12	Schweizerhofpark	9.6
	P13	Schlosspark Köpenick	1.76
	P14	Großer Müggelsee	258.47
	P15	Landschaftspark Herzberge	94.71
	P16	Volkspark Jungfernheide	176.85
Garden	G17	Gärten der Welt	93.16
	G18	Britzer Garten	85.46
	G19	Botanical Volkspark Pankow	62.01
Forest	F20	Grünau Forest	773.59
	F21	Tegeler Forest	1,367.50
	F22	Königsheide	131.3
	F23	Kaulsdorfer Seen	82.06
	F24	Barssee und Pechsee	3,110.46
Cemetery	C25	Steglitz	37.25
	C26	Leise Park	8.15

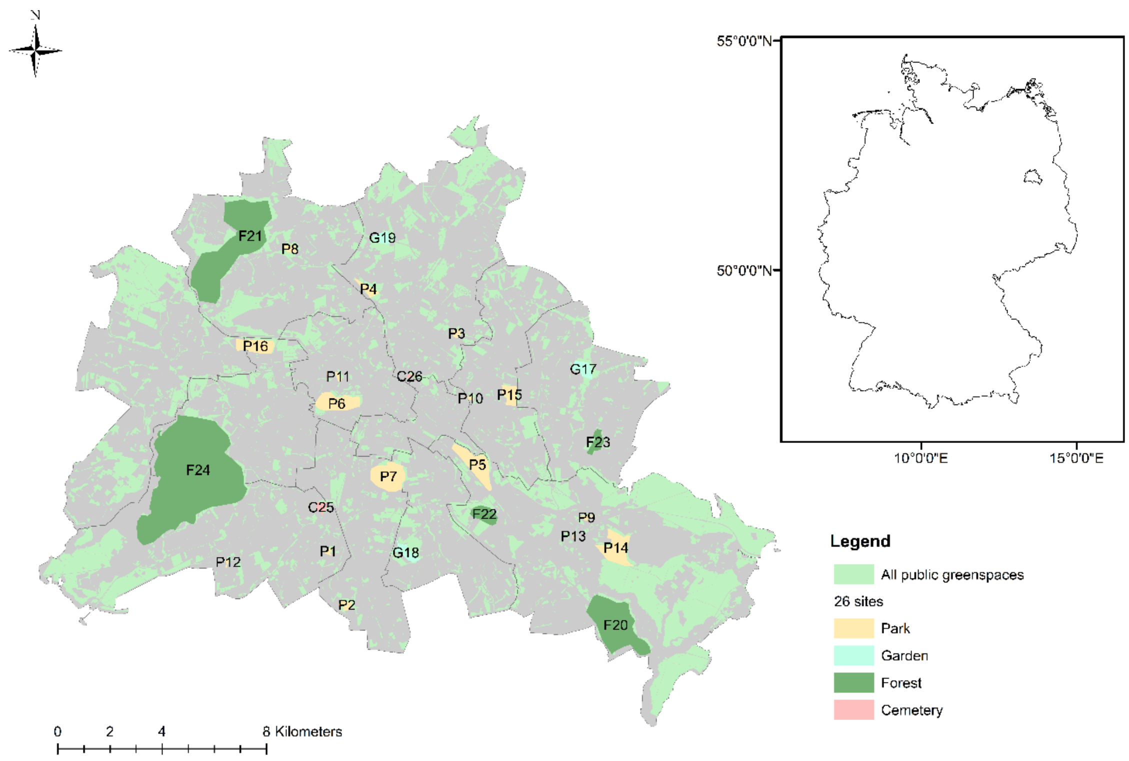

Figure 5-1. The locations of the 26 public greenspaces in Berlin.

2.2. Tweets acquirement and sentiment analysis

This study acquired the central points and the distance to the boundary of each green space through Google Earth Pro to georeference the range of each green space. According to the geolocation of the 26 public green spaces, 62,923 tweets were downloaded from the Twitter Advanced Search Interface (https://twitter.com/search-advanced from 2015 to 2019. The tweet languages with tweet numbers include German (35,610), English (21,595) and other languages (5,718) through linguistic determination with Langid (https://github.com/saffsd/langid.py). The tweet data contain emojis and text, which needs preprocessing for transformation into only text for sentiment analysis. The BeautifulSoup and Emoji toolkits were used to restore emoji icons transformed into corresponding text. In addition, hashtags, URLs, punctuation and a concise API were replaced with text, including part-of-speech tagging and noun phrase extraction. After preprocessing, all text was analyzed by TextBlob and TextBlobDE, a Python library tool with natural language processing (NLP). Sentiment analysis was applied to acquire human emotions from each tweet. Considering TextBlob with the limited application of language, tweets in other languages were translated into English for further analysis. Moreover, each green space gained the average sentiment and the tweet number, and the tweets in English and German were analyzed for cross-linguistic comparison. According to sentiment value, human emotions were classified as negative with sentiment less than -0.01, neutral emotions with sentiment between -0.01 and 0.01, and positive emotions with sentiment more than 0.01.

2.3. Landscape characteristics

Landscape characteristics are displayed to describe the green space quality of the 26 selected sites. In this study, 11 landscape characteristics were selected, including five physical characteristics (area, building, tree density, underground vegetation density, and water) and six activity characteristics (walking paths, playground, swimming infrastructure, open space, sports infrastructure, interesting plants, and animal interaction). Each landscape characteristic was qualified, including area classified through ArcGIS 10.7, tree density and underground vegetation density counted from on-site pictures by Google Earth Pro with low, medium, and high density, and other characteristics depending on their existence in the green spaces (Tables 3-1 and 3-2 in Appendix II). The correlation of the tweet number and sentiment value with landscape characteristics was analyzed by Spearman analysis using SPSS.

3. Results

3.1. Human emotions in different greenspaces

Human emotions in UGS depend on the dynamic interaction between human and environmental settings. Fig. 5-2 shows both number and sentiment differences in the 26 UGSs. The UGS with the largest number of tweets includes P6 with 41,711 tweets, followed by P15 with 6,676 and P5 with 5,495. Except for P7, F24, and P3 with tweet numbers of 2,500, 1,965, and 1,500, the other 20 green spaces had less than 1,000 tweets. Concerning sentiment value, the top three with the largest values were in P2, P4, and P9, with sentiments of 0.208, 0.178, and 0.151, respectively. In addition, P1, P12, and P10 had sentiments of 0.127, 0.119, and 0.113, respectively, with the other sites displaying values less than 0.11. Thus, most green spaces provided positive outcomes to human emotions, with differences due to the different UGS supplies. Simultaneously, the green spaces with the largest sentiment values were not the UGSs with the largest number of tweets.

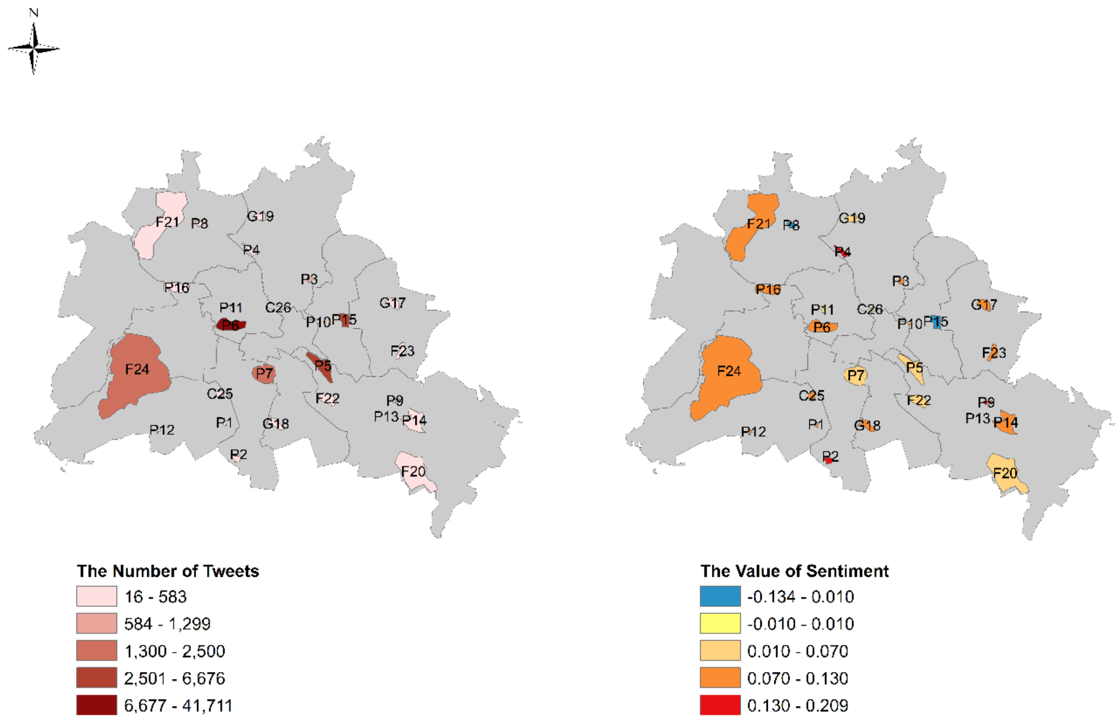

Figure 5-2. The number and sentiment of Tweets in the 26 public greenspaces.

3.2. Comparing sentiment in cross-linguistic tweets

From the comparison between English and German tweets, the tweet number and sentiment value of the English tweets were 35,610 and 0.091, and those of the German tweets were 21,595 and 0.061. Concerning that the sentiment value in the English tweets was higher than that in the German tweets, human emotions were more positive in the English tweets than in the German tweets. In Fig. 5-3, it reports that the sentiment of English tweets in most of the 26 UGSs was higher than that of German tweets. Moreover, the largest difference between the English-German tweets was in P8, where the English tweets showed positive emotions, while the Germans acquired negative emotions. The English and German tweets both had the highest sentiment in P2, while the lowest sentiment of the English and German tweets was in P15 and P8, respectively. Furthermore, the statistics of different types of UGSs showed that the sentiments of German tweets were more stable than those of English tweets. Concerning the UGS types, the highest sentiment of the English and German tweets was in gardens and parks, respectively, which reveals that visitors under cross-linguistic backgrounds could have different demands on UGS.

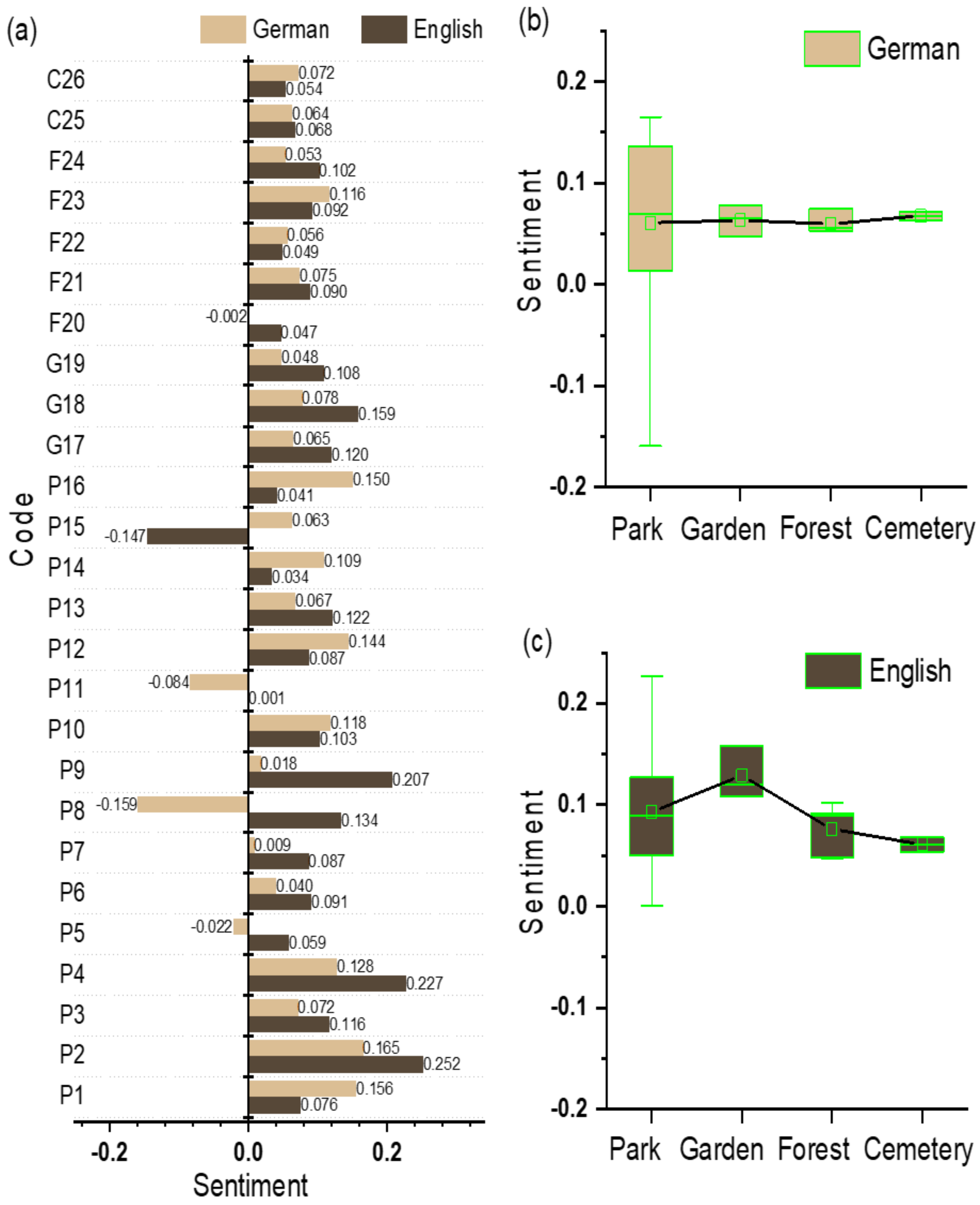

Figure 5-3. Sentiment of German and English tweets in the four types of greenspaces.

3.3. Correlation with landscape characteristics

The 11 landscape characteristics in the physical and activity landscapes correlated with the tweet number and sentiment value according to Spearman analysis. Table. 5-2 shows that UGS area had a significantly positive correspondence with the number of tweets in the all, English and German tweets. Additionally, the number of German tweets showed a positive correlation with water. Moreover, the sentiment of all tweets was significantly related to open space, with a correlation coefficient of 0.332 and a p-value of 0.098. The sentiment of English tweets positively correlated with building and interesting plants, with a correlation coefficient of 0.422 and a p-value of 0.032. In the German tweets, sentiment also had a positive correlation with swimming infrastructure, with a coefficient of 0.384 and a p-value of 0.053. From the results, we can see that landscape characteristics of UGS supply in promoting human positive emotions indicate different cross-cultural demands.

Table 5-2. Correlation analysis with landscape characteristics.

Landscape characteristics		Number of Tweets			Sentiment of Tweets		
		All	English	German	All	English	German
Physical characteristics	Area	.392*	.465**	.410**	-.184	-.215	-.237
	Tree density	-.154	-.146	-.078	-.040	.042	-.100
	Underground plant density	-.025	-.029	.058	.025	.157	-.017
	Building	-.010	-.026	.087	.031	.422**	-.093
	Water	.253	.221	.377*	-.081	-.102	.102
Activity characteristics	Animal interaction	.163	.182	.098	.150	.046	.228
	Playground	.237	.268	.113	-.113	-.144	-.134
	Swimming infrastructure	-.014	-.021	.043	.284	-.128	.384*
	Open space	.189	.176	.085	.332*	.319	.215
	Sports infrastructure	-.029	-.023	-.145	.064	.029	.017
	Interesting plants	.156	.106	.244	.178	.422**	-.089

* $p < 0.10$. ** $p < 0.05$.

4. Discussion

Human emotions respond dynamically to different urban green spaces and their features. In this study, sentiment analysis with Twitter data reveals the variance of sentiment value and the tweet number in the 26 UGSs. Understanding human emotions in different UGS supplies and human demands could transform relative mechanisms into green space planning. On the UGS supply, a recent study has also confirmed that UGS landscape quality can affect visual cues, resulting in different psychological responses among visitors (Brindley, Cameron et al. 2019). Moreover, green spaces with higher-level biodiversity and more attractive vegetation coverage can enhance the positive emotional outcomes among visitors (Schwartz, Dodds et al. 2019). From our results, human emotions in cross-linguistic tweets indicate distinctions across the four types of UGS, which implies differences in human demand due to cross-cultural influences. The green spaces with the largest tweet number presented lower sentiment, which could be explained by the interaction of high expectations before visiting but low satisfaction during the on-site experience (Price and Barrell 1984). In our opinion, to promote positive human emotions, the interaction between human demand and UGS supply is of importance in green space planning. Here, we discuss how to provide planning guidelines with the combination of UGS supply and human demand to enhance human positive emotions.

Human demands for UGS differ, partly because of cultural attributes. As human emotion mechanisms as recognition of demand, it could get influence from external factors, such as culture (Kuhn 2015). Our comparison between English and German tweets confirmed the existence of different emotional responses to different UGS types in a cross-linguistic background, with the largest sentiment value of English tweets in gardens but the largest value of German tweets in parks. This demonstrates the different human demands under a cross-linguistic background: visitors with a German background prefer parks, while visitors with an English background prefer gardens. Considering that German is the native language in our case study city Berlin, the comparison could imply that natives and immigrants have different demands on UGS. A previous study also investigated the differences in visual preferences for nature across background variables in the Netherlands through a survey of 500 residents (Van den Berg and Koole 2006).

A comparative study utilizing biocultural diversity (BCD) has identified differences in human behaviors under sociocultural differences by comparing the interaction between UGS and human behaviors through interviews in four European cities (Vierikko, Goncalves et al. 2020). Compared with previous studies, our study demonstrates significant differences in human demand under a linguistic background by comparing human emotions in different types of UGS supply with sentiment analysis from social media data (SMD) at the neighborhood scale.

Research based on SMD can provide multiple perspectives on human responses to UGS across different cultures at the neighborhood, city, and global scales. In addition, one of the important findings from this study is the distinctive demands between immigrants and natives regarding UGS. A study based on 618 questionnaires among immigrants from Islamic countries and the native Dutch found that natives strongly prefer the natural landscape, while immigrants hardly visit nonurban landscapes, such as wilderness (Buijs, Elands et al. 2009). In our opinion, due to the sense of belonging, immigrants may receive more benefits from UGS than natives when satisfying essential demands regarding, for example, entertainment and sports, in connection with nature. Thus, as sociocultural diversity is becoming more concerned with urban sustainability, meeting the cross-cultural demands of visitors is critical in green space planning for enhancing the positive outcomes of UGS supply.

Determining which landscape characteristics can contribute to positive emotions among the target population can yield design guidelines to improve the UGS supply and meet the human demand in cities. From our results, the sentiment of all tweets has a significant correlation with open space, which is of importance for human positive emotions. Moreover, a study of the relationship between emotions and environmental factors in 80 tourism attractions has also found that openness results in the variation of human emotions (Kang, Jia et al. 2019). Furthermore, our results confirm that the sentiment of English tweets positively correlates with the activity characteristics of interesting plants and buildings, while German tweets are related to the activity characteristics of swimming infrastructure. In our opinion, UGS planning requires certain landscape characteristics that promote positive emotions to meet the demands of residents from different cultural backgrounds. As specific objections contribute to human emotions, existing research has also suggested that the physical landscape can especially affect emotional responses (Berman, Kross et al. 2012). Vice versa, concluding from our study, activity characteristics could play a more important role than physical characteristics in enhancing positive emotions due to certain human requirements for entertainment in green spaces. We argue that understanding the interaction between UGS supply and human demand with emotional responses can clarify which landscape characteristics can promote positive emotions and meet the dynamic human demand for improving UGS supply.

As the activity landscape of UGS can enable environmental settings for a multi-functionalstage for visitors, green space planners could design characteristics to stimulate visitors to find their various roles in UGSs. For example, the reconstruction of Gorky Park in Moscow explicitly added the activities landscape to enhance the aspect of human entertainment in the UGS (Kalyukin, Boren et al. 2015). In addition, transferring human demand into UGS planning is vital for choosing landscape characteristics to improve the UGS supply. Considering the different demands among cross-cultural populations, immigrants require more attention in green space planning to strengthen their sense of belonging in cities. Combining landscape characteristics with sentiment analysis based on SMD can visualize the interaction of cross-cultural human demand with different UGS supplies by human emotional dynamics. SMD could stimulate more new insights into UGS sustainability by capturing human interaction with environmental settings at spatial-temporal scales (Ilieva and McPhearson 2018).

Future research on multicity comparisons is required to explore the spatial heterogeneity between landscape characteristics and human positive emotions at the regional and global levels. In green space planning, specific landscape characteristics enhancing positive emotions could help meet urban cross-cultural demand and UGS supply in the process of urban sustainable development.

5. Conclusion

Urban green space (UGS) is receiving more attention during the human health crisis. Determining human emotions is vital for exploring the interaction between UGS supply and human demand. However, there is a lack of relevant research on the impact of different supply and cross-cultural demands on human emotions in UGS. Therefore, this study investigated 26 public green spaces representing four types of UGS with 62,923 tweets from 2015 to 2019 to evaluate the emotional responses to different UGS supplies in a cross-cultural background. Human emotions were acquired through the sentiment and cross-linguistic analysis of tweets in different types of UGS and correlated with 11 landscape characteristics. This study demonstrates that most green spaces support positive emotions, with distinctive sentiment values in different UGSs. Simultaneously, the comparison between English and German tweets indicates that human demands differ across cultures, in particular between natives and immigrants. According to correlation analysis, certain landscape characteristics can promote human positive emotions, with cross-cultural distinctions. In our opinion, activity characteristics are significant in enhancing UGS positive outcomes; for example, open space, interesting plants, and swimming infrastructure significantly correlate with the sentiment of all English and German tweets. This study also illustrates that human emotions in UGSs can help visualize the relationship between different UGS supplies and cross-cultural demands. As positive emotions can reflect that the supply matches human demand, exploring landscape characteristics for promoting positive emotions could provide guidelines to improve UGS supply while meeting cross-cultural demands. This study also suggests that more concern about activity landscapes is crucial in green space planning and that research based on social media data (SMD) can evaluate human responses to green space. Understanding how to enhance positive emotions in UGS contributes to understanding the interaction between UGS supply and human demand for urban sustainable development.

Chapter 6.

Integrating Quantity and Quality to Assess Urban Green Space Improvement: Site-Specific Practices in Berlin

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Chapter 6. Integrating Quantity and Quality to Assess Urban Green Space Improvement: Site-Specific Practices in Berlin

Abstract: Urban green space (UGS) has gained much attention in terms of urban ecosystems and human health. Taking measures to improve green space in compact cities is important for urban sustainability. However, there is a knowledge gap between UGS improvement and planning management. Based on an integration of quantity and quality, this research aims to identify the UGS changes during urban development and suggestions for improving green space. We analyse land use changes and conduct a hotspot analysis of land surface temperature (LST) between 2005 and 2015 at the city scale and examine the changes of small, medium and large patches at the neighbourhood scale to guide decision-makers in UGS management. The results show that i) the redevelopment of urban brownfields is an effective method for increasing quantity, with differences depending on the regional functions; ii) small, medium and large patches of green space have significance in terms of improving the quality of temperature mitigation, with apparent coldspot clustering from 2005 to 2015; and iii) the integration of UGS quality and quantity in planning management is beneficial to green space sustainability. Green space improvement needs to emphasize the integration of UGS quantity and quality to accommodate targeted planning for local conditions.

Keywords: green city; land surface temperature; hotspot analysis; public engagement; planning practices; remote sensing

1. Introduction

Sustainable Development Goal 11 of the United Nations (UN) 2030 Agenda emphasizes making cities and human settlements inclusive, safe, resilient, and sustainable (UN (United Nations) 2015). Urban green space (UGS) plays a crucial role in urban human habitats and is expected to support 68% of the world population by 2050 (UN (United Nations) 2019). With the acceleration of urban problems, such as air pollution, urban flooding, urban heat, and human health crises, the need for UGS improvement has increasingly been recognized to maintain human wellbeing and support urban ecosystems (Bertram and Rehdanz 2015, Kremer, Haase et al. 2019).

UGS improvement has been discussed temporally in terms of a triad of concepts, namely, the “nature in cities”, the “nature for cities”, and the “nature of cities” (Pickett, Cadenasso et al. 2016), and spatially at the global, city and neighbourhood scales. UGS is generally defined as a space covered with vegetation and as the basic infrastructure of cities; it can take multiple forms, such as public parks, urban forests, community gardens, cemeteries, and natural conservation areas. Given that different forms of UGS have dynamic shapes, sizes, patterns, and ecosystem functions, more consideration should be given to specific local conditions for UGS improvement (Tan 2017). With land use modification and redevelopment for urban development (Xue, Zhang et al. 2016), understanding how to improve UGS has become a key point for providing universal access to safe, inclusive and accessible green space worldwide (Dye 2008).

Landscape ecology provides insight into UGS improvement (Wu 2008), suggesting a principle of green space related to structures as well as ecological functions (Wu, Jelinski et al. 2000). Generally, assessments of amount and ecological functions have been adopted in numerous studies. In terms of UGS amount, the methods for measuring quantity partly include the percentage of green space, greening rate, normalized difference vegetation index (NDVI) (Hope, Kimball et al. 1993, Gascon, Cirach et al. 2016), and green view index (Ki and Lee 2021). Taking into account UGS patches, the multifunctional management of land use is the basis of large, medium and small patches serving as urban green corridors and stepping stones in the UGS network (Zhang, Meerow et al. 2019). With green wedges, green ways, and green extension, urban space strategies for urban expansion under urbanization have demonstrated good connections by guiding the locations and amounts of UGS (Jim and Chen 2003).

Concerning ecological functions, the association between UGS patterns and ecosystem services provides the potential for UGS quality improvement. The ecological functions of UGS provide the benefits of mitigating temperature, storing carbon, purifying water and air, mitigating pollution, and promoting human mental and physical health (Tzoulas, Korpela et al. 2007, Pataki, Carreiro et al. 2011, Wolch, Byrne et al. 2014, Yang, Zhang et al. 2015). Methods based on remote sensing are beneficial for calculating ecosystem functions to guide UGS planning (Wellmann, Lausch et al. 2020). For example, the spatial heterogeneity of land surface temperature (LST) identifies the hot-cold spots that have a characteristic relationship with UGS patterns to enhance temperature mitigation (Kong, Yin et al. 2014, Zhou, Wang et al. 2017). Hotspots are defined as higher-temperature areas, while coldspots are defined as lower-temperature areas (Keramitsoglou, Daglis et al. 2012). In general, the higher the quality of UGS is, the lower the temperature. Hotspot analysis has the potential to optimize UGS planning based on the differential impact of patterns on ecological processes (Gao, Song et al. 2021). Combining the UGS amount and ecosystem functions, the integration of quantity and quality is needed to observe UGS improvement, but insufficient attention has been paid to this issue.

With urban development and population growth, compact cities are facing competition for land under anthropogenic progress, which presents obstacles in terms of UGS development (Haaland and van Den Bosch 2015). The compact city is being applied globally as an urban form for a sustainable urban future with the main characteristic being a higher density of urban living. To improve the UGS of compact cities, globally, cities have been exploring various strategies and designs. For example, some European and Chinese cities have expanded urban parks by transforming farmland into suburban areas (Lin 2007, Goetz and Jaksch 2018), and brownfields have been converted into green space in American and European cities (De Sousa 2003, Doick, Sellers et al. 2009). Community gardens and pocket parks in North America and Singapore and green belts in Europe have been established to strengthen UGS connection. In Finland, ecosystem services of carbon dioxide sequestration and recreation functions have been taken into account for the better design of green space to improve ecosystem quality (Niemelä, Saarela et al. 2010). UGS in Germany has a significant development goal of creating green space near residential areas (BMUB， 2007). Under the concept that “lucid waters and lush mountains are invaluable assets”, urban decision-makers in China are considering how to utilize UGS to drive economic growth (Chen, Gao et al. 2016). In Singapore, it is believed that UGS improvements support a sustainable economy by attracting talented and highly educated people to the area (Tan 2017). Given the consideration of the economy, ecology, and society, UGS in compact cities under land competition emphasizes planning practices for decision-makers (Dieleman and Wegener 2004, Bibri, Krogstie et al. 2020).

However, a gap between the linkage of UGS quantity and quality with planning management exists for decision-makers in terms of improving UGS in compact metropolitan areas. Due to the importance of UGS quantity and quality, the identification of specific strategies could provide information for targeted planning. On the one hand, increasing the quantity of green spaces in a limited area requires refined land use management; on the other hand, climate adaptation, considered an important function of green space, can demonstrate the UGS quality of temperature mitigation. Therefore, this study aims to determine the integration of UGS quantity and quality to achieve UGS improvement and suggest planning management. We chose Berlin as the study city, which is one of the greenest cities in Europe and a compact city with a growing population (Hansen, Olafsson et al. 2019). This research analyses spatiotemporal quantity changes in public UGS between 2005 and 2015 with land use changes at the city scale, identifies quality changes using the hot-cold spots of LST, and specifically demonstrates the changes of large, medium-small patches at the neighbourhood scale.

Our study aims to answer the following questions:

i) What are the changes in UGS quantity and quality between 2005 and 2015?

ii) What specific green space management has been undertaken at the neighbourhood scale that we can detect in terms of both quantity and quality?

iii) What conclusions for other large cities can be drawn from the data analysis performed for Berlin for this 10-year period?

2. Materials and methods

2.1. Study area

Berlin (52°27′N, 13°19′E) is in Northeast Germany. As the capital city of Germany, Berlin contains 12 administrative districts (Fig. 6-1). The city covers 891.1 $km^2$with 3.67 million people in 2019 and is estimated that its population will reach 4 million by 2030 (Senatsverwaltung für Stadtentwicklung und Wohnen 2020). Berlin UGS consists of forests, parks, allotment gardens, cemeteries, transportation green space and other areas. Public green space covers approximately 30% of the city area, which was confirmed by considering 2,800 public parks in 2014 (Kabisch and Haase 2014). According to the standard value in Berlin, accessibility to green space is defined as a minimum of 6 m^2 per capita and a maximum walking time of 15 minutes to the nearest green space (Coppel and Wüstemann 2017). The statistics of public UGS distribution in 12 districts show a difference, with suburban areas having the highest percentage (SenUVK and (Senate Department for Environment traffic and climate protection) 2019). Under population growth and urban development, the Berlin 2030 strategy demonstrates UGS implementation for the purpose of building a human-natural system and achieving a sustainable city (Berlin Senate 2015).

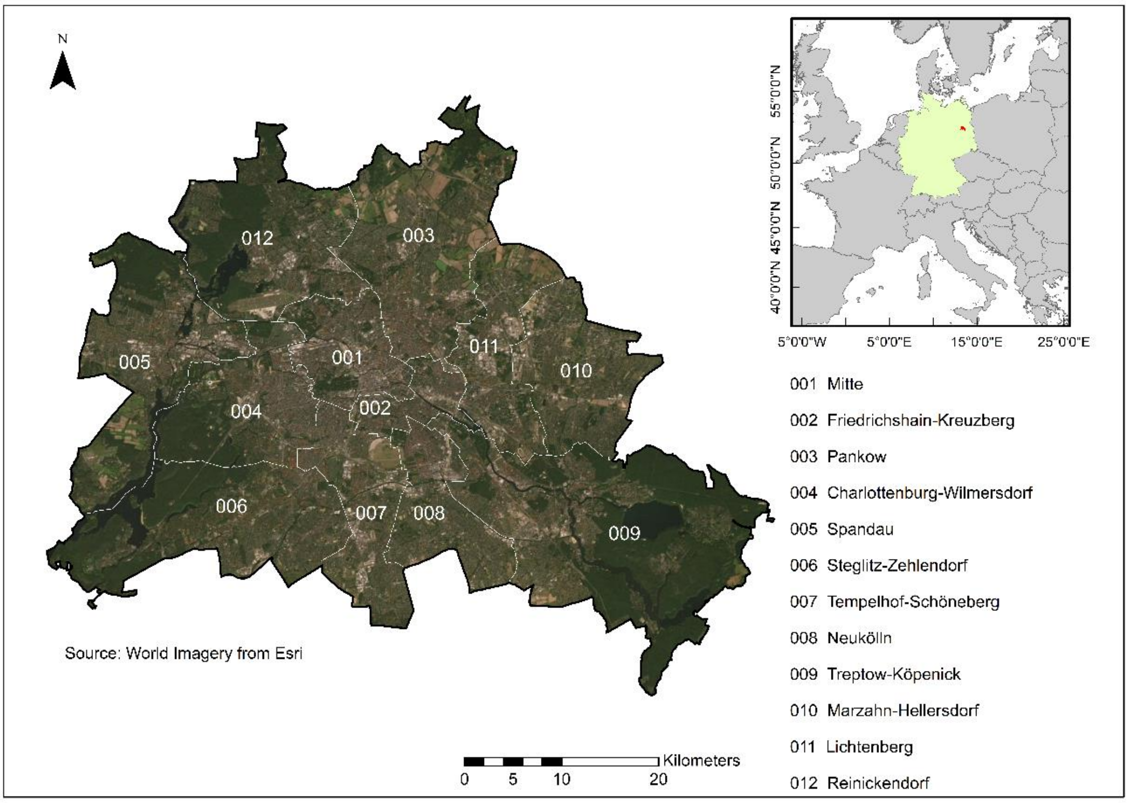

Figure 6-1. Study area map with 12 districts.

2.2. Land use change analysis and greening rate

This study applied the 2005 and 2015 land use data downloaded from the Berlin Senate Department of Urban Development and Housing (https://www.berlin.de/umweltatlas/en/land-use/). We further reclassified land use into five classes, including built-up area, green space, farmland, brownfield, and water. Land use changes were applied to calculate the area of the additional, remaining and decreased UGS between 2005 and 2015 in ArcGIS 10.7. This study focused on four types of public green space: forests, parks, cemeteries, and community gardens. The green rate of each district was illustrated by the green space percentage of the district area. For a further discussion on patch management, we divided the green space into three types according to patch area (PA)—small patches (PA < =2 ha), medium patches (2 ha < PA< = 10 ha), and large patches (PA > 10 ha)—based on the size of pocket parks, which are generally less than 2 ha (Nielsen, Van Den Bosch et al. 2014), and large forest areas, which are generally larger than 10 ha (Hashimoto, Natuhara et al. 2005).

2.3. NDVI and LST retrieval

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images in July 2006 and 2015 without clouds were downloaded from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/). LST was retrieved through the single-window method (Weng 2009), where land surface emissivity was obtained by the NDVI threshold method (Sobrino and Raissouni 2000). NDVI is an index of vegetation calculated from the band 4-near-infrared band (30 m) and the band 3-visible band (30 m) (USGS 2018).

2.4. Hotspot analysis and Pearson analysis

Hotspot analysis was conducted in ArcGIS 10.7 to calculate the Getis-Ord Gi* statistic and show the cluster pattern of LST hotspots, nonsignificant spots, and coldspots(Ord and Getis 1995). The value of Gi-Bin was utilized to determine the statistical significance of hot- and coldspots. Hotspot analysis, as a method of spatial analysis in geographic information system (GIS), has received much attention regarding LST heterogeneity and its relationship with land use management (Tran, Pla et al. 2017, Jamei, Rajagopalan et al. 2019). Such analysis identifies a vector of the LST characteristics to identify the consistency of temperature with high-value clustering as hotspots and low-value clustering as coldspots. The pattern of hot-cold spot changes can show the neighboring relationship among features (Ord and Getis 1995), which has been confirmed to be more accurate and effective to map and analyze the pattern cluster (Kalinic and Krisp 2018). In the clustering pattern, hotspots are represented by high LST value clustering, nonsignificant spots represent those areas with LST values ranging from high to low without apparent clustering; and coldspots are represented by low LST value clustering (Govind and Ramesh 2019). Additionally, Pearson analysis was used to analyse the correlation of LST and NDVI with PA.

3. Results

3.1. Quantity changes at the city scale

From the analysis of land use changes in the studied decade, an increase in green space and a decrease in built-up areas and farmlands were clearly apparent. UGS in total increased by 1,622.12 ha from 2005 to 2015. In Fig.6-2, it can be seen that the area increased was mainly transformed from built-up areas (1,236.55 ha) and brownfields (1,422.34 ha). The quantity changes in the east were greater than those in the west, mainly changing from built-up areas, brownfields, and farmlands to green space. Furthermore, the 12 districts showed an overall increase in the quantity of green space with different changes. The three districts with the largest additional green space were Pankow, Marzahn-Hellersdorf, and Treptow-Köpenick at 436.53 ha, 435.39 ha, and 406.79 ha, respectively (Table. 6-1). The districts with the highest rate of increase were Marzahn-Hellersdorf, Lichtenberg, and Tempelhof-Schöneberg, with rates of increase of 6.15%, 5.87%, and 5.49%, respectively. Mitte and Friedrichshain-Kreuzberg, as city cores, had less additional green space than did the other districts. The quantity changes in UGS in each district depended on the regional function conditions.

Table 6-1. Changes in public UGS from 2005 to 2015 in 12 districts.

District	**Increased (ha)**	**Decreased (ha)**	**Greening rate**	
			2005	**2015**
Marzahn-Hellersdorf	435.39	55.64	10.38	16.53
Lichtenberg	358.73	52.89	12.22	18.09
Tempelhof-Schöneberg	330.99	40.06	12.71	18.2
Spandau	287.19	13.63	25.83	28.81
Neukölln	125.24	12.57	16.99	19.5
Friedrichshain-Kreuzberg	63.13	13.26	9.75	12.2
Steglitz-Zehlendorf	221.79	55.84	32.57	34.19
Treptow-Köpenick	406.79	164.84	46.58	48.02
Mitte	68.27	22.65	16.98	18.14
Reinickendorf	156	67.81	31.14	32.12
Charlottenburg-Wilmersdorf	119.49	60.55	36.12	37.03
Pankow	436.53	349.26	26.31	27.15

*Greening rate is the percentage of green space to the district area.

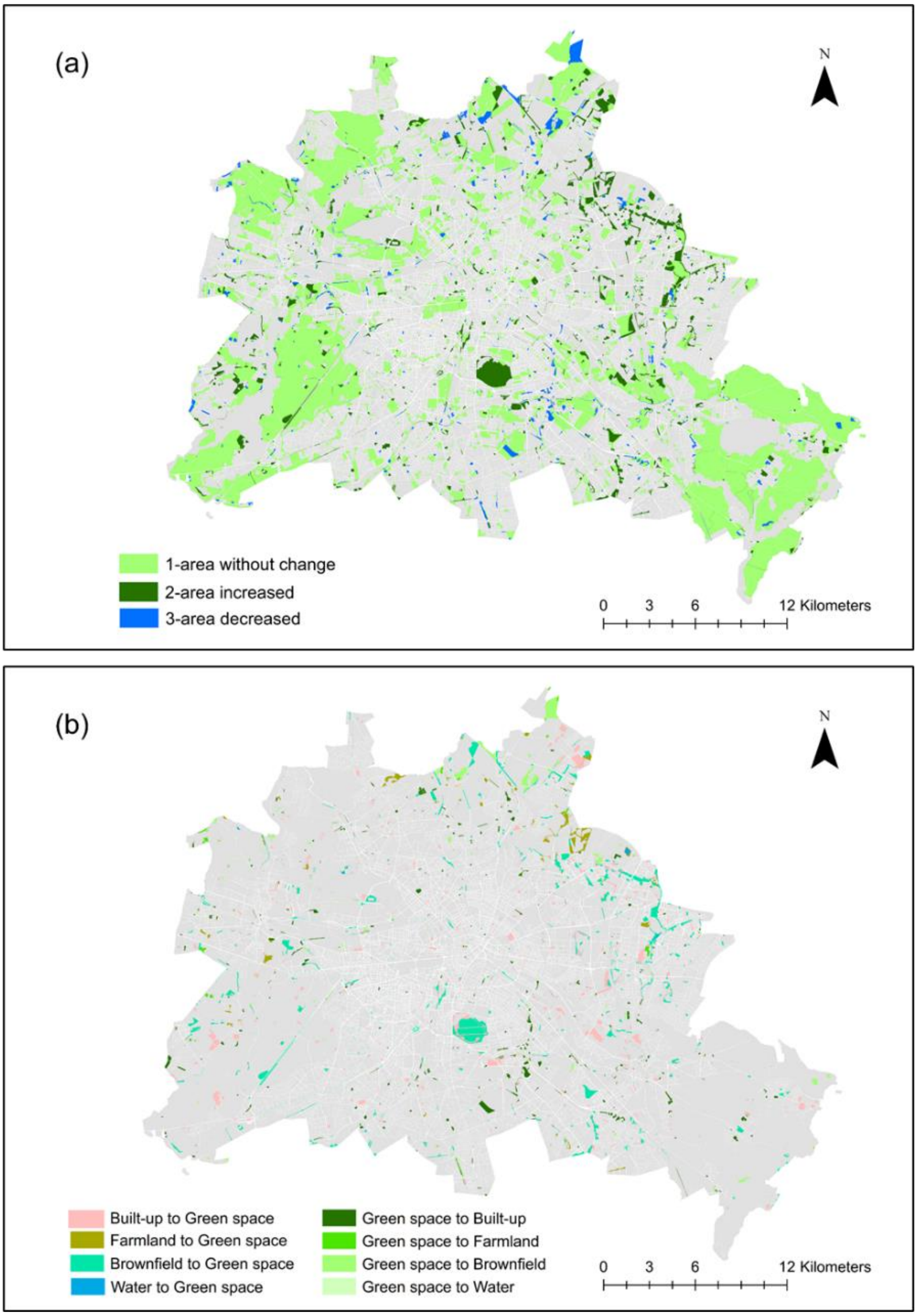

Figure 6- 2. (a) changes in public UGS between 2005 and 2015; (b) land use changes.

3.2. Quality changes with LST hot-cold spots at the patch scale

From the perspective of landscape ecology, large, medium, and small patches contribute to the quality of UGS modified through LST hotspot analysis. The minimum area of small patches in 2015 was less than that in 2005, and the maximum area of large patches in 2015 was larger than that in 2005. The number of large patches decreased from 372 to 371, with the area increasing by approximately 2,000 ha and the average NDVI being over 0.5. In comparison, medium patches increased in number, and their area rose by approximately 220 ha, with the average NDVI falling between 0.3 and 0.5. The number of small patches increased from 1,295 to 1,526, with an increase of approximately 110 ha, and the average NDVI existing between 0.3 and 0.5. Moreover, the hot- and coldspot pattern in Figure 4 demonstrates the changes in ecological functions to mitigate the temperature response to the pattern dynamics of the green space. In this decade, temperature mitigation effectively increased, as indicated by more coldspots in the LST. In addition, the remaining green space from 2005 to 2015 had Gi-Bin values from -1 to -3, which implied the strength of UGS quality, while some additional green space emerged in hotspots with G-Bin values larger than 1. Most hotspots were located in small and medium patches; in contrast, coldspots were mainly distributed in large patches. From Fig. 6-3, some large patches in the northeast were developed and present the cluster of coldspots compared with those in 2005. Furthermore, Table 6-2 shows a significantly negative correlation between LST and PA in small, medium and large patches, while NDVI was positively correlated with PA. This finding implied that the PA of green space has a positive correlation with UGS quality.

Table 6-2. Pearson analysis of LST, NDVI and PA in 2005 and 2015.

Correlation coefficients	**All patches**	**Small patches**	**Medium patches**	**Large patches**
2005 LST	-0.147**	0.031	-0.1561**	-0.360**
2015 LST	-0.179**	-0.017	-0.129**	-0.366**
2005 NDVI	0.192**	0.014	0.165**	0.336**
2015 NDVI	0.188**	0.050	0.147**	0.331**

** $p < 0.05$.

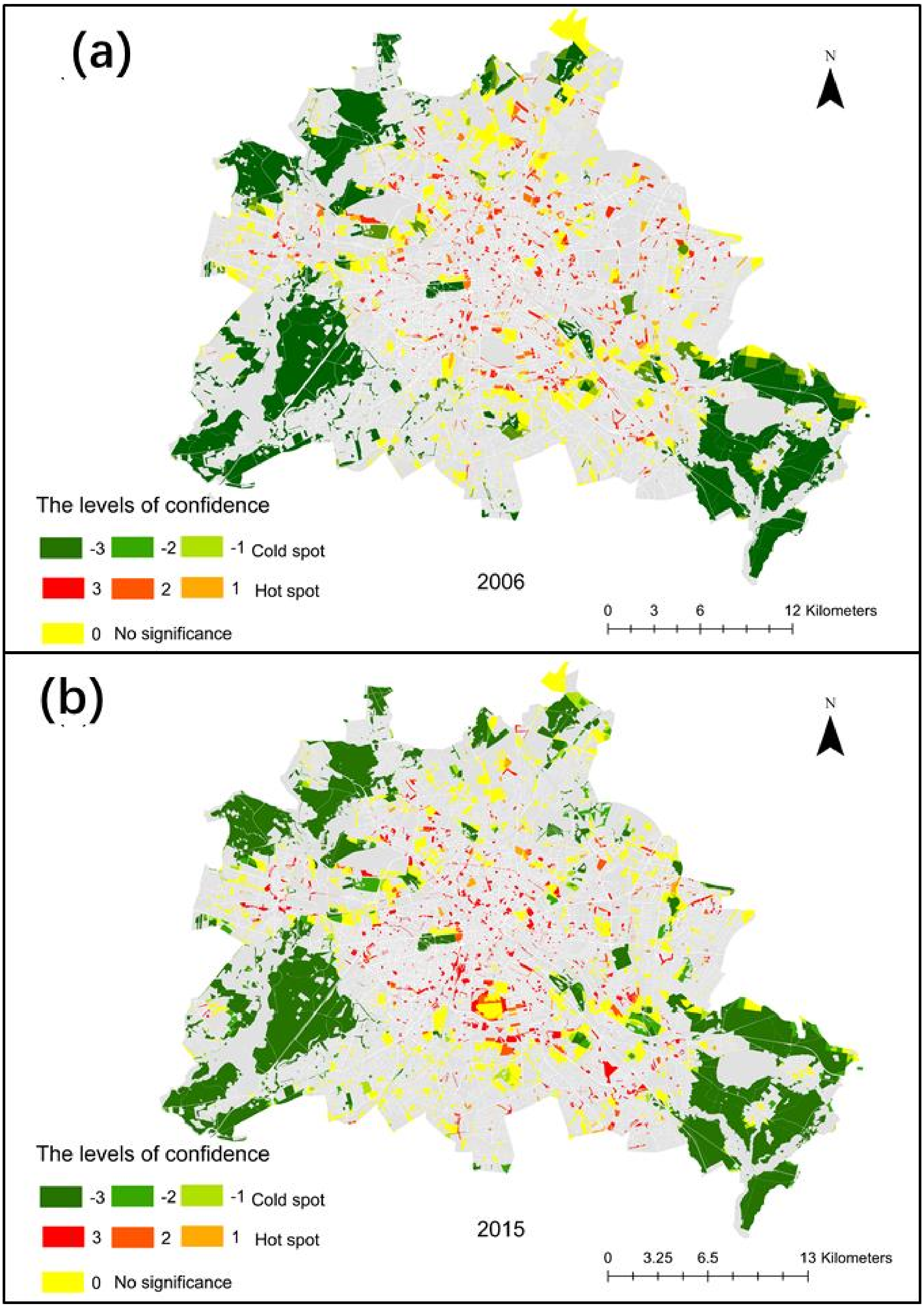

Figure 6-3. The level of confidence in hot and cold spot in 2005 and 2015. -3 represents 99% confidence in a coldspot, -2 represents 95% confidence in a coldspot, -1 represents 90% confidence in a coldspot, 0 represents no significance, 1 represents 99% confidence in a hotspot, 2 represents 95% confidence in a hotspot, and 3 represents 90% confidence in a hotspot.

3.3. Planning practices at the neighbourhood scale

To investigate the integration of quality and quantity for improving UGS in compact cities, we further explored three sites changes at the neighbourhood scale to provide guidance for decision-makers. First, increasing UGS quantity is considered during land redevelopment into large patches. Second, such management link improving the quality and UGS network. Third, increasing UGS with small and medium patches is practical in the city centre.

Site 1: Large patches increased by redeveloping brownfields

Increasing the quantity of large UGS patches by restoring brownfields could be an essential step in UGS improvement. Fig. 6-4 shows an example of Tempelhofer Feld, which was converted from the Berlin-Tempelhof airport and planned as a large inner park for promoting recreation and urban resilience. The airport was closed in 2008, and it was reopened for public use in 2010 as a public park with community participation (Hilbrandt 2017). As a flexible public space with resiliency goals, Tempelhofer Feld was designed to provide more space to develop ecological systems and human activities (Hättasch 2019). Community gardens, animal landscape conservation, history exhibition, project usage, and other recreational areas emerged in the park to provide multiple functions for both humans and nature. In the implementation processes, civic engagement played an important role in park events and activities (Hilbrandt 2017).

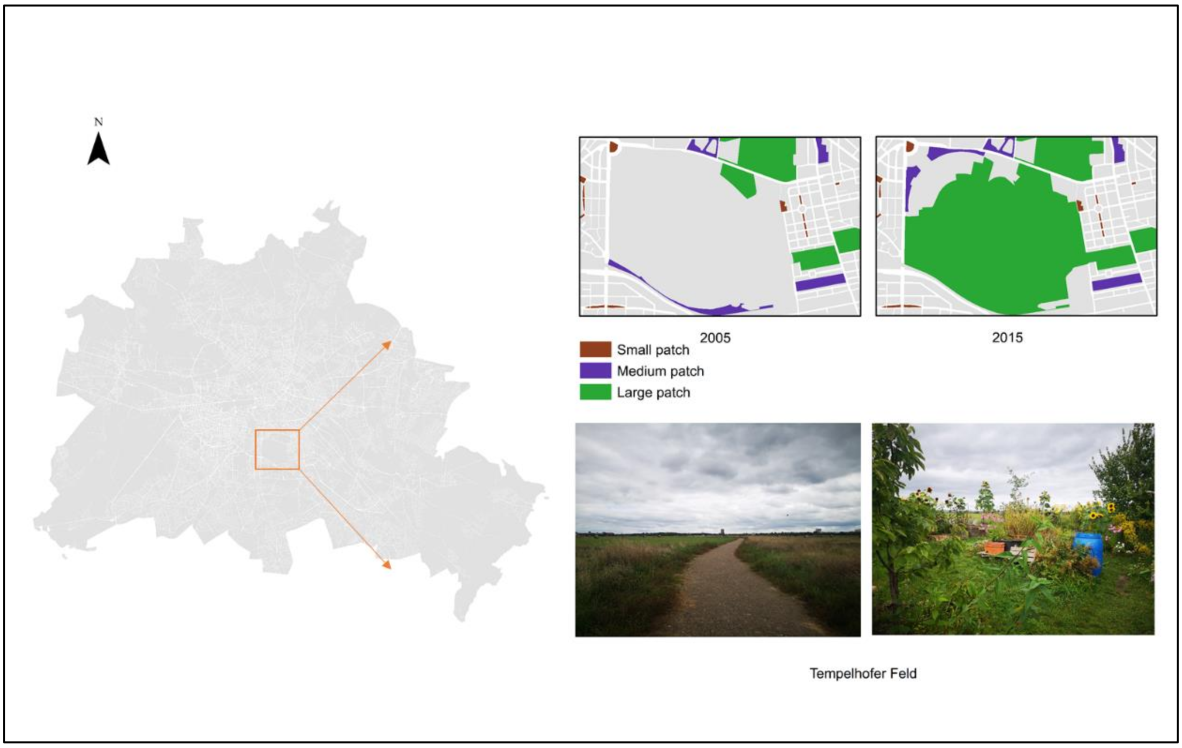

Figure 6-4. Tempelhof Park converted from a brownfield.

Site 2: Medium and large patches for improving urban green networks

Green space quantity contributed to urban green networks in terms of strengthening UGS quality. Fig. 6-5 shows the increase in the number of large, medium and small patches that developed into UGS networks and strengthened temperature mitigation. At this site, the small and medium patches increased through the transfer of the built-up area; similarly, the large patches were transformed mainly from brownfields and farmlands. Several polluted patches from postindustrial sites in 2005, such as Hobrechtswald, were redeveloped into green space with natural-based solutions for soil remediation by specific flora (Pataki, Carreiro et al. 2011). From the perspective of UGS quality, the LST hotspots in 2015 were less in number than those in 2006, demonstrating a positive impact on mitigating temperature. This finding also displayed that the linear green space of medium-sized patches was connected with large patches to a green network. Connectivity and networking provide better ecological functions than do separate green spaces for encompassing the use of linear and nonlinear elements in UGS management (Uy and Nakagoshi 2008). UGS quantity helps enhance network connectivity, benefiting UGS quality (Tian, Jim et al. 2014), which may need more consideration by decision-makers in UGS planning (Lin, An et al. 2021).

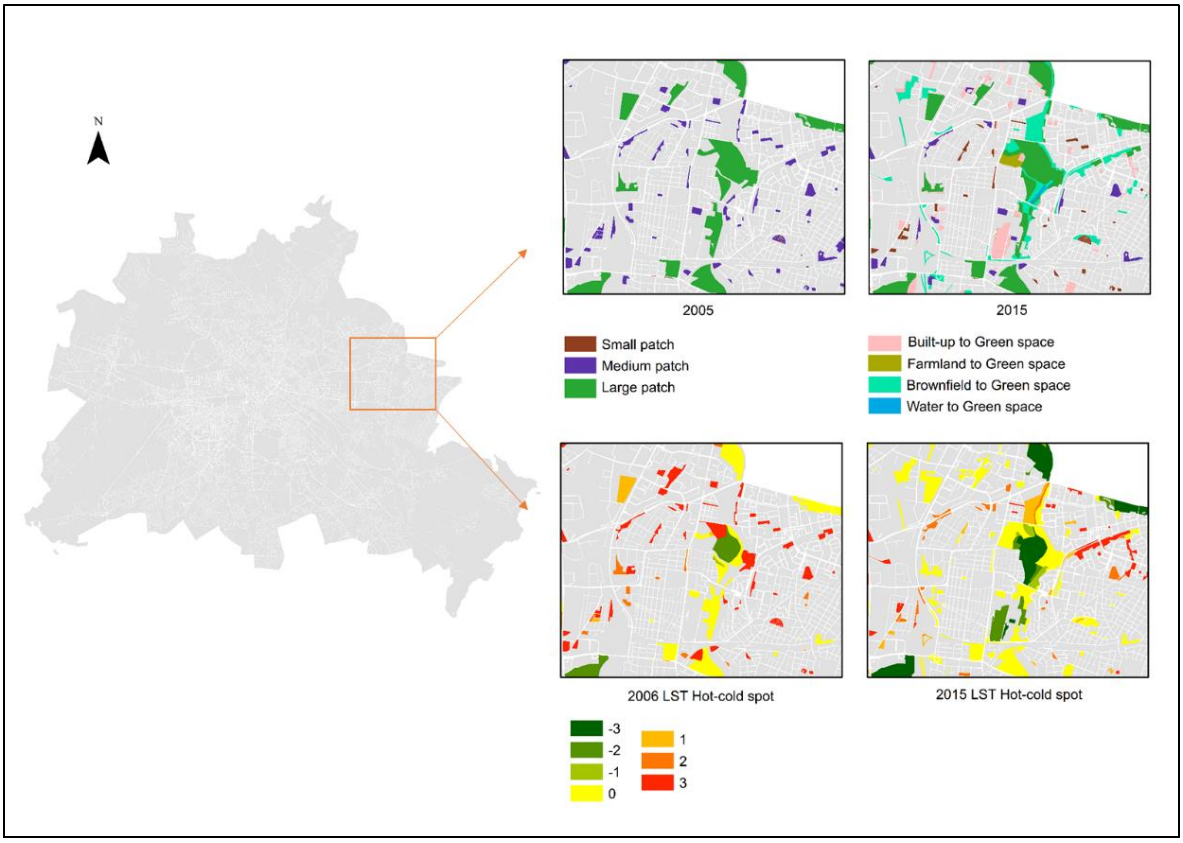

Figure 6-5. Additional green space in the northeast.

Site 3: The increase in medium and small patches in the city centre

City cores could have the potential to improve the quality and quantity of UGS, despite the limited space available due to the high density of buildings and the population. In Fig. 6- 6, the medium and small patches in the city cores increased linearly along with built-up areas and were connected with large patches to form green corridors. The largest patch, Tier Garden, a historically permanent green space in the city centre, was initially built for royal hunting sports and gradually opened to the public, with an area of 210 ha. Due to its high ecological quality and long history, it is the most popular inner-city park and urban natural area in Berlin among local residents and visitors (von Beyme 2019). As shown in Figure 6, enhancing ecological quality and enlarging the PA of existing UGS could improve recreational and ecological functions in the city core. The strategic practices in the city centre include connecting the nearest green patches to large patches, enlarging small patches into medium patches, and establishing small patches as linear patches along with built-up areas and city streets.

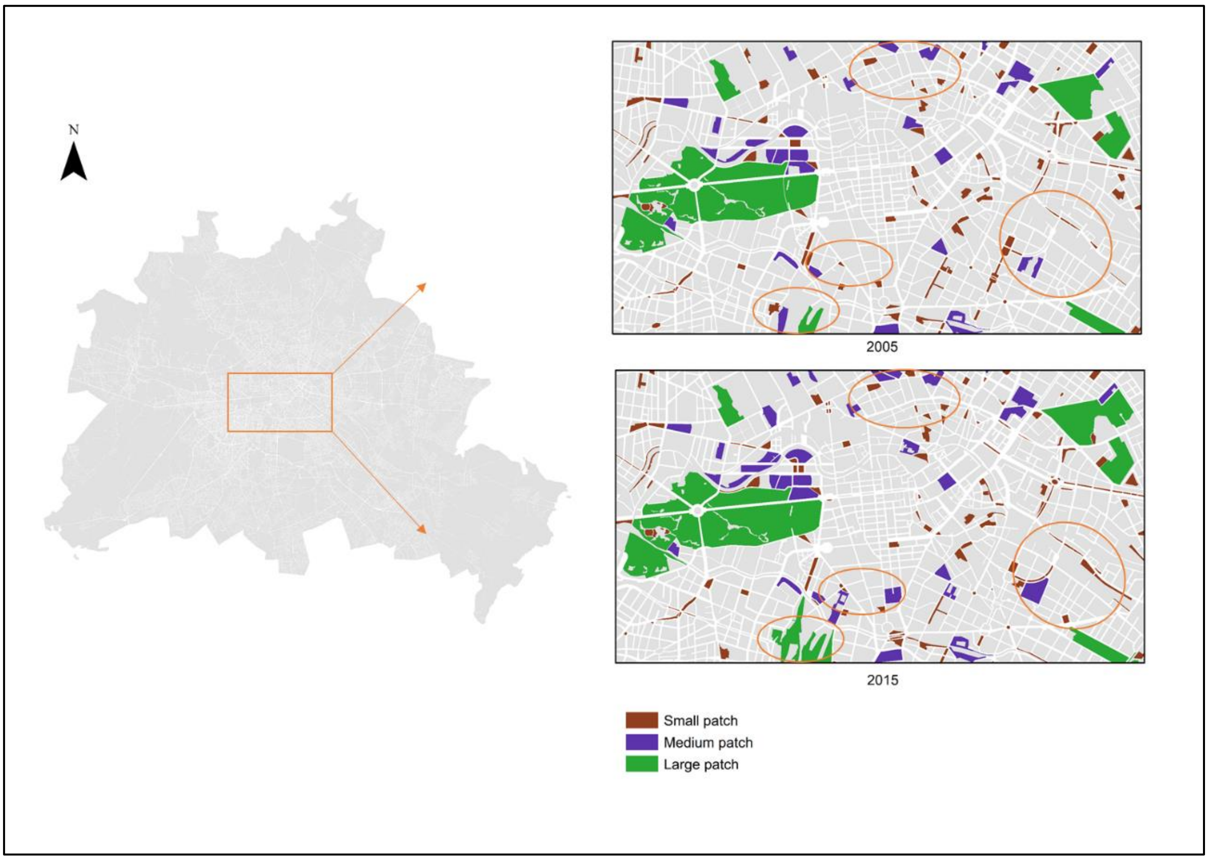

Figure 6-6. Green space in the city centre.

4. Discussion

4.1. Improvement in UGS quantity and quality

Improving the quantity and quality of green space in a compact city is necessary for urban sustainability. In our results, increasing quantity of UGS depends on land use planning in terms of transforming built-up areas, brownfields, and farmland into green space. In the Berlin 2030 strategy, the implementation of land use planning emphasizes the bidirectional development of the human-natural environment (Senate 2015). As Berlin is a postindustrial city, making comprehensive use of limited space is important for both urban systems and human wellbeing. Concerning the problems related to the management in urban shift, our results demonstrate that transforming brownfields into green space is practical. In particular, the restoration of polluted areas requires natural-based solutions that involve planting specific types of vegetation. Previous studies have also confirmed the potential for redeveloping brownfields (Siikamaki and Wernstedt 2008); for instance, improving green networks can increase human and city animal mobility (Zhong, Zhang et al. 2020). From the perspective of improving UGS quality with ecological functions, green space patterns directly affect ecological functional processes. In our research, the increase in LST coldspot clustering in 2015 demonstrates that the UGS quality of temperature mitigation has been improved. Under climate change, temperature mitigation and adaptation are receiving a great deal of attention in cities. Green space providing shade and evapotranspiration can directly regulate climate at the microscale and regional scale, which has heterogeneity in terms of patch size, shape, composition, and configuration. Previous studies have demonstrated that impervious surfaces that are converted to green space lack the presence of the cooling effect due to the underlying structures of the biotopes and soil (Sun and Chen 2017). As urban heat islands are common around the world, UGS improvement considering temperature mitigation and adaptation can enhance urban ecological functions (Heidt and Neef 2008). Totally, modifying land to act as green space to improve quantity with appropriate management can effectively strengthen UGS quality.

4.2. Different management approaches for UGS patches

This study on the 12 districts shows different strategies for improving UGS. For instance, in city cores, the strategy of increasing the number of small UGSs, such as the linear green space occurring along with built-up areas and streets, stimulates land potential. Numerous studies have confirmed the benefits of pocket parks in high-building-density areas (Lin, Lau et al. 2017). Moreover, enlarging existing UGSs can improve UGS quality, a topic that has received less attention. To improve UGS in different districts, it could be targeted to maximize land use potential, especially in compact cities. In addition, large, medium and small patches, as the foundations of green belts and corridors and as steppingstones in the UGS network, respectively, require different management strategies depending on the surroundings. The utilization of landscape ecology provides guidelines for increasing ecological quality. Different patches could bring planning strategies to enhance UGS. Related research has studied the changes and nonchanges at the patch scale to measure the loss, expansion and shrinkage to provide target-specific measurements to green space planners (Wang, Zhou et al. 2018). A larger patch size can enhance ecological functions more homogeneously in compact cities (Tian, Jim et al. 2014). In our research, with general goals and systematic planning (Kowarik 2019), the Berlin UGS strategy values the local nature through integrated planning approaches. Different UGS patches are managed by multiple methods; for example, most large patches are managed based on wild nature management, and small patches are managed based on the biotope factor. Furthermore, urban wildness is an important forest management goal related to maintaining biodiversity (Rink 2009). To determine the green index, the biotope area factor (in German: Biotopflächenfaktor (BFF)) was first proposed in 1990 in a Berlin landscape planning and tree policy document (Meinel, Hecht et al. 2006). This factor efficiently contributes to scientifically improving green quality according to the determined location for a green space in the city centre (Reinwald, Ring et al. 2019). Therefore, UGS efforts require not only systematic planning and detailed scientific management but also a scientific system to improve UGS for urban sustainability.

4.3. Improving UGS with practice inspiration

The increasing demand of people for UGS development in compact cities is influenced by the pursuit of green and healthy lifestyles (Rosol 2010) and environmental education (Otto and Pensini 2017). Public engagement in UGS strategies highlights the contributions of citizens to USG planning and management, as in the case of Tempelhofer Feld. Previous research in Berlin has confirmed that the concept of ecosystem services in governance can promote greenspace and its benefits to citizens (Kabisch 2015). Decision-makers in planning practices need to consider residents' requirements for UGS in terms of improving UGS and focus on the importance of urban governance to integrate UGS quantity and quality. Due to the demand for public participation in developing and developed cities, civic engagement can drive UGS development (Rall, Hansen et al. 2019) by building environmental educational infrastructure, guiding the public in managing private gardens, and supporting public organizations to protect UGS (Buijs, Hansen et al. 2019). Moreover, the involvement of multiple disciplines can address urban ecological problems by combining green space with public health, computer sciences, and biophysical chemistry to specifically improve UGS. For example, the Green Belt Berlin was established by integrating ecological, social, and cultural approaches (Kowarik 2019). Furthermore, multiple dialogues can provide opportunities in complex urban systems from the original concept to implementation with practical cooperation, such as resilient city congresses organized by the local government for sustainability to engage in a global, multirole conversation and contribute to city goals (Huck and Monstadt 2019). At the city scale, Berlin also has responsibility systems assigned to different commission groups and institutions to support scientific methods and provide advice for UGS management. Urban development with different stakeholders has been confirmed the importance in systematic approaches to governance in response to urban heat (Mahlkow, Lakes et al. 2016). In compact cities, public engagement and multicooperation are needed to improve UGS in the process of the development of sustainable cities.

5. Conclusion

Improving UGS in compact cities is a crucial urban strategy in response to climate change and human health crises. However, the knowledge gap between ecology research and planning management needs more attention in compact cities. The aim of our research was to illustrate the changes in quantity and quality among Berlin public green space and provide inspiration for compact cities. First, this study conducted an analysis of land use changes between 2005 and 2015 to determine UGS quantity changes in different districts at the city scale. Second, to assess UGS quantity, we retrieved and compared the spatiotemporal changes in the NDVI and LST through hotspot analysis at the patch scale. Third, the three selected sites demonstrated the changes of small, medium and large patches at neighbourhood scale for improving green space. Our results demonstrate that UGS improvement requires targeted strategies in different functional urban regions. To increase UGS quantity, an effective strategy is to redevelop brownfields. In terms of managing UGS quality, the integration of small, medium, and large patches with different planning is required to contribute to temperature mitigation and adaptation. UGS improvement requires a combination of quantity and quality with effective management to strengthen urban sustainable development.

Chapter 7.

“City self-learning” in Urban Planning for Enhancing Climate Resilience and Landscape Sustainability

Chapter 7. “City self-learning” in Urban Planning for Enhancing Climate Resilience and Landscape Sustainability

Abstract: Urban climate resilience is of increasing concern, especially for sustainable city transformation. However, a gap between urban planning implementation and ecological knowledge research still exists. To provide a new view of urban space planning with the city self-learning concept, this paper addresses the significance of identifying appropriate forms. This paper proposes a way to address the local city perspective regarding urban development. City self-learning is based on regional studies of urban ecology to demonstrate the potential of space planning and land management for enhancing city resilience. Similar to urban development research, this research selects different urban elements as units. The concept could contribute to urban characteristics, smart cities, and urban governance.

Keywords: urban resilience, urban form, cooling city, land functions

1. Introduction

Urban form for sustainable and inclusive cities is crucial to maintain an overarching framework that will benefit climate change and human wellbeing. According to the Report Cities and Pandemics: Toward a more just, green, and healthy future (UN-Habitat 2021), rethinking urban form and function is of concern during the pandemic for population increase, local living, health inequality, space connectivity, and urban actions. Cities have the characteristics of spatial heterogeneity due to various forms with different spatial configurations and compositions for economic, ecological, and social functions. There is growing evidence that urban planning mainstreams urban climate resilience at the city level (Friend, Jarvie et al. 2014).

To enhance urban climate resilience, how to effectively use urban space planning to mitigate temperature has long been discussed in urban ecology and city design. Commonly mentioned approaches include improving urban evaporation, increasing surface albedo and strengthening urban ventilation etc. (O'Malley, Piroozfar et al. 2015, Liu, Li et al. 2017, Taleghani 2018). Numerous studies have focused on the mitigation effects of green infrastructures and the link between their patterns and LST (Anguluri, Narayanan et al. 2017, Guo, Wu et al. 2019). For example, decreasing fragmentation of green infrastructures can help temperature mitigation, which is suggested for adoption in space planning (Li, Zhou et al. 2013); in addition, increasing tree canopies and greenery quality can enhance resilience to urban heat at the mesoscale and microscale (Breuste, Artmann et al. 2015, Berardi, Jandaghian et al. 2020). Different resilience scenarios have illustrated the application of biophilic structures such as cool roofs, green roofs, and white roofs on temperature mitigation (Soderlund and Newman 2015, Carvalho, Martins et al. 2017). Furthermore, urban agriculture can also increase city evapotranspiration to mitigate urban heat (Qiu, LI et al. 2013). Notably, urban ventilation, one of the significant causes of urban heat islands, needs more attention in urban planning and city design to build a climate neutrality city (He, Ding et al. 2020).

In terms of complex systems, cities have different spatial configurations and components, which have essentially been implemented with biotic and abiotic characteristics (Haase 2021). On climate mitigation, numerous studies have emphasized the contribution of green space and its pattern of connections with other spaces. The percent cover of greenspace, plant species, and structures has an influence on temperature mitigation. Increasing the patch size of greenspaces has a positive impact on temperature mitigation due to the decrease in space fragmentation and should be adopted in greenspace planning (Li, Zhou et al. 2013). The combination of vegetation and water can strongly promote the urban cooling effect in city design (Wu and Zhang 2018). More importantly, abiotic urban structures are also capable of increasing city climate resilience. For example, housing types have a relationship with urban ecosystem service provision, especially building density (Tratalos, Fuller et al. 2007) and building material. Climate resilience to urban heat has significant implications for sustainability and should guide land management (Elmqvist, Andersson et al. 2019) and responsible land governances with multiple functions (Mitchell, Enemark et al. 2015). The implementation of heatwave vulnerability maps in urban planning is recommended for increasing resilience (Hatvani-Kovacs, Bush et al. 2018). Holistic policy recommendations are made with a framework of public health, urban infrastructure, services and utilities, building and construction, and urban planning (Hatvani-Kovacs, Bush et al. 2018). Urban physical complexity in space planning has the capacity to analyze resilience, adaptability, and livability (Boeing 2018).

In addition, urban resilience requires benefits for human wellbeing, such as physical health, psychological health, and positive emotions. As urban form supports natural settings and satisfies human needs, the interaction between human-natural environments is vital to establishing characteristics of urban planning for promoting human health. Meanwhile, numerous studies have confirmed that the association between urban forms and human recreation suggests the separation of human settings from nature for improving ecological functions and their benefits (Soga, Yamaura et al. 2015). From the perspective of urban design, different functional spaces are important to meet the needs of ecology, the economy, and society (Lefebvre and Nicholson-Smith 1991). For example, to promote human health, the physical activity of walking and bicycling options might be required in urban planning for designing health-promotion environments (Frank and Engelke 2001). Urban space planning has the potential to support cool cities (Norton, Coutts et al. 2015), which promote human health due to the resulting environmental benefits (Barton and Tsourou 2013). In urban transformation, cross-city learning is suggested to improve city resilience and bridge differing perspectives regarding city limitations and implementations (Hölscher and Frantzeskaki 2021); there are numerous studies comparing different approaches for urban green spaces, society, building design, and urban development (Wu, Zhao et al. 2015, Kabisch, Strohbach et al. 2016, Williams, Logan et al. 2020). Meanwhile, knowing the landscape preferences of the cross-cultural communities for whom UGSs are provided is relevant information. From chapter four, local visitors may prefer a more natural landscape, for example, a wild forest; however, immigrations may prefer landscape characteristics that provide more entertainment and a sense of place. Thus, to satisfy human demand is crucial for a resilient city.

There is still a lack of research regarding guidance for urban spaces practices that increase climate resilience in local cities (Sharifi, Roosta et al. 2021). In terms of the significance and heterogeneity of urban form, the discussion of urban planning in a given city is required for enhancing city resilience. Thus, this session aims to propose the concept of "city self-learning" in urban planning.

2. The conception of city self-learning

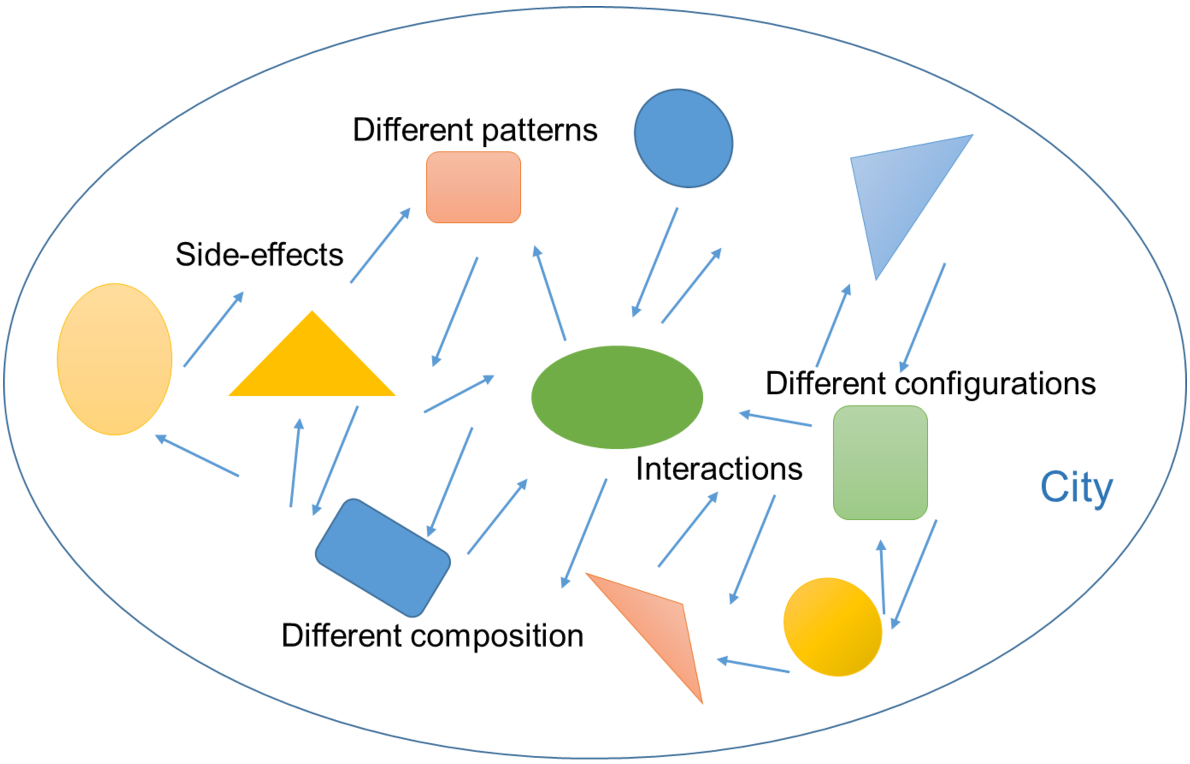

Figure 7-1. The draft conception for city self-learning.

City self-learning means enhancing urban resilience through spatial heterogeneity to institute urban forms with different compositions and configurations in a given city. The processes in Fig. 7-1 are based on existing patterns designed to compare their ecological effects on climate mitigation and health promotion. This figure reflects the association among land uses, land functions, and land potential with an inner comparison at a local level. From the above studies in Berlin, the results demonstrate the spatial heterogeneity of the land compositions of NDVI, NDBI and NDWI on the cooling effect of different land uses. Due to the various combinations of green, blue, and gray infrastructures, land patterns represent diversity in a given city and the different processes of temperature mitigation, carbon storage, cultural ecosystem promotion, etc. Mapping functional heterogeneity can determine the highest resilience with appropriate patterns; these data could further be applied in future urban planning. Meanwhile, the study of Berlin green space illustrates UGS improvement strategies by using temporal comparisons over a decade (Chen, Haase et al. 2021). Three sites at the neighborhood scale have shown the connections between the changes in quantity and quality for temperature mitigation. To understand the connection with human wellbeing, social media data acquired with geo-located points can detect human emotions, which reflect human responses to the environment. In particular, the demographic composition in different cities has differences depending on the social, historical, and economic background (Champion 2001), even in cities in the same country. The percentages of mitigation, migration and local people vary by city and therefore influence urban situations in different manners (Card 2009). City self-learning, based on the association between population composition and landscape patterns, could provide guidance for urban planning to satisfy the demands of various communities. Spatial heterogeneity in temporal-spatial perspectives can support city resilience by changing spatial compositions and configurations (Cadenasso, Pickett et al. 2007, Xiang, Huang et al. 2021). Overall, city self-learning is needed to account for the unique ecological, societal, and economic situations in a given city and permits urban planning to adapt to the local conditions.

3. The possible application of “city self-learning”

The city self-learning concept explores city forms using inner spatial and temporal comparisons. It aims to provide insight into urban space planning for enhancing city resilience and human wellbeing. This section mainly demonstrates three perspectives regarding its applications for defining urban characteristics, building a smart city, and governing urban human-natural balance.

3.1. To define urban characteristics

In the process of urbanization, cities with different cultural and environmental backgrounds have different characteristics. Urbanization has been linked to both traditional development and health issues (Vlahov, Freudenberg et al. 2007). The structures of building density, greenery ratio, street patterns, population size, city history, and other factors determine urban characteristics in several ways, including physical (Kolokotroni and Giridharan 2008), ecological, sociodemographic, and cultural patterns. Building styles, social communities, urban landscapes, and local cultures are found to be the basis of urban development. At a global level, cities are listed on both global and national scales and are defined from economic, ecological, and social perspectives. For example, in Germany, Berlin is the capital city, while Munich is the economic center. In China, Beijing is the capital city, while Shanghai is the economic center. Such a relationship also existed in the American cities of Washington and New York, the Indian cities of New Deli and Mumbai, and the Russian cities of Moscow and St. Petersburg. The relationship among cities is vital to determining the role of a city at the global and national levels. Moreover, several standards and indices provide navigation for urban development; for example, the human development index (HDI) reflects the income per capita, education, and life expectancy to provide a national performance ranking (Sagar and Najam 1998) and is a vital index of quality of life (Michaels, Rauch et al. 2012). The HDI was released in 1990 from the United Nations Development Programme (UNDP).

However, at the local scale, urban planning must be implemented to define a city by its development. The concept of city self-learning relies on spatial heterogeneity in urban structures to compare multiple landscape ecologies, determine the best practices, and enhance city resilience. City self-learning calls for the exploration of building styles, public spaces, greenery design, and other mixture patterns to obtain the greatest advantages or the highest number of urban characteristics, which could indicate a city landmark. Meanwhile, urbanization in different areas should result in different patterns of urban development. According to the urbanization rate, cities can be categorized by high, medium, and low urbanization rates into large, medium, and small cities, respectively; cities of different sizes are driven by different strategies of urban transformation. For example, from 2000 to 2024, 86% of urbanization growth is expected to be in cities of developing counties in Asia, Latin America, and Africa (Montgomery 2008). Due to the increase in the urban population, urban transformation needs to focus on urban space expansion in rapid urbanization areas, especially in rural–urban linkages, while in low urbanization areas, district updating could require more attention to maintain human demands in cities. In addition, one of the most significant strategies in the cities of Western Europe and North America with low urbanization rates is building transformation.

3.2. Improving resilience with smart green space

For urban greenery, city self-learning could focus on vegetation localization to enhance city resilience. Vegetation localization supports relationships between ecology and society through urban green planning. This planning process can include native species and alien species and balances ecological supplies and social demands. Tree species in urban planning have more diversity, based on comparisons in ten major Nordic cities (Sjöman, Östberg et al. 2012). More specifically, planting landscapes such as urban tree-planting contributes to urban regeneration and benefits landscape patterns from outside to inside, city image and structures, and the strength of urban attraction and technology development (Young 2011, Conway and Vander Vecht 2015). Considering the variety of plant species, atmospheric conditions, soil, and biology at the local level is important for plant cultivation, as are considerations regarding density, canopy cover, species choice and other factors (van Breugel, Hall et al. 2011). In addition to environmental conditions, green space structures at vertical and horizontal levels have different ecological impacts, such as urban cooling effects, sponge city systems, soil carbon storage, and stormwater management (Bartens, Day et al. 2008). Meanwhile, human responses to planting landscapes in parks are also crucial to determining park usage and citizens' wellbeing (Arnberger, Eder et al. 2021, Wang, Jiang et al. 2021). Taken together, city self-learning could give an account of spatial heterogeneity in urban ecology, mapping hot-cold spots and relevant forms of UGS for urban transformation. Based on their significant ecological effects, planting species and composition structures could reflect approaches that characterize and complement the local environment.

Below is an illustration of a smart green operator with mobile app data, local conditions, and the analysis systems for green space sustainability (Fig. 7-2). This is a multisource disciplined approach, with a focus on smart urban green space, integrated environmental education, public assessment, ecosystem service valorization, and scientific planning parties as a whole, to develop smart green space service chain products to meet the needs of the government, the public, scientific research, planning and other multisocial roles. Taking trees as the starting point, the cloud spatial data platform of forest trees is established based on remote sensing computing, geographic systems, and computing through sensors, geospatial coordinates, ecosystem service values, and spatial data of forest tree databases. Three scales, basic attribute information, geospatial information, and ecosystem service value information, were used based on 3S (GIS, GPS and RS) technology to establish a database. The goals were to quantify and spatially display the ecosystem service values of trees through 3S technology + modeling method and obtain forest growth environment information based on sensors. Through the cell phone app "3N Greenland", it can show the survival status and ecosystem service value of forest trees in a natural education and popular way, establish a cultural tree propaganda story for this space and dynamically show the value of forest trees by clicking.

At the same time, the post-experience comment function is developed to collect the public's experience after visiting in the green space for feedback on the problems and needs of forest trees. To actively attract the public to the app's functional services, additional development of related knowledge games and community offline activities are needed. By combining green space data and public demand data from the app with the local public health data, we can quantify and analyze the balance of demands by people and health services with the ecosystem service of the green space for a certain space, then integrate the geospatial analysis and ecological method into planning processes to achieve scientific planning for the green space. In addition, the sensor can carry out timely warnings of fire and pest damage and provide environmental monitoring for green space growth to ensure the state of the tree growth environment. The final realization of intelligent green space includes a constructed supply and demand model, automated display, spatialized supply, and demand. We can focus on a certain area to finally realize the green space growth - supply and demand - planning of terminal automatic equipment.

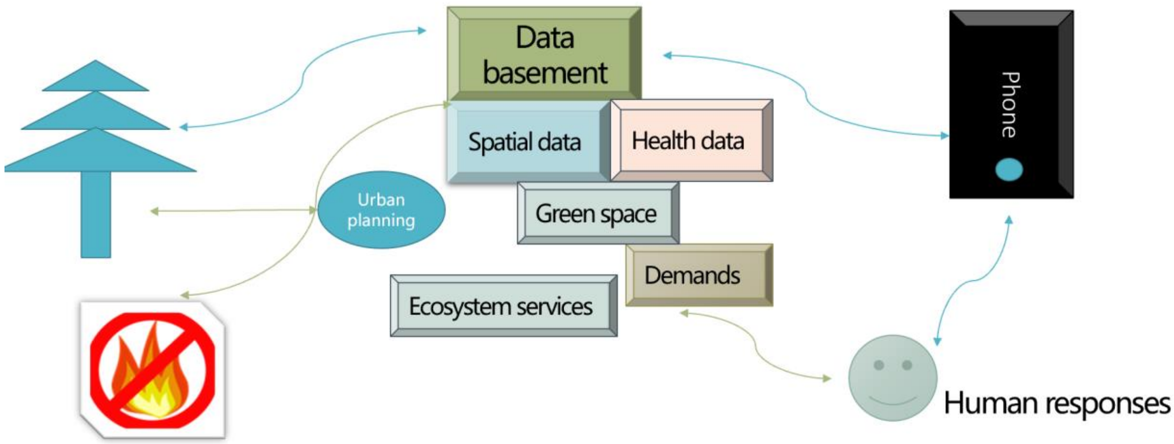

Figure 7-2. An illustration of smart green monitoring with the city self-learning concept.

3.3. To provide suggestions for urban governance

Urban development governance is crucial to define the direction and processes of development. Urban space contributes to ecological functions in climate adaptation and social benefits to human wellbeing. The future direction of urban development has been illustrated through the concept of sustainable development goals, while different cities require specific terms for specific cultures and social structures. In the previous chapter, the Berlin studies used spatial comparison to show city self-learning and demonstrate the comparison of urban spaces with different functions and characteristics for urban resilience. These processes could help decision-makers choose relevant urban forms to enhance city resilience and promote human emotions. Meanwhile, with the development of digitalization, an urban future codeveloped with technology has led to an increasing emphasis on urban sustainability (Brindley, Cameron et al. 2019). In the processes of a smart city with city-self learning, the integration of big data in a given city could contribute to the exploration of an objective question.

In my opinion, urban governments need to focus on the function-oriented aims of resilient cities and carbon-neutral cities; the configuration-oriented aims of garden cities, compact cities, and sponge cities; and the integrated aims of sustainable cities. Urban form, having variety in a given city, displays urban heterogeneity in space compositions and configurations and their related functions (Rapoport 2016). By comparing the different functional spaces, space planning and land management have the capacity to increase urban functions. City self-learning could form urban units that contain all different functional spaces for urban ecosystems and human wellbeing. The urban inner capacity for sustainable development could be identified in governance with the demonstration of city form heterogeneity and its relevance in urban ecology. Moreover, to serve citizens as urban subjects, the urban environment has people-oriented functions for residence, entertainment, transportation, economic activities, human health, etc. Similar to the research on human wellbeing with sentiment in Chapter 5, human emotions change with landscape characteristics of green space, which could provide guidance for park management. Based on the Berlin study, combining UGS quantity and quality offers a clear measurement for enhancing urban resilience to maximize urban land potential to increase urban ecological functions and promote human health (Chen, Haase et al. 2021). Thus, city self-learning could produce local solutions with space heterogeneity and its relative social and ecological effects and provide governance suggestions for a sustainable city.

4. Conclusion

In the context of city resilience, urban planning strategies that help cities adapt to climate change and promote human wellbeing are of significance. In this section, the concept of city self-learning is proposed to identify spatial compositions and configurations that have the largest potential for enhancing resilience. Taking into account climatic, sociocultural, and economic influences, city self-learning can characterize space planning from the city scale to the neighborhood scale. Thus, exploring intrinsic advantages by qualifying ecosystem services and human demand in a certain city can define the inner regularity of urban planning.

Chapter 8. Summary

Chapter 8. Summary

1. Conclusion

This project conducts four studies to propose the eight-type spaces in human-natural systems for city resilience, to analyze the improvement of urban green spaces from quality and quantity perspectives, to determine the relationship between UGS landscape characteristics and human emotions and to illustrate the concept of city self-learning for urban space planning.

(1). Different strategies in the eight-type spaces across human-natural systems

Land surface temperature and its correlation with NDVI, NDBI, and NDWI were used to demonstrate the different temperature patterns in human-natural systems for eight-type spaces that integrate land uses and urban functions. There are human systems with H1 residential area, H2 commercial area, H3 public service, H4 open space and natural systems with N5 natural green, N6 farmland, N7 brownfield, and N8 water. Meanwhile, spaces with differential functions have different impacts on temperature mitigation due to their varied composition of green, grey, and blue infrastructures. Urban planning has the potential to improve urban temperature mitigation in different functional spaces. In the process of temperature increase and decrease, the difference in LST in Berlin has shown spatial heterogeneity for climate resilience in the eight types of spaces, for which open spaces and brownfields have the largest potential. The combination of hot-cold spots and temperature values in each patch indicate that side effects of the surrounding environment influence climate resilience.

(2). Improving urban green spaces with natural supply and human demand

The interaction of UGS supply and human demand with sentiment analysis from Twitter data demonstrates the relevance of different UGS characteristics and human emotions; the activities within the landscape contribute more to positive emotions than the physical landscape. Especially for studying green spaces, the integration of UGS quality and quantity in Berlin has illustrated that UGS planning needs to balance bidirectional improvements by redeveloping brownfields into greenspaces to increase UGS quantity and enlarging the existing greenspace to enhance UGS quality. Moreover, in planning implementation, different patches illustrate several strategies to improve UGS with linear shapes and different configurations of patches and public participation. UGS improvement for city resilience not only considers the human demands of different cultures but also maintains the ecological processes of natural supplies.

(3). The concept of city self-learning for urban sustainability

These studies focus on one city and investigate different urban spaces and their spatial heterogeneity. Studies in a given city can provide multiple viewpoints through which to understand the mechanisms and effects of space functions, land changes, and related ecological processes for urban sustainable development at the local scale. The concept of city self-learning can support local comparisons to determine the balance of human-natural systems to enhance city resilience. It emphasizes the insights of urban inner capacity for urban definitions, smart green spaces, and urban governance to potentially enhance city resilience.

2. Suggestions for urban sustainability

Urban systems are composed of nature and human systems. The 17 sustainable development goals include all the issues humans must address to save the earth. Since the urban city provides dominant human habitat, it can be considered a significant unit for sustainable development; all the issues addressed by the 17 SDG goals occur in cities. Apparently, human well-being and human activity could be the driving factors in the process of urban transformation. Urban implementation depends on urban planning, design, and governance. Urban spaces are the basis of urban sustainability due to their diverse functionality and landscape design. In most situations, the three effects of society, economy, and ecology are considered directional principles in urban development. In contrast to human and natural systems, urban planning requires reevaluating the connections among different human systems and natural systems with the interactions of demands and supplies. When planning green spaces, the conditions of natural elements could be the main driving factors for combining the facilities with human activities. In human systems, human activities and demands are the main drivers of communities, age groups, demand levels, and other factors; and the related facilities for human activities can be surrounded by nature. In Chinese “odd that is the melt of emotions into landscape”.

3. Further research

As urbanism is a complex system with ecological, social, and economic parts, urban spaces in human-natural systems can be transformed into a bidirectional pattern. The balance between natural supply and human demand could be achieved under the two polarizations of nature and humans. Further studying the separate components and configurations shows that the patterns of each type of space have differences in spatial heterogeneity. To increase city resilience, the illustration of each space could explain the changes in ecosystem services and spatial patterns, to explore the reason for spatial differences and to determine the potential for urban transformation and urban planning. Considering the qualification of ecosystem functions, in response to climate change, land surface temperature exposes spatial differences and spatial planning relationships due to the impact of urban surfaces on temperature. Furthermore, urban development and human activities mainly change land use and land cover to support human life. LST is a surface parameter that demonstrates the energy exchange between land and atmosphere. The potential to increase climate resilience by utilizing these eight types of spaces needs to be firmly grasped to overcome development bottlenecks and obstacles. It is important to look at the differences in human demands on urban spaces, maintain basic functions of human life, and explore differences of landscape preferences, as different cultural backgrounds can result in different demands on urban spaces.

Urban spaces with a balance between supply and demand could be used for sustainable development. In the process, a viewpoint based on an interdisciplinary approach that combines computer science, remote sensing, social science, and big data can enhance urban capacity for a resilient, green, healthy, and sustainable habitat for human life. Overall, urban spaces need more discussion regarding the combination of land use and land functions across natural and human systems, the balance between natural supply and human demand, the pattern and course of spatial heterogeneity, and the potential to enhance city resilience with sustainable urban planning.

Urban spaces are complex but have regularity in several methods and concepts. For sustainable development in cities, creative ways to think about implementations and integrations utilize crossing spaces, elements, and cultures in urban human-natural systems. To make a sustainable city, urban spaces are essential.

Appendix

Appendix I Abbreviation Items

IPCC, Intergovernmental Panel on Climate Change

UN, United Nations

LULC, land use and land cover

UHI, urban heat island

LST: land surface temperature

COVID-19, coronavirus disease 2019

NDVI, normalized difference vegetation index

NDWI, normalized difference water index

NDBI, normalized difference build-up index

CHNAS, the coupled human and natural systems

CHNS, the coupled human-natural systems

ESs, ecosystem services

CESs, cultural ecosystem services

SMD, social media data

NASA, the National Aeronautics and Space Administration

USGS, United States Geological Survey

MODIS, Moderate Resolution Imaging Spectroradiometer

ESA, European Space Agency

UGS, urban green space

PA, patch area

ISP, impervious surface percentage

GIS, geographical information system

LCZs, local climate zones

NLP, natural language processing

DN, digital number

UNDP, United Nations Development Programme

HDI, human development index

ETS, eight-type spaces

Appendix II Supplementary

1. Satellite data

Berlin locates in the northeast of Europe, land sat data was downloaded from the U.S Geological Survey (USGS) including the whole area of Berlin. Considering the cloudy factors, the research adopts Landsat 5 in 2006, and Landsat 5, 7, and 8 in 2015 for the research.

Date	Landsat Type	WRS_Path	WRS_Row
20060706	Landsat 5	193	023
20150410	Landsat 8	193	023
20150707	Landsat 7	193	023
20161003	Landsat 8	193	023

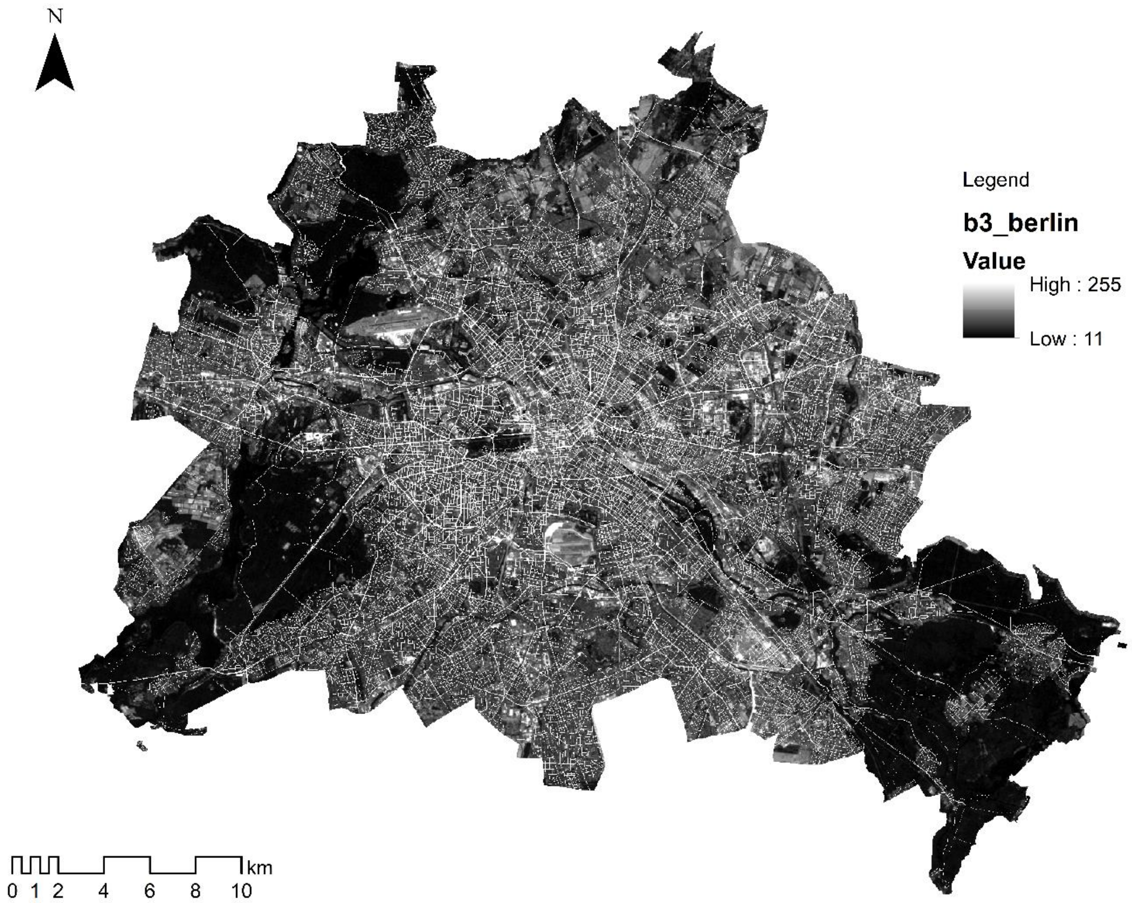

Figure II-1. Landsat5-Band 3 from July 2006 Berlin.

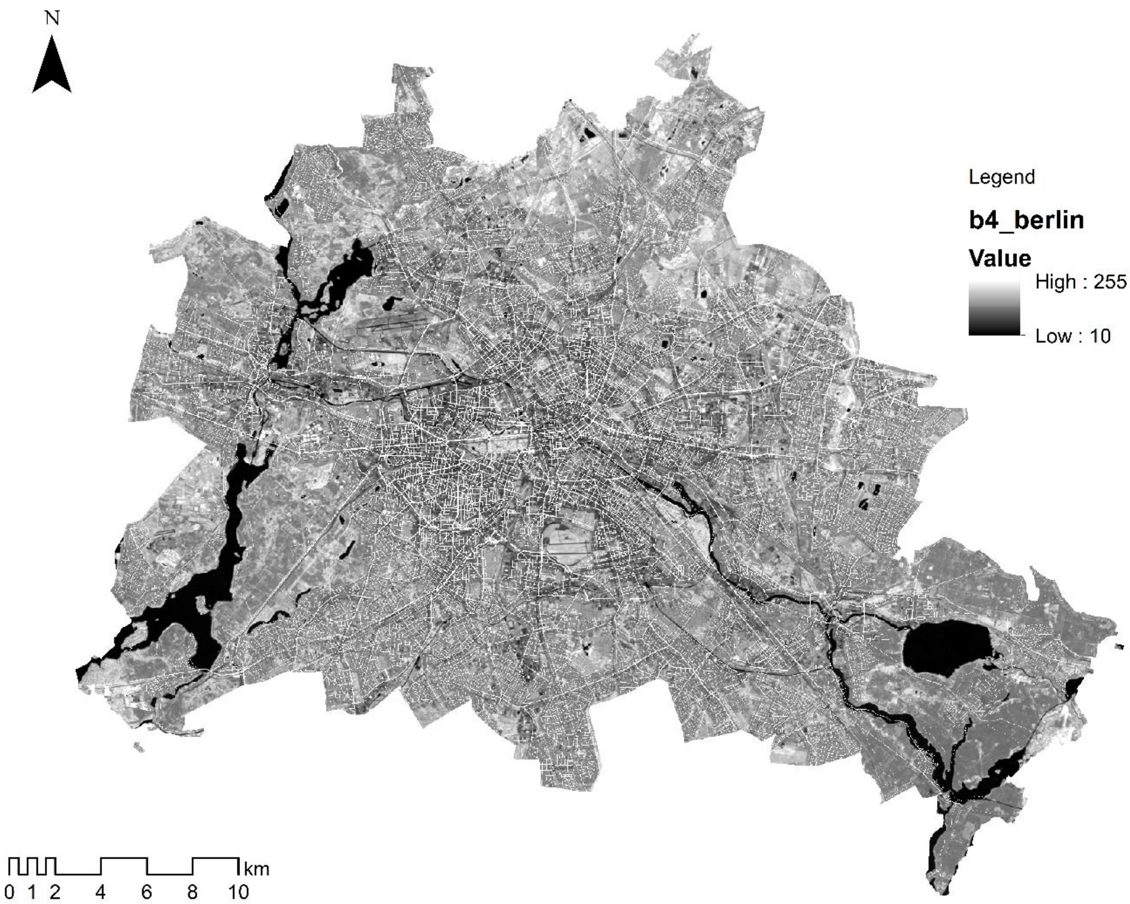

Figure II-2. Landsat5-Band 4 from July 2006 Berlin**.**

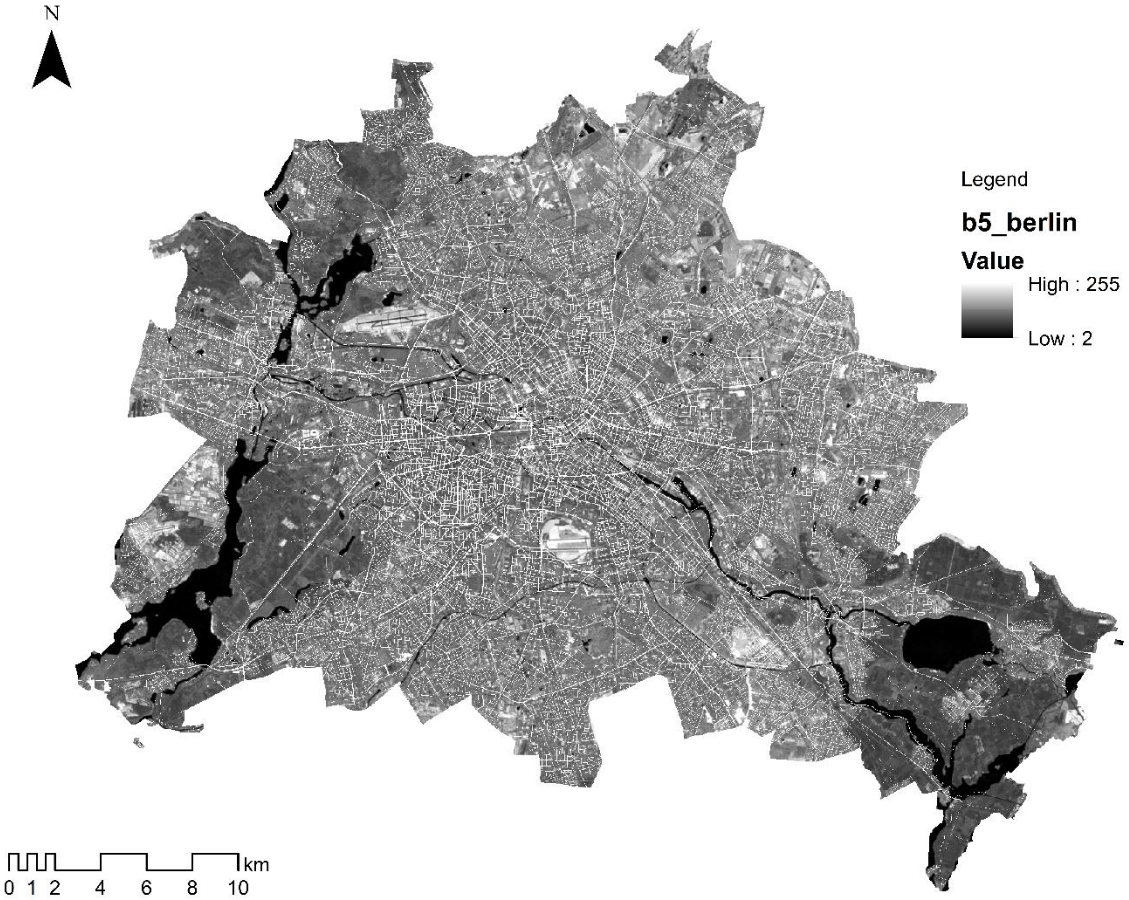

Figure II-3. Landsat5-Band 5 from July 2006 Berlin.

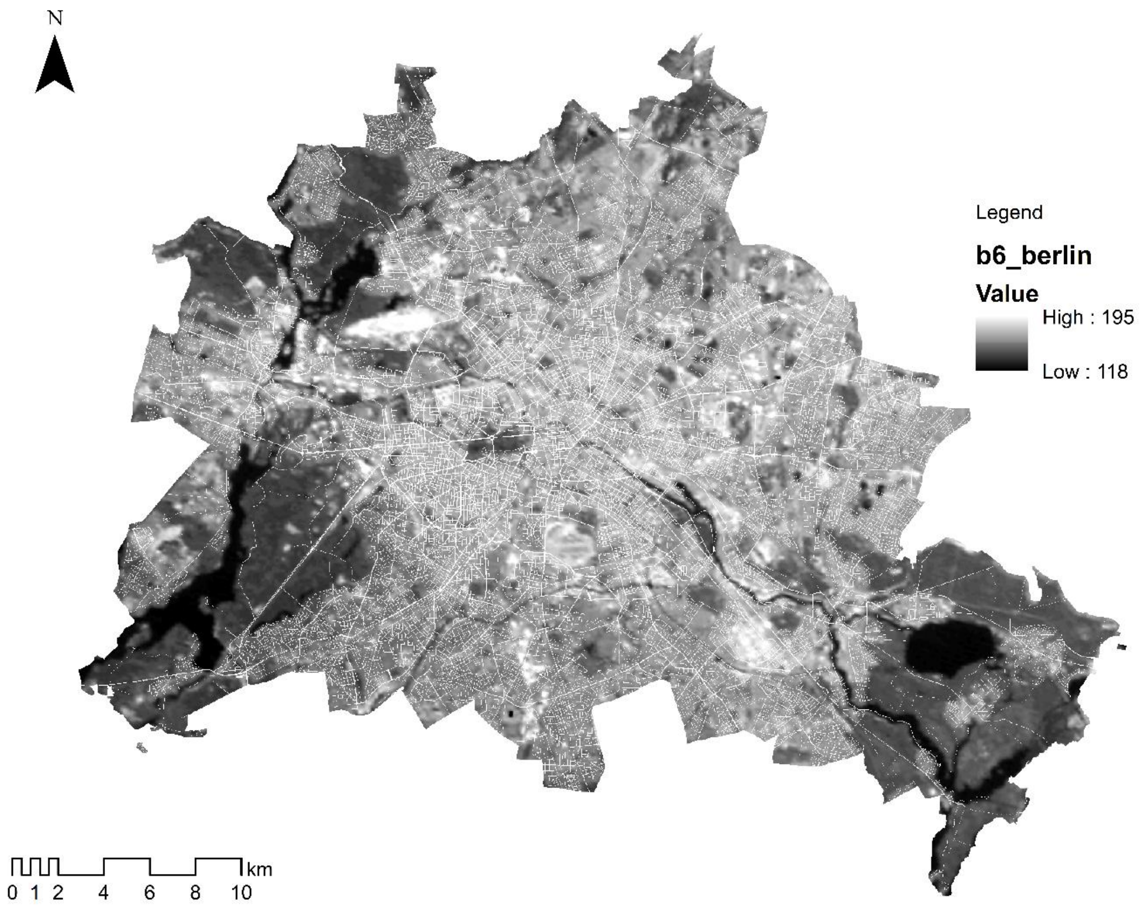

Figure II-4. Landsat5-Band 6 from July 2006 Berlin.

Figure II-5. Landsat7-Band 3 from July 2015 Berlin.

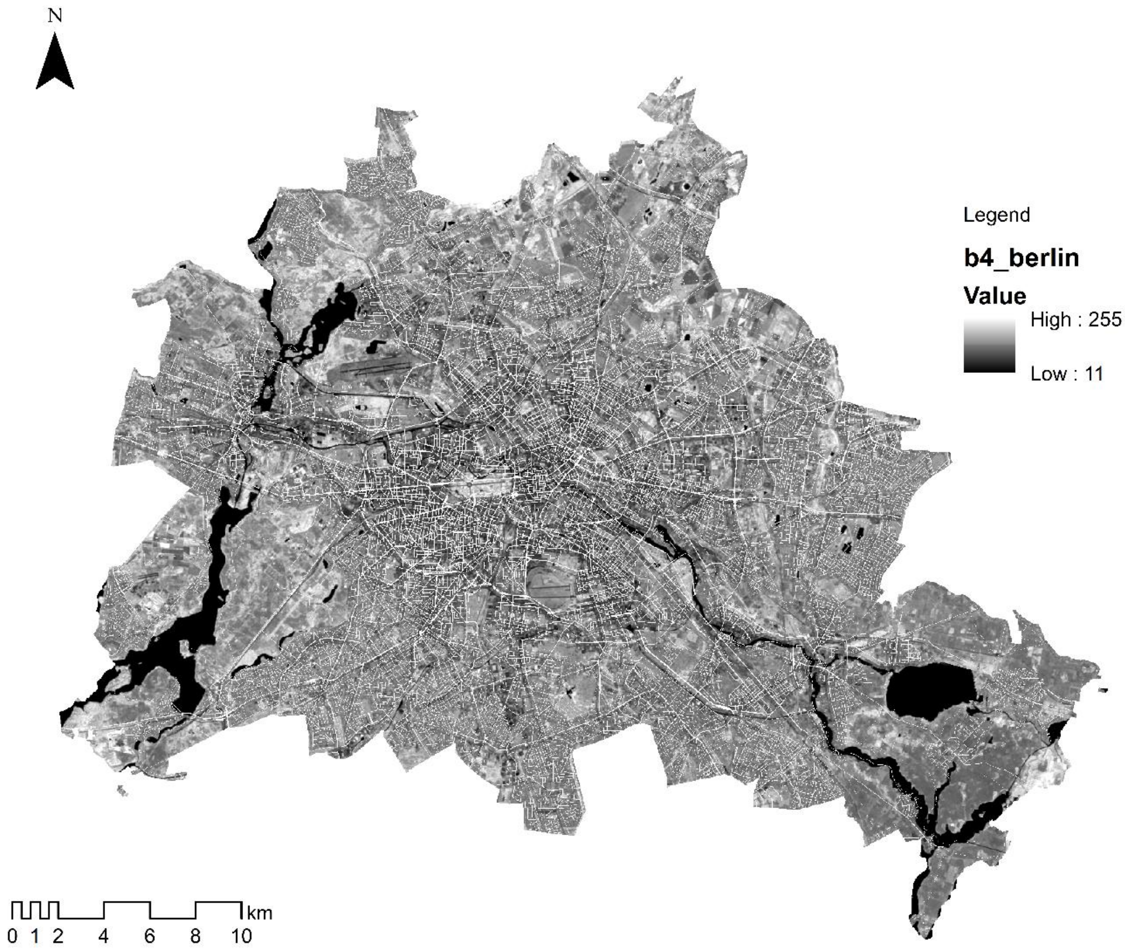

Figure II-6. Landsat7-Band 4 from July 2015 Berlin.

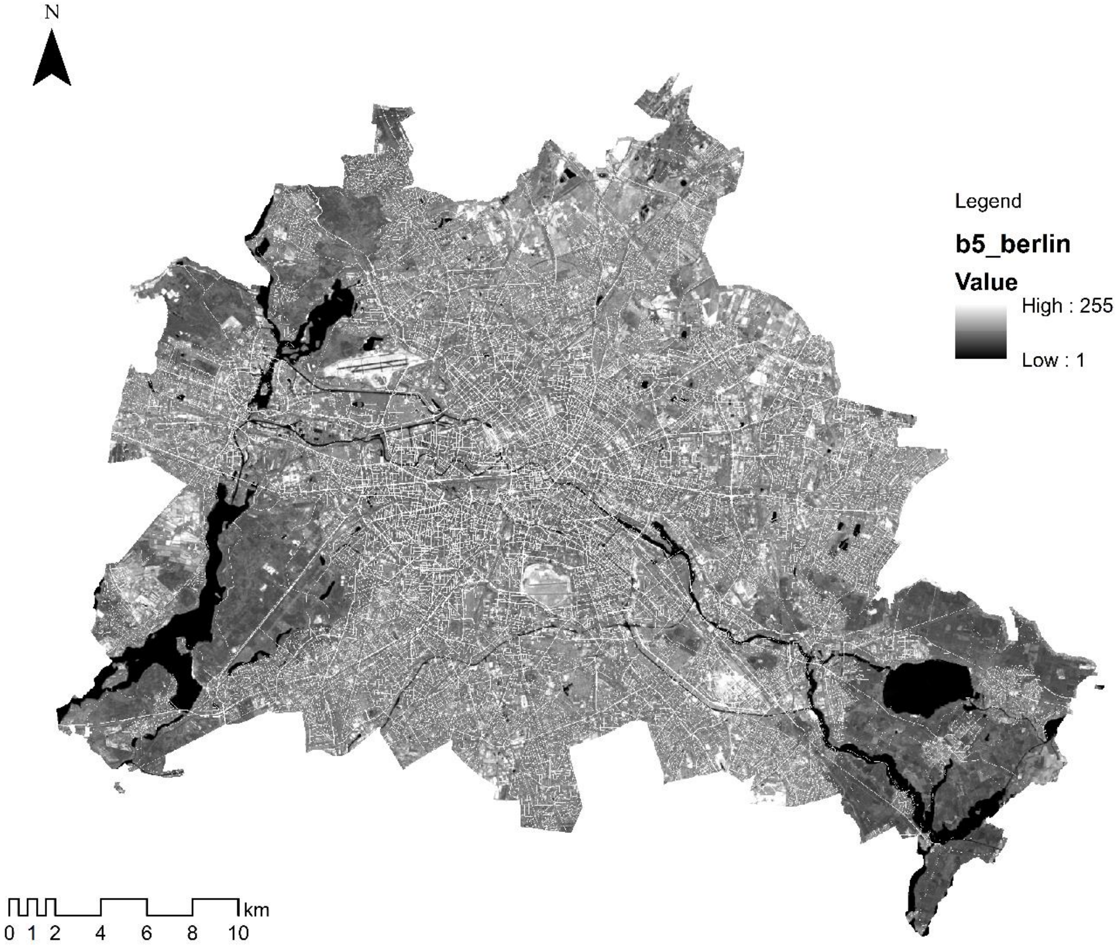

Figure II-7. Landsat7-Band 5 from July 2015 Berlin.

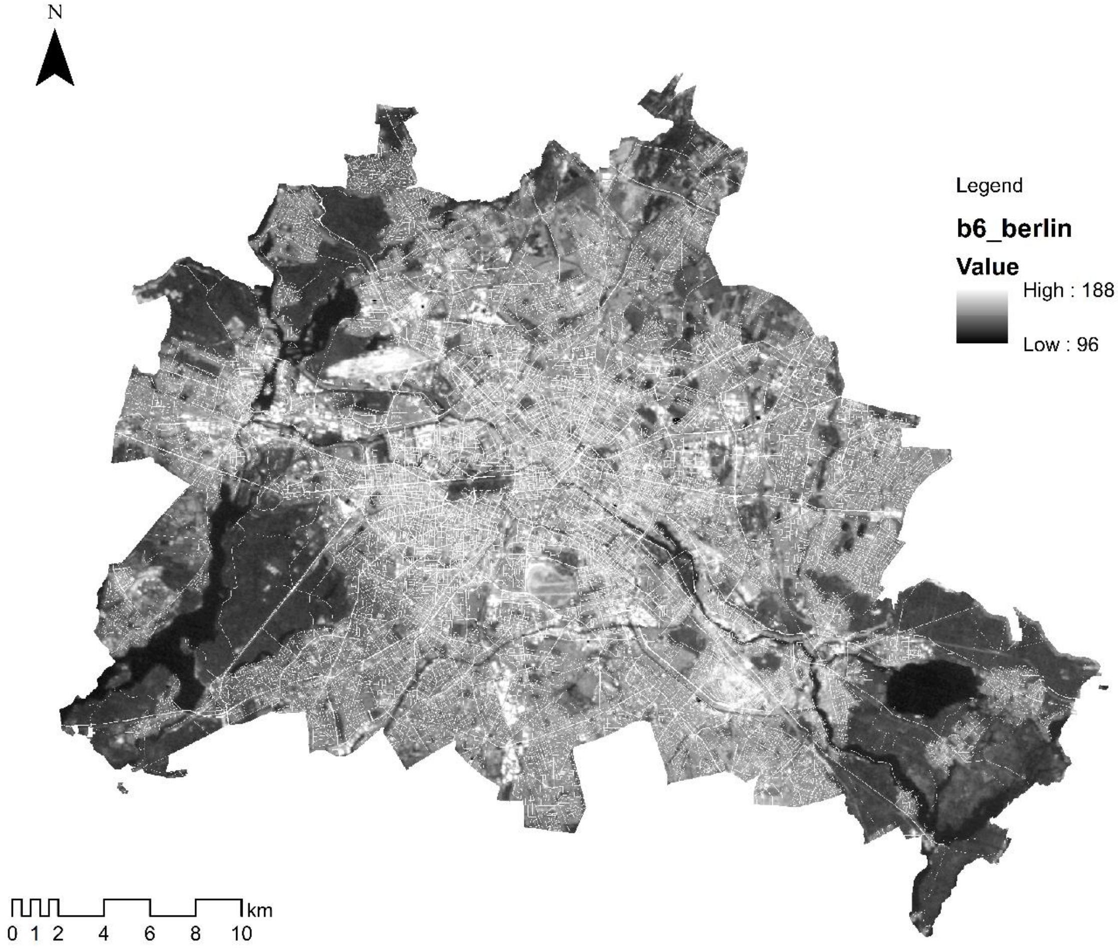

Figure II-8. Landsat7-Band 6 from July 2015 Berlin.

2. Land use data

In this research, 2005 and 2015 land use data of Berlin are from Senatsverwaltung für Stadtentwicklung und Umwelt.

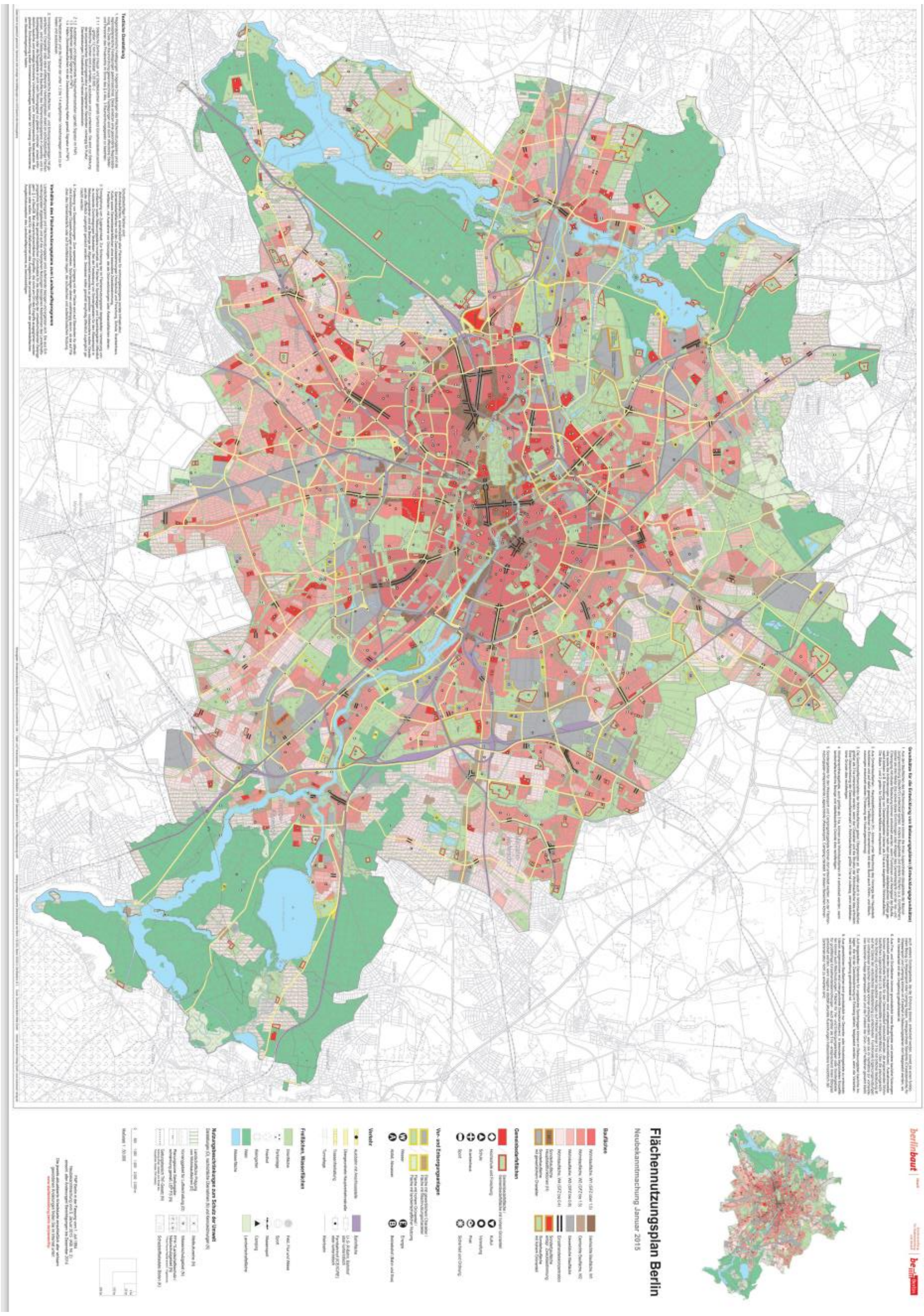

Figure II-9. 2015 Berlin land use data from Senatsverwaltung für Stadtentwicklung und Umwelt.

2. Social media data

Social media data were downloaded from the website with geo-location of 26 urban green spaces.

Table II-1. Geo-location data of 26 urban green spaces.

Sep	Central point location		Range (km)	Name
	Latitude1	Longitude1		
1	52.47322	13.40431667	1	tempelhofpark
2	52.51377	13.34933611	1	tiergarden
3	52.51393	13.36714167	1	tiergarden
4	52.55412	13.46366944	0.6	weiseersee
5	52.48822	13.47111111	1	Treptowerpark
6	52.48281	13.48808611	0.7	Treptowerpark
7	52.47472	13.49191389	0.7	Treptowerpark
8	52.41025	13.697075	1.5	KrummeLaake
9	52.44311	13.57301944	0.3	SchlossparkKöpenick
10	52.44322	13.73496667	1.5	Wilhelmshagen
11	52.43668	13.614975	1	Mulggelsee
12	52.45331	13.58361389	0.3	Bellevuepark
13	52.45418	13.589025	0.3	Bellevuepark
14	52.38804	13.61640556	1.2	Grunauforest
15	52.40198	13.60885556	1.2	Grunauforest
16	52.65194	13.39990833	1.2	TegelerFließtal
17	52.57463	13.23882778	0.5	TegelerFors
18	52.59116	13.24070278	1.2	TegelerFors
19	52.61602	13.26660833	1.5	TegelerFors
20	52.54398	13.28791944	0.5	Jungfernheide
21	52.544	13.27355833	0.5	Jungfernheide
22	52.47181	13.22371111	3	BarsseeundPechsee
23	52.44054	13.18801389	1.5	BarsseeundPechsee
24	52.43393	13.41746389	0.6	Britzergarten
25	52.42931	13.42631111	0.5	Britzergarten
26	52.45386	13.49348333	1	Königsheide
27	52.43124	13.3512	0.3	Gemeindepark
28	52.40124	13.36785833	0.6	FreizeitparkMarienfelde
29	52.48184	13.33853056	0.45	RudolphWildePark
30	52.48328	13.326325	0.5	RudolphWildePark
31	52.48137	13.33244167	0.5	RudolphWildePark
32	52.45599	13.34398611	0.5	FriedhofSteglitz
33	52.42469	13.25996944	0.3	Schweizerhofpark
34	52.42032	13.269275	0.3	HeinrichLaehrPark
35	52.41591	13.27081111	0.3	HeinrichLaehrPark
36	52.60606	13.39395833	0.6	BotanischerPankow
37	52.59931	13.31045278	0.5	Steinbergpark

38	52.57587	13.3856	0.5	VolksparkSchönholzerHeide
39	52.58027	13.37493056	0.5	VolksparkSchönholzerHeide
40	52.51806	13.47731667	0.3	StadtparkLichtenberg
41	52.52341	13.51199444	1.2	LandschaftsschutzgebietHerzberge
42	52.53588	13.57980833	0.9	Gartenderwelt
43	52.4929	13.59048611	0.7	KaulsdorferSee
44	52.49982	13.59134444	0.4	KaulsdorferSee
45	52.46593	13.55226111	1.5	WuhlheideKöpenick
46	52.47691	13.58156389	1.2	WaldspielplatzDäumlingsweg
47	52.4653	13.60698611	1.2	WaldspielplatzDäumlingsweg
48	52.40636	13.51746111	0.4	parkRudowAltglienicke
49	52.40208	13.51863333	0.2	parkRudowAltglienicke
50	52.52946	13.355725	0.3	SportparkPoststadion
51	52.52689	13.35709722	0.2	SportparkPoststadion
52	52.52995	13.42177778	0.3	LeisePark
53	52.54521	13.38482778	0.4	Humboldthainpark
54	52.57695	13.40799167	0.4	Schlosspark
55	52.57936	13.41514167	0.3	Schlosspark
56	52.54902	13.42223333	0.2	HumannplatzSpielplatz
57	52.57999	13.17449722	2	SpandauerForst
58	52.54123	13.18938611	0.4	spektpark
59	52.63679	13.49806389	0.4	Schloßparkbuch
60	52.63044	13.51533889	0.25	LandeseigenerFriedhof
61	52.65074	13.48301944	0.9	bucherforest
62	52.64161	13.47129167	1	bucherforest
63	52.5757	13.49429167	0.4	Malchowersee
64	52.57349	13.488325	0.4	Malchowersee
65	52.56997	13.48881111	0.2	Malchowersee

Table II-2. The five characteristics of physical landscape.

Type	Code	Name	Physical landscape				
			Area	**Building**	**Tree density**	**Underground vegetation density**	**Water**
Park	P1	Gemeindepark Lankwitz	2	1	2	2	2
	P2	Freizeitpark Marienfelde	3	1	2	3	2
	P3	Weißer See	3	1	2	1	2
	P4	Volkspark Schönholzer Heide	4	2	2	2	1
	P5	Treptower Park	5	2	2	2	2
	P6	Tiergarten	5	2	3	3	2
	P7	Tempelhofer Feld	5	1	1	2	1
	P8	Steinbergpark	3	2	2	2	2
	P9	Bellevuepark	3	2	2	1	1
	P10	Stadtpark Lichtenberg	2	2	2	2	2
	P11	Sportpark Poststadion	2	1	2	2	1
	P12	Schweizerhofpark	2	1	2	2	1
	P13	Schlosspark Köpenick	1	2	2	2	2
	P14	Großer Müggelsee	5	1	1	2	2
	P15	Landschaftspark Herzberge	4	1	1	1	2
	P16	Volkspark Jungfernheide	5	2	2	1	2
Garden	G17	Gärten der Welt	4	2	2	2	2
	G18	Britzer Garten	4	2	2	2	1
	G19	Botanical Volkspark Pankow	4	2	2	2	1
Forest	F20	Grünau Forest	6	1	3	3	2
	F21	Tegeler Forest	6	1	3	2	2
	F22	Königsheide	4	1	3	2	2
	F23	Kaulsdorfer Seen	4	1	3	3	2
	F24	Barssee und Pechsee	7	1	3	3	2

Cemetery	C25	Steglitz	3	2	2	2	2
	C26	Leise Park	2	2	2	2	1

* Area measured in levels from 1 to 7; Tree density and underground vegetation density measured with an index of 1, 2 and 3, indicating low, medium and high density; Building and water measured with an index of 1 and 2, indicating nonexistence and existence.

Table II-3. The six characteristics of activity landscapes.

Type	Code	Name	Activity landscape					
			Animal interaction	Playground	Swimming infrastructure	Open space	Sports infrastructure	Interesting plants
Park	P1	Gemeindepark Lankwitz	2	2	1	2	2	2
	P2	Freizeitpark Marienfelde	2	2	1	2	2	1
	P3	Weißer See	1	1	1	2	1	1
	P4	Volkspark Schönholzer Heide	1	1	1	2	1	1
	P5	Treptower Park	1	2	1	2	1	1
	P6	Tiergarten	1	2	1	2	1	2
	P7	Tempelhofer Feld	1	2	1	2	2	1
	P8	Steinbergpark	1	2	1	2	2	1
	P9	Bellevuepark	1	2	1	2	1	2
	P10	Stadtpark Lichtenberg	1	1	1	2	1	1
	P11	Sportpark Poststadion	1	2	1	2	2	1
	P12	Schweizerhofpark	1	1	1	2	1	1
	P13	Schlosspark Köpenick	1	1	1	2	1	2
	P14	Großer Müggelsee	1	2	2	2	2	1
	P15	Landschaftspark Herzberge	2	2	1	2	1	1
	P16	Volkspark Jungfernheide	1	2	2	2	1	1
Garden	G17	Gärten der Welt	1	2	1	2	1	2
	G18	Britzer Garten	2	2	2	2	2	2
	G19	Botanical Volkspark Pankow	1	1	1	2	1	2

Forest	F20	Grünau Forest	1	1	1	1	1	1
	F21	Tegeler Forest	1	1	1	2	1	1
	F22	Königsheide	1	1	1	1	1	1
	F23	Kaulsdorfer Seen	1	1	2	2	1	1
	F24	Barssee und Pechsee	1	1	1	1	1	2
Cemetery	C25	Steglitz	1	2	1	2	2	1
	C26	Leise Park	1	2	1	1	1	1

*Measured with an index where 1 indicates nonexistence and 2 indicates existence in the green space

Table II-4. The original data collection of 34 UGS in Berlin.

Pre-code	Name	Type	District	Area	Year	Monument
1	BarsseeundPechsee	2	Charlottenburg-Wilmersdorf	30428100	1986	no
2	Bellevuepark	1	Treptow-Köpenick	162900	1766	yes
3	Botanical volkspark pankow	3	pankow	621900	1909	yes
4	Britzergarten	3	Neukölln	853200	2002	no
5	Freizeitpark Marienfelde	1	Tempelhof-Schöneberg	359100	2010	no
6	FriedhofSteglitz	4	Steglitz-Zehlendorf	338400	1875	yes
7	Garten der welt	3	Marzahn-Hellersdorf	920700	2007	no
8	Gemeindepark Lankwitz	1	Steglitz-Zehlendorf	99900	1910	yes
9	Grünau	2	Treptow-Köpenick	7403400	N/A	no
10	HeinrichLaehrPark	1	Steglitz-Zehlendorf	325800	1906	no
11	Jungfernheide park	1	Charlottenburg-Wilmersdorf	1678500	1896	yes
12	KaulsdorferSee	2	Marzahn-Hellersdorf	806400	1930	no
13	KrummeLaake	1	Treptow-Köpenick	5679900	1927	no
14	Königsheide	2	Treptow-Köpenick	1269900	1920	no
15	Landschaftspark Herzberge	1	Lichtenberg	929700	2010	no
16	Leise Park	4	pankow	66600	2012	no
17	Malchowersee	1	Lichtenberg	560700	1953	no
18	Großer Müggelsee	1	Treptow-Köpenick	2469600	1893	no

19	the Rudow-Altglienicke landscape park	1	Neukölln	239400	2009	no
20	Schlosspark Köpenick	1	Treptow-Köpenick	18000	1964	yes
21	Schweizerhofpark	1	Steglitz-Zehlendorf	90900	1853	no
22	sportpark poststadion	1	Mitte	99900	2014	no
23	Stadtpark Lichtenberg	1	Lichtenberg	72900	1907	no
24	Steinbergpark	1	Reinickendorf	294300	1875	yes
25	TegelerFließtal	2	pankow	2133000	N/A	no
26	Tegeler forest	2	Reinickendorf	13160700	N/A	no
27	Tempehof Park	1	Tempelhof-Schöneberg	2976300	2010	no
28	The big Tiergaten	1	Mitte	2075400	1740	yes
29	Treptower Park	1	Treptow-Köpenick	2310300	1876	yes
30	VolksparkSchönholzerHeide	1	pankow	499500	1921	yes
31	Däumlingsweg	2	Treptow-Köpenick	2846700	N/A	no
32	Weißer See	1	Pankow	208800	1912	no
33	Wilhelmshagen-Woltersdorfer Dünenzug	2	Treptow-Köpenick	1886400	N/A	no
34	WuhlheideKöpenick	2	Treptow-Köpenick	2892600	1919	no

*1 parks, 2nature greens, 3 gardens, and 4cemeteries

Table II-5. The original data of Tweets number and sentiment value.

Pre-code	Name	Count	Count_en	Count_de	Count_other	Mean	Mean_en	Mean_de	Mean_other
1	BarsseeundPechsee	1965	1137	772	56	0.0831	0.1024	0.0531	0.1048
2	Bellevuepark	41	26	13	2	0.151	0.2073	0.0177	0.2855
3	Botanical volkspark pankow	43	17	21	5	0.066	0.1082	0.0476	-0.0002
4	Britzergarten	256	88	153	15	0.1108	0.1585	0.0776	0.1696
5	Freizeitpark Marienfelde	20	10	10	0	0.2085	0.252	0.165	0
6	FriedhofSteglitz	78	25	52	1	0.0728	0.068	0.0635	0.6764
7	Garten der welt	583	160	405	18	0.0802	0.1204	0.0649	0.0671
8	Gemeindepark Lankwitz	158	45	107	6	0.1271	0.076	0.1557	0.0003
9	Grünau	75	31	44	0	0.0184	0.0468	-0.0016	0

10	HeinrichLaehrPark	1	1	0	0	0.3	0.3	0	0
11	Jungfernheide park	123	45	67	11	0.1048	0.0413	0.1504	0.0868
12	KaulsdorferSee	102	28	72	2	0.1073	0.0918	0.1163	0.0003
13	KrummeLaake	7	1	6	0	-0.0714	0.3	-0.1333	0
14	Königsheide	60	29	30	1	0.0515	0.0486	0.056	0.0006
15	Landschaftspark Herzberge	6676	6311	314	51	-0.1349	-0.1466	0.0632	0.0932
16	Leise Park	112	34	75	3	0.0654	0.0538	0.072	0.0319
17	Malchowersee	1	0	1	0	0	0	0	0
18	Großer Müggelsee	226	51	173	2	0.0912	0.0343	0.1091	-0.0062
19	the Rudow-Altglienicke landscape park	24	9	14	1	0	0	0	0
20	Schlosspark Köpenick	214	40	174	0	0.0776	0.1218	0.0674	0
21	Schweizerhofpark	16	7	9	0	0.1194	0.0871	0.1444	0
22	sportpark poststadion	354	338	16	0	-0.003	0.0009	-0.0844	0
23	Stadtpark Lichtenberg	165	43	122	0	0.1139	0.103	0.1177	0
24	Steinbergpark	24	8	16	0	-0.0617	0.1338	-0.1594	0
25	TegelerFließtal	6	0	6	0	0	0	0	0
26	Tegeler forest	490	360	130	0	0.0855	0.0895	0.0745	0
27	Tempehof Park	2500	1917	583	0	0.0687	0.087	0.0086	0
28	The big Tiergaten	41711	25042	16669	0	0.0707	0.0909	0.0404	0
29	Treptower Park	5495	3775	1720	0	0.0333	0.0587	-0.0223	0
30	VolksparkSchönholzerHeide	137	69	68	0	0.1781	0.2272	0.1282	0
31	Däumlingsweg	186	19	167	0	0.2232	0.0353	0.2446	0
32	Weißer See	1299	538	761	0	0.0901	0.1161	0.0716	0
33	Wilhelmshagen-Woltersdorfer Dünenzug	11	2	9	0	0.0618	0.34	0	0
34	WuhlheideKöpenick	1591	830	761	0	0.0755	0.0748	0.0763	0

* en means the tweets in English, de means the tweets in German, other means the tweets in other languages. Mean is the average value of sentiment.

References

References

1. Adger, W. N., K. Brown, D. R. Nelson, F. Berkes, H. Eakin, C. Folke, K. Galvin, L. Gunderson, M. Goulden and K. O'Brien (2011). "Resilience implications of policy responses to climate change." Wiley Interdisciplinary Reviews: Climate Change **2**(5): 757-766.
2. Ahlström, H., A. Williams and S. S. Vildåsen (2020). "Enhancing systems thinking in corporate sustainability through a transdisciplinary research process." Journal of Cleaner Production: 120691.
3. Akbari, H. and D. Kolokotsa (2016). "Three decades of urban heat islands and mitigation technologies research." Energy and Buildings **133**: 834-842.
4. Alavipanah, S., D. Haase, T. Lakes and S. Qureshi (2017). "Integrating the third dimension into the concept of urban ecosystem services: A review." Ecological indicators **72**: 374-398.
5. Alberti, M. (2005). "The effects of urban patterns on ecosystem function." International regional science review **28**(2): 168-192.
6. Alberti, M. and J. M. Marzluff (2004). "Ecological resilience in urban ecosystems: linking urban patterns to human and ecological functions." Urban ecosystems **7**(3): 241-265.
7. Almeida, M. d. C., M. J. Telhado, M. Morais, J. Barreiro and R. Lopes (2020). "Urban resilience to flooding: triangulation of methods for hazard identification in urban areas." Sustainability **12**(6): 2227.
8. Ambrey, C. and C. Fleming (2014). "Public greenspace and life satisfaction in urban Australia." Urban Studies **51**(6): 1290-1321.
9. Aminpour, P., S. A. Gray, A. J. Jetter, J. E. Introne, A. Singer and R. Arlinghaus (2020). "Wisdom of stakeholder crowds in complex social–ecological systems." Nature Sustainability: 1-9.
10. Anderson, J. R. (1976). A land use and land cover classification system for use with remote sensor data, US Government Printing Office.
11. Anguluri, R., P. J. U. F. Narayanan and U. Greening (2017). "Role of green space in urban planning: Outlook towards smart cities." Urban Forestry & Urban Greening **25**: 58-65.
12. Arnberger, A. and R. Eder (2011). "The influence of age on recreational trail preferences of urban green-space visitors: a discrete choice experiment with digitally calibrated images." Journal of Environmental Planning Management **54**(7): 891-908.

13. Arnberger, A., R. Eder, S. Preiner, T. Hein and U. Nopp-Mayr (2021). "Landscape Preferences of Visitors to the Danube Floodplains National Park, Vienna." Water **13**(16): 2178.
14. Assembly, U. G. (2015). "Transforming our world : the 2030 Agenda for Sustainable Development,." A/RES/70/1 **available at:** https://www.refworld.org/docid/57b6e3e44.html
15. Assessment, M. E. (2001). Millennium ecosystem assessment, Millennium Ecosystem Assessment.
16. Attaianese, E. and G. Duca (2012). "Human factors and ergonomic principles in building design for life and work activities: an applied methodology." Theoretical Issues in Ergonomics Science **13**(2): 187-202.
17. Barbieri, F., F. Ronzano and H. Saggion (2016). What does this emoji mean? a vector space skip-gram model for twitter emojis. Calzolari N, Choukri K, Declerck T, et al, editors. Proceedings of the Tenth International Conference on Language Resources and Evaluation (LREC 2016); 2016 May 23-28; Portorož, Slovenia. Paris: European Language Resources Association (ELRA); 2016. p. 3967-72., ELRA (European Language Resources Association).
18. Barbosa, O., J. A. Tratalos, P. R. Armsworth, R. G. Davies, R. A. Fuller, P. Johnson and K. J. Gaston (2007). "Who benefits from access to green space? A case study from Sheffield, UK." Landscape and Urban planning **83**(2-3): 187-195.
19. Baró, F., D. Haase, E. Gómez-Baggethun and N. Frantzeskaki (2015). "Mismatches between ecosystem services supply and demand in urban areas: A quantitative assessment in five European cities." Ecological indicators **55**: 146-158.
20. Bartens, J., S. D. Day, J. R. Harris, J. E. Dove and T. M. Wynn (2008). "Can urban tree roots improve infiltration through compacted subsoils for stormwater management?" Journal of Environmental Quality **37**(6): 2048-2057.
21. Barton, H. and C. Tsourou (2013). Healthy urban planning, Routledge.
22. Batchelor, P. (1969). "The origin of the garden city concept of urban form." the Society of Architectural Historians **28**(3): 184-200.
23. Bechtel, B., P. J. Alexander, J. Böhner, J. Ching, O. Conrad, J. Feddema, G. Mills, L. See and I. Stewart (2015). "Mapping local climate zones for a worldwide database of the form and function of cities." ISPRS International Journal of Geo-Information **4**(1): 199-219.

24. Beil, K. and D. Hanes (2013). "The influence of urban natural and built environments on physiological and psychological measures of stress—A pilot study." International journal of environmental research and public health **10**(4): 1250-1267.
25. Bell, S. L., C. Phoenix, R. Lovell and B. W. Wheeler (2014). "Green space, health and wellbeing: Making space for individual agency." Health Place **30**: 287-292.
26. Berardi, U., Z. Jandaghian and J. Graham (2020). "Effects of greenery enhancements for the resilience to heat waves: A comparison of analysis performed through mesoscale (WRF) and microscale (Envi-met) modeling." Science of the Total Environment **747**: 141300.
27. Berardi, U., Z. Jandaghian and J. Graham (2020). "Effects of greenery enhancements for the resilience to heat waves: A comparison of analysis performed through mesoscale (WRF) and microscale (Envi-met) modeling." Science of the Total Environment **747**: 141300.
28. Berlin Senate (2015). "Berlin Strategy: Urban Development Concept Berlin 2030." https://www.stadtentwicklung.berlin.de/planen/stadtentwicklungskonzept/download/strategie/BerlinStrategie_Broschuere_en.pdf.
29. Berman, M. G., E. Kross, K. M. Krpan, M. K. Askren, A. Burson, P. J. Deldin, S. Kaplan, L. Sherdell, I. H. Gotlib and J. Jonides (2012). "Interacting with nature improves cognition and affect for individuals with depression." Journal of affective disorders **140**(3): 300-305.
30. Bertram, C. and K. Rehdanz (2015). "The role of urban green space for human well-being." Ecological Economics **120**: 139-152.
31. Bibri, S. E., J. Krogstie and M. Kärrholm (2020). "Compact City planning and development: emerging practices and strategies for achieving the goals of sustainable development." Developments in the Built Environment: 100021.
32. Biswas, R. and S. Sen (2020). "Urban Eco-Psychological Attitude during COVID-19 'Lockdown': A Survey." International Journal of Creative Research Thoughts **8**(7).
33. BMUB, (2007). "Nationale Strategie zur biologischen Vielfalt [National Biodiversity Strategy] " Kabinettsbeschluss vom 7 **November 2007.** http://www.biologischevielfalt.de/fileadmin/NBS/documents/broschuere_biolog_vielfalt_strategie_bf.pdf.
34. Boeing, G. (2018). "Measuring the complexity of urban form and design." Urban Design International **23**(4): 281-292.

35. Bojinski, S., M. Verstraete, T. C. Peterson, C. Richter, A. Simmons and M. Zemp (2014). "The Concept of Essential Climate Variables in Support of Climate Research, Applications, and Policy." Bulletin of the American Meteorological Society **95**(9): 1431-1443.
36. Bouchaud, J.-P., J. D. Farmer and F. Lillo (2009). How markets slowly digest changes in supply and demand. Handbook of financial markets: dynamics and evolution, Elsevier**:** 57-160.
37. Breuste, J., M. Artmann, J. Li and M. Xie (2015). Special issue on green infrastructure for urban sustainability, American Society of Civil Engineers.
38. Breuste, J., D. Haase and T. Elmqvist (2013). "Urban landscapes and ecosystem services." Ecosystem services in agricultural urban landscapes: 83-104.
39. Brindley, P., R. W. Cameron, E. Ersoy, A. Jorgensen and R. Maheswaran (2019). "Is more always better? Exploring field survey and social media indicators of quality of urban greenspace, in relation to health." Urban Forestry & Urban Greening **39**: 45-54.
40. Buder, S. (1990). Visionaries and planners: the garden city movement and the modern community, Oxford University Press on Demand.
41. Buijs, A., R. Hansen, S. Van der Jagt, B. Ambrose-Oji, B. Elands, E. L. Rall, T. Mattijssen, S. Pauleit, H. Runhaar and A. S. Olafsson (2019). "Mosaic governance for urban green infrastructure: Upscaling active citizenship from a local government perspective." Urban Forestry & Urban Greening **40**: 53-62.
42. Buijs, A. E., B. H. Elands and F. Langers (2009). "No wilderness for immigrants: Cultural differences in images of nature and landscape preferences." Landscape and Urban Planning **91**(3): 113-123.
43. Cadenasso, M. L., S. T. Pickett and K. Schwarz (2007). "Spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification." Frontiers in Ecology and the Environment **5**(2): 80-88.
44. Cai, M., C. Ren, Y. Xu, K. K.-L. Lau and R. Wang (2018). "Investigating the relationship between local climate zone and land surface temperature using an improved WUDAPT methodology–A case study of Yangtze River Delta, China." Urban Climate **24**: 485-502.
45. Cameron, R. W., P. Brindley, M. Mears, K. McEwan, F. Ferguson, D. Sheffield, A. Jorgensen, J. Riley, J. Goodrick and L. Ballard (2020). "Where the wild things are! Do urban green spaces with greater avian biodiversity promote more positive emotions in humans?" Urban ecosystems **23**(2): 301-317.

46. Card, D. (2009). "How immigration affects US cities." Making cities work: Prospects and policies for urban America: 158-200.
47. Carvalho, D., H. Martins, M. Marta-Almeida, A. Rocha and C. Borrego (2017). "Urban resilience to future urban heat waves under a climate change scenario: A case study for Porto urban area (Portugal)." Urban Climate **19**: 1-27.
48. Ceron, A., L. Curini, S. M. Iacus and G. Porro (2014). "Every tweet counts? How sentiment analysis of social media can improve our knowledge of citizens' political preferences with an application to Italy and France." New media & society **16**(2): 340-358.
49. Champion, A. G. (2001). "A changing demographic regime and evolving poly centric urban regions: Consequences for the size, composition and distribution of city populations." Urban studies **38**(4): 657-677.
50. Chen, H., Q. Deng, Z. Zhou, Z. Ren and X. Shan (2022). "Influence of land cover change on spatio-temporal distribution of urban heat island—a case in Wuhan mean urban area." Sustainable Cities and Society: 103715.
51. Chen, J., J. Gao and W. Chen (2016). "Urban land expansion and the transitional mechanisms in Nanjing, China." Habitat International **53**: 274-283.
52. Chen, J., B. Jiang, Y. Bai, X. Xu and J. M. Alatalo (2019). "Quantifying ecosystem services supply and demand shortfalls and mismatches for management optimisation." Science of the Total Environment **650**: 1426-1439.
53. Chen, S., D. Haase, B. Xue, T. Wellmann and S. Qureshi (2021). "Integrating Quantity and Quality to Assess Urban Green Space Improvement in the Compact City." Land **10**(12): 1367.
54. Chen, T., E. C. Hui, J. Wu, W. Lang and X. Li (2019). "Identifying urban spatial structure and urban vibrancy in highly dense cities using georeferenced social media data." Habitat International **89**: 102005.
55. Chen, W., H. Huang, J. Dong, Y. Zhang, Y. Tian and Z. Yang (2018). "Social functional mapping of urban green space using remote sensing and social sensing data." ISPRS Journal of Photogrammetry and Remote Sensing **146**: 436-452.
56. Chen, X.-L., H.-M. Zhao, P.-X. Li and Z.-Y. Yin (2006). "Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes." Remote sensing of environment **104**(2): 133-146.

57. Chen, X., F. Li, X. Li, Y. Hu and P. Hu (2020). "Evaluating and mapping water supply and demand for sustainable urban ecosystem management in Shenzhen, China." Journal of Cleaner Production **251**: 119754.
58. Chen, Y. (2013). "New approaches for calculating Moran's index of spatial autocorrelation." PloS one **8**(7): e68336.
59. Churchill, H. S. (1962). "The city is the people." (W. W. Norton & Company).
60. Colglazier, W. (2015). "Sustainable development agenda: 2030." Science **349**(6252): 1048-1050.
61. Conway, T. M. and J. Vander Vecht (2015). "Growing a diverse urban forest: Species selection decisions by practitioners planting and supplying trees." Landscape and Urban Planning **138**: 1-10.
62. Coolen, H. and J. Meesters (2012). "Private and public green spaces: meaningful but different settings." Journal of Housing the Built Environment **27**(1): 49-67.
63. Coppel, G. and H. Wüstemann (2017). "The impact of urban green space on health in Berlin, Germany: Empirical findings and implications for urban planning." Landscape and Urban Planning **167**: 410-418.
64. Dainton, B. (2016). Time and space, Routledge.
65. Dale, M. R. and M.-J. Fortin (2014). Spatial analysis: a guide for ecologists, Cambridge University Press.
66. Das, S. and D. P. Angadi (2020). "Land use-land cover (LULC) transformation and its relation with land surface temperature changes: A case study of Barrackpore Subdivision, West Bengal, India." Remote Sensing Applications: Society Environment **19**: 100322.
67. De Donder, L., T. Buffel, S. Dury, N. De Witte and D. Verte (2013). "Perceptual quality of neighbourhood design and feelings of unsafety." Ageing society **33**(6): 917.
68. De Sousa, C. A. (2003). "Turning brownfields into green space in the City of Toronto." Landscape and Urban Planning **62**(4): 181-198.
69. Dieleman, F. and M. Wegener (2004). "Compact city and urban sprawl." Built Environment **30**(4): 308-323.
70. Doick, K. J., A. Peace and T. R. Hutchings (2014). "The role of one large greenspace in mitigating London's nocturnal urban heat island." Science of the total environment **493**: 662-671.
71. Doick, K. J., G. Sellers, V. Castan-Broto and T. Silverthorne (2009). "Understanding success in the context of brownfield greening projects: The requirement for outcome

evaluation in urban greenspace success assessment." Urban Forestry & Urban Greening **8**(3): 163-178.

72. Donahue, M. L., B. L. Keeler, S. A. Wood, D. M. Fisher, Z. A. Hamstead and T. McPhearson (2018). "Using social media to understand drivers of urban park visitation in the Twin Cities, MN." Landscape and Urban Planning **175**: 1-10.
73. Douglas, I. (2012). "Urban ecology and urban ecosystems: understanding the links to human health and well-being." Current Opinion in Environmental Sustainability **4**(4): 385-392.
74. Du, H., X. Song, H. Jiang, Z. Kan, Z. Wang and Y. Cai (2016). "Research on the cooling island effects of water body: A case study of Shanghai, China." Ecological indicators **67**: 31-38.
75. Dulal, H. B. (2017). "Making cities resilient to climate change: Identifying “win–win” interventions." Local Environment **22**(1): 106-125.
76. Dunham, J. and B. Rieman (1999). "Metapopulation structure of bull trout: influences of physical, biotic, and geometrical landscape characteristics." Ecological Applications **9**(2): 642-655.
77. Dye, C. (2008). "Health and urban living." Science **319**(5864): 766-769.
78. Elmqvist, T., E. Andersson, N. Frantzeskaki, T. McPhearson, P. Olsson, O. Gaffney, K. Takeuchi and C. Folke (2019). "Sustainability and resilience for transformation in the urban century." Nature Sustainability **2**(4): 267-273.
79. Endlicher, W., G. Jendritzky, J. Fischer and J.-P. Redlich (2008). Heat waves, urban climate and human health. Urban ecology, Springer**:** 269-278.
80. Ettehadi Osgouei, P., S. Kaya, E. Sertel and U. Alganci (2019). "Separating built-up areas from bare land in mediterranean cities using sentinel-2a imagery." Remote Sensing **11**(3): 345.
81. Fernández-Götz, M. and D. Krausse (2017). Eurasia at the dawn of history: Urbanization and social change, Cambridge University Press.
82. Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily and H. K. Gibbs (2005). "Global consequences of land use." Science **309**(5734): 570-574.
83. Forman, R. T. (1995). "Some general principles of landscape and regional ecology." Landscape Ecology **10**(3): 133-142.
84. Forman, R. T. and M. Godron (1981). "Patches and structural components for a landscape ecology." BioScience **31**(10): 733-740.

85. Formica, S. and M. Uysal (2006). "Destination attractiveness based on supply and demand evaluations: An analytical framework." Journal of Travel Research **44**(4): 418-430.
86. Frank, L. D. and P. O. Engelke (2001). "The built environment and human activity patterns: exploring the impacts of urban form on public health." Journal of planning literature **16**(2): 202-218.
87. French, M., A. Trundle, I. Korte and C. Koto (2021). Climate Resilience in Urban Informal Settlements: Towards a Transformative Upgrading Agenda. Climate Resilient Urban Areas, Springer**:** 129-153.
88. Friend, R., J. Jarvie, S. O. Reed, R. Sutarto, P. Thinphanga and V. C. Toan (2014). "Mainstreaming urban climate resilience into policy and planning; reflections from Asia." Urban Climate **7**: 6-19.
89. Friend, R. and M. Moench (2013). "What is the purpose of urban climate resilience? Implications for addressing poverty and vulnerability." Urban Climate **6**: 98-113.
90. Fu, Y., X. Lu, Y. Zhao, X. Zeng and L. Xia (2013). "Assessment impacts of weather and land use/land cover (LULC) change on urban vegetation net primary productivity (NPP): A case study in Guangzhou, China." Remote Sensing **5**(8): 4125-4144.
91. Gabriel, K. M. and W. R. Endlicher (2011). "Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany." Environmental Pollution **159**(8-9): 2044-2050.
92. Gao, Z., K. Song, Y. Pan, D. Malkinson, X. Zhang, B. Jia, T. Xia, X. Guo, H. Liang and S. Huang (2021). "Drivers of spontaneous plant richness patterns in urban green space within a biodiversity hotspot." Urban Forestry & Urban Greening **61**: 127098.
93. Gascon, M., M. Cirach, D. Martínez, P. Dadvand, A. Valentín, A. Plasència and M. J. Nieuwenhuijsen (2016). "Normalized difference vegetation index (NDVI) as a marker of surrounding greenness in epidemiological studies: The case of Barcelona city." Urban Forestry & Urban Greening **19**: 88-94.
94. Gehl, J. (2013). Cities for people, Island press.
95. Geng, D. C., J. Innes, W. Wu and G. Wang (2021). "Impacts of COVID-19 pandemic on urban park visitation: a global analysis." Journal of forestry research **32**(2): 553-567.
96. Geyer, H. S. and T. Kontuly (1993). "A theoretical foundation for the concept of differential urbanization." International Regional Science Review **15**(2): 157-177.

97. Ghosh, S. and A. Das (2018). "Modelling urban cooling island impact of green space and water bodies on surface urban heat island in a continuously developing urban area." Modeling Earth Systems and Environment **4**(2): 501-515.
98. Gillespie, A., S. Rokugawa, T. Matsunaga, J. S. Cothern, S. Hook and A. B. Kahle (1998). "A temperature and emissivity separation algorithm for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images." IEEE transactions on geoscience and remote sensing **36**(4): 1113-1126.
99. Giri, C. P. (2012). Remote sensing of land use and land cover: principles and applications, CRC press.
100. Goetz, S. J. and T. Jaksch (2018). Agricultural transformation and land use in Central and Eastern Europe, Routledge.
101. Gottdiener, M. (2010). The social production of urban space, University of Texas Press.
102. Govind, N. R. and H. Ramesh (2019). "The impact of spatiotemporal patterns of land use land cover and land surface temperature on an urban cool island: a case study of Bengaluru." Environmental monitoring and assessment **191**(5): 1-20.
103. Goward, S. N. (1981). "Thermal behavior of urban landscapes and the urban heat island." Physical Geography **2**(1): 19-33.
104. Griffith, D. A. (1987). "Spatial autocorrelation." A Primer.
105. Grigoraș, G. and B. Urițescu (2019). "Land use/land cover changes dynamics and their effects on surface urban heat island in Bucharest, Romania." International Journal of Applied Earth Observation and Geoinformation **80**: 115-126.
106. Grilo, F., P. Pinho, C. Aleixo, C. Catita, P. Silva, N. Lopes, C. Freitas, M. Santos-Reis, T. McPhearson and C. Branquinho (2020). "Using green to cool the grey: Modelling the cooling effect of green spaces with a high spatial resolution." Science of the Total Environment **724**: 138182.
107. Guerri, G., A. Crisci, A. Messeri, L. Congedo, M. Munafò and M. Morabito (2021). "Thermal Summer Diurnal Hot-Spot Analysis: The Role of Local Urban Features Layers." Remote Sensing **13**(3): 538.
108. Guha, S., H. Govil and M. Besoya (2020). "An investigation on seasonal variability between LST and NDWI in an urban environment using Landsat satellite data." Geomatics, Natural Hazards Risk **11**(1): 1319-1345.
109. Guha, S., H. Govil, N. Gill and A. Dey (2021). "A long-term seasonal analysis on the relationship between LST and NDBI using Landsat data." Quaternary International **575**: 249-258.

110.Gungor, S. and A. T. Polat (2018). "Relationship between visual quality and landscape characteristics in urban parks." Journal of Environmental Protection and Ecology **19**(2): 939-948.

111.Guo, G., Z. Wu and Y. Chen (2019). "Complex mechanisms linking land surface temperature to greenspace spatial patterns: evidence from four southeastern Chinese cities." Science of The Total Environment **674**: 77-87.

112.Haaland, C. and C. K. van Den Bosch (2015). "Challenges and strategies for urban green-space planning in cities undergoing densification: A review." Urban forestry and urban greening **14**(4): 760-771.

113.Haase, D. (2021). "Continuous integration in urban social-ecological systems science needs to allow for spacing co-existence." Ambio **12**: 1-6.

114.Haase, D. (2021). Integrating ecosystem services, green infrastructure and nature-based solutions—new perspectives in sustainable urban land management. Sustainable Land Management in a European Context, Springer, Cham**:** 305-318.

115.Haase, D., B. Güneralp, B. Dahiya, X. Bai and T. Elmqvist (2018). "Global urbanization." The Urban Planet: Knowledge Towards Sustainable Cities **19**: 326-339.

116.Haase, D., N. Larondelle, E. Andersson, M. Artmann, S. Borgström, J. Breuste, E. Gomez-Baggethun, Å. Gren, Z. Hamstead and R. Hansen (2014). "A quantitative review of urban ecosystem service assessments: concepts, models, and implementation." Ambio **43**(4): 413-433.

117.Hale, R. C., K. P. Gallo, T. W. Owen and T. R. Loveland (2006). "Land use/land cover change effects on temperature trends at US Climate Normals stations." Geophysical Research Letters **33**(11).

118.Hamann, U. and S. Karakayali (2016). "Practicing Willkommenskultur: migration and solidarity in Germany." Intersections **2**(4).

119.Hansen, R., A. S. Olafsson, A. P. van der Jagt, E. Rall and S. Pauleit (2019). "Planning multifunctional green infrastructure for compact cities: What is the state of practice?" Ecological indicators **96**: 99-110.

120.Hartig, T., G. W. Evans, L. D. Jamner, D. S. Davis and T. Gärling (2003). "Tracking restoration in natural and urban field settings." Journal of environmental psychology **23**(2): 109-123.

121.Hashimoto, H., Y. Natuhara and Y. Morimoto (2005). "A habitat model for Parus major minor using a logistic regression model for the urban area of Osaka, Japan." Landscape and Urban Planning **70**(3-4): 245-250.

122.Hättasch, M. (2019). "Permanent Reinvention: The Lives of Berlin's Tempelhof Airport." Thresholds: 57-74.

123.Hatvani-Kovacs, G., J. Bush, E. Sharifi and J. Boland (2018). "Policy recommendations to increase urban heat stress resilience." Urban Climate **25**: 51-63.

124.He, B.-J., L. Ding and D. Prasad (2020). "Wind-sensitive urban planning and design: Precinct ventilation performance and its potential for local warming mitigation in an open midrise gridiron precinct." Journal of Building Engineering **29**: 101145.

125.He, B.-J., D. Zhao, X. Dong, K. Xiong, C. Feng, Q. Qi, A. Darko, A. Sharifi and M. Pathak (2022). "Perception, physiological and psychological impacts, adaptive awareness and knowledge, and climate justice under urban heat: A study in extremely hot-humid Chongqing, China." Sustainable Cities and Society: 103685.

126.Heerwagen, J. (2009). "Biophilia, health, and well-being." Restorative commons: Creating health and well-being through urban landscapes: 39-57.

127.Hegetschweiler, K. T., S. de Vries, A. Arnberger, S. Bell, M. Brennan, N. Siter, A. S. Olafsson, A. Voigt and M. Hunziker (2017). "Linking demand and supply factors in identifying cultural ecosystem services of urban green infrastructures: A review of European studies." Urban Forestry & Urban Greening **21**: 48-59.

128.Heidt, V. and M. Neef (2008). Benefits of urban green space for improving urban climate. Ecology, planning, and management of urban forests, Springer**:** 84-96.

129.Heikinheimo, V., E. D. Minin, H. Tenkanen, A. Hausmann, J. Erkkonen and T. Toivonen (2017). "User-generated geographic information for visitor monitoring in a national park: A comparison of social media data and visitor survey." ISPRS International Journal of Geo-Information **6**(3): 85.

130.Heikinheimo, V., H. Tenkanen, C. Bergroth, O. Järv, T. Hiippala and T. Toivonen (2020). "Understanding the use of urban green spaces from user-generated geographic information." Landscape and urban planning **201**: 103845.

131.Hernández-Guzmán, R., A. Ruiz-Luna and C. González (2019). "Assessing and modeling the impact of land use and changes in land cover related to carbon storage in a western basin in Mexico." Remote Sensing Applications: Society Environment **13**: 318-327.

132.Hilbrandt, H. (2017). "Insurgent participation: consensus and contestation in planning the redevelopment of Berlin-Tempelhof airport." Urban Geography **38**(4): 537-556.

133.Holling, C. S. (1973). "Resilience and stability of ecological systems." Annual review of ecology and systematics **4**(1): 1-23.

134.Hölscher, K. and N. Frantzeskaki (2021). "Perspectives on urban transformation research: transformations in, of, and by cities." Urban Transformations **3**(1): 1-14.

135.Home, R., M. Hunziker and N. Bauer (2012). "Psychosocial outcomes as motivations for visiting nearby urban green spaces." Leisure Sciences **34**(4): 350-365.

136.Honey-Roses, J., I. Anguelovski, J. Bohigas, V. Chireh, C. Daher, C. Konijnendijk, J. Litt, V. Mawani, M. McCall and A. Orellana (2020). "The impact of COVID-19 on public space: a review of the emerging questions." Cities & health: 1-17.

137.Hope, A., J. Kimball and D. Stow (1993). "The relationship between tussock tundra spectral reflectance properties and biomass and vegetation composition." International Journal of Remote Sensing **14**(10): 1861-1874.

138.Huck, A. and J. Monstadt (2019). "Urban and infrastructure resilience: Diverging concepts and the need for cross-boundary learning." Environmental Science Policy **100**: 211-220.

139.Hull IV, R. B. and A. Harvey (1989). "Explaining the emotion people experience in suburban parks." Environment behavior **21**(3): 323-345.

140.Hull IV, R. B. and M. M. McCarthy (1988). "Change in the landscape." Landscape Urban Planning **15**(3-4): 265-278.

141.Hurlimann, A., S. Moosavi and G. Browne (2021). "Urban planning policy must do more to integrate climate change adaptation and mitigation actions." Land Use Policy **101**: 105188.

142.Ilieva, R. T. and T. McPhearson (2018). "Social-media data for urban sustainability." Nature Sustainability **1**(10): 553-565.

143.IPCC (2016). "Global Warming of 1.5ºC." An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

144.Iturriza, M., L. Labaka, J. Hernantes and A. Abdelgawad (2020). "Shifting to climate change aware cities to facilitate the city resilience implementation." Cities **101**: 102688.

145.Ives, C. D., C. Oke, A. Hehir, A. Gordon, Y. Wang and S. A. Bekessy (2017). "Capturing residents' values for urban green space: Mapping, analysis and guidance for practice." Landscape and Urban Planning **161**: 32-43.

146.Jamei, Y., P. Rajagopalan and Q. C. Sun (2019). "Spatial structure of surface urban heat island and its relationship with vegetation and built-up areas in Melbourne, Australia." Science of The Total Environment **659**: 1335-1351.

147. Jenerette, G. D., S. L. Harlan, A. Buyantuev, W. L. Stefanov, J. Declet-Barreto, B. L. Ruddell, S. W. Myint, S. Kaplan and X. Li (2016). "Micro-scale urban surface temperatures are related to land-cover features and residential heat related health impacts in Phoenix, AZ USA." Landscape Ecology **31**(4): 745-760.

148. Jennings, V., L. Larson and J. Yun (2016). "Advancing sustainability through urban green space: Cultural ecosystem services, equity, and social determinants of health." International Journal of environmental research public health **13**(2): 196.

149. Jim, C. Y. and S. S. Chen (2003). "Comprehensive greenspace planning based on landscape ecology principles in compact Nanjing city, China." Landscape and urban planning **65**(3): 95-116.

150. Jiménez-Muñoz, J. C., J. A. Sobrino, D. Skoković, C. Mattar and J. Cristóbal (2014). "Land surface temperature retrieval methods from Landsat-8 thermal infrared sensor data." IEEE Geoscience and remote sensing letters **11**(10): 1840-1843.

151. Jiménez-Muñoz, J. C. and J. A. Sobrino (2003). "A generalized single-channel method for retrieving land surface temperature from remote sensing data." Journal of geophysical research: atmospheres **108**(D22).

152. Jusuf, S. K., N. H. Wong, E. Hagen, R. Anggoro and Y. Hong (2007). "The influence of land use on the urban heat island in Singapore." Habitat international **31**(2): 232-242.

153. Kabisch, N. (2015). "Ecosystem service implementation and governance challenges in urban green space planning—The case of Berlin, Germany." Land use policy **42**: 557-567.

154. Kabisch, N. and D. Haase (2014). "Green justice or just green? Provision of urban green spaces in Berlin, Germany." Landscape and Urban Planning **122**: 129-139.

155. Kabisch, N., M. Strohbach, D. Haase and J. Kronenberg (2016). "Urban green space availability in European cities." Ecological indicators **70**: 586-596.

156. Kalinic, M. and J. M. Krisp (2018). Kernel density estimation (KDE) vs. hot-spot analysis–detecting criminal hot spots in the City of San Francisco. Proceeding of the 21st Conference on Geo-information Science.

157. Kalma, J. D., T. R. McVicar and M. F. McCabe (2008). "Estimating land surface evaporation: A review of methods using remotely sensed surface temperature data." Surveys in Geophysics **29**(4): 421-469.

158. Kalnay, E. and M. Cai (2003). "Impact of urbanization and land-use change on climate." Nature **423**(6939): 528.

159. Kalyukin, A., T. Boren and A. Byerley (2015). "The second generation of post-socialist change: Gorky Park and public space in Moscow " Urban geography **36**(5): 674-695.
160. Kang, Y., Q. Jia, S. Gao, X. Zeng, Y. Wang, S. Angsuesser, Y. Liu, X. Ye and T. Fei (2019). "Extracting human emotions at different places based on facial expressions and spatial clustering analysis." Transactions in GIS **23**(3): 450-480.
161. Kaplan, R. (1983). The role of nature in the urban context. Behavior and the natural environment, Springer**:** 127-161.
162. Kara, S. (2011). "Supply and demand: Human trafficking in the global economy." Harvard International Review **33**(2): 66.
163. Keramitsoglou, I., I. A. Daglis, V. Amiridis, N. Chrysoulakis, G. Ceriola, P. Manunta, B. Maiheu, K. De Ridder, D. Lauwaet and M. F. Paganini (2012). "Evaluation of satellite-derived products for the characterization of the urban thermal environment." Journal of Applied Remote Sensing **6**(1): 061704.
164. Khan, S. M., M. Chowdhury, L. B. Ngo and A. Apon (2020). "Multi-class twitter data categorization and geocoding with a novel computing framework." Cities **96**: 102410.
165. Ki, D. and S. Lee (2021). "Analyzing the effects of Green View Index of neighborhood streets on walking time using Google Street View and deep learning." Landscape and Urban Planning **205**: 103920.
166. Kim, M., K. Song and J. Chon (2021). "Key coastal landscape patterns for reducing flood vulnerability." Science of The Total Environment **759**: 143454.
167. Koch, F., L. Bilke, C. Helbig and U. Schlink (2018). "Compact or cool? The impact of brownfield redevelopment on inner-city micro climate." Sustainable cities and society **38**: 31-41.
168. Kolokotroni, M. and R. Giridharan (2008). "Urban heat island intensity in London: An investigation of the impact of physical characteristics on changes in outdoor air temperature during summer." Solar energy **82**(11): 986-998.
169. Kondo, M. C., J. M. Fluehr, T. McKeon and C. C. Branas (2018). "Urban green space and its impact on human health." International journal of environmental research public health **15**(3): 445.
170. Kong, F., H. Yin, C. Wang, G. Cavan and P. James (2014). "A satellite image-based analysis of factors contributing to the green-space cool island intensity on a city scale." Urban Forestry & Urban Greening **13**(4): 846-853.

171. Kothencz, G., R. Kolcsár, P. Cabrera-Barona and P. Szilassi (2017). "Urban green space perception and its contribution to well-being." International journal of environmental research public health **14**(7): 766.
172. Kowarik, I. (2019). "The “Green Belt Berlin”: Establishing a greenway where the Berlin Wall once stood by integrating ecological, social and cultural approaches." Landscape and Urban Planning **184**: 12-22.
173. Kowarik, I. (2019). "The “Green Belt Berlin”: Establishing a greenway where the Berlin Wall once stood by integrating ecological, social and cultural approaches." Landscape and Urban Planning **184**: 12-22.
174. Kramer, D. B., J. Hartter, A. E. Boag, M. Jain, K. Stevens, K. A. Nicholas, W. J. McConnell, Liu and Jianguo (2017). "Top 40 questions in coupled human and natural systems (CHANS) research." Ecology and Society **22**(2).
175. Kramer, D. B., J. Hartter, A. E. Boag, M. Jain, K. Stevens, K. A. Nicholas, W. J. McConnell and J. Liu (2017). "Top 40 questions in coupled human and natural systems (CHANS) research." Ecology Society **22**(2).
176. Kremer, P., A. Haase and D. Haase (2019). "The future of urban sustainability: Smart, efficient, green or just? Introduction to the special issue." Sustainable Cities and Society **51**: 101761.
177. Krier, R. and C. Rowe (1979). Urban space, Academy editions London.
178. Kuhn, L. K. (2015). Emotion recognition in the human face and voice, Brunel University London.
179. Kyriakodis, G. and M. Santamouris (2018). "Using reflective pavements to mitigate urban heat island in warm climates-Results from a large scale urban mitigation project." Urban Climate **24**: 326-339.
180. Labaka, L., P. Maraña, R. Giménez and J. Hernantes (2019). "Defining the roadmap towards city resilience." Technological Forecasting and Social Change **146**: 281-296.
181. Lafortezza, R., G. Carrus, G. Sanesi and C. Davies (2009). "Benefits and well-being perceived by people visiting green spaces in periods of heat stress." Urban Forestry & Urban Greening **8**(2): 97-108.
182. Lausch, A., T. Blaschke, D. Haase, F. Herzog, R.-U. Syrbe, L. Tischendorf and U. Walz (2015). "Understanding and quantifying landscape structure–A review on relevant process characteristics, data models and landscape metrics." Ecological Modelling **295**: 31-41.

183.Lazdinis, M., P. Angelstam and H. Pülzl (2019). "Towards sustainable forest management in the European Union through polycentric forest governance and an integrated landscape approach." Landscape Ecology **34**(7): 1737-1749.

184.Lee, G. and I. Hong (2013). "Measuring spatial accessibility in the context of spatial disparity between demand and supply of urban park service." Landscape and Urban Planning **119**: 85-90.

185.Lefebvre, H. and D. Nicholson-Smith (1991). The production of space, Oxford Blackwell.

186.Lengen, C. (2015). "The effects of colours, shapes and boundaries of landscapes on perception, emotion and mentalising processes promoting health and well-being." Health & Place **35**: 166-177.

187.Leslie, P., J. T. McCabe, M. Bollig, C. Greiner, E. Fratkin, J. G. Galaty, K. Homewood, S. Lansing, F. Lu and E. F. Moran (2013). "Response diversity and resilience in social-ecological systems." Current Anthropology **54**(2): 000-000.

188.Li, H., F. Meier, X. Lee, T. Chakraborty, J. Liu, M. Schaap and S. Sodoudi (2018). "Interaction between urban heat island and urban pollution island during summer in Berlin." Science of The Total Environment **636**: 818-828.

189.Li, W., Y. Bai, Q. Chen, K. He, X. Ji and C. Han (2014). "Discrepant impacts of land use and land cover on urban heat islands: A case study of Shanghai, China." Ecological Indicators **47**: 171-178.

190.Li, X. and W. Zhou (2019). "Optimizing urban greenspace spatial pattern to mitigate urban heat island effects: Extending understanding from local to the city scale." Urban Forestry & Urban Greening **41**: 255-263.

191.Li, X., W. Zhou and Z. Ouyang (2013). "Relationship between land surface temperature and spatial pattern of greenspace: What are the effects of spatial resolution?" Landscape and Urban Planning **114**: 1-8.

192.Li, Y., J. Qiu, B. Zhao, M. Pavao-Zuckerman, A. Bruns, S. Qureshi, C. Zhang and Y. Li (2017). "Quantifying urban ecological governance: A suite of indices characterizes the ecological planning implications of rapid coastal urbanization." Ecological Indicators **72**: 225-233.

193.Li, Z.-L., B.-H. Tang, H. Wu, H. Ren, G. Yan, Z. Wan, I. F. Trigo and J. A. Sobrino (2013). "Satellite-derived land surface temperature: Current status and perspectives." Remote sensing of environment **131**: 14-37.

194.Likens, G. and W. Cronon (2012). Humans as components of ecosystems: the ecology of subtle human effects and populated areas, Springer Science & Business Media.

195.Lim, K. H., K. E. Lee, D. Kendal, L. Rashidi, E. Naghizade, Y. Feng and J. Wang (2019). Understanding sentiments and activities in green spaces using a social data–driven approach. Smart Cities: Issues and Challenges, Elsevier**:** 77-107.

196.Lim, K. H., K. E. Lee, D. Kendal, L. Rashidi, E. Naghizade, S. Winter and M. Vasardani (2018). The grass is greener on the other side: Understanding the effects of green spaces on Twitter user sentiments. Companion Proceedings of the The Web Conference 2018.

197.Lin, B. and X. Ouyang (2014). "Energy demand in China: Comparison of characteristics between the US and China in rapid urbanization stage." Energy conversion and management **79**: 128-139.

198.Lin, G. C. (2007). "Reproducing spaces of Chinese urbanisation: new city-based and land-centred urban transformation." Urban Studies **44**(9): 1827-1855.

199.Lin, P., S. S. Y. Lau, H. Qin and Z. Gou (2017). "Effects of urban planning indicators on urban heat island: a case study of pocket parks in high-rise high-density environment." Landscape and Urban Planning **168**: 48-60.

200.Lin, Y., W. An, M. Gan, A. Shahtahmassebi, Z. Ye, L. Huang, C. Zhu, L. Huang, J. Zhang and K. Wang (2021). "Spatial Grain Effects of Urban Green Space Cover Maps on Assessing Habitat Fragmentation and Connectivity." Land **10**(10): 1065.

201.Liu, C., M. Yang, Y. Hou and X. Xue (2021). "Ecosystem service multifunctionality assessment and coupling coordination analysis with land use and land cover change in China's coastal zones." Science of The Total Environment **797**: 149033.

202.Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz and J. Lubchenco (2007). "Complexity of coupled human and natural systems." Science **317**(5844): 1513-1516.

203.Liu, L. and Y. Zhang (2011). "Urban heat island analysis using the Landsat TM data and ASTER data: A case study in Hong Kong." Remote Sensing **3**(7): 1535-1552.

204.Liu, X., X.-X. Li, S. Harshan, M. Roth and E. Velasco (2017). "Evaluation of an urban canopy model in a tropical city: the role of tree evapotranspiration." Environmental Research Letters **12**(9): 094008.

205.Liu, Y., T. Hiyama and Y. Yamaguchi (2006). "Scaling of land surface temperature using satellite data: A case examination on ASTER and MODIS products over a heterogeneous terrain area." Remote Sensing of Environment **105**(2): 115-128.

206.Liu, Y., J. Peng and Y. Wang (2018). "Efficiency of landscape metrics characterizing urban land surface temperature." Landscape and Urban Planning **180**: 36-53.

207.López-Mosquera, N. and M. Sánchez (2011). "Emotional and satisfaction benefits to visitors as explanatory factors in the monetary valuation of environmental goods. An application to periurban green spaces." Land Use Policy **28**(1): 151-166.

208.Ludwig, D., B. Walker and C. S. Holling (1997). "Sustainability, stability, and resilience." Conservation ecology **1**(1).

209.Lynch, K. (1954). "The form of cities." Scientific American **190**(4): 54-63.

210.Mabon, L. and W.-Y. Shih (2018). "What might 'just green enough'urban development mean in the context of climate change adaptation? The case of urban greenspace planning in Taipei Metropolis, Taiwan." World Development **107**: 224-238.

211.Mahlkow, N., T. Lakes, J. Donner, J. Köppel and M. Schreurs (2016). "Developing storylines for urban climate governance by using Constellation Analysis—insights from a case study in Berlin, Germany." Urban Climate **17**: 266-283.

212.Makhzoumi, J. and G. Pungetti (2003). Ecological landscape design and planning, Taylor & Francis.

213.Malbéteau, Y., O. Merlin, S. Gascoin, J. P. Gastellu, C. Mattar, L. Olivera-Guerra, S. Khabba and L. Jarlan (2017). "Normalizing land surface temperature data for elevation and illumination effects in mountainous areas: A case study using ASTER data over a steep-sided valley in Morocco." Remote Sensing of Environment **189**: 25-39.

214.Marando, F., E. Salvatori, A. Sebastiani, L. Fusaro and F. Manes (2019). "Regulating ecosystem services and green infrastructure: assessment of urban heat island effect mitigation in the municipality of Rome, Italy." Ecological Modelling **392**: 92-102.

215.Martinez, G. and S. Häyrynen (2021). Cultural Analysis and Climate Resilience. Culture and Climate Resilience, Springer**:** 5-13.

216.Maslow, A. and K. Lewis (1987). "Maslow's hierarchy of needs." Salenger Incorporated **14**: 987.

217.Masoudi, M. and P. Y. Tan (2019). "Multi-year comparison of the effects of spatial pattern of urban green spaces on urban land surface temperature." Landscape and Urban Planning **184**: 44-58.

218.McDonnell, M. J., A. K. Hahs and J. H. Breuste (2009). Ecology of cities and towns: a comparative approach, Cambridge University Press.

219.McDonnell, M. J. and S. T. Pickett (1990). "Ecosystem structure and function along urban-rural gradients: an unexploited opportunity for ecology." Ecology: 1232-1237.

220.McGarigal, K. (2006). "Landscape pattern metrics." Encyclopedia of environmetrics **3**.

221.McGarigal, K. (2017). "Landscape metrics for categorical map patterns."

222.McLeod, S. (2007). "Maslow's hierarchy of needs." Simply psychology **1**: 1-8.

223.Meerow, S. and M. Stults (2016). "Comparing conceptualizations of urban climate resilience in theory and practice." Sustainability **8**(7): 701.

224.Meinel, G., R. Hecht and W. Socher (2006). Städtisches Grünvolumen–neuer Basisindikator für die Stadtökologie? Bestimmungsmethodik und Ergebnisbewertung [Urban green volume – new baseline indicator for urban ecology? Estimation methodology and evaluation of results.] In: Schrenk, M. (Eds.): CORP 2006 & Geomultimedia06, 13.-16. Februar 2006, Wien.

225.Meyerson, F. A., L. Merino and J. Durand (2007). Migration and environment in the context of globalization, Wiley Online Library.

226.Michaels, G., F. Rauch and S. J. Redding (2012). "Urbanization and structural transformation." The Quarterly Journal of Economics **127**(2): 535-586.

227.Mieszkowski, P. and E. S. Mills (1993). "The causes of metropolitan suburbanization." Journal of Economic perspectives **7**(3): 135-147.

228.Milcu, A. I., J. Hanspach, D. Abson and J. Fischer (2013). "Cultural ecosystem services: a literature review and prospects for future research." Ecology society **18**(3).

229.Ming, Y., Y. Liu and X. Liu (2022). "Spatial pattern of anthropogenic heat flux in monocentric and polycentric cities: The case of Chengdu and Chongqing." Sustainable Cities and Society **78**: 103628.

230.Mirzaei, P. A. (2015). "Recent challenges in modeling of urban heat island." Sustainable cities and society **19**: 200-206.

231.Mirzaei, P. A. and F. Haghighat (2010). "Approaches to study urban heat island–abilities and limitations." Building environment **45**(10): 2192-2201.

232.Mitchell, D., S. Enemark and P. J. L. U. P. Van der Molen (2015). "Climate resilient urban development: Why responsible land governance is important." **48**: 190-198.

233.Moll, G. and J. Petit (1994). "The Urban Ecosystem: Putting Nature Back in the Picture." Urban forests **14**(5): 8-15.

234.Monda, K. L., P. Gordon-Larsen, J. Stevens and B. M. Popkin (2007). "China's transition: the effect of rapid urbanization on adult occupational physical activity." Social science & medicine **64**(4): 858-870.

235.Montgomery, M. R. (2008). "The urban transformation of the developing world." science **319**(5864): 761-764.

236.Morini, E., A. G. Touchaei, F. Rossi, F. Cotana and H. Akbari (2018). "Evaluation of albedo enhancement to mitigate impacts of urban heat island in Rome (Italy) using WRF meteorological model." Urban climate **24**: 551-566.

237.Mumford, L. (2016). The culture of cities, Open Road Media.

238.Munroe, D. K., M. S. Crandall, C. Colocousis, K. P. Bell and A. T. Morzillo (2019). "Reciprocal relationships between forest management and regional landscape structures: applying concepts from land system science to private forest management." Journal of Land Use Science **14**(2): 155-172.

239.Mytton, O. T., N. Townsend, H. Rutter and C. Foster (2012). "Green space and physical activity: an observational study using Health Survey for England data." Health place **18**(5): 1034-1041.

240.Nahuelhual, L., A. Carmona, M. Aguayo and C. Echeverria (2014). "Land use change and ecosystem services provision: a case study of recreation and ecotourism opportunities in southern Chile." Landscape Ecology **29**(2): 329-344.

241.Nelson, J. and C. Ho (2020). Multicultural Cities. Understanding Urbanism, Springer**:** 135-149.

242.Neteler, M. (2010). "Estimating daily land surface temperatures in mountainous environments by reconstructed MODIS LST data." Remote sensing **2**(1): 333-351.

243.Nielsen, A. B., M. Van Den Bosch, S. Maruthaveeran and C. K. van den Bosch (2014). "Species richness in urban parks and its drivers: a review of empirical evidence." Urban Ecosystems **17**(1): 305-327.

244.Niemelä, J., S. R. Saarela, T. Söderman, L. Kopperoinen, V. Yli Pelkonen, S. Väre and D. J. Kotze (2010). "Using the ecosystem services approach for better planning and conservation of urban green spaces: a Finland case study." Biodiversity Conservation **19**(11): 3225-3243.

245.Norton, B. A., A. M. Coutts, S. J. Livesley, R. J. Harris, A. M. Hunter and N. S. Williams (2015). "Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes." Landscape and Urban planning **134**: 127-138.

246.O'Malley, C., P. Piroozfar, E. R. Farr and F. Pomponi (2015). "Urban Heat Island (UHI) mitigating strategies: A case-based comparative analysis." Sustainable Cities and Society **19**: 222-235.

247.Oke, T. R. (1973). "City size and the urban heat island." Atmospheric Environment (1967) **7**(8): 769-779.

248. Oke, T. R. (1982). "The energetic basis of the urban heat island." Quarterly Journal of the Royal Meteorological Society **108**(455): 1-24.
249. Okumus, D. E. and F. Terzi (2021). "Evaluating the role of urban fabric on surface urban heat island: The case of Istanbul." Sustainable Cities and Society **73**: 103128.
250. Ord, J. K. and A. Getis (1995). "Local spatial autocorrelation statistics: distributional issues and an application." Geographical analysis **27**(4): 286-306.
251. Ossola, A., G. D. Jenerette, A. McGrath, W. Chow, L. Hughes and M. Leishman (2021). "Small vegetated patches greatly reduce urban surface temperature during a summer heatwave in Adelaide, Australia." Landscape and Urban Planning **209**: 104046.
252. Oteros-Rozas, E., B. Martín-López, N. Fagerholm, C. Bieling and T. Plieninger (2018). "Using social media photos to explore the relation between cultural ecosystem services and landscape features across five European sites." Ecological Indicators **94**: 74-86.
253. Otto, S. and P. Pensini (2017). "Nature-based environmental education of children: Environmental knowledge and connectedness to nature, together, are related to ecological behaviour." Global Environmental Change **47**: 88-94.
254. Özgüner, H. (2011). "Cultural differences in attitudes towards urban parks and green spaces." Landscape Research **36**(5): 599-620.
255. Pal, S. and S. Ziaul (2017). "Detection of land use and land cover change and land surface temperature in English Bazar urban centre." The Egyptian Journal of Remote Sensing and Space Science **20**(1): 125-145.
256. Pamukcu-Albers, P., F. Ugolini, D. La Rosa, S. R. Grădinaru, J. C. Azevedo and J. Wu (2021). "Building green infrastructure to enhance urban resilience to climate change and pandemics." Landscape Ecology: 1-9.
257. Park, R. E. (1915). "The city: Suggestions for the investigation of human behavior in the city environment." American journal of sociology **20**(5): 577-612.
258. Parker, A. M. (2001). Neighborhood recreation parks--are they historically significant? , uga.
259. Pataki, D. E., M. M. Carreiro, J. Cherrier, N. E. Grulke, V. Jennings, S. Pincetl, R. V. Pouyat, T. H. Whitlow and W. C. Zipperer (2011). "Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions." Frontiers in Ecology the Environment **9**(1): 27-36.
260. Peel, M. C., B. L. Finlayson and T. A. McMahon (2007). "Updated world map of the Köppen-Geiger climate classification." Hydrology and earth system sciences **11**(5): 1633-1644.

261.Pei, T., S. Sobolevsky, C. Ratti, S.-L. Shaw, T. Li and C. Zhou (2014). "A new insight into land use classification based on aggregated mobile phone data." International Journal of Geographical Information Science **28**(9): 1988-2007.

262.Pickett, S., M. Cadenasso and J. Grove (2005). "Biocomplexity in coupled natural–human systems: a multidimensional framework." Ecosystems **8**(3): 225-232.

263.Pickett, S. T., W. R. Burch, S. E. Dalton, T. W. Foresman, J. M. Grove and R. Rowntree (1997). "A conceptual framework for the study of human ecosystems in urban areas." Urban ecosystems **1**(4): 185-199.

264.Pickett, S. T. and M. L. Cadenasso (1995). "Landscape ecology: spatial heterogeneity in ecological systems." Science **269**(5222): 331-334.

265.Pickett, S. T., M. L. Cadenasso, D. L. Childers, M. J. McDonnell and W. Zhou (2016). "Evolution and future of urban ecological science: ecology in, of, and for the city." Ecosystem health and Sustainability **2**(7): e01229.

266.Plumwood, V. (2005). "Belonging, Naming and Decolonisation." Habitus: A sense of place: 371.

267.Plunz, R. A., Y. Zhou, M. I. C. Vintimilla, K. Mckeown, T. Yu, L. Uguccioni and M. P. Sutto (2019). "Twitter sentiment in New York City parks as measure of well-being." Landscape and urban planning **189**: 235-246.

268.Polèse, M., R. E. Stren and R. Stren (2000). The social sustainability of cities: Diversity and the management of change, University of Toronto Press.

269.Price, D. D. and J. J. Barrell (1984). "Some general laws of human emotion: Interrelationships between intensities of desire, expectation, and emotional feeling." Journal of personality **52**(4): 389-409.

270.Qi, J., B. He, M. Wang, J. Zhu and W. Fu (2019). "Do grey infrastructures always elevate urban temperature? No, utilizing grey infrastructures to mitigate urban heat island effects." Sustainable Cities and Society **46**: 101392.

271.Qin, Z., A. Karnieli and P. Berliner (2001). "A mono-window algorithm for retrieving land surface temperature from Landsat TM data and its application to the Israel-Egypt border region." International journal of remote sensing **22**(18): 3719-3746.

272.Qiu, G.-y., H.-y. LI, Q.-t. Zhang, C. Wan, X.-j. Liang and X.-z. Li (2013). "Effects of evapotranspiration on mitigation of urban temperature by vegetation and urban agriculture." Journal of Integrative Agriculture **12**(8): 1307-1315.

273.Qureshi, S., S. N. Shorabeh, N. N. Samany, F. Minaei, M. Homaee, F. Nickravesh, M. K. Firozjaei and J. J. Arsanjani (2021). "A New Integrated Approach for Municipal Landfill

Siting Based on Urban Physical Growth Prediction: A Case Study Mashhad Metropolis in Iran." Remote Sensing **13**(5): 949.

274.Rahnema, S., S. Sedaghathoor, M. S. Allahyari, C. A. Damalas and H. El Bilali (2019). "Preferences and emotion perceptions of ornamental plant species for green space designing among urban park users in Iran." Urban Forestry & Urban Greening **39**: 98-108.

275.Rall, E., R. Hansen and S. Pauleit (2019). "The added value of public participation GIS (PPGIS) for urban green infrastructure planning." Urban Forestry & Urban Greening **40**: 264-274.

276.Rammig, A., M. Bahn, C. Vera, T. Knoke, C. Paul, B. Vollan, K. Erb, R. D. Bardgett, S. Lavorel and K. Thonicke (2020). Adaptive capacity of coupled social-ecological systems to absorb climate extremes. Climate Extremes and Their Implications for Impact and Risk Assessment, Elsevier**:** 257-278.

277.Rapoport, A. (2016). Human aspects of urban form: towards a man—environment approach to urban form and design, Elsevier.

278.Reinwald, F., Z. Ring, F. Kraus, A. Kainz, T. Tötzer and D. Damyanovic (2019). Green Resilient City-A framework to integrate the Green and Open Space Factor and climate simulations into everyday planning to support a green and climate-sensitive landscape and urban development. IOP Conference Series: Earth and Environmental Science, IOP Publishing.

279.Reis, G. and W.-M. Roth (2009). "A feeling for the environment: Emotion talk in/for the pedagogy of public environmental education." The Journal of Environmental Education **41**(2): 71-87.

280.Richardson, E., J. Pearce, R. Mitchell, P. Day and S. Kingham (2010). "The association between green space and cause-specific mortality in urban New Zealand: an ecological analysis of green space utility." BMC public health **10**(1): 240.

281.Rink, D. (2009). "Wilderness: The nature of urban shrinkage? The debate on urban restructuring and restoration in Eastern Germany." Nature and Culture **4**(3): 275-292.

282.Roberts, H., J. Sadler and L. Chapman (2019). "The value of Twitter data for determining the emotional responses of people to urban green spaces: A case study and critical evaluation." Urban studies **56**(4): 818-835.

283.Rongali, G., A. K. Keshari, A. K. Gosain and R. Khosa (2018). "A mono-window algorithm for land surface temperature estimation from Landsat 8 thermal infrared sensor data: a case study of the Beas River Basin, India." Pertanika J Sci Technol **26**(2): 829-840.

284. Rosol, M. (2010). "Public participation in post-Fordist urban green space governance: The case of community gardens in Berlin." International Journal of Urban and Regional Research **34**(3): 548-563.

285. Sagar, A. D. and A. Najam (1998). "The human development index: a critical review." Ecological economics **25**(3): 249-264.

286. Santamouris, M. (2013). "Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments." Renewable and Sustainable Energy Reviews **26**: 224-240.

287. Saunders, W. and J. Becker (2015). "A discussion of resilience and sustainability: Land use planning recovery from the Canterbury earthquake sequence, New Zealand." International journal of disaster risk reduction **14**: 73-81.

288. Scherer, D., U. Fehrenbach, T. Lakes, S. Lauf, F. Meier and C. Schuster (2013). "Quantification of heat-stress related mortality hazard, vulnerability and risk in Berlin, Germany." DIE ERDE–Journal of the Geographical Society of Berlin **144**(3-4): 238-259.

289. Schuster, C., K. Burkart and T. Lakes (2014). "Heat mortality in Berlin–Spatial variability at the neighborhood scale." Urban Climate **10**: 134-147.

290. Schwartz, A. J., P. S. Dodds, J. P. O'Neil-Dunne, C. M. Danforth and T. H. Ricketts (2019). "Visitors to urban greenspace have higher sentiment and lower negativity on Twitter." People Nature **1**(4): 476-485.

291. Scott, M. (2021). Resilience, Risk, and Policymaking. COVID-19 and Similar Futures, Springer**:** 113-118.

292. Senate, B. (2015). "Berlin Strategy: Urban Development Concept Berlin 2030." https://www.stadtentwicklung.berlin.de/planen/stadtentwicklungskonzept/download/strategie/BerlinStrategie_Broschuere_en.pdf.

293. Senatsverwaltung für Stadtentwicklung und Wohnen (2020). "Bevölkerungsprognose für Berlin und die Bezirke 2018 – 2030 [Population forecast for Berlin and the districts 2018 - 2030] " https://www.stadtentwicklung.berlin.de/planen/bevoelkerungsprognose/download/2018-2030/Bericht_Bevprog2018-2030.pdf.

294. SenUVK and (Senate Department for Environment traffic and climate protection) (2019). "public green area in Berlin: area overview of the districts."

https://www.berlin.de/sen/uvk/_assets/natur-gruen/stadtgruen/daten-und-fakten/ausw_13.pdf.

295. Shanahan, D. F., B. B. Lin, R. Bush, K. J. Gaston, J. H. Dean, E. Barber and R. A. Fuller (2015). "Toward improved public health outcomes from urban nature." American journal of public health **105**(3): 470-477.

296. Sharifi, A., M. Roosta and M. Javadpoor (2021). "Urban Form Resilience: A Comparative Analysis of Traditional, Semi-Planned, and Planned Neighborhoods in Shiraz, Iran." Urban Science **5**(1): 18.

297. Shirani-Bidabadi, N., T. Nasrabadi, S. Faryadi, A. Larijani and M. S. Roodposhti (2019). "Evaluating the spatial distribution and the intensity of urban heat island using remote sensing, case study of Isfahan city in Iran." Sustainable cities and society **45**: 686-692.

298. Sigala, M. (2008). "A supply chain management approach for investigating the role of tour operators on sustainable tourism: the case of TUI." Journal of cleaner production **16**(15): 1589-1599.

299. Siikamaki, J. and K. Wernstedt (2008). "Turning brownfields into greenspaces: Examining incentives and barriers to revitalization." Journal of health politics, policy and law **33**(3): 559-593.

300. Silvestri, S., L. Zaibet, M. Y. Said and S. C. Kifugo (2013). "Valuing ecosystem services for conservation and development purposes: a case study from Kenya." Environmental science policy **31**: 23-33.

301. Sjöman, H., J. Östberg and O. Bühler (2012). "Diversity and distribution of the urban tree population in ten major Nordic cities." Urban Forestry & Urban Greening **11**(1): 31-39.

302. Slonecker, E. T., D. B. Jennings and D. Garofalo (2001). "Remote sensing of impervious surfaces: A review." Remote Sensing Reviews **20**(3): 227-255.

303. Sobrino, J. and N. Raissouni (2000). "Toward remote sensing methods for land cover dynamic monitoring: Application to Morocco." International journal of remote sensing **21**(2): 353-366.

304. Sobrino, J. A., J. C. Jiménez-Muñoz and L. Paolini (2004). "Land surface temperature retrieval from LANDSAT TM 5." Remote Sensing of environment **90**(4): 434-440.

305. Soderlund, J. and P. J. A. e. s. Newman (2015). "Biophilic architecture: a review of the rationale and outcomes." **2**(4): 950-969.

306.Soga, M., Y. Yamaura, T. Aikoh, Y. Shoji, T. Kubo and K. J. Gaston (2015). "Reducing the extinction of experience: association between urban form and recreational use of public greenspace." Landscape and Urban Planning **143**: 69-75.

307.Song, H., G. Li, S. F. Witt and B. Fei (2010). "Tourism demand modelling and forecasting: how should demand be measured?" Tourism economics **16**(1): 63-81.

308.Sreetheran, M. and C. C. K. Van Den Bosch (2014). "A socio-ecological exploration of fear of crime in urban green spaces–A systematic review." Urban Forestry & Urban Greening **13**(1): 1-18.

309.Sreetheran, M., C. C. K. J. U. F. Van Den Bosch and U. Greening (2014). "A socio-ecological exploration of fear of crime in urban green spaces–A systematic review." **13**(1): 1-18.

310.Statistics Office (2019). "Berlin-Brandenburg Migration Background." https://www.statistik-berlin-brandenburg.de/webapi/jsf/tableView/tableView.xhtml.

311.Stedman, R. C. (2003). "Is it really just a social construction?: The contribution of the physical environment to sense of place." Society & Natural Resources **16**(8): 671-685.

312.Steeneveld, G. J., S. Koopmans, B. G. Heusinkveld and N. E. Theeuwes (2014). "Refreshing the role of open water surfaces on mitigating the maximum urban heat island effect." Landscape and Urban Planning **121**: 92-96.

313.Stewart, I. D. and T. R. Oke (2012). "Local climate zones for urban temperature studies." Bulletin of the American Meteorological Society **93**(12): 1879-1900.

314.Stewart, I. D., T. R. Oke and E. S. Krayenhoff (2014). "Evaluation of the 'local climate zone'scheme using temperature observations and model simulations." International journal of climatology **34**(4): 1062-1080.

315.Sun, R. and L. Chen (2017). "Effects of green space dynamics on urban heat islands: Mitigation and diversification." Ecosystem Services **23**: 38-46.

316.Sun, Y. and Y. Shao (2020). "Measuring visitor satisfaction toward peri-urban green and open spaces based on social media data." Urban Forestry & Urban Greening **53**: 126709.

317.Sun, Z., X. Li, W. Fu, Y. Li and D. Tang (2013). "Long-term effects of land use/land cover change on surface runoff in urban areas of Beijing, China." Journal of Applied Remote Sensing **8**(1): 084596.

318.Taha, H. (1997). "Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat." Energy and buildings **25**(2): 99-103.

319.Takebayashi, H. and M. Moriyama (2007). "Surface heat budget on green roof and high reflection roof for mitigation of urban heat island." Building and environment **42**(8): 2971-2979.

320.Taleghani, M. J. U. c. (2018). "The impact of increasing urban surface albedo on outdoor summer thermal comfort within a university campus." **24**: 175-184.

321.Tam, B. Y., W. A. Gough and T. Mohsin (2015). "The impact of urbanization and the urban heat island effect on day to day temperature variation." Urban Climate **12**: 1-10.

322.Tamosiunas, A., R. Grazuleviciene, D. Luksiene, A. Dedele, R. Reklaitiene, M. Baceviciene, J. Vencloviene, G. Bernotiene, R. Radisauskas and V. Malinauskiene (2014). "Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study." Environmental Health **13**(1): 20.

323.Tamosiunas, A., R. Grazuleviciene, D. Luksiene, A. Dedele, R. Reklaitiene, M. Baceviciene, J. Vencloviene, G. Bernotiene, R. Radisauskas and V. J. E. H. Malinauskiene (2014). "Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study." **13**(1): 20.

324.Tan, P. Y. (2017). Perspectives on Greening of Cities Through an Ecological Lens. Greening Cities, Springer**:** 15-39.

325.Taylor, P. D., L. Fahrig, K. Henein and G. J. O. Merriam (1993). "Connectivity is a vital element of landscape structure." 571-573.

326.The World Bank (2020). "Urban population ".

327.Thonicke, K., M. Bahn, S. Lavorel, R. D. Bardgett, K. Erb, M. Giamberini, M. Reichstein, B. Vollan and A. Rammig (2020). "Advancing the understanding of adaptive capacity of social-ecological systems to absorb climate extremes." Earth's Future **8**(2).

328.Tian, Y., C. Y. Jim and Y. Tao (2012). "Challenges and strategies for greening the compact city of Hong Kong." Journal of Urban Planning Development **138**(2): 101-109.

329.Tian, Y., C. Y. Jim and H. Wang (2014). "Assessing the landscape and ecological quality of urban green spaces in a compact city." Landscape and urban planning **121**: 97-108.

330.Tost, H., M. Reichert, U. Braun, I. Reinhard, R. Peters, S. Lautenbach, A. Hoell, E. Schwarz, U. Ebner-Priemer and A. Zipf (2019). "Neural correlates of individual differences in affective benefit of real-life urban green space exposure." Nature neuroscience **22**(9): 1389-1393.

331.Tran, D. X., F. Pla, P. Latorre-Carmona, S. W. Myint, M. Caetano and H. V. Kieu (2017). "Characterizing the relationship between land use land cover change and land surface temperature." Journal of Photogrammetry Remote Sensing **124**: 119-132.

332.Tran, D. X., F. Pla, P. Latorre-Carmona, S. W. Myint, M. Caetano and H. V. Kieu (2017). "Characterizing the relationship between land use land cover change and land surface temperature." ISPRS Journal of Photogrammetry and Remote Sensing **124**: 119-132.

333.Tratalos, J., R. A. Fuller, P. H. Warren, R. G. Davies and K. J. Gaston (2007). "Urban form, biodiversity potential and ecosystem services." Landscape and urban planning **83**(4): 308-317.

334.Tyler, S., E. Nugraha, H. K. Nguyen, N. Van Nguyen, A. D. Sari, P. Thinpanga, T. T. Tran and S. S. Verma (2016). "Indicators of urban climate resilience: A contextual approach." Environmental science & policy **66**: 420-426.

335.Tzoulas, K., K. Korpela, S. Venn, V. Yli-Pelkonen, A. Kaźmierczak, J. Niemela and P. James (2007). "Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review." Landscape and Urban Planning **81**(3): 167-178.

336.Ulivieri, C., M. Castronuovo, R. Francioni and A. Cardillo (1994). "A split window algorithm for estimating land surface temperature from satellites." Advances in Space Research **14**(3): 59-65.

337.Umwelt, S. f. (2019). "Öffentliche Grünflächen in Berlin."

338.Umweltatlas, B. (2015). "Actual Land Use."

339.UN-Habitat (2021). "Cities and Pandemics: Towards a More Just, Green and Healthy Future."

340.UN (United Nations) (2015). "Sustainable development goals, Goal 11 (SDG 11)." http://www.un.org/sustainabledevelopment/cities/

341.UN (United Nations) (2019). "World Urbanization Prospects 2018: Highlights " https://population.un.org/wup/Publications/Files/WUP2018-Highlights.pdf.

342.USGS (2016). "Landsat 8 (L8) data users handbook." Department of the Interior US Geological Survey, LSDS-1574.

343.USGS (2018). Landsat 7 Data Users Handbook-v1, Department of the Interior US Geological Survey.

344.USGS (2018). "Landsat 7 Data Users Handbook-v1." Department of the Interior US Geological Survey.

345.Uy, P. D. and N. Nakagoshi (2008). "Application of land suitability analysis and landscape ecology to urban greenspace planning in Hanoi, Vietnam." Urban Forestry & Urban Greening **7**(1): 25-40.

346. van Breugel, M., J. S. Hall, D. J. Craven, T. G. Gregoire, A. Park, D. H. Dent, M. H. Wishnie, E. Mariscal, J. Deago and D. Ibarra (2011). "Early growth and survival of 49 tropical tree species across sites differing in soil fertility and rainfall in Panama." Forest Ecology Management **261**(10): 1580-1589.
347. Van den Berg, A. E. and S. L. Koole (2006). "New wilderness in the Netherlands: An investigation of visual preferences for nature development landscapes." Landscape Urban Planning **78**(4): 362-372.
348. Van den Berg, M., M. van Poppel, I. van Kamp, S. Andrusaityte, B. Balseviciene, M. Cirach, A. Danileviciute, N. Ellis, G. Hurst and D. Masterson (2016). "Visiting green space is associated with mental health and vitality: A cross-sectional study in four european cities." Health & place **38**: 8-15.
349. Van den Bosch, M. and Å. O. Sang (2017). "Urban natural environments as nature-based solutions for improved public health–A systematic review of reviews." Environmental research **158**: 373-384.
350. Venter, Z., D. Barton, V. Gundersen, H. Figari and M. J. E. R. L. Nowell (2020). "Urban nature in a time of crisis: recreational use of green space increases during the COVID-19 outbreak in Oslo, Norway."
351. Verburg, P. H., K. Kok, R. G. Pontius and A. Veldkamp (2006). Modeling land-use and land-cover change. Land-use and land-cover change, Springer: 117-135.
352. Vierikko, K., P. Goncalves, D. Haase and e. al (2020). "Biocultural diversity(BCD) in European cites-interactions between motivations, experiences, and environment in public parks " Urban Forestry & Urban Greening **48**: 126501.
353. Vierikko, K., Paula Gonçalves, Dagmar Haase, Birgit Elands and e. al (2020). "Lived biocultural diversity in European parks – do public parks concurrently support interrelationships between people and nature? ." Urban Forestry & Urban Greening **48**: 126501.
354. Vlahov, D., N. Freudenberg, F. Proietti, D. Ompad, A. Quinn, V. Nandi and S. Galea (2007). "Urban as a determinant of health." Journal of urban health **84**(1): 16-26.
355. Vogt, C. A., K. L. Andereck and K. J. A. o. T. R. Pham (2020). "Designing for quality of life and sustainability." **83**: 102963.
356. Volkova, S., T. Wilson and D. Yarowsky (2013). Exploring demographic language variations to improve multilingual sentiment analysis in social media. Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing.

357.von Beyme, K. (2019). Kulturstadt und Kulturarchitektur in Berlin [City of Culture and Cultural Architecture in Berlin] Hauptstadt Berlin, Springer**:** 219-226.

358.Walker, B., C. S. Holling, S. R. Carpenter, A. J. E. Kinzig and society (2004). "Resilience, adaptability and transformability in social–ecological systems." **9**(2).

359.Wang, J., W. Zhou, Y. Qian, W. Li and L. Han (2018). "Quantifying and characterizing the dynamics of urban greenspace at the patch level: A new approach using object-based image analysis." Remote Sensing of Environment **204**: 94-108.

360.Wang, K. and S. Liang (2009). "Evaluation of ASTER and MODIS land surface temperature and emissivity products using long-term surface longwave radiation observations at SURFRAD sites." Remote Sensing of Environment **113**(7): 1556-1565.

361.Wang, R., W. Jiang and T. Lu (2021). "Landscape characteristics of university campus in relation to aesthetic quality and recreational preference." Urban Forestry & Urban Greening **66**: 127389.

362.Wang, X. (2009). "Analysis of problems in urban green space system planning in China." Journal of Forestry Research **20**(1): 79-82.

363.Wang, X., X. Dong, H. Liu, H. Wei, W. Fan, N. Lu, Z. Xu, J. Ren and K. J. E. s. Xing (2017). "Linking land use change, ecosystem services and human well-being: A case study of the Manas River Basin of Xinjiang, China." **27**: 113-123.

364.Wang, Y., E. Dai, L. Yin and L. Ma (2018). "Land use/land cover change and the effects on ecosystem services in the Hengduan Mountain region, China." Ecosystem Services **34**: 55-67.

365.Wang, Z.-H. (2022). "Reconceptualizing urban heat island: Beyond the urban-rural dichotomy." Sustainable Cities and Society **77**: 103581.

366.Wellmann, T., A. Lausch, E. Andersson, S. Knapp, C. Cortinovis, J. Jache, S. Scheuer, P. Kremer, A. Mascarenhas and R. Kraemer (2020). "Remote sensing in urban planning: Contributions towards ecologically sound policies?" Landscape and Urban Planning **204**: 103921.

367.Weng, Q. (2009). "Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends." ISPRS Journal of photogrammetry and remote sensing **64**(4): 335-344.

368.Weng, Q. (2020). "Impacts of Urbanization on Land Surface Temperature and Water Quality."

369.Weng, Q. and P. Fu (2014). "Modeling annual parameters of clear-sky land surface temperature variations and evaluating the impact of cloud cover using time series of Landsat TIR data." Remote Sensing of Environment **140**: 267-278.

370.Weng, Q., H. Liu and D. Lu (2007). "Assessing the effects of land use and land cover patterns on thermal conditions using landscape metrics in city of Indianapolis, United States." Urban ecosystems **10**(2): 203-219.

371.Weng, Q., D. Lu and J. Schubring (2004). "Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies." Remote sensing of Environment **89**(4): 467-483.

372.Westermann, S., M. Langer and J. Boike (2011). "Spatial and temporal variations of summer surface temperatures of high-arctic tundra on Svalbard—implications for MODIS LST based permafrost monitoring." Remote Sensing of Environment **115**(3): 908-922.

373.Williams, B., P. Laslett and W. G. Runciman (1962). "The idea of equality."

374.Williams, T. G., T. M. Logan, C. T. Zuo, K. D. Liberman and S. D. Guikema (2020). "Parks and safety: a comparative study of green space access and inequity in five US cities." Landscape and urban planning **201**: 103841.

375.Wilson, E., F. Nicol, L. Nanayakkara, A. J. J. o. E. P. Ueberjahn-Tritta and Planning (2008). "Public urban open space and human thermal comfort: The implications of alternative climate change and socio-economic scenarios." **10**(1): 31-45.

376.Wolch, J. R., J. Byrne and J. P. Newell (2014). "Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'." Landscape and urban planning **125**: 234-244.

377.Wu, J. (2004). "Effects of changing scale on landscape pattern analysis: scaling relations." Landscape ecology **19**(2): 125-138.

378.Wu, J. (2008). "Making the case for landscape ecology an effective approach to urban sustainability." Landscape journal **27**(1): 41-50.

379.Wu, J. (2013). "Landscape sustainability science: ecosystem services and human well-being in changing landscapes." Landscape ecology **28**(6): 999-1023.

380.Wu, J. (2014). "Urban ecology and sustainability: The state-of-the-science and future directions." landscape and urban planning **125**: 209-221.

381.Wu, J., D. E. Jelinski, M. Luck and P. T. Tueller (2000). "Multiscale analysis of landscape heterogeneity: scale variance and pattern metrics." Geographic information sciences **6**(1): 6-19.

382.Wu, W., S. Zhao, C. Zhu and J. Jiang (2015). "A comparative study of urban expansion in Beijing, Tianjin and Shijiazhuang over the past three decades." Landscape and urban planning **134**: 93-106.

383.Wu, Z. and Y. J. S. Zhang (2018). "Spatial variation of urban thermal environment and its relation to green space patterns: Implication to sustainable landscape planning." **10**(7): 2249.

384.Xiang, Y., C. Huang, X. Huang, Z. Zhou and X. Wang (2021). "Seasonal variations of the dominant factors for spatial heterogeneity and time inconsistency of land surface temperature in an urban agglomeration of central China." Sustainable Cities and Society **75**: 103285.

385.Xiao, R., Q. Weng, Z. Ouyang, W. Li, E. W. Schienke and Z. Zhang (2008). "Land surface temperature variation and major factors in Beijing, China." Photogrammetric Engineering Remote Sensing **74**(4): 451-461.

386.Xing, H. and Y. Meng (2018). "Integrating landscape metrics and socioeconomic features for urban functional region classification." Computers, Environment Urban Systems **72**: 134-145.

387.Xue, B., L. Zhang, Y. Geng, B. Mitchell and W. Ren (2016). "Extended land-use coding system and its application in urban brownfield redevelopment: Case study of Tiexi District in Shenyang, China." Journal of Urban Planning and Development **142**(3): 05015014.

388.Yang, J., S. Jin, X. Xiao, C. Jin, J. C. Xia, X. Li and S. Wang (2019). "Local climate zone ventilation and urban land surface temperatures: Towards a performance-based and wind-sensitive planning proposal in megacities." Sustainable Cities and Society **47**: 101487.

389.Yang, J., J. Ren, D. Sun, X. Xiao, J. C. Xia, C. Jin and X. Li (2021). "Understanding land surface temperature impact factors based on local climate zones." Sustainable Cities and Society **69**: 102818.

390.Yang, L., L. Zhang, Y. Li and S. Wu (2015). "Water-related ecosystem services provided by urban green space: A case study in Yixing City (China)." Landscape and Urban Planning **136**: 40-51.

391.Young, R. F. (2011). "Planting the living city: Best practices in planning green infrastructure—Results from major us cities." Journal of the American Planning Association **77**(4): 368-381.

392.Yu, X., X. Guo and Z. Wu (2014). "Land surface temperature retrieval from Landsat 8 TIRS—Comparison between radiative transfer equation-based method, split window algorithm and single channel method." Remote Sensing **6**(10): 9829-9852.

393.Yue, W., J. Xu, W. Tan and L. Xu (2007). "The relationship between land surface temperature and NDVI with remote sensing: application to Shanghai Landsat 7 ETM+ data." International journal of Remote Sensing **28**(15): 3205-3226.

394.Zaidi, R. Z. and M. J. U. S. Pelling (2015). "Institutionally configured risk: Assessing urban resilience and disaster risk reduction to heat wave risk in London." **52**(7): 1218-1233.

395.Zhang, N., J. Zhang, W. Chen and J. Su (2022). "Block-based variations in the impact of characteristics of urban functional zones on the urban heat island effect: A case study of Beijing." Sustainable Cities and Society **76**: 103529.

396.Zhang, S. and W. Zhou (2018). "Recreational visits to urban parks and factors affecting park visits: Evidence from geotagged social media data." Landscape and urban planning **180**: 27-35.

397.Zhang, X., N. Chen, H. Sheng, C. Ip, L. Yang, Y. Chen, Z. Sang, T. Tadesse, T. P. Y. Lim and A. Rajabifard (2019). "Urban drought challenge to 2030 sustainable development goals." Science of the Total Environment **693**: 133536.

398.Zhang, Z., S. Meerow, J. P. Newell and M. Lindquist (2019). "Enhancing landscape connectivity through multifunctional green infrastructure corridor modeling and design." Urban Forestry & Urban Greening **38**: 305-317.

399.Zheng, Z., W. Zhou, J. Yan, Y. Qian, J. Wang and W. Li (2019). "The higher, the cooler? Effects of building height on land surface temperatures in residential areas of Beijing." Physics Chemistry of the Earth, Parts A/B/C **110**: 149-156.

400.Zhong, Q., L. Zhang, Y. Zhu, C. Konijnendijk van den Bosch, J. Han, G. Zhang and Y. Li (2020). "A conceptual framework for ex ante valuation of ecosystem services of brownfield greening from a systematic perspective." Ecosystem Health and Sustainability **6**(1): 1743206.

401.Zhou, L., F. Hu, B. Wang, C. Wei, D. Sun and S. Wang (2022). "Relationship between urban landscape structure and land surface temperature: Spatial hierarchy and interaction effects." Sustainable Cities and Society **80**: 103795.

402.Zhou, W., S. T. Pickett and M. L. J. L. e. Cadenasso (2017). "Shifting concepts of urban spatial heterogeneity and their implications for sustainability." **32**(1): 15-30.

403.Zhou, W., J. Wang and M. L. Cadenasso (2017). "Effects of the spatial configuration of trees on urban heat mitigation: A comparative study." Remote Sensing of Environment **195**: 1-12.

404.Zhou, X. and H. Chen (2018). "Impact of urbanization-related land use land cover changes and urban morphology changes on the urban heat island phenomenon." Science of the Total Environment **635**: 1467-1476.

405.Zhou, X. and M. P. J. M. o. E. Q. A. I. J. Rana (2012). "Social benefits of urban green space."

406.Zukin, S., P. Kasinitz and X. Chen (2015). Global cities, local streets: Everyday diversity from New York to Shanghai, Routledge.

Eidesstattliche Erklärung

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Erklärung: Hiermit erkläre ich, die Dissertation selbstständig und nur unter Verwendung der angegebenen Hilfen und Hilfsmittel angefertigt zu haben. Ich habe mich nicht anderwärts um einen Doktorgrad in dem Promotionsfach beworben und besitze keinen entsprechenden Doktorgrad. Die Promotionsordnung der Mathematisch-Naturwissenschaftlichen Fakultät, veröffentlicht im Amtlichen Mitteilungsblatt der Hum-boldt-Universität zu Berlin Nr. 42 am 11. Juli 2018, habe ich zur Kenntnis genommen.

Declaration: I declare that I have completed this thesis independently using only the aids and tools specified. I have not applied for a doctor's degree in this doctoral subject elsewhere and do not hold a corresponding doctor's degree. I have taken due note of the Faculty of Mathematics and Natural Sciences PhD Regulations, published in the Official Gazette of Humboldt-Universität zu Berlin no. 42 on July 11 2018.

Shanshan Chen

23.5.2022

Zusammenfassung

In dieser Dissertation werden vier Studien durchgeführt, um die acht Arten von Räumen in Mensch-Natur-Systemen für die Widerstandsfähigkeit von Städten vorzuschlagen, die Verbesserung von städtischen Grünflächen unter qualitativen und quantitativen Gesichtspunkten zu analysieren, die Beziehung zwischen UGSLandschaftsmerkmalen und menschlichen Emotionen zu bestimmen und das Konzept der selbstlernenden Stadt für die städtische Raumplanung zu veranschaulichen. (1). Unterschiedliche Strategien in den Acht-Typen-Räumen in Mensch-Natur-Systemen. (2). Verbesserung der städtischen Grünflächen mit natürlichem Angebot und menschlicher Nachfrage. (3). Das Konzept der selbstlernenden Stadt für urbane Nachhaltigkeit. (4) Für die städtische Nachhaltigkeit erfordert die Planung eine Neubewertung der Verbindungen zwischen den verschiedenen menschlichen und natürlichen Systemen mit den Wechselwirkungen zwischen Bedarf und Versorgung Städtische Räume sind komplex, weisen aber in verschiedenen Methoden und Konzepten Regelmäßigkeiten auf. Für eine nachhaltige Entwicklung in Städten sind kreative Denkansätze für die Umsetzung und Integration von sich überschneidenden Räumen, Elementen und Kulturen in städtischen Mensch-Natur-Systemen erforderlich. Um eine nachhaltige Stadt zu schaffen, sind urbane Räume unerlässlich.

Abstract

This dissertation conducts four studies to propose the eight-type spaces in human-natural systems for city resilience, to analyze the improvement of urban green spaces from quality and quantity perspectives, to determine the relationship between UGS landscape characteristics and human emotions and to illustrate the concept of city self-learning for urban space planning. (1). Different strategies in the eight-type spaces across human-natural systems. (2). Improving urban green spaces with natural supply and human demand. (3). The concept of city self-learning for urban sustainability. (4) For urban sustainability, planning requires reevaluating the connections between different human-natural systems with the interactions of demands and supplies. Dissertation title: Exploring Urban Spaces across Human-Natural systems And the Potential to Enhance City Resilience Urban spaces are complex but have regularity in several methods and concepts. For sustainable development in cities, creative ways to think about implementations and integrations utilize crossing spaces, elements, and cultures in urban human-natural systems. To make a sustainable city, urban spaces are essential.