

**A SOCIAL-ECOLOGICAL UNDERSTANDING OF URBANIZATION:  
A CASE OF WUHAN, CHINA**

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## Dedication

I would like to dedicate this thesis to my family.

My husband,

Pengfeng Yang

Our dear sons,

Yunfei Ouyang, Yunhao Ouyang

And beloved daughter,

Melody Ouyang.

## Abstract

Since the introduction of economic reforms in the late 1970s, China has experienced phenomenal economic growth along with rapid urbanization. The accelerated urbanization coincides with remarkable social-economic transformations and urban landscape changes. A city, as an urban system, is composed of social and physical subsystems that interact with each other. Equally assessing each component is necessary for a comprehensive understanding of the urbanization process.

The goal of this thesis research is to deconstruct the urbanization process through a social-ecological perspective. More specifically, this study examines social transformations, physical evolutions, and their relationships. Four research questions are proposed as (1) How does urban social landscape transform in time and space? (2) What trends are apparent in the urban land growth process and spatial heterogeneity? (3) How does social transformation relate to urban land growth, within a spatio-temporal perspective? and (4) How do social-demographic features relate to residents' use and perception of urban green open spaces, focusing on the ecological services provided by and the need to improve those spaces?

Given the lack of research on second-tier cities' growth processes, this study selects Wuhan, a megacity in central China, as a case study, with a focus on its urban development zone (UDZ). A social-ecological approach is applied to study the multi-dimensional features of an urban system.

The thesis is in paper format, containing five chapters. Besides the Introduction (Chapter 1) and Conclusion (Chapter 5), the main body consists of three articles. These three articles correspond to the four research questions proposed. Chapter 2 responds to the first research question by addressing how the urban social landscape transforms. Chapter 3 seeks to answer the second and third questions by evaluating urban land growth and its links with social factors from a spatio-temporal perspective. Chapter 4 matches the fourth question by seeking to understand residents' preferences and feelings toward the urban green open space.

Chapter 1 introduces the research context, reviews the urban ecology theory and relevant empirical research, as well as assesses the social-ecological approach related to studying the urban system. In this chapter, we also propose an improved social-ecological system (ISES) framework which guides the equally weighted study of both social and physical subsystems in an urban area.

Chapter 2 (the first paper) seeks to investigate progressive transformations in the social dimensions of Wuhan UDZ while also focusing on their spatial transformations, using national census data in 1990, 2000, and 2010. We used varimax rotated principal component analysis (PCA) for the extraction of social dimensions and ArcMap for spatial visualization. This allows us to further analyze the spatial distribution of social clusters. The results suggest that industrial relocation, educational attainment increase, population aging, and migration are the main characteristics of social transformation during 1990 and 2010. Industrial relocation along with the spatial separation appeared as principal social dimensions in the 1990s but became more prominent in the 2000s, accompanied by the improvement of workers' education levels. Aging population presented spatial movement outward from the city center. Population mobility increased significantly, and immigration became an important social dimension and presented spatial expansion in the 2000s. The socio-spatial patterns transform with a combination of concentric rings and sectoral clusters in different stages. These transformations are formed by

the regional push-pull forces and the centripetal-centrifugal forces inside the city. We conclude that the social landscape transforms in a way with diversity and inclusion. Government dominates socio-spatial transformations in the initial stages, while market plays an increasing role in the later stages. To build a more inclusive society requires continuous and systematic improvement of relevant policies.

Chapter 3 (the second paper) discusses urban land growth patterns and answers how social factors are associated with the evolution patterns between 1990 and 2010. We extract land cover information based on Landsat images with the vegetation area – impervious surface – water area (V-I-W) model and examine the urban growth patterns during various stages using landscape metrics of the area, aggregation, and shape. Then, we apply geographically weighted regression (GWR) to depict the link between urban land metrics and social factors. The results show that urban land coalescence and diffusion simultaneously exist; the city center is dominated by redevelopment, infilling, edge expansion; and the peripheral areas by outlying expansion. GWR coefficient surfaces show little differences in the models between social factors and urban land area metrics PLAND while remarkable differences are present in the coefficients of GWR models for the urban land patch shape irregularities and social factors. Urban land growth patterns relate to the government-led land supply system, the functional zoning of urban space planning, and the agglomeration and dispersion of social space under the market orientation. The authors conclude that urban management should consider the coexistence of different spatial growth modes and introduce factors such as social preferences in the urban land layout. This may apply to rapidly urbanizing areas.

Chapter 4 (the third paper) aims to understand social-natural relationships, with a focus on how socio-demographic features can shape residents' preference toward green open spaces and their perceptions of ecological services and improvements. Data is collected through online questionnaire surveys and interviews. The results indicate that preferences toward green open spaces vary among different social groups. Demands for improvement to green open spaces are rooted in residents' appreciation for daily relaxation and health benefits, and link with their preference for visiting. However, how residents perceive green open spaces' benefits does not rely only on an in-person visit. Interaction experience with nature and knowledge of natural development affect perception of daily use and health-related services. Residents' perceptions of green open space's ecological functions are associated with the changes in nature reported by those respondents. Responses to improving green open space reflect the residents' pursuit of the aesthetics and practicality of such spaces. Though respondents are commonly aware of the ecological importance of green open space, there are differences in their willingness to voluntarily participate in its management. We conclude that to encourage the public to participate in configuration and improvement of green open spaces through a variety of ways, including considering residents' opinions, is an efficient way in order to better social-ecological relationships.

Chapter 5 reviews the main findings and conclusions, research limitations as well as future possibilities. This study establishes a dialogue between urban social and physical subsystems, with an integrated quantitative study of the urbanization process, emphasizing the relationships between two urban subsystems. It provides a comprehensive social-ecological view on a second-tier city based on the social and physical transformations that occurred in Wuhan during a transitional period of a socialist market economy. We conclude that the development of China's second-tier cities between 1990 and 2010 is characterized by the transformations of social dimensions and landscape, the coexistence of multiple urban spatial development modes, and the spatial differentiation between the center and the periphery of the city. The GWR

models present spatial non-stationary relationships between social factors and the urban patch shape regularities. The further examination of social-natural relationships finds that residents' social-demographic features and environmental experience affect their perceptions toward green open space, especially ecological services and improvement necessity. The evolution of urban social and physical systems and their relationships has brought increased attention to inclusive urban social management, public participatory planning, and people-centered social and ecological interactions. This research provides a constructive rethinking of second-tier cities' growth in China and may serve as a reference for other rapidly urbanizing areas.

## Résumé

Depuis la réforme économique en Chine à la fin des années 1970, la Chine a connu un essor économique important, ainsi qu'une urbanisation rapide. Cette urbanisation accélérée s'accompagne des transformations socioéconomiques importantes et d'une modification du paysage urbain. Une ville en tant que système urbain est composée de sous-systèmes sociaux et physiques qui interagissent entre eux. Il est nécessaire d'étudier de manière égale chaque sous-système pour bien comprendre le processus d'urbanisation.

Le but de cette recherche est de décortiquer le processus d'urbanisation selon une perspective socioécologique. Ainsi, cette étude analyse les transformations sociales, les évolutions physiques et leurs relations. 4 questions de recherche sont proposées : 1) comment le paysage urbain social se transforme-t-il dans le temps et l'espace ? 2) Quelles sont les principales tendances dans le processus de croissance du paysage urbain et de l'hétérogénéité spatiale ? 3) Comment la transformation sociale est-elle reliée à la croissance du paysage urbain en adoptant une perspective spatio-temporelle ? Et 4) comment les caractéristiques sociodémographiques sont-elles reliées à l'utilisation et à la perception des espaces verts urbains extérieurs par les citoyens avec une attention particulière sur les services écologiques fournis par ces espaces et sur le besoin de les améliorer ?

Étant donné le manque de recherches sur le processus de développement des villes de second rang, cette étude choisit Wuhan, une mégapole du centre de la Chine, comme cas, en se concentrant sur sa zone de développement urbain. Cette thèse est présentée en format papier et contient cinq chapitres. Outre l'introduction (chapitre 1) et la conclusion (chapitre 5), le corps de la thèse est constitué de trois articles correspondants aux quatre questions de recherche proposées. Le chapitre 2 répond à la première question de recherche en se concentrant sur la transformation du paysage social urbain. Le chapitre 3 cherche à répondre aux questions 2 et 3 en mettant l'accent sur la croissance des terres urbaines en lien avec l'aspect social dans une perspective spatio-temporelle. Finalement, le chapitre 4 répond à la quatrième question pour comprendre l'opinion des citoyens par rapport aux espaces verts dans un contexte urbain.

Le chapitre 1 présente le contexte de la recherche, examine la théorie de l'écologie urbaine et les recherches appliquées pertinentes, et évalue l'approche socio-écologique liée à l'étude du système urbain. Dans ce chapitre, nous proposons également un concept amélioré à propos des systèmes socio-écologiques qui analyse les sous-systèmes sociaux, ainsi que physiques dans une zone urbaine.

Le chapitre 2 (le premier article) vise à étudier les transformations progressives des dimensions sociales de la zone de développement urbain de Wuhan tout en se concentrant sur la transformation spatiale, en utilisant les données du recensement national de 1990, 2000 et 2010. Nous avons utilisé l'analyse en composantes principales (ACP) avec rotation Varimax pour l'extraction des dimensions sociales et ArcMap pour la visualisation spatiale. Ceci nous permet d'analyser davantage la distribution spatiale des regroupements sociaux. Les résultats suggèrent que la modernisation industrielle, l'amélioration du système d'éducation, le vieillissement de la population et la migration sont tous des caractéristiques principales de la transformation sociale entre 1990 et 2010. Les délocalisations industrielles ainsi que la séparation spatiale sont apparues comme les principales dimensions sociales dans les années 1990 mais sont devenues plus importantes dans les années 2000, accompagnées par l'amélioration du niveau d'éducation des travailleurs. Le vieillissement de la population présentait un mouvement spatial vers l'extérieur du centre-ville. La mobilité de la population a

considérablement augmenté et l'immigration est devenue une dimension sociale importante et a présenté une expansion spatiale dans les années 2000. Les modèles socio-spatiaux se transforment avec une combinaison d'anneaux concentriques et de grappes sectorielles à différentes étapes. Ces transformations sont formées par les forces push-pull régionales et les forces centripètes-centrifuges à l'intérieur de la ville. Nous concluons que le paysage social se transforme d'une manière avec la diversité et l'inclusion. Le gouvernement domine les transformations socio-spatiales dans les étapes initiales, tandis que le marché joue un rôle croissant dans les étapes ultérieures. Pour construire une société plus inclusive, il faut une amélioration continue et systématique des politiques pertinentes.

Le chapitre 3 (le deuxième article) traite des modèles de croissance des territoires urbains et répond à la question de savoir comment les facteurs sociaux sont associés aux modèles d'évolution entre 1990 et 2010. Nous extrayons des informations sur la couverture terrestre basées sur des images Landsat avec le modèle zone de végétation – surface imperméable – zone d'eau (V-I-W) et examiner les modèles de croissance urbaine au cours des différentes étapes à l'aide de mesures du paysage de la zone, de l'agrégation et de la forme. Ensuite, nous avons appliqué la régression pondérée géographiquement pour décrire le lien entre les données métriques du territoire urbain et les différents facteurs sociaux. Les résultats montrent que la coalescence et la dispersion des terres urbaines existent simultanément; le centre-ville est dominé par le réaménagement, le remplissage, l'expansion des bords et les zones périphériques par la dispersion. Les surfaces des coefficients GWR montrent peu de différences dans les modèles entre les facteurs sociaux et les métriques de superficie urbaine PLAND tandis que des différences remarquables sont présentes dans les coefficients des modèles GWR pour les irrégularités de forme des parcelles urbaines et les facteurs sociaux. Les modèles de croissance des terres urbaines sont liés à des facteurs sociaux sous le contrôle de l'expansion par le système de fourniture de terres dominé par le gouvernement, le zonage fonctionnel par la planification spatiale de la ville et l'orientation par la construction d'infrastructures. Les auteurs concluent que la gestion urbaine devrait considérer la coexistence de différents modes de croissance spatiale et introduire des facteurs tels que les préférences sociales dans l'aménagement du territoire urbain. Cela peut s'appliquer aux zones à urbanisation rapide.

Le chapitre 4 (le troisième article) vise à comprendre les relations sociales-naturelles, en mettant l'accent sur la façon dont les caractéristiques sociodémographiques peuvent façonner la préférence des résidents pour les espaces verts ouverts et leurs perceptions des services et des améliorations écologiques. Les données sont recueillies au moyen d'enquêtes par questionnaire en ligne et d'entretiens. Les résultats indiquent que les préférences envers les espaces verts ouverts varient selon les différents groupes sociaux. Les demandes d'amélioration des espaces verts sont enracinées dans l'appréciation des résidents pour la détente quotidienne et les bienfaits pour la santé, et sont liées à leur préférence pour les visites. Cependant, la façon dont les résidents perçoivent les avantages des espaces verts ouverts ne repose pas uniquement sur une visite en personne. L'expérience d'interaction avec la nature et la connaissance du développement naturel affectent la perception de l'utilisation quotidienne et des services liés à la santé. Les perceptions des résidents sur les fonctions écologiques des espaces verts sont associées aux changements de nature signalés par ces répondants. Les réponses à l'amélioration des espaces verts reflètent la quête des résidents de l'esthétique et de la praticité de ces espaces. Bien que les répondants soient généralement conscients de l'importance écologique des espaces verts ouverts, il existe des différences dans leur volonté de participer volontairement à sa gestion. Nous concluons qu'encourager le public à participer à la configuration et à l'amélioration des espaces verts de diverses manières, y compris en tenant compte de l'opinion des résidents, est un moyen efficace pour améliorer les relations socio-écologiques.

Le chapitre 5 résume les résultats et les conclusions et discute des limites de la recherche ainsi que des possibilités pour des recherches futures. Cette étude établit un lien entre les sous-systèmes sociaux et physiques urbains, avec une étude quantitative intégrée du processus d'urbanisation, en mettant l'accent sur les relations entre ces deux sous-systèmes urbains. Une vision socioécologique complète d'une ville de second rang est fournie, basée sur des transformations sociales et physiques qui se sont produites à Wuhan pendant une période de transition vers une économie socialiste et paysagère. Nous concluons que le développement des villes de second rang en Chine comme Wuhan entre 1990 et 2010 est caractérisé par la diversification des dimensions sociales et paysagères, la coexistence de multiples modes de développement spatial urbain et la différenciation spatiale entre le centre de la ville et la périphérie. Les modèles GWR présentent des relations spatiales non stationnaires entre les facteurs sociaux et les régularités de la forme des patches urbains. Un examen plus approfondi des rapports entre l'aspect social et écologique révèle que les caractéristiques sociodémographiques et l'expérience environnementale des citoyens influencent leur perception des espaces verts extérieurs, dont leurs services écologiques et la nécessité d'améliorer ces espaces. L'évolution des systèmes sociaux et physiques urbains et de leurs relations a attiré l'attention sur une gestion urbaine sociale plus inclusive avec une planification participative du public et des interactions sociales et écologiques centrées sur les citoyens. Cette recherche permet de repenser de manière constructive la croissance des villes de second rang en Chine et peut servir de référence pour d'autres zones à urbanisation rapide.

## 摘要

自 1970 年代后期开始实行经济改革以来，中国经历了经济飞速发展以及快速城市化。加速的城市化伴随着社会经济的巨大转变和城市景观的变化。城市系统由彼此相互作用的社会子系统和物理子系统组成。为了全面了解城市化进程，必须对每一个组成部分进行同等的评估。

本论文的研究目的是从社会生态视角解构城市化进程，即同等权重地考察社会转型、物理演进及其关系。研究提出四个问题：（1）城市社会景观如何在时间和空间上转变？（2）在城市土地增长过程和空间异质性方面有哪些明显趋势？（3）从时空角度来看，社会转型与城市土地增长有何关系？（4）居民的社会特征如何与其对城市绿地的使用偏好和感知相关联，特别是对绿地提供的生态服务和改善这些空间的必要性的感知？

鉴于文献缺乏对中国二线城市增长过程的研究，本研究选取武汉市（中国中部的一个特大城市）作为案例，重点研究其城市发展区。社会生态方法被用于研究城市系统的多学科特征。

本论文采用文章形式，共分五章。除引言（第 1 章）和结论（第 5 章）外，主体包括三篇文章。这三篇文章对应于提出的四个研究问题。第 2 章回应了第 1 个研究问题，聚焦于城市社会景观的转型。第 3 章通过强调城市土地增长及其与社会因素的时空联系，回答第 2 和第 3 个问题。第 4 章匹配第 4 个问题，理解居民对城市绿色开敞空间的偏好和感受。

第 1 章介绍了研究背景，回顾了城市生态学的相关理论和实证研究，并评估了研究城市系统的社会-生态方法。在本章中，我们提出了改进的社会-生态系统（ISES）框架。该框架强调城市地区研究中对社会和物理子系统需进行同等权重的考察。

第 2 章（第 1 篇论文）基于 1990 年、2000 年和 2010 年的全国人口普查数据，研究武汉都市发展区（UDZ）的社会维度的渐进式转型，同时关注其空间演进。本章使用最大方差旋转主成分分析来提取社会维度并采用 ArcMap 探索空间特征。结果表明：在 1990-2010 年期间，产业升级、受教育程度提高、老龄化和人口迁移是城市社会转型的主要特征。产业转移和空间分离在 1990 年代成为主要的社会维度，但在 2000 年代更为突出，伴随着职工受教育水平的提高。老龄化人口呈现从市中心向外移转的空间特征。人口流动显著增加，移民在 2000 年代成为重要的社会维度，并呈现空间扩张。社会景观格局在不同阶段通过同心圆环和扇形团簇形态的组合形态而转变。这些转变是由区域的推拉力和城市内部的向心力和离心力综合作用形成的。我们得出结论，社会景观转型以多样性和包容性为特点。政府在初始阶段主导着社会空间转型，而市场在后期发挥着越来越大的作用。建设更加包容的社会需要不断系统地完善相关政策。

第 3 章（第 2 章论文）讨论了 1990-2010 年间城市土地的增长模式，并回答了社会因素如何与城市土地增长的模式相关联。研究基于 Landsat TM 影像与城市 V-I-W（植被-不透水面-水域）模型提取土地覆盖信息，并运用面积、斑块聚集度和形状等景观指标分析不同阶段的城市空间增长的模式。在此基础上，我们运用地理加权回归（GWR）来描述城市土地指标与社会因素之间的联系。结果表明，城市土地聚集与扩散并存，城市中心以再开发、填充、斑块边缘扩张为主，外围以扩散发展为主。城市土地面积指标（PLAND）的 GWR 模型的社会因素系数差异不显著，而城市土地斑块形状（FRAC\_AM）的模型的系数存在显著差异。城市土地增长模式涉及政府主导的建设用地供应体系、城市空间规划功能分区、以及市场作用下的社会集聚与分散。作者得出结论，城市管理应考虑不同空间增长模式的共存，并在城市土地布局中引入社会偏好等因素。这或亦可适用于其他快速城市化的地区。

第 4 章（第 3 篇论文）旨在了解社会-自然关系，重点关注社会特征如何影响居民对绿色开敞空间的偏好以及他们对生态服务和改善的看法。数据是通过在线问卷调查和访谈收集的。结果表明，不同社会群体对绿色开敞空间的偏好不同。改善绿色开敞空间的需求植根于居民对日常放松和健康益处的欣赏，并与他们访问绿地空间的偏好有关。然而，居民如何感知绿色开敞空间的福祉并不仅仅依赖于实地访问参观。与自然的互动体验和对自然发展的认知会影响对居民对日常使用和与健康相关的服务的感知。受访者对绿色开敞空间生态功能的感知与他们所报告的自然景观变化有关。对改善绿色开敞空间的反馈反映了居民对此类空间的美学和实用性的追求。虽然受访者普遍意识到绿色开敞空间的生态重要性，但他们自愿参与管理的意愿存在差异。我们的结论是，通过多种方式鼓励公众参与绿色开敞空间的配置和改善，包括考虑居民的意见，是改善社会生态关系的有效途径。

第 5 章回顾了研究的主要发现并总结升华了结论，讨论了研究的局限性以及未来的可能性。这项研究建立了城市社会和物理子系统之间的对话，并对城市化过程进行了综合的定量研究，强调了两个城市子系统之间的关系。它基于社会主义市场经济转型时期武汉城市社会景观转型和物理景观演进，提供了研究中国二线城市发展的整合的社会生态视角。研究发现，中国二线城市在 1990 年至 2010 年之间的发展具有社会维度多元化、城市空间发展多模式并存、以及城市发展中心-边缘空间分异等特点。GWR 模型呈现了社会因素与城市斑块形状规则程度之间的空间非平稳关系。对社会-自然关系的进一步考察，发现居民的社会特征和环境体验会影响他们对绿色开敞空间生态服务和改善必要性的感知。城市社会和自然系统及其关系的演变使人们越来越关注包容性社会管理、公众参与式的规划以及以人为本的社会-生态互动。本研究为中国二线城市的生长提供了建设性的反思，可作为其他快速城市化地区的参考。

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## List of Acronyms

AICc	Akaike Information Criterion
ANOVA	ANalysis Of VAriance
BCI	Biophysical Composition Index
BT images	Brightness Temperature images
BTS	Bartlett's Test of Sphericity
CBD	Central Business District
COVID-19	COronaVirus Disease 2019
DPPR	Drive-Pattern-Process-Result
FRAC_AM	Area-weighted Mean patch FRACtal dimension
GDP	Gross Domestic Product
GIS	Geographical Information Systems
GWR	Geographically Weighted Regression
IS	Impervious Surface
ISA	Impervious Surface Area
ISES framework	Improved Social-Ecological System framework
KMO test	Kaiser-Meyer-Olkin test
LPI	Largest Patch Index
MBCI	Modified Biophysical Composition Index
MNDWI	Modified Normalized Difference Water Index
OLS regression	Ordinary Least Square regression
PCA	Principal Component Analysis
PD	Patch Density
PLAND	Proportion of the LANDscape
SES	Social-Ecological system
TA	Total Area
TC components	Tasseled Cap components
TCT	Tasseled Cap Transformation
TM	Thematic Mapper
TOA	Top Of Atmosphere
UDZ	Urban Development Zone
UE framework	Urban Ecological framework

UGOS	Urban Green Open Space
USD	US Dollar
USGS	United States Geological Survey
V-I-S	Vegetation – Impervious surface – Soil
V-I-S-W	Vegetation – Impervious surface – Soil – Water area
V– I–W	Vegetated area–Impervious surface–Water area
WTO	World Trade Organization
YUAN RMB	Chinese YUAN, RenMinBi

# Chapter 1 Introduction

## 1. Context

### 1.1. China's urbanization<sup>1</sup> and urban system studies

After 1949's socialist revolution, China's first three decades were marked by centralized planning and city-based industrialization, as well as low levels of urbanization and a short-term anti-urbanization (Ma, 2002). Since the introduction of economic reform in the late 1970s, China has experienced a transitional period moving from a planned economy to a socialist market economy. During the process, China's population continues to shift residence from rural to urban area, with a proportion of urban population growing from 17.92%<sup>2</sup> in 1978 to 63.89%<sup>3</sup> in 2020, which is projected to be 75% in 2030<sup>4</sup> (Figure A1). China had an urbanization rate<sup>5</sup> of 4.13% during the 1990s and 3.93% in the 2000s, with a corresponding 153 million and 205 million net increase of urban residents respectively (Table A1). The urbanization rate of 3.18% during the 2010s coincides with urban population growth of over 240 million. The process involves social and physical landscape transformations in an urban environment.

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<sup>1</sup> UNESA, 2018. Urbanization refers to “the gradual shift in residence of the human population from rural to urban areas”. It presents a corresponding increase in the proportion of people living in the urban areas, and the living ways adaptation process. 68% of the world population is projected to live in urban areas by 2050. <https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html#:~:text=Projections%20show%20that%20urbanization%2C%20the.and%20Africa%2C%20according%20to%20a>. (Retrieved on June 15<sup>th</sup>, 2021).

<sup>2</sup> <https://www.statista.com/statistics/270162/urbanization-in-china/> (Retrieved on Mar, 20, 2021).

<sup>3</sup> Source: China's 7<sup>th</sup> national census.

<sup>4</sup> Rise of China's super cities: New era of urbanization. <http://www.morganstanley.com.au>2019-supercities>. (Retrieved on May 16, 2020).

<sup>5</sup> Rate of urbanization is defined as “the increase in the proportion of urban population over time, calculated as the rate of growth of the urban population minus that of the total population. Positive rates of urbanization result when the urban population grows at a faster rate than the total population” (UNICEF). UNICEF, 2012. <https://www.unicef.org/sowc2012/pdfs/SOWC-2012-DEFINITIONS.pdf> (Retrieved on June 15<sup>th</sup>, 2021).

Over the past 40 years of reform and opening up<sup>6</sup>, coastal cities in southeast China have risen with the development of special economic zones. During this period, affected by differences in industrialization and population migration, the spatial pattern of urban population rate transited from “high in the north and low in the south” to “high in the east and low in the west” (Li and Sun, 2020)<sup>7</sup>. The spatial heterogeneity of urbanization is outstanding. The urban population rate in many and western regions are far below the national average. In recent years, with the implementation of the strategy for the rise of the central region and the large-scale development of the western region, the process of urbanization in the central and western regions was greatly accelerated. The provincial capital cities in the central region, such as Wuhan, Zhengzhou, and Hefei have continuous growth in their population.

The number of cities with a population over 1 million or more in China increased from 18 in 1981 (the beginning of reform and opening up) to 93 in 2020<sup>8</sup>. Among them, there are 9 cities with a population of 8 million or more in 2020. The process of urbanization is not only reflected in the increase in urban population, but also in the structure of cities. Large cities attract the population from small and medium-sized cities through the agglomeration effect.

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<sup>6</sup> China's reform and opening up or economic reform is also called "Socialism with Chinese Characteristics" and "Socialist Market Economy". The reform is characterized by marketization with Chinese characteristics and has been implemented in two stages since the late 1970s. Before the reform, the Chinese economy was dominated by state ownership and central planning. The first stage of the reform, from the late 1970s to the early 1980s, focused primarily on “de-collectivization of agriculture, the opening up of the country to foreign investment and allowing entrepreneurs to start businesses”. The “privatization and outsourcing of state-owned enterprises, as well as the elimination of protectionist laws and regulations”, dominated the second stage, which took place in the late 1980s and 1990s. China became a member of the World Trade Organization (WTO) in 2001. Since then, the private economy has grown substantially. China has changed dramatically over the last 40 years as a result of economic reforms, with benefits from the rise of industry, poverty reduction, and urban growth. There are also disadvantages from environmental pollution, social inequity, and wealth disparity. Continuous reforms are aimed at solving existing social and environmental problems. (Edited based on ‘Chinese economic reform’, from [https://en.wikipedia.org/wiki/Chinese\\_economic\\_reform#](https://en.wikipedia.org/wiki/Chinese_economic_reform#), accessed on Aug. 25<sup>th</sup>, 2021)

<sup>7</sup> In 1981, there were 18 cities in China with a population of more than 1 million urban areas, of which the northern region accounted for 2/3. These cities developed during the planned economy period, represented by heavy and chemical industrial cities such as coal, steel and other heavy and chemical industries, and their distribution in Northeast and North China. After the reform and opening up, along with the establishment of special economic zones, coastal cities have gradually opened up, the household registration management system has begun to loose, and the southeast coastal cities have risen. The spatial pattern of urban population ratio has shifted from “high in the north and low in the south” to “high in the east and low in the west”. (Li and Sun, 2020)

<sup>8</sup> Source: 第一财经. 2021-04-19. 中国城区人口破百万城市达 93 个：江苏、山东占比最高. (Translation in English: China has 93 cities with a population of over one million: Jiangsu and Shandong have the highest proportions.) <https://news.sina.com.cn/c/2021-04-19/doc-ikmyaawc0628810.shtml>. ( Access on 2021-08-25)

Second-tier cities such as Hangzhou, Nanjing, Wuhan, Zhengzhou, Chengdu, and Xi'an have sustained rapid population growth in recent years. At the same time, with the development of urban railways and high-speed railways, the suburbanization and multi-centralization of the population of large cities are also worthy of attention.

Social development is accompanied with urban physical landscape evolution. China's government plays a prominent role in the rapid urbanization process, while introducing market means to improve the efficiency of urban growth and harmonizing the relationship between people and resources. Outstanding socio-economic transformations such as industrial upgrading, population migration<sup>9</sup>, education attainment increase, and population aging attract increasing academic interest (Feng et al., 2018; Wu et al., 2019; Dong and Goodburn, 2020). These changes are associated with varieties of reforms such as industry development strategy, household registration system (Hukou)<sup>10</sup>, higher education expansion, real estate marketization, urban construction land provision.

Urban growth brings with it many socio-economic benefits. However, it also results in negative ecological impacts such as social segregation, human-nature interaction decline, air pollution, urban noise, and so on. Studying the urbanization process is important for sustainable urban management, with a focus on the examination of the transitions of social-ecological relationships.

Scholars evaluate urbanization through population growth, urban land expansion, and economic growth (Van Vliet et al., 2019; Sun and Zhang, 2021) in an urban area. Most

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<sup>9</sup> In China, Internal migration is one phenomenal feature referring to the Hukou system in China. According to China National Census in 1982, 1990, 2000, and 2010, the migrant worker population is 6.6 million, 21.3 million, 121 million, and 221 million respectively. From 1990 to 2019, the migrant workers increased from 21.3 million up to 291 million. In 2019, 34% of the migrants were intra-provincial and 40% inter-provincial. (China labor bulletin. Migrant workers and their children. (May-11, 2020). <https://clb.org.hk/content/migrant-workers-and-their-children>. Retrieved on Feb. 12, 2021).

<sup>10</sup> China established its household registration (Hukou) system in 1958, classifying citizens as urban Hukou or rural Hukou residents. Initially, Hukou is a measure to control population mobility. After the reforms in the late 1970s, Hukou has been gradually loosened allowing rural migrant workers to inflow into cities to work. Rural Hukou residents and urban Hukou ones have different accessibility to public services such as subsidized housing, education, job opportunity, etc. (Chan, 2010).

literature explores how social-economic growth drives urban expansion, or how urban spatial growth results in ecological impacts or risks.

To better understand the urban system, a comprehensive point of view is needed. Researchers tend to equally treat social and physical subsystems in an urban area, with the proposal of social-ecological approaches based on the theory of urban ecology (Endlicher et al., 2007; Alberti, 2008; Marzluff et al., 2008; Ostrom's, 2009; Alberti et al., 2011; Barot et al., 2019). This approach interprets the urban ecosystem as separate social and physical subsystems that interact with each other. It covers both two subsystems and their relationships within an urban system. But with this methodology how to equally assess social and physical subsystems in their relationships is still not addressed. And meanwhile, the existing literature seldom examines an urban system in China comprehensively through a social-ecological perspective.

Usually, Chinese cities are divided into multiple tiers.<sup>11</sup> Tier-1 cities such as Beijing, Shanghai, and Guangzhou have been developed ahead as peer cities providing examples to other locales (Lu et al., 2019; Garriga et al., 2020). Current literature features a focus on the first-tier cities rather than on the lower-tier ones. However, Tier-2 cities<sup>12</sup> have some special development paths, showing the academic and practical value for exploring the processes. It is important to find the common laws or differences between separate tier cities which may provide a reference for other lower-tier regions' urbanization management.

Wuhan, central China's mega-city, is one of the most second-tier cities. Wuhan is positioned as a national center, a transportation hub nationally and regionally. Wuhan's

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<sup>11</sup> These are the tiers that more well-known Chinese cities fall under: Tier 1: direct-administrative municipalities, including Beijing, Shanghai, Guangzhou and Shenzhen. Tier 2: provincial capital cities and sub-provincial capital cities, such as Chengdu, Nanjing, Hangzhou, Xi'an, Wuhan, Harbin, etc. Tier 3: Mainly prefectural capitals and county level cities such as Wenzhou, Guilin, Dongguan, Hohhot, etc.

<sup>12</sup> Source: 前瞻产业研究院. 2020年中国新一线城市对比报告 (Translation in English: 2020 China's new first-tier cities comparison report). [http://pg.jrj.com.cn/acc/Res/CN\\_RES/INDUS/2020/3/30/ee34dc8f-aca3-44b5-b4fc-c2542cf27183.pdf](http://pg.jrj.com.cn/acc/Res/CN_RES/INDUS/2020/3/30/ee34dc8f-aca3-44b5-b4fc-c2542cf27183.pdf). Retrieved on Oct. 15, 2020. This report named the fastest-growing second-tier cities as the new first-tier cities. The top fifteen new first-tier cities are constantly changing. In 2019, these cities included Chengdu, Hangzhou, Chongqing, Wuhan, Xi'an, Suzhou, Tianjin, Nanjing, Changsha, Zhengzhou, Dongguan, Qingdao, Shenyang, Ningbo, and Kunming. Between 2013 and 2018, Zhengzhou, Dalian, Xiamen, Suzhou, Jinan, and Wuxi were among the 15 new first-tier cities in different years.

population reached over 11.08 million in 2018, up from 6.90 million in 1990, representing an increase of 5.18 million. In 2019, the city reached an incoming population<sup>13</sup> of 2.87 million. Wuhan has been in a stage of rapid urbanization. Thus, an examination of the urban system transformation and the social-physical relationships is very essential. However, the current literature only offers a biased view of Wuhan, focusing primarily on urban land expansion and related simulation, but less on social transformation and its relationships to urban spatial evolution (Liu et al., 2020; Yang et al., 2020a; Liang et al., 2021).

This thesis research aims to visualize China's urbanization process and spatial heterogeneity. Considering that most literature retains a bias on either social or physical components, in this research we pay equal attention to the social transformations and physical landscape changes as well as their relationships. The study is with an improved social-ecological system (ISES) framework, exploring the social relationships with urban land and green space respectively. The study expects to provide constructive rethinking of China's urbanization and to suggest a perspective for policy making to achieve sustainable development.

## **1.2. Thesis organization**

The thesis is organized into five chapters. Besides the introduction (Chapter 1) and conclusion (Chapter 5), there are three chapters offered in the main body. Chapter 2 presents a study on urban social landscape transformation based on census data; Chapter 3 focuses on urban physical landscape evolution based on Landsat images and the relationships with social factors extracted in Chapter 2, and Chapter 4 explores social-natural relationships based on data extracted from questionnaires and interviews.

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<sup>13</sup> Incoming population (also called inflow population, influx population) refers to the non-registered population who reside in this area. The population who has left the place of household registration to live in other regions is referred to as the 'floating population', which include inflow population and outflow population. Outflow population refers to the registered population who left this area registered to live in other places.

## **2. Literature review**

This research seeks to examine the urbanization process based on urban ecology theory and a social-ecological approach. The literature review covers the historical pathways of the theory and the methods, as well as the empirical application of a social ecological approach in an urban system.

### **2.1. Study of urban system from natural and social perspectives**

In recent decades, there has been a pronounced increase in agreement that the urban system is an integrated domain involving both humans and their living urbanizing environment (Alberti, 2008; Tan et al., 2020). Humans, the living environment, and the relationships between the two make up the three key elements in an urban system. In this case, humans are dominant actors, and the physical landscape is an objective display. As a science, urban ecology was formally defined in the ecological studies in the early 1970s (Veg, 2010), as an interdisciplinary theory aiming to understand how human and ecological processes coexist in human-dominated systems and help societies to become more sustainable (Marzluff, J. et al., 2008; McPhearson et al., 2016).

Urban ecology has been previously regarded as a sub-discipline of biology and ecology, which is rooted in the study of the nature of cities and employed to address biological patterns and the consequent environmental processes in urban areas (Park et al., 1925; Endlicher et al., 2007; Verma et al., 2020). Since urban systems are created by humans, there is growing interest in how the biophysical processes are influenced. With a focus on the biophysical subsystem, socio-economic components are understood as influential factors of physical environmental changes, while economic drivers are biased compared to social ones. In this domain, research focuses on biophysical structures, interrelationships between different components, and the evolution process.

Social characteristics and transformations in cities are equivalent-weight components as physical ones. In terms of human intervention in an urban system, the biophysical focus could not meet the demands of urban ecosystem research (Pickett et al., 1997). Social ecology thus defines urban ecology from an anthropocentric perspective, applying natural ecological concepts to the theory of human behavior (Endlicher et al., 2007). This forms the foundation of the growing research focusing on social processes and complexities in an urban system. Contemporary literature examines social structures, transitions, and impacts to provide information for social sustainability. Population migration, social gentrification, social segregation, etc. are widely involved in urban social studies (Ergenc and Altun, 2020). By projecting the social dimensions on physical landscapes, the urban mosaic is proposed with integrating social layouts over urban land. Meanwhile, academic interests in the social impacts of natural ecology are growing (Wolch et al., 2014).

Along with increasing interest in the spatiotemporal transformations of urban growth processes and patterns, extended research relates to the corresponding ecological services or impacts (Costanza et al., 1997). Ecosystem goods and services are other perspectives, pertaining to the users, to dissect the urban physical subsystem. Academics explore common laws or differences for ecological consequences related to biophysical processes, natural space losses, energy consumptions, city efficiency, and so on, with a comparison between different cases (Zhao et al., 2006; Song et al., 2015; Li et al., 2017; Zhang et al., 2017b; Mao et al., 2018). Local studies usually concentrate on people's demands, preferences, or perceptions toward natural spaces (Riechers et al., 2016). This reflects a perspective concerning the social involvement in urban ecological management.

Biophysical ecology and sociology provide different perspectives to examine the structure, transition, and cycle of the urban system. However, both their approaches are biased and lack a comprehensive understanding of the urban system by choosing to favor either the natural or

human subsystem (McIntyre et al., 2008; Forman, 2016). To better understand the complexities of the urban system, human and ecology subsystems should be equally assessed. This requires an integrated social-ecological approach, which offers an equivalent examination for both the physical and social subsystems in an urban context (Han, 2012; Colding and Barthel, 2019).

## **2.2. Social-ecological approach to an urban system**

### **2.2.1. Theoretical development of social ecology**

A social-ecological study employs interdisciplinary approaches to examine the urbanization process, pattern, and impacts from multiple dimensions, understanding the urban system from an integrated perspective. This approach is rooted in the urban ecology theory. “Ecology in cities,” “ecology of cities,” and “ecology for cities” define the urban ecology approach from various perspectives in different stages (Wu et al., 2013; McPhearson et al., 2016; Pickett et al., 2016). The social-ecological approach belongs to the ecology of cities, which examines cities as an ecosystem composed of the interactions between human and natural subsystems. Approaches within urban ecology have consisted of different focuses, leading to biophysical bias and sociology bias (Figure 1). “Ecology in cities” is an applicable approach developed from the biophysical ecology in urban areas, and “ecology for cities” emphasizes the planning, management, or technology of urban areas, as compared to “ecology in/of cities” (McPhearson et al., 2016). Some scholars combine urban sustainability with the “ecology for cities” approach (Childers et al., 2015; Pickett et al., 2016). This study adopts the “ecology of cities” approach, considering the urban system as a complicated ecosystem interacted by human and natural subsystems while quantifying the interactions.

This temporal view presents a conceptual track with ecology in, of, and for cities (Figure 1). The concept of “ecology in cities” was rooted in the early 1900s. At first, there was emphasis on biophysical ecology, which is strongly biased to observe natural subsystems. The “ecology

	Ecology in cities	Ecology of cities					Ecology for cities
2010s						Integrated urban social ecology	Emphasizing actions with focus on engineering, technology, etc. to sustainability.
2000s						<b>The Baltimore School</b>	
1990s						ecosystem services	
1980s						<b>Los Angeles School</b> Landscape ecology	
1970s						University-based integrated programs <b>Urban Ecology</b>	
1960s			Factorial social ecology	Urban mosaic			
1950s		<b>The New York School</b>	Social Area Analysis				
1940s		<b>The Chicago School</b>					
1930s							
1920s							
1910s	Biophysical ecology						
1900s							
	<b>Bio-physical ecology</b>	<b>Urban sociology</b>	<b>Quantitative analysis of urban society</b>	<b>Social factorial ecology and application</b>	<b>Apply social-ecological vision into urban study</b>	<b>Integrating human and natural subsystems</b>	
<b>Urban ecology with the development from bias toward integration</b>							

**Figure 1** Development of urban ecology study

(adapted from Wu et al., 2013; McPhearson et al., 2016)

for cities” was formed during the recent decades. “Ecology of cities” reflects the mainstream recognition of urban systems as well as the research approach. It has developed in phases, from the initiation of urban sociology as remarked by the Chicago School to the introduction of

human ecology into natural ecology, to the integration of both social and natural subsystems, followed by the New York School and Los Angeles School.

The Chicago School of Urban Sociology combined the concept and laws of plant and animal competition and adaptation processes with urban societal development. It borrowed the concepts of physical ecology such as “succession, competition, and metabolism” to clarify the mechanisms of urban social structural transition (Park et al, 1925; Grove, 1997). The goal of the Chicago School is to study the transformations and conceptualization of urban sociology, represented by three typical models: concentric zone model (Burgess, 1925), sector model (Hoyt, 1939), and multiple nuclei model (Harris and Ullman, 1945). The models offer researchers different spatial perspectives for studying urban ecology, focusing on a transect comparison between different zones. For example, placing an emphasis on central urban and periphery, comparing different zones divided by the linear infrastructure such as road and river systems.

Nevertheless, the Chicago School has also received some criticism (Hawley 1986). For example, some scholars utilizing this approach prefer to emphasize the stratification of commercial functions in residential areas, or the decisive significance of commercial functions on the scale of residential areas, but ignore individual and family behaviors. The Chicago School also emphasizes the competitive relationship between communities, while relatively neglecting positive social interaction, tolerance, and compromise.

The cases of New York, Los Angeles, and Baltimore have left impressive footprints with various perspectives on urban growth (Pickett, 2015). The former two are from the perspective of urban sociology. The Baltimore School is more inclined to the view of natural ecology while also considering social factors as driving forces. The New York School emphasizes central business district (CBD) the most productive area, while the Los Angeles School focuses on urban sprawl, with high-tech industry as the main drivers of urban social structure development

(Gottdiener, 2002). The New York and Los Angeles cases are concerned with urban societies' structural changes, with attention to the social impacts caused by the development of the central business district and high-tech industries, respectively. The Baltimore School proposed a comprehensive social-ecological view to adapt the complexity of urbanization study (Grove et al., 2015; Pickett et al., 2008). It aims to understand the urban system from an integrated social-ecological perspective, giving equal weight to the study of social and physical subsystems. "Spatial, temporal and organizational integration"<sup>14</sup> is the key focus of the Baltimore School (Pickett, 2015).

When using a social-ecological approach, the complex interrelationship of social and physical systems is a focal point. The study of urban ecology has developed through recognizing humans as a user/driver which plays an interactive role alongside nature. Meanwhile, interrelations among the components within both social and physical subsystems are recognized in the process of urban growth. However, there is still room for improvement for researchers to better present the social-ecological approach conceptually and quantitatively.

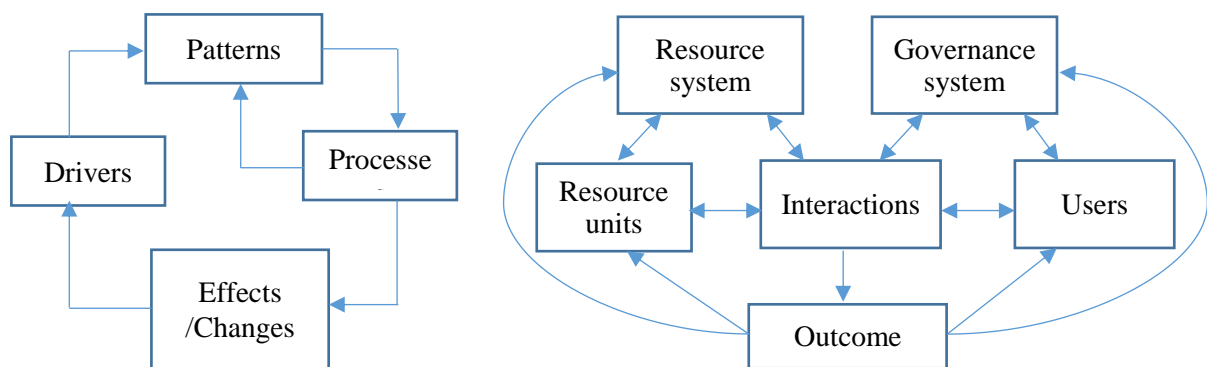
In summary, the development of schools of urban ecology presents a path from introducing the biophysical concept into urban social subsystem study to urban sociology aiming to deconstruct social evolution, and further to treat social and physical subsystems with equal weight. The move to quantify social and ecological processes with the spatial approach, which is one of the key points of social-ecological studies, is now attracting increased research interest as it holds much room for further advances.

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<sup>14</sup> The spatial mosaic of social and physical subsystems should be examined to understand the interrelationships between different components which influence urbanization processes. The longitudinal perspective provides historical experience and knowledge that similar development could learn from. Organizational complexity refers to the decisions and behaviors at different levels such as individual, household, community, governance levels (Pickett, 2015).

### 2.2.2. Social-ecological framework

With the consensus that the urban system is a complex domain of natural and societal subsystems dominated by humans, scientists are increasingly interested in understanding the relationships between humans and nature within an integrated perspective (Alberti et al., 2011, Binder, 2013; McGinnis and Ostrom, 2014; Andersson et al., 2021). Alberti et al. (2003) initiated an urban ecological (UE) framework and Marzluff et al. (2008) proposed an updated version. Later Ostrom (2009) published a social-ecological system (SES) framework. Both the UE and the SES frameworks focused on the interactions between social and natural subsystems with the consideration of social and ecological subsystems. The UE framework emphasizes the characteristics of the urban ecosystem, diagnosing the interactions between urban social and physical subsystems as flow of Drive-Pattern-Process-Result (DPPR) (Figure 2a). The UE framework is an ecological-biased approach that emphasizes urban patterns driven by socio-economic forces, processes, and results. Ostrom’s (2009) SES framework emphasizes the interactions between users and natural resources, with the equal weights of social and physical subsystems (Figure 2b).



a) UE (DPPR) framework (Marzluff et al., 2008)

b) SES framework (Ostrom, 2009)

**Figure 2** UE (DPPR) and SES frameworks published

These interactions play roles in both the social and resource system. The SES framework aims to analyze the “mechanisms” of the potential loss of natural resources such as fisheries, forests, and water, which is especially valuable for natural-resources-dependent regions or ecosystems (Ostrom, 2009). The UE framework emphasizes the spiral growth of urban forms based on the flow of DPPR, with bias on the physical subsystems recognizing humans as drivers, whereas the SES framework stresses the equal importance of ecology (resources) and the human (users and governors), as well their interactions, with underlining how the growth process is presented on and reflected by the interactions within components of the urban systems.

Both UE (DPPR) and SES frameworks emphasize the relationships between humans and nature in an urban area. The UE (DPPR) framework examines the explanatory relationships between society and nature, while the SES framework focuses on the reciprocal interactions between social and natural subsystems based on the equal weight on both.

### **2.2.3. Theoretical study in China’s cities**

Chinese scholars have shown a strong interest in studying urban ecology since the 1980s. Wu et al. (2014) summarize the development as three periods: “the emergent period (1983–1989), the early growth period (1990–1999), and the rapid development period (2000–present)”.

During the 1980s, Chinese scholars started to introduce western countries’ urban ecology theories and approaches. At the start of the 1980s, Xue (1980) introduced classical urban forms proposed in sociology based on the study of German cities. Later on, Dong (1982) introduced urban study views from Europe, USA, and Japan, while Song (1983) concentrated on European experiences of urban ecology study. Ma and Wang (1984) improved the definition of an urban system as a socio-economic-natural complex, based on the work of Odum (1983). Research on China’s urban ecology in this stage focuses more on natural subsystems belonging to biology domains. Related to urban sociology, China’s scholars started to conduct empirical studies on

specific cases such as Beijing (Xu et al., 1989), applying a practical application of factorial analysis. In this stage, related research in China mainly focus on the introduction of theories and empirical application of approaches which had already been adopted during the study of cities located in western countries.

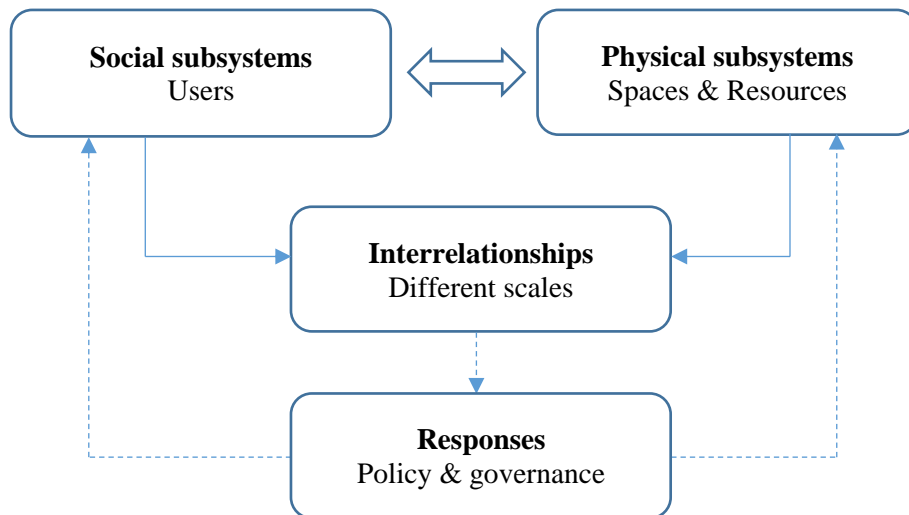
During the 1990s, landscape ecology, as an important subfield of urban ecology, focused on urban environmental problems and eco-city planning. Its combination with remote sensing and GIS attracted a wider range of researchers. In the sociological study, more of China's cases such as Beijing, Nanjing, Guangzhou featured empirical application of factorial analysis (Gu and Kesteloot, 1997; Zhou et al., 1998).

Since the 2000s, urban ecology studies have shown concerns for the environmental impacts of urbanization by focusing their assessment on the consequences and planning solutions. A selection of studies begin to move towards urban growth modelling, ecosystem services of natural spaces in an urban area, and urban sustainability assessment. Meanwhile, more scholars revisit and open new cases of factorial analysis in order to explore urban landscape transformations (Gu and Shen, 2003; Li et al., 2008; Zhou and Ye, 2013; Han, 2012; Liu and Cao, 2017). These developments of research focus indicate that urban ecology studies in China are mainly oriented by practical sustainable urbanization. This field is based on the introduction of theory from Europe and North America, with practical improvement when applied to Chinese cities. Urban ecology studies cover natural environment, urban land growth, and social areas. But the existing literature shows a substantial bias to center on physical landscape detection rather than the social one, and solutions are therefore concentrated on the environmental or ecological problems which urbanization has induced. From this perspective, China's urban ecology research draws on relevant theories from high-income countries. Considering the regional characteristics of urbanization and its mechanisms, further empirical

research is needed to extract the uniqueness of the social-ecological relationship of Chinese cities.

#### 2.2.4. Improved social-ecological system (ISES) framework

We propose an Improved Social-Ecological System (ISES) framework (Figure 3) based on Marzluff et al.'s (2008) and Ostrom's (2009) studies.



**Figure 3** Improved social-ecological system (ISES) framework

(Adapted from Ostrom, 2009; Marzluff et al., 2008; Alberti et al., 2003)

The ISES framework highlights the equal weight of urban social and physical subsystems while emphasizing the interrelationships between both at different scales in spatial, temporal, and organizational forms. The response toward policy and governance adaptation is the result of social-physical interrelationships. However, policy and governance can also act as drivers to initiate a social or physical transformation. The adapted framework features urban ecosystems with the identification of social components (users) and physical components (resources and spaces). Social subsystems refer to different stakeholders (e.g., natural resource users, or beneficiaries), with the interactions among social components. Physical subsystems refer to urban spaces and natural resources which provide ecological goods and services. The interrelationships between urban social and physical subsystems are complicated at

hierarchical levels, such as individual, community, and societal levels: the links connecting them respond in related urban policies and governance, which then play roles in affecting urban social and physical landscapes to develop into a further status.

Due to the barrier between different disciplines, the application of the social-ecological approach is still a challenging task. The variables for this approach vary depending on the field. The ISES framework delineates the boundaries and variables of the urban social and physical subsystems. Urban social subsystems are quantified using the indexes referring to demographics, ages, migration, household type, education, employment, housing, etc. The “users,” a broad term, represents different stakeholders or beneficiaries within an urban ecosystem. Urban physical subsystems are defined by the interrelationships among urban land and the biophysical environment, while the natural landscape contains green space and wetland, serving urban dwellers with ecological and spiritual benefits. Urban physical subsystems are thus defined as the landscape for enhancing urban dwellers’ living quality. The interrelationships between urban social and physical subsystems are nested in hierarchical levels, including individual, community, and societal levels. Different users (e.g., stakeholders, beneficiaries) have a variety of perceptions and preferences toward physical landscape heterogeneities and dynamics. Physical landscape dynamics indicate the presence of interactions within the physical subsystem as well as with social subsystems. The relationships further result in response to urban policies and governance, which influence the urban social and physical landscape to develop into an additional status.

### **2.3. Empirical studies**

As outlined in the ISES framework, the empirical review focuses on literature that quantifies urban growth through the relationship between social and physical landscapes.

### **2.3.1. Social subsystem study**

Since the advent of urban sociology in the 1920s, research on quantifying social transformations in an urban area has increasingly received greater attention over time. Beginning in the 1950s, quantitative and spatial approaches evolved by incorporating factorial analysis with spatial analysis tools in social-ecology studies. Shevky and Bell (1955) introduce social area analysis when they combine factorial analysis with spatial displaying in a metropolitan region of the San Francisco Bay Area. In the 1960s, the term “factorial ecology” was proposed (Sweetser, 1965). At that time, factorial social ecology developed through urban case studies in North American and European cities. These studies revealed the urban social-spatial structure and improved approaches in urban ecology. Shevky and Bell (1955) quantify urban societies using indicators of three dimensions of urban structure: “socioeconomic status (economic status or social rank), family status (familism or stage in life-cycle), and ethnic status (ethnic or minority groups)”. Murdie (1969) proposes the mosaic model for the urban ecological structure, organizing the urban ecological structure as mosaics of social layers and physical status. Murdie’s (1969) urban mosaic model indicates that the social-spatial patterns of three dimensions (economic, family, and ethnic status) carry distinct associations with the classical urban land-use models. Economic status relates to the multiple nuclei model, while family status corresponds with the concentric model and ethnic status relates to the sectoral model. The social area analysis allows quantitative thoughts about urban social dimensions and their spatial features, while the urban mosaic model presents conceptual patterns mapping the urban social mosaic onto the physical landscape. The critics of the factorial ecological approach and the urban mosaic model (Rees, 1971; Hunter, 1972) mainly assert that (1) the approach is too simple to measure such complexities wherever an urban system belongs; (2) it ignores the complicated human subjective characteristics such as self-learning and the ability to adjust ; and (3) the approach only concerns social structural dynamics based on the interactions within

social systems, taking natural systems as the context, without further exploration of quantification of the reciprocal relationships between social and natural systems.

The increasing complexity of urban development determines that the factorial approach should be further explored. Upon the traditional social dimensions concluded by Shevky and Bell (1955) and Murdie (1969), scholars have explored other indicators in an urban area. For example, Herbert (1967) adds the dimension of technology and new industrial development in the study of San Francisco; other scholars examine indicators such as gender, age, population density, and housing vacancy rates when studying North American and European cities (Herbert, 1967; Heins, 1972). During the same periods, behavior indicators have also been introduced into the urban social ecological study (Thernstrom, 1964). Since the early 1980s, the spatial analysis approach has been utilized to illustrate social landscape during different periods (Hunter and Baumer, 1982; Davies and Murdie, 1991; Dempsey et al., 2011). Many other significant factors referring to both social and physical aspects, such as population migration, new occupations, social inequalities, and urban growth patterns, are considered with the neo-economic development (Knox and Pinch, 2010; Mergener and Maier, 2019).

Since the 1990s, factorial ecology has been popularly revisited in cities of high-income countries, like Sydney, Australia (Flood, 2000), Canadian metropolitan areas (Townsend and Walker, 2002), Hamburg, Germany (Meyer, 2003), and Baltimore, U.S.A. (Grove et al., 2006). During the 2000s, mapping of the social areas became an interesting field of related research (Wyly, 2007; Spielman and Thill, 2008; Ball and Petsimeris, 2010). Another emerging trend is to integrate social transformations with landscape ecology, to fully understand urban ecosystems (McPhearson et al., 2016; Pickett et al., 2020).

Regarding scholastic endeavors to China's cities, the first wave of factorial social ecological research appeared in the 1980s and 1990s, mainly in Beijing, Nanjing and Guangzhou (Xu et al., 1989; Yeh et al., 1995; Gu and Kestellot, 1997), which have again been

revisited in the 2000s (Gu and Shen, 2003; Zhou et al., 2006; Han, 2012). However, research on specific cities is very limited and cannot meet the needs of the emerging development of China's second-tier cities.

Social features vary throughout development stages. For example, the factorial ecology of Western cities is more concerned with “urban restructuring” (Thörn, 2012), “urban segregation” (Musterd and Ostendorf, 2013), and suburbanization along with post-industrialization (Davidson and Wyly, 2012), while the study of developing regions focuses more on internal migration from rural to urban, developing industry, and social equity (Li et al., 2013; Magnani and Zhu, 2015). Revisiting factorial social ecology not only demonstrates the suitability of the approach but also reveals the urban social transformations during a specific period. It is particularly essential in emerging and rapidly urbanizing countries or regions, where the urban social landscape has undergone remarkable changes in recent decades and the data can support deeper exploration and visualized presentation.

### **2.3.2. Physical subsystem study**

Land coverage refers to “the observed physical and biological cover of the Earth’s surface,” which is a proxy of the physical ecosystem and landscape (UNSD, 2005). The remote sensing data is used for land cover extraction and landscape heterogeneity analysis, with the utility of geographical information systems (GIS). The classification of land cover, to a great extent, is constrained by the resolution of the remote sensing images. Land cover and landscape heterogeneity dynamics are of great concern to planners and policymakers (Ganasri et al., 2013; Zhou et al., 2017). To examine the urban system process, different urban land models are proposed according to land coverage status quo and research objectives, for example V-I-S (vegetation – impervious surface – soil) and V-I-S-W (vegetation – impervious surface – soil – water) models (Ridd, 1995; Aina et al., 2019).

As indicated by the models, the impervious surface is the element of urban space, while the natural subsystem mainly refers to vegetation area, soil, and wetland. Urbanization characterizes diversely in different socio-economic stages, thus researchers focus on distinct features of urban land growth in dissimilar-income countries and regions. Urban sprawl and shrinkage in high-income countries and regions have been attracting research interests over the past decades, so do urban expansion in middle- and low-income countries (Wiechmann and Pallagst, 2012; Chen et al., 2016; Reis et al., 2016; Wolff and Wiechmann, 2018). Scholars pay particular attention to the interrelationships between different classes of urban landscapes, especially how urban growth impacts green spaces such as parks or gardens, which are closely associated to residents' life quality, and how urban expansion causes losses of high-quality agro-land (Song et al., 2015). In this case, urban land, being recognized as dominated land use, is considered as a direct force of the natural landscape. Besides, it is understood that urban growth causes ecological impacts on goods and services provided by the natural system of green and open spaces (Nor et al., 2017).

Literature in this field analyzes urban landscape structure and distribution using metrics referring to the area, density, shapes, aggregation, division, and connectivity, while some examine urban spatial growth patterns and related ecological impacts based on the metrics (Aguilera et al., 2011; Bosch et al., 2020). Some metrics have strong linear correlations. Thus, it is necessary to screen metrics when using them to explore urban land patterns. Literature concentrating on urban growth presents a strong interest in urban growth mode and the corresponding ecological benefits and impacts (Schneider and Woodcock, 2008). For example, urban coalescence and diffusion, or infilling, expansion, and sprawl, are popular terms applied to urban growth modes description (Estoque and Murayama, 2015; Meng et al., 2020). The urban growth modes are theoretically initiated based on urban cases in high-income countries and widely applied. However, in the emerging rapidly urbanizing countries and regions, it is

essential to study more cases to explain their uniqueness and provide a reference for constructing the urban growth modes. Furthermore, researchers are interested in explaining the modes with different perspectives such as space provision, industrial development, project-oriented, life-cost-oriented, etc. (Liu et al., 2019). In this domain, economic and market forces are widely considered in urban growth studies, whereas social transformations are less likely to be examined, even though it is the inherited components of the human subsystem that should be equally assessed in a social-ecological system.

When urban land growth is widely considered as a dominant domain in urban studies, the transitions of the natural subsystems are weighted the same (Sadler et al., 2010). Physical landscape refers to different classes of land coverage. Impervious surface and natural landscape influence each other in spatial distribution. From a biological view, green networks are vessels of the urban system while bodies of water are the lungs, which indicates the ecological significance of the natural resources and spaces. The distribution and richness of vegetation space and wetland in an urban area, as the core of the natural subsystem providing life-related ecological services, attract increasing academic interests (Belmeziti et al., 2018; Vidal et al., 2020). Ecological products and goods provision are determined by the richness of those resources and their spatial distribution, which benefit the public while balancing society and nature (Palliwoda et al., 2020). Researchers care about how residents enjoy the benefits of green open spaces as well as how they perceive the qualities of those areas, with a focus on specific urban parks or gardens (Chen et al., 2009). In high-income countries, the preference-, cognition-, and feeling-related study are earlier than that in China. This is linked to the theory of Maslow's hierarchy of needs<sup>15</sup>, which asserts that the spiritual need of people will arise to a

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<sup>15</sup> Maslow's hierarchy of needs divides human's needs into five hierarchies (Maslow, 1943; 1945). The model depicts human needs in a hierarchy, in which the lower-tier needs should be satisfied before individuals are motivated to attend to the higher-tier needs. From the bottom toward the upper tiers, the needs are physiological, safety, love and belongingness, esteem and self-actualization. The order is not rigid. In the updated model, cognitive and aesthetic needs are included (Maslow, 1954) and later transcendence needs (Maslow, 1994).

higher level when the material provisions reach certain levels (Koltko-Rivera, 2006; Abulof, 2017). In recent years, with the advancement of the "people-oriented" development model<sup>16</sup>, in China, the experiences of residents in the urban green infrastructure have attracted remarkable attention from the academic community (Chen, 2015; Kothencz et al., 2017). Yet this focus is typically geared towards specific parks or greenways, while there is rarely a broader spatial view applied.

### **2.3.3. Relationships study**

Interactions between social and physical landscapes are presented in distinct aspects. To comprehensively understand it, this literature splits its focus on the impervious surface (urban land) and natural spaces (green and open spaces) respectively. Studies on urban spatial growth are interested in how urban spatial evolution affects natural open spaces transformation and how socioeconomic factors drive physical evolution (Nor et al., 2017; Wu et al., 2019), while the literature on green and open spaces explores how humans prefer to enjoy those spaces and how the services are perceived (Farahani and Maller, 2019; Gozalo et al., 2019). How the two aspects complement each other is what comprises the comprehensive understanding of social-physical relationships.

With regards to the urban physical landscape, scholars who study impervious surface expansion and natural spatial evolution often do so by focusing on the roles of socioeconomic drivers (Li et al., 2017). They also examine population migration and clustering based on urban spatial planning and development (Lin et al., 2020). Literature commonly recognizes that socioeconomic development drives urban growth (Zhai et al., 2020), but few aim to explain the relationships between social development and urban growth patterns. On the other hand,

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<sup>16</sup> "Since the 18th National Congress of the CPC in 2012, a people-oriented development philosophy has been promoted with the stress on how to improve people's livelihoods, while not to let any person be left behind in the efforts to build a well-off society in an all-around way." [https://www.chinadaily.com.cn/kindle/2017-08/10/content\\_30417521.htm](https://www.chinadaily.com.cn/kindle/2017-08/10/content_30417521.htm) (Retrieved on Feb. 20<sup>th</sup>, 2020)

while ‘global’ regression is widely adopted to model urban growth (Luo et al., 2019; Shu et al., 2017), few consider a ‘local’ regression that investigates the spatial non-stationary of the relationships. In recent years, the ‘local’ spatial statistical approach is increasingly employed to model the relationships, for which Geographically Weighted Regression (GWR) is widely adopted. Literature detects the relationships between social and ecological subsystems with GWR, from varied perspectives, such as illustrating urban growth using socioeconomic variables (Manganelli et al., 2016), analyzing urban expansion using indicators referring to linear infrastructure, housing environment, and investment potential (Mondal et al., 2015). Research affirms that specific socio-economic factors could explain the urban spatial evolution. Some academics in this field demonstrate that land cover could illustrate specific socioeconomic phenomena through studies of relationships between the natural landscape and housing prices (Irwin et al., 2014), between residential segregation and tree canopy (Locke et al., 2021).

As the natural components of physical subsystems, vegetation space and wetlands are closely connected to human preferences in an urban area. Investigation of human-nature relationships could provide valuable information to further interpret the relationships between physical and social subsystems. Predominantly the literature which analyzes socioeconomic factors influencing accessibility to urban public green spaces are based on the diagnosis of the distribution of this public open space, and present their findings as offering a basis for land use planning (Kim and Nicholls, 2016; Li and Liu, 2016). Also, these scholars emphasize how residents’ lives are correlated with the vegetation areas and show how they perceive the improvement of those spaces, with a focus on specific green parks or wetlands and further deduct the findings’ illustration on planning and management to a regional level (Kothencz et al., 2017). However, less studies attempt the exploration of the social relationships with both preferences and perceptions, directly at a city level.

What is worthy of recognition is that many studies have endeavored to explain urban land cover heterogeneities and dynamics with the socio-economic viewpoint or to interpret social phenomena from a physical landscape point of view. Related research contributes to quantifying the relationships between urban social and physical subsystems. However, due to the bias from different disciplines or perspectives, few studies thus far have sought to understand the relationships based on a comprehensive examination of both social and physical development. Measuring and visualizing the relationships is still challenging.

#### **2.4. Chinese cities' study: The progresses and limitations**

As the most rapidly urbanizing country in the world, scholars have become attracted to China's urbanization process (Guan et al., 2018; Buckingham and Chan, 2018), to obtain referential experiences and knowledge. Since the launch of the economic reform, China has experienced the first wave of urbanization among its coastal cities as well as in the first-tier cities (Han and Wang, 2013). During this period, the economic development zones have created vast employment opportunities which have attracted floating workers who are supported by the reform of China's household registration system (Gu et al., 2020). Since the 1990s, along with the overall promotion of marketization in a variety of fields that are closely related to people's lives, the lower-tier cities, and the hinterland cities have been emerging with their gradually remarkable urbanizing process. This process has been reflected in social and economic spheres, the development of urban space, and management of natural landscape (Zou and Zhao, 2018).

To examine the urbanization process, literature usually concentrates on one aspect such as demographics, economics, or urban space and landscape (Lin et al., 2018; Lin et al., 2020; Song et al., 2021). The focus depends on the priority of a researcher's main discipline. Literature on interactions in the social subsystem looks at the polarization between the income of different social groups, or residential segregation between local and influx populations (Gu,

2001; Roitman et al., 2017; Ahmed et al., 2020). Studies on interactions in the physical subsystems focus on evaluating the impacts of urban expansion on natural spaces and resource losses (Zhao et al., 2006; Zhou et al., 2018). Since the late 1980s, scholars have studied and revisited the static spatial distribution of social areas in cities such as Beijing, Nanjing, and Guangzhou (Han, 2012; Cai et al., 2020; Shi and Dorling, 2020; Yang et al., 2020b). However, research on the dynamics of urban social landscape transformation has chiefly been conducted on just a few cities (Liu and Cao, 2017).

When examining the connection between human and natural subsystems, economic and population density are the focus of human subsystems, while urban expansion and landscape heterogeneity are that of physical subsystems. Most literature recognizes the human-dominated socio-economic factors as pivotal drivers for urban expansion and physical landscape evolution, in which domain, population density is underlined (Liu et al., 2005; Chen et al., 2014). Few studies examine urbanization processes through investment increases in industrial parks as well as the implementation of population attractive policies referring to household registration and housing.

Studies of an urban system complex require a multidisciplinary framework/approach in order to better integrate all of the active features. With a social-ecological approach, one should examine an urban system from varieties of perspectives including social and physical, and also take care to evaluate their interrelationships. Though the social-ecological approach is widely adopted by scholars (Andersson et al., 2021), urban studies are still constrained by disciplines with social or physical bias. From a social-ecological perspective, few of China's cities have been comprehensively examined over the past few decades.

Several mismatches are found when comparing the literature to an ideal social-ecological study on Chinese cities. The first is the data resolution mismatch. Most of the time, researchers could collect fine resolution data for urban land cover, benefiting from big data. However, they

hardly obtain the fine resolution data sets for social development, which is limited by statistics or census. The study of the relationship between physical and social subsystems then becomes constrained by the resolution mismatch. The second mismatch is between ‘global’ regression modeling of the relationships in literature and the relationships’ spatial non-stationarity. Thus, ‘local’ regression should be considered to fit the demand. The third mismatch is between the static relationships study and demand of spatio-temporal transformations of those relationships. This mismatch may be due to the constraints of available data. The fourth mismatch is between focus on specific cases and the demand to centralize on the emerging, rapidly urbanizing areas. In China, the top-tier cities draw the most attention while the focus on the lower-tier cities is much less, which is not matching the remarkable development status quo. Furthermore, the temporal consistency of urban social data and physical landscape data is often difficult to guarantee.

This study seeks to analyze the urbanization process by mitigating those mismatches from data preparation through spatial statistical methods. The research takes the second-tier city Wuhan as a case to examine social-ecological relationships during its urbanization process, providing experience and knowledge for sustainable management. It aims to offer a comprehensive view on Wuhan and may provide valuable references for other regions, as a microcosm of the second-tier, river-basin, and hinterland cities.

### **3. Research design**

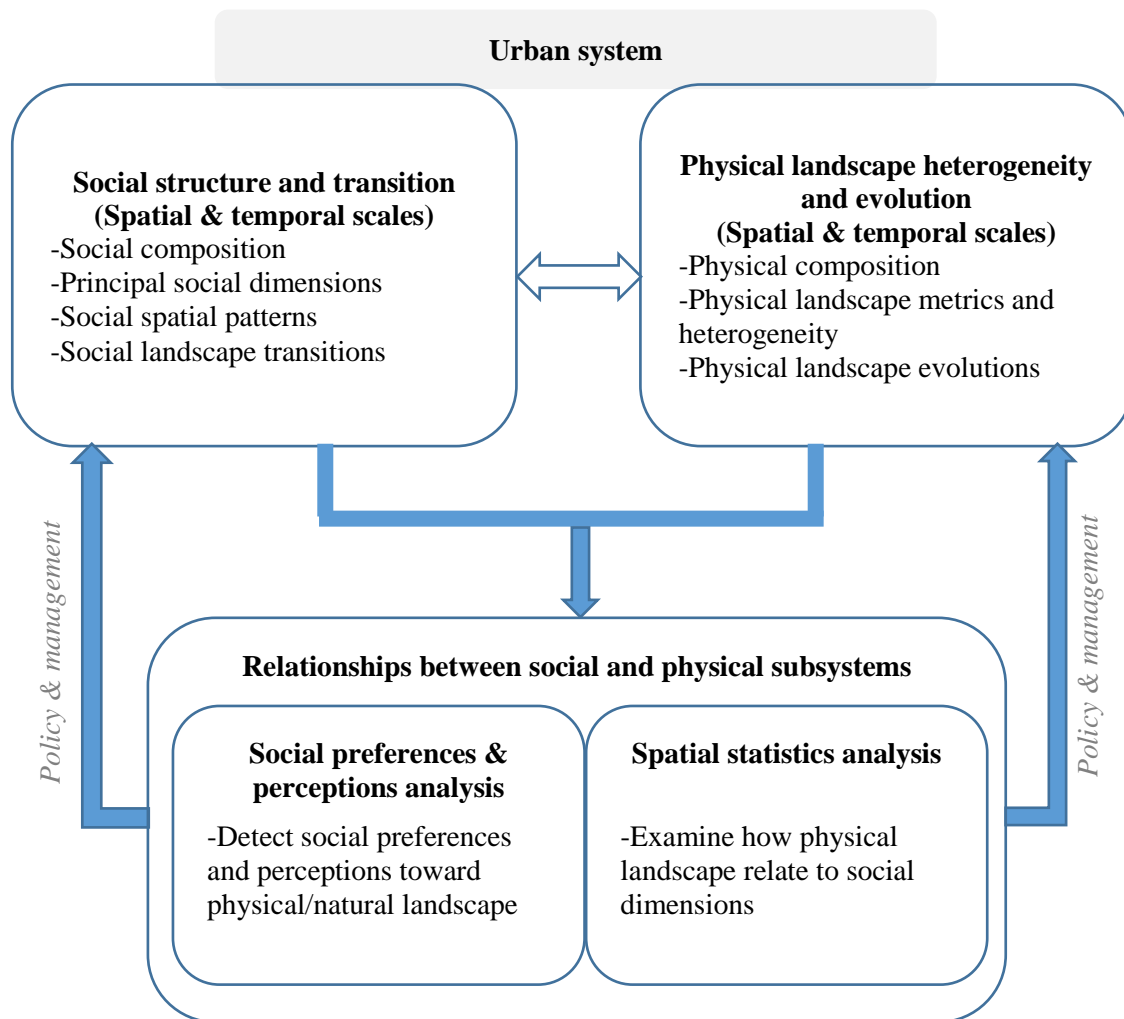
The social and physical landscape of an urban system has rich heterogeneity in time and space. To fully understand an urban system, its features, social and physical transformations, and the relationships between the two should be investigated. The proposed framework, research objectives, and questions are clarified in this section.

### **3.1. Proposed Conceptual Framework**

Social and natural subsystems interact with each other in an urban area, driving the complex urbanization process with integrating power. When socioeconomic factors influence land cover changes, humans perceive the ecological functions differently which further influences social preferences and behaviors when using those urban natural spaces. Likewise, humans' positive perceptions of urban natural landscape drive individuals and communities to increase their demand for such spaces.

The framework of this research is constructed under the guidance of IESE. The urban area is viewed as a complex ecosystem with interaction between social and physical landscapes. Figure 4 illustrates the framework to understand the interactions between urban social and physical subsystems while placing equal emphasis on both. The interactions are hierarchically nested in individual, community, and society levels, which further result in social and physical landscape dynamics, with the policy and management response. The integrated framework understands the core components - social structure and transitions, physical landscape heterogeneity and evolution, and their relationships - in an urban system. In both subsystems, the composition, patterns, and transitions are prioritized, while examination of the interactions between the social and physical subsystems is an area of emphasis. Human activities directly affect urban landscape evolution while urban spatial development orients the social transitions vice versa. Urban land growth coincides along with the natural landscape changes, while the process interacts with social transformations. The natural system provides society with ecological goods and services while social features affect people's preference for natural spaces as well as perceptions of related ecological services. The measurement of these relationships have two different focuses, one is on the spatially non-stationarities of the relationships based on the 'local' regression model, the other is on individual's perceptions which will be analyzed based on social groups. Governments respond to these relationships to fit urban policies. This

process then plays a role in the social and physical landscape by developing them into a further status. The policies related to economic development and urban planning are considered extraneous variables which are not introduced into the quantifying examination of the urban growth process.



**Figure 4** Concept framework of social-ecological approach studying an urban system

(Adapted based on Alberti et al., 2003; Ostrom, 2009; Wu et al., 2013)

An urban system is composed of the social subsystem and the physical subsystem that interact with each other. The relationships expressed with the bi-direction arrow line between the social and physical subsystems presents the mutual dependence between both. The interrelationships are quantified by the spiral cyclic flow (one-direction arrow lines composed

of the flow) which can be quantitatively modelled or qualitatively analyzed. Each component in the flow can be an initiative one causing the next step to transition. For example, policy and management is induced by the relationships, yet it also plays roles to initiate changes in the social and physical subsystems.

A social subsystem is described through social composition, principal social dimensions, social spatial patterns, and social landscape transitions. Social composition is the description of a population in a given sample of a certain area. Social composition includes the characteristics of age, gender, education, residence, occupation, income, and so on. Data of social composition is the foundation of social dimensions extraction. Spaces (areas) of principal social dimensions form social landscapes. The transitions of the social landscape are analyzed in a temporal perspective.

A physical subsystem is described based on landscape ecology, with physical composition, landscape metrics and heterogeneity, and landscape evolutions. The physical composition is defined under a land cover model for an urban system, for example, V-I-W (Vegetation area- Impervious surface area –Water area), V- I- W-S (Vegetation area- Impervious surface area – Water area - Soil) model. Extraction of the specific composition is the basis for landscape metrics computation. Landscape metrics are “algorithms that quantify the spatial structure of land cover patterns within a defined geographic area”.<sup>17</sup> The term ‘landscape metrics’ has historically referred exclusively to the metrics used for quantifying patterns in categorical maps (McGarigal et al. 2012). Based on landscape metrics referring to area, density, aggregation, regularity, the spatial heterogeneities of landscape patterns in the study area are analyzed and the evolutions in a time series are presented.

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<sup>17</sup> Landscape metrics is also known as “spatial pattern metrics, spatial pattern indices, or landscape pattern metrics.” Sources from AM-54 - Landscape Metrics. <https://gistbok.ucgis.org/bok-topics/landscape-metrics>. (Accessed on June 25<sup>th</sup>, 2019.)

Spatial and temporal scales are defined by the data resolution. Spatial scale in a social subsystem presents as regional, city, community, and individual; while in a physical subsystem it presents as regional, city, community, grid or area defined by researcher. The unit of analysis on the transformation and relationships is based on the spatial scale of the basic data resolution and their matching in both subsystems. Although census data is popularly accepted for expressing social subsystems, the social survey through questionnaire, interview, observation, or social media, is the other data sources that retain a variety of focuses or nuances. For the physical subsystem, category maps of land use or land cover is the basis, which can be extracted from remote sensing images with varieties of spatial and temporal resolution.

Interrelationships between the social and physical subsystems compose the dynamics of an urban system. To explore the interrelationships, it is important to quantify using statistical models and analyze qualitatively using survey data which offer different perspectives. Social dimensions and physical landscape metrics are variables introduced to model the relationships, for which spatial statistical regression is recommended and popularly applied. Another perspective is from social preferences and perceptions toward physical landscape, particularly toward natural landscape in an urban environment. The social perceptions perspective is a complementary one for the quantitative modelling of the relationships. The regression emphasizes quantitative modelling based on which spatial features are extracted, while the social perceptions concentrate on qualitative (semi-quantitative) study based on sampling survey data by questionnaire, interview, observation, etc. When a variety of physical landscape components are employed as focus, social perceptions focus particularly on natural landscape in an urban area which is a complementary to the focus on impervious surfaces.

This framework places equal emphasis on the social and physical subsystems, taking their interacting process as the promotion of the spiral evolution of the urban system. Under the social-ecological system framework, urban land and green open space in an urban ecosystem

are different focuses to be studied. A social-ecological perspective explores not only how humans intervene within the urban spatial pattern, but also how humans are served or enjoy the broader services provided by those spaces, which in turn affects the application of human interventions in those same spaces. In an urban ecosystem, natural open space plays an important role in the services to a sustainable urban social-ecological relationship, thus study on both humans' interventions, as well as their perceptions, which may influence their preference and behaviors, are valuable.

Landscape ecology and ecological services are two subfields in the 'ecology of city' studies, which explore landscape patterns as well as its ecological consequences and services. Survey and analysis of public perceptions provide an efficient way to assess the ecological impacts or services from a social perspective. In other words, when using statistical models to quantify the regression relationships between urban physical landscape and socio-economic factors, it is complementary to assess this relationship through the public's view with qualitative research. This also presents an opportunity to analyze how urban spatial evolution affects natural open space from the public's point of view.

Urban development is represented by impervious surface growth, which directly affects the spatial pattern of green open spaces. The natural open environment changes negatively or positively, with subsequent ecological consequences or benefits. In an urban environment, the natural open spaces provide not only material services but also spiritual ones, for which the assessment is more likely relying on subjective feeling. Thus public perception is a recognized essential component for the social ecological study in an urban ecosystem.

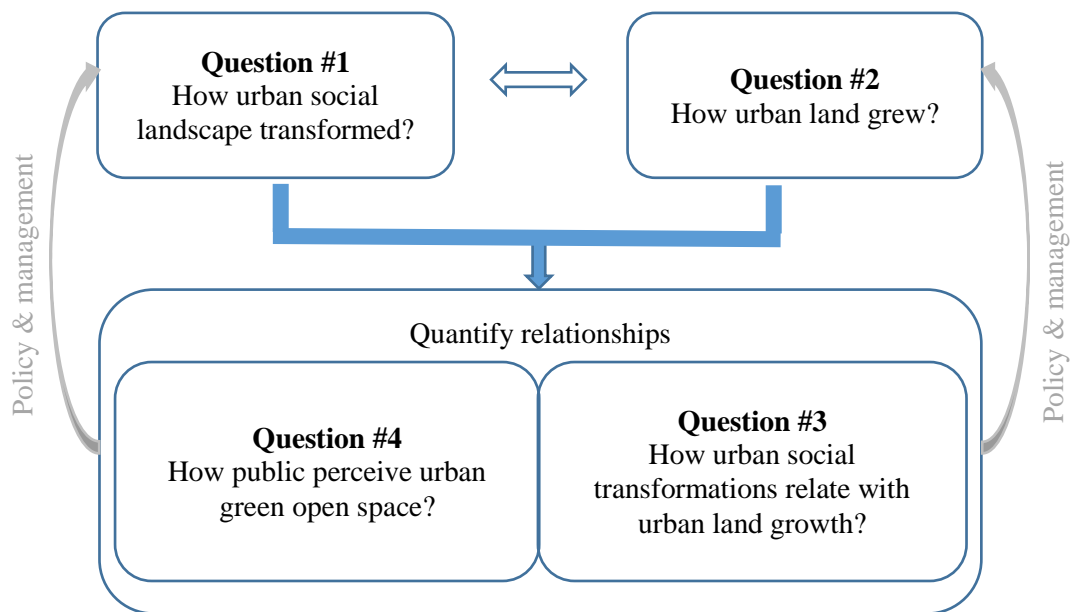
Green open space is the principal component of a natural environment in an urban area which benefits residents in their daily life. Landscape patterns of green open spaces are directly interrelated with urban land growth. Thus, besides exploration of urban spatial growth patterns

and the relationships with social factors, a public perception survey and analysis is a complementary perspective for better understanding social-ecological relationships.

### 3.2. Research Objective and Questions

This research seeks to examine the transformation of urban social and physical subsystems and the relationships between both, from a spatiotemporal perspective. The quantification methods include factor analysis, geospatial statistical approaches, and social survey analysis.

The proposed research is broken down into 4 questions, with the internal logic shown in Figure 5.



**Figure 5** Research questions

Question 1: How does the urban social landscape transform in time and space?

Question 2: What trends are apparent in the urban land growth process and spatial heterogeneity?

Question 3: How does social transformation relate to urban land growth, with a spatiotemporal perspective?

Question 4: How do social-demographic features relate to residents' use and perception of urban green open spaces, focusing on the ecological services provided by and the need to improve those spaces?

The research is designed to demonstrate that (1) urbanization is the process interacted by the social and physical landscapes, (2) urban social landscape transformation significantly associates with urban spatial growth heterogeneity, and (3) social preferences and perceptions toward urban green open space represent the relationships among social and natural elements that complement the modeling of the relationships among social transformation and urban spatial growth.

### **3.3. Research Case: Wuhan**

Wuhan, the capital of 29°58' -31°22' Hubei Province, is one of the largest cities in central China. It is located in the east of Jiangnan Plain, at longitude 113°41' -115°05' east and latitude 29°58'-31°22' north. Wuhan is an important transportation hub of China's waterway, railway, and high-speed railway network, known as the 'Eastern Chicago'. It is also a political, economic, and educational center in central China.

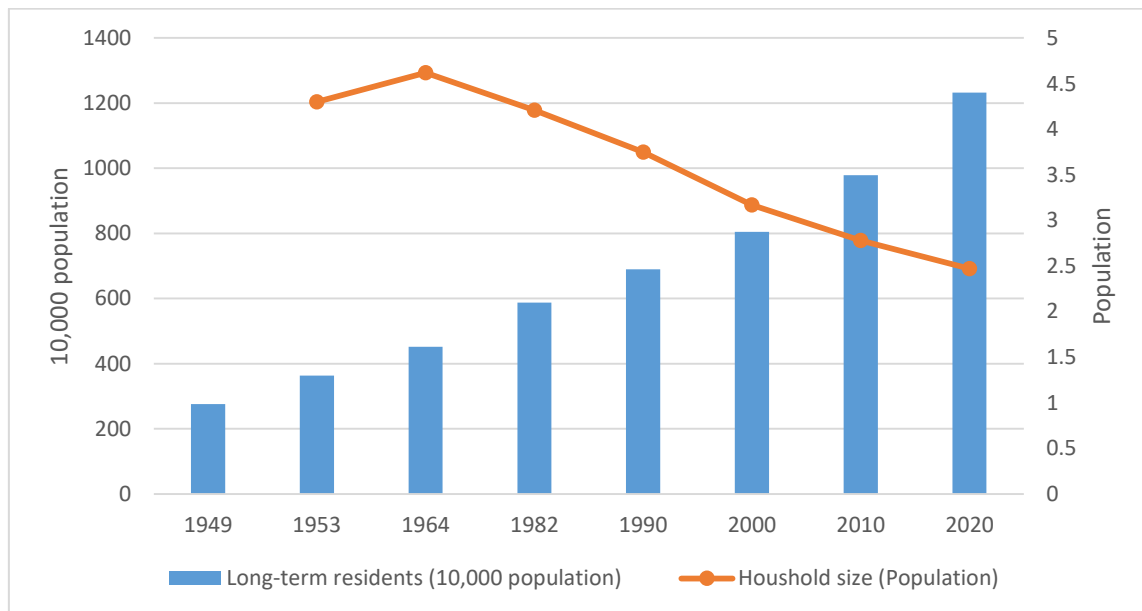
Wuhan is a historic and cultural city with well-known Chu Culture and the Red Culture, evolving through three traditional towns Hankou, Hanyang, and Wuchang<sup>18</sup>, separated by the Yangtze River and the Han River since the formation of the city. Wuhan is the cradle of urban civilization in the Yangtze River valley and the oriental tea port of ancient tea roads. It is also one of the bases for the establishment of modern China.

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<sup>18</sup> Hankou is in the west of the Yangtze River and north of the Han River, which used to have many foreign concessions distributed along the Yangtze River. Hanyang is on the opposite bank of the Han River in Hankou, dominated by industrial distribution. Wuchang is located on the opposite bank of the Yangtze River in Hankou, where education and technology dominate.

Over the past few decades, Wuhan’s status has steadily emerged from a regional center to a national center<sup>19</sup>, with continuous industrial transformations and consistent economic growth. Its growth has been remarkable over the past decades, with corresponding notable social transformation as well as spatial expansion.

Wuhan’s long-term residents and its incoming population have grown dramatically since 1990. The population grew from 6.69 million in 1990 to 12.33 million in 2020 representing an increase of 84.30% (Figure 6), and the influx rose dramatically from 0.42 million in 1990 to 3.95 million<sup>20</sup> in 2020, showing a 8.40-fold rise. During that same period, the GDP in Wuhan



**Figure 6** Wuhan long-term residents and household size

<sup>19</sup> “According to the National New Urbanization Plan (2014-2020), China has 17 megacities whose population is more than 5 million. But to be listed as a national central city, a city should not only have a large population, but also be the engine of regional development. The plan identified the first batch of national central cities in 2010: Beijing, Tianjin, Shanghai, Chongqing and Guangzhou. In 2016, Chengdu, Wuhan and Zhengzhou were added to the list.” Source: China Daily (Updated: 2018-02-09). National central cities. <http://www.chinadaily.com.cn/a/201802/09/WS5a7ce35fa3106e7dcc13baec.html>. (Retrieved on Oct. 20, 2020)

<sup>20</sup> Among them, the long-term influxing residents increased from 0.21 million in 1990 to 2.87 million in 2020.

developed from 2.71 billion USD to 227.37 billion USD<sup>21</sup> with a top ten rank among Chinese cities. Moreover, the city has been experiencing remarkable land-use transformations and urban social dynamics (Du et al., 2010; Zeng et al., 2015). Wuhan urban land allocation has grown quickly since 1990, with a 3.86-fold increase in the UDZ from 166.36 km<sup>2</sup> in 1990 to 828.74 km<sup>2</sup> in 2016<sup>22</sup>. In the same period, areas and distributions of green space and wetland changed significantly.

As the ‘Chicago City of China’, Wuhan was the first city directly under the central government, historically. Its pace of development slowed during the 1970s and 1980s but has been speeding up since that point in time. Wuhan’s urban expansion and industry development were rated in the top 10 of China during the 2010s. It is one of the largest cities in the Yangtze River Economic Belt and the largest city in the middle section. To date, Wuhan has emerged as an important industrial, financial, commercial and educational hub in central China. The urban area, urban area growth rate, long-term registered population, and GDP between 2014 and 2019 have remained in the top 10 in China’s cities (Figure 7, Figure A2, Figure A3).

In this case study, it is understood that Wuhan is a rapidly growing second-tier city in central China, and its status at the center of China’s economy continues to rise. It is a typical city along the river while also being a traditionally heavy industrial city that has undergone remarkable industrial structural upgrading and redevelopment<sup>23</sup>. Wuhan is a strong

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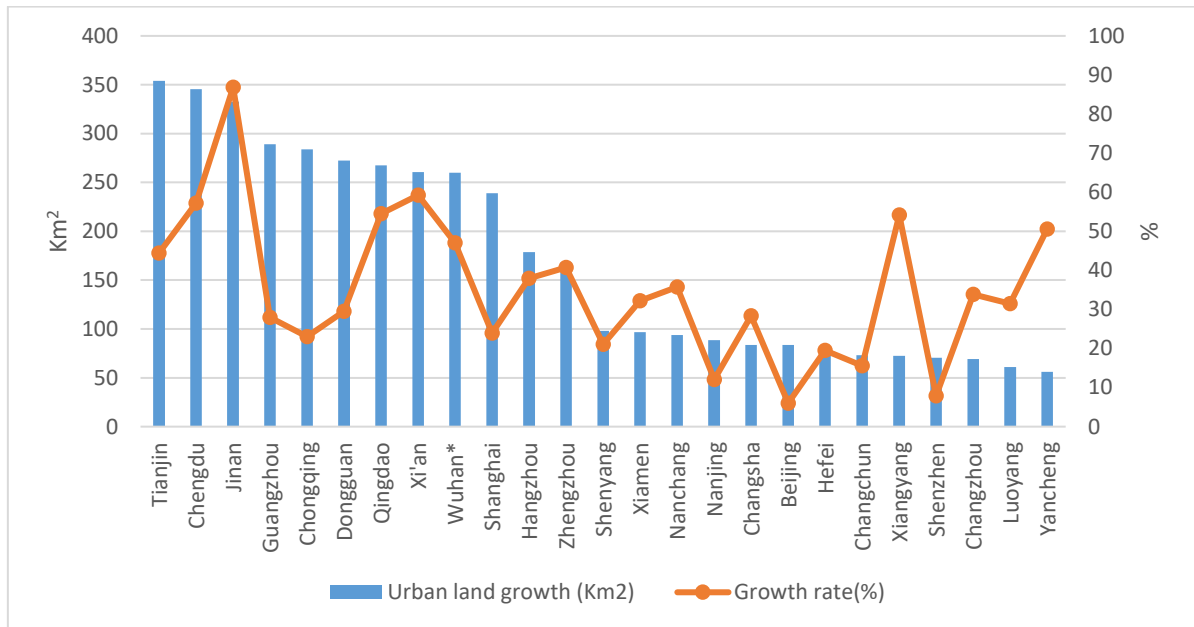
<sup>21</sup> Source: Wuhan Statistical Yearbook. 1 USD = 6.53 YUAN RMB, currency exchange rate on 29 December, 2020.

<sup>22</sup> Derived from Landsat images.

<sup>23</sup> Industrial upgrading is defined as ‘the process by which economic actors—nations, firms, and workers—move from low-value to relatively high-value activities in global production networks’ (Gereffi et al., 2005). Industrial upgrading is industrial transition by increasing the capacities of local industries for value added generation, economic diversification, exports and employment creation. (Industrial Upgrading and Modernization Programme (IUMP). <https://www.unido.org/our-focus-advancing-economic-competitiveness/industrial-upgrading-and-modernization-programme-iump#:~:text=The%20Industrial%20Upgrading%20and%20Modernization,diversification%2C%20exports%20and%20employment%20creation>. Accessed on June 15<sup>th</sup>, 2021.)

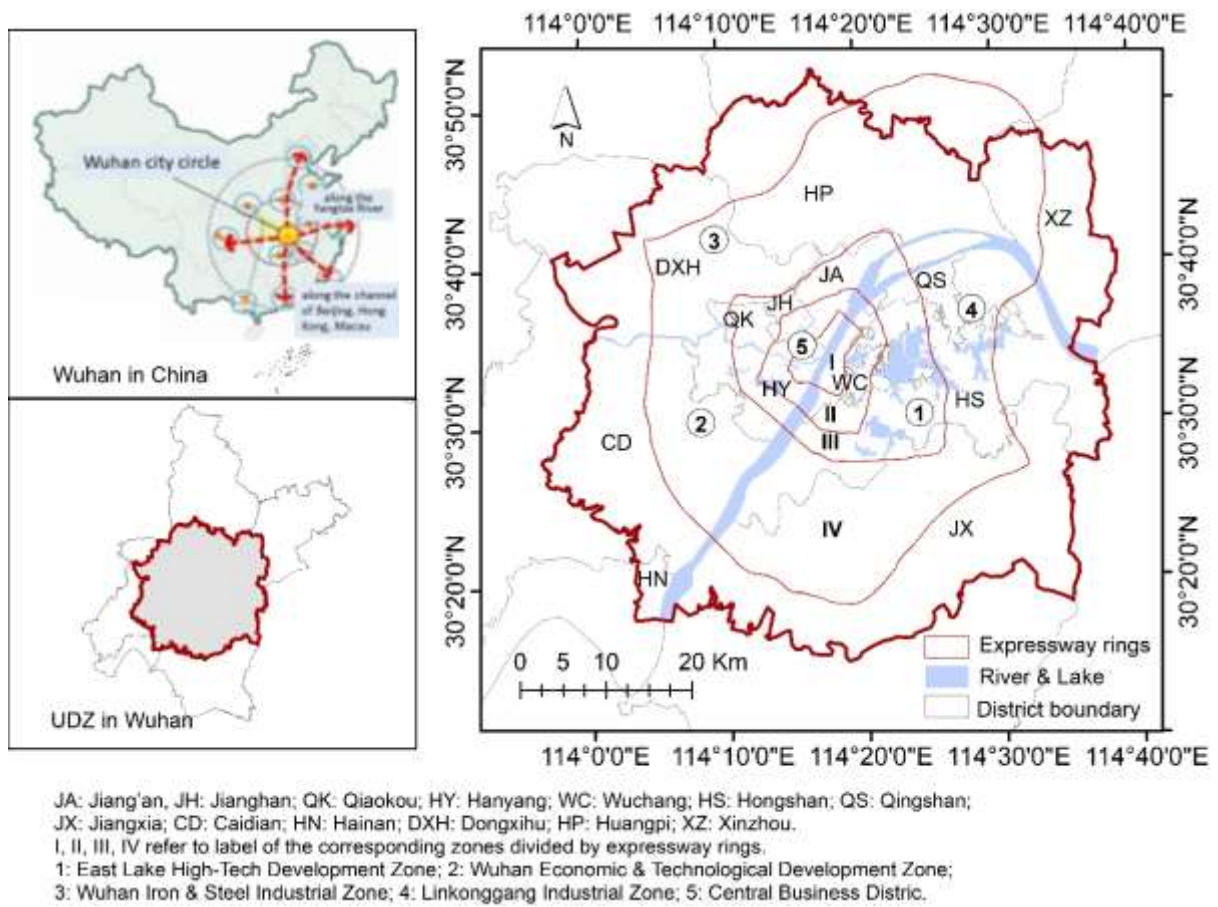
The industrial upgrade in China is presented in four stages, from resource-based industry (1978-1985), to labor-intensive industry (1986-1995), electrical industry (1996-2000), and high-tech industry (2001-) (Yu, 2012).

representative of many second-tier cities found along inland China. Its characteristics enable the analysis of Wuhan's urbanization process and the relationship between society and ecology to provide useful information for general urban management and a reference for other rapidly emerging areas.



**Figure 7** Urban land growth in China's cities (2014-2019)

The city of Wuhan is composed of thirteen districts, seven of which are part of the central city (details see Table A2.). Since 1990, urban expansion has been concentrated in the urban development zone (UDZ), as presented by the Wuhan City Master Plan (2010-2020), covering the central city and some suburbs. In 2010, a total of 135 neighborhoods made up the UDZ. The UDZ is also the most active socio-economic restructuring area in Wuhan, which leads to the focus of this study (Figure 8). It is further defined by four expressways that form concentric radiating rings from the city center to the periphery. These expressways divide the UDZ into four primary development zones named Zone I, Zone II, Zone III, and Zone IV. Additionally, several planned economic development zones represent the cluster of corresponding industry types in Wuhan UDZ.

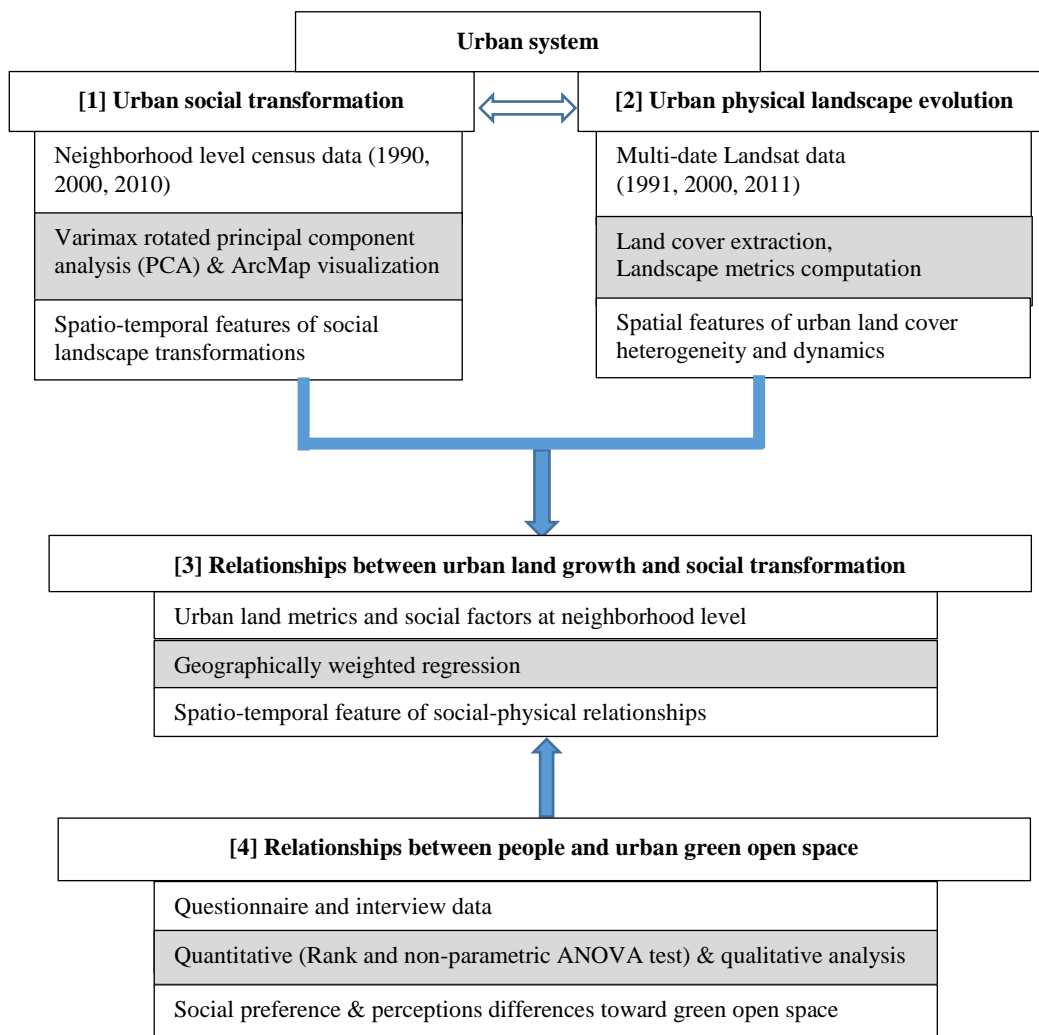


**Figure 8** Map of Wuhan

### 3.4. Research Data and Method

The research data and method is described in Figure 9.

Step 1 is the study on urban social transformation analysis. The dataset is based on Wuhan Census in 1990, 2000, and 2010. Varimax rotated principal component analysis (PCA) is used for social dimension reduction (see Chapter 2). The spatial patterns of the social urban structure are explored with the support of ArcMap. Furthermore, features of the spatio-temporal transformation and the mechanisms are also discussed.



**Figure 9** Research data and method

Step 2 is for the study of urban physical landscape evolution, based on multi-date Landsat images in 1991, 2000, 2011 downloaded from USGS (United States Geological Survey, <http://www.usgs.gov>). Remote sensing indices are used to extract land cover, with V-I-W (vegetation area – impervious surface – water area) urban model and focusing on the impervious surface (see Chapter 3). Urban land metrics referring to the area, aggregation, and shape are computed using FRAGSTATS software. The spatial heterogeneities and patterns of urban spatial growth are explored based on these metrics.

Step 3 quantifies the relationships between urban land metrics (obtained from step 2) and urban social factors (obtained from step 1), being modeled with geographical statistical methods and geographically weighted regression (GWR) (see Chapter 3). The spatial pattern of the relationships is explored based on the GWR coefficient surfaces.

Step 4 examines the relationships between humans and nature, as a complementary part of the social-physical relationships. It is based on the questionnaire and interview data (see Chapter 4). We quantitatively and qualitatively analyze the survey data, with the focus on how social features, or experience with natural environment changes, differentiate residents' preferences for the use of urban green open space and their awareness of the ecological importance and improvement necessity.

Together, Step 3 and Step 4 compose the examination of the relationships between social and physical subsystems in an urban area. Meanwhile, Steps 1 and 2 focus on the exploration of the transformations of and within those subsystems. Further, we extract management-related illustrations through the above research. Regarding the thesis organization, Steps 1 and 4 make up Chapter 2 and 4 respectively, while the Steps 2 and 3 form Chapter 3.

### **3.5. Thesis Organization**

The thesis is in paper format, containing five chapters (Table 1). Besides introduction (Chapter 1) and conclusion (Chapter 5), the main body consists of three articles. These three articles correspond to the four research questions proposed. Chapter 2 responds to the first research question with a focus on the urban social landscape transformation. Chapter 3 seeks to answer questions (2) and (3) by emphasizing urban land growth and its link with social factors from a spatio-temporal perspective. Chapter 4 matches the fourth question, understanding residents' preferences and perceptions toward the urban green open space. Also, the Appendix is attached to show the parameters of factor analysis, to explain the proposed remote sensing indices along with the questionnaire designed for survey data collection.

**Table 1** Thesis organization

<b>Chapter</b>	<b>Theme and objective</b>
Chapter 1	<p>This chapter includes an introduction, literature review, and research design.</p> <p>The introduction provides a background of urbanization, along with a brief overview of the reasoning behind this study and its general expectations.</p> <p>The literature review presents theoretical and empirical contributions of social-ecological approaches and China's urbanization study.</p> <p>This research design clarifies the proposed socio-ecological framework, research objectives and questions, a research flowchart, thesis organization, and anticipated contributions.</p>
Chapter 2 (Article 1)	<p>Spatiotemporal Transformation of Urban Social Landscape</p> <p>This chapter aims to find the general rules of how the social dimensions and social areas of second-tier cities in China have transformed while analyzing the mechanisms driving the evolution and the connection with broader decision making.</p>
Chapter 3 (Article 2)	<p>Understanding Urban Land Growth through a Social-spatial Perspective</p> <p>The main purpose of this chapter is to examine the growth pattern of Wuhan, a fast-growing second-tier megacity in China and analyze social dimensions' relationship with the spatial-temporal evolution, which may provide a reference for cities in rapidly urbanizing countries or regions.</p>
Chapter 4 (Article 3)	<p>Residents' Preferences and Perceptions toward Green Open Spaces in an Urban Area</p> <p>This chapter offers a better understanding of residents' views of green open space and their perceptions of its ecological services and potential improvements. Further, it focuses on the linking between different social factors and views.</p>
Chapter 5	<p>Conclusions</p> <p>This chapter summarizes the findings of the research, clarifies its limitations, and proposes areas of focus for future studies.</p>
Appendix	<p>The appendices include parameters of Varimax rotated PCA for social dimension reductions, remote sensing images selected and parameters for data process to extract urban landscape information, and the questionnaire design for assessing residents' preferences and feeling toward green open spaces.</p>

## Appendix

**Table A1** China's urbanization since 1970

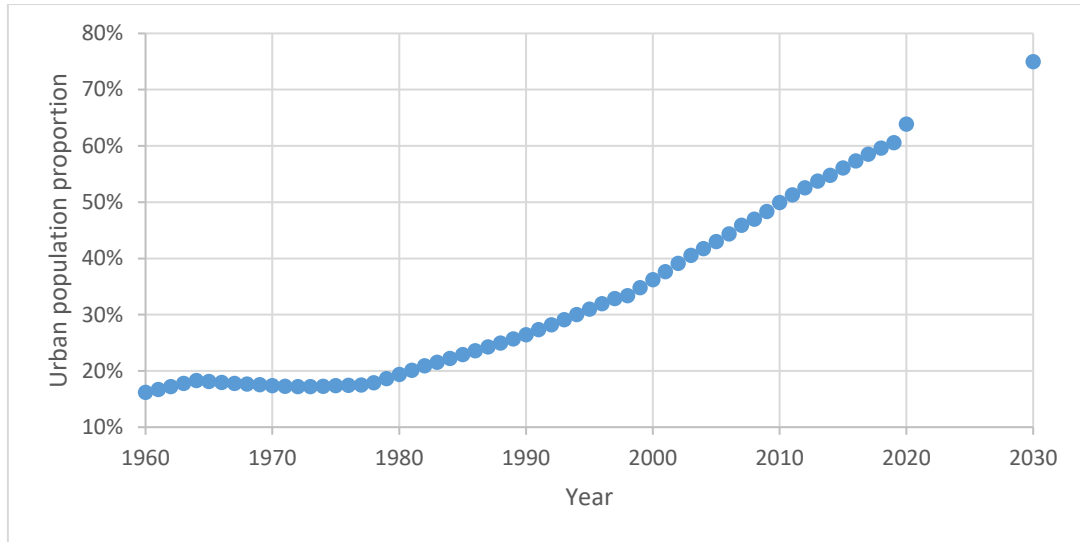
Year	Population		% of Urban Population to Total		
	Urban Population*	Total Population*			
2020	901,991,162	1,439,323,776	63.89%		
2010	658,498,663	1,368,810,615	49.23%		
2000	452,999,147	1,290,550,765	35.88%		
1990	300,165,618	1,176,883,674	26.44%		
1980	189,947,471	1,000,089,235	19.36%		
1970	142,386,810	827,601,394	17.40%		
Year	Population Growth		Growth Rate		Urbanization Rate**
	Urban Population	Total Population	Urban Population	Total Population	
2010-2020	243,492,499	70,513,161	3.70%	0.52%	3.18%
2000-2010	205,499,516	78,259,850	4.54%	0.61%	3.93%
1990-2000	152,833,529	113,667,091	5.09%	0.97%	4.13%
1980-1990	110,218,147	176,794,439	5.80%	1.77%	4.03%
1970-1980	47,560,661	172,487,841	3.34%	2.08%	1.26%

\*Data source: China statistics and National Census.

\*\*Rate of urbanization is defined as “the increase in the proportion of urban population over time, calculated as the rate of growth of the urban population minus that of the total population. Positive rates of urbanization result when the urban population grows at a faster rate than the total population” (UNICEF). UNICEF, 2012. <https://www.unicef.org/sowc2012/pdfs/SOWC-2012-DEFINITIONS.pdf> (Retrieved on June 15th, 2021).

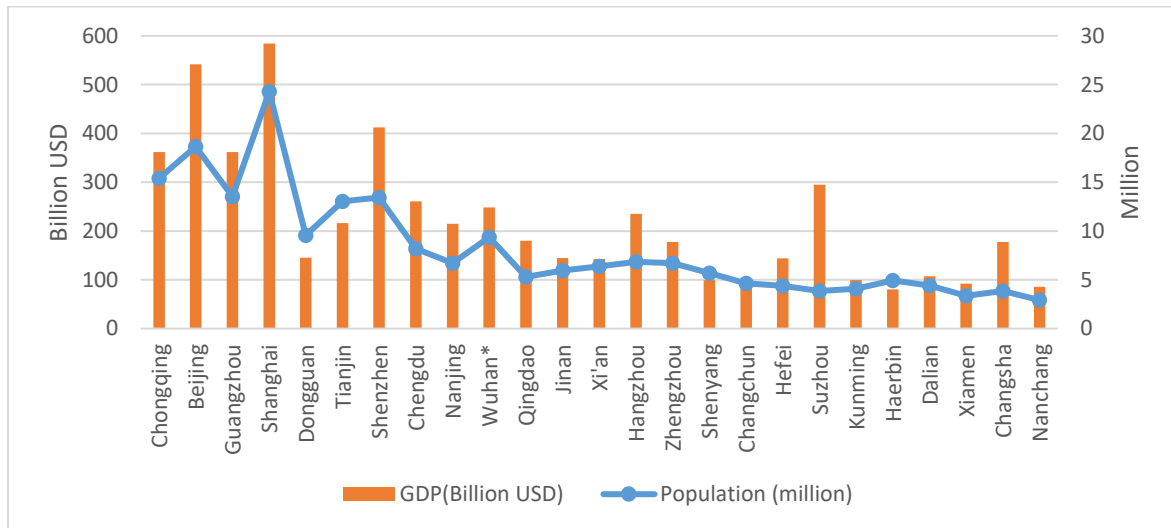
**Table A2** Wuhan urban development zone (UDZ)

District		Characteristics	Location
Hankou	JA (Jiang'an) JH (Jianghan) QK (Qiaokou)	Historically a commercial area, with Wuhan city-level government. The early CBD is located in Hankou, especially QK. The city government is mainly located along the Yangtze River, especially in JA District. Recent years, the CBD function has been enhanced, especially in Zone I and Zone II. At the same time, green open space is re-developed along the Yangtze River and Han River.	North of Han River and Yangtze River
	DXH (Dongxihu)	West to Hankou, developed rapidly within the past twenty years. Linkonggang Economic Technology Development Zone and Taiwan Businesspeople Investment and Development Zone are located in DXH District.	West of Hankou
Hanyang	HY (Hanyang)	Historically it is a heavy-industry zone, sub-CBDs developed in recent twenty years, residential development grew fast and green open spaces (re)development was implemented. Wuhan Economic Technology Development Zone is located in HY District.	South of Han River and west of Yangtze River
Wuchang	WC (Wuchang)	Provincial government located in WC District. With historical sites related to revolution. Recent years, re-development of cities to sub-CBDs and residential areas has been enhanced.	South and east of Yangtze River
	QS (Qingshan)	Historically, QS is historically heavy industrial, where pollution was a problem influencing living quality. The natural environment has been improved quite obviously during recent decades through industrial upgrading and ecological redevelopment. Iron-Steel Industrial Zone is located in QS District.	
	HS (Hongshan)	HS is an educational and high-tech district, with lots of universities and institutes located in this area. The East Lake Scenery Conservation Zone is also located in this district. Recent years, the high-tech industrial zone expanded rapidly eastward and southward with college town development. Donghu High-Tech Development Zone and Wuhan Chemistry Industrial Zone located in HS District.	
Other	periphery	Developed with satellite towns and industrial parks. Yangluo Port Industrial Zone, Jiangxia Economic Development Zone, Panlongcheng Economic Development Zone, Caidian Economic Development Zone located in the northeast, southeast, northwest, and southwest of Wuhan UDZ, respectively.	Areas out of expressway ring III

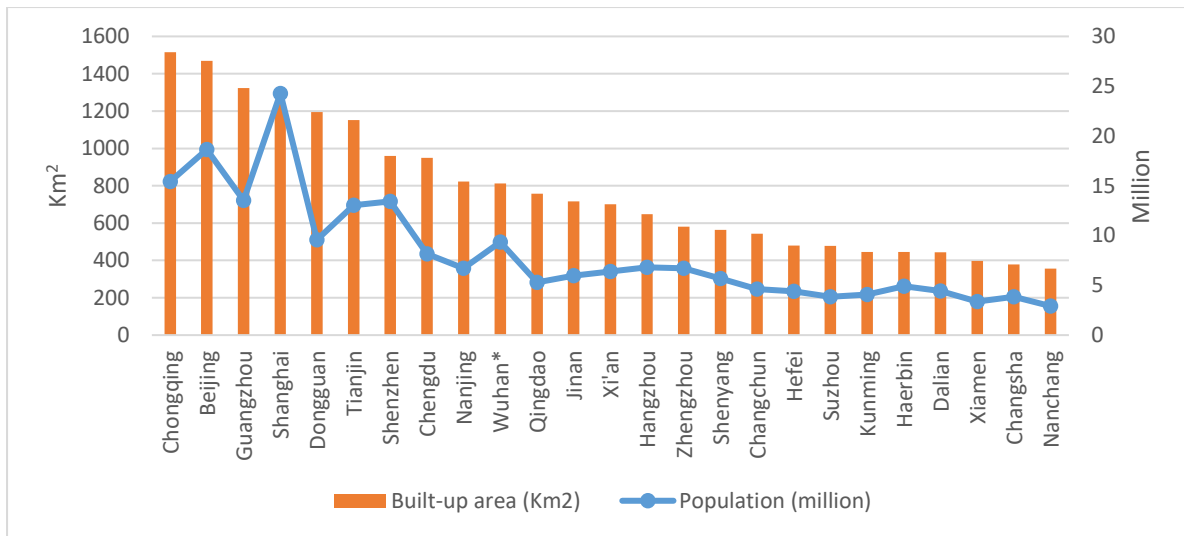


Data source:

- (1) <https://www.statista.com/statistics/270162/urbanization-in-china/> (Retrieved on Mar, 20, 2021);
- (2) The data in 2020 is extracted from “China’s 7<sup>th</sup> national census”;
- (3) The urban population rate in 2030 projected is extracted from “Rise of China’s super cities: New era of urbanization. [\*\*Figure A1\*\* Growth of China’s urban population proportion](http://www.morganstanley.com.au>2019-supercities.”</a> (Retrieved on May 16, 2020).</li>
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**Figure A2** Population and GDP in China’s top cities (2014-2019)



**Figure A3** Built-up area and population in China's top cities (2014-2019)

## Chapter 2 Spatiotemporal Transformation of Urban Social Landscape: A Case Study of Wuhan, China<sup>24</sup>

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<sup>24</sup> This chapter is improved based on a paper submitted to the journal *SOCIAL INDICATORS RESEARCH* (Impact factor 3.056, 2021). Submission: Oct 2019; Major revision: June 2020; Second-round revision: Feb. 2021.)

# Spatiotemporal Transformation of Urban Social Landscape: A Case Study of Wuhan, China

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## Abstract

Urbanization is accompanied by tremendous social transformations. However, the transformation of social dimensions and their spatial features has received little attention to date. This paper seeks to investigate progressive changes within the social dimensions of Wuhan's urban development zone (UDZ) while focusing on their associated spatial transformations, based on census data for Wuhan collected in 1990, 2000, and 2010. We used varimax rotated principal component analysis (PCA) to extract social dimensions, and also ArcMap to visualize the spatial distribution of social factor scores. The results suggest that industrial relocation, educational attainment increase, population aging, and population migration are the main characteristics of social transformation during 1990 and 2010. Industrial relocation along with the spatial separation appeared as principal social dimensions in the 1990s but became more prominent in the 2000s, accompanied by the improvement of workers' education levels. Aging population presented spatial movement outward from the city center. Population mobility increased significantly, and immigration became an important social dimension and presented spatial expansion in the 2000s. The socio-spatial patterns transform with a combination of concentric rings and sectoral clusters in different stages. These transformations are formed by the regional push-pull forces and the centripetal-centrifugal forces inside the city. We conclude that the social landscape transforms in a way with diversity and inclusion. Government dominates socio-spatial transformations in the initial stages, while market plays an increasing role in the later stages. To build a more inclusive society requires continuous and systematic improvement of relevant policies.

**Keywords** Urban social dimension · varimax rotated principal component analysis · socio-spatial transformation · second-tier cities · China

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## 1 Introduction

Since the socialist market economy reform in China in 1978, great changes have taken place in its cities. By the early 1990s, the first-tier cities<sup>25</sup> and Southeast coastal cities had implemented initial social and economic reforms. Consequently, rural-to-urban migration began to rapidly increase in these cities (Cao et al., 2000). Since the early 1990s, reforms have continued to influence the utilization of natural resources, population management, and housing marketization. Reforms at both local and national levels have promoted the diversification of urban social-spatial transitions, highlighting the shift from a planned economy to market-oriented development (Liu and Cao, 2017). Under these reforms, residential segregation and social stratification increased, reshaping the social space of the city. Therefore, deconstructing China's urban social dimensions in the last three decades has great significance to urban planning in the transitional period.

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<sup>25</sup> The city tier system is a hierarchical classification of Chinese cities with four categories. Although Chinese government does not recognize an official definition of the tier system, it is frequently referred to by various media publications and academic papers. The tier system has gained wide popularity in recent years as a point of reference. According to the city classification of the National Bureau of Statistics in the residential sales price survey, the first-tier cities are Beijing, Shanghai, Guangzhou and Shenzhen. The second tier-tier cities are provincial capital cities, autonomous capital cities and other sub-provincial cities, including Wuhan, Hangzhou, Nanjing, Tianjin, Chengdu, etc. The third- and fourth-tier cities are the rest (China National Bureau of Statistics, 2018).

Since the 1920s, research on urban social space has been influenced by the Chicago School of Urban Ecology (Burgess, 1925; Hoyt, 1939; Harris and Ullman, 1945). This was then followed by the social factorial analysis and the Urban Mosaic model proposed by Shevky and Bell (1955) and Murdie (1969), which aimed to quantify and map urban social structures. Notably, the social factorial analysis approach became widely used in the 1980s, especially in studies on cities of high-income countries (Goodchild and Janelle, 1984), and the use of the model was renewed at the turn of the century (Flood, 2000; Etienne, 2008; Bieri et al., 2012). Early literature, as in the 1980s, mainly repeated the social dimensions of socioeconomic status, family status, and ethnicity, which coincided with traditional social spatial models. However, since the 2000s, owing to the rapid urbanization and (post)industrialization, it is limited to use only traditional social dimensions to explain the evolution of the social landscape, although post-industrialization and institutional concepts were introduced in later studies (Cao and Villeneuve, 1998; Flood, 2000). This paper aims to deconstruct the social dimensions by highlighting indicators such as population mobility, industrial upgrading<sup>26</sup> and relocation, which reflect the emerging characteristics of Chinese cities' development during the transitional period.

In the last three decades, the transitions from the planned economy to the market economy were major concerns in the socialist states of Eastern Europe and China (Li, 2005; Wei and Yan, 2006; Stanilov, 2007; Brade et al., 2009). The first wave of China's study was represented by Chinese scholars, such as Xu et al. (1989), Gu and Kesteloot (1997), and Zhou et al. (1998), with a focus on the urban social-spatial structure of these first-tier cities Beijing, Shanghai, Guangzhou, and the second-tier city Nanjing in the 1980s and 1990s. Related conclusions in these studies on first-tier cities revealed that in the 1980s population density, educational levels of residents, occupational structure (workers and managers), residential house quality, age structure of population in household, were the main factors composing the urban social dimensions (Xu et al., 1989). However, during the 1990s, immigration and urban expansion emerged as principal factors (Zhou et al., 2006). Since the 1990s, studies based on either census or survey data have been used to emphasize the transitional economic context (Gu and Shen, 2003; Li et al., 2008; Xue and Huang, 2008). Studies show that in the 1980s and 1990s, the first-tier cities shared similar characteristics of social spatial patterns as a combination of concentric rings and sectoral distributions (Han, 2012). Literature emphasizes the factors such as industry relocation/upgrading in the 1980s and 1990s and the absorption of new immigrants in the 1990s, as the major factors that reflected the social transformations of these cities (Gu and Kesteloot, 1997). The first-tier cities' social spatial transformations disclose that the planned economic system continues to play an important role in the formation of the urban social landscape, prompting a similarity within the characteristics of transformation noted in these urban social areas<sup>27</sup> (Zhou and Ye, 2013). Since researchers found similarities in the social space evolution of China's first-tier cities in the 1980s and 1990s, we expect to study whether the second-tier cities will take an identical or a different path.

When exploring the social dimensions in cities of high-income countries, factors such as family, class, ethnicity, etc. are at the center of attention (Squires et al., 1989; Berg, 2010; Arapoglou, 2012). For example, research on the city of Quebec, in Canada, finds that the upper class and upper middle class are mainly concentrated in the rich vegetation areas or along the riverbanks in the city. In the city center, small living spaces are concentrated with lower-class housing (Cao and Villeneuve, 1998). In Eastern European countries, it is common for upper-middle and upper-tier residents to move out of the city center, which is affected by the transformation of the city center and dissatisfaction with the living environment (Brade et al., 2009). Since 1990, suburbs in the United States have had increasing racial and ethnic diversity, due to the lower cost of living as more residents migrate from inner city areas. Social segregation among different ethnicities is often noticeable, especially in cities with large ethnic populations (Williams and Emamdjomeh, 2018). When studying Chinese cities, however, researchers are more concerned with the factors of rural-urban migration, employment, or population aging (Lin et al., 2011; Wang and Fan, 2012; Yi et al. 2014; Wang et al., 2016). The difference between these two perspectives is brought about by the fact that high-income countries have mature market mechanisms, which significantly affect residents' social space choices; whereas in China, an upper-middle-income country, features transitions from a planned economy to a socialist market economy, a foundation which affects residents' choice of work or residence location with more non-market mechanisms – even though the market power increases dramatically (Gaudreau and Cao, 2015). The research on high-income countries attempts to explain both the static

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<sup>26</sup> Industrial upgrading is industrial transition by increasing the capacities of local industries for value added generation, economic diversification, exports and employment creation (IUMP (Industrial Upgrading and Modernization Programme). <https://www.unido.org/our-focus-advancing-economic-competitiveness/industrial-upgrading-and-modernization-programme>-jump#:~:text=The%20Industrial%20Upgrading%20and%20Modernization.diversification%2C%20exports%20and%20employment%20creation. Accessed on June 15<sup>th</sup>, 2021).

The industrial upgrade in China is presented in four stages, from resource-based industry (1978-1985), to labor-intensive industry (1986-1995), electrical industry (1996-2000), and high-tech industry (2001-) (Yu, 2012).

<sup>27</sup> The social areas are the grading zones of the factor scores. In this study, social areas are visualized with ArcMap. Variety of social areas compose of social landscape.

social structures and dynamic social transformations, while studies on Chinese cities pay more attention to static socio-spatial differences in a certain period rather than transformations throughout different periods. Constrained by the data disclosure, most research on social transformations focuses only on specific social indicators, such as the influx population's right to access public services, or the health concerns of the elderly, etc. (Yi et al. 2014; Wang et al., 2016).

In comparison to the high focus on first-tier cities, attention on lower-tier cities in China is relatively scarce, even though there are only a few studies on second-tier cities such as Nanjing (Wu et al., 2014), Tianjin (Liu and Cao, 2017). Low-tier cities have developed rapidly in recent years with significant urban social transitions. Nonetheless, research on lower-tier cities is essential for enhancing and updating the study of urban socio-spatial dynamics in China. This study will provide more insights into spatial planning and urban management by focusing on the social structural transition processes and assessing their impact on social differentiation by selecting Wuhan, a second-tier city and one of the largest cities in central China, as the case study.

To date, six national censuses have been conducted in China, between 1953 and 2010. However, due to the limitations of data disclosure, only a few studies are based on the most recent census that stresses the social structure in the 2000s. Additionally, due to the constraints of data disclosure at the local level, research on urban social landscape based on the census focuses less on the micro-scale (Qiao and Huang, 2013; Shen, 2013). At the neighborhood-level, research focuses more on one single social factor, such as migrants (Li et al., 2014), rather than on multiple dimensions simultaneously. These restrictions in previous studies indicate the need to conduct other research that depicts social structure dimensions on an extensive regional or community level. The main objective of this study is to find the general rules of how the social dimensions and social areas of second-tier cities in China have transformed, while analyzing the mechanisms driving the evolution and the connection with decision making. To achieve this objective, three major questions were proposed: (1) How does the urban social landscape transform in Wuhan? (2) What are the mechanisms? And (3) what role does social spatial evolution play in urban social planning and management?

This paper is structured into four parts, along with the introduction. In Section 2 we describe the study area, variables, data process methods, and extraction of factors. Then in Section 3, we interpret the urban social dimensions, summarize the connotation and spatial characteristics of the transformations, and conceptualize the social spatial models. Section 4 focuses on discussing the similarities and differences of Wuhan's urban social landscape transformation with the literature results, and the transformation mechanism, followed by the concluding remarks in Section 5.

## 2 Research design

### 2.1 Research site

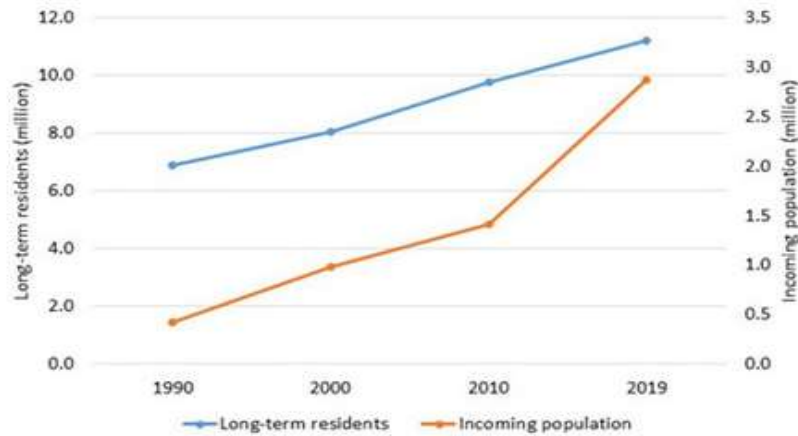
Wuhan, the capital of Hubei Province, is one of central China's largest cities and acts as a transportation hub known as the 'Eastern Chicago.' It is a historic and cultural city with well-known Chu Culture and the Red Culture, evolving through three traditional towns<sup>28</sup> segregated by rivers since the formation of the city. Wuhan has become one of the largest second-tier cities in China, with its fast-growing economy and rapid population growth. Wuhan's long-term residents have grown dramatically since 1990 (**Figure 1**). The total number of long-term residents has increased from nearly 7 million in 1990 to over 11 million in 2019, and among them the incoming population from 0.42 million in 1990 to 2.87 million in 2019.<sup>29</sup>

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<sup>28</sup> Wuhan has experienced the evolution of three traditional towns. They are Hankou (west of the Yangtze River and north of the Han River), Hanyang (west of the Yangtze River and south of the Han River) and Wuchang (east and south of the Yangtze River). Traditional towns are mainly concentrated in the city center near the intersection of rivers.

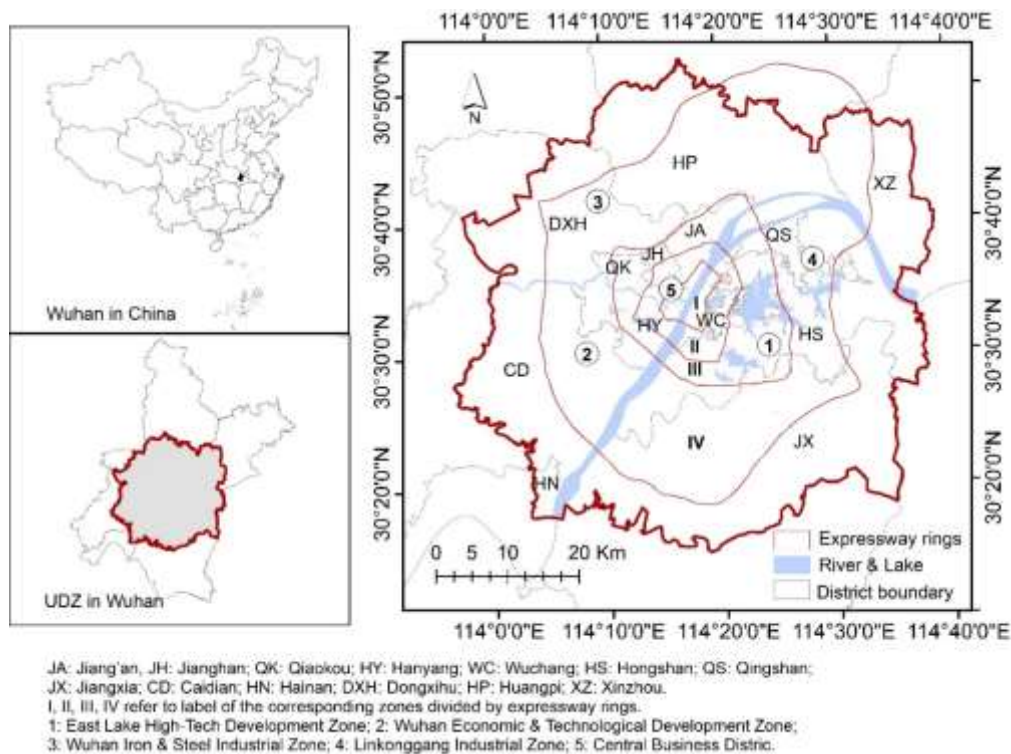
<sup>29</sup> Census divides population into household registered population and floating population. According to the sixth census, the long-term residents include the population registered in this jurisdiction who also live here, the population registered outside this jurisdiction but reside in this jurisdiction for longer than half a year, the population with registration pending, permanent residents in this jurisdiction but leave this jurisdiction shorter than six months. Floating population refers to the population who has left the place of household registration to live in other places. Internationally, similar groups are called "internal migration". In addition, the floating population can be divided into inflow population (also called incoming population, influx population) and outflow population. Inflow population refers to the non-registered population who reside in this area, and outflow population refers to the registered population who left this area registered to live in other places.

Source: China national statistical bureau. China national census 2010 (国家统计局. 中国 2010 年人口普查资料). <http://www.stats.gov.cn/tjsj/pcsj/rkpc/6rp/indexch.htm>



**Figure 1** Wuhan population growth

The city of Wuhan comprises thirteen districts, seven of which are part of the central city. Two natural segmentation belts, formed by the Yangtze River and Han River, also add to the city’s urban social-spatial characteristics. Since 1990, urban expansion has been concentrated in the urban development zone (UDZ), as presented by the Wuhan City Master Plan (2010-2020), covering the central city and certain suburbs. The UDZ is also the most active socio-economic restructuring area in Wuhan, therefore it is a primary focus of this study (**Figure 2**).



**Figure 2** Research site map

As shown in **Figure 2**, the UDZ is further defined by four expressways that form concentric radiating rings from the city center to the suburbs. These expressways divide the UDZ into four primary development zones named Zone I, Zone II, Zone III, and Zone IV. Additionally, there are several planned economic development

zones which represent the cluster of corresponding industry types in Wuhan UDZ. During the study periods, the number of neighborhoods in Wuhan UDZ was 131, 128, and 135 in 1990, 2000, and 2010 respectively.

## 2.2 Data and method

### 2.2.1 Data preparation

The Wuhan censuses of 1990, 2000, and 2010 are the main sources of data for this study. Urban social factors have been selected based on a literature review (Flood, 2000; Han, 2012; Liu and Cao, 2017; Han et al., 2018) and the availability of census data, which includes migration, age composition, marital status, education, employment, and occupation stratified by different incomes. Social dimensions such as family structure, economic class, and ethnicity are greatly emphasized in the literature. In this study, we will explore more social dimensions related to industrial transitions and discover the spatial features of such.

We screened the variables based on the Pearson correlation coefficient to select the appropriate variables for further analysis<sup>30</sup>. A total of 14 variables<sup>31</sup> were identified to represent various aspects of urban socio-economic development in Wuhan (**Table 1**). We calculated the skewness standard error of variables in different years, and these values are 0.212, 0.214, 0.209 in 1990, 2000, and 2010 respectively<sup>32</sup>. With the selected variables, we then extracted social dimensions using varimax rotated principal component analysis (PCA).

**Table 1** Selection of indicators and variables

Indicator	Variable
Urbanization	Non-agricultural population
Immigration	Local population
	Intra-provincial immigrants*
	Inter-provincial immigrants
Age	Population aged 0-14 (Minor Dependent)
	Population aged over 65 (Elders)
Marital status	Married population
	Divorced or widowed population
Education	High school educated population
	Highly educated population
Employment	Secondary industry employment
	Tertiary industry employment
Income level of occupation	Population with high-income occupation
	Population with low-income occupation

\* In 1990, it is population reside here less than 1 year but leave the registration county/city over 1 year, including both inter- and intra-provincial incoming population.

### 2.2.2 Varimax rotated Principal Component Analysis (PCA)

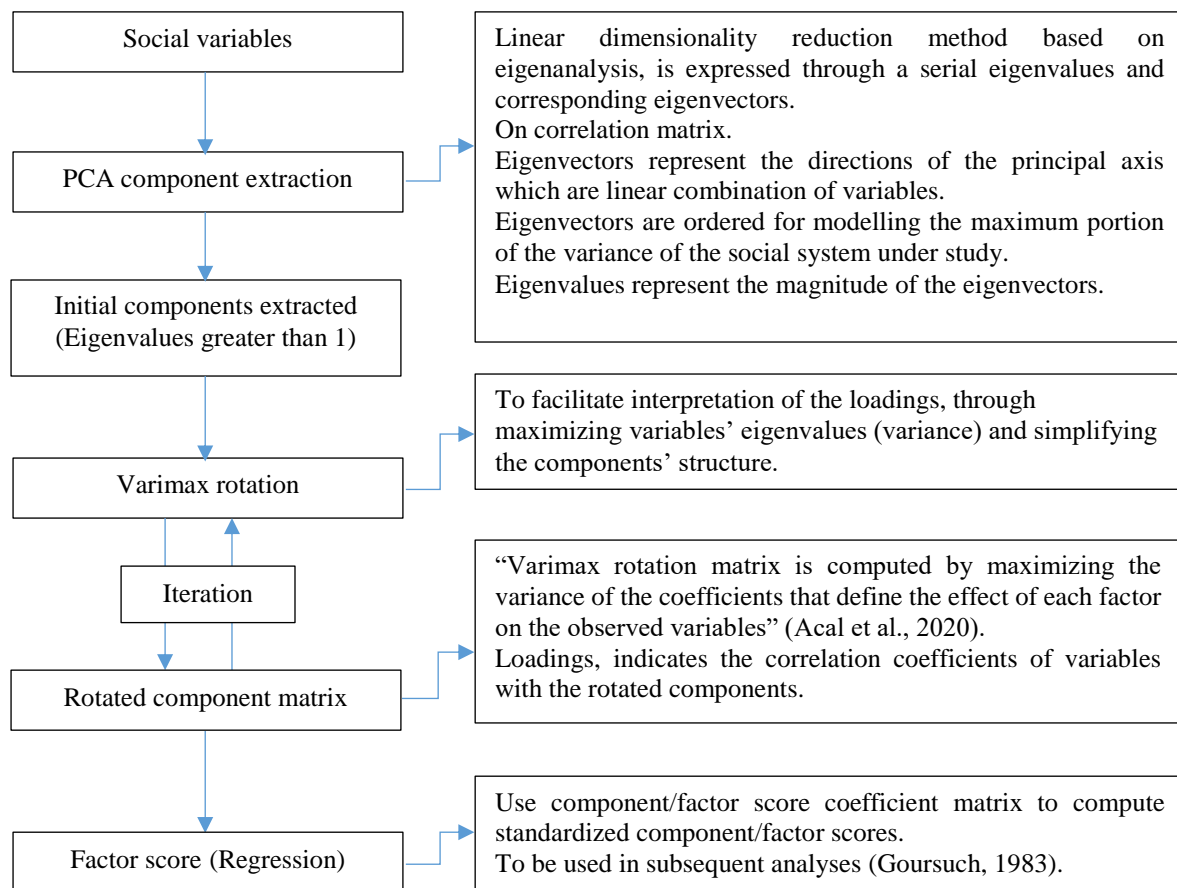
The social structural variables collected from the census data are screened, which is the basis of the analysis. The social variables are of different population dimensions. For example, age structure is presented as the percentage of minor dependents, middle-age population, and elderly; whereas employment structure is presented as the percentage of employment in different (primary, secondary, tertiary) industries. Each social dimension is based on census categories such as household registration, age, education, employment, and occupation, which are presented with the variables of social structure. To reduce the dimensions, varimax rotated PCA is adopted. To ensure that this approach is clearly understood, the key and synonymous terms associated with varimax rotated PCA are listed in **Table A1**.

Varimax rotated PCA is a popular approach in social factorial ecology which originated in the 1970s and developed over the subsequent decades. This thesis reduced social dimensions using this approach. That is, the initial principal components are extracted with PCA, followed by varimax rotation in order to obtain the maximum loadings of variables to factors/components. Components/factors' scores are computed with a regression approach and then used for further analysis. **Figure 3** shows the flowchart of varimax rotated PCA.

<sup>30</sup> For the variables interpreting the same census category, if the correlation coefficients are equal or greater than 0.9, only one is kept.

<sup>31</sup> We also conduct varimax rotated PCA

<sup>32</sup> According to the rule of thumb, if the skewness standard error is between -0.5 and 0.5, the data are approximately symmetrical.



**Figure 3** Route of varimax rotated PCA

Mathematically, PCA is a widely accepted approach of dimensionality reduction based on the linear transformation of the variables' correlations/covariance. The principal components present the dimensions based on the orthogonal principal axis. That is, "the eigenvectors and eigenvalues of a covariance (or correlation) matrix represent the "core" of a PCA: The eigenvectors (principal components) determine the directions of the new feature space, and the eigenvalues determine their magnitude. In other words, the eigenvalues explain the variance of the data along the new feature axes."<sup>33</sup> Variables with high loads represent the meaning of the corresponding components (Shrestha, 2021). The Varimax rotation following PCA maximizes the variance of coefficients and the differences of the variables' loadings to outstand the uniqueness of each component. The rotation simplifies the interpretation of each component without changing the interrelationships between variables and between the components.

Principal components extracted are ordered from high to low percentage of variance (eigenvalues) represented. The eigenvalues are computed based on the eigenvectors (directions) of the observed data. The loadings of variables on each of the rotated components (factors) indicate how close these variables are correlated with the corresponding components (factors). Thus, in each year, we can interpret the connotations of social dimensions (factors) based on the meaning of the high-load variables. We can also analyze social landscapes based on the spatial distribution of factor scores. Although, the eigenvalues of factors do not represent the meaning in reality, they do justify the idea that the connotation of the social dimensions (factors) represented by high-load variables are comparable among different years or different regions. The social dimensions with varied connotations in different years indicate transformations, the validity of which has been demonstrated by both mathematical as well as sociological studies (Liu and Cao, 2017; Shrestha, 2021).

From a sociological perspective, PCA is applied as a dimensionality reduction approach as well as an approach under factor analysis to deconstruct and reconstruct urban systems. This approach was widely applied

<sup>33</sup> Principal Component Analysis in 3 Simple Steps. [https://sebastianraschka.com/Articles/2015\\_pca\\_in\\_3\\_steps.html](https://sebastianraschka.com/Articles/2015_pca_in_3_steps.html) (Accessed on July 15, 2019).

when factorial ecology studies were booming during the 1970s and 1980s. The improvement in mathematical technique, as well as its application in urban studies, has continued over the last three decades. Scholars not only use it in the studies of social dimensional reduction in a static year or period but also in the comparison study between different cities, or temporally in one city. Thus, the literature provides empirical justification of the PCA application in urban social landscape transformation studies (Chow and Coulton, 1998; Jolliffe and Uddin, 2000; Yao and Zhang, 2014).

The factor/component scores are obtained with regression methods which standardize factors for further spatial analysis or regression modelling. The social areas visualized with ArcMap are the grading zones of the factor scores. A variety of factors and grading areas of scores compose the social landscape based on the linear-transformation process. The changes of dimensional connotations reflect the transformations of interrelationships between variables as well as between factors. The original census can offer valuable complementary information for corresponding interpretations.

The neighborhood has changed throughout the periods, both in terms of boundaries and numbers<sup>34</sup>. We have compared administrative maps from different years and tried to adjust the neighborhood boundaries to make them comparable. To find the influence of neighborhood number changes, we compared the varimax rotated PCA results using the neighborhoods before and after adjustment. The results show that it has slight impacts on the factors extracted based on the Eigenvalue greater than 1 and on the orders of the variables' loadings on each factor (**Table A2, A3**). Therefore, we used the boundaries without adjustment for analysis spatially and temporally. Furthermore, since the neighborhoods with boundary changes are distributed sporadically, it does not affect much on the spatial pattern summaries. From another angle, the neighborhood changes brought about the spatial nuance of social landscapes, which indicates an impact of management intervention.

### 2.2.3 Data process procedure

Firstly, we measured if the sampling data could pass the Kaiser-Meyer-Olkin (KMO) test and Bartlett's Test of Sphericity (BTS)<sup>35</sup>, which are prerequisites for factor analysis. We then employed a PCA approach to obtain the initial factor solution. We further chose Varimax<sup>36</sup>, an orthogonal rotation method, as a means of highlighting the variables that explain the connotation (Flood, 2000; Liu and Cao, 2017). Augments have existed for a long time in academic studies, for which rotation methods, either orthogonal or oblique, should be employed. According to Tabachnick & Fidell (2007, p646), "if the absolute value of correlations among factors" based on oblique rotation are "less than 0.32", then "the factor correlations are likely not driven by the data, and the results can be considered 'nearly orthogonal', and the orthogonal rotation method should produce the same or very similar result with the oblique rotation". We tested oblique (Promax) rotation as well as orthogonal (Varimax) rotation and found similar results between both structures. Also, the correlations between different factors are low. In this situation, the orthogonal rotation is well accepted, with a simpler structure for further discussion.

Based on the loadings of variables on each factor and urban features of society, we named factors, defined the corresponding connotation, and compared the transformations of the connotation in different periods. A regression method was then selected to estimate factor score coefficients which were used for the score calculation. Factor scores are the basis for visualizing social landscape using ArcMap and exploring socio-spatial transformations. When comparing urban social factors' connotations and spatial features, we conceptualize the social landscape transformations features as well as discuss the mechanisms within the Wuhan context and from a broader region.

## 2.3 Factor extraction

The eigenvalue greater than 1.0 rule (also known as the Kaiser rule) and use of a scree plot are a popular approach for making the decision on the number of factors to be extracted. The Kaiser rule retains all factors with eigenvalues greater than 1.0. The essence is that a factor worth retaining should at least have a greater variance, or say, a stronger explanatory power, than any of the original measurement variables contained in the factor (Zwick & Velicer, 1986), where the maximum eigenvalue of a single measurement variable is 1.0. A scree plot is a graphical representation of eigenvalues. In a scree plot, where the size of the eigenvalue decreases sharply, an additional factor adds relatively little information. Factor extraction is defined by this turning point. Using the Kaiser rule may under- or over-estimate due to the influence of sample quality, while scree plot may have more

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<sup>34</sup> Four types of neighborhood information changes are found. One is neighborhood name changes without boundary changes. This is the most frequent one. The second one is neighborhood combination. For example, two neighborhoods combined into one. The third one is neighborhood split, turning from one into two. And the fourth one is a redefinition of the boundary.

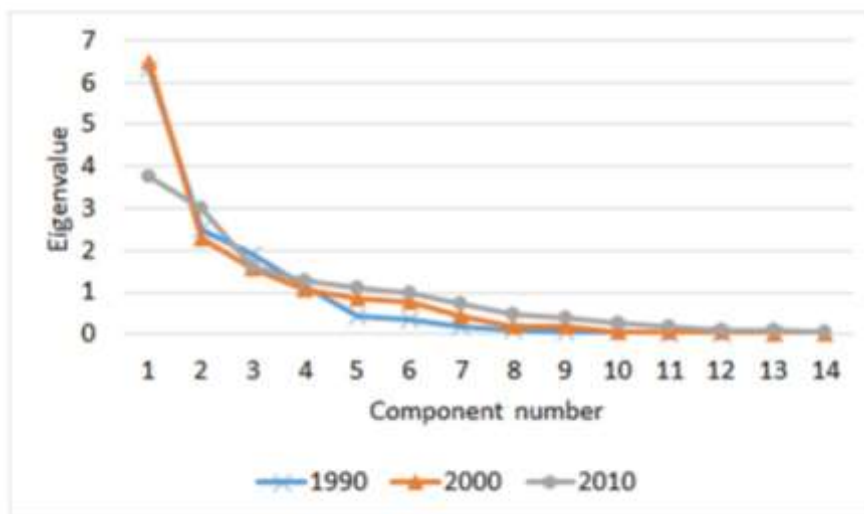
<sup>35</sup> The KMO test measures 'sampling adequacy. This measure varies between 0 and 1, and values closer to 1 are better'. The BTS tests 'the null hypothesis that the correlation matrix is an identity matrix'. This null hypothesis should be rejected for factor analysis. (Source: <https://stats.idre.ucla.edu/spss/output/factor-analysis/>)

<sup>36</sup> Varimax is to 'minimize the number of variables that have high loadings on each factor, which simplifies the interpretation of the factors'. (Source: <https://stats.idre.ucla.edu/spss/output/factor-analysis/>)

than one elbow<sup>37</sup>. Thus, both the Kaiser rule and scree plot should be used with caution as the results may be overestimated or underestimated (Zwick & Velicer, 1982; Zwick and Velicer, 1986; Thomposon, 2004; Yong and Pearce, 2013).

To decide the number of factors to be extracted, we compared the results based on both scree plot and eigenvalue. In this research, the scree plot shows two points with slope conversing from steep to flat with which the factor numbers are 2-2-3 or 5-4-7 in 1990, 2000, and 2010 respectively (**Figure 4**). The 2, 2, and 3 factors underestimate the social dimensions while the 5, 4, and 7 factors overestimate. That is, the fifth factor in 1990 only presents 3.47% of variance which is noticeably low, while both the 6th and 7th factors in 2010 present immigration information and the occupation which has been split from the employment factors. The under- or over- extraction based on scree plots may be related to the sample size which is coincident with the assertion that “the scree test is only reliable when you have a sample size of at least 200” (Yong and Pearce, 2013). Eigenvalue equals and greater than 1 covers factors with a higher percentage of variance in 1990 and 2000, it also mitigates the over-extraction of the social dimensions in 2010. Thus, we chose to extract the factors based on the Kaiser rule.

Four principal factors are extracted for 1990 and 2000, and five factors for 2010. Those factors extracted explained 91.17% (1990), 81.36% (2000), and 76.64% (2010) of the total variation of the social subsystems represented by a set of census variables in Wuhan UDZ.



**Figure 4** Scree plots in different years

The loadings shown in the rotated factor matrix (**Table 2**) disclose how the social variables associate with each of the rotated factors. A positive loading indicates a positive correlation between a variable and a factor while a negative loading represents a negative correlation. Factors explain the variance of the dataset based on the variables with high loads. Thus we chose to name factors after the variables with higher loads giving consideration to the meaning in reality. The changes in these factors and their high-load variables represent the transformations of social dimensions in Wuhan. As indicated in **Table 2**, the composition of the major factors has undergone tremendous transformations reflecting the social structure change of Wuhan over the past three decades. The mapping of the scores of these principal factors proves the dynamics of Wuhan’s urban social landscape.

<sup>37</sup> The point where the slope of the curve of the eigenvalues is clearly leveling off is often called the ‘elbow.’ The point of separation is where the number of factors should be generated by the analysis.

**Table 2** Rotated Factor Matrix

1990 <sup>a</sup>	%	2000 <sup>b</sup>	%	2010 <sup>c</sup>	%
<b>Factor 1</b>		<b>Factor 1</b>		<b>Factor 1</b>	
<b>Non-agricultural industry worker, High income population</b>	<b>45.55%</b>	<b>Tertiary industry worker, High income population</b>	<b>37.45%</b>	<b>Tertiary Industry Worker</b>	<b>21.17%</b>
High school educated population	0.964	Highly educated population	0.923	Tertiary industry employees	0.887
Non-agricultural population	0.956	High-income-occupation population	0.903	Non-agricultural population	0.835
Secondary industry employees	0.860	Tertiary industry employees	0.794	High school educated population	0.802
High-income-occupation population	0.789	Non-agricultural population	0.786	High-income-occupation population	0.513
Tertiary industry employees	0.776	Minor dependent	-0.822		
Low-income-occupation population	-0.984	Married population	-0.806		
Minor dependent	-0.913	Low-income-occupation population	-0.696		
<b>Factor 2</b>		<b>Factor 2</b>		<b>Factor 2</b>	
<b>Single and Higher educated population</b>	<b>16.30%</b>	<b>Secondary industry worker</b>	<b>19.50%</b>	<b>Married population with minor dependent</b>	<b>17.28%</b>
Highly educated population	0.803	Secondary industry employees	0.864	Married population	0.876
Married population	-0.853	High school educated population	0.647	Minor dependent	0.703
		Inter-provincial immigrants	-0.524	Highly educated population	-0.803
<b>Factor 3</b>		<b>Factor 3</b>		<b>Factor 3</b>	
<b>Aging Population</b>	<b>16.22%</b>	<b>Aging Population</b>	<b>14.61%</b>	<b>Local Population &amp; Aging Population</b>	<b>16.99%</b>
Elders	0.955	Elders	0.910	Local population	0.854
Divorced or widowed population	0.938	Divorced or widowed population	0.865	Elders	0.842
				Divorced or widowed population	0.759
<b>Factor 4</b>		<b>Factor 4</b>		<b>Factor 4</b>	
<b>Immigrants &amp; Local Population</b>	<b>13.10%</b>	<b>Immigrants &amp; Local Population</b>	<b>9.79%</b>	<b>Secondary Industry worker</b>	<b>12.36%</b>
Local population	0.886	Local population	0.748	Secondary industry employees	0.743
Immigrants	-0.909	Intra-provincial immigrants	-0.783	Low-income-occupation population	-0.794
				<b>Factor 5</b>	
				<b>Immigrants</b>	<b>8.85%</b>
				Inter-provincial immigrants	0.826
				Intra-provincial immigrants	0.569

Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization

a. Rotation converged in 6 iteration (1990); b. Rotation converged in 7 iteration (2000); c. Rotation converged in 8 iteration (2010).

### 3 Urban social dimension extraction and deconstruction

Deconstructing the urban social dimensions focuses on establishing relationships between various principal factors to understand how they relate to socio-spatial transformations in different periods. It shows the relationship between society and space by focusing on various aspects such as age, employment, education, income, and migration. In this study, deconstruction is based on variable loadings on factors and spatial distribution features of factor scores. We describe the factors with the categories of connotations as illustrated in **Table 2**, while visualizing the social spatial evolution in the maps of factor scores (**Figure 5, Figure A1**). **Figure A1** shows the

enlarged maps of factor scores presenting the area within the third expressway wing to outstand the high-density neighborhoods in the city center while **Figure 5** expresses the whole study area.

### 3.1 Workforce

In 1990, Factor 1, the main workforce, was characterized by low-income occupational population as well as non-agricultural industry workers. Those who engaged in secondary or tertiary industries were linked to high-income occupations. As illustrated in **Table 2**, Factor 1 explains 45.55% of the total variance and is best presented by low-income occupational population, minor dependents, high school educated population, non-agricultural workers, and high-income occupational population. Since population mobility was low in the 1980s, these laborers in high-income occupations were mostly part of the local population. High school education was dominant since China had not yet reformed to expand higher education in this period. The non-agricultural industry workers distribute mainly in the central city area and Wuhan Iron and Steel Industrial Zone. Low-income and dependent minor populations have negative loadings of -0.984 and -.913 respectively and are concentrated in the periphery of the central city (**Figure 5 (a)**).

The variables with high loads for Factor 1 in 1990 formed the main information of Factor 1 and Factor 2 in 2000. In 2000, Factor 1 consisted of tertiary industry workers with high-income occupations. This group has education at a college-level and is mostly linked with unmarried singles (**Figure 5 (e)**). Factor 2 represents secondary industry employment with a high school education background, with positive loadings of 0.864 and 0.647 respectively. This factor has a negative linkage with immigrants from other provinces. The higher score value areas of Factor 2 indicate clusters of those working in secondary industry with a high school education background. From the spatial distribution aspect (**Figure 5 (f)**), the areas of secondary industry employment distribute mostly in the Iron and Steel Industrial Zone in QS District, followed by Zone II and III in the west of Yangtze River. There is a change in the link between educational background and employment. In 1990, the main workforce of non-agricultural industry was high school educated, including secondary industry and tertiary industry. When it comes to Factor 2 in 2000, the population with a high school attainment has a high load, which is linked to secondary industry employment; while the highly educated population has a high load on Factor 1, which is linked to tertiary industry occupations. This transformation is mainly due to the reforms that expanded and promoted the development of higher education (Cheng, & Zhou, 2015). The population with low-income occupation and immigrants from other provinces are concentrated mainly in the periphery of the central city, indicating the priority of the marginal location choice by the low-income floating population<sup>38</sup>.

In 2010, Tertiary industry workers and secondary industry workers were with high loads on Factor 1 and Factor 4 respectively. Factor 1 is represented by tertiary industry workers with a load 0.887, non-agricultural population (0.835), high school educated population (0.802), and high-income-occupation population (0.513). According to the factor score map (**Figure 5 (i)**), in 2010, high-score areas for tertiary industry employment distribute in the city center, especially along the Yangtze River, while those for secondary industry employment has been relocated to the urban fringe area in Zone III and IV (**Figure 5 (l)**).

Summarily, the 1980s workforce in the secondary industry concentrated in the city center but has been expanding and shifting in the subsequent years. In the 1990s, it declined in Zones I and II, accompanied by relocation in Zone III and IV. In the 2000s, the secondary industry employment expanded and was reorganized, relocating preferentially within or outside Zone III.

### 3.2 Highly educated population

Factors extracted in 1990, 2000, and 2010 show the transformation of links between population with highly educated background and employment.

In 1990, Factor 2 presented the highly educated population with a positive loading (0.803), whereas married people had a negative loading (-0.853). This designates the unmarried population with higher education backgrounds as the social dimension Factor 2. In this case, a higher factor score indicates clusters of the highly educated single population, which mainly concentrated in HS District, especially in the East Lake High-tech Development Zone, where there agglomerate high-tech industries, universities and institutes (**Figure 5 (b)**).

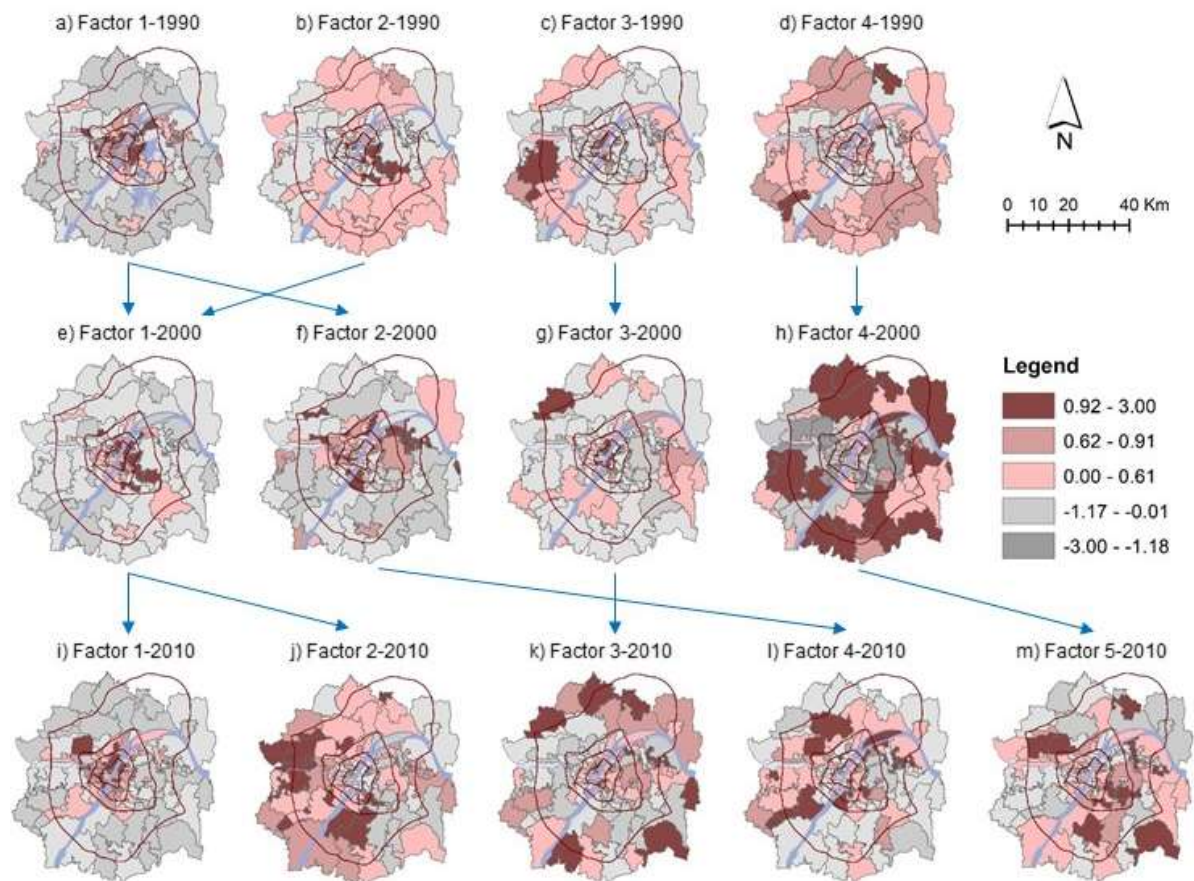
In 2000, Factor 1 presented a positive link between highly educated population (0.923) with high-income occupations (0.903) employed in the tertiary industry (0.794). According to Cheng and Zhou (2015), high-tech industry developments and industrial transformations were one of the main focuses during China's development of the urban industry in the 1990s. This helped to initiate education reform as the main foundation for the modernization of Wuhan's society and economy thereby influencing employment opportunities. Employment of the population with post-secondary educational background and high-income occupation in the tertiary industry expresses the results of the urban industrial transformation. A higher score of Factor 1 indicates the spatial

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<sup>38</sup> Floating population refers to the population who has left the place of household registration to live in other places. Internationally, similar groups are called "internal migration".

aggregations<sup>39</sup> of the labor force with post-secondary education and high-income occupations and vice versa. The social areas with the highest score are mainly agglomerated in the Optical Valley (upgrade area of East Lake High-Tech Development Zone), and the central business area of the city (**Figure 5 (e)**). The low-value areas are located in the periphery of the central city.

In 2010, Factor 2 represented the highly educated population (-.803) and the married population (0.876) with minor dependents (0.703). From a spatial distribution perspective, the highly educated population (represented by the lower score areas) are concentrated in WC District, the intensive areas of the University in HS District, and the Iron and Steel Industrial Zone in QS District (**Figure 5 (f)**). Factor areas with higher scores represent married population with minor dependents, to a great extent, indicating small-sized households in this stage.



**Figure 5** Social spatial transformations

### 3.3 Aging Population

Like many other countries, China is inevitably facing population aging, which has become more and more pronounced since the late 1970s. The aging trend is closely associated with the birth waves during the 1950s and 1960s. It is also due to a prolonged human life span based on improved living standards and health welfare policies. The one-child policy affects population aging through a decrease of the proportion of minor dependents to the total population. The elderly population formed the third factor in 1990 in Wuhan, featuring a population over 65 (0.955) along with a divorced or widowed population (0.938). In 2000, this factor stayed unchanged with the same contributing variables. However, the local population (0.854) joins the elderly population (0.842) to form the third factor in 2010, indicating a link between aging and the local population in Wuhan. It also implies that immigrants are mainly workforces and their minor dependents may migrate with them.

<sup>39</sup> “The concept of spatial aggregation has been defined in two different ways, that is, the number of neighbors within a habitat unit (Lloyd 1967) or on the distance to the nearest neighbor (Clark and Evans 1954).” (Bouchard et al., 2018).

Spatially, the highest score areas of Factor 3 (Aging population) in 1990 located in Zone I of Hankou, while expanded to Wuchang and Hanyang in 2000. In 2010, the higher score areas mainly distributed within the East Lake Scenery district and suburban area (**Figure 5 (c, g, k)**). Comparison between different years' landscape shows that clusters of aging population mainly distributed in the city center from 1990 to 2000 but shifted to the urban fringe in 2010.

### 3.4 Mobility

In 1990, Factor 4 mainly represents the local population with household registration and is characterized by a negative loading (0.886) for the immigrant population and positive loading (-0.909) for the local population. From the factor score analysis, the high score indicates the spatial aggregation of the local population whereas the lower score means the spatial aggregation of the influx population. The higher score areas of Factor 4 in 1990 visualize the residential clusters of incoming population in the periphery of the central urban area (**Figure 5 (d)**), reflecting the concentration of immigrating populations in the urban fringe.

In 2000, the immigrant population was mainly reflected in Factor 2 and Factor 4. The intra-provincial immigrant has a negative loading of -0.524 in Factor 2, for which secondary industry employment (0.864) and high school educated population (0.647) are with positive loadings. The inter-provincial immigrant has a negative loading of -0.783 in Factor 4, for which local population is with a positive loading of 0.748. Areas with high values of factor scores for intra-provincial immigrant population cluster in the fringe of the city center.

In 2010, Factor 5 represented both inter- and intra-provincial population migration with load 0.826 and 0.529 respectively. In terms of the spatial features of factor scores, higher value areas present clusters of the inflow population. The map (**Figure 5 (m)**) is evident that the clustered areas of the inflowing population are mainly distributed in Zone IV, showing a spatially outward shift of the immigrant population's residence since 2000.

The spatial feature of the residence of the immigrants in the fringe areas of the city center is in line with the social characteristics of Wuhan. In 2010, higher factor score areas were in Wuchang and Hankou. Within the old center in Hankou, the higher score areas are mainly in QK and JH districts which are the traditional centers. In Wuchang, they are located along the Yangtze River (between the second bridge and the Yangtze River tunnel).

### 3.5 Urban social landscape transformations and conceptual pattern

The analysis of the principal factors of 1990, 2000, and 2010 illustrates the progressive transformations in the social landscape of Wuhan. The evolution of its social space is summarized in **Figure 6**.

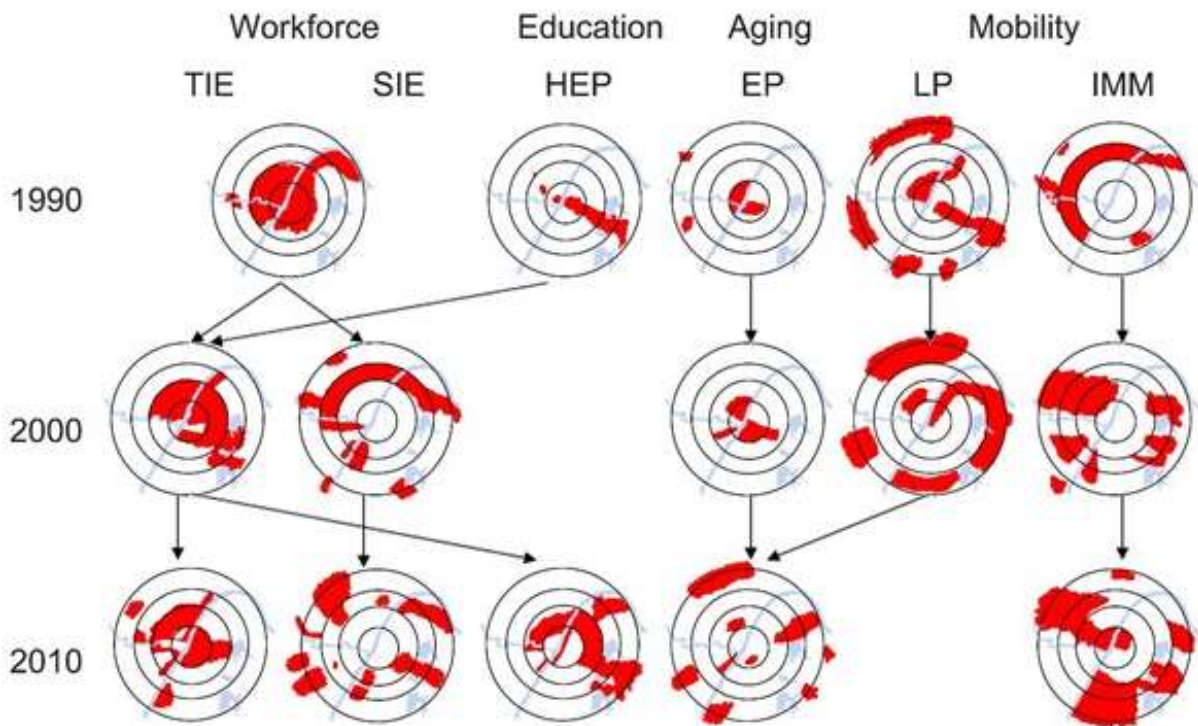
In the 1980s, the social communities in the central city area and Wuhan Iron and Steel Zone were mainly dominated by the close connections between employment in the secondary or tertiary industries and high-income occupational population who has a high school education background. During this period, the highly educated population linking with the unmarried population forms a separate factor, which is concentrated in university-aggregate areas in HS District.

The social development in the 1990s featured the agglomeration of tertiary industries in the city center and the relocation of the traditional secondary industries. The latter leads to the continuous expansion and clusters of secondary industry employment in the outer-city periphery, for example, in Wuhan's economic technological development zone. Meanwhile, a spatial expansion of a highly educated population links with the tertiary industry employment in the urban center. Immigrants' residential areas expand into the fringe of the city center.

In the 2000s, there were notable changes in the city center and outer city periphery that affected the distribution of tertiary and secondary industry employment. These become the main drivers of social, cultural, and economic transformations. Factors representing the married population with minor dependents to a great extent indicate the small-sized household in this stage. Highly educated population spatially expands, linking with the unmarried population due to the concentration of colleges and universities. Aging population linking with the local population shows a decline in the city center. Immigrants in this period constitute a separate factor that influences urban society, with spatial clusters moving toward periphery areas in multiple directions.

## 4 Urban socio-spatial transformation pattern and mechanisms

The transformation of Wuhan's urban social space reflects the social and demographic trends of China's second-tier cities. These changes are consistent with Wuhan's reconstruction process over the past three decades. Some notable features of social space evolution are related to the city's traditional history and its natural distribution of rivers/lakes. As discussed below, the transformation of Wuhan's social landscape is motivated by the driving force of the larger area and the centripetal and centrifugal forces within the city.



TIE: Tertiary Industrial Employment; SIE: Secondary Industrial Employment; HEP: Highly Educated Population; EP: Elder Population; LP: Local Population; IMM: Immigrants

**Figure 6** Conceptual diagram of urban social factors

#### 4.1 Urban social spatial transformation

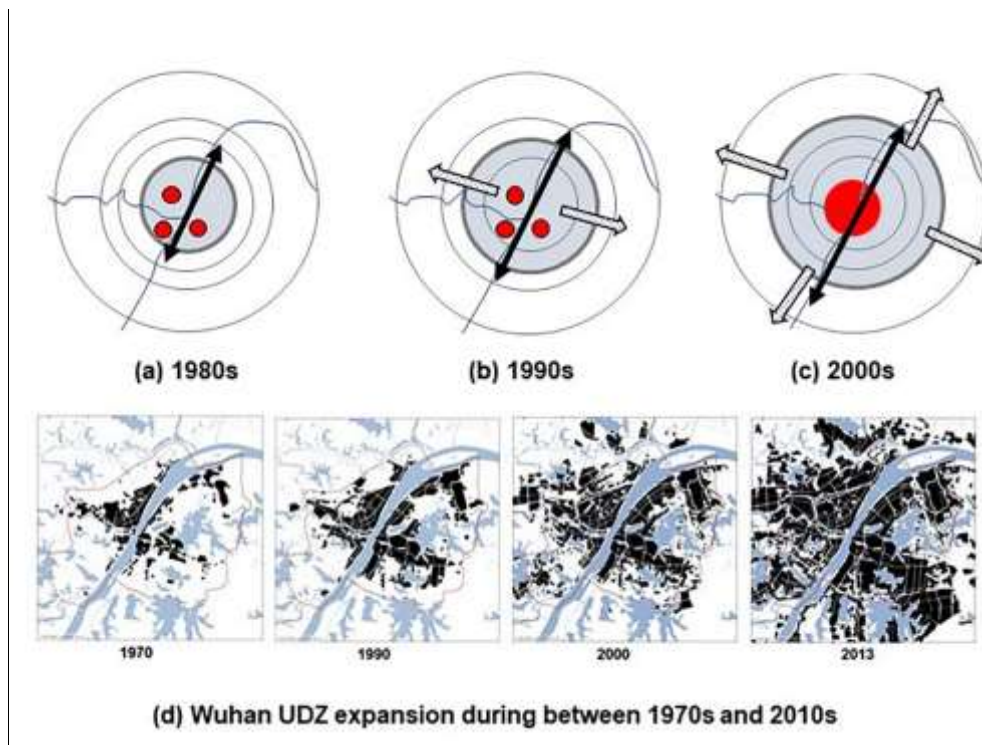
##### 4.1.1 From three towns to one big city: hollowing, expansion, and combination

Wuhan's urban social-spatial evolution presents the following characteristics: (1) the hollowing of residence and the reshaping of the urban center function; (2) the social space expanding significantly along the river and the east-west axis; (3) the development of three traditional towns to one modern city.

The hollowing of residence is specifically manifested by the local population's and the elderly's movement outward of the city center. This process has also resulted from the residential community reconstruction to improve the living conditions which push the low-income population out. From an industrial employment perspective, the urban center has evolved from a mixed distribution of both secondary and tertiary industries to a tertiary industry functional zone.

The social space extends along the river and the east-west axis. Natural geographical conditions form a certain centripetal force to the evolution of urban social space. Both sides of the Yangtze River form a development axis in the direction of north-south. In the east-west direction, Han River and the main road between East Lake and South Lake (located in Wuchang) constitute an attraction axis. Among them, the formation and expansion of the eastward axis were driven by the expansion of higher education in the 2000s on the one hand and the development of high-tech industries on the other.

These three traditional towns have been gradually transitioning into one modern city (**Figure 7**). Before 2000, the industrial optimization and population structure of Hankou, Hanyang, and Wuchang were significantly different, showing the relatively stable industrial features in each area. However, after 2000, with the further adjustment of the industrial layout, the city center formed a tertiary industry-led function. As a result, the differentiation of the three towns weakened and began merging towards the direction of a modern city in urban planning.



**Figure 7** Conceptual model of urban social landscape transformations (Wuhan urban social space was characterized as 'the traditional three-town city center and the Yangtze River axis' in the 1980s, 'the integrated urban center, strengthened Yangtze River axis, and the east-west wings' in the 1990s, and 'the expanded urban center, Yangtze River axis, and multi-clusters' in the 2000s. The physical landscape expansion during the corresponding period gives the images from an axis-oriented pattern to a big city.)

#### 4.1.2 Comparison with classic models

As a heavy industry city, Wuhan's social spatial transformation is relatively lagging when compared with the first-tier cities due to its slow economic growth prior to the 1990s. In the 2000s, when the city's economic growth accelerated, transformations of the social landscape were also quite significant. Its social-spatial transformations have strong local features, especially in the layout supported or constrained by natural conditions (e.g., distributed along riverbanks or along the main road between great lakes). In addition, the upgrading of traditional industry, development of education bases and attraction of talent to the high-tech industry are also important features of Wuhan's social landscape transformations. In the 1990s, these transformations reflected the functional division of multi-city centers segregated by rivers. In the 2000s, with the further improvement of social and economic functions, the advantages of large cities highlight the soft power of attracting talent. During this period, Wuhan's central position was in strength with support of a large regional transportation network that is unmatched by other second-tier cities.

The transformation of Wuhan's social landscape presents the fusion of different classic models. The classic social space models refer to concentric rings, sectors, and multiple nuclei. Wuhan's social space is undergoing a transformation process, from the multiple core model (traditional three towns) to the multiple nuclei model that combines concentric rings and sectoral clusters. This is the integration of multiple spatial models. The transformation of the urban social landscape is social performance in urban industrial upgrading and rearrangement.

The classic model looks at the urban social areas from perspectives of family, income, and ethnicity. In addition to the family (aging population, family structure), economic class (education, occupation), ethnicity (immigrants), Wuhan's social dimension highlights the function of industry, especially the transfer of the employed population through industrial upgrading and relocation. In China, industrial upgrading reshapes urban social areas and promotes the coordinated development of social and economic ecology.

#### 4.2 Push-pull, centripetal-centrifugal forces form social landscape transformations

From the perspective of social ecology, urban social transformations are the manifestation of economic development which adapt to economic transformations. This process is comprehensively affected by the pushing

and pulling forces in large regions. Within the city, social-spatial transformations depend on the comparison of centripetal and centrifugal forces.

#### *4.2.1 Push and pull: Regional forces*

Push force is the driver in people's original area of residence which promotes them to leave to other places, while pull force is that in a new place which attracts a population to relocate there.

The push forces are mainly formed due to the lack of job opportunities, fewer public services, less transport links, and less educational opportunities, or poor medical care, which are often associated with rural areas or small towns. The most important pull force of the city is generated by a loose household registration policy which attracts a certain population to migrate from their original place to this city. The household registration policy is matching with the economic development and the corresponding demands of workers. The macro-economic strategies offer this city development priority, for example, upgrading Wuhan's central position from provincial to national<sup>40</sup> (Figure A2) and enhancing Wuhan's economic importance on the central section of the Yangtze River Economic Belt. Those strategies increase Wuhan's pull forces by improving the city's economic development environment in the transitional period. In detail, the pull forces are embedded in varied employment opportunities, higher income, quality of education, improved standards of living, access to health care, availability of other public services, and future prospects for individuals and families. The pull force is associated with the level of urbanization and industrialization, as reflected in the city's social and economic accumulation, policies of population resettlement, and employment.

In the 2000s, the Chinese central government focused on the importance of the central region's development. During the same period, a high-speed railway network was formed in China. The railway enhanced Wuhan's pull force for attracting a floating population and accelerated urbanization. In terms of industry, the upgrading that began in the 1990s experienced rapid developments in the 2000s, creating more employment opportunities. During this period, the Wuhan government also carried out a series of reforms to the settlement policy to further attract additional population.

#### *4.2.2 Centripetal and centrifugal: Forces within the city*

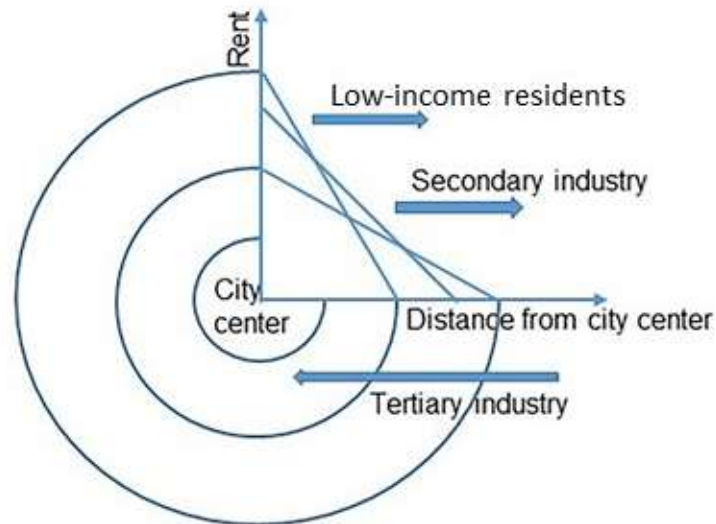
Centripetal and centrifugal forces determine economic and social interactions, involving spatial infrastructures, which orient the city growth from the inner city outward to the periphery. The centripetal force is influenced by the advantage of employment opportunity, the infrastructure network, the more convenient accessibility to public services, etc., while the centrifugal force is mainly affected by higher cost for residence in the city center, as well as traffic congestion, higher population density, or lower quality of natural ecology. Wuhan's population rapidly increased in the 2000s, as a result of regional push-pull forces formed by population migration policies, economic development and advances in rapid transportation network building. The centripetal forces are generated by gentrified society in the redeveloped or newly developed neighborhood, by employment opportunities, and by this convenient transit system. The centrifugal forces are formed under the government's removal of the "three olds" and market-oriented high residential cost in the city center. In the market economy environment, the centrifugal forces of the old city center reconstruction and land rent bidding on the original resident population became apparent in the 2000s. Some of the main drivers of urban social landscape transformation include the relocation of industry and reconstruction of residential houses. Industrial enterprises freed up prime locations through relocation and used compensation funds to upgrade industry structures. The prime location was then replaced by a commercial use that could afford higher rents. In addition, the reconstruction of communities has been improving the living environment of many residents in the old urban area.

Before 1997, communities in old cities of Wuhan were rebuilt in their original region and only physical (house) compensation was implemented with the principle of "compensation according to the original area". Therefore, the local population density in the old city has not changed much due to the improved living environment, while these improvements are not obvious. However, since 1997, the owners of soon-to-be-demolished housing can choose monetary or physical compensation, within which monetary compensation is encouraged. After implementing monetary compensation, developers and residents have a certain flexibility in supplying and buying houses respectively. The developer has cut the obstacles of "rebuilding on the original location" and can build suitable types of houses according to market demand. After receiving the monetary compensation, the homeowner can choose the location and size of the new house according to their needs and affordability.

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<sup>40</sup> Wuhan's status in China has been continuing to improve, from a provincial capital city in the 1980s to a provincial regional central city in the 1990s, then to a national regional central city in the 2000s, and finally to a national central city in the 2010s. This not only reflects Wuhan's central position in the circulation of people, logistics, and information in large areas but also demonstrates the changes in economic and geographical conditions in the large areas. The improvement of the city's status also means the reform of the national industrial and financial policies that support urban socio-economic development.

The reform of this city's compensation system has shifted the relocation of residential community spaces from forced to voluntary. The old city center that transformed physical spaces has reshaped the urban social structure. Therefore, in the 1990s, the elderly population in the city center showed an increase; while in the 2000s, they present a trend of moving outward from the center. The relocation of industries and residential communities reflects the pursuit of land market value in Wuhan's social and economic transformations, that is, the realization of bidding for land rent in Wuhan (**Figure 8**), during which period the government's finances are highly dependent on land transfers<sup>41</sup>.



**Figure 8** Bid-rent based relocation in Wuhan (Revised based on bid-rent model by Alonso (1964))

Wuhan's bid-rent model can be explained from two aspects, one is the government-led land supply and zoning, and the other is the development of market-oriented commercial real estate. China has established a planned quota system for the supply of construction land, and the urban macro-spatial pattern has been proposed through zoning. Since the 1980s, the location theory from Europe and the bid-rent theory from North America have been adopted by China's urban planning and have actively guided the zoning of land functions. Therefore, although the zoning of urban space is dominated by government-led allocation, it is guided by the realization of the maximum value of urban land. With the market-oriented reform of land supply, urban space has become a product of the combination of bidding and economic agglomeration. For example, the secondary industry moves to the periphery of the city center and develops in industrial parks; the tertiary industry develops toward the city center. For residential properties, higher prices promote the migration of low-income people out of the city center. On the one hand, this is the result of the redevelopment of the city center, and on the other hand, it is also a manifestation of the gentrification of the city center. In summary, industrial relocation and the replacement of residential locations are all manifested as the result of the bid-rent model. Although in China, it is based on the integration of the government and the market.

#### 4.3 Urban social management with more inclusion<sup>42</sup>

As economic institutions transformed, social planning and management started to shift from a top-down approach to being more inclusive. Similar to the first-tier cities in the 1980s, the social landscape of Chinese cities depended on the top-down system. At this stage, the planned economy remained dominant, and its impact on the urban social landscape was reflected in the planned allocation of housing and employment. The work unit reflects

<sup>41</sup> The dependence of Wuhan's local finance on land transfer fee is higher than 0.7, ranking top 10 among big cities in China. In 2007, the dependence was as high as 0.86. (Data source: Research Institute of Taxation, State Administration of Taxation (2014).)

<sup>42</sup> "Social inclusion is defined as the process of improving the terms of participation in society, particularly for people who are disadvantaged, through enhancing opportunities, access to resources, voice and respect for rights." (ESA-UN. Chapter 1 Identifying social inclusion and exclusion. <https://www.un.org/esa/socdev/rwss/2016/chapter1.pdf>. Accessed on June 20<sup>th</sup>, 2020)

the employment-residential relationship at this stage. As the socialist market economy advanced in the 1990s, market allocation played a gradually increasing role in housing, population mobility, and education. In the 2000s, the proportion of market allocation increased dramatically along with the reforms. The market has been and continues to exert considerable influence in the evolution of the social landscape. Consistent with the economic system, urban social space management and governance has undergone a gradual process of evolving from more exclusive to more inclusive.

The transformation of the social landscape is accompanied by social diversification<sup>43</sup>, when people with different social demographic characteristics migrate to a community. Along with social diversity, inclusion is more essential than ever, especially for vulnerable people and families such as the low-income population, immigrants, or elders. For example, **Figure 9** explains how social management and governance has been reforming from exclusive to inclusive. When targeted to a floating population who left their original household registration place to reside in this city, the registration related policies referring to employment and unemployment insurance, house purchase right, public compulsory education accessibility, medical care, and pension coverage, have been reforming from totally exclusive to fully inclusive, for which some are still undergoing this process. Nevertheless, it is clear that to develop a more inclusive society is a growing trend for urbanization and for sustainable urban social development.

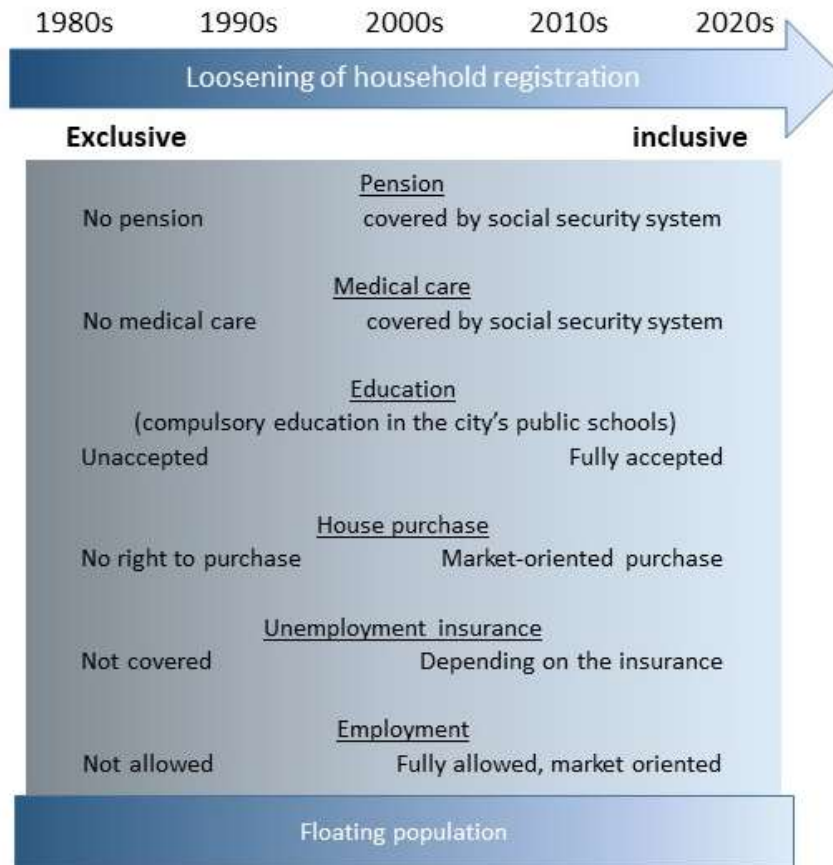
One of the most powerful drivers of social landscape transformation is housing policy. Its reform in the city of Wuhan highlights a market-oriented decision-making process. In the 2000s, the overall promotion of the housing market led to the differentiation of residential areas in the city center which became more dependent on social class and income level. However, the development of affordable housing for low-income people was seriously overlooked. According to Zhang et al. (2011), affordable housing in Wuhan was mostly distributed in the urban periphery and relatively deviated from the rapid public transport. This can also help to interpret immigrants' spatial features of choosing to cluster in neighborhoods that surround the city center.

The household registration system had far-reaching influences on the floating population increase and distribution. This is depicted by the population of immigrants in 1990 which is the lowest when compared to 2000 and 2010. The floating population cannot enjoy the same rights as the registered residents in employment, labor training, children's education, housing and other aspects, nor can they enjoy relevant rights and interests. Since the 1990s, Wuhan has been enacting regulations to lower the threshold for the incoming population to access public services. For example, in 1995, Wuhan registration and temporary residence permits were applied to the incoming population. In the 2000s, with increased demands for urban economic development and the recognition of a booming immigrant population, Wuhan eliminated administrative charges for the incoming population. In 2010, Wuhan replaced the temporary residence permit system with a residence permit system, which would dilute the difference in status between the migrant population and local citizens. These policy changes gradually narrowed the gaps between the incoming groups and the local population as regards to their rights to access housing, education, medical care, and other essential services. Even though the temporary residence policies were lagging behind the demands, it slowly mitigated the social differences of immigrants to the local population. Recently, Wuhan has issued preferential housing purchase and settlement policies to attract highly educated talent. The reform of immigrants' housing policies will promote the reduction of differences in the rights and interests of residents due to household registration and potentially form a more inclusive social landscape. In other words, with the implementation of more inclusive policies, the living space of immigrants is more integrated with the local population.

Social management is now more people-oriented and inclusive, valuing varying socio-economic attributes of residents throughout decision-making processes. The threshold for diverse groups of people to contribute to urban development and gain access to public services continues to flatten. From another perspective, this supplies a platform for different individuals to engage in social affairs. So far, social management has been transforming from more exclusive to more inclusive in China's second-tier city.

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<sup>43</sup> Diversity is defined by a variety of differences between individuals. Social diversification is the process of changes in the social demographic characteristics of communities, accompanied by the transitions of relations between social groups. It can be simply described as a community with an increasing variety of socio-demographic characteristics. For example, the household registration system reforms encourage an influx of population from various places, whereas industrial clusters in corresponding zones attract workers to reside in nearby communities, changing the neighborhood's demographics and thereby increasing social diversity. Redevelopment of the old city center attracts high-income residents as well as tertiary industrial employees and their families to live in communities within this area, thus enhancing the social diversity. These transitions promote communities to become more socially diverse. The expansion of immigrants' spatial distribution indicates the diversification in corresponding neighborhoods. Residential location preference under the existing market coincides with the social diversification process. In detail, at the neighborhood level, the social diversification occurs when the demographic structure changes. The variance is presented, for example, between immigrants and local population, between higher-educated employees and lower-educated ones, between aging population households and small-sized married-population-with-kids households, between populations working in a variety of units.



**Figure 9** Urban social management and governance transformation

## 5. Conclusion

This study relies on the latest three census data sets (1990, 2000, 2010) and varimax rotated PCA to provide an important review of social landscape transformations and their mechanisms in China's second-tier city Wuhan. It is supported by relevant research in the 1980s which focuses on the beginning of the socialist market economy that has led to its overall development.

Since the 1980s, the social areas of the second-tier city Wuhan have undergone significant transformations. The space of the secondary industry employment developed outward from the city center, and that of the tertiary industry employment continued to expand in the city center. This transformation became more prominent in the 2000s than in the 1990s. The landscape transformation of industrial employment is accompanied by the improvement of workers' education levels. In terms of population aging, elderly populations have gradually moved out of the city center. In the 2000s, population mobility increased significantly and immigration became an important social dimension. However, the process of responding to these changes was lagging behind in comparison to first-tier cities. The local population shows a spatial characteristic of decline in the city center which implicates relocation. The spatial characteristics such as the spatial hollowing of the secondary industry are present in the second-tier city, which is like those in the first-tier cities, but the performance period in the second-tier city is relatively late. Affected by industrial relocation/upgrading, the social space transformations of this period are characterized by a combination of continuous (outward expansion) and discontinuous (sporadic transfer). Wuhan's social landscape exhibits concentric rings and sectoral-shaped social-spatial patterns, and additionally presents a significant axial expansion characteristic that is closely related to the distribution of rivers, lakes, industrial parks, infrastructure lines and nodes.

The push-pull forces at the macroscopic spatial scale, as well as the centripetal-centrifugal forces inside the city, promote the transforming urban social landscape. Push and pull forces are formed when there is less employment opportunity, less income in rural areas and loose of temporary residence and loose household registration policies in a Chinese city. The push-pull force has promoted Wuhan to form economic and social attractions that are matched with the city's positioning in central China.

The centripetal and centrifugal forces within the city are related to policies/plans for secondary industrial relocation, housing, education, household registration, etc. The city center carries centripetal force due to land rent bidding, while rapid transit networks and industrial development have promoted social clustering. However, this cannot be achieved without policy reforms that affect the urban social landscape transformations at the macro level. From a broader perspective, the transformations of the urban social landscape are guided by industrial upgrading and zoning, marketization of housing, and lowering of the household registration threshold.

The case of Wuhan shows that national and local policies continue to affect the urban social landscape transformations, bringing order to them. The transformation of the social areas in the second-tier city has been promoted by the important role of planned economic system in the 1990s, and the role played by the market economy in the 2000s which has grown significantly. The role of the planned economy in the social spatial transformation in the second-tier city is like that in first-tier cities, but its timeline trails behind.

This article may provide reference to other second-tier cities in China and cities in other rapidly urbanizing regions. In addition to the classic social dimensions involving family, economic class, and ethnicity, industrial relocation reshapes urban social landscape patterns in the Chinese second-tier city. Moreover, compared with high-income countries, China's internal population migration is a distinctive feature. With changes in the socio-economic environment, domestic immigrants in China possess a higher degree of flexibility in the choice of residence and employment during the 2000s, which is quite different from the opportunities present to this group during the 1980s or 1990s. These characteristics implicate that, for cities in countries and regions with similarities, the study should regard industrial relocation and internal migration as special social dimensions.

The limitation of this study is that the setting of variables is restricted by the census indicators. For example, we use occupation to refer to income level, although its correlation became weaker in the 2000s. A combination with survey data in the future might be helpful for deepening the research findings.

Social landscape transformed in a way that promotes diversity, which is linked to inclusion. The concerns of vulnerable populations should be emphasized more under a market environment. A comprehensive system related to household registration, employment, housing, and education, should be continuously improved to build a more inclusive society.

#### Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

#### Author Contributions

Conceptualization, L.Z. and H.C.; methodology, L.Z., R.H., and H.C.; validation, L.Z.; formal analysis, L.Z.; investigation, L.Z.; resources, L.Z.; data curation, L.Z.; writing—original draft preparation, L.Z.; writing—review and editing, L.Z., R.H., and H.C.; visualization, L.Z.; supervision, H.C.; project administration, H.C.; funding acquisition, L.Z. and H.C. All authors have read and agreed to the version of the manuscript.

## Appendix

**Table A1** Key and synonymous terms associated with varimax rotated PCA

Eigenvectors	Eigenvalues	Component loadings	Principal components
Direction part	Scale part (number)	Correlation coefficients, Factor loadings	Eigenvectors explaining the maximum portion of variance
Unit-scaled loadings	Variances explained by Principal axis	Correlation coefficient between the original variables and the unit-scaled components	Principal factors
Coefficients of orthogonal rotated variables	Variances along eigenvector	Component coefficients	Principal vectors
	Amount of variability eigenvector captured	Information of the amount of variance, magnitude	Principal axes
		Restore the original correlation matrix	Principal directions
		Multiple eigenvector by sq. root of the eigenvalue, the loading is the bare coefficient by the amount of variance, which make the coefficient to be measure of association.	

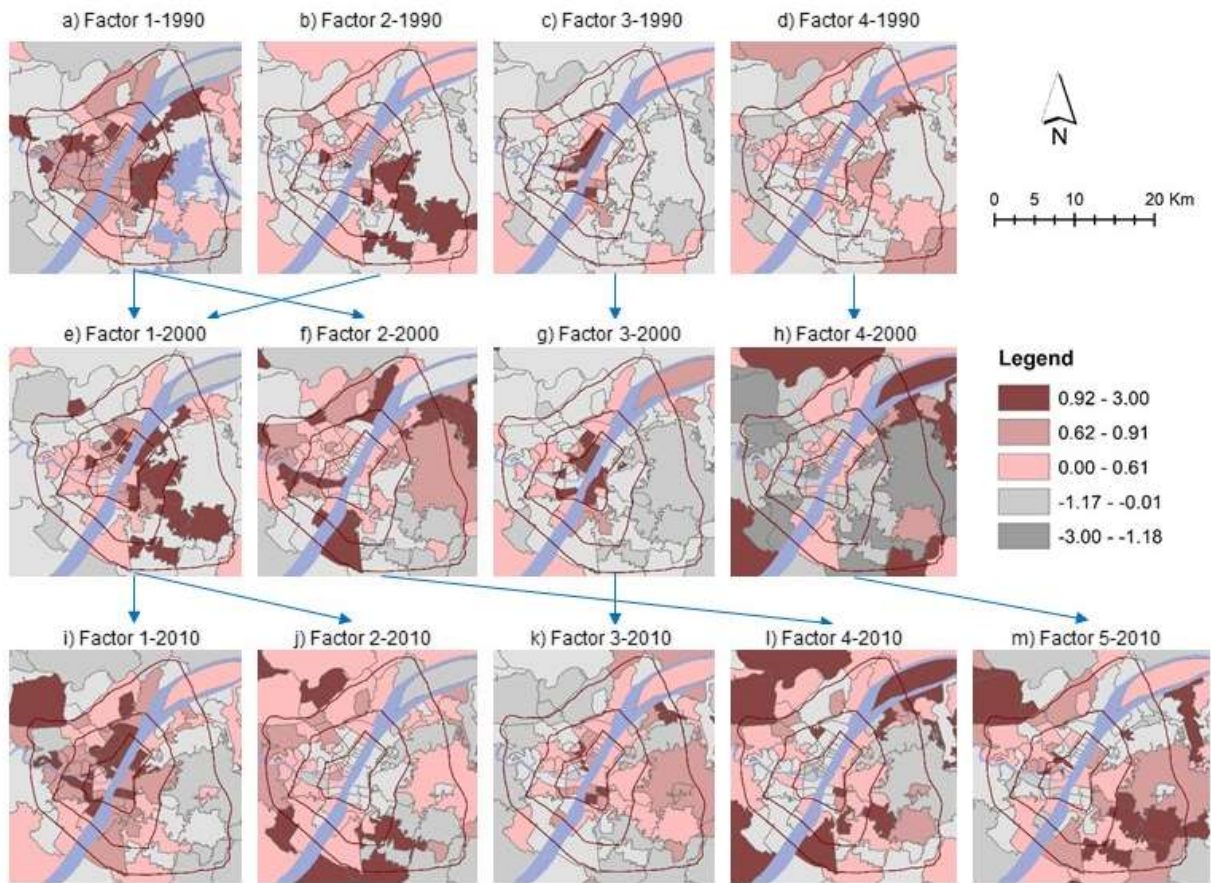
**Table A2** Percentage of Variance each rotated factor explains (2010)

Factors	Rotation Sums of Squared Loadings (After adjustment)			Rotation Sums of Squared Loadings (Before adjustment)		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.99	21.37	21.37	2.96	21.17	21.17
2	2.42	17.26	38.64	2.42	17.28	38.44
3	2.39	17.05	55.69	2.38	16.99	55.43
4	1.71	12.19	67.88	1.73	12.36	67.79
5	1.23	8.75	76.63	1.24	8.85	76.64

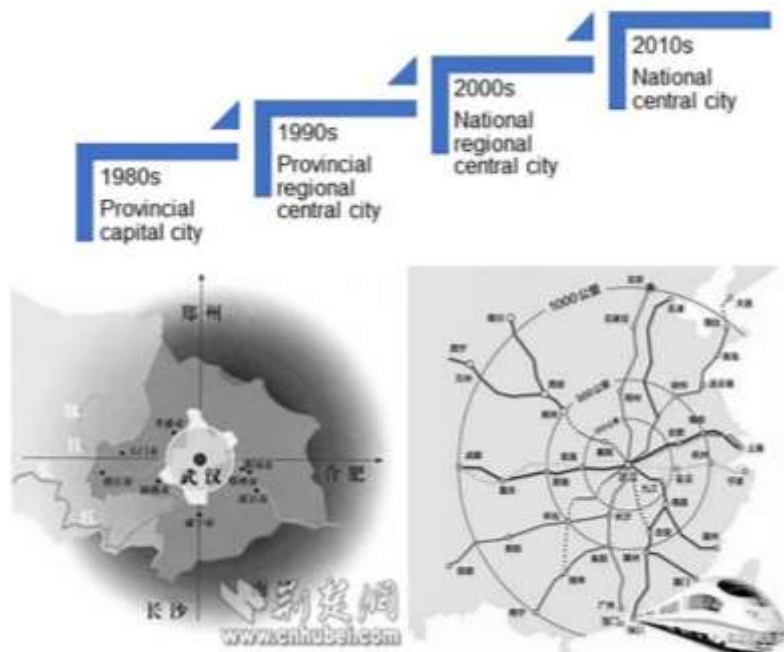
**Table A3** Comparison of varimax rotated PCA results (before and after neighborhood number adjustment, 2010)

	Rotated component metrics (After adjustment)					Rotated component metrics (Before adjustment)				
	1	2	3	4	5	1	2	3	4	5
Non-agricultural population	<b>0.840</b>	-0.288	0.159	0.211	0.035	0.835	<b>-0.287</b>	0.170	0.221	0.041
Local population	-0.181	0.124	<b>0.851</b>	-0.101	0.026	-0.168	0.115	<b>0.854</b>	-0.099	0.031
Intra-provincial immigrants	0.136	0.182	-0.360	-0.252	<b>0.581</b>	0.148	0.157	-0.373	-0.249	<b>0.569</b>
Inter-provincial immigrants	-0.145	-0.115	0.126	0.016	<b>0.817</b>	-0.148	-0.097	0.127	0.008	<b>0.826</b>
Minor dependent	-0.323	<b>0.691</b>	0.176	0.021	0.134	-0.309	<b>0.703</b>	0.153	0.020	0.139
Elders	0.129	0.272	<b>0.842</b>	0.006	-0.011	0.138	0.265	<b>0.842</b>	0.008	-0.008
Married population	0.101	<b>0.874</b>	0.229	0.066	-0.036	0.113	<b>0.876</b>	0.218	0.065	-0.036
Divorced or widowed population	0.325	0.339	<b>0.762</b>	-0.262	-0.029	0.342	0.331	<b>0.759</b>	-0.260	-0.026
High school educated population	<b>0.803</b>	0.144	0.003	0.066	-0.163	<b>0.802</b>	0.153	0.018	0.070	-0.164
Highly educated population	0.229	<b>-0.801</b>	-0.232	0.213	0.168	0.211	<b>-0.803</b>	-0.228	0.220	0.176
Secondary industry employees	-0.282	0.155	-0.185	<b>0.751</b>	-0.119	-0.295	0.160	-0.168	<b>0.743</b>	-0.124
Tertiary industry employees	<b>0.887</b>	-0.228	-0.058	-0.230	0.038	<b>0.887</b>	-0.231	-0.063	-0.230	0.040
High-income-occupation population	<b>0.526</b>	-0.272	0.126	0.488	0.350	<b>0.513</b>	-0.265	0.117	0.498	0.360
Low-income-occupation population	-0.371	0.173	0.100	<b>-0.782</b>	0.066	-0.352	0.174	0.106	<b>-0.794</b>	0.069

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 9 iterations



**Figure A1** Social spatial transformations (city center)



**Figure A2** Upgrade of Wuhan's positioning (A regional central city Wuhan in the strategic planning of central China, source: [http://hb.ifeng.com/news/jjcs/detail\\_2013\\_07/05/967640\\_0.shtml](http://hb.ifeng.com/news/jjcs/detail_2013_07/05/967640_0.shtml); A national central city Wuhan in a high-speed railway network, source: [https://www.sohu.com/a/141307147\\_770237](https://www.sohu.com/a/141307147_770237). Accessed on Feb. 2<sup>nd</sup>, 2018)

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## Chapter 3 Understanding Urban Land Growth through a Social-Spatial Perspective<sup>44</sup>

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# Understanding Urban Land Growth through a Social-spatial Perspective

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**Abstract:** To understand the urbanization process, it is essential to detect urban spatial growth and to study relations with social development. In this study, we take Wuhan as a case to examine urban land growth patterns and assess how social factors relate to the urban land evolutions taking place between 1990, 2000, and 2010. We first classify land cover using Landsat images and examine the urban growth patterns during various stages based on landscape metrics regarding the area, density, and shape. Afterwards, principal component analysis and census data are used to extract key social factors. Thirdly, we apply geographically weighted regression (GWR) to depict the link between urban land metrics and social factors. The results indicate that the urban land coalescence and diffusion simultaneously exist, for which redevelopment, infilling, and edge expansion dominate the city center, and diffusion dominates the peripheral areas. Local regression models better fit the relationships between the social factors and the urban land patch shape regularities, while global regression better fits those with urban land areas. Coefficient surfaces of industrial relocation, educational level increase, and population aging in the GWR models with urban land patch shape regularities present the spatial transformation of social-physical relationships. The research provides a social-spatial perspective to understand urban land growth. It can be concluded that sustainable urban management should consider the coexistence of different urban spatial growth models and underline social transitions when examining the urban growth process. This should work for cities in rapidly urbanizing countries or regions.

**Keywords:** urban land growth; urban expansion; fractal dimension; social transition; geographically weighted regression (GWR); Wuhan; China

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## 1. Introduction

The changes in growth patterns caused by China's rapid urbanization process are remarkable. Currently, widely accepted concepts of urban growth are related to population, economic, and spatial growth [1]. Spatial growth is concerned with the changes in the geographical space occupied by impervious surfaces, which connects to human intervention. It is also the focus of this research. Urban spatial growth is described as an alternating process of diffusion and coalescence in high-income countries [2,3]. The two are considered to occur at various stages, showing a spiral upward trend. The growth is presented through five common forms "infilling, extension, linear development, sprawl, and large-scale projects" [4].

The different growth patterns among cities distinguish the corresponding development stages and characteristics, and a simultaneous occurrence of these patterns is also common [5]. While population agglomeration and economic growth promote sustained urban growth, they have also accelerated the pace of suburbanization and the shrinking of urban centers [6,7]. Having first been carried out in high-income countries and regions, urban expansion and contraction have long been the focus of urban studies. In China's large cities, urban expansion has been the focal point of research in the past two decades [8–13], while research on urban shrinkage, redevelopment, or suburbanization has only appeared in recent years [14–16]. Case studies comparing cities in China to those in high-income

countries/regions also exist [17]. However, research on urban management has yet to overcome the challenges of handling the different processes of growth and contraction [1].

Scholars tend to study urban growth patterns from a macro spatial scale and compare the patterns in different-income countries, to find common laws or differences for urban spatial growth in various stages. Findings on Beijing, Shanghai, Tianjin, and Guangzhou show that urban growth in these cities has almost been dominated by a coalescent period in the 1990s and 2000s with edge expansion [18]. Comparisons between 25 global cities in the 1990s, including Wuhan and Guangzhou, classified cities into four types as low-, high-, expansive-, and frantic-growth cities, suggesting that no low-density sprawl is shown in the Chinese case cities [19]. Both Wuhan and Guangzhou are categorized into high-growth cities with rapid, fragmented development. Though a few cities are studied, the results are coarse and offer little to understand how the human forces contribute to the urban land growth with spatial differences. Thus, to explore the spatial features of urban land growth a case study at the neighborhood level and from a social perspective is essential.

In recent years, most studies draw attention to single, developed cities in China. Li et al. (2017a) find that a variety of growth modes such as infilling, edge expansion, and leapfrog expansion concurrently took place in Beijing urban growth during 2000 and 2010 [20]. Gong et al. (2018) draw a similar conclusion for Guangzhou where the different modes developed alongside a reposition of “relative dominance” to reflect a dramatic process of change [21]. Lei (2019) finds that during 1988–1999 and 1999–2011, Shenzhen developed with more expansion in 1988–1999 and 1999–2011, and “a higher percentage of infilling” in 2011–2015 [22]. Studies on other second-tier cities such as Tianjin and Nanjing draw similar findings. Chen et al. (2016) find that in 1980–2013, Nanjing grew from a mixed distribution to the spatial separation “of residential and manufacturing land” [23]. This process enabled Nanjing to transform from a compact mononuclear city into a polycentric one, dominated on different stages by “infilling, extension, and enclave”. Liu et al. (2019) suggest that Tianjin’s growth was dominated by edge expansion, strongly pushed by government planning within a project-driven development zone [5]. Thus, the existing literature successfully explores urban land growth patterns within single cities, but more case studies on the second-tier cities in China are still essential in order to find a common law or differences for the growth process and to provide valuable information for city management in the future.

Multi-mode-growth of urban spaces has led to significant spatial heterogeneity within cities to a certain extent. To better serve the community’s residents, sustainable management needs to consider the complexity of the urban growth process. The spatial heterogeneity of urban growth is not only a result of existing physical conditions, but also of the social structures and performances of human interaction [24–27]. With the support of urban ecology theory and social ecology framework, researchers have developed strong academic interests in examining the relationships between social transformation and urban land growth [28–30]. It has become a consensus that the urban system is a human-dominated one. In an urban system, the social subsystem and the physical subsystem have the same weight, and the two interact with each other. With the socio-ecological approach, researchers can understand the relationships between social and physical subsystems as a spirally upward drive-pattern-process-result (DPPR) flow or equally weighted bilateral interactions [29,31]. No matter from which point of view, the social-ecological approach regards the relationships between society and physical subsystems as an important field for studying the process of urban growth, providing valuable information for urban space management. From another point of view, due to the limitations of data, skills, methods, how to examine these relationships still has a lot of room for improvement [32].

Empirically, urban spaces grow with the dominance of linear elements such as traffic lines and river/lake banks, constrained by the supply of land suitable for development, which is defined by natural elements such as hills/mountains, rivers/lakes as well as conservatory zones [24,33]. Besides physical factors, socio-economic development has also been recognized as both a trigger, as well as a consequence, of urban spatial growth [26,27]. Academic attention toward socio-economic forces in literature is mainly focused on temporal relationships, for which population density and GDP are the most popular explanatory variables to interpret urban spatial growth. However, concurrently focusing on the dual dimensions of time and space is not common when exploring how social factors are associated with urban growth. Furthermore, the literature on the relationships based on cross-sectional data is scarce, mainly due to data unavailability [33], though a few studies based on cross-sectional data

sets are published. For example, Han (2012) studies the dynamics of social influences on Beijing urban land growth over a period of twenty years, between 1980 and 2000 [12], suggesting that significant associations with spatial non-stationarities are present at the relationships between social and physical subsystems. Despite the extensive research on the driving mechanisms of economic development on urban spatial growth, there is still a lack of analyses from the perspective of social dimensions such as age, employment, family size, mobility, and so on.

Global regression approaches such as Ordinary Least Square (OLS) regression, stepwise regression, and logit regression are popular methods used to model the relationships between demographic characteristics, economic development, and urban land patterns [27]. The global regression generates only one equation for the entire study area, with no exploration of the geographical variances. However, to explore the spatial variances of the relationships, Geographically Weighted Regression (GWR), a local regression approach, is employed widely. GWR introduces geographic coordinates that define spatial locations as independent variables, and its results reflect the spatial non-stationarity of the regression models between explanatory variables and the dependent one [34]. Although the existing literature detects how physical elements and economic development affect urban land growth [35,36] it is now necessary to pay more attention to the social factors' links with this growth.

The main purpose of this research is to examine the growth pattern of a fast-growing second-tier megacity in China, using Wuhan as a case, and to analyze the social dimensions' relationship with the spatial-temporal evolution. Using this research on Wuhan, it is possible to better understand the foundation for urban spatial changes, especially from a social perspective, and to create new references for framing eventual urban planning policies in second-tier cities of China and cities in other rapidly urbanizing countries or regions. Specific questions are broken down to: (1) What are the spatial characteristics of urban land growth and the center-periphery relationships, measuring with landscape metrics? (2) How are urban spatial changes related to socio-demographic transformations? and (3) How do these relationships evolve longitudinally?

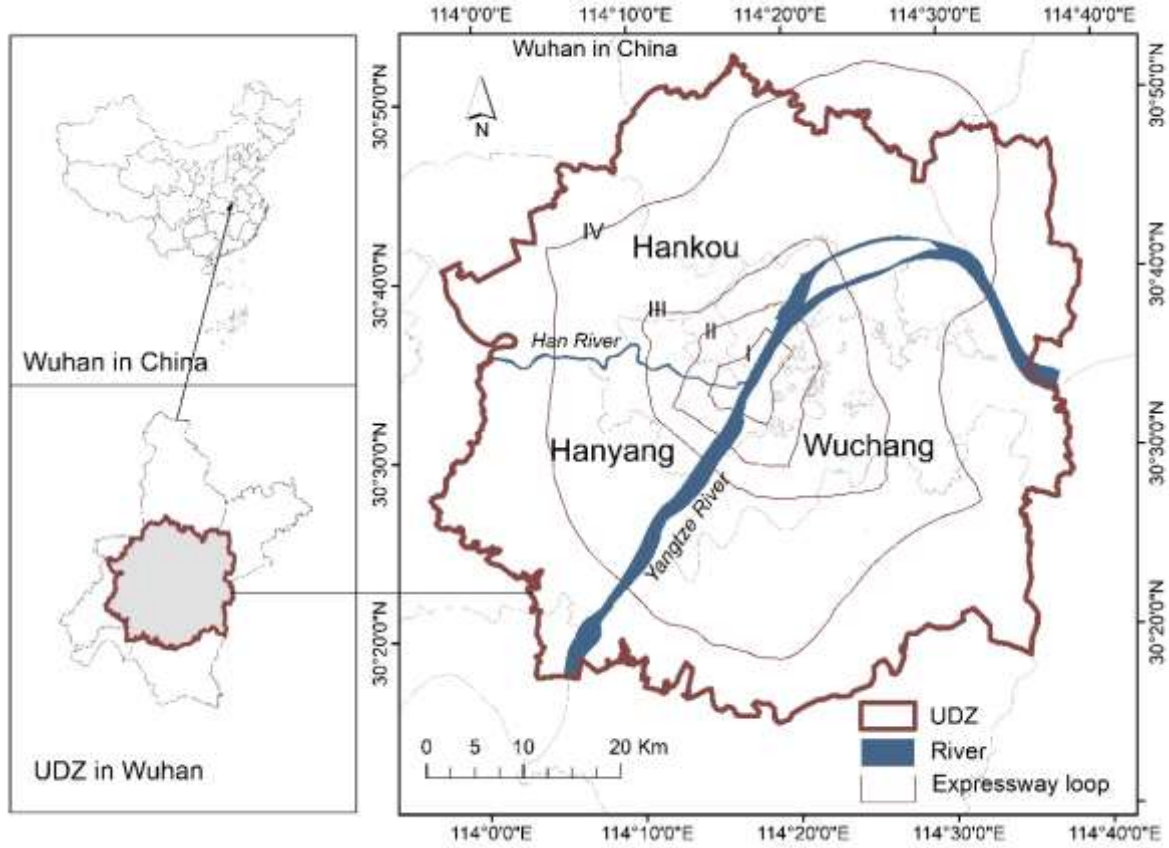
## **2. Materials and Methods**

This study combines remote sensing and GIS technology with landscape metrics to map and quantify the spatiotemporal features of the Urban Development Zone (UDZ), the fastest growing area, in Wuhan from 1990 to 2010. We used impervious surfaces to measure the evolution of urban space and to analyze growth patterns. The research focuses on comparing the growth in neighborhood units and depicting the local differences in social relationships. This approach is outstanding within the existing literature because it provides a distinct perspective on urban growth research. To achieve the objective, we carried out the extraction of urban land and computation of selected landscape metrics, the dimensionality reduction and extraction of social factors, and the regression modeling of the relationships.

### *2.1. The Study Area*

Wuhan is the capital of the Hubei Province, being recognized as the base of the New Cultural Revolution and a major transportation hub in central China (Figure 1). Physically, Wuhan is divided by the Yangtze River and the Han River and many other smaller bodies of water. Over the past few decades, Wuhan's status has steadily been elevated from a regional center to a national center, with a continuous transformation of industrial and consistent economic growth. Wuhan is a representative second-tier city in terms of population and investment agglomeration. Its growth is remarkable in the recent two decades, with corresponding notable social transformation as well as spatial expansion.

In the research period, the population density is decreasing in the city center, coinciding with traditional secondary industry removal and residential community redevelopment. The percentage of tertiary industry employment increased significantly in the urban center in the 1990s, and in the periphery of the urban center in the 2000s. The percentage of secondary industry employment shows a continuous decline in the urban center and a significant increase in the periphery of the urban center in the 2000s (Figure A1).



**Figure 1.** Map of the study area. Hankou, Hanyang, and Wuchang are three regions that are divided by the Yangtze River and the Han River. I, II, III, IV refer to the expressway loops from the center to the periphery.

## 2.2. Urban Land Extraction and Metrics Selection

We prepared temporal Landsat 5 Thematic Mapper (TM) images for the extraction of urban land. Rich-vegetation images in June and July were screened. However, because there are no suitable cloud-free images in 1990 and 2010, we considered a replacement with those in 1991 and 2011. Thus, the TM images employed are from 1991, 2000, and 2011, matching the social dimensions in 1990, 2000, and 2010, respectively. We then cut the images to the study area. The land cover extraction is based on the I–V–W (Impervious surface–vegetated area–water area) urban model. Band math is employed for the extraction (Appendix B). The water area was first masked using the modified normalized difference water index (MNDWI) [37]. The impervious surfaces were then extracted using a Modified Biophysical Composition Index (MBCI) we proposed, based on the Biophysical Composition Index (BCI) [38], for better distinguishing urban land and bare soil. The rest are vegetation areas. An example of land cover extraction is presented in Figure 2.

$$\text{MBCI} = \frac{[(BT + B + W) / 3 - G]}{[(BT + B + W) / 3 + G]} \quad (1)$$

where top of atmosphere reflectance (TOA) and brightness temperature (BT) images are used for MBCI computation. BT is [0, 1] standardized bright temperature extracted from the thermal band (Formula (2)). B, W, and G stand for [0, 1] standardized brightness, wetness, and greenness are calculated using the Formula (3)–(5) based on the first, second, and third principal components of Tasseled Cap Transformation (TCT), respectively.

$$BT = \frac{(BT_0 - BT_{\min})}{(BT_{\max} - BT_{\min})} \quad (2)$$

where  $BT_0$ ,  $BT_{\min}$ ,  $BT_{\max}$  are the observed, minimum, and maximum values of the bright temperature, respectively, and

$$B = (TC1 - TC_{min}) / (TC1_{max} - TC1_{min}) \quad (3)$$

$$G = (TC2 - TC2_{min}) / (TC2_{max} - TC2_{min}) \quad (4)$$

$$W = (TC3 - TC3_{min}) / (TC3_{max} - TC3_{min}) \quad (5)$$

where TC1, TC2, TC3 are the first three TC components; TC<sub>i</sub><sub>min</sub> and TC<sub>i</sub><sub>max</sub> are the minimum and maximum values of the *i*<sup>th</sup> (*i* = 1, 2, 3) TC components, respectively. The brightness, greenness, and wetness surfaces are computed using the TCT coefficients of Landsat 5 TM data proposed by Crist et al. (1986) [39].

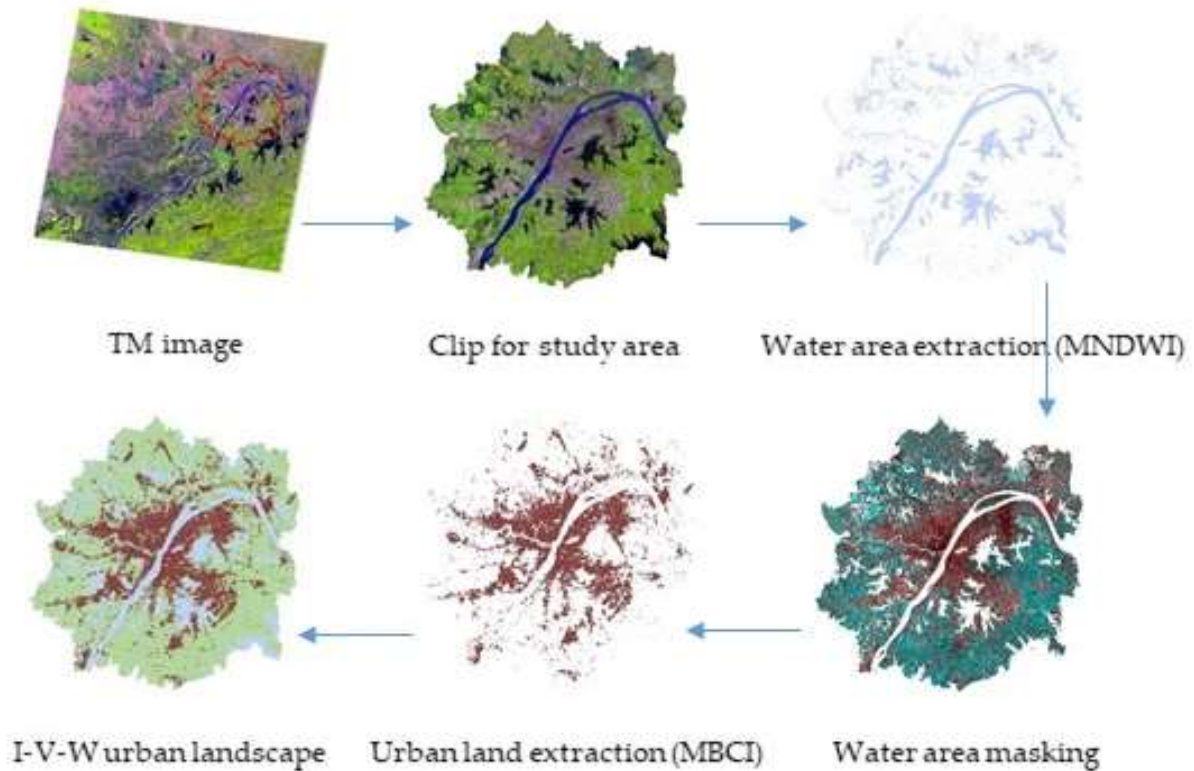


Figure 2. Example of the land cover extraction process (2011).

### 2.3. Selected Urban Land Metrics

The approaches favoured by researchers in the literature consulted tend to focus on quantifying urban land growth patterns and further evaluate a variety of spatial, demographic, or social characteristics associated with those patterns [19,40]. Landscape metrics are widely introduced to describe the growth pattern [41,42]. Based on the connotation of the landscape indexes, the interrelationships in this case (Table C1) and in literature [1,40,43], we selected the total area (TA) of the impervious surface, the proportion of the landscape (PLAND), the patch density (PD), the largest patch index (LPI), and the area-weighted classification dimensions (FRAC\_AM) to present the area, density, aggregation, and shape. PD measures the fragmentation as well as the scatter dispersion of urban land, while LPI gives a view on how the biggest patches occupy the total landscape. They work together to express the composition and outstanding of the urban landscape. FRAC\_AM measures the regularity or irregularity of the urban landscape patches. The indicators and their implications for urban land growth patterns are explained in Table 1 [1,40,43]. Class-level metrics are computed with a 4-neighborhood rule in each neighborhood to assess the area, dispersion, and shape regularity of urban land. The computation is based on 30mX30m landscape pixels. Different spatial units are employed for the metrics analysis, at a city level and also a neighborhood level. In detail, the study area is used as the unit for analyzing the overall changes, the 2010 neighborhoods are the units for comparison of the

temporal changes, and neighborhoods in corresponding years are the units for matching the 1990, 2000, and 2010 census to model the social-physical relationships.

**Table 1.** Landscape metrics and urban land growth pattern.

Metrics	Value	Meaning	Significance
TA	$\geq 0$	Total area of impervious surface, representing the size of urban space	Differences of size of urban land present overall view of urban growth
PLAND	$\geq 0$	Percentage of the area of urban land to the total area	Changes of urban land percentage reveal urban spatial growth pattern including improvement, infilling and expansion
PD	$\geq 0$	Patch density, number of patches per unit of total landscape. Here, urban patches are defined as homogenous regions of urban land.	A higher value of patch density indicates a more scattered and fragmented distribution of urban land patches. The value of PD is expected to increase until the later stages of individual urban patches gradually merge into continuous areas.
LPI	(0, 100]	Largest Patch Index, the percentage of urban land area comprised by the largest patch	LPI is a simple measure of the dominance of urban land patch
FRAC_AM	[1,2]	Area-weighted mean patch (AM) fractal dimension equals 2 times the logarithm of patch perimeter divided by the logarithm of patch area, with the adjustment of patch area abundance (multiplied by the proportional of patch area to the sum of patch areas).	FRAC approaches 1 for shapes with simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters.

#### 2.4. Social Factors Computation

Most studies in the current literature take population density and economic indexes as independent variables to interpret the urban landscape from only a temporal serial [44,45]. Few scholars interpret urban landscape with integrated social factors, which cover more information about the social subsystem. Thus, it is our assertion that extraction of social factors is foundational for the quantitative measurement of relationships between social transitions and urban land growth. This study selected social variables based on census data in 1990, 2000, and 2010, to build a social factors system, which was further used to regress with urban landscape metrics for the interpretation of evolution. The variable selection was based on the rule that the correlation coefficient between variables in the same category is not equal or greater than 0.9. Fourteen variables (thirteen variables for 1990 due to the limitation of population mobility census) were selected; referring to people's age, migration, employment, education, and urbanization based on the census data. To reduce social dimensions, we used principal component analysis and eigenvalue greater than 1 criterion to extract the initial components. We further chose Varimax, an orthogonal rotation, to get clearer factor loadings and divisions. The social factors are named according to the loadings, and the meaning in the urban environment. The factor scores were computed with a regression approach, which was further employed to model the relationships with urban landscape metrics.

#### 2.5. Regression Relation Modelling

A regression approach was employed to explore how to interpret urban land metrics from the social dimensions. This approach was chosen to examine if GWR, which is designed to identify whether relationships vary across space, better fits the relationships with the hypothesis that the regression

relationships are spatially non-stationary in the study area, based on neighborhood unit. Traditional spatial data analysis widely uses global models, such as OLS regression. The basic assumption of global model variables is that the relationship between predictors and outcome variables is spatially stationary. However, local regression, which explore the spatial non-stationarity of the relationships, might fit better than a global one. GWR is a statistical technique that allows measuring spatial changes in the relationship between explanatory variables and dependent variables within the framework of a local model [46]. The GWR model can be expressed as:

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^k (\beta_j(u_i, v_i)\chi_{ij} + \hat{\epsilon}_i) \quad (6)$$

where  $y_i$  is the value of the predicted variable at the coordinate location  $i$ ,  $(u_i, v_i)$  represents the coordinates of  $i$ ,  $\beta_0(u_i, v_i)$  and  $\beta_j(u_i, v_i)$  indicates the estimated intercept and coefficient for variable  $j$  at the coordinate location  $i$ .

Researchers typically utilize the Akaike Information Criterion (AICc) to compare the results from a “global” OLS regression with those from the “local” GWR [47,48]. Smaller AICc indicates that the introduction of spatial information can improve model fitting. Specifically, we first ran stepwise OLS regression to find the best models and obtained the significant social variables, which will be used to form the GWR model further (Figure 3). We tested the spatial autocorrelation of regression residuals using global Moran’s I. The null hypothesis is rejected while the p-value is significant ( $\leq 0.10$ ), indicating the residuals clustered or scattered, rather than randomly distributed in space [49].

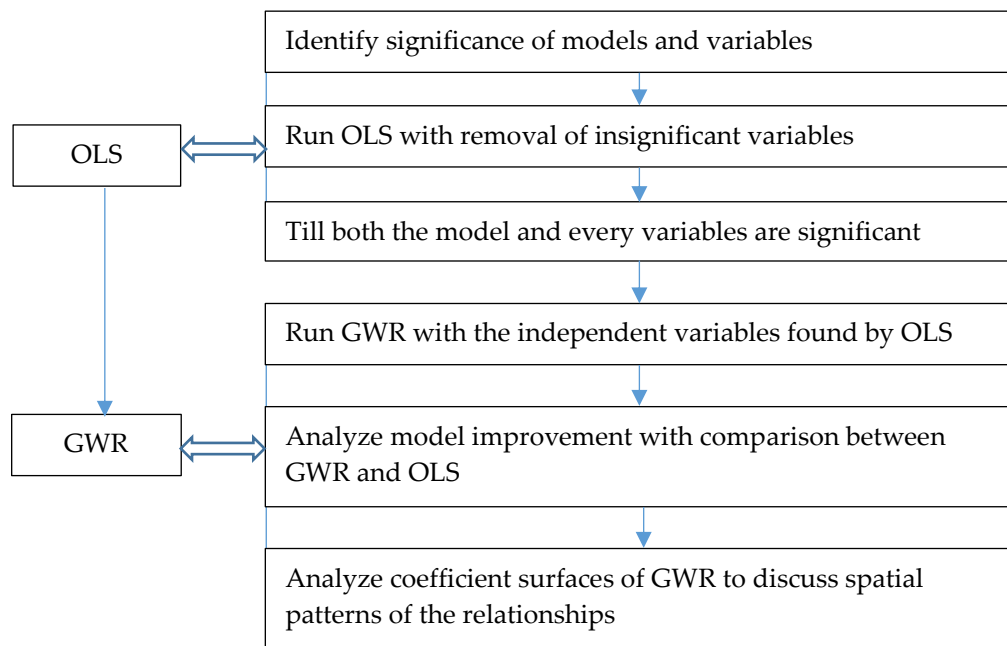


Figure 3. Regression modelling process.

### 3. Results

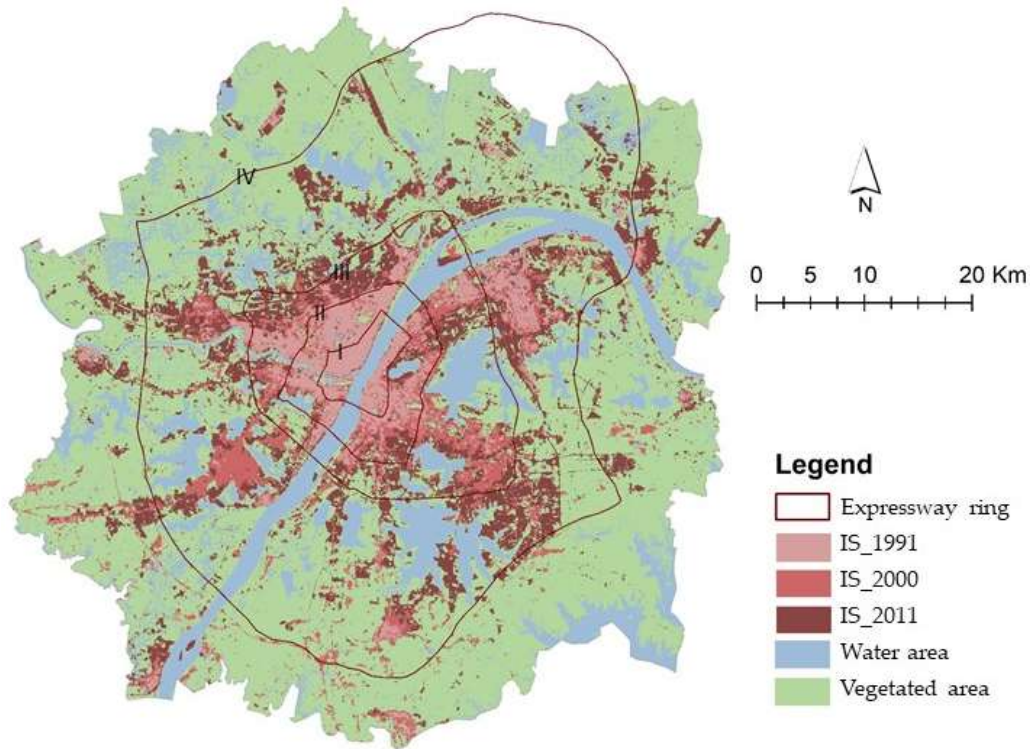
#### 3.1. Urban Landscape Evolution

##### 3.1.1. An overall view

The overall analysis is using the study area as a metrics computation unit. The result indicates that Wuhan’s urban land has continued to grow rapidly since the 1990s. It has expanded from 16636 ha in 1991 to 73328 ha in 2010, an increase of up to 3.41 times (Figure 4, Table 2). The spatial growth accelerated in 2000 when China fully implemented a market-oriented reform of real estate and the financial system, higher education, etc. Furthermore, the average annual increase of urban land was 1848 ha during 1991–2000, and 3467 ha during 2000–2011. During the 2000s, Wuhan’s urban space had an annual growth as rapid as 1.87 times that in the 1990s. The acceleration of urban land growth since

2000 shows a temporal escalation of urban space. Wuhan's urban land has continued growing since then. Wuhan's urban land growth ranks in the top ten of China's cities, just as its population and economic development do (Figure A2). The value of PD and LPI, from the density and aggregation perspective, also continue to rise, with an acceleration during the 2000s. Compared to the density and aggregation metrics, the shape measurements do not present the same trends. From a global view, FRAC\_AM had a slight decline during the 1990s and an increase between 2000 and 2011.

The overall metrics of TA and PLAND of urban land demonstrate a trend of urban land growth with edge or leapfrog expansion, while LPI expresses infilling or edge expansion in Wuhan during the 1990s and 2000s. The shape metrics of FRAC\_AM disclose an infilling development in the earlier stage and an expansion in the latter, based on the regularity of the urban landscape patches.



**Figure 4.** Urban land growth from 1990 to 2010. (IS: Impervious Surface).

**Table 2.** Urban land metrics in Wuhan Urban Development Zone (UDZ)\*.

Urban land	1991	2000	2011	1991–2000	2000–2011
TA (ha)	16635.87	34537.5	73328.31	17901.63	38790.81
PLAND (%)	5.17	10.73	22.78	5.56	12.05
PD	1.16	1.31	2.28	0.15	0.97
LPI	1.62	2.93	7.71	1.31	4.78
FRAC_AM	1.245	1.239	1.270	-0.006	0.031

\* The metrics are computed using the study area as the unit.

### 3.1.2. A neighborhood view

To detect the spatial differences of urban landscape within the study area, we further compute the metrics using a 4-neighborhood rule, using 2010 neighborhoods as the computation units, to compare the evolution during the 1990s and 2000s. The comparison reveals how the urban land area, patch size or density, and patch regularity change and what spatial differences are presented.

### 3.1.2.1. A view with static value of the metrics

Through the box plots of urban land metrics (Figure 5), we can see that the area of urban land (PLAND) at the neighborhood level continued to increase when compared to the lowest, the first quartile, the median, and the third quartile value of the metrics from 1990 through 2010. So does LPI. PD shows a continued increase of the lowest during the two decades. It shows a decrease of the second quartile, the median, the third quartile, and the maximum value in the 1990s, but has an increase in the 2000s except the maximum value. The FRAC\_AM shows a stable minimum value in the 1990s but an increase in the 2000s. The second quartile, the median, and the third quartile value keep increasing during the two decades. But the maximum value shows a decrease in the 1990s and increase in the 2000s.

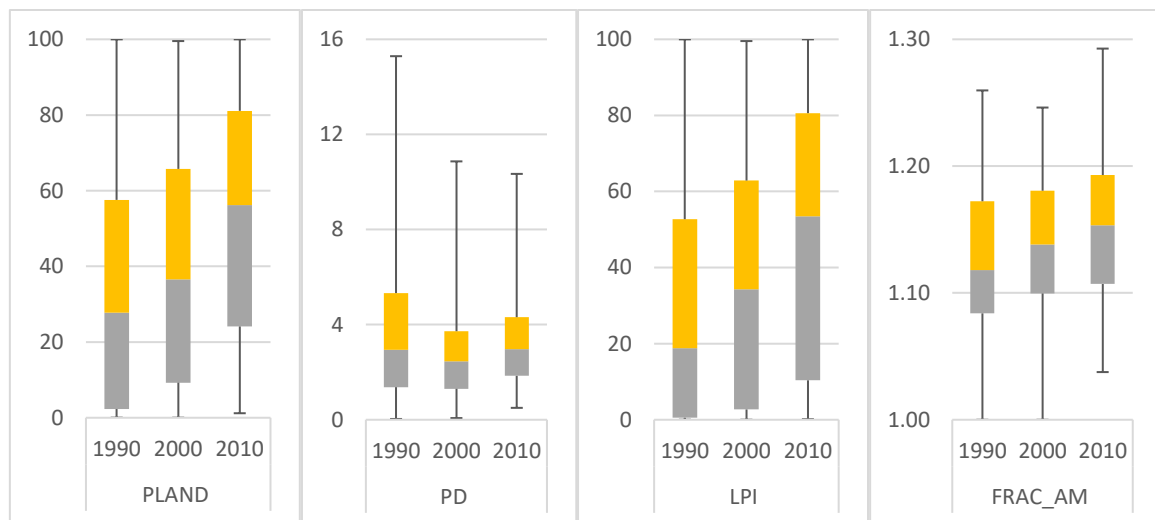


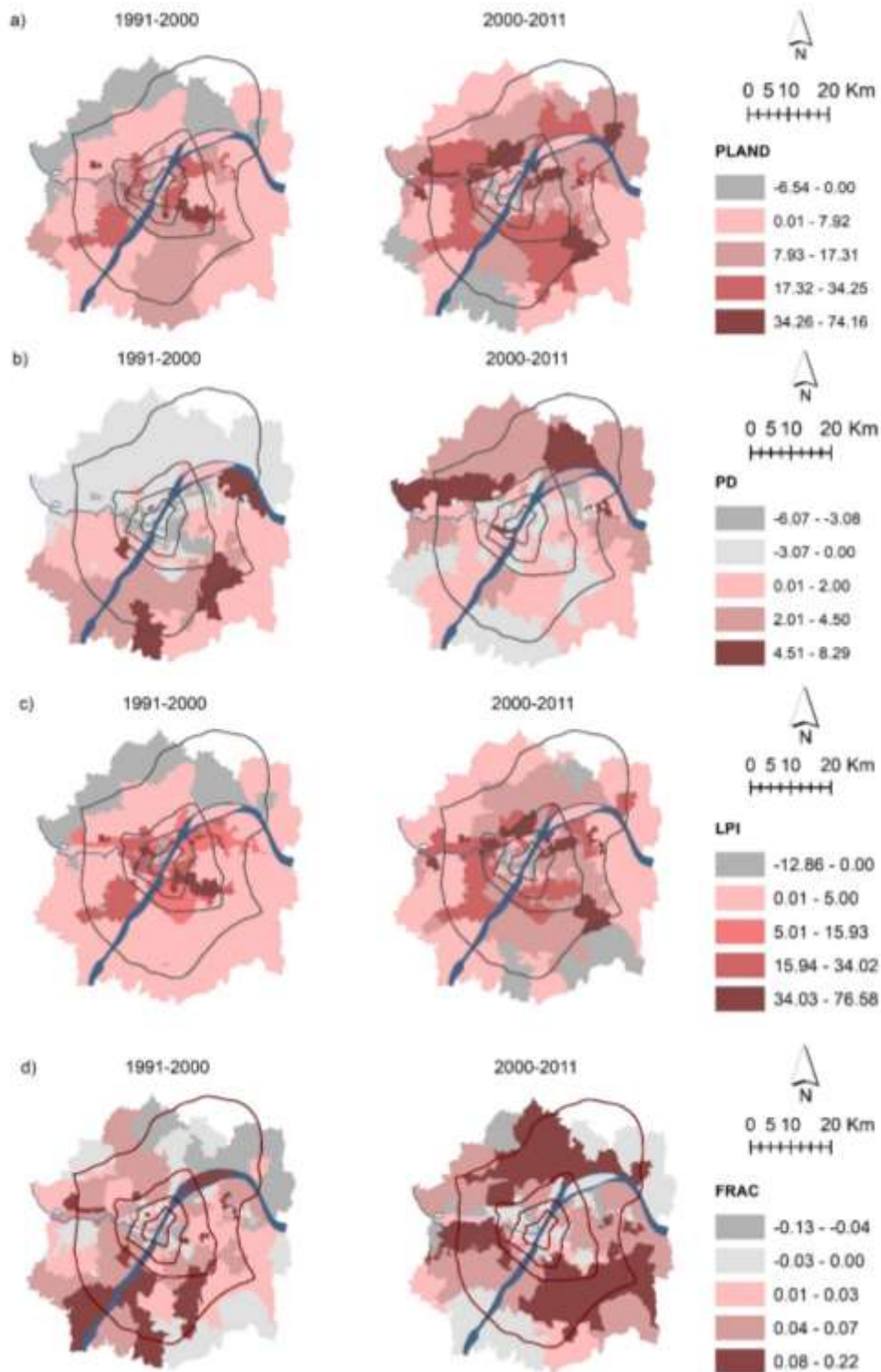
Figure 5. Box plots of urban landscape metrics.

The spatial differences disclose urban land growth patterns during various stages. In the maps with a static value of the metrics in different years (Figure A3), the city center is featured with a higher PLAND, lower PD, higher LPI, and lower FRAC. It shows that the city center with the above features grew continuously while surrounding the center expanded with fragmented urban land patches.

### 3.1.2.2. A view with change values of the metrics

Figure 6 presents the spatial features of urban landscape changes, including PLAND (a), PD (b), LPI (c), and FRAC (d). The shifts in PLAND and LPI show similar spatial characteristics, with a decrease in the city center and an increase in the neighborhood with significant urban land expansion. PLAND decreases throughout 1991 and 2011 in some neighborhoods in the city center, within the expressway Ring II. In the 1990s, urban land regeneration took place mostly in the areas north of the Han River and west of the Yangtze River, with the famous commercial center redevelopment. In the 2000s, the decrease of urban land in the city center is mainly a cause of the renewal of green and wetland along the Han River and Yangtze River. The changes of LPI show similar features of spatial distribution.

Shapes of patches represent urban land infilling or expansion, with a decrease or increase in the value of FRAC\_AM. In the 1990s, FRAC\_AM decreased in most neighborhoods of the city center (within expressway Ring II). Those with a significant increase of FRAC\_AM in the 1990s are located out of Ring II, and especially in some satellite towns out of Ring III. At the same time, neighborhoods in the north and northeast of the Yangtze River have a decreasing FRAC\_AM. In the 2000s, the neighborhoods with decreasing FRAC\_AM expanded from the city center to the east-west axis along the Han River and the main road between the East Lake and the South Lake. Those with an increasing FRAC\_AM distribute



**Figure 6.** Urban land metrics changes: (a) Changes of PLAND; (b) Changes of PD; (c) Changes of LPI; (d) Changes of FRAC\_AM. Using 2010 neighborhoods as metrics computation units.

in various directions, especially out of expressway Ring III. All of these changes indicate that in the city center, urban land grows with an infilling pattern while diffusion occurs mostly in the surrounding area. In the 1990s, the expansion in the outer area was outstanding in some neighborhoods in the south of the UDZ while it extended in different directions.

PD, the index for patch density, shows that the decrease is more outstanding in the 1990s than in the 2000s, with a concentration on the east-west axis (west along the Han River and east along the main

road), as well as along the Yangtze River at the east bank. In the latter period, the decrease of PD in the city center continues with a slight degree. The PD decrease in the city center indicates a result of infilling development with more edge-expansion or conversion of built-up space into permeable surface.

Combining the area, density, and shape indexes, we can see that the city center is in a regeneration stage between 1991 and 2011, though the city center expands dynamically. The regeneration presents not only as infilling development of urban land but also as a replacement of urban land with development of more green or wet spaces. The redevelopment in the city center reshapes the urban land and permeable surface patches and provides an improved micro-environment for communities.

From the perspective of three traditional towns' (centers') growth, the improvement of urban landscape takes place in Hankou, the traditional commercial center during the earlier stage before the integrated development of the three towns. In the latter stage, the improvement expands to Hanyang, and Wuchang, with more concentration along the Han River and the Yangtze River. During the 1990s, a slight increase of PLAND occurs within the expressway Ring I and partially in Ring II, which combined with the FRAC\_AM decrease can be identified as infilling development. During the 2000s, a slight increase of PLAND takes place in Ring II with a decrease of the FRAC\_AM, for which coalescence dominates the development. Outstanding expansion of urban land during the 1990s occurs to the east (axis along the main road constrained by rivers), west (dispersed distributed expansion), and south (with the trigger of high increscent secondary industry zone) part, with a combination of the decreased LPI (which indicates the higher fragmentation of urban landscape patches) particularly in the east-west direction. Expansion in the 2000s mainly occurs out of Ring II, for which the FRAC\_AM presents an outstanding increase (indicating the irregularity of urban landscape patches) in the surrounding neighborhoods, which are in line with the expressway network.

### 3.1.3. Urban land growth mode indicated by change of value of urban land metrics

Changes in the value of landscape metrics reveals a pattern of urban spatial evolution. Based on the literature [1,40,43], we describe urban land development/redevelopment in three types: infilling, edge expansion, outlying expansion. Infilling and edge expansion lead to the patch size increase and patch density decrease. Outlying expansion, which may present as enclave expansion, linear expansion, could result in an increase or decrease in patch fragmentation or dispersion [5,23,50,51]. Redevelopment may decrease the urban land patch fragmentation and increase the patch shape regularities through human intervention. It also potentially results in the fragmented and scattered urban land patch distribution. **Table 3** listed the development models indicated by the value changes of urban land metrics, which is the basis of further discussions regarding the evolution of urban land patterns.

**Table 3.** Urban land development mode indicated by change of value of urban land metrics.

	Decrease	Increase
PLAND	Urban land regeneration, redevelopment, occur mostly in the city center	Urban land development (infill or expansion)
PD	(Re)development, infilling, or edge expansion, less fragmented or scattered, or less segregated by other landscape	(Re)development, more fragmented or scattered, or more divided by other landscape
LPI	Urban land (re)development with decrease of the largest patch size with other landscape encroachment; Urban land expansion such as enclave or linear expansion	Urban land coalescence with infilling or edge expansion
FRAC_AM	Urban land (re)development, infilling, or edge expansion	Urban land (re)development, diffusion with more fragmented or scattered distribution

### 3.2. Interpretation of Urban Landscape by Social Factors

#### 3.2.1. Extraction of Social Factors

The numbers of urban social dimensions extracted according to eigenvalues greater than 1 are 4, 4, and 5 in 1990, 2000, and 2010, respectively (Table 4). In 1990, the first dimension (Factor 1) is employment in nonagricultural industries, the second one (Factor 2) is the higher educated population, the third one (Factor 3) is the elderly population, followed by the local population and inflow population (Factor 4). Unlike the first and second dimensions, in 2000, the third and fourth dimensions changed only slightly. In 2000, the first dimension was employment in the tertiary industry, among which the load of a higher educated population reflects its close relationship with employment in the tertiary industry. The second dimension is employment in the secondary industry, which is closely related to the population with a high school education. Employment in the tertiary industry is still the first dimension in 2010, but educational background closely relates to changes from higher levels in post-secondary and post-graduate attainment in 2000 to high school in 2010. At the same time, higher education and the single population become the second dimension. The third dimension is still the aging population. Employment in the secondary industry constitutes the fourth dimension, which is negatively correlated with low-income occupations, reflecting the advantages of the optimization, and upgrading of the secondary industry accompanied by employment income. During this period, the floating population constituted the fifth dimension of urban society. Changes in social dimensions and their connotations will be reflected in the physical landscape, with specific patterns.

#### 3.2.2. Regression Results

##### 3.2.2.1. Variables and modelling preparation

We computed the urban landscape metrics regarding the area, density, shape regularity, and aggregation at neighborhood level (using 1990, 2000, 2010 neighborhoods respectively as landscape metrics computation units) to match the format of the explanatory variables and used them as dependent variables. The social factors represent the social subsystem with the transforming dimensions. Since PLAND is associated with LPI, and FRAC\_AM is closely related to TA (Table C1), we used PLAND, PD, and FRAC\_AM to conduct the regression simulation. The stepwise OLS regression determines the appropriate combination of significant explanatory variables (Table C2), which provided a basis for constructing the GWR model.

##### 3.2.2.2. GWR results

Based on the goodness-of-fit for the regression model and standard residual spatial autocorrelation (Table 5), the GWR results for PLAND and FRAC\_AM are more representative. In other words, the  $R^2$  adjusted of the GWR for PD is as low as 0.0609 in 2000 and 0.0818 in 2010, and the p-value of Moran's I is insignificant. The lower  $R^2$  adjusted the lower the model fits. A significant p-value of Moran's I test is expected for the non-randomly spatial distribution of the standard residuals of regression models, and vice versa.

The GWR models for the urban land area (PLAND) show that it is highly explained by the explanatory social variables, with  $R^2$  adjusted of 0.6843 (1990), 0.5953 (2000), and 0.5100 (2010) (Table 5). From 1990 to 2010, the nonagricultural industrial employed population presented significant associations with urban land growth (PLAND), with the transition from a mixed distribution of tertiary and secondary industry in 1990 to a split of the nonagricultural industry as tertiary and secondary becoming defined as a different dimension in 2000 and 2010. In 2010, the link between the tertiary industry and urban space was significant, different from that of the secondary industry. The higher educated population was insignificantly associated with the urban land area in 1990 but significantly associated with it after this point in time. Secondary industrial employment associated with urban land areas significantly in 2000, but insignificantly in 2010. In 2010, only two social dimensions including tertiary industrial employment, local population and aging population significantly linked with urban land areas.

**Table 4.** Social factors extracted, % of variance, and variable loadings.

Social variables		1990				2000				2010				
		Nonagricultural industry worker, High income population	Single and Higher educated population	Aging Population	Immigrants & Local Population	Tertiary industry worker, High income population	Secondary industry worker	Aging Population	Immigrants & Local Population	Tertiary Industry Worker	Married population with minor dependent	Local Population & Aging Population	Secondary Industry worker	Immigrants
		F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4	F5
<b>% of variance (%)</b>		<b>45.55</b>	<b>16.30</b>	<b>16.22</b>	<b>13.10</b>	<b>37.45</b>	<b>19.50</b>	<b>14.61</b>	<b>9.79</b>	<b>21.17</b>	<b>17.28</b>	<b>16.99</b>	<b>12.36</b>	<b>8.85</b>
Urbanization	Nonagricultural population	0.956				0.786				0.835				
	Local population					0.886				0.748				
Migration	Intra-provincial immigrants									-0.783				
	Inter-provincial immigrants					-0.909								
Age	Minor dependent	-0.913				-0.822				0.703				
	Elders	0.955				0.910				0.842				
Marital status	Married population	-0.853				-0.806				0.876				
	Divorced or widowed population	0.938				0.865				0.759				
Education background	High school educated population	0.964				0.647				0.802				
	Highly educated population	0.803				0.923				-0.803				
Employment	Secondary industry employment	0.860				0.864				0.743				
	Tertiary industry employment	0.776								0.887				
Occupation by income	High-income-occupation population	0.789				0.903				0.513				
	Low-income-occupation population	-0.984				-0.696				-0.794				

Note: Secondary/tertiary industry employment represents the population who work in the secondary/tertiary industry.

Occupation by income refers to the population divided by different income-levels and occupation, which is concentrated to the population with occupations. It reveals the transformation of relationships between occupation and income

**Table 5.** Parameters of geographically weighted regression (GWR) results.

	1990	2000	2010	1990	2000	2010	1990	2000	2010
Dependent variable	PLAND	PLAND	PLAND	PD	PD	PD	FRAC_AM	FRAC_AM	FRAC_AM
<b>OLS Result</b>									
Explanatory social variables	Factor 1*	Factor 1*	Factor 1*	Factor 1*	Factor 1	Factor 1*	Factor 1*	Factor 1*	Factor 1*
	Factor 2	Factor 2*	Factor 2	Factor 2*	Factor 2**	Factor 2	Factor 2	Factor 2*	Factor 2*
	Factor 3*	Factor 3*	Factor 3*	Factor 3*	Factor 3**	Factor 3	Factor 3*	Factor 3*	Factor 3*
	Factor 4*	Factor 4*	Factor 4	Factor 4	Factor 4	Factor 4**	Factor 4	Factor 4	Factor 4*
			Factor 5			Factor 5			Factor 5
<b>GWR parameters</b>									
Bandwidth	629966	629966	22435	629966	629966	620964	11791	11791	18911
Residual squares	43936	53279	60448	723	411	505	0.1981	0.1645	0.2013
Effective number	4.01	5.01	9.56	4.01	3.01	3.01	22.86	28.31	17.38
Sigma	18.60	20.81	21.95	2.39	1.81	1.96	0.0428	0.0406	0.0414
AICc	1144.05	1147.96	1224.58	606.05	520.75	569.53	-437.64	-435.58	-463.98
R <sup>2</sup>	0.6916	0.6081	0.5413	0.4024	0.0777	0.0956	0.4963	0.4693	0.4905
R <sup>2</sup> adjusted	0.6843	0.5953	0.5100	0.3882	0.0629	0.0818	0.3945	0.3239	0.4195
<b>Global Moran's I of standard residuals of GWR</b>									
Index	0.2120	0.1814	0.1112	0.0211	0.0234	-0.0180	-0.0065	0.0137	0.0558
ZScore	9.2705	8.6915	5.2575	1.2307	1.4402	-0.4698	0.0524	0.9911	2.8029
PValue	0.0000*	0.0000*	0.0000*	0.2184	0.1498	0.6385	0.9582	0.3216	0.0051*

Note: \* An asterisk next to a number indicates a statistical significance level  $p < 0.01$ .

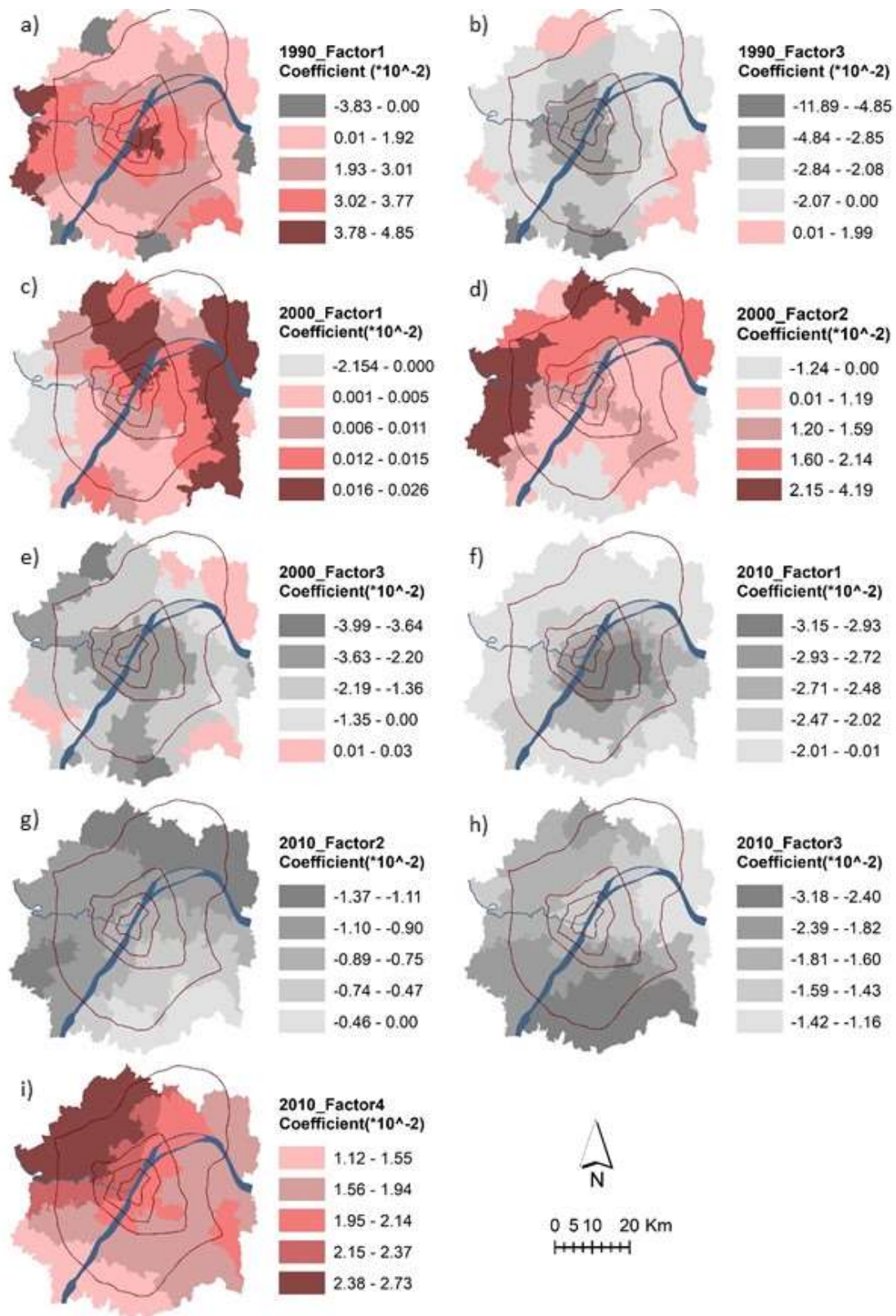
Kernel type for GWR: Fixed; Bandwidth method: AICc. Binary strategies are for spatial weight metrics computation (i.e., a feature is either a neighbor (1) or not (0)).

The GWR models for FRAC\_AM, to a great extent, indicate how close the urban land patch regularity associates to human interventions, with R<sup>2</sup> adjusted 0.3945 in 1990, 0.3239 in 2000, and 0.4195 in 2010. The models reveal the spatial differences of coefficients in each neighborhood, indicating that the sensitivity of urban land patch shape regularities to social factors is different. The social factors significantly associated with FRAC\_AM are the nonagricultural industrial employment (Factor 1) and higher-educated population (Factor 2) in 1990, which transited to the tertiary industrial workers (Factor 1), higher educated population (Factor 2), aging population (Factor 3), and secondary industrial population (Factor 4) in 2010. The significant factors in 2000 are similar to those in 1990, apart from the nonagricultural industries. The study demonstrates that urban land patch shape regularity is significantly associated with the social landscape at neighborhood level. Regarding the standard residuals of the GWR models, the p value of Global Moran's I was not significant in 1990 and 2000, but was significant in 2010.

### 3.2.2.3. Spatial features revealed by GWR coefficient surfaces

The GWR coefficient surface (Figure 7) reveals the spatial variations in the association of explanatory variables with urban land metrics and helps to better understand how humans intervene in the urban land patch shapes and growth spatial patterns. The transitions provide information for policies and local planning at various scales. In PLAND's GWR model, the coefficients of social variables differ little in space. Therefore, we focus on analyzing and interpreting the coefficient surface of the patch shape index FRAC\_AM.

The coefficient surface for GWR in 1990 indicates that the associations of nonagricultural employment (Factor 1) and the elderly population (Factor 3) with the degree of regularity of urban land



**Figure 7.** Coefficient of GWR interpreting FRAC\_AM in 1990, 2000, and 2010. (a) Coefficient of Factor 1 in 1990; (b) Coefficient of Factor 3 in 1990; (c) Coefficient of Factor 1 in 2000; (d) Coefficient of Factor 2 in 2000; (e) Coefficient of Factor 3 in 2000; (f) Coefficient of Factor 1 in 2010; (g) Coefficient of Factor 2 in 2010; (h) Coefficient of Factor 3 in 2010; (i) Coefficient of Factor 4 in 2010.

patch shapes present a pattern of concentric circles outward from the city center. The coefficients of factor 1 and factor 3 are opposite, and their associations (expressed as the absolute value of the coefficient) with the irregularity of urban patches show a downward trend from the city center to the outskirts. The coefficient of Factor 1 is positive, revealing that the nonagricultural industry development has an increased relationship with the shape index of urban land patches. The lower the value of the shape index, the simpler the shape. Additionally, the growth of the nonagricultural industry increases the irregularity of urban land patch shapes. The land patch shape index in the urban center is sensitive to the nonagricultural industry and the coefficients decrease with growing distance from the city center. Factor 3 is the elderly population, which is strongly associated with big-sized families (Pearson  $R=0.615$ ,  $p<0.01$ ). This factor, therefore, not only represents the elderly but also provides information on family size. Contrary to Factor 1, the regression coefficient of the elderly to the urban land patch shape regularity is negative. The absolute values of the coefficients also decrease from the city center to the periphery. In 1990, both the sensitivities of Factor 1 and Factor 3 (the absolute values of the coefficients) showed a decrease from the city center outwards. This was closely related to the concentration of urban social and economic development during this period and the aggregation of the city center.

In 2000, employment in the tertiary industry (Factor 1), employment in the secondary industry (Factor 2), and the elderly (big-size families) (Factor 3) had significant relationships with the regularity of urban land patch shapes. The regression coefficients of Factor 1 and Factor 2 are mostly positive, and those of Factor 3 are predominantly negative. The coefficients of Factor 1 show a low-to-high trend from southwest to northeast, and those of Factor 2 show a low-to-high trend from southeast to northwest. Factor 3 has greater coefficients in the city center, along the Han River, and in the southeast. The spatial pattern of coefficient surfaces of nonagricultural industrial employments (Factor 1 and Factor 2) has transitioned from concentric circles in 1990 to sectoral differences separated by the main axis in 2000. The links of population aging (with decreased association with big-size families, Pearson  $R = 0.473$ ,  $p<0.01$ ) are manifested as concentric circles extending westward and southeastward. The east-west axis is composed of the Han River and the eastward main road, reflecting the links of employment in the tertiary industry; while the north-south axis is formed by the Yangtze River, which reflects the association of employment in the secondary industry.

The coefficients of the 2010 GWR model show that employment in the tertiary industry (Factor 1), higher educated population (Factor 2), and the aging population (associated with small-size family) (Factor 3) have a negative association with the degree of urban land patch shape regularity. The links with secondary industry employment (Factor 4) are positive. That is to say, the more developed the secondary industry, the higher the shape index value, and the more irregular the land patch shape. Those neighborhoods are in the developing stage. Conversely, the more developed the tertiary industry, the simpler the shape of the urban land patch, the more spatially aggregated the presence of the highly educated and the elderly, the simpler the shape of the urban land patch. Such neighborhoods are relatively mature and have the most human intervention in the urban landscape. In terms of spatial characteristics, how the coefficients of employment in the secondary industry, higher educated population, and the elderly relate with urban land patch shape regularity presents as a sectoral form, while the links between the employment-population in the tertiary industry and patch shape regularity are in the form of concentric circles. The neighborhoods with high coefficients of secondary industrial employment are mainly located in Hankou, north of the Han River and west of the Yangtze River. Those with high coefficients of tertiary industrial employment are mainly located in the city center. The neighborhoods most linked with the higher educated population are mainly located in the southeast region. The higher educated population in this area is spatially aggregated, due to the clustered distribution of research institutes and universities. Those areas with a high coefficient of the elderly (small-scale households) are distributed in the northeastern region. This area is led by the port industry and the chemical industry.

## **4. Discussion**

### *4.1. Urban Land Growth Pattern*

Rapid urbanization reshapes the social and physical landscape within urban areas. With the spatial aggregation of tertiary industry and the improvement of the natural spaces, the city center evolves with

the increase or decrease of impervious surface and the more regular patch shapes. Infilling and edge expansion result in more regularity of shape as well as larger sized urban land patches. Meanwhile, the city outskirts brought by expansion imply a higher fragmentation and dispersion. Urban land growth generates a compact and aggregated center and a more fragmented outskirts. The fragmentation of urban land does not present an outstanding degradation with the distance to the city center, due to biased development along the road and river axis as well as different socio-economic clusters. However, focusing on the development axis, the degradation of urban land aggregation and increased fragmentation followed by the distance is still the common phenomena within other cities [17,19].

Urban spatial growth patterns vary depending on the socio-economic stage of the study area. Since the 1990s, China's second-tier city has been in a transitional stage, defined by rapid population agglomeration and economic growth, resulting in the continued growth of urban land, with small areas of infilling or redevelopment in the city center. During the latter decade, the scope of infilling in urban centers has expanded, and the fringe areas demonstrate multidirectional expansion. This is different from the development in the earlier decade when the urban growth relied on existing built-up areas and along the river and transportation axis. Overall, the urban center has been expanding, which is dominated by redevelopment, infilling development, or patch-edge expansion, while the outer areas are dominated by varieties of expansion, such as fringe expansion, enclave expansion, and industrial park clustered expansion. Industrial structural upgrading and second industry removal put forward land use optimization. Therefore, the accompanying development of urban expansion and infill is the main theme of China's urban growth.

Redevelopment in the city center of Wuhan has taken place during the past two decades, which is outstanding in the latter decade. It has been promoted through the reconstruction of the old city center and the relocation of polluting industries. Rather than increasing impervious surface area, redevelopment is more focused on improving vegetation areas or renewing wetland areas. The shrinkage of urban land in some neighborhoods of the city center reflects urban natural ecological development. The redevelopment thus marks both industrial structural upgrading as well as natural environmental improvement.

#### *4.2. Heterogeneity of Interpretation from Social Perspective*

Cities are important carriers of social-economic development. The urban spatial form is significantly associated with socio-economic growth. The formation of China's second-tier cities is still in its coalescence stage, coinciding with population and economic agglomeration, which presents as infilling and expansion of urban land. The evolution of the urban social landscape has a significant association with land growth. Different social clusters and their intervention in urban growth form spatial differences in urban landscapes. The links of social evolution with the urban landscape were in the form of concentric circles in 1990, changed to a sectoral form with an outstanding axis in 2000, and further developed into a combination of concentric circles and sectoral form in 2010.

From 1990 to 2010, the spatial differentiation of nonagricultural industries closely linked with the urban spatial landscape. In 1990, the first social dimension, nonagricultural employment, was mostly in the central area of the city. In 2000, nonagricultural employment formed two social dimensions as employment in the tertiary industry and employment in the secondary industry, and the sectoral form was characterized by axial segregation along the river and the main road. In 2010, employment in the tertiary industry was concentrated in urban centers, while the secondary industry showed sectoral spatial characteristics. In the 1990s, the transformation of traditional industries was in its infancy, and its association with urban landscape spatial heterogeneity was relatively weak. In the 2000s, the effect of industrial restructuring was remarkable. At this stage, the socialist market economy was promoted in an all-around way, and the dual-track development of planned industrial restructuring and market-oriented industrial clusters promoted the rapid construction of industrial parks. The industrial park attracts capital and employment concentration, which further promotes the development of urban space. While transforming traditional secondary industries into high-tech and high-value-added ones, they have also shifted from being dispersed in the center of the city to being concentrated in the periphery of the city. This change over time has an impact on the formation of a sectoral pattern of urban land. The transformation and spatial transfer of the secondary industry are accompanied by the expansion of the tertiary industry in the urban center.

The elderly population is also a significant factor related to the growth of urban space. This factor reflects the family size closely related to it. The weight of big-size households was higher in the 1990s, while that of small households increased significantly in the 2000s.

In contrast to 1990, the population with a higher-income occupation became a significant factor associated with urban land growth in the 2000s. In 1990, the nonagricultural industry workers mainly had educational backgrounds at the high school level. In 2000, the population with higher educational attainment was linked to tertiary industry employment. During the 2000s, the highly educated population showed spatial expansion in the urban growth process.

Urban spatial patterns reflect social and economic policies on the physical landscape. For example, the industrial upgrading policy explains the relocation of traditional industries as well as the cluster of industrial parks. The higher educated population is, on the one hand, the product of China's higher education reform, while it is also the result of Wuhan's local talent attraction as a city where high-tech industries and universities are gathered. Moreover, the elderly population and reduced family size are a manifestation of the long-term implementation of China's population policy.

Compared with 1990 and 2000, the floating population, an important part of urban society, became a social dimension with an expanding distribution in 2010. However, its intervention in urban land use is not significant. In 2010, the influence of social factors on the shapes of urban land patches in Wuhan reflected spatial heterogeneity at neighborhood level, and so did that in 1990 and 2000.

#### *4.3. Illustration on Urban Growth Simulation and Management*

By portraying how the physical landscape relates to social factors through spatial and longitudinal perspectives, the urban reshaping process is disclosed.

The population in the urban area has been agglomerating during the two decades, though population in the city center became less dense due to the redevelopment and the market-oriented spatial reallocation, as well as the specialization of urban spatial functional zoning. As policies unlock to encourage people to migrate to bigger cities, through the loosening of household registration or the targeted attraction of a higher-educated population through the launch of formal institutes of research, urban growth is expected to present a continuous agglomeration. On the other hand, although the population density in the central areas of the second-tier city is declining, land infill development continues, which is linked with the agglomeration of the tertiary industry. The population density is growing in the peripheral areas of the city center. Multi-mode development needs to be considered concurrently to respond to socio-economic development to better serve the needs of people.

Interpreting urban landscape metrics through social factors offers an approach to predict urban spatial patterns. Thus, following up with social landscape transformations is essential for introducing the social dimensions as important predictors to simulate urban space. This study also provides a reference for urban managers considering different socio-economic policies' scenarios when configuring urban landscape. For example, policies related to the household registration system, real estate market, and large projects that orient industrial clustering should be considered.

Different scenario-based social dimensions and social landscapes are expected to result in different urban land growth patterns. In most urban areas, impervious surface expansion dominates spatial growth. Based on an ecological-friendly people-centered development mode, redevelopment and improvement have been outstanding in the city center. The expansion of the urban center accelerated in the second-tier city during the 2000s, though it lags in stages compared with first-tier cities [12]. Given the high cost of reversion from impervious surfaces to permeable ones, governmental dominance is very essential during the process rather than at the market hand. The regeneration of green space or wetland is accompanied by traditional industry removal or community redevelopment which further benefit residents with a better environment.

#### *4.4. An integrated forces by governmental plan and market orientation*

Urban land growth is a manifestation of the dual role of the government and the market. Among them, the scale of new construction land, infrastructure network, and functional-zone-led industrial parks are configured by planned power, while the supply of residential land is the result of the integration of plan and market. Social preferences also play a role in this process. The new urban construction land is distributed in a quota system dominated by the national-level government. In

terms of urban functional zoning and housing policies, local governments have the flexibility to formulate their policies. Therefore, the scale and speed of urban growth are largely affected by national-level policies. The functional areas within the city are defined by the local government (approved at the national level) and so does configuration of infrastructure networks. On the basis of this government-led formation of the urban space, the market plays a role in the social-physical relationships, especially since the 2000s. This process is accompanied by the reform of China's new urban construction land use provision policy. In 1987, China initially launched the paid use of urban construction land, mainly in the form of agreement. In 2002, commercial, tourism, entertainment, commercial residential and other business land must be sold through bidding, auction and listing. In 2007, industrial land was added in the scope of bidding, auction and listing. Though new construction land is constrained by the quota, the local government has the capacity to manage the redevelopment of existing urban land, particularly focusing on 'three olds' (old town, old village, and old factory).

The allocation and adjustment of secondary industrial land was mainly based on agreement from 1990 to 2010. In the 1990s, in the process of promoting the development of industrial clusters, Wuhan City planned multi-cluster industrial parks and layout of industrial zones which formed the spatial patterns (Figure A4). Among them, the national level industrial zones such as East Lake High-Tech Industrial Zone, Wuhan Economic and Technological Development Zone, Linkonggang Taiwanese Investment Development Zone, and Yangluo Industrial Development Zone are industrial zones located in four directions: east, southwest, west, and northeast. In the 2000s and 2010s, the agglomeration of these industrial areas expanded rapidly, accompanied by corresponding social agglomeration.

Regarding the choice of residential location, the commercialization of planned housing was carried out in the 1990s. In the 2000s, housing entered the marketization stage with the reform of land transfer methods, and residents' choice of residential location was more directly affected by market prices. Although in the redevelopment of the existing construction land, the planned force played roles on certain residential relocations.

In the past decades, the development of Wuhan's rapid transportation infrastructure network has provided the foundation for the development of urban peripheral industrial clusters and satellite towns. On the other hand, the development of rapid transit networks and nodes within the city provides a foundation and opportunity for social mobility inside this city. Especially in the 2000s and beyond, with the continuous construction of bridges and tunnels (Figure A5), the social connections segregated by the two rivers (four banks and three towns) became more frequent. In terms of urban social landscape, the scope of employment in the tertiary industry in the central area has been expanding, while employment in the secondary industry is distributed in various directions around the city.

Overall, the quota of new construction land area restricts the speed of urban expansion, and the plan defines urban spatial functions. The location preference of social groups reflects the individual's preference under the governmental policies about allocation of construction land and zoning.

## 5. Conclusions

This study takes a major step in identifying urban land growth patterns and the relationships with social factors, from spatial and longitudinal perspectives. We conclude that urban land growth, to some extent, is the physical manifestation of a set of interrelated socioeconomic factors. It provides a social perspective for urban land growth, through the social dimensions' interpretation of physical landscape distribution and evolution. The examination of this relationship provides a social perspective for understanding the process of urban growth. At the same time, the urban social-physical relationships are resulting from the government quota for supplying new construction land, infrastructure supplying, and urban spatial zoning, as well as from market-oriented residential land supply and social preferences toward a certain location.

In this case, urban land patterns are significantly associated with the nonagricultural industry, the highly educated, and the aging population. Industrial removal and structural upgrading present a crucial association with urban land growth patterns, with which education level increase is accompanied. The aging is reflected in the urban landscape with the implication of big-size families during the former decade and small-size families in the latter. From a spatial pattern perspective, the social links with the urban land growth are conceptualized as a concentric form in 1990, a sectoral form along the river and road axis in 2000 and a mixed pattern with concentric and sectoral in 2010.

These relationships portray that China's second-tier city's landscape evolution is closely associated with industry relocation and ecological environment improvement. While the government's strategies do signal ecologically friendly redevelopments, cities are still facing ecological challenges brought by the loss of vegetation area and wetland. The social-physical links implicate that social dynamics should be emphasized in the configuration of urban land as well as the permeable surface.

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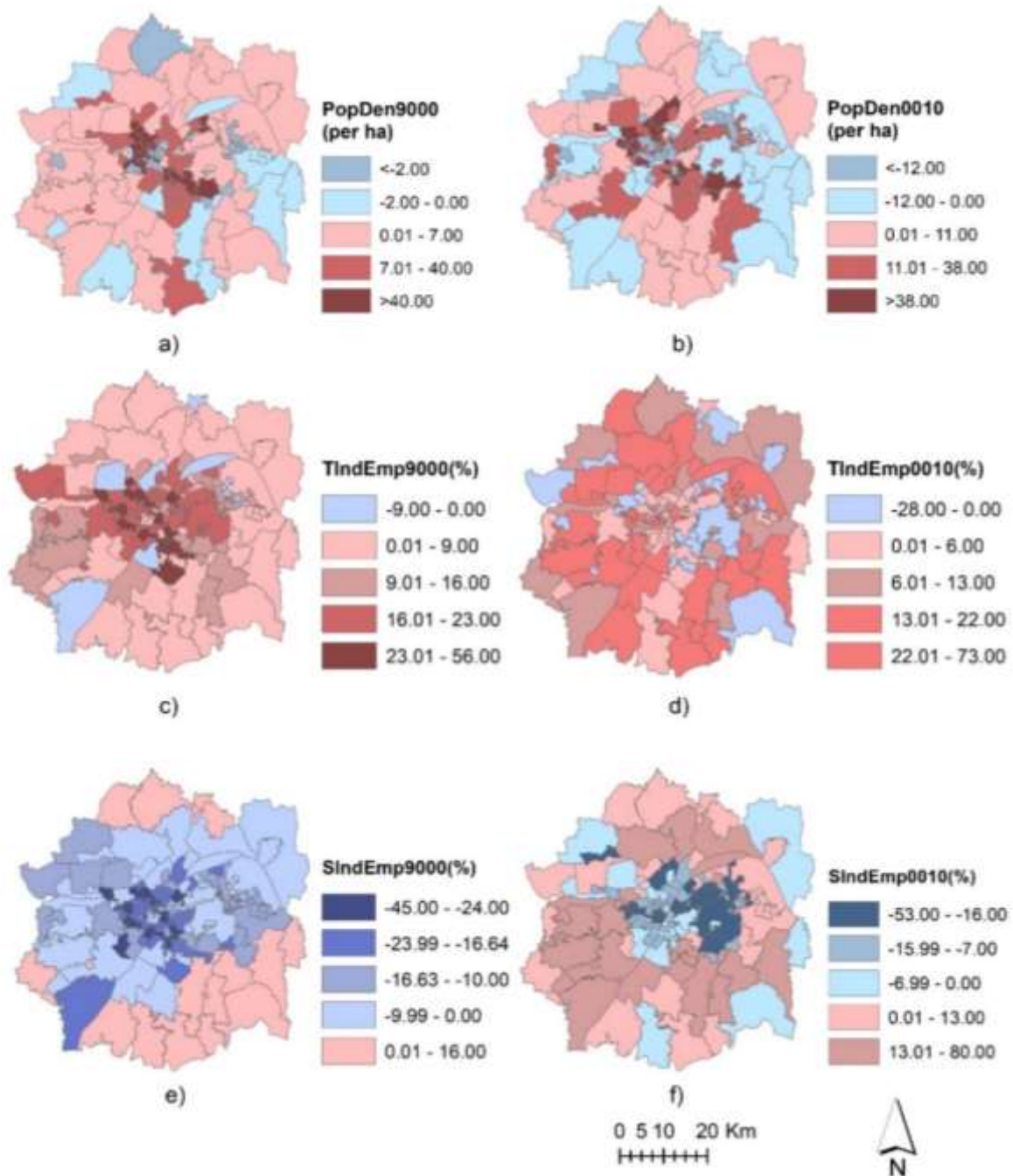
**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The remote sensing images are from open source on the U.S. Geological Survey (USGS) website. But the census data are not publicly available due to the restriction of confidentiality agreement.

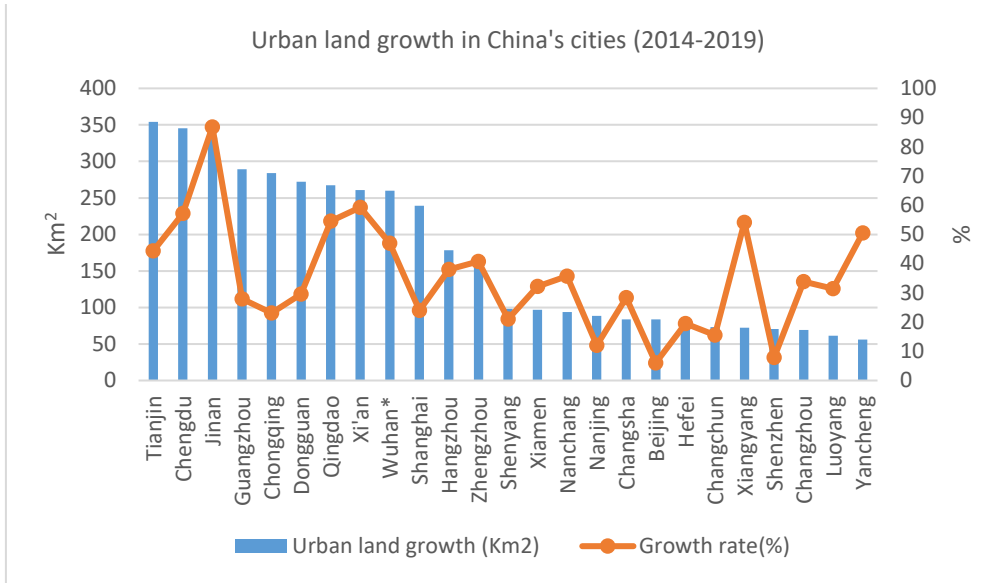
**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix

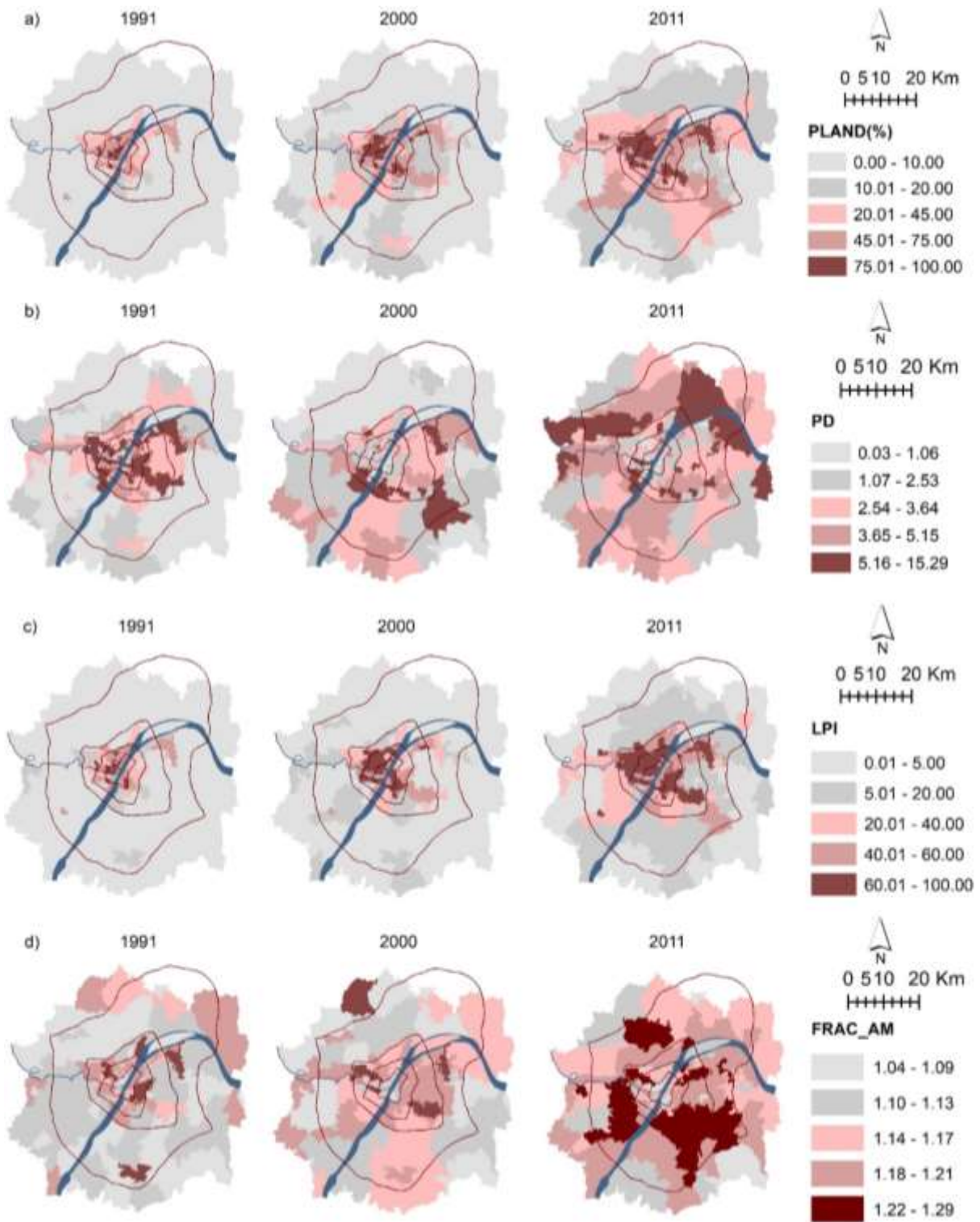
### Appendix A: Social structure, urban land growth, and urban land metrics



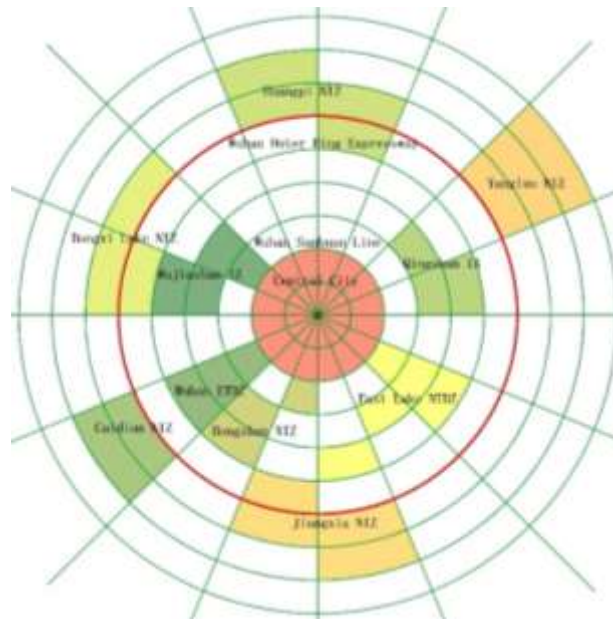
**Figure A1.** Population density and industrial structure (employment) changes. (a) Change of population density between 1990 and 2000; (b) Change of population density between 2000 and 2010; (c) Change of tertiary industry employment between 1990 and 2000; (d) Change of tertiary industry employment between 2000 and 2010; (e) Change of secondary industry employment between 1990 and 2000; (f) Change of secondary industry employment between 2000 and 2010. The population density is decreasing in the city center ((a), (b)). The industrial upgrading has significantly reshaped the urban center. The employment of the tertiary industry increased significantly in the urban center in the 1990s (c), and in the periphery of the urban center in the 2000s (d). The employment of the secondary industry shows a continuous decline in the urban center (e) and a significant increase in the periphery of the urban center in the 2000s (f).



**Figure A2.** Urban land growth in China's cities (2014-2019)



**Figure A3.** Urban land metrics maps. (a) Maps of PLAND; (b) Maps of PD; (c) Maps of LPI; (d) Maps of FRAC\_AM. The dynamics of the urban land distribution present that the urban land first expands along rivers and the main road axis, then toward others. The expansion is mostly defined by outward and multidirectional characteristics. In the 1990s, the urban space expansion concentrated in the southwest and the east. During the 2000s, however, impervious surfaces expanded to the west and the northeast to the Yangtze River. In 2011, urban land presents distributions in various directions.



**Figure A4.** Wuhan Industry Cluster. (IZ: Industrial Zone, NIZ: National Industrial Zone, NTDZ: National Technology Development Zone; ETDZ: Economic & Technology Development Zone)



**Figure A5.** Wuhan bridge-and-tunnel network by 2020.<sup>45</sup>

<sup>45</sup> Source: Analysis of "Layout Planning of Crossing Channels of the Yangtze River Main Line (2020-2035)" (《长江干线过江通道布局规划(2020--2035年)》解析). <http://www.whtpi.com/Exchange/14/3202.html>. (Accessed on June 30th, 2019.)

## Appendix B: Process of Urban Land Extraction

In this study, land cover is extracted based on the I–V–W (Impervious surface–vegetated area–water area) urban model. Surface reflectance images, top-of-atmosphere reflectance (TOA) images, and bright temperature (BT) images converted from the thermal band are collected, to better fit the requirement of band math further used for the band math employed for the extraction. The water area was first masked using the modified normalized difference water index (MNDWI) [37].

To extract impervious surfaces, we proposed a Modified Biophysical Composition Index (MBCI), based on the Biophysical Composition Index (BCI) [38]. The BCI is for better distinguishing urban land and bare soil. It is computed based on Tasseled Cap Transformation (TCT), particularly relying on the first three components, which represent brightness, greenness, and wetness. MBCI introduces bright temperatures (converted from the thermal band) into the BCI equation. To ensure that MBCI is more accurate in identifying impervious surfaces, we compared the separability of MBCI and BCI based on training samples, for which we selected 207 pixels for urban lands (impervious surface) and 611 for the permeable surface in 2011, 207 and 661 in 2000, and 207 and 661 in 1991. The comparison shows that MBCI has more significant separability than BCI. Based on the training samples, the threshold value for impervious is determined as  $-0.05$ ,  $-0.25$ , and  $-0.25$  for 1991, 2000, and 2011, respectively. The impervious surfaces are then drawn according to the MBCI threshold.

In detail, the formulas for MNDWI and MBCI are as follows.

$$\text{MNDWI} = (\text{Green} - \text{MIR}) / (\text{Green} + \text{MIR}) \quad (1)$$

Surface reflectance data is used for MNDWI computation, where Green and MIR represent the green band (Band 2) and the middle infrared band (Band 5), respectively.

$$\text{BCI} = [(B + W)/2 - G] / [(B + W)/2 + G] \quad (2)$$

for which TOA images are used for the computation and where B, W, and G stand for [0, 1] standardized brightness, wetness, and greenness are calculated using the equations based on the first, second, and third principal components of Tasseled Cap Transformation (TCT), respectively.

$$B = (\text{TC1} - \text{TC}_{1\min}) / (\text{TC1}_{\max} - \text{TC1}_{\min}) \quad (3)$$

$$G = (\text{TC2} - \text{TC2}_{\min}) / (\text{TC2}_{\max} - \text{TC2}_{\min}) \quad (4)$$

$$W = (\text{TC3} - \text{TC3}_{\min}) / (\text{TC3}_{\max} - \text{TC3}_{\min}) \quad (5)$$

where TC1, TC2, TC3 are the first three TC components;  $\text{TC}_{i\min}$  and  $\text{TC}_{i\max}$  are the minimum and maximum values of the  $i^{\text{th}}$  ( $i = 1, 2, 3$ ) TC components, respectively. The brightness, greenness, and wetness surfaces area computation using the TCT coefficients of Landsat 5 TM data are proposed by Crist et al. (1986) [39] (Table B1).

**Table B1.** Landsat-5 TM Tasseled Cap Coefficients [39].

Band	TM1	TM2	TM3	TM4	TM5	TM7
Brightness	0.2909	0.2493	0.4806	0.5568	0.4438	0.1706
Greenness	-0.2728	-0.2174	-0.5508	0.7221	0.0733	-0.1648
Wetness	0.1446	0.1761	0.3322	0.3396	-0.6210	-0.4186

$$\text{MBCI} = [(\text{BT} + B + W) / 3 - G] / [(\text{BT} + B + W) / 3 + G] \quad (6)$$

TOA and BT images are used for MBCI computation, where BT is [0, 1] standardized bright temperature extracted from the thermal band, which is computed as:

$$\text{BT} = (\text{BT}_0 - \text{BT}_{\min}) / (\text{BT}_{\max} - \text{BT}_{\min}) \quad (7)$$

where  $\text{BT}_0$ ,  $\text{BT}_{\min}$ ,  $\text{BT}_{\max}$  are the observed, minimum, and maximum values of the bright temperature, respectively.

## Appendix C: Correlation coefficient and OLS regression results

**Table C1.** Coefficient of Pearson correlation between different metrics (example in 2010).

	TA	PLAND	PD	LPI	TE	ED
TA	1	-0.258**	0.087	-0.317**	0.854**	0.205*
PLAND	-0.258**	1	-0.405**	0.987**	-0.563**	0.024
PD	0.087	-0.405**	1	-0.475**	0.288**	0.601**
LPI	-0.317**	0.987**	-0.475**	1	-0.610**	-0.064
FRAC_AM	0.653**	-0.252**	0.326**	-0.317**	0.533**	0.660**
	LSI	FRAC_AM	PARA_AM	CONTIG_AM	COHESION	AI
CA	0.647**	0.653**	-0.042	0.042	-0.168	-0.059
PLAND	-0.757**	-0.252**	-0.739**	0.744**	0.423**	0.791**
PD	0.416**	0.326**	0.433**	-0.436**	-0.232**	-0.435**
LPI	-0.797**	-0.317**	-0.714**	0.719**	0.425**	0.775**
FRAC_AM	0.521**	1	-0.013	0.011	-0.309**	-0.107

Note: \*, \*\*, \*\*\* indicates  $p < 0.10$ ,  $< 0.05$ ,  $< 0.01$ , respectively. TA: Total (Class) Area, PLAND: Percentage of Landscape, PD: Patch Density, LPI: Largest Patch Index, TE: Total Edge, ED: Edge Density, LSI: Landscape Shape Index, FRAC: Fractal Dimension Index, PARA: Perimeter-Area Ratio Distribution, CONTIG: Contiguity Index Distribution, COHESION: Patch Cohesion Index, AI: Aggregation Index. \_AM: Area weighted mean.

**Table C2.** Parameters of ordinal least square (OLS) regression results.

	1990	2000	2010	1990	2000	2010	1990	2000	2010
<b>OLS Result</b>									
Dependent variable	PLAND	PLAND	PLAND	PD	PD	PD	FRAC_AM	FRAC_AM	FRAC_AM
Coefficient of independent variables (Robust_Pr)									
Intercept	33.5362*	40.7276*	52.7519*	3.7354*	2.6679*	3.3940	1.1252*	1.1377*	1.1497*
Factor 1	21.8452*	20.4507**	21.9042*	1.5795*	0.1666	-0.5135*	0.0209*	0.0109*	-0.0193*
Factor 2	-0.7297	8.4416**	-2.9126	0.9426*	0.4094**	0.0736	0.0042	0.0101*	-0.0088*
Factor 3	16.6594*	11.5608*	-4.4899*	-0.6016*	-3.0086**	0.1001	-0.0199*	-0.0217*	-0.0189*
Factor 4	-1.8137*	-5.2675*	-1.9733	-0.1459	-0.2211	0.3666**	-0.0023	0.0016	0.0195*
Factor 5			2.1369			0.1608			-0.0012
<b>OLS diagnostics</b>									
Number of observations	131	128	135	131	128	135	131	128	135
AICc	1146.04	1147.96	1226.63	607.74	524.01	574.61	-421.38	-438.03	-459.02
R <sup>2</sup>	0.6921	0.6081	0.5256	0.4046	0.0856	0.1054	0.2903	0.2851	0.4023
A <sup>2</sup> adjusted	0.6823	0.5953	0.5072	0.3858	0.0559	0.0707	0.2648	0.2618	0.3791
Joint F-statistic	70.80*	47.40*	28.58*	21.41*	2.88*	3.04*	12.89*	12.26*	17.36*
Joint Wald statistic	346.29*	303.52*	226.89*	140.18*	12.94*	15.33*	38.38*	60.06*	106.66*
Koenker (BP) statistic	17.22*	10.73*	8.67	1.79	9.91*	0.72	9.31	10.53*	2.47
Jarque-Bera statistic	1.64	1.52	0.34	257.27*	41.83*	58.72*	3.27	2.43	2.74

Table C2. Continued.

	1990	2000	2010	1990	2000	2010	1990	2000	2010
<b>OLS (with removal of insignificant variables)</b>									
Dependent variable	PLAND	PLAND	PLAND	PD	PD	PD	FRAC_AM	FRAC_AM	FRAC_AM
Coefficient of independent variables (Robust_Pr)									
Intercept	33.5362*	40.7276*	68.0000*	3.7354*	2.6679*	3.3940*	1.1252*	1.1377*	1.1497*
Factor 1	21.8452*	20.4507**	18.9590*	1.5795*		-0.5135*	0.0209*	0.0109*	-0.0193*
Factor 2		8.4416**		0.9426*	0.4094**			0.0101*	-0.0088*
Factor 3	16.6594*	11.5608*	9.1971*	-0.6016*	-3.2286**		-0.0199*	-0.0217*	-0.0189*
Factor 4	-1.8137*	-5.2675*				0.3666**			0.0195*
<b>OLS diagnostics</b>									
Number of observations	131	128	135	131	128	135	131	128	135
AICc	1144.05	1147.96	1334.10	606.04	520.76	569.53	-423.01	-440.05	-461.14
R <sup>2</sup>	0.6916	0.6081	0.2902	0.1024	0.0776	0.0955	0.2754	0.2841	0.4018
A <sup>2</sup> adjusted	0.6843	0.5953	0.2795	0.3883	0.0628	0.0818	0.2641	0.2667	0.3834
Joint F-statistic	94.94*	47.40*	26.99*	28.50*	5.26*	6.97*	24.32*	16.39*	21.83*
Joint Wald statistic	347.62*	303.52*	72.09*	125.93*	8.22*	13.21*	33.55*	58.70*	102.18*
Koenker (BP) statistic	16.96*	10.73*	1.44	1.71	7.78*	0.47*	8.79*	4.07	1.90
Jarque-Bera statistic	1.77	1.52	2.44	260.96*	37.30*	54.16*	4.43	2.09	3.00

Notes on Interpretation

\* An asterisk next to a number indicates a statistically significant p-value ( $p < 0.01$ ).

[a] Coefficient: Represents the strength and type of relationship between each explanatory variable and the dependent variable.

[b] Probability and Robust Probability (Robust\_Pr): Asterisk (\*) indicates a coefficient is statistically significant ( $p < 0.01$ ); if the Koenker (BP) Statistic [f] is statistically significant, use the Robust Probability column (Robust\_Pr) to determine coefficient significance.

[c] Variance Inflation Factor (VIF): Large Variance Inflation Factor (VIF) values ( $> 7.5$ ) indicate redundancy among explanatory variables.

[d] R-Squared and Akaike's Information Criterion (AICc): Measures of model fit/performance.

[e] Joint F and Wald Statistics: Asterisk (\*) indicates overall model significance ( $p < 0.01$ ); if the Koenker (BP) Statistic [f] is statistically significant, use the Wald Statistic to determine overall model significance.

[f] Koenker (BP) Statistic: When this test is statistically significant ( $p < 0.01$ ), the relationships modeled are not consistent (either due to non-stationarity or heteroskedasticity). You should rely on the Robust Probabilities (Robust\_Pr) to determine coefficient significance and on the Wald Statistic to determine overall model significance.

[g] Jarque-Bera Statistic: When this test is statistically significant ( $p < 0.01$ ) model predictions are biased (the residuals are not normally distributed).

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## Chapter 4 Residents' Preferences and Perceptions toward Green Open Spaces in an Urban Area<sup>46</sup>

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# Residents' Preferences and Perceptions toward Green Open Spaces in an Urban Area

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**Abstract:** Green open spaces are an important part of the natural–social ecosystem, providing ecological services that maintain the healthy development of cities and society. Residents' perceptions of these benefits are largely related to their social-economic background as well as their familiarity with the development of green open spaces in their neighborhoods. Understanding residents' perceptions of green open space will contribute significantly to urban planning by providing practical information that facilitates residents' needs. Using the urban development zone (UDZ) of Wuhan, this study aims to understand residents' preference toward green open space and their perceptions of ecological services and improvement, with the focus on the linking between social factors, preference, and views. In this study, data are collected through online questionnaire surveys and interviews. The results demonstrate how respondents' views vary and which social factors significantly relate to them. Significant changes in natural space changes are reflected in the public's perception of the ecological functions of these spaces. Responses to improving green open space reflect the residents' pursuit of natural affinity and practicality. We conclude that it is better to enhance public involvement by providing residents' views, which helps to recognize actual needs in long-term green open space planning.

**Keywords:** public perception; green open space; preference; ecosystem services; China

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## 1. Introduction

Throughout the past few decades, Chinese cities have dramatically evolved in terms of their physical landscapes and social economies [1]. Meanwhile, residents are becoming more aware of the negative ecological impacts of urban growth, such as increased urban pollution, health concerns, and reduced social-natural interactions. Green open spaces, including parks, gardens, greenbelt areas, wetland, etc., act as a place for socializing while also providing a variety of natural and social-ecological services, such as improved micro-climates, purified air and improvement of the soil and water environment [2]. In this study, respondents' perceptions of these benefits are mostly influenced by their social-economic backgrounds and their familiarity with the development of green open space in their neighborhoods [3]. Understanding their views will contribute significantly to urban planning by providing practical information that facilitates residents' needs.

In an urban ecosystem, green open space is recognized as a crucial subsystem [4]. The attention toward green open space in cities of different income-level countries varies due to different socio-economic conditions. Equity, health, and safety benefits related to a high quality of life are typically of greater concern for residents in cities of high-income countries [5,6], while the loss of natural resources and degradation of natural subsystems caused by urban expansion are more concerning to those in lower-income countries [7]. Most research conducted on cities of middle- or low-income countries assert that the key cause of vegetation loss is urbanization, leading to a range of perceived environmental problems [8–10]. In China, a middle-high-income country, both the ecological impacts of urbanization on green open space and ecological services provided by such draw the attention of researchers [11]. Nonetheless, how the public perceives the impacts and the services, and how they understand engagement with relevant planning and management is still being studied [12].

This study looks at the urban development zone (UDZ) of Wuhan, a second-tier city in central China, which is used to investigate residents' perception of green open space. The green open spaces in this study mainly refer to city parks, street parks, and community parks, which contain water areas and gray open spaces or not. The main objective is to better understand residents' preferences toward green open space and their perceptions of ecological services and improvement, with the focus on the linking between different social factors and views. To achieve the objective, three questions are proposed: (1) What are the main features of residents' preference and perceptions of green open space and their links? (2) How do the social features of residents affect their preference and perceptions of green open spaces' ecological services and their improvement? (3) What can we learn for public participation in green open space planning and management?

## 2. Literature Review

Interactions between natural and social subsystems initiate the process of urban growth. The public's understanding of green open space emphasizes awareness of social and ecological functions of the natural landscape. Their enjoyment of these spaces is based on and a result of their understanding of the benefits they can provide [13]. Residents' preferences are related to their social characteristics and their perception of the quality of green open spaces. The literature found that the use of open green space is related to attributes like gender, age, income, education level, race, and cultural group [14,15]. A study by Jim and Shan (2013) in Guangzhou, China, shows that improving health and promoting children's growth have received great attention [15]. Wendel et al. (2012) in Latin American countries found that there are gender differences in the use of green space and that the inequality of urban green space distribution is widespread [16]. From the perspective of gender and age, residents demonstrate significant differences in the use of open green spaces. The research grouped the park visitors based on their social characteristics or visiting preferences based on a social perspective. The distribution and accessibility of green spaces play an important role in residents' preferences. Studies on Chinese cities such as Shanghai [17], Beijing [18], and Wuhan [19] show that the accessibility of green parks is related to the economic level of residents. In other words, it is similar to the conclusion that the area and abundance of urban green space in high-income countries are significantly related to the income level of residents [20,21].

Natural subsystems provide tangible and intangible ecological services. A great amount of literature focuses on how green open space benefits residents' health and life quality [22,23]. Residents' views of the services implicate their concern with different facets of urban development. Generally, residents notice more practical benefits than ecological ones [24]. For instance, they believe that urban parks are an appropriate location for exercise or socialization and they recognize the safety when visiting green open space as well as the environmental quality for their enjoyment of the exposure [25].

Residents' preferences in visiting will affect their perception of the importance of open green spaces to natural and social-ecological well-being. The concerns of well-being between groups with different behavior preferences are different, reflecting on the perception of ecological and cultural services. The social services of the ecosystem can strengthen the connection between people and nature and between people. Lo and Jim's (2012) research on Hong Kong states that "green space is mainly appreciated for its practical microclimate and convenient facilities, not because of its environmental and social functions"; "residents demand richer natural elements and auxiliary facilities"; and "Effective public participation" [14].

Residents' perceptions of the quality of the green open space and the degree of completeness of facilities affect their visit purpose. In turn, the residents' visiting purposes affect their perceptions of green space defects and their improvement needs [26]. Generally speaking, the status and quality of the green open space will affect the behavior preferences of the visitors, and the behavior preferences of the visitors in turn affect their attention to the required configuration. Residents will pay attention to the natural and social services of the green open space while also benefiting from their visit. Visit preference is associated with benefit perception. Residents who visit frequently are more concerned about the health promotion of green open spaces. At the same time, the green open space provides a

place to promote social interaction, potentially promoting social interaction, although the service is different in the perception and preferences of different social groups. Additionally, from the perspective of the human living environment, personal growth and living environment will affect their perception, especially a good natural environment in childhood and adult perception of changes in the natural environment, both of which will have an impact on preferences and needs.

Though the existing research stresses the public's attitude toward and perceptions of cultural-ecological services of green open space, it rarely detects the relationships between residents' preference and the influence on their perceptions of corresponding benefits provided by natural subsystems. Perceptions of benefits are affected not only by socioeconomic factors, like family status, economic class, or ethnic group [27,28], but also by their experiences with nature. Scholars find that the experience of interacting with the natural environment in one's childhood affects his or her awareness of the natural landscape and preference for usage when he or she grows up [29]. Residents' experiences with the evolving environment also shape local awareness of land-use history which further affects their perceptions [30–32]. However, only a few studies incorporate these experiences into influencing factors, with focus on childhood experiences, not witnessing natural space changes.

Existing literature on public preferences toward greenness usually concentrate on specific urban parks [33], providing deductible findings that contribute to urban greenness planning and management. For example, Ayala-Azcárraga et al. (2019) compares nine parks in México City and finds that there is "a close relationship between patterns of visitor use and urban parks components such as distance, tree abundance, safeness, playground qualities and cleanliness" [34]. Studying urban green spaces without focusing on specific parks can provide more universal information for the planning and management of such spaces. The literature focuses on research on preferences and perceptions based on differences in social attributes, and it is a good attempt to incorporate preferences and changes in the living environment into influencing factors.

Knowledge of the use of green open spaces, such as exposure time and experience, is crucial to explain services provided by those spaces [35,36]. How the use of green open space relates to people's opinions on the improvement of the space attracts the interests of researchers in the fields of environment and health [37], as well as community green space configuration [38] to name a few. Likewise, continuing to explore this topic is valuable for practical green open space provision in urban areas. Though literature focusing on perceptions of different services is popular, it is rare to compare or connect those facets, which will be done in this study.

This research introduces social characteristics, visiting preferences, experiences of environmental change, etc., to independent variables to analyze perceptions, attempting to establish the relationship between population, preference, and perception, as well as the relationship between preferences, services, and improvement. The study did not set a specific group of interviewees and communities and aimed to provide a basis for urban planning decision making on the social differences in the perception of residents in generalized urban spaces.

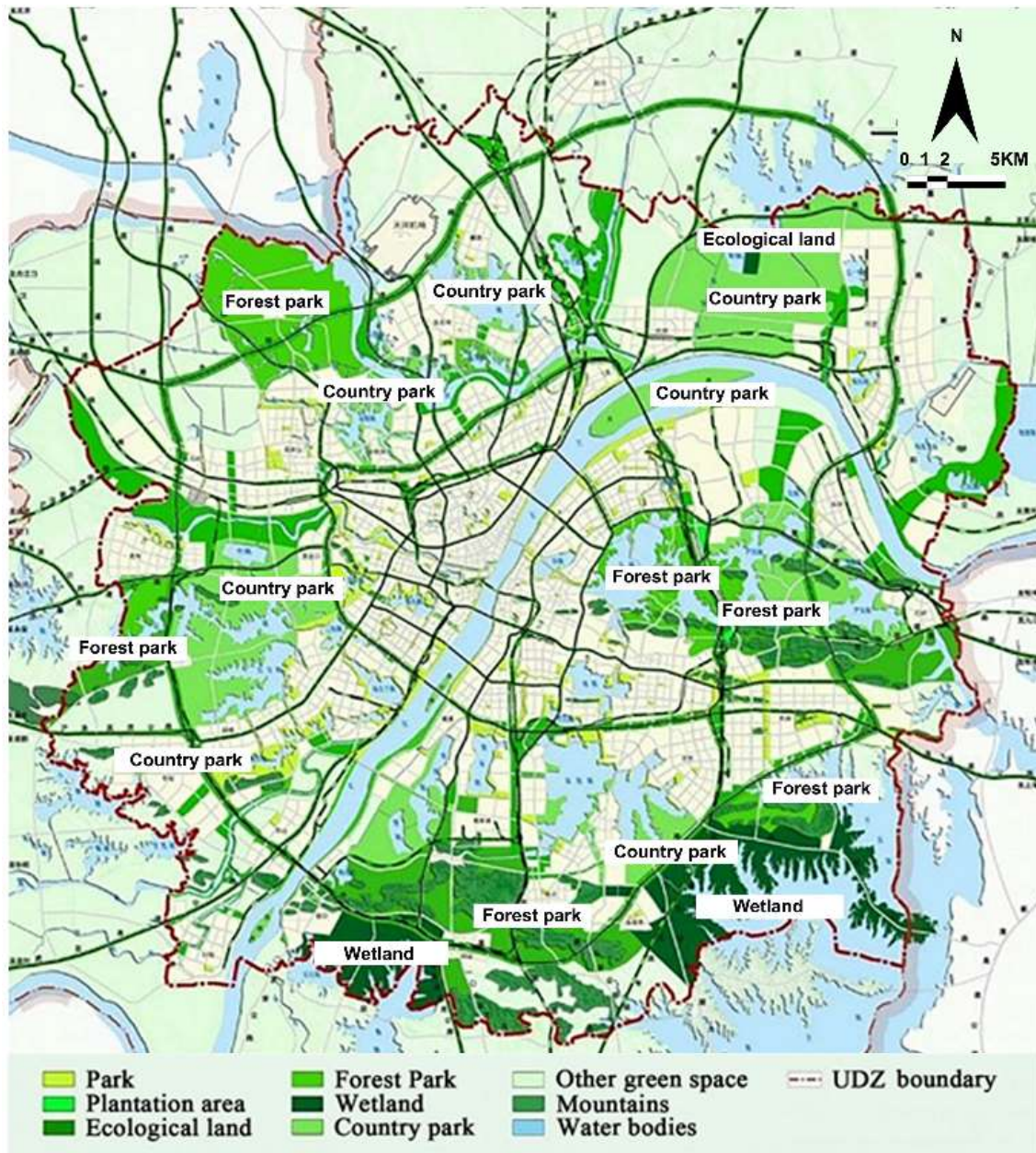
### **3. Study Area and Methods**

#### *3.1. Study Area*

Wuhan, the capital city of Hubei, is a large city located in central China. Being segregated by two natural belts, the Yangtze and Han rivers, Wuhan is historically a commercial center and transportation hub. This research focuses on the UDZ of Wuhan as defined in the latest city planning, where the remarkable physical and social transformations have been taking place. Wuhan urban land has grown quickly since 1990, with a 3.86-fold increase in the UDZ from 166.36 km<sup>2</sup> in 1990 to 828.74 km<sup>2</sup> in 2016. The population and GDP data are from the Wuhan Statistical Yearbook. The urban expansion data are derived from Landsat images. Wuhan has also experienced dramatic socio-economic growth, with its population increasing from 6.90 million in 1990 to 11.08 million in 2018. During that same period, its GDP increased from USD 2.71 billion to USD 227.37 billion (USD 1 = YUAN RMB 6.53, currency exchange rate on 29 December 2020). In the 1990s and early 2000s, significant transformations of green space and water area (wetland) to impervious surface occurred, accompanied by urban growth and

population aggregation. Since the latter half of the 2000s, Wuhan has been paying more attention to the renewal, redevelopment, and conservation of its green and water space.

Figure 1 shows the Wuhan UDZ green system plan between 2010 and 2020, describing the structural and spatial characteristics of the various types of green spaces. Parks and urban vegetated areas, which are the focus of this survey, constitute the major parts of green open spaces in the urban area. Small-scale green spaces in the city center provide services to nearby communities while big parks serve residents in larger areas.



**Figure 1.** Map of study area. Edited based on urban development zone (UDZ) Green System Plan Map in the comprehensive Plan of Wuhan. <http://gtghj.wuhan.gov.cn/wu/pc-992-61109.html>.

### 3.2. Data Collection and Analysis

Questionnaire surveys are a popular approach to obtain data for semi-quantitative analysis, while interviewing is often chosen for qualitative studies. In most studies, either questionnaire surveys or interviews are selected for analysis, with few using both. Since closed-question surveys have limitations on the disclosure of information implicated behind the data, personal interviews can be used to extract

complementary information [39]. The surveys for this study were designed based on the literature [11,23,40–43], with consideration of the characteristics of the case city. Data was collected to advance this study through an online survey and interview among the selected participants to represent the population of Wuhan. Furthermore, a web questionnaire was created using Questionnaire Star. The questionnaire link was then delivered by snowballing through WeChat, a popular social media platform in China. The snowballing began with acquaintances, colleagues, students, family, and neighbors. Data was collected automatically as participants completed the questionnaire, and the results could be downloaded.

The questionnaire was split into four parts, with closed-ended questions. It consisted of questions regarding personal information, residents' preferences of using green open spaces, and their perceptions of ecological services provided by, and improvement necessity of, those spaces.

The questionnaire survey provided an overview of the perspectives towards the ecological roles of green open space. However, more information was needed to fully address our research questions. Thus, we interviewed selected respondents based on their social variety and willingness to participate. The interview was held using WeChat one-one audio or video chat mode, and the content of the interview was typed based on the consent of the participants.

When analyzing the questionnaire data, we used percentages to assess the structure of perceptions in each category. We further quantified the perceptions with a Likert 5-scale coding. That is, "strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree" are coded as 1, 2, 3, 4, and 5, respectively. A "a nonparametric rank-based" Kruskal-Wallis test was then conducted to determine in which social groups perceptions were significantly different. This helped to decide if the differences "between two or more groups of an independent variable" were statistically significant [44]. We took demography, preference, and experience information of respondents as independent variables, including gender, age, occupation, length of residence, preference of visiting green open space, and experience of green space changes.

To briefly describe the detailed differences between different groups, we further calculated a mean score to rank the perceptions. In statistics, it is often believed that data collected at the ordinal level should not use measurements at the interval level [45]. Many statistical theorists believe that it is impossible to calculate the mean of the codes denoting individual categories of the Likert scale [46]. However, in *Advances in Health Sciences Education*, Norman (2010) affirms that means and other parametric statistics can be utilized for Likert scale data analysis without concern of "getting the wrong answer", based on the dissection of critical arguments and empirical literature dating back to the 1930s [47]. In a psychological study, Uher (2018) also claims that parametric methods are effective for quantitative analysis of rating scale data [48]. Many empirical studies show that the mean score is even robust for ranking of Likert-scale data [49]. They simplify the ranking and provide information about likelihood, although there are differences in the structures behind the mean scores. Thus, we adopted the mean score to further identify the differences of perceptions between social groups and only used the scores for ranking. The mean score is equal to the sum of "the proportion of respondents at different degrees agreeing multiplied by the corresponding value code", which means that a smaller mean score would reflect a greater disagreement from respondents.

### *3.3. Information of Respondents*

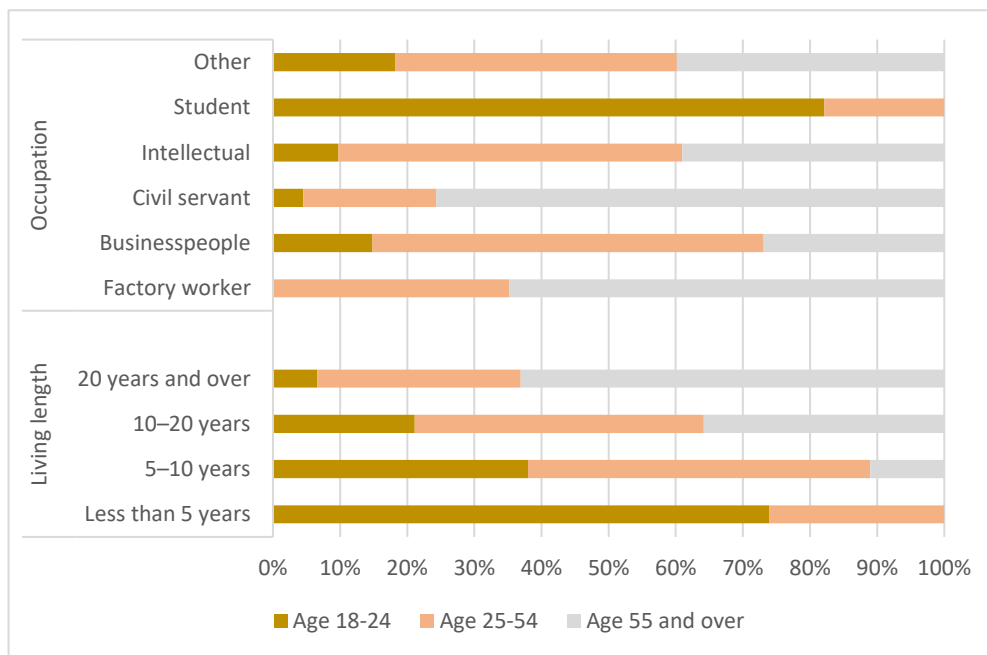
In total, 418 participants were recruited. Those who failed to verify their current and recent residence in Wuhan were dropped ( $n = 93$ ). A total of 325 participants constitutes our final sample, with 44.31% male and 55.69% female: 17.23% aged 18–25 (young), 59.08% aged 25–54 (middle-aged), and 23.69% aged 55 and over (elderly) (Table 1). Of the young respondents, 76.80% are students, whereas among the elderly group, 29.90% are civil servants, 18.20% are factory workers, and 14.30% are intellectuals. Occupations in the middle-aged group are relatively even, compared to the young or senior groups.

**Table 1.** Personal characteristics of respondents.

Personal Characteristics		Percentage (%)	Personal Characteristics		Percentage (%)
Gender	Male	44.31	Occupation	Factory worker	10.15
	Female	55.69		Businessperson	10.46
Age	Age 18–24	17.23		Civil servant	12.00
	Age 25–54	59.08		Intellectual	15.08
	Age 55 and over	23.69		Student	23.08
Education	Middle school or less	2.15		Other	29.23
	High school	10.15	Less than 5 years	25.85	
	College or above	87.69	5–10 years	18.46	
Hukou *	Urban Hukou	76.31	Residential length	10–20 years	9.54
	Rural Hukou	23.69		20 years and over	46.15

\* Hukou refers to the household registration status in China. It implicates where the person was raised. Hukou is different from districts/areas. In urban areas, there are also rural Hukou residents who are living in urban villages in this city or from other rural areas. Hukou implicates respondents' experience with nature in childhood, that is, respondents with rural Hukou, to a great extent, have more experience with more natural interaction rather than those with an urban one.

Respondents with different occupations and residential lengths have different age structures. The younger group has a higher proportion of students and has lived in Wuhan for a shorter period, while the elderly group has a higher proportion of factory workers and has lived in Wuhan for longer periods of time (Figure 2).



**Figure 2.** Age structure for respondents with different occupations and residential lengths.

#### 4. Preferences and Perceptions of Green Open Space

Green open space provides many ecological services. The results demonstrate how selected participants use these spaces and link it to their perceptions toward the improvement of such areas. Moreover, how respondents perceive the benefits of these spaces is also shown. These findings can help us to understand the relations between perceptions and their social characteristics, as well as links between various facets of such views.

#### 4.1. Benefits Provided by Green Open Space

##### 4.1.1. Use of Green Open Space: Enjoying Benefits in Person

Regarding the frequency of visits to green open space, 24.62% report that they visit daily; 28.31% visit weekly, 16.00% monthly, and 31.08% seldom visit. The structure in different ages, occupations, and residential length groups (Figure 3) shows that the elderly are likely to visit green spaces frequently, with 42.90% visiting daily. The young group has higher proportions (39.30%) of weekly visits. Among occupation groups, civil servants report the most frequent visits.

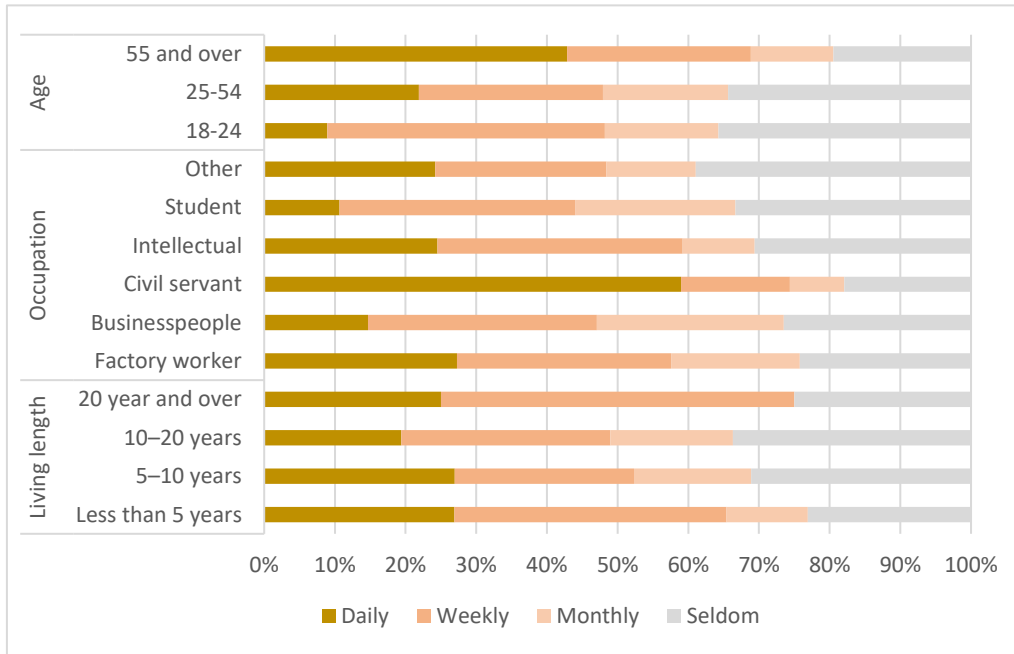


Figure 3. Frequency of visits by different social groups.

In terms of experiences with green space loss or gain in their neighborhoods, 12.00% of respondents report a great loss and 23.08% a slight one. Over a quarter (26.46%) claim no changes have occurred. Of all respondents, 28.92% and 9.54%, respectively, have seen a slight and great gain (Figure 4).

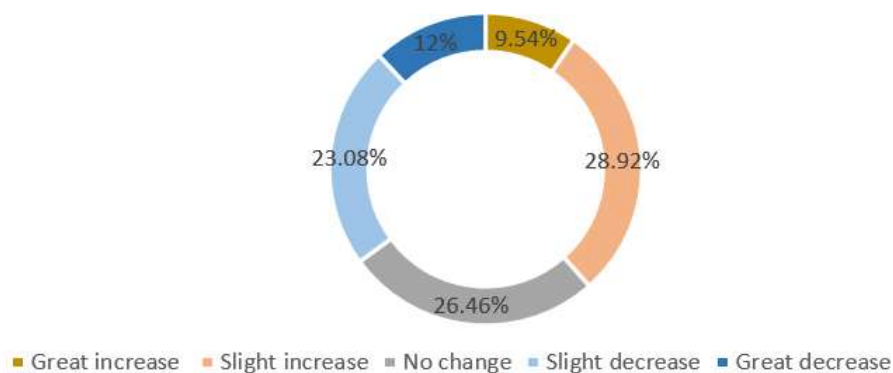
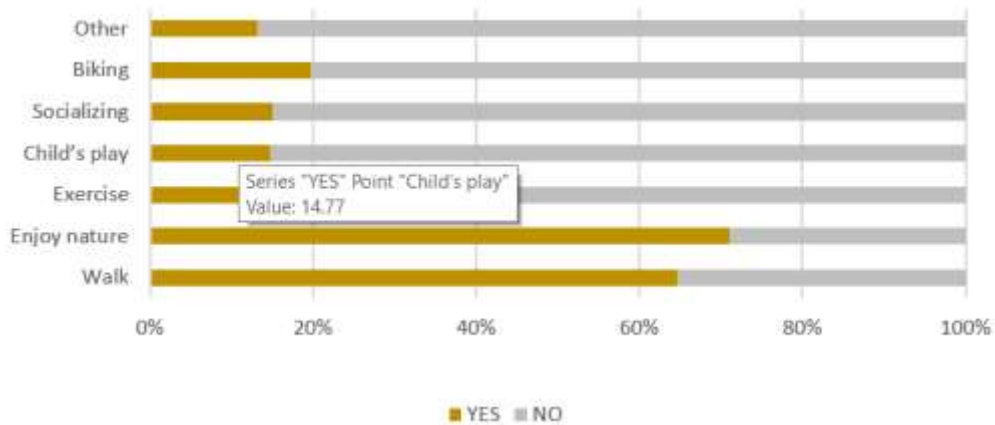


Figure 4. Perceived loss or gain of green space.

Respondents were asked their main reasons for visiting green open space. The question contains multiple choices, which means a respondent may visit with multiple motives. For example, one may visit green open spaces to walk, enjoy nature, and socialize at the same time. Thus, the intentions are overlapping and not mutually exclusive. The data was then coded into dichotomies based on each

intention, in which “Yes (Y)” means to choose one option, such as to walk, “No (N)” means that option is not chosen. Overall, most respondents visit green open space to enjoy nature (71.08%), walk (64.62%), or exercise (43.08%). Bicycling, social interactions, child’s play, or other purposes are less common at 19.69%, 15.08%, 14.77%, and 13.23%, respectively (Figure 5).



**Figure 5.** Green open space visit intention.

Social groups in the categories of age, Hukou, and occupation have significant differences for the in-person enjoyment of green open space (Table 2), while gender and education have little influence. Younger and middle-aged participants tend to visit more to walk, enjoy nature, socialize, and ride their bicycles. Middle-aged respondents and elders mainly go for exercise and child’s play. Urban Hukou participants enjoy visiting green open space to exercise, which links to individuals’ health, whereas those with rural Hukou prefer going for walks, enjoying nature, socializing, and bicycle riding.

**Table 2.** P values of Kruskal–Wallis test: Social differences in intentions to visit.

Intentions to Visit	Walk		Enjoy Nature		Exercise		Child’s Play		Socializing		Biking		Other	
	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Age	0.00 ***		0.00 ***		0.29		0.03 **		0.02 **		0.00 ***		0.86	
Hukou	0.05 *		0.07 *		0.03 **		0.11		0.02 **		0.11		0.49	
Occupation	0.09 *		0.39		0.20		0.00 ***		0.06 *		0.37		0.30	
Residential length	0.08 *		0.01 ***		0.35		0.02 **		0.01 **		0.29		0.10	

P value: \*\*\*, \*\*, \* indicate the significance at the level of 0.01, 0.05, and 0.10, respectively. “Y” means “Yes” for the choice of that visit purpose and “N” means “No” with no selection of that purpose.

Selected social differences of visit intention are shown in Figure 6. Civil servants have the greatest intentions to visit green open space for exercise while students have the lowest. Intellectuals have the highest interest in enjoying these spaces for child’s play while students enjoy it for bicycle riding. This suggests that intellectuals consider the developmental benefits children may gain from green open space, compared to other occupational groups. Socializing in green open space is preferred the most by students, followed by businesspeople and intellectuals. The groups who rarely visit to socialize are factory workers, followed by civil servants.

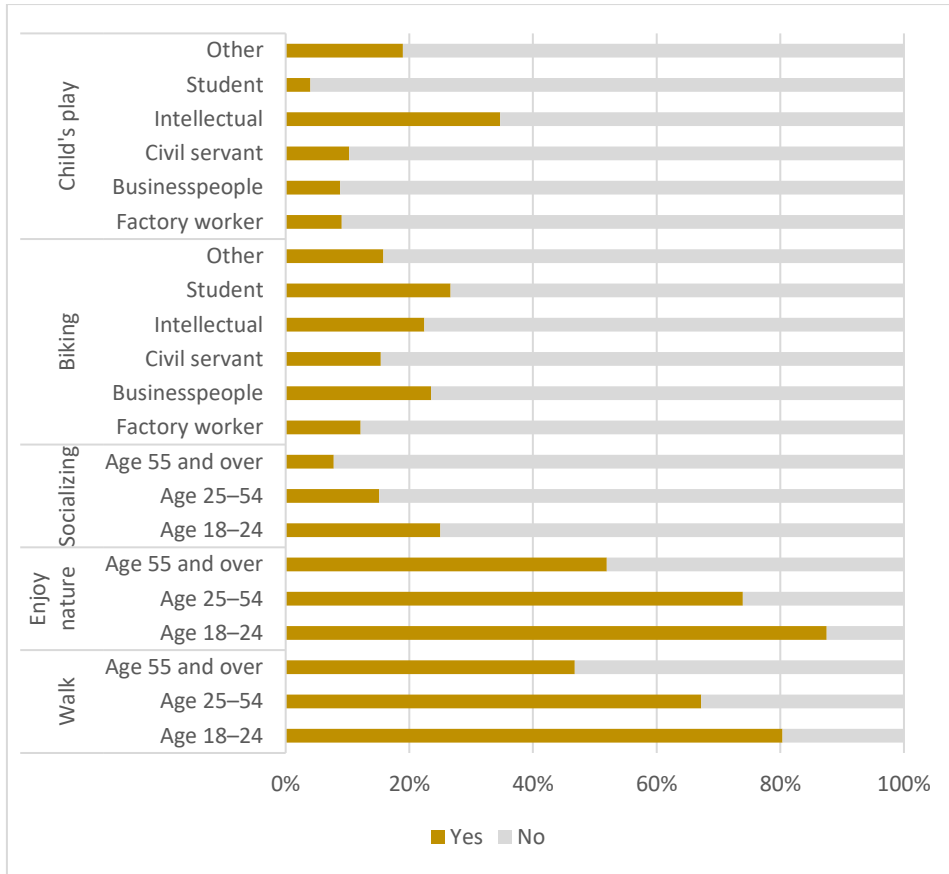


Figure 6. Purposes of visits by different occupational respondents.

#### 4.1.2. Perceptions of Benefits

Respondents' awareness of the ecological services of open green spaces are most reflected by the importance of nature in their daily life [34]. Answers to the question "To what extent do you agree that green open spaces provide residents with the natural and social-ecological services?" show that the key concerns are air quality, noise reduction, and mitigation of urban heat island effects (Figure 7). When deciding if "green space and wetland significantly improve air quality", 87.69% of respondents agree and 1.23% disagree. Natural spaces are crucial habitats for biodiversity, while 4.92% of respondents disagree, showing less concern about habitats than for air quality improvement, noise reduction, and mitigation of urban heat island effects.

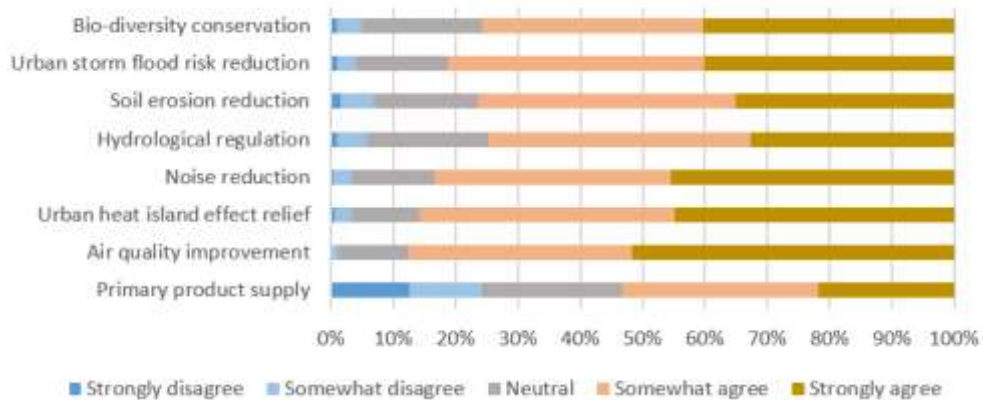
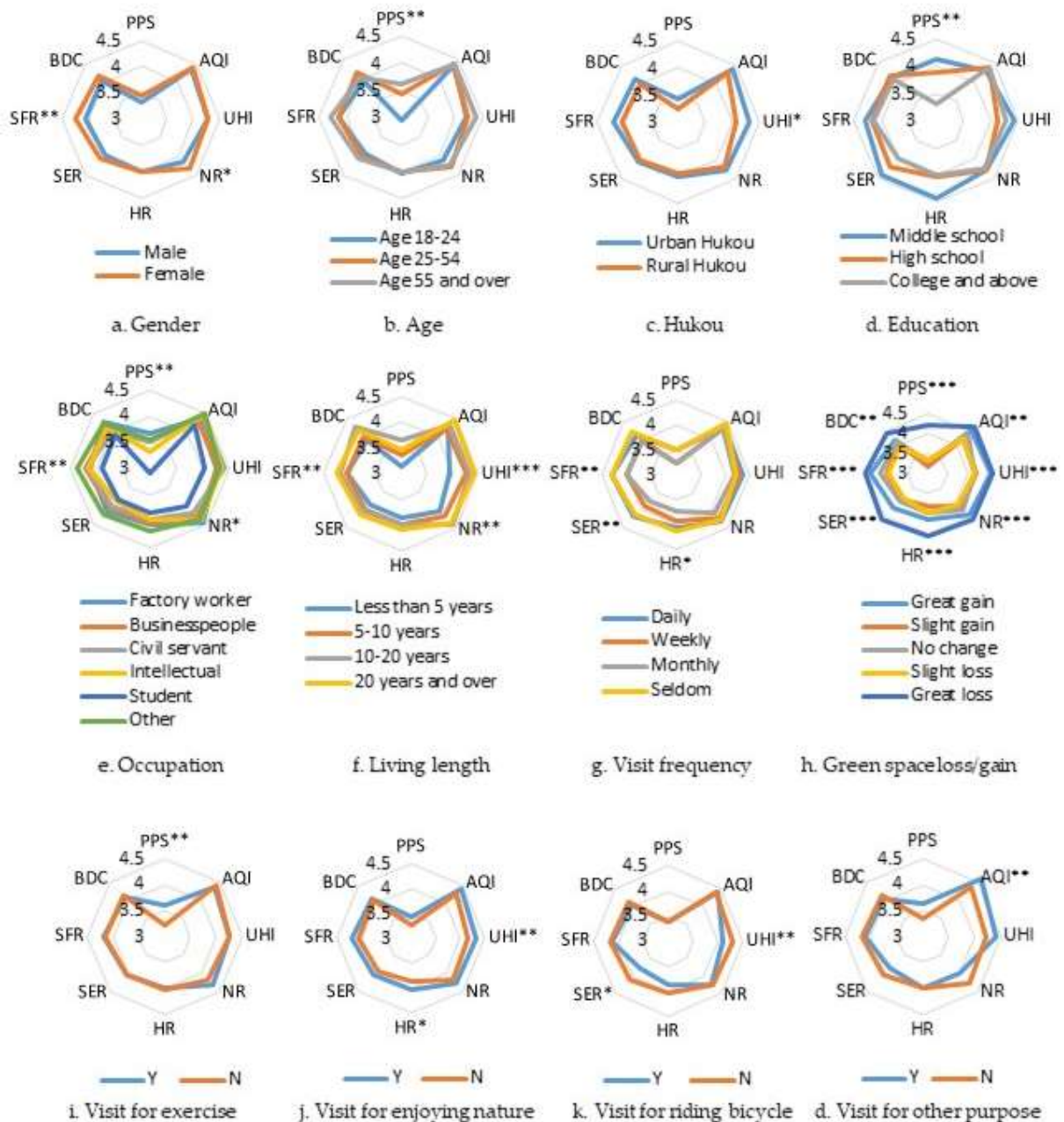


Figure 7. Perceptions of ecological services of green open spaces.

Figure 8 provides the mean score of perception based on different social groups. In detail, gender affects perceptions of noise reduction by green open spaces, as fewer males (4.15) agree than females (4.33), which is the same when evaluating the services of storm flood reduction (male 4.05 and female 4.25). Hukou, which implies more experience with nature, influences how the benefits of urban heat



PPS: primary product supply; AQI: air quality improvement; UHR: urban heat island relief; NR: noise reduction; HR: hydrological regulation; SER: soil erosion reduction; SFR: storm flood risk reduction; BDC: bio-diversity conservation  
P value: \*\*\*, \*\*, \* indicates the significance of Kruskal Wallis' test at the level of 0.01, 0.05, and 0.10, respectively.

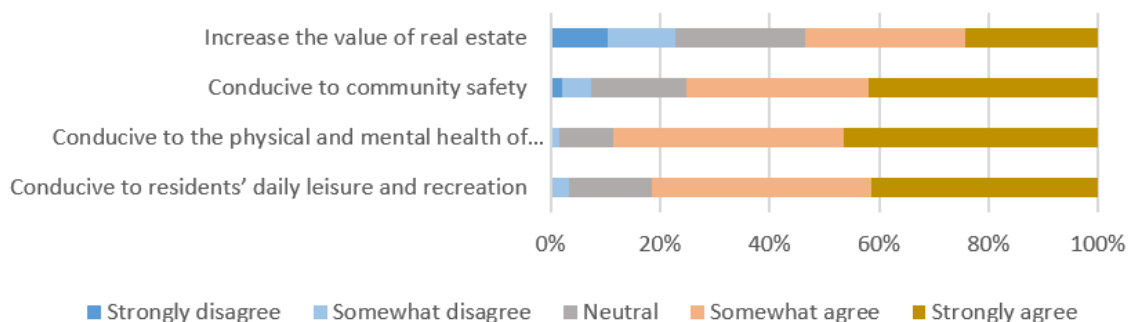
**Figure 8.** Social differences in perception of ecological services (based on mean scores listed in Table A1).

island effect relief are perceived, with urban Hukou people (4.33) agreeing more than rural (4.06). Differences in age groups are only significant when they perceive primary product supply by green open spaces, for which elders agree (3.61) more and young people disagree (2.95) more. This is concurrent with differences by occupational categories as well as educational background. People with

a higher educational background (3.31) tend to be more neutral than those with lower educational background (i.e., high school-educated population (4.14) and middle school-educated population (3.88)). Among occupation groups, those with the most neutral perceptions are students (2.93). Students also disagree with the services of noise reduction (4.00) and urban flood risk mitigation (3.89), compared to other occupations. A longer period of residency in Wuhan leads to a greater appreciation of the benefits of urban heat island mitigation and noise reduction by green open spaces. In-person visits to green open spaces affect residents' perception of services, such as primary product supply, air quality improvement, urban heat island relief, etc.

Experience of green space changes is reflected significantly in residents' perception of ecological services. Those who reported experiences of decreased green space tend to agree more strongly with natural space and a scattered distribution increase than those without, followed by those with experience of a great increase in green space.

From a social perspective, green open spaces benefit residents by promoting health and providing them with a place to relax. They also affect the value of residential properties. The benefits for physical and mental health are most important to residents, with 46.46% strongly agreeing and 42.15% somewhat agreeing (Figure 9). Only 1.54% participants opposed. It indicates that respondents recognize the vitality of green open space for their health in an urban context, with the least disagreement, no matter how frequently or for what purpose they visit the space. Of all respondents, 81.54% agree and 3.38% disagree that green open space acts as a place for daily leisure and recreation which benefits their daily lives. Much different from the three aspects above, green open spaces' effects on real estate value gained lower approval, with 22.77% of respondents disagreeing, suggesting that the other factors play more important roles.

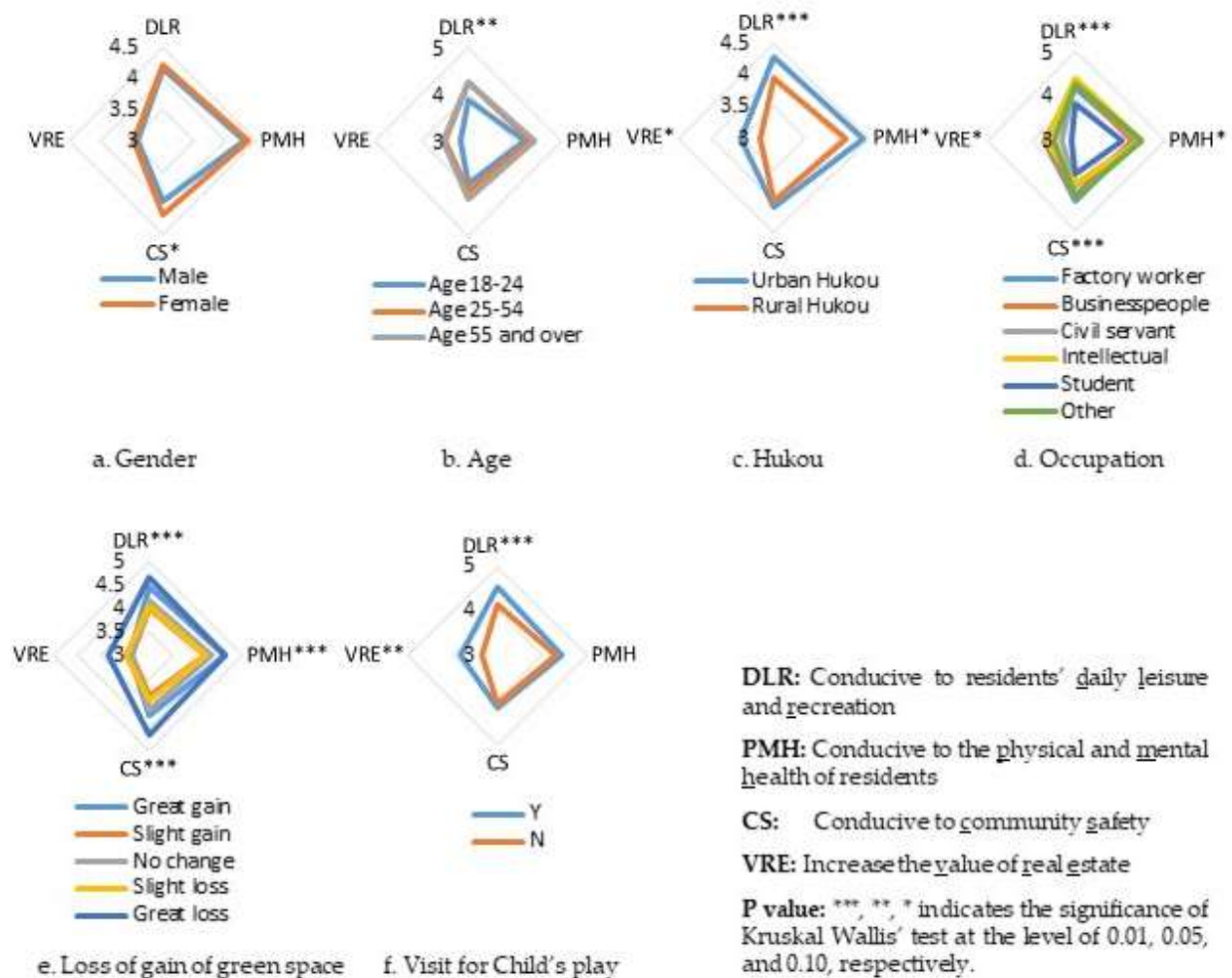


**Figure 9.** Perceptions of social services provided by green open space.

Evaluating the social difference based on mean score (Figure 10) shows that in regard to gender it is females (4.17) who tend to agree more strongly with green open spaces' ability to promote community safety, while males (3.95) are more neutral or disagree. Age also plays a significant role in the feeling about the daily use of green open space. Elders (4.27) and middle-aged respondents (4.25) tend to agree more strongly than younger respondents (3.89). Those with urban Hukou agree more than those with rural Hukou with social-ecological services being a place for residents' daily leisure and recreation, conducive to physical and mental health, as well as for increasing real estate value. Discrimination is not significant when perceiving the community safety benefits provided by green open space. Educational background does not influence social-ecological services perceived, while occupation does. When evaluating the services of green open space for daily relaxation, students (3.83) tend to be more neutral or disagree, compared to the other occupations. Students thought similarly of other possible benefits like health, safety, and real estate value. When evaluating community safety benefits provided by green open space, those most neutral and in disagreement are students (3.73), followed by intellectuals (3.98) and civil servants (4.00), while factory workers (4.36) and businesspeople (4.21) are in greatest agreement. Students present the lowest mean score (3.11), followed by civil servants (3.31), when evaluating green open spaces' function to increase real estate value. Those

who have lived in Wuhan for a long time more strongly agree with these social services than newer residents, with significant discrimination when evaluating services of daily relaxation and health provided by green open space. The frequency of visits has little influence on participants' perceptions of these services. People who visit green open spaces for child's play pay great attention to the improvement of related facilities in these spaces.

Experience of green space changes significantly affects participants' perceptions of services for daily relaxation, promotion of health, and community safety. Those who experienced great changes, both decreases and increases, demand more for the social-ecological services.



**Figure 10.** Differences in social service perception (based on mean scores listed in Table A2).

#### 4.2. Disadvantages of Green Open Space

A person's view towards green open space quality depends on their intentions when visiting the area in question. People are more interested in benefiting from specific elements that meet their requirements. For example, those who visit to walk or enjoy nature will be more likely to recognize if it lacks green space. Those who mostly go to walk can also distinguish when walking trails are limited, whereas those who go for bicycle rides notice bicycle trails. It also suggests that respondents are more likely to perceive the shortage of exercise facilities, regardless of the reason for which they visit the green open space.

#### 4.2.1. Perceptions toward Natural Space Improvement

The question for perception toward green open space improvement is “To what extent do you agree that improvement of natural elements and auxiliary facilities are essential in your neighborhood?”

In terms of natural space improvements, participants are concerned most with the quality of water bodies, followed by the development of wetlands and green areas (Figure 11). Of all respondents, 75.08% agree that developing additional green space is important to their communities while 8.31% do not. Furthermore, 79.07% and 64.00% of respondents agree that the enhancement of vegetation richness and the dispersion of green space is significant. Of the respondents, 75.38% recognize that developing or restoring wetlands is essential for their neighborhoods while 10.15% disagree. In terms of improving water quality and restoring wetland, 4.00% and 8.31% disagree that it is necessary.

Those who disagree mainly report an improvement or no change in the quality of water bodies. The results show that a person’s experience with natural space change affects their view of the necessity of improvement. An increase in natural space may reduce the perceived necessity of the improvement, while a decrease may play an opposite role.

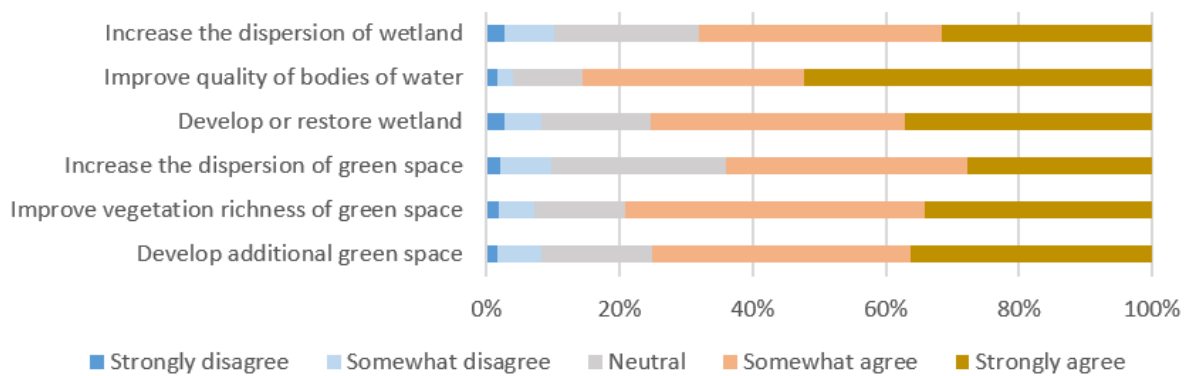
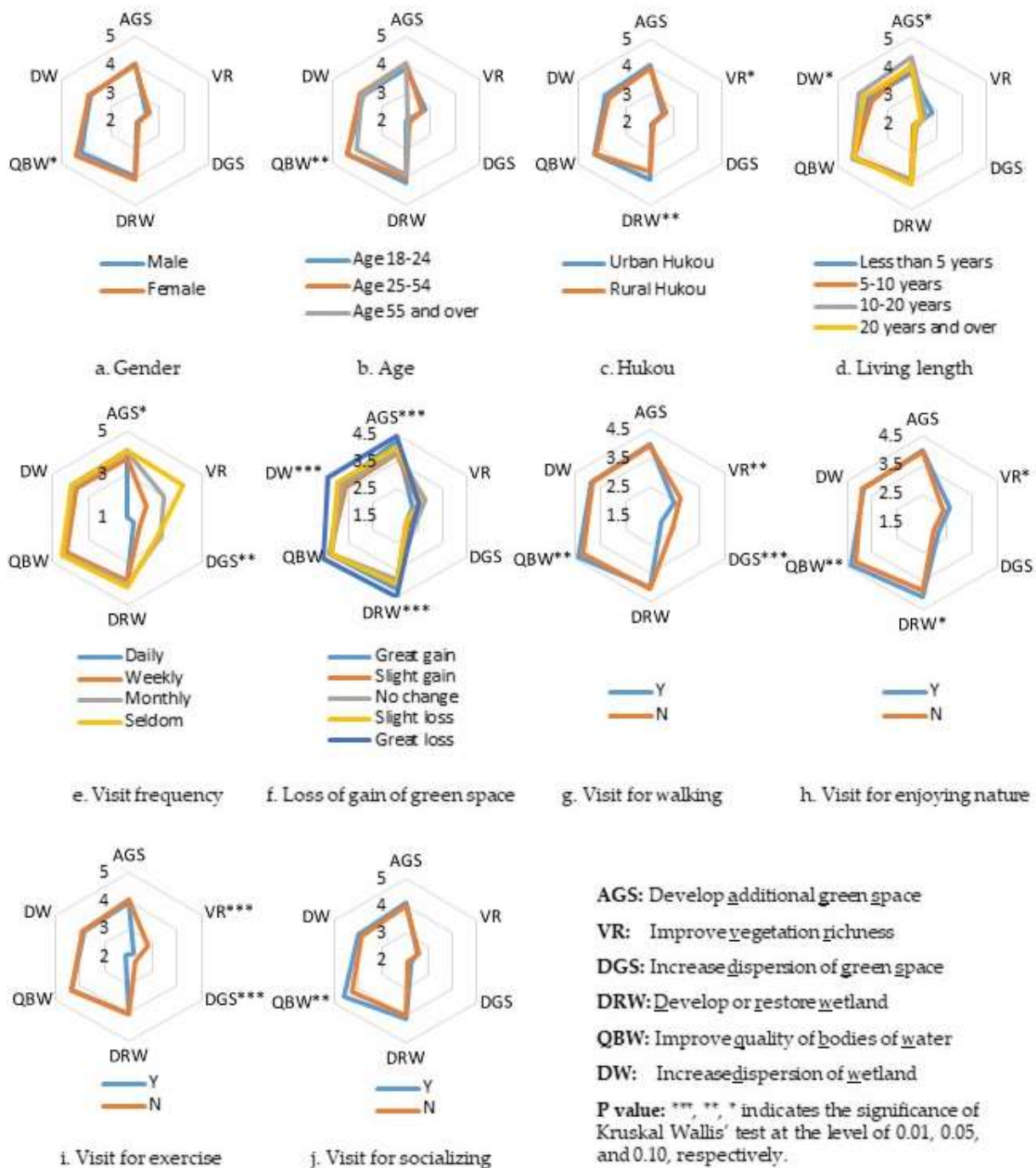


Figure 11. Perception of green open space improvement.

Comparing mean scores (Figure 12), gender and age clearly affect perceptions of the need to improve the quality of bodies of water, for which males (4.22) agree less than females (4.41), and elders (4.05) are less likely to agree than middle-aged (4.41) and young (4.41) residents. Hukou affects residents’ perception of improving vegetation richness and developing or restoring wetland; urban Hukou people (2.50) are in greater disagreement that improving vegetation richness is needed than rural Hukou residents (2.66) but more agree that developing or restoring wetland is important (urban Hukou 4.08 and rural Hukou 3.82).

In terms of preferences, respondents’ visiting frequency affects their evaluation of the necessity to increase the dispersion of green space. Those who visit often disagree more than those who visit less. In-person services enjoyed by visitors are associated with the need for improvements to green open spaces (Figure 12). Enjoying green open space to walk, enjoy nature, and exercise is significantly associated with perceptions of improving vegetation richness, increasing the dispersion of green space, developing wetland, and improving the quality of bodies of water.

Regarding reported experience of green space changes, respondents that experienced a great decrease in green space present the strongest agreement with the necessity to develop additional green space in their neighborhoods. A similar perception also represents the importance of developing or restoring wetland.

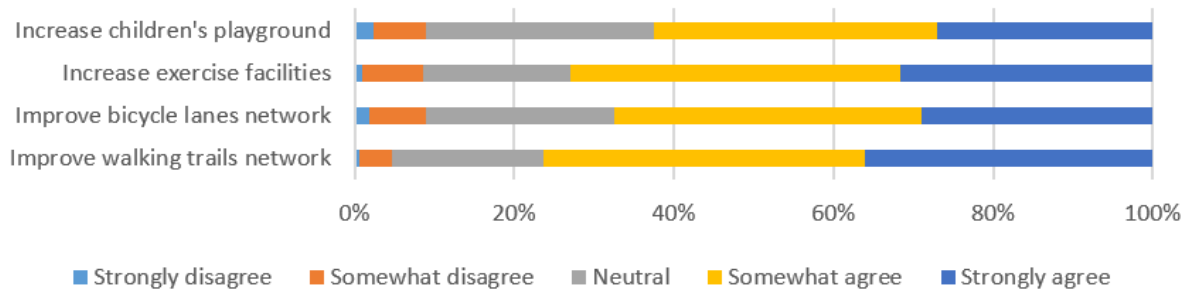


**Figure 12.** Social difference of natural space improvement perceptions (based on mean score listed in Table A3).

#### 4.2.2. Perceptions of Needed Facility Improvement

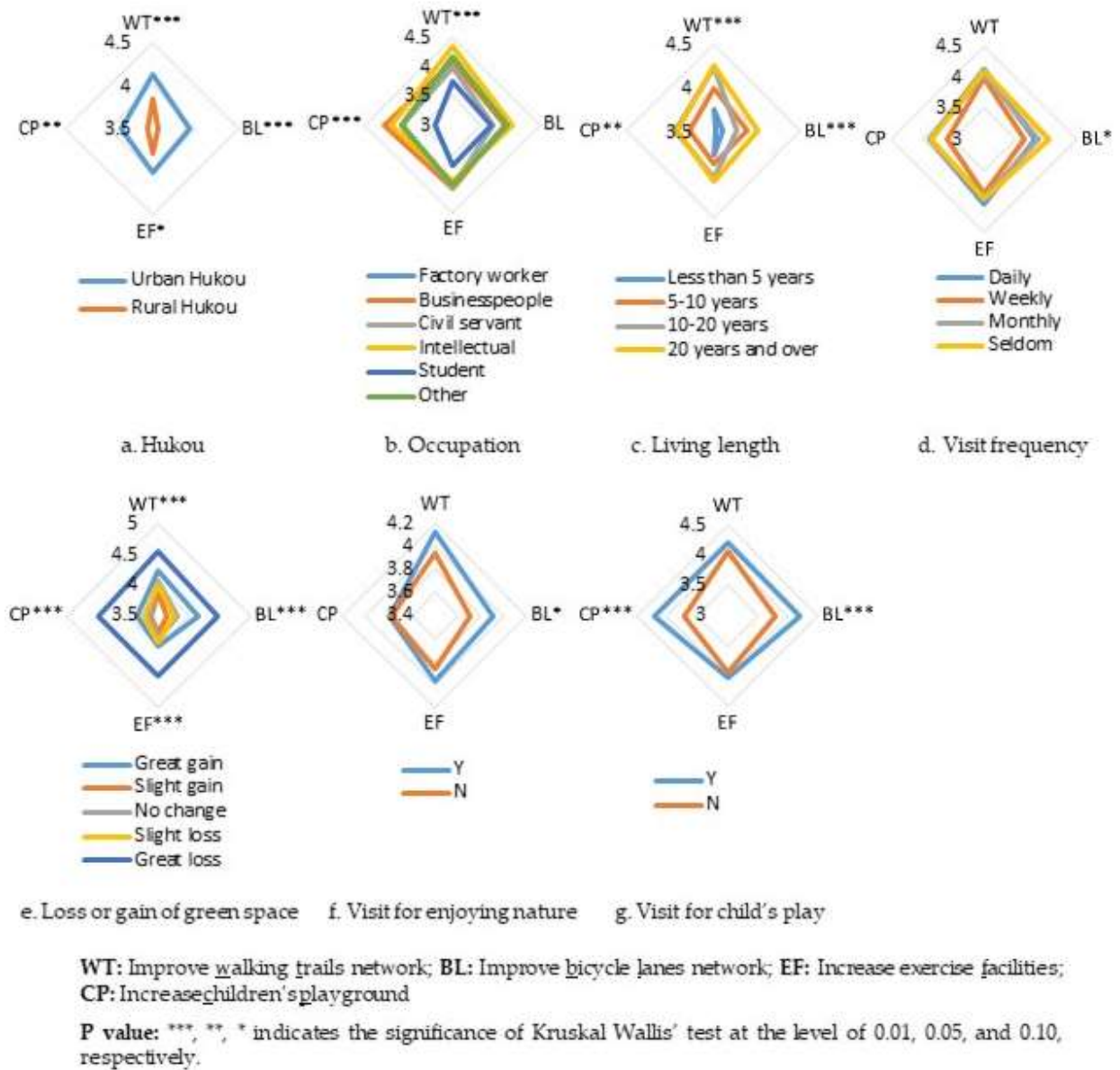
In terms of improving auxiliary facilities in green space, the survey focuses on the importance of enhancing trails, exercise facilities, bicycle lanes, and children's playgrounds. Of the respondents, 76.31% agree and 4.62% disagree that improving trails is significant (Figure 13). Regarding the increase in exercise facilities, 72.92% of respondents agree that it is important in their neighborhoods and 8.62% disagree. Among those who disagree, 92.86% use green space for a variety of reasons except exercise. Of the respondents, 67.38% agree and 8.92% disagree that improving bicycle trails is obligatory. Of those who disagree, 89.65% visit green open space by foot to walk, with no motive of bicycling; only 10.35% visit for bicycling but none notice a lack of trails. Furthermore, 62.46% agree and 9.23% disagree

that improving children’s playgrounds is important. However, none of the interviewees who visit green open space for children’s play disagree. In summary, the necessity for auxiliary facilities improvement in green open space relies on the residents’ intention for visiting, indicating a practically oriented demand for improvements.



**Figure 13.** Perception of facility improvement in green open space.

Gender, age, and education do not significantly impact residents’ perceptions of the needed improvements to facilities in urban green spaces (Figure 14). Hukou is of greater influence, with rural populations more likely to be neutral or disagree that facilities should be improved. Different occupations face significant discrimination when evaluating the necessity of improving facilities. Students tend to be the most neutral and likely to disagree on increasing walking trails (3.75) and children’s playgrounds (3.28). Intellectuals agree most with increasing walking trails (4.35) and children’s playgrounds (4.04), followed by businesspeople (4.15). The length of residency also influences perceptions of facility improvement; those who have lived in Wuhan longer are more in favor of facility improvements than those with shorter residency. In terms of the reported experience of green space changes, those who have witnessed a great decrease in green space agree much more strongly with the necessity of facility improvement than the other respondents.



**Figure 14.** Social difference in perception of facility improvement (based on mean scores listed in Table A4).

### 4.3. Interview Results

We interviewed eighteen participants. The interviewees included seven (almost 40%) males and eleven (slightly over 60%) females. Their occupations vary, with one factory worker, four businesspeople, three civil servants, five researchers, and five students. They live in various districts with different lengths of residency, ranging from 3 years to more than 20 years. Eight of the interviewees visit green open space daily, four visit weekly, and the other six visit monthly or less. The objectives behind the interviews were to gain more insight into what affects respondents' visiting frequencies to green open space, how they perceive benefits, impacts, and improvements of green open space, and their willingness to participate in green open space planning and management. The interview results are briefly presented in Table 3.

**Table 3.** Summary of interview.

Question Theme	Summary	Example Quote(s)
Proximity of green open space	<p>Twelve interviewees claim that the proximity of green open space in their neighborhoods is the most important factor affecting their visit frequency.</p> <p>Six interviewees do not believe the proximity is a determinant for their visit frequency. Four of them state they do not have much flexible time due to busy schedules. The other two rarely visit since it is not a habit.</p>	<p><i>"In my neighborhood, the green open space is close by and very convenient to be accessed. I go there every morning and evening to dance. It is very important for my health,"</i> expressed a 50-year-old female researcher.</p> <p><i>"I am very busy with my business and hardly have leisure time to visit the green open space, even though it is not far away. But I really enjoy the green environment as I walk by,"</i> said a 32-year-old businessman.</p>
Green open space improvement demand	<p>Fourteen participants approve of improving natural space as well as auxiliary facilities in their neighborhood.</p> <p>Four participants do not express their view on the necessity. Two of them enjoy high-quality green open space close to their residential community and the other two have witnessed a great increase in green space in their neighborhoods.</p>	<p><i>"I would prefer to increase the green open space and fitness facilities in my neighborhood. I visit the space 2-3 times per week to walk and enjoy nature, often I use the facilities to exercise. This mitigates my back aches and promotes my health,"</i> a 38-year-old civil servant said.</p> <p><i>"In my neighborhood, there is ample green open space, with exercise facilities such as basketball court, tennis court, etc. I enjoy the space and facilities very often. So I don't think it is necessary to make improvements,"</i> a 32-year-old researcher.</p>
Daily relaxation and health benefits	<p>Fourteen participants express that green open spaces in their neighborhoods are important for their daily relaxation and promote residents' health due to the social-natural interaction. The other four are neutral or seldom visit the green open space.</p>	<p><i>"Green open space is very important for high-quality life. I reside close to JiangTan park and visit there almost every day, for enjoying nature and relaxation. I notice that it is really good for my health,"</i> said a 50-year-old civil servant.</p> <p><i>"Green open space is of great significance to a high-quality environment and is beneficial to the daily life of residents. But for me, green space does not mean a place to relax every day, because I am too busy at work and rarely go outdoors in my free time,"</i> a 35-year-old businessman.</p>
Negative impacts of green open space	<p>Fourteen participants share positive opinions regarding the benefits provided by green open space. They hardly express concerns of any negative effects.</p> <p>However, four participants note the noise caused by visitors and safety risks in the green open space they visit.</p>	<p><i>"The green open space I usually visit is only a 5-min walk away from my apartment. I am used to going there every day. In the morning and evening, many residents living nearby dance here, which is very lively. But sometimes it is too noisy,"</i> an interviewee who lives in an apartment near the street park.</p> <p><i>"The open green space in the community where I live is a bit remote and lacks lighting, so for safety, I usually go there during the day,"</i> a 22-year-old student said.</p>
Willingness to participate	<p>Nine participants show willingness to be engaged in green open space configuration and maintenance. They are more likely to be middle aged.</p> <p>Five participants doubt the effectiveness of the public's contribution since they feel decision makers will not take residents' opinions seriously.</p> <p>The other four participants do not give clear opinions about their participation willingness.</p>	<p><i>"I am very enthusiastic to be involved in the configuration and maintenance of green open spaces in the community. For example, I often collect residents' needs and provide suggestions to the Property Management Board. If more residents participate, the community will have a better environment. I believe many hands make light work,"</i> a 45-year-old female researcher. She is a member of the owners' committee in her community.</p> <p><i>"Volunteers participating in the maintenance of community green space can promote the beautification of the community. I often engage in this type of voluntary work. I am also willing to provide feedback for the configuration and enhancement of landscaping in the community, but there are few such channels. I don't think these proposals would be taken seriously by decision-makers. Economic interests are often sought first by developers,"</i> said a 24-year-old student.</p>

## 5. Discussions

### 5.1. Respondents' Preferences of Green Open Space and Link with Perceptions

The survey results show that respondents most enjoy visiting green open space to be around nature, go walking, and exercise. This is coincident with the findings for Guangzhou in China [35] and for Gyeongsan City in the Republic of Korea [41]. However, perceived benefits of green open space differ between this study and Jim and Shan's [15] results. For example, while popular in Jim and Shan's study, child's play is not a most common benefit enjoyed by residents in this research. This is due to differences in sampling as the sampling in this study focuses on those over 18 years old and a small proportion have minors, whereas the literature includes samples aged 14–18. Socializing is recognized as a minor function that fewer people enjoy. The results support findings in Guangzhou [15] and in Malaysia [50] that residents might not use urban green open space as an important place for social interaction, although it offers the environment for it.

Intentions to visit in person are connected to respondents' perceptions of improvements of natural space, distribution, and corresponding facilities. Those who visit to go walking, enjoy nature or exercise prefer the improvement of natural elements such as increasing greenness and water areas in green open spaces, while those who go for child's play are interested in the improvement of auxiliary facilities such as children's playgrounds. An understanding of needed facility improvements demonstrates a practical orientation demand which has also been found in Chinese cities such as Guangzhou [15] and Zhengzhou [51]. The improvements then attract more visits which further enhance people's cognition of the corresponding services.

Similar findings in the literature focusing on other regions, such as cities in the Netherlands [38], show that youth prefer to use green open space for socializing more than elders do. Meanwhile, businesspeople and students tend to socialize more than other occupational groups. Elders mostly prefer going to green open space for exercise, indicating a health concern associated with age, which is also reflected in the literature about elder visitors' behaviors or concerns [39,52].

Rural Hukou implicates more natural and social interaction in residents' growing experience. It also results in higher preferences for walking, enjoying nature, and socializing. This finding implies that growing up in a more natural environment has an inherent effect on adults' preference for green open space. It is in line with the claim that childhood experience later influences an individual's green place visiting behavior into adulthood, which has been studied in cities of Britain [53].

Intellectuals, who mainly have highly educated backgrounds, prefer child's play in green open space the most, compared with other occupational respondents. This is mostly caused by the greater proportion of intellectuals with children in the survey. It further implies that the amount of time a child is exposed to nature can have a long-term impact on their preferences and perceptions.

The findings are relevant to urban planning with its practical yet socially dynamic demands of green open space. Thereby, it suggests that green open space configuration planning should be organized with particular attention to the social structure of neighborhoods being served close by. For example, in neighborhoods with more youth, bicycle trails and more social interaction facilities should be considered. In neighborhoods with more minors, children's playgrounds should be addressed, and parking lots might be a potential demand. In neighborhoods with more elders, daily exercise facilities should be stressed.

Social–natural interactions have been changing along with urban evolution. Respondents' preferences relate to their childhood experiences with the social and natural environment and are affected by the actual environment they are in currently. In terms of social interactions, those who live in a traditional neighborhood or a workplace neighborhood have more familiarities and prefer more socializing rather than those in a modern neighborhood. However, increasing developments of new technology and high-rise vertical residential structures, to a great extent, decreased social contact. Therefore, designing people-friendly green open space is helpful for the promotion of social interaction.

In current neighborhoods, the feasibility to add more green space or wetland is largely constrained by reality, even though respondents express strong demands. In the regenerated neighborhoods, a soft landscape has been improved according to the planning criteria about property ratios and green space

percentages. In upcoming neighborhoods, decision makers should consider the census information regarding population structure, which is the mainstay variable that determines the use of green open space. Corresponding designs should be introduced according to the demographic structure and the surveyed demands for green open space.

### *5.2. Social Factors' Influences on Residents' Perceptions*

The ecological services closely related to daily life and enjoyment, such as fresh air, urban heat island relief, and urban noise mitigation, attract more agreement than other services that relate indirectly. The results in Guangzhou, China express similar beliefs [35]. Through these services, green open space benefits respondents' daily life and health [54]. Demands for improvement to green open space from the perspective of area, richness, configuration, and auxiliary facilities are rooted in residents' appreciation for daily relaxation and health benefits. An improved green open system then provides better benefits for respondents' daily leisure as well as their personal health. However, even though participants strongly agree that green open space is beneficial for daily relaxation and health, it does not reflect upon their use of these spaces when looking at frequency and intention of visiting. It reveals that green open space benefits people without relying only on an in-person visit.

Participants mostly agree that green open spaces are consistent with their health and needs for daily leisure or relaxation. Differences between those with different types of Hukou (urban versus rural), as well as in terms of length of residency, indicate that experience interacting with nature and knowledge of natural development affect perception of daily use and health-related services provided by green open spaces. This supports studies of experiences in nature [55]. These differences are also found when residents evaluate the benefits of urban heat island relief by green open space. In Wuhan, the "Furnace City", which has extremely high temperatures in specific seasons, the heat island relief function is recognized as being very important to local residents. The perception of this service is also demonstrated in another "Furnace City", Nanjing [56].

Compared with other occupational groups, factory workers agree the most that green open spaces reduce noise. In neighborhoods relying on the traditional secondary industry, improvements to green open space have been outstanding since the 2000s. The transition influences residents' feelings about the improvement of the environment, especially regarding noise mitigation. Noise reduction services are also strongly agreed upon by those living in Wuhan longer and those who have experienced great changes in natural space.

A relatively higher proportion of respondents disagree that green open space is conducive to community safety. There are, however, disagreements between the perspectives of interviewees as some respondents highlighted the negative impact of visitors on the space itself, such as too many crowds, or too much noise, and the occurrences of environmental degradation that can result from visitor traffic. Findings on Chinese cities mainly stress the positive contribution of green open space to residential environment. In China's high-density cities, the scarcity of green open spaces means that these spaces have more positive effects on the living environment than negative impacts. Further, more conveniently accessible green open space (based on increased dispersion) and rich greenness may increase real estate value, though a higher proportion of respondents disagree with this claim than with other social services.

### *5.3. Influence of Experience on Cognition*

Hukou, residential length, and reported green space change are three factors referring to respondents' experiences. Rural Hukou implies that respondents were raised in an environment with more interaction with the natural environment and people. Regarding length of residency, those who have lived in Wuhan longer may have more experience and knowledge about urban landscape evolution as well as its ecological services. Another experience-related factor is reported green space changes in the neighborhoods in which respondents reside. Respondents who were raised in an urban environment tend to agree more with the claim that green open space is important for both natural and

social services than those in a rural environment and those who have lived in Wuhan longer agree more with the improvement than those with a shorter length of residency.

Experience of development in green space alters perspectives toward the areas. Taking it as an independent variable is effective to get clear results about its influences on one's perception. Nonetheless, since it is perceived information, it is better to interpret the findings combined with those based on objective information. Respondents share a variety of experiences with natural space changes. How someone uses and sees natural space changes directly affects how important they think the space and resources are, as well as how involved they are in contributing to a healthy urban ecological system. Respondents who experienced a great decrease in green space approve more of green open spaces' significance for ecological services, indicating that a bigger magnitude of environmental degradation has a greater impact on the benefits perceived by residents. The increasing awareness of natural environment promotes more demands for more widely dispersion of green open space in areas near respondents' places of residence.

When determining the differences between services, participants express greater concern about air quality, noise, and flood-related services than hydrological regulation and habitat conservation. One reason is that the former aspects are more directly linked to life quality that residents can directly feel than the latter. Another reason is that most who strongly approve of those benefits have had an experience with environmental degradation at the former stage of urban construction and improvement at the latter stage. The personal experience of environmental quality dynamics strengthens their agreement with the benefits green open space provides.

#### *5.4. Implication on Public Participation*

Respondents' perceptions toward the improvement of green open spaces show that the public can provide suggestions on improving those spaces based on their visits, experience, and overall expectations. Public involvement in community green open space configuration and maintenance is common in cities of high-income countries [57]. This approach is gradually being implemented in Chinese cities. Starting in the mid-2000s, large cities in China began an inclusive system for city planning [58], in which capacity ratio and green open space configuration for residential layout are open to the public. This is a remarkable step towards public involvement in China's city planning. In addition, at the community level, residents are encouraged to participate in the maintenance and management of green open spaces, by contributing to activities such as cleaning parks, adopting trees, and providing suggestions.

The participants' suggestions to improve green open space demonstrate the potential benefit that could be obtained through their engagement in micro-spatial natural open space management. Their concerns link with the intentions of natural space visits. However, it does not mean they necessarily have a strong willingness to participate in the decision-making process, even though valuable information can be obtained from the public. As shown in the interview results, residents' views on the effects of this process are mixed. These differences are caused by varying occupations and experiences with the policy-making institution as well as how public participation plays a role in the system. To promote public participation in a more practical and inclusive process, pre-training needs to be stressed to update information about public processes as well as other stakeholders' concerns.

## **6. Conclusions**

This study provides an in-depth analysis of the social preferences and perceptions toward green open space. It refers to the public's involvement with natural landscape evolution and how the landscape can shape people's preferences and perceptions, with a comprehensive understanding of ecological services of, and importance to improve, green open space. It considers Wuhan's characteristics of bodies of water, which are typical in central or southern Chinese cities.

It can be concluded that green open spaces play an important role in maintaining a good quality of residents' daily life and outdoor activities, based on the respondents' preferences and perceptions in the study area of the Wuhan UDZ. Green open space provides many services, such as being an outdoor

venue for walking, enjoying nature, exercising, child's play, social interactions, and so on. Preferences vary among different social groups, which results in different perceptions of ecological services provided by green open spaces and the necessary improvements to such spaces. Green open spaces offer an environment for society to connect with nature. How respondents use those spaces for socializing attracts relatively less concern compared with other services. Social interactions are important for healthy social ecology. To encourage residents to enjoy more of the services urban green open spaces provide it is better to learn planning and design from other large cities. The natural ecological services enjoyed by respondents reflect their concern about relative environmental disadvantages. This is related not only to their usage, but also to their experiences with the evolution of the natural subsystem. Even though the ecological services are enjoyed and recognized by respondents, this does not necessarily indicate voluntary participation in green open space management. Cities with relatively mature institutes of volunteer enrollment and training may provide reference to Chinese cities, even though there may be differences in culture and institutes.

The research provides findings that support the literature from social perspectives. In terms of theory, it also highlights the contributions of environmental experience-based knowledge to perception and the impact of residents' use of green open space on their perception. It enriches ideas regarding social-natural subsystem interactions within an urban area. Moreover, a semi-quantitative (questionnaire survey) and qualitative (interview) analysis are combined to eliminate the drawbacks of either approach. Therefore, this research should be considered an upgrade of other approaches in the literature.

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## Appendix

**Table A1.** Social differences in perception of ecological services (Mean score and p value).

Social features		Ecological services							
		Primary product supply	Air quality improvement	Urban heat island effect relief	Noise reduction	Hydrological regulation	Soil erosion reduction	Storm flood risk reduction	Bio-diversity conservation
Gen-der	Male	3.31	4.35	4.26	4.15	4.01	3.97	4.05	4.03
	Female	3.44	4.40	4.27	4.33	4.01	4.08	4.25	4.15
	P value	0.28	0.74	0.84	0.08*	0.72	0.16	0.04**	0.40
Age	18-24	2.95	4.39	4.21	4.11	4.04	3.95	4.13	3.96
	25-54	3.42	4.37	4.23	4.30	4.00	4.03	4.13	4.16
	55 and over	3.61	4.40	4.39	4.25	4.00	4.09	4.29	4.05
	P value	0.01**	0.96	0.44	0.38	0.99	0.63	0.58	0.33
Hu-kou	Urban	3.42	4.41	4.33	4.27	4.02	4.04	4.19	4.13
	Rural	3.26	4.29	4.06	4.19	3.95	4.00	4.06	4.00
	P value	0.23	0.45	0.07*	0.91	0.56	0.98	0.54	0.66
Education	Middle school	4.14	4.29	4.43	4.29	4.43	4.43	4.29	4.14
	High school	3.88	4.36	4.12	4.30	4.03	4.21	4.18	4.18
	College and above	3.31	4.39	4.28	4.25	3.99	4.00	4.16	4.09
	P value	0.03**	0.72	0.68	0.90	0.39	0.20	0.99	0.80
Occupation	Factory worker	3.67	4.36	4.27	4.45	4.06	4.15	4.12	4.24
	Businesspeople	3.56	4.32	4.29	4.29	4.03	4.06	4.21	4.09
	Civil servant	3.51	4.41	4.41	4.18	3.95	4.00	4.18	4.00
	Intellectual	3.33	4.49	4.37	4.37	3.96	3.88	4.16	4.14
	Student	2.93	4.19	4.03	4.00	3.83	3.83	3.89	3.92
	Other	3.55	4.49	4.34	4.34	4.17	4.22	4.37	4.22
	P value	0.02**	0.21	0.16	0.05*	0.31	0.10	0.03**	0.26
Living length	Less than 5 years	3.15	4.30	3.96	4.04	3.86	3.85	4.05	3.94
	5-10 years	3.37	4.25	4.27	4.18	4.00	4.00	4.07	4.03
	10-20 years	3.65	4.35	4.32	4.42	4.00	4.06	4.19	4.29
	20 years and over	3.46	4.49	4.43	4.37	4.09	4.13	4.26	4.18
	P value	0.20	0.19	0.00***	0.02**	0.21	0.14	0.33	0.15
Frequency of visits	Daily	3.51	4.39	4.36	4.31	4.08	4.20	4.31	4.13
	Weekly	3.23	4.33	4.28	4.25	3.93	3.89	3.99	4.00
	Monthly	3.25	4.33	4.17	4.10	3.75	3.75	4.00	3.96
	Seldom	3.49	4.46	4.23	4.29	4.15	4.16	4.29	4.25
	P value	0.26	0.63	0.76	0.69	0.05*	0.02**	0.01**	0.26
Green space change	Great increase	3.26	4.55	4.58	4.45	4.13	4.19	4.45	4.16
	Slight increase	3.19	4.26	4.19	4.18	3.82	3.89	4.01	4.06
	No change	3.29	4.43	4.16	4.26	3.97	4.00	4.20	4.10
	Slight decrease	3.33	4.27	4.17	4.07	3.96	3.87	3.99	3.95
	Great decrease	4.23	4.67	4.62	4.62	4.54	4.59	4.56	4.44
	P value	0.00***	0.01**	0.00***	0.00***	0.00***	0.00***	0.00***	0.03**
In-person visiting purpose (P value)	Walk	0.96	0.99	0.69	0.99	0.48	0.91	0.73	0.97
	Enjoy nature	0.32	0.11	0.04**	0.25	0.09*	0.13	0.11	0.48
	Exercise	0.02**	0.51	0.88	0.34	0.82	0.86	0.86	0.59
	Child's play	0.34	0.46	0.69	0.93	0.18	0.40	0.95	0.72
	Socializing	0.72	0.12	0.78	0.83	0.21	0.98	0.67	0.74
	Ride bicycle	0.90	0.91	0.06*	0.74	0.33	0.06*	0.75	0.67
	Other	0.15	0.03**	0.22	0.10	0.77	0.74	0.93	0.54

P value: \*\*\*, \*\*, \* indicates the significance at the level of 0.01, 0.05, and 0.10, respectively.

The comparison of in-person visiting purposes for respondents who choose one purpose is those who don't choose this purpose.

**Table A2.** Differences in social services perception (Mean score and P value).

		Conducive to residents' daily leisure and recreation	Conducive to the physical and mental health of residents	Conducive to community safety	Increase the value of real estate
Gender	Male	4.15	4.30	3.95	3.40
	Female	4.23	4.36	4.17	3.48
	P value	0.42	0.87	0.07*	0.68
Age	18-24	3.89	4.21	3.89	3.16
	25-54	4.25	4.33	4.07	3.49
	55 and over	4.27	4.42	4.21	3.55
	P value	0.03**	0.35	0.23	0.10
Hu-kou	Urban	4.27	4.40	4.10	3.52
	Rural	3.95	4.13	3.99	3.22
	P value	0.01***	0.02*	0.29	0.04*
Occupation	Factory worker	4.18	4.36	4.36	3.70
	Businesspeople	4.32	4.24	4.21	3.65
	Civil servant	4.38	4.41	4.00	3.31
	Intellectual	4.39	4.47	3.98	3.69
	Student	3.83	4.05	3.73	3.11
	Other	4.26	4.47	4.27	3.48
	P value	0.00***	0.02*	0.00***	0.02*
Living length	Less than 5 years	3.89	4.13	3.88	3.17
	5-10 years	4.15	4.17	4.10	3.45
	10-20 years	4.29	4.35	4.23	3.42
	20 years and over	4.36	4.51	4.14	3.61
	P value	0.00***	0.00***	0.20	0.05*
Green space change	Great increase	4.48	4.61	4.26	3.39
	Slight increase	4.02	4.21	3.86	3.36
	No change	4.17	4.34	4.12	3.35
	Slight decrease	4.07	4.20	3.91	3.47
	Great decrease	4.67	4.64	4.67	3.87
	P value	0.00***	0.00***	0.00***	0.14
In-person visiting purpose (P value)	Walk	0.63	0.91	0.97	0.60
	Enjoy nature	0.46	0.29	0.44	0.51
	Exercise	0.63	0.47	0.61	0.82
	Child's play	0.00***	0.46	0.57	0.02**
	Socializing	0.25	0.92	0.33	0.92
	Ride bicycle	0.14	0.92	0.86	0.78
	Other	0.76	0.05*	0.90	0.36

P value: \*\*\*, \*\*, \* indicates the significance at the level of 0.01, 0.05, and 0.10, respectively.

The comparison of in-person visiting purposes for respondents who choose one purpose is those who don't choose this purpose.

**Table A3.** Mean score of perceptions of natural space improvement (Mean score and P value).

		Develop additional green space	Improve vegetation richness	Increase dispersion of green space	Develop or restore wetland	Improve quality of bodies of water	Increase dispersion of wetland
Gender	Male	4.04	2.46	2.04	3.97	4.22	3.84
	Female	3.99	2.60	2.13	4.05	4.41	3.89
	P value	0.42	0.56	0.93	0.69	0.07*	0.57
Age	18-24	3.89	2.79	2.02	4.21	4.41	3.79
	25-54	4.03	2.65	2.12	4.01	4.41	3.90
	55 and over	4.06	2.08	2.06	3.90	4.05	3.86
	P value	0.42	0.83	0.60	0.26	0.01**	0.78
Hu-kou	Urban	4.04	2.50	2.08	4.08	4.33	3.90
	Rural	3.94	2.66	2.12	3.82	4.29	3.75
	P value	0.43	0.08*	0.48	0.04**	0.93	0.38
Living length	Less than 5 years	3.82	2.82	2.07	3.98	4.31	3.77
	5-10 years	4.05	2.50	2.05	3.95	4.32	3.63
	10-20 years	4.35	2.58	2.19	3.94	4.39	4.16
	20 years and over	4.04	2.38	2.09	4.08	4.32	3.95
	P value	0.08*	0.40	0.31	0.44	0.83	0.09*
Frequency of visits	Daily	4.13	1.00	1.35	3.89	4.30	3.96
	Weekly	3.77	2.00	1.72	3.91	4.17	3.74
	Monthly	4.04	3.00	2.79	4.04	4.40	3.85
	Seldom	4.14	4.00	2.65	4.20	4.44	3.92
	P value	0.06*	0.72	0.02**	0.27	0.26	0.52
Green space change	Great increase	4.32	2.19	1.97	4.19	4.32	3.87
	Slight increase	3.85	2.49	2.04	3.93	4.31	3.63
	No change	3.86	2.73	2.27	3.81	4.29	3.78
	Slight decrease	4.03	2.55	1.95	4.03	4.24	3.99
	Great decrease	4.49	2.46	2.18	4.51	4.59	4.41
	P value	0.00***	0.24	0.54	0.00***	0.16	0.00***
In-person visiting purpose (P value)	Walk	0.66	0.03**	0.00***	0.96	0.02**	0.21
	Enjoy nature	0.35	0.05*	0.18	0.05*	0.01**	0.82
	Exercise	0.43	0.00***	0.00***	0.87	0.79	0.56
	Child's play	0.15	0.81	0.28	0.38	0.47	0.57
	Socializing	0.73	0.77	0.35	0.54	0.02**	0.36
	Biking	0.66	0.86	0.52	0.72	0.21	0.44
	Other	0.20	0.44	0.01***	0.37	0.43	0.66

P value: \*\*\*, \*\*, \* indicates the significance at the level of 0.01, 0.05, and 0.10, respectively.

The comparison of in-person visiting purposes for respondents who choose one purpose is those who don't choose this purpose.

**Table A4.** Social difference in perception of facility improvement in green open space (Mean score and P value).

Improvement of facilities		Improve walking trails network	Improve bicycle lanes network	Increase exercise facilities	Increase children's playground
Hu-kou	Urban	4.14	3.94	4.00	3.85
	Rural	3.84	3.57	3.78	3.55
	P value	0.00***	0.00***	0.09*	0.04**
Occupation	Factory worker	4.18	3.91	4.03	3.85
	Businesspeople	4.09	3.91	4.09	4.15
	Civil servant	4.00	3.69	4.05	3.85
	Intellectual	4.35	4.02	3.96	4.04
	Student	3.75	3.68	3.69	3.28
	Other	4.17	3.94	4.03	3.86
	P value	0.01**	0.17	0.39	0.00***
Living length	Less than 5 years	3.75	3.61	3.77	3.48
	5-10 years	4.00	3.88	3.87	3.78
	10-20 years	4.23	3.77	4.03	3.94
	20 years and over	4.25	4.00	4.07	3.92
	P value	0.00***	0.02**	0.13	0.02**
Frequency of visits	Daily	4.13	3.83	4.04	3.89
	Weekly	4.00	3.66	3.88	3.58
	Monthly	4.04	3.88	3.92	3.87
	Seldom	4.11	4.04	3.96	3.84
	P value	0.63	0.06*	0.80	0.17
Green space change	Great increase	4.23	4.16	4.00	3.84
	Slight increase	3.89	3.64	3.80	3.62
	No change	4.06	3.80	3.87	3.66
	Slight decrease	3.99	3.75	3.93	3.73
	Great decrease	4.56	4.46	4.49	4.49
	P value	0.00***	0.00***	0.00***	0.00***
In-person visiting purpose (P value)	Walk	0.67	0.72	0.77	0.66
	Enjoy nature	0.14	0.08*	0.15	0.80
	Exercise	0.49	0.29	0.11	0.97
	Child's play	0.28	0.01**	0.50	0.00***
	Socializing	0.78	0.39	0.58	0.96
	Biking	0.29	0.28	0.92	0.19
	Other	0.04*	0.85	0.43	0.30

P value: \*\*\*, \*\*, \* indicates the significance at the level of 0.01, 0.05, and 0.10, respectively.

The comparison of in-person visiting purposes for respondents who choose one purpose is those who don't choose this purpose.

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# Chapter 5 Conclusion

## 1. Review of the research

### 1.1. Research approach and organization

The economic reforms of the 1970s have led China to rapid urbanization with cities' remarkable developments. Analyzing the urban growth processes can provide a valuable resource for supporting sustainable management. This thesis aims to examine the urbanization process, using the Wuhan urban development zone (UDZ) as a case study, from comprehensive perspectives referring to both social and physical evolutions, as well as the transformation of their relationships.

This study is based on urban ecology theory, which recognizes that an urban system is human-dominated where social and physical subsystems interact with each other. To examine an urban system, we consider both the social and physical subsystems equally, with a proposed ISES (improved social-ecological system) framework to guide the detailed research. The ISES is an extension of a social-ecological approach which stresses the value of the social relationships with a separate focus on urban land growth and green open space (natural system).

We proposed four questions: (1) How does the urban social landscape transform in time and space? (2) What trends are apparent in the urban land growth process and spatial heterogeneity? (3) How does social transformation relate to urban land growth, with a spatio-temporal perspective? And (4) how do social-demographic features relate to residents' use and perception of urban green open spaces, focusing on the ecological services provided by and the need to improve those spaces? Question (3) and (4) are for the social relationships with urban land (impervious surface) growth and green open space (natural system) respectively, with different databases and quantifying approaches. As this thesis is in paper format, three articles (chapters) are completed to answer these questions.

## **1.2. Findings about social landscape transformations**

In Chapter 2, we use varimax rotated PCA and ArcMap spatial analysis to detect the social dimensional transformations and to visualize the spatial changes. This study is based on the Wuhan census data sets for 1990, 2000, and 2010, at the neighborhood level. To match the spatial unit of the social data unit, the urban land metrics are also computed at the neighborhood level (Chapter 3).

The results from the social landscape analysis (Chapter 2) highlight three aspects: the social dimensional transformation, the social-spatial transition, and the deductive findings on what leads to and what is implicated by the socio-spatial changes. The main social dimensions are industrial relocation, education level increase, population aging, and migration. The transformations present not only in the dimensional connotations, but also in the spatial distributions. Secondary and tertiary industrial employments formed one social dimension in 1990, while becoming separate dimensions in the later decades. Industrial separation not only includes a physical removal of secondary industry and aggregation of tertiary industry in the city center, but also links to the increase of the workers' educational background. Moreover, the aging population formed a social dimension, with a combination of the local population in 2010. Also, population migration, as another social dimension, presents expanded spatial distribution in the 2000s. Spatial features show a central-periphery pattern of the social landscape, with a hollowing of secondary industry and aging population. Aggregation of the tertiary industry is an important feature of the city center while immigrants show a dynamic relocation in the periphery along with the expansion of the city center. These social transformations are conceptualized as the concentric ring and sectoral-shaped spatial patterns for different dimensions in various stages. Urban social transformations, to a high extent, result from corresponding pull-push forces regionally and centripetal-centrifugal forces within city.

### **1.3. Findings about social-physical relationships with focus on urban land growth**

This study of the physical landscape evolution and its relationships with social factors are presented in two parts. The first focus is on urban land (Chapter 3) and the second one on green open spaces (Chapter 4). Landsat images in 1991, 2000, and 2011 are used to match the social analysis. We extract physical landscapes based on V-I-W (vegetation area - impervious surface - water area) model, with an MDWI (modified normalized difference water index) for water area extraction and a proposed MBCI (modified biophysical composition index) for urban land. We further compute urban land metrics referring to the area, aggregation, and shape to analyze the urban spatial growth patterns and to model social-physical relationships.

The results presented in Chapter 3 reveal a variety of urban land growth modes such as infilling, edge expansion, and outlying expansion which co-existed during 1990 and 2010, showing a center-periphery pattern. In the city center, redevelopment with infilling and development with patch-edge expansion took place simultaneously. While in the periphery, outlying expansion is more intentional. Redevelopment in the city center is associated with the relocation of the traditional secondary industry as well as the improvement of the living environment through converting urban land to vegetation area and wetland. Regression results demonstrate that urban land area (PLAND) ‘globally’ associates with social factors referring to social factors. GWR (geographically weighted regression) for urban land patch shape and social factors reveals spatially non-stationary relationships. The relationships of urban land patch shape and social factors form concentric, axial, and sectoral patterns, when focusing on various social variables.

### **1.4. Findings about social-natural relationships with focus on green open space**

Chapter 4 explores the social-physical relationships from the public’s perception perspective, with focus on the natural components of the urban system (Chapter 4). Based on the questionnaire surveys and interviews, we evaluate residents’ preferences towards green

open spaces usage, understand their perceptions toward the improvement necessity of those spaces and toward the general ecological services those spaces provide. Gender, age, education, Hukou, occupation, and residential length are the main social characteristics of the respondents that this research focuses on, while the reported environmental experience represented by the perceived loss or gain of green space is considered an influential factor that impacts interviewees' feedback. The results reveal that preference for green open spaces links to respondents' feelings toward needed improvements of those spaces, which directly express people's practical-oriented demands. Different social groups have differing opinions on the ecological services of green open spaces. Participants mostly agree that green open spaces are beneficial to their daily life and health, but the benefits are not reliant on an in-person visit only, as most respondents recognize that the presence of open green spaces directly contributes to the ecological well-being of their wider urban setting. A lower proportion of respondents agree that green open space is conducive to community safety and higher real estate value. Regarding the links between experiences and beliefs, we find that how participants individually use green open spaces and how they regard changes to those spaces directly affects their perceptions concerning the importance of those spaces. For example, those who have experienced a great decrease in green space tend to provide a higher evaluation of the ecological benefits that green space can provide, and prefer more dispersed spatial distribution of the spaces. Regarding public engagement in green open space management, the interviewing results suggest different levels of willingness.

## **2. Conclusions**

This research contributes to a methodological examination of the urbanization process in China's second-tier city by using a social-ecological perspective. It constructs a dialogue between urban social and physical subsystems. It presents an integrated quantitative study of the urbanization process that emphasizes the relationships between social and physical

subsystems, with a visualized presentation of this connection. The regression models are built to focus on the relationships between urban land and social development. A questionnaire survey is conducted to explore the relationships between social and natural spaces. The two perspectives provide complementary angles to understand the urbanization process with a social-ecological approach. The research focuses on Wuhan but possibly provides valuable references to rapidly urbanizing or emerging cities elsewhere.

Through this research, the unique characteristics of China's urban social-ecological system can be drawn. The research offers an integrated empirical social-ecological framework which has been applied to the case of Wuhan UDZ. Studies have shown that the urban social and physical landscape growth presents a "center-periphery" pattern, which is a process with diversity and inclusion. This process is driven by the integration of external pull and push as well as internal centripetal and centrifugal forces, which is under the government powers combined with market orientation. Spatial non-stationary relationships between urban land metrics and social factors are demonstrated via fitted GWR models. It is also accompanied by the public's awareness of green open spaces and their different levels of willingness to participate in decision-making that can affect the management of these spaces.

### **2.1. Characteristics of China's urban social-ecological system**

Through evaluation of the social-physical landscape development and their relationships in Wuhan, the uniqueness of China's second-tier city can be extracted. In China, the macro policy at the national level provides a blueprint for urban social and physical growth, and the preferences of social groups can be used to explain social-ecological relationships at the micro spatial level.

National-level policies, such as the household registration policy and new construction land supply policy, guide population migration and regulate urban spatial expansion scale and rate. Corresponding local policies constrain migrants' accessibility to public services, and thus

influence the population inflow to the city. The household registration policy reflects the differences in the rights and interests of residents in all aspects of residence, house purchase, education, employment, medical welfare, etc., and therefore it is the most fundamental policy which affects urban social development. From the physical aspect, these national-level policies referring to new construction land quota or the strategic plan of industrial development affect the city's expansion rate and scale. Local governmental planning on land use zoning, and infrastructure configuration also guide the spatial distribution of both urban land as well as societies. The infrastructure network guides the urban land growth along the lines or surrounding the nodes. Local government dominates redevelopment of existing built-up areas that transmit into the social landscape, particularly in the city center. The development of natural open space is another aspect of urban landscape change.

The social preference for residential location is affected by factors such as the market price of real estate, public service accessibility, commuting time, and the quality of ecological environment. The formation of their distribution is based on mandatory or voluntary factors. Compulsory force plays roles when a community or work unit (factory) has been rebuilt in another place, while voluntary force plays roles on an individual's or a household's preferences which are most especially related to their affordability.

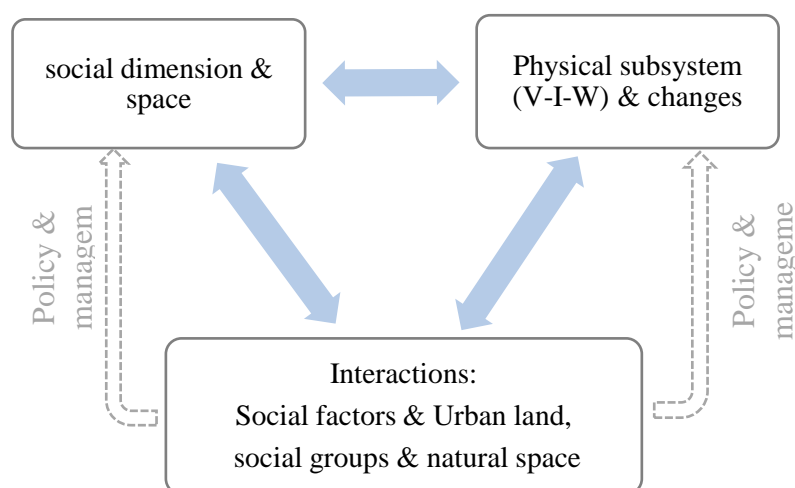
The market mechanism in China influencing residents' preference for a certain residential location is not different from that of high-income countries, except for cultural background and corresponding influences. However, there are indeed differences between China's macro-level policies and those of market-oriented countries. China uses command policies to regulate and guide the social and physical growth of cities, while high-income countries mainly rely on market-oriented policies. Since China's reform and opening up, the theories of land location in Europe and the approach of urban sociology research in North America have been gradually introduced and adopted by China's urban planning and sociology study, combined with the

characteristics of China's urban land provision in practice. Therefore, the bid-rent model, which is a market distribution of urban space, shows a certain degree of applicability regardless of whether one is looking at the city-level spatial planning or at neighborhood-level location preference by individuals or enterprises.

## 2.2. An integrated empirical social-ecological framework

The research is under the guidance of the improved social-ecological system (ISES) framework (see Chapter 1). It clarifies that the urban social subsystem is the interacted system among different social groups with spatial and temporal transitions, recognizes urban landscape heterogeneities and dynamics as the focus of physical subsystems. The ISES defines humans as users as well as interveners of the urban physical landscape.

In this study, the ISES is further explained as an empirical framework, with its application in the case of Wuhan (Figure 1). The practical framework examines social subsystems with social dimensional and spatial transformations, assesses physical subsystems with V-I-W-model-based landscape distribution and changes. It explores the relationships between the two subsystems both from two perspectives, one is between social factors and urban land metrics using local regression model, the other one is between social and natural space based on



**Figure 1** Practical social-ecological framework for urban study

questionnaires and interviews. Compared to recent academic literature (Marzluff et al., 2008; Ostrom, 2009; Pickett et al., 2016; Pickett et al., 2020), this focus on both urban and natural areas offers mutually complementary insights for a better understanding of the relationships.

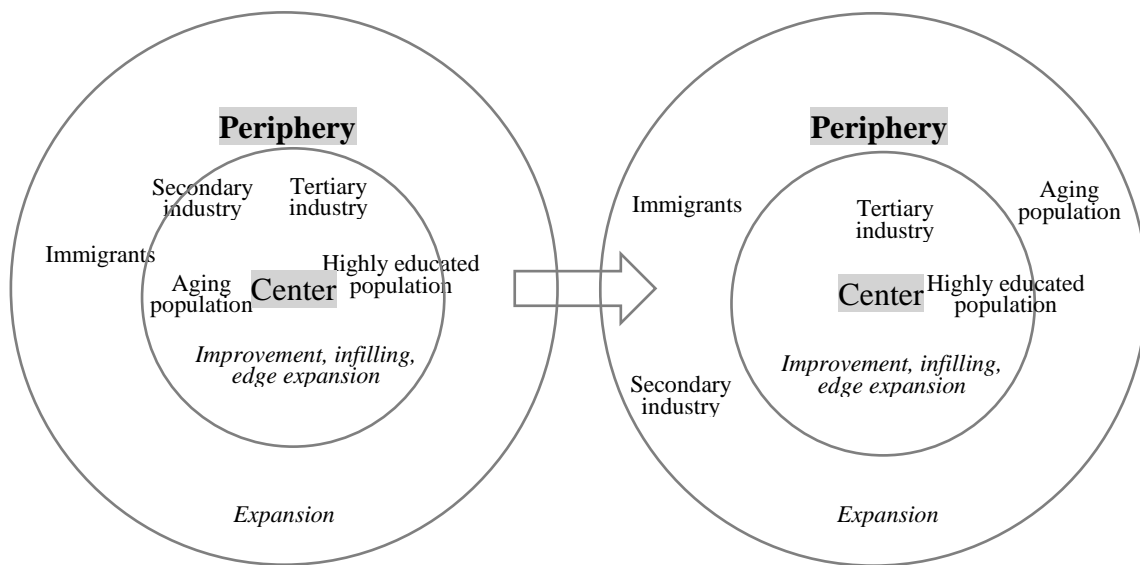
### **2.3. A center-periphery pattern of urban growth**

When examining the urban social landscape transformation and urban land growth between 1990 and 2010, the process presents as a center-periphery pattern. This pattern has dynamic spatial characteristics in different periods (see Chapter 2 and Chapter 3). The center transitioned with the features of secondary industrial removal, tertiary industrial aggregation, aging population decline, and highly educated population clustering, while the periphery area is associated with a secondary industrial clustering, and immigrants' residential aggregation (see Chapter 2). The urban land growth shows improvement with infilling and edge expansion in the center while expansion dominates the periphery (see Chapter 3).

The center-periphery pattern of both the social and physical landscape indicates a coordination of their growth, which are as a coalescence a dominant socio-economic stage. Meanwhile, the functional redevelopment in the center took place during the past decades (Figure 2). The center transitions with tertiary industry aggregation and the relocation of the traditional industry. The improvement of the natural environment through reconfiguring of green open spaces also plays a role, which was more prominent during the late decade.

Unlike the redevelopment in the center, expansion dominates the periphery, with more conversion of vegetated area to the impervious surface. Along with functional adjustment, industrial employment is also accompanied by the increase of workers' education level. The highly educated population links with the tertiary industry employment in 2000 but by 2010 has formed a separate social dimension. During the research period, migrants clustered in the periphery neighborhoods which dynamically moved outward along with the expansion of the city center. The center-periphery pattern also is presented when examining the relationships

between social factors and urban land patch shape regularities, with a concentric pattern for regression coefficient surface of tertiary industry employment and a combination of axial and sectoral patterns for those of the other social factors (see Chapter3). The center-periphery pattern demonstrates aggregation of the economy and decline of the residential population in the city center, relocation of secondary industry, expansion of urban land, expansion of (floating) population in the periphery, and coalescence in the broader urban region.



**Figure 2** Transition of center-periphery pattern

#### 2.4. A growth with diversity, inclusion, and involvement

The urban system grows with a process of social diversity increase (see Chapter 2). The society follows economic reforms for which marketization gradually contributes more. During this process, inclusion became more essential than ever, especially for vulnerable people and families such as the low-income household, floating population, or elders.

Reforms related to household registration, settlement of migrants, access to higher education, and support for low-income families, are more inclusive to encourage the population to become involved in public services. Regarding immigrants whose spatial distribution expands rapidly, their access to the city's public services has been improved impressively in

the later decade, which is a change associated with the settlement policies and relevant systematic reforms. The inclusive policies referring to floating population settlement are pushed by the social transformations and seem to be problem reactive, rather than forward thinking. However, to enhance the competitiveness of the city, local policies attracting talents are anticipatory, which are also manifested in a settlement.

Social diversity is closely connected with social inclusion. In China's urbanization process, social inclusion is quite essential, particularly in the period of economic transitions from plan to socialist market. Equal access to residence, education, jobs, medicals, finances, etc. are important aspects for social inclusion. During the urbanization process, although reforms in a variety of fields have been continuing, the exclusion caused by planned policies such as the household registration system, housing policies, higher education enrollment policies, make reforms a necessity to promote social inclusion.

The diversity of societies based on inclusive policies is increasing while the policies to promote social inclusion are constantly improving. This occurred particularly along with the loosening of household registration<sup>47</sup>. Market-oriented housing policy attracts population who can afford the preferred locations, which may increase social demographic diversities in a community<sup>48</sup>. With the improvement of living standards and residing conditions, a healthy social-nature relationship is also concerned in an inclusive society (Chapter 4), which implies the differences of accessibility toward ecological space are narrowing down.

Social diversifications not only promote reforms in management but suggest the need for more public involvement in the relevant decision-making process. Residents' involvement is

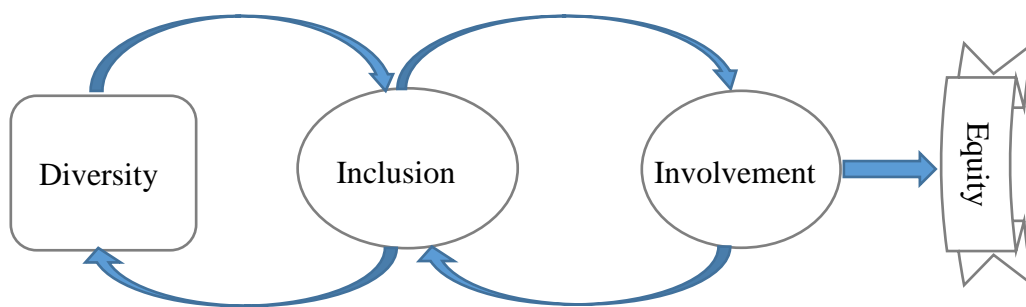
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<sup>47</sup> For example, in the early days with the loosening of household registration restrictions, although migrants were allowed to register for temporary household registration, their rights to employment, training or education, housing, and medical care were seriously lacking. Relevant access is gradually opened to the migrant population in cities in subsequent reforms. Reforms have promoted the social involvement of these groups.

<sup>48</sup> Limited by the 2000 and 2010 census data, we did not adopt variables related to living space. The housing distribution in 2000 relied more on the power of the plan, while the distribution in 2010 was more market-oriented. It can be expected that the comparison of data on living space and area in 2010 and 2020 will bring more discoveries about the relationship between social groups and living conditions.

the basis for a variety of societies to equally access public service, which is coincident with the people-center urbanization strategy in China.

An inclusive society benefits its communities with the attraction of population with diverse socio-demographic characteristics. China's cities' social-ecological relationships are formed on a foundation of governmental policies. It is in the early stage of residents' involvement and expects more participation. Public's involvement provides suggestive information (such as comments, demands, and expectation) and action (voluntary work) to improve the inclusive policies as well as to promote societies' equal accessibilities to public services. Public involvement increases social inclusion along with social network development and collaboration in the participation process (Figure 3).

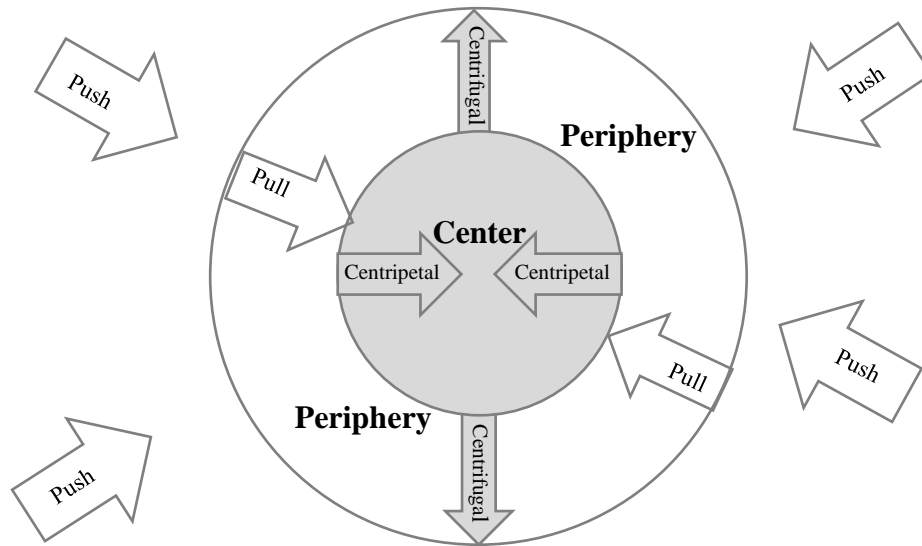


**Figure 3** Diversity, inclusion, and involvement

## **2.5. An integration of external and internal forces driving urban growth**

The city grows under the integrated forces of external pull and push forces as well as of internal centripetal and centrifugal forces (Figure 4), being shaped through both social and physical sides (see Chapter 2 and Chapter 3). A regional development strategy enhanced the central position of Wuhan from a provincial center to a regional and then to a national one. The upgrading of the positioning is supported by serial policies in industrial allocation, land provision, financial support, and so on. Wuhan, as the central city, attracts spatial aggregation of population and industries, with its employment opportunities, higher income, loose household registration, and other benefits. The push forces generated in the original registered

places, mainly referring to less job opportunities, fewer public services, less transport links, and less educational opportunities.



**Figure 4** Forces of urban growth from both regional and city perspectives

Within the city, centripetal and centrifugal forces also play important roles. Local socio-economic policies attract population, investment, and industries, which then form centripetal forces for urban growth. The centripetal forces push the city center to expand by necessity to accommodate these growing elements. Centrifugal forces link with the marketization of land and housing provision, transit network, and transportation system improvement within an urban area. The marketization of land provision attracts those who can afford land rent in the highest productive center, meanwhile, the seeking for land rent results in a centrifugal force for the local population moving out from the city center. The bid-rent rule also pushes secondary industries to remove from the city center to the periphery industrial zone where the pull forces work from the industrial functional cluster. High-tech industries agglomerate close to the institutional and educational area, under zonal planning as well as based on the centripetal forces of the industrial cluster.

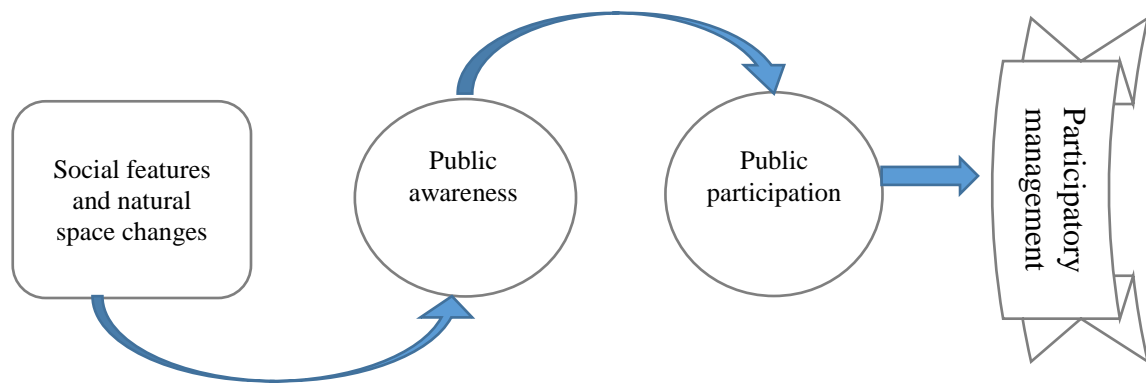
Urban growth is a process under the influence of government and market forces. The external force is mainly the reflection of the government's power at the macro-spatial level to the realization of the urbanization and industrialization strategy, while the internal force primarily reflects the realization of the government-led urban spatial zoning and planning, as well as the market-oriented social preference for (re)locations.

## **2.6. A process to raise public awareness on green open spaces and on taking part in decision making**

Urbanization is a process of social and physical landscape transformations, which further raises public awareness on green open spaces as well as guide people towards taking part in related decision-making (see Chapter 4). Urban land growth brings both positive and negative impacts on natural system development. The positive aspects take place in the city center resulting from the functional adjustment and redevelopment which was more outstanding in the last decade, while the loss of natural open space dominates the periphery and is a significant concern practically and academically.

Along with the natural system development, public awareness of green open spaces is noted. Experiences of decreased green space (expressed by the length of residence and reported loss/gain of green space in the neighborhood) is associated with a higher proportion of those who strongly agree that the ecological services provided by those spaces are vital. Also, the dissimilarities in the interactive experience with the natural environment implied by the Hukou are manifested in the significant differences in preference and cognition of the green open spaces. Respondents' awareness of green open spaces is also presented as their evaluation of the necessity of improvement of those spaces, which is preference-oriented, that is, based on various intentions of visiting the spaces. The affirmation of the improvement necessity and the ecological services both express the participants' awareness that green open spaces are closely related to daily life and health.

The public's natural system awareness is shaped by their social features and their experience concerning natural space changes. It then promotes public participation in the urban natural system management related decision making (Figure 5). The interviews in this study do suggest that the public wants to be engaged in the decision-making process, although both positive and negative opinions exist in these types of responses.



**Figure 5** Process to raise public awareness and participating

Social diversity and social-ecological interactions encourage public involvement in urban spatial development decision-making, especially when aiming at green space configuration and maintenance, at a micro-spatial scale. Individual involvement helps to achieve participatory management of an urban system.

Overall, China is considered a planned economy when compared to other high-income countries, but the market mechanism that has emerged since the country's reform and opening up is playing an increasingly crucial role in urban growth. Land supply is dependent on macro-level planned allocation and micro-level market allocation. Planning allocation focuses on the provision of urban infrastructure, such as parks and open spaces, while the market mechanism plays a key role in commercial land and housing supply. However, the market can only play a limited role in determining where industrial land will be located. Land allocation, to a great extent, determines the formation of social space. Residents' ability to pay and preferences for

the living environment affect their choices of residential locations. This is prominent in the vulnerable social groups' choices of residential location. On the other hand, the living environment, supporting facilities, public services, and green open spaces affect the residents' preference for residential location, which in turn affects the residents' demand for ecological space. This also indicates the necessity for the public to participate in the planning, design, management, and maintenance of urban space and community environment in the process of market allocation of urban land and ecological space.

### **3. Limitations and future study**

Although this research answers the questions proposed from a social-ecological perspective and contributes to urban ecology theoretically and methodologically, there are still some limitations due to data constraints or a lack of consideration of some uncertainties.

#### **3.1. Census-based limitation and further study**

Literature seldom examines social landscape transformations since the neighborhood-level data is not fully released. China's censuses are based on a one-decade gap. Thus, we are only able to examine the historical year until 2010, based on the available census data. Furthermore, limitations exist due to the updates of the census category. For example, the released 1990 immigrants' category covers those who left registered places and resided in this city over one year, for which in the latter census covers those who left registered places and resided in this city over half a year. More categories, such as housing and health, have also been introduced in the census gradually. However, the comparison requires more information, which will only become available once the latest census is released.

China has completed the seventh national census at the end of 2020. The latest census data is expected to be released with details in a couple of years. The social-ecological study based on the updated data will supply further information for exploring the social landscape transformation, and the relationships between social and urban land evolutions. It is expected

that the urban social transformations in the 2010s will show the trend in the two decades since 1990. The latest census also increases the compatibility of the indicators with those in 2010, particularly in the category of housing and health, based on which we can examine social transformations and the relationships with urban spatial growth more comprehensively, with focus on social residential segregation as well as relationships between health and urban landscape evolution.

### **3.2. Consideration with uncertainty such as pandemic**

We had conducted this research for years, designing and preparing data before the occurrence of COVID-19. The unexpected pandemic has had far-reaching influences on societies and social-natural relationships. Natural open spaces can benefit life quality and support psychological health, especially during the pandemic period. How to reconsider urban natural open spaces planning and management, and improve social-natural interactions, is valuable to be studied, as a life-quality related research topic, through a social-ecological perspective.

### **3.3. Exploration of governmental roles**

In this study, government power is regarded as an exogenous variable. Although relevant policies such as land supply and household registration reform have been discussed as mechanisms to promote the transformation of the social landscape and the evolution of the physical landscape, these discussions are still relatively weak and cannot fully demonstrate the government's management and control of urban social and physical space in the process of urbanization, especially during the period of economic system transformation. Therefore, the quantitative and qualitative exploration of government power as an endogenous variable is one of the focuses of further research.

### **3.4. Comparison with other cities**

Due to the limitation of the released census data, this research relies on an examination of urban social and physical growth based on the Wuhan case. Although it provides a microcosm of China's second-tier cities' development, if it can be compared with other second-tier or first-tier cities, it will enrich the social-ecological studies of China's cities and provide a more solid foundation for future research frameworks and methods. A comparative perspective can also inspire us to distinguish experiences, and lessons, for reference in second- and third-tier cities and other rapidly urbanizing areas.

## Appendix

### Appendix I. Varimax rotated principal component analysis (PCA) results

This appendix is for detailed results of varimax rotate PCA which support Chapter 2 the research about the social landscape transformation.

#### Appendix I-i. Varimax rotated PCA results (1990)

**Table I-1** Descriptive Statistics (1990)

		Std.	
	Mean(%)	Deviation(%)	Analysis N
Non-agricultural population	61.53	37.31	131
Local population	91.28	6.03	131
Immigrants	0.39	0.68	131
Minor dependent	22.64	5.21	131
Elders	6.21	2.13	131
Married population	69.88	4.66	131
Divorced or widowed population	6.64	1.82	131
High school educated population	21.25	9.19	131
Highly educated population	6.69	8.57	131
Secondary industry employees	44.03	19.68	131
Tertiary industry employees	33.03	17.56	131
High-income-occupation population	17.53	10.60	131
Low-income-occupation population	38.84	24.56	131

**Table I-2** Correlation Matrix<sup>a</sup> (1990)

	Non-agricultural population	Local population	Immigrants	Minor dependent	Elders	Married population	Divorced or widowed population	High school educated population	Highly educated population	Secondary industry employees	Tertiary industry employees	High-income-occupation population	Low-income-occupation population
Non-agricultural population	1.00	-0.01	-0.02	-0.88	0.28	-0.02	0.03	0.94	0.55	0.75	0.83	0.80	-0.93
Local population	-0.01	1.00	-0.64	0.21	0.14	-0.02	0.28	-0.07	0.03	-0.30	-0.06	0.06	0.21
Immigrants	-0.02	-0.64	1.00	-0.06	-0.13	0.00	-0.18	-0.01	-0.03	0.11	0.03	-0.05	-0.06
Minor dependent	-0.88	0.21	-0.06	1.00	-0.12	0.24	0.20	-0.87	-0.65	-0.75	-0.80	-0.80	0.93
Elders	0.28	0.14	-0.13	-0.12	1.00	0.34	0.92	0.26	-0.16	0.01	0.35	0.07	-0.08
Married population	-0.02	-0.02	0.00	0.24	0.34	1.00	0.37	0.08	-0.64	0.17	-0.18	-0.29	0.03
Divorced or widowed population	0.03	0.28	-0.18	0.20	0.92	0.37	1.00	-0.01	-0.38	-0.21	0.07	-0.20	0.21
High school educated population	0.94	-0.07	-0.01	-0.87	0.26	0.08	-0.01	1.00	0.44	0.77	0.81	0.77	-0.92
Highly educated population	0.55	0.03	-0.03	-0.65	-0.16	-0.64	-0.38	0.44	1.00	0.20	0.66	0.86	-0.55
Secondary industry employees	0.75	-0.30	0.11	-0.75	0.01	0.17	-0.21	0.77	0.20	1.00	0.39	0.44	-0.88
Tertiary industry employees	0.83	-0.06	0.03	-0.80	0.35	-0.18	0.07	0.81	0.66	0.39	1.00	0.87	-0.76
High-income-occupation population	0.80	0.06	-0.05	-0.80	0.07	-0.29	-0.20	0.77	0.86	0.44	0.87	1.00	-0.79
Low-income-occupation population	-0.93	0.21	-0.06	0.93	-0.08	0.03	0.21	-0.92	-0.55	-0.88	-0.76	-0.79	1.00

**Table I-3** KMO and Bartlett's Test (1990)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.676
Bartlett's Test of Sphericity	Approx. Chi-Square	2880.373
	df	78
	Sig.	0.000

**Table I-4** Communalities (1990)

	Initial	Extraction
Non-agricultural population	1.000	0.952
Local population	1.000	0.834
Immigrants	1.000	0.830
Minor dependent	1.000	0.919
Elders	1.000	0.962
Married population	1.000	0.802
Divorced or widowed population	1.000	0.964
High school educated population	1.000	0.943
Highly educated population	1.000	0.928
Secondary industry employees	1.000	0.914
Tertiary industry employees	1.000	0.905
High-income-occupation population	1.000	0.912
Low-income-occupation population	1.000	0.987

Extraction Method: Principal Component Analysis.

**Table I-5** Total Variance Explained (1990)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.31	48.53	48.53	6.31	48.53	48.53	5.92	45.55	45.55
2	2.52	19.35	67.88	2.52	19.35	67.88	2.12	16.30	61.85
3	1.89	14.55	82.44	1.89	14.55	82.44	2.11	16.22	78.07
4	1.14	8.74	91.17	1.14	8.74	91.17	1.70	13.10	91.17
5	0.45	3.47	94.64						
6	0.33	2.52	97.16						
7	0.16	1.25	98.41						
8	0.08	0.59	99.00						
9	0.05	0.40	99.41						
10	0.04	0.32	99.73						
11	0.02	0.16	99.89						
12	0.01	0.09	99.98						
13	0.00	0.02	100.00						

Extraction Method: Principal Component Analysis.

**Table I-6** Component Matrix<sup>a</sup> (1990)

	Component			
	1	2	3	4
Non-agricultural population	0.947	0.220	-0.021	-0.073
Local population	-0.139	0.345	0.753	-0.357
Immigrants	0.044	-0.321	-0.655	0.543
Minor dependent	-0.956	0.048	0.051	-0.016
Elders	0.134	0.897	0.019	0.374
Married population	-0.181	0.601	-0.530	-0.357
Divorced or widowed population	-0.172	0.911	0.073	0.315
High school educated population	0.926	0.230	-0.119	-0.134
Highly educated population	0.701	-0.399	0.477	0.222
Secondary industry employees	0.738	0.035	-0.464	-0.390
Tertiary industry employees	0.874	0.165	0.160	0.296
High-income-occupation population	0.900	-0.079	0.299	0.085
Low-income-occupation population	-0.963	-0.014	0.181	0.165

Extraction Method: Principal Component Analysis.

**Table I-7** Rotated Component Matrix<sup>a</sup> (1990)

	Component			
	1	2	3	4
Non-agricultural population	0.956	0.118	0.149	0.042
Local population	-0.122	0.091	0.158	0.886
Immigrants	-0.018	0.040	-0.029	-0.909
Minor dependent	-0.913	-0.268	0.030	0.115
Elders	0.174	-0.126	0.955	0.061
Married population	0.062	-0.853	0.265	0.004
Divorced or widowed population	-0.112	-0.217	0.938	0.157
High school educated population	0.964	0.011	0.116	0.008
Highly educated population	0.500	0.803	-0.171	0.067
Secondary industry employees	0.860	-0.325	-0.216	-0.149
Tertiary industry employees	0.776	0.446	0.317	-0.051
High-income-occupation population	0.789	0.529	0.010	0.101
Low-income-occupation population	-0.984	-0.057	0.087	0.088

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

**Table I-8** Component Transformation Matrix (1990)

Component	1	2	3	4
1	0.957	0.283	0.006	-0.055
2	0.140	-0.433	0.837	0.304
3	-0.147	0.641	0.084	0.749
4	-0.205	0.568	0.541	-0.586

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Table I-9** Component Score Coefficient Matrix (1990)

	Component			
	1	2	3	4
Non-agricultural population	0.171	-0.039	0.039	0.048
Local population	0.004	0.011	-0.022	0.526
Immigrants	-0.058	0.107	0.123	-0.579
Minor dependent	-0.143	-0.042	0.010	0.043
Elders	0.001	0.045	0.477	-0.078
Married population	0.111	-0.469	0.007	0.048
Divorced or widowed population	-0.038	0.018	0.456	-0.022
High school educated population	0.187	-0.105	0.009	0.042
Highly educated population	0.007	0.373	-0.006	0.020
Secondary industry employees	0.220	-0.325	-0.194	0.015
Tertiary industry employees	0.076	0.213	0.204	-0.077
High-income-occupation population	0.094	0.198	0.028	0.057
Low-income-occupation population	-0.191	0.103	0.081	-0.007

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Table I-10** Component Score Covariance Matrix (1990)

Component	1	2	3	4
1	1.000	0.000	0.000	0.000
2	0.000	1.000	0.000	0.000
3	0.000	0.000	1.000	0.000
4	0.000	0.000	0.000	1.000

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Appendix I-ii. Varimax rotated PCA results (2000)**

**Table I-11** Descriptive Statistics (2000)

	Mean(%)	Std. Deviation(%)	Analysis N
Non-agricultural population	61.16	31.38	128
Local population	66.47	18.18	128
Intra-provincial immigrants	30.89	12.96	128
Inter-provincial immigrants	11.75	5.93	128
Minor dependent	17.01	5.15	128
Elders	7.36	2.24	128
Married population	71.42	7.68	128
Divorced or widowed population	6.28	2.03	128
High school educated population	23.97	9.41	128
Highly educated population	11.73	11.59	128
Secondary industry employees	30.46	15.19	128
Tertiary industry employees	48.46	23.17	128
High-income-occupation population	17.68	10.46	128
Low-income-occupation population	46.14	21.45	128

**Table I-12 Correlation Matrix<sup>a</sup> (2000)**

	Non-agricultural population	Local population	Intra-provincial immigrants	Inter-provincial immigrants	Minor dependent	Elders	Married population	Divorced or widowed population	High school educated population	Highly educated population	Secondary industry employees	Tertiary industry employees	High-income-occupation population	Low-income-occupation population
Non-agricultural population	1.00	-0.12	-0.05	-0.27	-0.89	0.43	-0.42	0.06	0.92	0.64	0.57	0.82	0.83	-0.90
Local population	-0.12	1.00	-0.29	0.18	0.30	0.21	0.04	0.19	-0.21	-0.04	-0.23	-0.36	-0.14	0.26
Intra-provincial immigrants	-0.05	-0.29	1.00	-0.03	-0.20	-0.13	-0.27	-0.25	-0.01	0.08	0.06	0.07	0.09	-0.07
Inter-provincial immigrants	-0.27	0.18	-0.03	1.00	0.22	-0.15	-0.12	-0.03	-0.30	-0.06	-0.24	-0.18	-0.22	0.28
Minor dependent	-0.89	0.30	-0.20	0.22	1.00	-0.30	0.55	0.08	-0.84	-0.69	-0.54	-0.81	-0.82	0.87
Elders	0.43	0.21	-0.13	-0.15	-0.30	1.00	0.12	0.69	0.44	-0.01	0.01	0.39	0.25	-0.22
Married population	-0.42	0.04	-0.27	-0.12	0.55	0.12	1.00	0.26	-0.22	-0.80	-0.05	-0.44	-0.58	0.38
Divorced or widowed population	0.06	0.19	-0.25	-0.03	0.08	0.69	0.26	1.00	0.07	-0.38	-0.06	0.03	-0.13	0.10
High school educated population	0.92	-0.21	-0.01	-0.30	-0.84	0.44	-0.22	0.07	1.00	0.44	0.60	0.79	0.71	-0.86
Highly educated population	0.64	-0.04	0.08	-0.06	-0.69	-0.01	-0.80	-0.38	0.44	1.00	0.15	0.62	0.84	-0.61
Secondary industry employees	0.57	-0.23	0.06	-0.24	-0.54	0.01	-0.05	-0.06	0.60	0.15	1.00	0.19	0.31	-0.77
Tertiary industry employees	0.82	-0.36	0.07	-0.18	-0.81	0.39	-0.44	0.03	0.79	0.62	0.19	1.00	0.81	-0.72
High-income-occupation population	0.83	-0.14	0.09	-0.22	-0.82	0.25	-0.58	-0.13	0.71	0.84	0.31	0.81	1.00	-0.80
Low-income-occupation population	-0.90	0.26	-0.07	0.28	0.87	-0.22	0.38	0.10	-0.86	-0.61	-0.77	-0.72	-0.80	1.00

a. Determinant = 1.404E-8

**Table I-13** KMO and Bartlett's Test (2000)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.719
Bartlett's Test of Sphericity	Approx. Chi-Square	2196.907
	df	91
	Sig.	0.000

**Table I-14** Communalities (2000)

	Initial	Extraction
Non-agricultural population	1.000	0.966
Local population	1.000	0.698
Intra-provincial immigrants	1.000	0.660
Inter-provincial immigrants	1.000	0.343
Minor dependent	1.000	0.918
Elders	1.000	0.895
Married population	1.000	0.804
Divorced or widowed population	1.000	0.804
High school educated population	1.000	0.897
Highly educated population	1.000	0.916
Secondary industry employees	1.000	0.808
Tertiary industry employees	1.000	0.848
High-income-occupation population	1.000	0.880
Low-income-occupation population	1.000	0.953

Extraction Method: Principal Component Analysis.

**Table I-15** Total Variance Explained (2000)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.48	46.29	46.29	6.48	46.29	46.29	5.24	37.45	37.45
2	2.28	16.25	62.55	2.28	16.25	62.55	2.73	19.50	56.96
3	1.57	11.21	73.76	1.57	11.21	73.76	2.05	14.61	71.57
4	1.06	7.60	81.36	1.06	7.60	81.36	1.37	9.79	81.36
5	0.84	6.02	87.37						
6	0.76	5.45	92.82						
7	0.43	3.08	95.90						
8	0.19	1.38	97.28						
9	0.16	1.15	98.42						
10	0.07	0.50	98.92						
11	0.06	0.44	99.36						
12	0.05	0.35	99.72						
13	0.03	0.21	99.92						
14	0.01	0.08	100.00						

Extraction Method: Principal Component Analysis.

**Table I-16** Component Matrix<sup>a</sup> (2000)

	Component			
	1	2	3	4
Non-agricultural population	0.952	0.209	0.044	-0.118
Local population	-0.271	0.258	0.607	-0.436
Intra-provincial immigrants	0.120	-0.447	-0.241	0.623
Inter-provincial immigrants	-0.282	-0.223	0.458	-0.059
Minor dependent	-0.955	0.026	0.018	-0.070
Elders	0.308	0.800	0.273	0.292
Married population	-0.548	0.534	-0.459	-0.090
Divorced or widowed population	-0.085	0.834	0.177	0.265
High school educated population	0.887	0.290	-0.147	-0.056
Highly educated population	0.749	-0.427	0.404	-0.100
Secondary industry employees	0.551	0.098	-0.569	-0.413
Tertiary industry employees	0.865	0.076	0.128	0.280
High-income-occupation population	0.907	-0.103	0.218	0.011
Low-income-occupation population	-0.934	-0.041	0.203	0.193

Extraction Method: Principal Component Analysis.

a. 4 components extracted.

**Table I-17** Rotated Component Matrix<sup>a</sup> (2000)

	Component			
	1	2	3	4
Non-agricultural population	0.786	0.534	0.238	0.081
Local population	-0.035	-0.351	0.121	0.748
Intra-provincial immigrants	0.121	-0.116	-0.140	-0.783
Inter-provincial immigrants	0.015	-0.524	-0.154	0.211
Minor dependent	-0.822	-0.445	-0.107	0.181
Elders	0.211	0.087	0.910	0.118
Married population	-0.806	0.267	0.265	0.108
Divorced or widowed population	-0.179	-0.014	0.865	0.152
High school educated population	0.627	0.647	0.289	-0.022
Highly educated population	0.923	-0.030	-0.249	0.037
Secondary industry employees	0.180	0.864	-0.162	0.054
Tertiary industry employees	0.794	0.250	0.311	-0.243
High-income-occupation population	0.903	0.243	0.059	-0.046
Low-income-occupation population	-0.696	-0.684	-0.006	0.023

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 7 iterations.

**Table I-18** Component Transformation Matrix (2000)

Component	1	2	3	4
1	0.860	0.486	0.107	-0.112
2	-0.234	0.302	0.861	0.336
3	0.451	-0.742	0.207	0.450
4	0.035	-0.350	0.452	-0.820

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Table I-19** Component Score Coefficient Matrix (2000)

	Component			
	1	2	3	4
Non-agricultural population	0.114	0.117	0.050	0.118
Local population	0.098	-0.129	-0.012	0.553
Intra-provincial immigrants	0.013	-0.141	0.066	-0.617
Inter-provincial immigrants	0.115	-0.248	-0.053	0.149
Minor dependent	-0.126	-0.054	-0.033	0.080
Elders	0.047	-0.095	0.468	-0.033
Married population	-0.263	0.276	0.094	0.026
Divorced or widowed population	-0.037	-0.067	0.450	-0.029
High school educated population	0.044	0.193	0.081	0.028
Highly educated population	0.256	-0.159	-0.138	0.117
Secondary industry employees	-0.114	0.459	-0.205	0.160
Tertiary industry employees	0.153	-0.078	0.179	-0.182
High-income-occupation population	0.194	-0.053	0.009	0.024
Low-income-occupation population	-0.055	-0.235	0.078	-0.081

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Table I-20** Component Score Covariance Matrix (2000)

Component	1	2	3	4
1	1.000	0.000	0.000	0.000
2	0.000	1.000	0.000	0.000
3	0.000	0.000	1.000	0.000
4	0.000	0.000	0.000	1.000

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Appendix I-iii. Varimax rotated PCA results (2010)**

**Table I-21** Descriptive Statistics (2010)

	<b>Mean(%)</b>	<b>Std. Deviation(%)</b>	<b>Analysis N</b>
Non-agricultural population	61.55	28.86	135
Local population	56.63	20.67	135
Intra-provincial immigrants	52.67	17.67	135
Inter-provincial immigrants	13.99	6.31	135
Minor dependent	9.49	2.69	135
Elders	8.76	3.99	135
Married population	66.46	12.95	135
Divorced or widowed population	7.07	2.90	135
High school educated population	25.32	9.45	135
Highly educated population	24.22	18.07	135
Secondary industry employees	29.98	16.00	135
Tertiary industry employees	59.22	22.55	135
High-income-occupation population	21.18	18.34	135
Low-income-occupation population	45.25	20.04	135

**Table I-22 Correlation Matrix<sup>a</sup> (2010)**

	Non-agricultural population	Local population	Intra-provincial immigrants	Inter-provincial immigrants	Minor dependent	Elders	Married population	Divorced or widowed population	High school educated population	Highly educated population	Secondary industry employees	Tertiary industry employees	High-income occupation population	Low-income occupation population
Non-agricultural population	1.00	-0.06	0.02	-0.04	-0.38	0.21	-0.10	0.27	0.63	0.51	-0.07	0.72	0.56	-0.41
Local population	-0.06	1.00	-0.18	0.07	0.31	0.63	0.23	0.58	-0.06	-0.34	-0.19	-0.21	-0.05	0.18
Intra-provincial immigrants	0.02	-0.18	1.00	0.17	-0.07	-0.10	-0.06	-0.06	-0.01	0.07	-0.04	0.11	-0.03	0.13
Inter-provincial immigrants	-0.04	0.07	0.17	1.00	0.02	0.00	-0.11	0.00	-0.10	0.06	-0.04	-0.07	0.16	0.13
Minor dependent	-0.38	0.31	-0.07	0.02	1.00	0.16	0.63	0.15	-0.24	-0.50	-0.01	-0.38	-0.15	0.24
Elders	0.21	0.63	-0.10	0.00	0.16	1.00	0.42	0.80	0.11	-0.34	-0.03	-0.02	0.03	0.10
Married population	-0.10	0.23	-0.06	-0.11	0.63	0.42	1.00	0.42	0.11	-0.65	0.02	-0.08	-0.10	0.07
Divorced or widowed population	0.27	0.58	-0.06	0.00	0.15	0.80	0.42	1.00	0.33	-0.45	-0.26	0.20	-0.01	0.23
High school educated population	0.63	-0.06	-0.01	-0.10	-0.24	0.11	0.11	0.33	1.00	-0.08	-0.03	0.56	0.27	-0.26
Highly educated population	0.51	-0.34	0.07	0.06	-0.50	-0.34	-0.65	-0.45	-0.08	1.00	-0.04	0.35	0.45	-0.37
Secondary industry employees	-0.07	-0.19	-0.04	-0.04	-0.01	-0.03	0.02	-0.26	-0.03	-0.04	1.00	-0.54	-0.05	-0.36
Tertiary industry employees	0.72	-0.21	0.11	-0.07	-0.38	-0.02	-0.08	0.20	0.56	0.35	-0.54	1.00	0.43	-0.22
High-income occupation population	0.56	-0.05	-0.03	0.16	-0.15	0.03	-0.10	-0.01	0.27	0.45	-0.05	0.43	1.00	-0.56
Low-income occupation population	-0.41	0.18	0.13	0.13	0.24	0.10	0.07	0.23	-0.26	-0.37	-0.36	-0.22	-0.56	1.00
Non-agricultural population		0.24	0.43	0.31	0.00	0.01	0.13	0.00	0.00	0.00	0.21	0.00	0.00	0.00
Local population	0.24		0.02	0.22	0.00	0.00	0.00	0.00	0.26	0.00	0.02	0.01	0.27	0.02
Intra-provincial immigrants	0.43	0.02		0.02	0.22	0.12	0.25	0.25	0.47	0.21	0.32	0.11	0.38	0.06
Inter-provincial immigrants	0.31	0.22	0.02		0.41	0.49	0.11	0.50	0.11	0.25	0.31	0.20	0.03	0.07
Minor dependent	0.00	0.00	0.22	0.41		0.03	0.00	0.04	0.00	0.00	0.44	0.00	0.04	0.00
Elders	0.01	0.00	0.12	0.49	0.03		0.00	0.00	0.11	0.00	0.36	0.41	0.39	0.13
Married population	0.13	0.00	0.25	0.11	0.00	0.00		0.00	0.11	0.00	0.40	0.18	0.13	0.20
Divorced or widowed population	0.00	0.00	0.25	0.50	0.04	0.00	0.00		0.00	0.00	0.00	0.01	0.46	0.00
High school educated population	0.00	0.26	0.47	0.11	0.00	0.11	0.11	0.00		0.19	0.35	0.00	0.00	0.00
Highly educated population	0.00	0.00	0.21	0.25	0.00	0.00	0.00	0.00	0.19		0.34	0.00	0.00	0.00
Secondary industry employees	0.21	0.02	0.32	0.31	0.44	0.36	0.40	0.00	0.35	0.34		0.00	0.27	0.00
Tertiary industry employees	0.00	0.01	0.11	0.20	0.00	0.41	0.18	0.01	0.00	0.00	0.00		0.00	0.00
High-income occupation population	0.00	0.27	0.38	0.03	0.04	0.39	0.13	0.46	0.00	0.00	0.27	0.00		0.00
Low-income occupation population	0.00	0.02	0.06	0.07	0.00	0.13	0.20	0.00	0.00	0.00	0.00	0.00	0.00	

a. Determinant = 6.339E-5

**Table I-23** KMO and Bartlett's Test (2010)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.575
Bartlett's Test of Sphericity	Approx. Chi-Square	1242.107
	df	91
	Sig.	0.000

**Table I-24** Communalities (2010)

	<b>Initial</b>	<b>Extraction</b>
Non-agricultural population	1.000	0.859
Local population	1.000	0.781
Intra-provincial immigrants	1.000	0.572
Inter-provincial immigrants	1.000	0.729
Minor dependent	1.000	0.632
Elders	1.000	0.798
Married population	1.000	0.834
Divorced or widowed population	1.000	0.871
High school educated population	1.000	0.699
Highly educated population	1.000	0.820
Secondary industry employees	1.000	0.709
Tertiary industry employees	1.000	0.900
High-income-occupation population	1.000	0.725
Low-income-occupation population	1.000	0.801

Extraction Method: Principal Component Analysis.

**Table I-25** Total Variance Explained (2010)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Non-agricultural population	3.74	26.70	26.70	3.74	26.70	26.70	2.96	21.17	21.17
Local population	2.98	21.31	48.01	2.98	21.31	48.01	2.42	17.28	38.44
Intra-provincial immigrants	1.62	11.54	59.55	1.62	11.54	59.55	2.38	16.99	55.43
Inter-provincial immigrants	1.27	9.08	68.63	1.27	9.08	68.63	1.73	12.36	67.79
Minor dependent	1.12	8.01	76.64	1.12	8.01	76.64	1.24	8.85	76.64
Elders	1.00	7.14	83.78						
Married population	0.73	5.20	88.98						
Divorced or widowed population	0.46	3.27	92.25						
High school educated population	0.39	2.78	95.03						
Highly educated population	0.28	2.03	97.05						
Secondary industry employees	0.17	1.22	98.27						
Tertiary industry employees	0.12	0.83	99.11						
High-income-occupation population	0.09	0.61	99.72						
Low-income-occupation population	0.04	0.28	100.00						

Extraction Method: Principal Component Analysis.

**Table I-26** Component Matrix<sup>a (2010)</sup>

	Component				
	1	2	3	4	5
Non-agricultural population	-0.654	0.652	-0.075	0.027	0.017
Local population	0.540	0.458	0.034	0.472	-0.236
Intra-provincial immigrants	-0.106	-0.097	0.396	-0.102	0.620
Inter-provincial immigrants	0.004	-0.060	0.292	0.606	0.523
Minor dependent	0.686	0.011	-0.178	-0.041	0.358
Elders	0.438	0.699	-0.102	0.305	-0.117
Married population	0.593	0.397	-0.308	-0.305	0.369
Divorced or widowed population	0.408	0.823	0.126	0.070	-0.080
High school educated population	-0.347	0.629	-0.126	-0.397	0.096
Highly educated population	-0.818	-0.169	0.096	0.316	-0.119
Secondary industry employees	0.012	-0.331	-0.761	0.092	0.109
Tertiary industry employees	-0.618	0.575	0.324	-0.282	0.052
High-income-occupation population	-0.579	0.366	-0.233	0.349	0.280
Low-income-occupation population	0.566	-0.113	0.671	-0.099	-0.086

Extraction Method: Principal Component Analysis.

a. 5 components extracted.

**Table I-27** Rotated Component Matrix<sup>a (2010)</sup>

	Component				
	1	2	3	4	5
Non-agricultural population	0.835	-0.287	0.170	0.221	0.041
Local population	-0.168	0.115	0.854	-0.099	0.031
Intra-provincial immigrants	0.148	0.157	-0.373	-0.249	0.569
Inter-provincial immigrants	-0.148	-0.097	0.127	0.008	0.826
Minor dependent	-0.309	0.703	0.153	0.020	0.139
Elders	0.138	0.265	0.842	0.008	-0.008
Married population	0.113	0.876	0.218	0.065	-0.036
Divorced or widowed population	0.342	0.331	0.759	-0.260	-0.026
High school educated population	0.802	0.153	0.018	0.070	-0.164
Highly educated population	0.211	-0.803	-0.228	0.220	0.176
Secondary industry employees	-0.295	0.160	-0.168	0.743	-0.124
Tertiary industry employees	0.887	-0.231	-0.063	-0.230	0.040
High-income-occupation population	0.513	-0.265	0.117	0.498	0.360
Low-income-occupation population	-0.352	0.174	0.106	-0.794	0.069

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 8 iterations.

**Table I-28** Component Transformation Matrix (2010)

Component	1	2	3	4	5
1	-0.561	0.665	0.405	-0.271	-0.078
2	0.733	0.201	0.648	-0.054	-0.017
3	0.044	-0.269	-0.032	-0.898	0.344
4	-0.340	-0.444	0.561	0.300	0.531
5	0.174	0.498	-0.318	0.165	0.770

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Table I-29** Component Score Coefficient Matrix (2010)

	Component				
	1	2	3	4	5
Non-agricultural population	0.252	-0.062	0.079	0.086	0.017
Local population	-0.131	-0.149	0.433	0.010	0.028
Intra-provincial immigrants	0.126	0.219	-0.261	-0.143	0.470
Inter-provincial immigrants	-0.088	-0.032	0.101	0.059	0.674
Minor dependent	-0.039	0.326	-0.039	0.092	0.176
Elders	0.003	-0.017	0.369	0.067	0.013
Married population	0.139	0.454	-0.083	0.104	0.046
Divorced or widowed population	0.113	0.047	0.274	-0.110	-0.012
High school educated population	0.324	0.183	-0.101	0.004	-0.123
Highly educated population	-0.019	-0.336	0.046	0.066	0.089
Secondary industry employees	-0.112	0.123	-0.046	0.466	-0.047
Tertiary industry employees	0.326	-0.004	-0.088	-0.204	-0.004
High-income-occupation population	0.121	-0.037	0.096	0.289	0.299
Low-income-occupation population	-0.081	-0.022	0.004	-0.448	0.031

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Table I-30** Component Score Covariance Matrix (2010)

Component	1	2	3	4	5
1	1.000	0.000	0.000	0.000	0.000
2	0.000	1.000	0.000	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	1.000

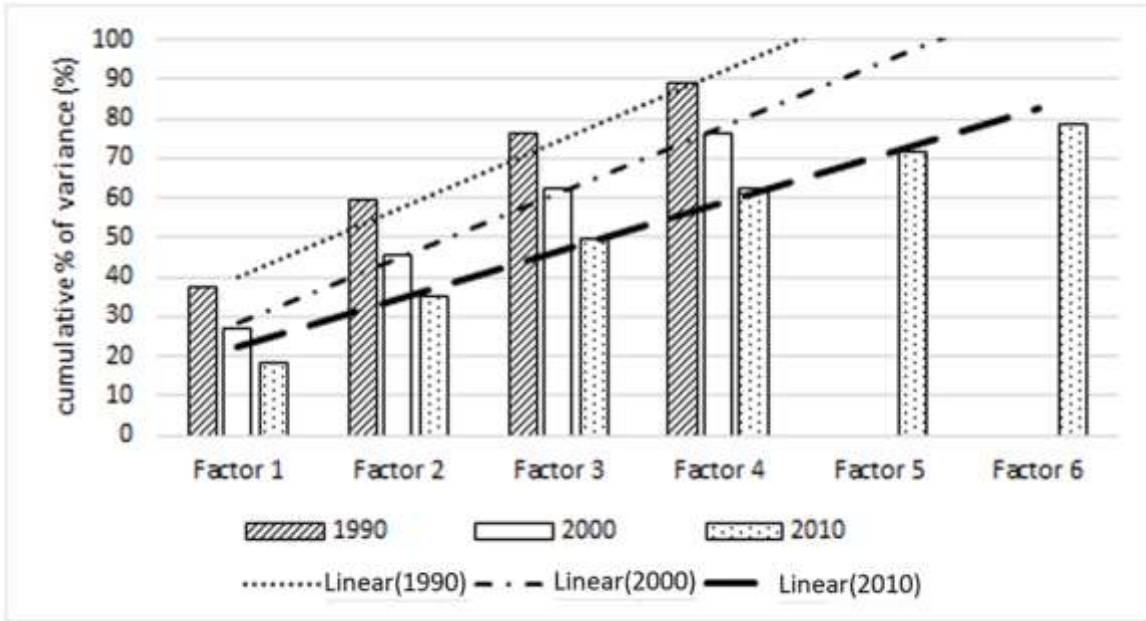
Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

**Appendix I-iv Social landscape transformations including dwelling space and health variables**

**Table I-31** List of indicators and variables (with dwelling space and health variables)

<b>Indicator</b>	<b>Variable</b>
Population urbanization	Non-agricultural population
Immigration	Local population (with Hukou)
	Immigrants from this province *
	Immigrants from other province
Age	Population aged 0-14
	Population aged over 65
Marriage status	Married population
	Divorced or widowed population
Household size	2-generation household
	3-generation-and-above household
Education background	High school educated population
	Highly educated population
Employment	Secondary industry employment
	Tertiary industry employment
Income level of occupation	Population with high-income occupation
	Population with low-income occupation
Living space size	Household with small living space
	Household with medium living space
	Household with large living space
Elders' Health	Less healthy elders aged over 60



**Figure I-1** Scree plots in different years (Including dwelling space and health variables)

**Table I-32** Rotated Component Matrix<sup>a (1990)</sup> (Including dwelling space and health variables)

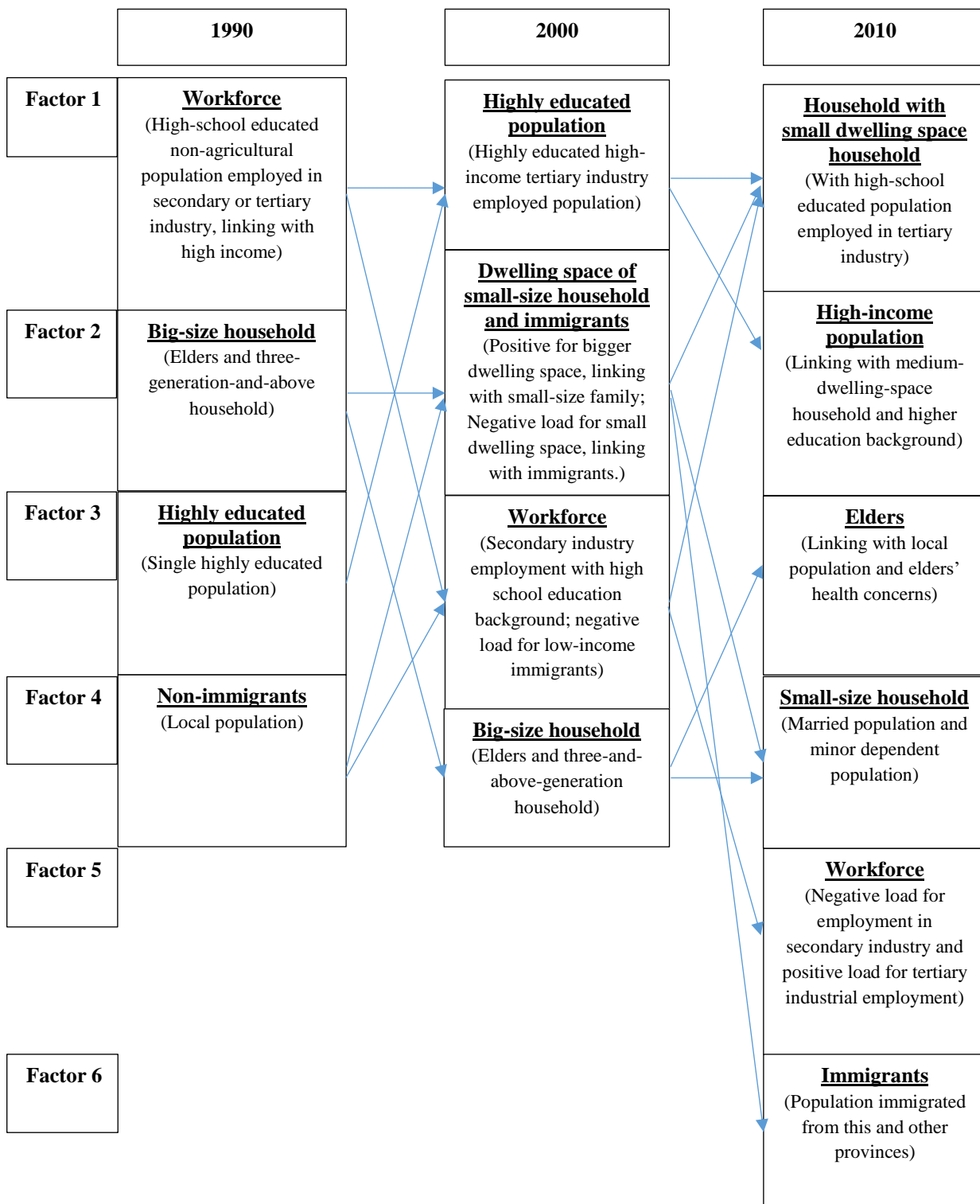
Variable	Factor-1990			
	1	2	3	4
Non-agricultural population	<b>.954</b>	.166	.101	.051
Local population (with Hukou)	-.124	.123	.088	<b>.892</b>
Immigrants from this province*	-.016	-.016	.041	<b>-.902</b>
Immigrants from other province	NA			
Population aged 0-14	<b>-.915</b>	-.023	-.260	.122
Population aged over 65	.146	<b>.916</b>	-.137	.109
Married population	.039	.271	<b>-.853</b>	.008
Divorced or widowed population	-.141	<b>.883</b>	-.226	.205
2-generation household	-.190	<b>-.965</b>	.006	.035
3-generation-and-above household	.009	<b>.835</b>	-.037	-.033
High school educated population	<b>.960</b>	.143	-.005	.013
Highly educated population	.517	-.152	<b>.796</b>	.064
Secondary industry employment	<b>.860</b>	-.169	-.334	-.165
Tertiary industry employment	<b>.774</b>	.319	.429	-.030
Population with high-income occupation	<b>.797</b>	.024	.514	.106
Population with low-income occupation	<b>-.987</b>	.048	-.044	.093
Household with small living space	NA			
Household with medium living space	NA			
Household with large living space	NA			
Less heathy elders aged over 60	NA			

**Table I-33** Rotated Component Matrix<sup>a</sup> (2000) (Including dwelling space and health variables)

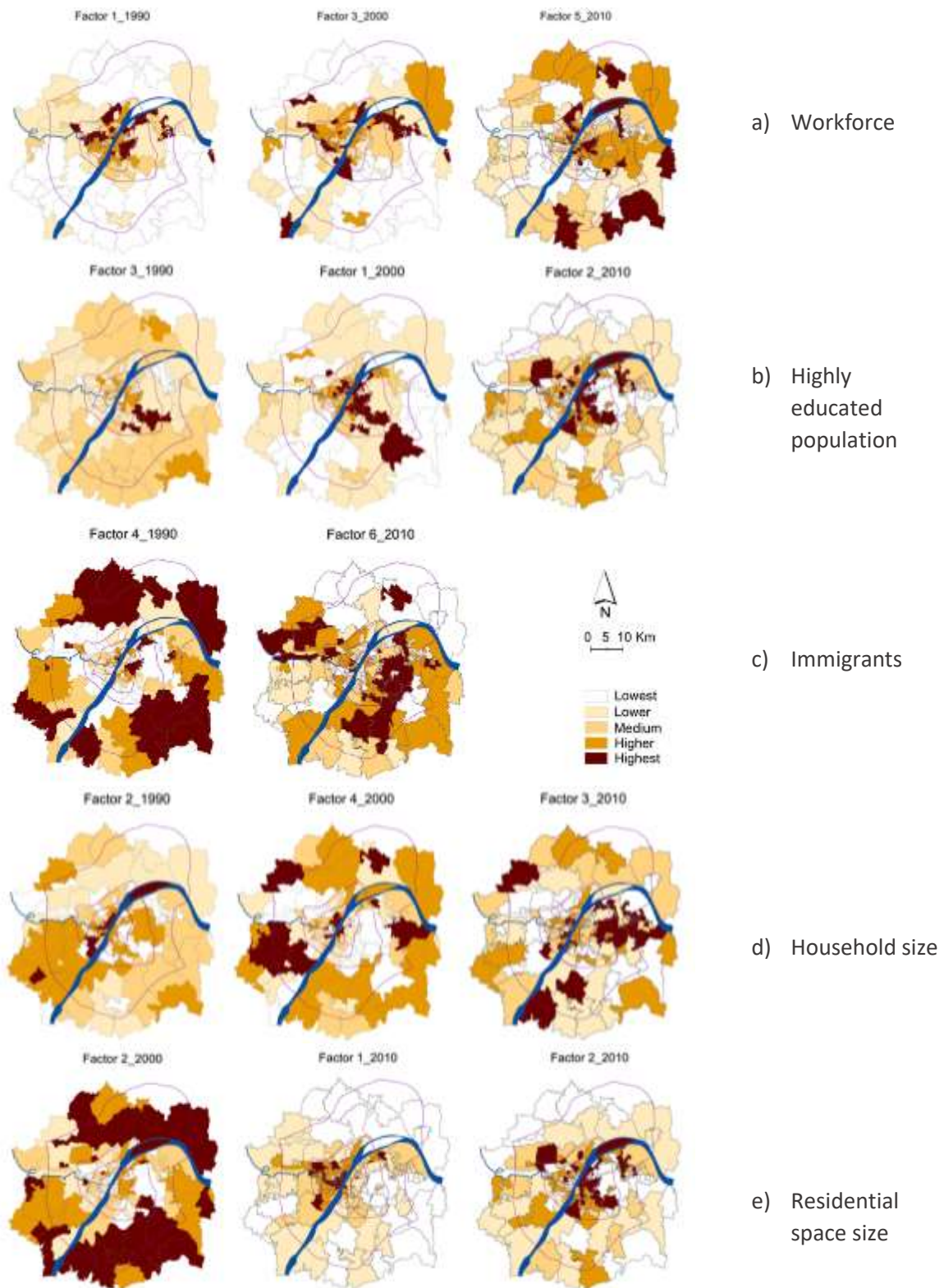
Variable	Factor-2000			
	1	2	3	4
Non-agricultural population	<b>.736</b>	-.243	.564	.206
Local population (with Hukou)	.037	<b>.558</b>	-.232	.499
Immigrants from this province*	.066	<b>-.480</b>	-.180	-.445
Immigrants from other province	.014	.012	<b>-.560</b>	-.023
Population aged 0-14	<b>-.764</b>	.415	-.420	.006
Population aged over 65	.160	-.345	.110	<b>.843</b>
Married population	<b>-.809</b>	.117	.280	.265
Divorced or widowed population	-.231	-.317	-.020	<b>.784</b>
2-generation household	-.243	<b>.683</b>	.050	-.249
3-generation-and-above household	-.056	.090	-.044	<b>.678</b>
High school educated population	.558	-.305	<b>.680</b>	.193
Highly educated population	<b>.951</b>	.085	.010	-.186
Secondary industry employment	.139	-.149	<b>.803</b>	-.161
Tertiary industry employment	<b>.727</b>	-.433	.267	.128
Population with high-income occupation	<b>.891</b>	-.116	.286	.021
Population with low-income occupation	<b>-.654</b>	.218	<b>-.674</b>	.029
Household with small living space	.192	<b>-.880</b>	.259	.078
Household with medium living space	-.121	<b>.836</b>	-.338	-.127
Household with large living space	-.377	.521	<b>-.555</b>	-.115
Less healthy elders aged over 60	NA			

**Table I-34** Rotated Component Matrix<sup>a</sup> (2010) (Including dwelling space and health variables)

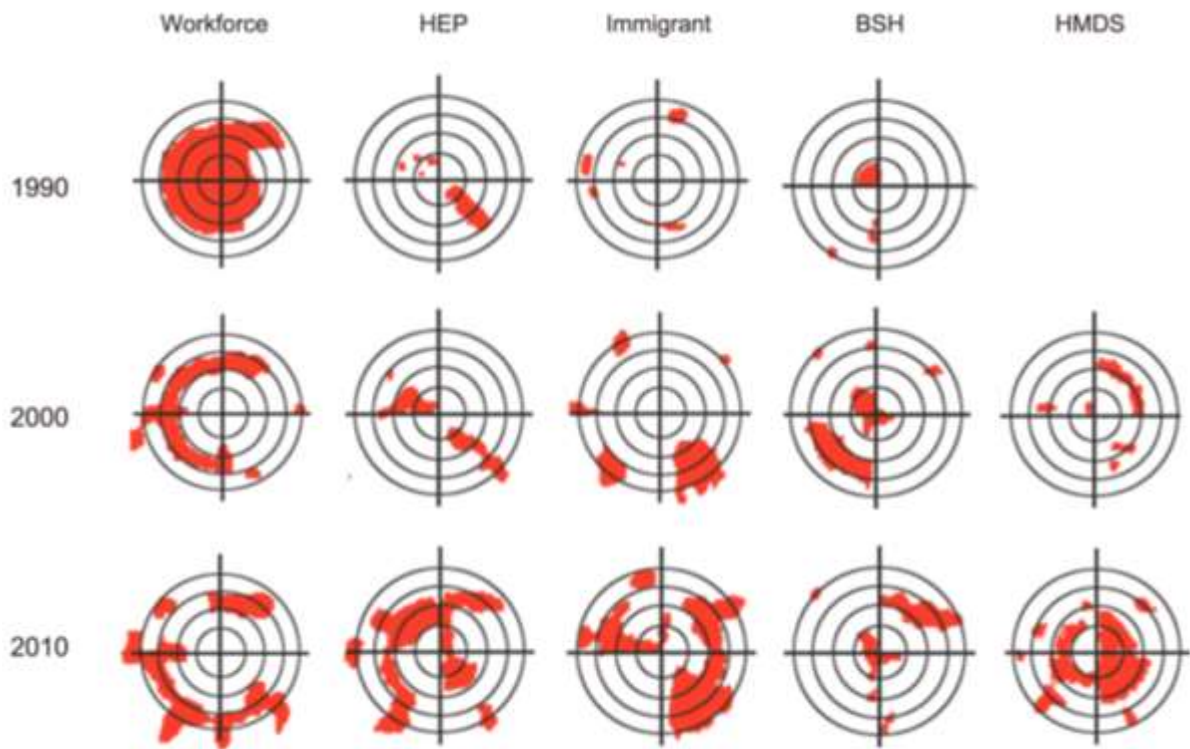
Variable	Factor-2010					
	1	2	3	4	5	6
Non-agricultural population	.520	<b>.702</b>	.197	-.196	.126	-.016
Local population (with Hukou)	-.338	-.014	<b>.763</b>	.200	.205	-.033
Immigrants from this province*	.242	-.102	-.125	-.032	-.127	<b>.742</b>
Immigrants from other province	-.190	.084	.044	-.034	.148	<b>.762</b>
Population aged 0-14	-.399	-.065	.039	<b>.798</b>	.058	.030
Population aged over 65	.013	.090	<b>.870</b>	.264	-.012	.006
Married population	.119	-.033	.201	<b>.884</b>	-.060	-.074
Divorced or widowed population	.298	-.055	<b>.792</b>	.322	.229	.010
2-generation household	NA					
3-generation-and-above household	NA					
High school educated population	<b>.720</b>	.326	.134	.113	-.017	-.121
Highly educated population	-.076	<b>.541</b>	-.280	<b>-.683</b>	.135	.071
Secondary industry employment	-.155	.130	-.093	.033	<b>-.904</b>	-.032
Tertiary industry employment	<b>.700</b>	.394	-.030	-.154	<b>.501</b>	-.022
Population with high-income occupation	.078	<b>.808</b>	-.003	-.091	.196	.086
Population with low-income occupation	-.079	<b>-.718</b>	.160	.102	.310	.245
Household with small living space	<b>.868</b>	-.232	-.094	-.102	.156	.069
Household with medium living space	.177	<b>.741</b>	.079	.050	-.363	.059
Household with large living space	<b>-.865</b>	-.367	-.064	.042	.064	-.088
Less healthy elders aged over 60	.120	-.045	<b>.645</b>	-.293	-.208	-.088



**Figure I-2** diagram of social dimensional transformations (including dwelling space and health variables).



**Figure I-3** Factor maps revealing social landscape transformations (With consideration of dwelling space size and healthy variables)



HEP: Highly Educated Population; BSH: Big-Size Household; HMDS: High-income population with Medium-size Dwelling Space

**Figure I-4** Diagram of social landscape transformations (including dwelling space and health variables).

## Appendix II. Remote sensing data collection and process

This appendix supports the analysis of urban land growth in Chapter 3. It includes a list of remote sensing data and the separability analysis of MBCI and BCI used to distinguish between impervious and permeable surfaces. To examine up-to-date urban development patterns, this study also analyzed the urban land use in 2016. However, since there is no matching census data in 2016 to support the modelling of urban land metrics through social factors, we only attach the relevant parameters for computing the 2016 MBCI.

### Appendix II-i. Remote sensing data list

**Table II-1** Remote sensing data list\*

<b>Data ID</b>	<b>Date</b>
LT051230391991071901T1	19910719
LT051230392000072701T1	20000727
LT051230392011060801T1	20110608
LC081230392016072301T1	20160723

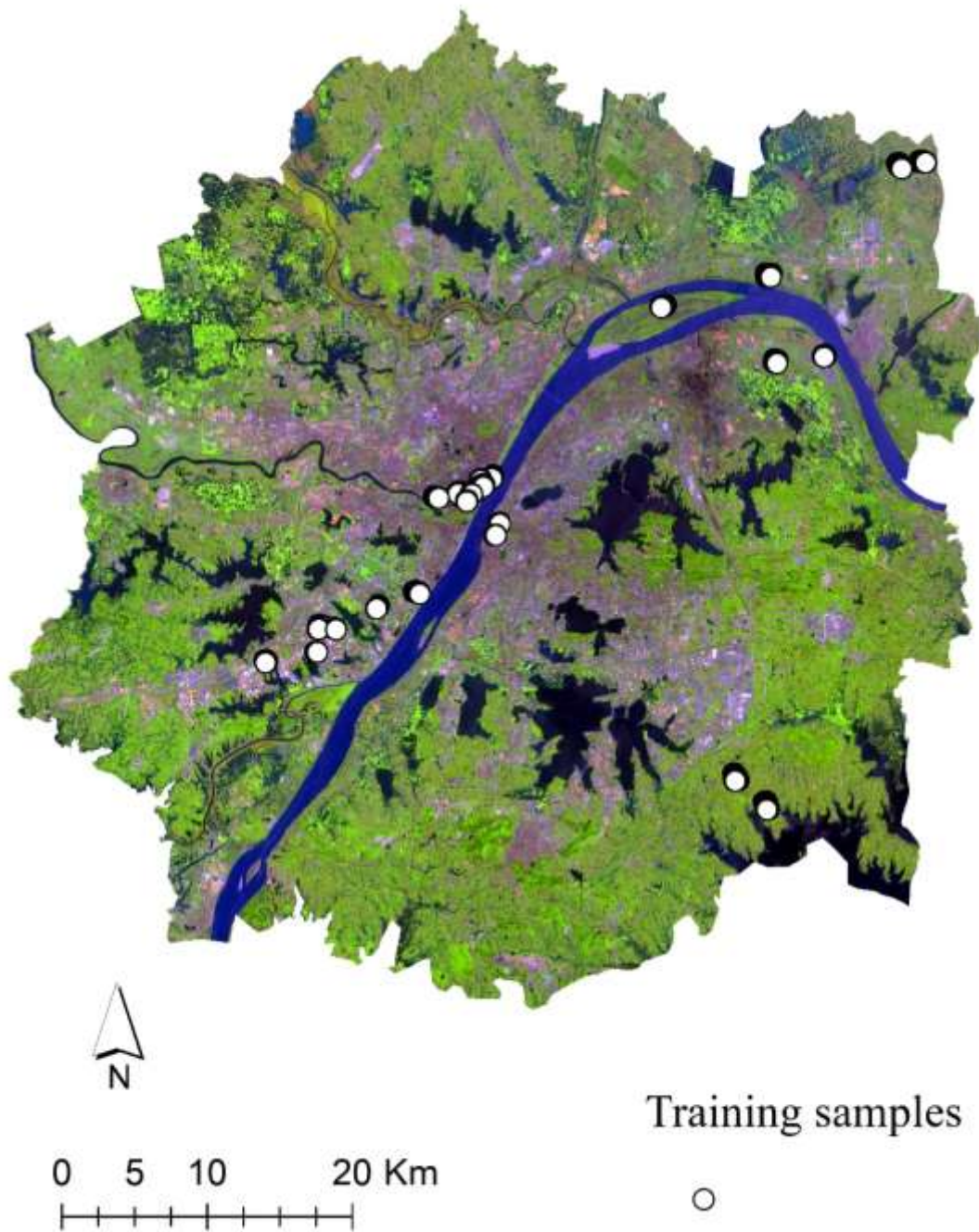
\* Landsat 5 TM data is collected for 1991, 2000, 2011 while Landsat 8 data is for 2016, including surface reflectance data, TOA, and brightness temperature data.

**Table II-2** TCT coefficients for Landsat-8 at-satellite reflectance (Baig et al., 2014)\*

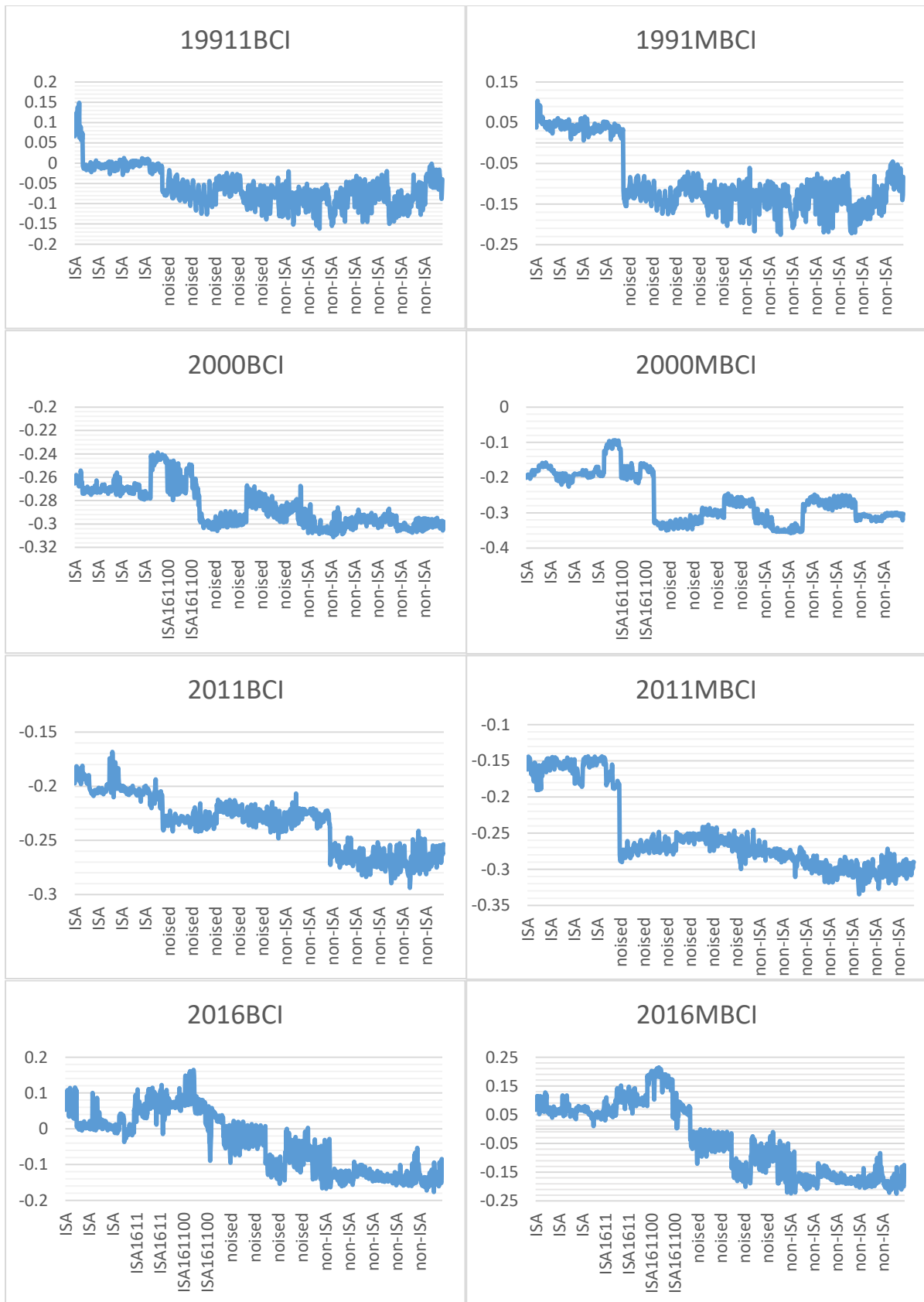
<b>Band</b>	<b>Blue</b>	<b>Green</b>	<b>Red</b>	<b>NIR</b>	<b>SWIR1</b>	<b>SWIR2</b>
<b>Feature</b>	<b>TM2</b>	<b>TM3</b>	<b>TM4</b>	<b>TM5</b>	<b>TM6</b>	<b>TM7</b>
Brightness	0.3029	0.2786	0.4733	0.5599	0.5080	0.1872
Greenness	-0.2941	-0.2430	-0.5424	0.7276	0.0713	-0.1608
Wetness	0.1511	0.1973	0.3283	0.3407	-0.7117	-0.4559

\* Table II-2 is the parameters of the Tasseled Cap Transformation (TCT) that we use to compute BCI and MBCI in 2016.

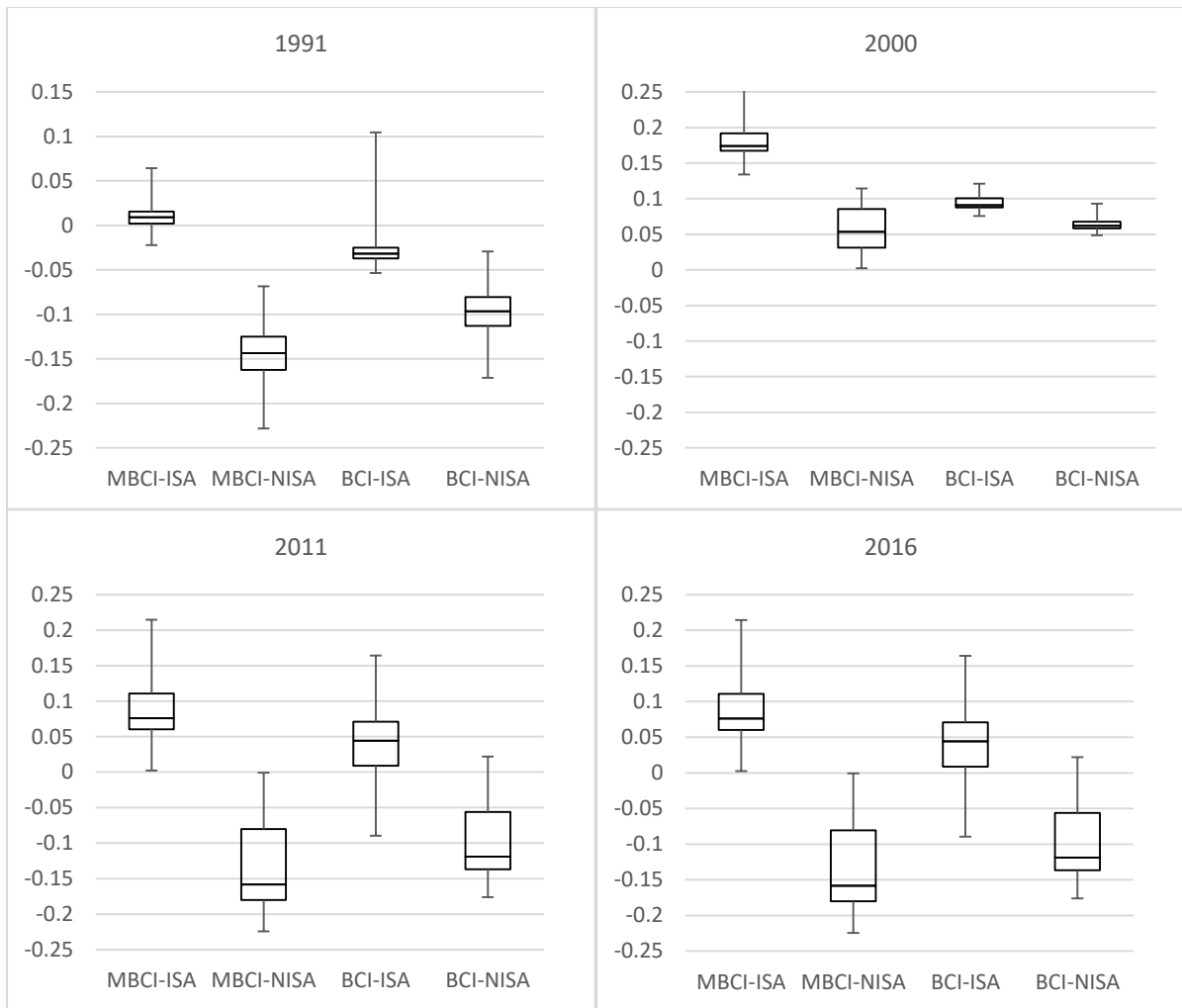
**Appendix II-ii. Separability of BCI and MBCI for discriminating ISA and NISA**



**Figure II-1** Training sample map BCI and MBCI comparison



**Figure II-2** Spectral separability of BCI and MBCI for discriminating ISA and NISA



**Figure II-3** Separability box plots of BCI and MBCI for discriminating ISA and NISA

## Appendix III. Questionnaire

### Appendix III-i. Questionnaire in English

#### Questionnaire

Thank you for participating in the 15-20 minute survey about perceptions of urban green open space in your neighborhood and the ecological impacts of urban expansion in Wuhan. The questionnaire focuses on the public's preference and perception of urban green open space, urban expansion, and its ecological, social, and economic impacts. Likewise, it will address the importance of measures and policies to improve social and natural ecology interactions.

Your participation in this questionnaire is completely confidential. Your response to this questionnaire is for research purposes only. We expect that your answer is as accurate as possible. Please add details and comments on the questions if you have any. Thanks for your participation.

#### I. Personal Information.

---

<b>A Personal Information</b>	
1	In which gender group do you belong? <input type="checkbox"/> Male <input type="checkbox"/> Female
2	In which age group do you belong? <input type="checkbox"/> 18-24 <input type="checkbox"/> 25-54 <input type="checkbox"/> 55 or above
3	What is the highest degree, certificate or diploma you have obtained? <input type="checkbox"/> Middle school or less <input type="checkbox"/> High school <input type="checkbox"/> Post-secondary diploma or above
4	Which of the following best describes your current occupation? <input type="checkbox"/> Factory workers <input type="checkbox"/> Business people <input type="checkbox"/> Civil servants <input type="checkbox"/> Intellectuals/teachers/researchers <input type="checkbox"/> Student <input type="checkbox"/> Other
5	Do you have an urban Hukou or a rural Hukou? <input type="checkbox"/> Urban Hukou <input type="checkbox"/> Rural Hukou
6	How long have you lived in Wuhan? <input type="checkbox"/> Less than 5 years <input type="checkbox"/> 5-10 years <input type="checkbox"/> 10-20 years <input type="checkbox"/> More than 20 years
7	In which district are you residing? <input type="checkbox"/> Qiaokou District <input type="checkbox"/> Jiangnan District <input type="checkbox"/> Jiang'an District <input type="checkbox"/> Hanyang District <input type="checkbox"/> Wuchang District <input type="checkbox"/> Hongshan District <input type="checkbox"/> Qingshan District <input type="checkbox"/> Other District
8	In which zone are you residing? <input type="checkbox"/> Within Expressway Ring I <input type="checkbox"/> Within Expressway Ring II <input type="checkbox"/> Within Expressway Ring III <input type="checkbox"/> Out of Expressway Ring III

---

- 
- |    |  |   |
|----|--|---|
| 9  | According to the height of building, in which group your residential community belongs to? | <input type="checkbox"/> Low-rise building community<br><input type="checkbox"/> Multi-story building community<br><input type="checkbox"/> Mid-rise building community<br><input type="checkbox"/> High-rise building community<br><input type="checkbox"/> Super-high-rise building community |
| 10 | Which of following best describes your residential status?                                 | <input type="checkbox"/> Reside alone<br><input type="checkbox"/> Reside with 2-3 persons<br><input type="checkbox"/> Reside with 4-5 persons<br><input type="checkbox"/> Reside with 6 and more persons (Including myself)   |
| 11 | How often do you travel domestically?  | <input type="checkbox"/> Several times a year <input type="checkbox"/> once a year<br><input type="checkbox"/> once several years <input type="checkbox"/> very seldom  |
| 12 | Have you travelled abroad?   | <input type="checkbox"/> Yes <input type="checkbox"/> No  |
- 

**II. Perception of changes of urban green and open space (UGOS) in your neighbourhood.**

This section focuses on your perception of UGOS in your neighbourhood or in the adjacent ones.

**II-I. Use of and attitude toward UGOS in your neighbourhood**

Section II-I focuses on residents' use and attitudes towards UGOS (B). Please select the appropriate answer in the list.

---

**B How do you use the UGOS in your neighbourhood?**

---

- |    |   |  |
|----|---|--|
| 13 | How do you often go to the UGOS?  | <input type="checkbox"/> Walk <input type="checkbox"/> Ride bicycle<br><input type="checkbox"/> Drive car <input type="checkbox"/> Other   |
| 14 | How often do you visit the UGOS?  | <input type="checkbox"/> Daily <input type="checkbox"/> Weekly<br><input type="checkbox"/> Monthly <input type="checkbox"/> Very seldom  |
| 15 | What is your main purpose of visiting the UGOS?                                     | <input type="checkbox"/> Walk <input type="checkbox"/> Enjoy nature<br><input type="checkbox"/> Exercise <input type="checkbox"/> Child's play<br><input type="checkbox"/> Social interaction<br><input type="checkbox"/> Ride bicycle <input type="checkbox"/> Other  |
| 16 | What elements do you think are not available in the UGOS that you visit frequently? | <input type="checkbox"/> Green space <input type="checkbox"/> Water surface<br><input type="checkbox"/> Grey space<br><input type="checkbox"/> Sports facility for daily exercise<br><input type="checkbox"/> Child's playground<br><input type="checkbox"/> Walking trails<br><input type="checkbox"/> Bicycle lanes <input type="checkbox"/> Other |
-

## II-II. Perception of changes of UGOS in your neighbourhood

To what extent do you perceive the change of UGOS during the recent years in your neighborhood (C)? The Lickert scale “1, 2, 3, 4, and 5” is corresponding to “Great decrease, Slight decrease, No change, Slight increase, Great increase”.

C	Changes of UGOS in your neighbourhood	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
17	Change in the area of urban green space	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
18	Changes in the vegetation richness of urban green space	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
19	Changes in the degree of dispersion of urban green space distribution	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
20	Change in the area of bodies of water	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
21	Change in the quality of bodies of water	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
22	Change in the degree of dispersion of bodies of water distribution	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

## II-III. Perception of the needed improvements of UGOS in your neighbourhood

To what extent do you agree that improvement of natural elements and auxiliary facilities are essential for the UGOS in your neighborhood (D)? The Lickert scale “1, 2, 3, 4, and 5” is corresponding to “Strongly disagree, Somewhat disagree, Neutral, Somewhat agree, Strongly agree”.

D	Needed improvements	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
23	Develop additional green space	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
24	Improve vegetation richness of green space	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
25	Increase the dispersion of green space distribution	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
26	Develop or restore wetland	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
27	Improve quality of bodies of water	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
28	Increase the dispersion of wetland distribution	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
29	Improve walking trails network	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
30	Improve bicycle lanes network	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
31	Increase exercise facilities	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
32	Increase children's playground	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

## II-IV. Perceptions of landscape-ecology relationship in your neighbourhood

To what extent do you agree that green open spaces provide residents with the natural and social ecological services (E)? Please indicate the level of your agreement on a scale from 1 to 5, where 1 is “Strongly disagree”, and 5 is “Strongly agree”.

<b>E</b>	<b>Ecosystem services provided by green open space in your neighbourhood</b>					
33	Primary product supply	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
34	Air quality improvement	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
35	Urban heat island effect relief	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
36	Noise reduction	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
37	Hydrological regulation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
38	Soil erosion reduction	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
39	Urban storm flood risk reduction	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
40	Bio-diversity conservation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
41	Conducive to residents' daily leisure and recreation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
42	Conducive to the physical and mental health of residents	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
43	Conducive to community safety	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
44	Increase the value of real estate	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

### **III. Perception of urban impervious surface area (ISA) expansion and its socio-ecological impacts in Wuhan.**

This section focuses on your perception of the urban ISA expansion and the corresponding socio-ecological impacts in Wuhan. We use the Lickert scale to divide cognition into five levels.

#### **III-I. Perception of ecological impacts of ISA expansion.**

To what extent do you agree that urban ISA expansion causes significant loss of natural resources and increases urban pollution and vulnerability (F, G)? The Lickert scale “1, 2, 3, 4, and 5” is corresponding to “Strongly disagree, Somewhat disagree, Neutral, Somewhat agree, Strongly agree”.

<b>F</b>	<b>Loss of natural resources</b>					
45	Loss of urban green spaces	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
46	Loss of water area	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
47	Loss of high-quality agricultural land	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
48	Loss of bio-diversity	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

<b>G Increase of urban pollution and vulnerability</b>						
49	Increase of air pollution	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
50	Increase of water pollution	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
51	Increase of soil pollution	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
52	Increase of soil erosion	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
53	Increase of emission of green-house gases (e.g., CO <sub>2</sub> )	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
54	Increase of urban noise	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
55	Increase of urban storm flood risk	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### III-II. Perception of social and economic impacts of ISA expansion.

To what extent do you agree that urban ISA expansion causes a significant decrease of socio-ecological interactions and increases the socio-economic cost (H, I)? The Lickert scale “1, 2, 3, 4, and 5” is corresponding to “Strongly disagree, Somewhat disagree, Neutral, Somewhat agree, Strongly agree”.

<b>H Society-nature interaction</b>						
56	Decrease accessibility to green spaces	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
57	Decrease accessibility to water scenery	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
58	Reduce frequency of visiting green space	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
59	Reduce frequency of visiting bodies of water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
60	Decrease society-nature interaction	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>I Socio-economic cost</b>						
61	Increase residential segregation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
62	Increase loss of social interaction	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
63	Increase travel time between job and residence	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
64	Increase traffic congestion	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
65	Increase water consumption	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
66	Increase energy consumption	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
67	Increase health concerns	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
68	Increase crime concerns	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
69	Increase safety concerns	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**III-III. Perception of the importance of measures and policies to increase society-nature interactions and to protect UGOS.**

To what extent do you agree that the measures below play a significant role in improving human-nature interactions (J) and mitigating the negative impacts of urban ISA expansion (K)? The Lickert scale “1, 2, 3, 4, and 5” is corresponding to “Strongly disagree, Somewhat disagree, Neutral, Somewhat agree, Strongly agree”.

<b>J Measures to improve UGOS and its accessibility</b>						
70	Increase physical area of vegetation and water surface	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
71	Increase fragmentation of vegetation and water surface	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
72	Improve public transit system for access UGOS	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
73	Improve the walking trail and bicycle lane network for access UGOS	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>K Measures to protect and develop UGOS system</b>						
74	Red line control for urban ISA expansion	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
75	Urban forest park conservation and construction	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
76	Urban blue line (lakeshore, river shore, etc.) control	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
77	Urban wetland restoration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
78	High-quality cultivated land conservation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

**IV. Interview involvement**

We are looking for people to participate in an interview to discuss UGOS use and developments in your neighbourhood. Your participation is completely voluntary and will only be used for research purposes. If you are willing to participate, please provide your contact information or contact us directly via email or phone message. When we have received your information, we will make appointment with you for the interview. Thank you!

## Interview Questionnaire

Interviewee:

Interviewer:

Date:

Time:

[Thank participant for agreeing to be interviewed. Explain confidentiality and attain verbal consent.]

1. Is there green open space nearby your neighborhood? Do you visit it often?
2. Do you think that the improvement of natural spaces as well as auxiliary facilities in your neighborhood are essential? Why?
3. How do you evaluate the importance of green open spaces in relevance to your daily relaxation and health?
4. Do you think it is necessary for residents to participate in the maintenance and management of the green open space in the community? What are your thoughts on the configuration of open space?
5. What negative impacts of green open spaces do you feel exist in your neighborhood? Do you have any suggestions to improve it?
6. Do you think it is necessary for residents to participate in green open space configuration and maintenance? Are you willing to be engaged in? Why?
7. What changes of urban green spaces and bodies of water have you noticed in the area since you first moved there? Are these changes positive or negative, in your view?
8. Do you think that with the expansion of the urban impervious surface, the interactions between society and nature have improved or decreased? In what ways?
9. Do you recognize any relationship between the richness of urban open spaces and the public's preference to residence location and daily recreation? What is it?
10. Do you think it is necessary for residents to participate in the planning of open space in the community? What are the concerns of community residents in the allocation of open space?
11. What impact do you think the UGOS allocation of the community has on the value of real estate and the choice of residents?
12. Are there any short-term or long-term policies to protect urban natural resources that you think the government should adopt, along with the expansion of urban ISA? Why?

## Appendix III-ii. Questionnaire in Chinese

### 调查问卷

感谢您参与关于城市绿地开敞空间的 15-20 分钟的问卷调查。本问卷旨在探讨居民对城市不透水面扩张及其对所在社区和武汉市城市绿地和开敞空间的影响的认知。该问卷主要关注公众对城市不透水面扩张及其生态、社会、经济影响的认知、以及对改善社会-生态互动的举措和政策重要性的认知。

您参与这份问卷调查是完全保密的。您在此问卷中的回答仅用于研究目的。我们希望您的回答尽可能准确。如果您有问题或选项以外的回答，请添加细节。感谢您的参与。

#### 第一部分. 被调查人信息

该部分 (A) 为被调查人的个人信息，涉及年龄、性别、户籍、受教育程度、职业、收入水平等。

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#### A 个人信息

---

- |   |                    |                                  |  |   |                              |  |                              |
|---|--------------------|----------------------------------|--|---|------------------------------|--|------------------------------|
| 1 | 您的性别是…             | <input type="checkbox"/> 男       | <input type="checkbox"/> 女   |   |                              |  |                              |
| 2 | 您属于哪个年龄段?          | <input type="checkbox"/> 18-24 岁 | <input type="checkbox"/> 25-54 岁<br><input type="checkbox"/> 55 岁及以上 |   |                              |  |                              |
| 3 | 您获得的最高学位、证书或文凭是什么? | <input type="checkbox"/> 初中或以下   | <input type="checkbox"/> 高中<br><input type="checkbox"/> 大学及以上        |   |                              |  |                              |
| 4 | 下列哪一项最能描述您目前的职业?   | <input type="checkbox"/> 工厂工人    | <input type="checkbox"/> 农民<br><input type="checkbox"/> 商务人士         | <input type="checkbox"/> 公务人员<br><input type="checkbox"/> 知识分子/教师/科研人员<br><input type="checkbox"/> 学生 | <input type="checkbox"/> 其他  |  |                              |
| 5 | 您有城市户口还是农村户口?      | <input type="checkbox"/> 城市户口    | <input type="checkbox"/> 农村户口  |   |                              |  |                              |
| 6 | 您在武汉住了多久了?         | <input type="checkbox"/> 少于 5 年  | <input type="checkbox"/> 5-10 年<br><input type="checkbox"/> 10-20 年  | <input type="checkbox"/> 20 年以上   |                              |  |                              |
| 7 | 您居住在在武汉什么区?        | <input type="checkbox"/> 硚口区     | <input type="checkbox"/> 江汉区   | <input type="checkbox"/> 江岸区<br><input type="checkbox"/> 汉阳区  | <input type="checkbox"/> 武昌区 | <input type="checkbox"/> 洪山区<br><input type="checkbox"/> 青山区 | <input type="checkbox"/> 其他区 |
-

- 
- 8 您居住在几环以内？
- 一环以内       二环以内  
 三环以内       三环以外
- 9 从建筑层高而言，您所居住的小区符合那一选项？
- 低层（1-3层）建筑为主  
 多层（4-6层）建筑为主  
 小高层（7-11层）建筑为主  
 高层（12-30层）建筑为主  
 小高层（31层及以上）建筑为主
- 10 以下哪种情况较恰当地描述您的居住状态？
- 独自居住  
 2-3人居住  
 4-5人居住  
 6人及以上居住
- 11 您在国内旅游的频率符合哪个选项？
- 一年多次       一年一次  
 几年一次       非常少
- 12 您是否海外旅游过？
- 是       否
- 

## 第二部分：您对所在社区城市开敞空间变化的认知。

本节重点关注您对所在社区或邻近社区的城市绿地与开敞空间变化的看法。

### II-I. 您对社区绿地与开敞空间的使用

第 II-I 部分侧重于居民对城市绿地与开敞空间的使用(B)。请在以下选项中选择适合的选项。如果没有最佳选项，请添加您的具体答案。

---

#### B 您如何使用社区的绿地与开敞空间

---

- 13 您一般如何去该绿地与开敞空间？
- 步行     骑自行车  
 开车     其它
- 14 您访问绿地与开敞空间的频率如何？
- 每天     每周  
 每月     非常少
- 15 您访问绿地与开敞空间的主要目的是什么？
- 散步     享受自然  
 锻炼     孩童游乐  
 社交     骑行  
 其他

- 16 您经常访问的绿地与开敞空间缺少哪方面的元素?
- 绿地       水面  
 灰色开敞空间  
 日常锻炼的运动设施  
 儿童游乐场地     步游道  
 自行车道    其他

## II-II. 您对所在社区绿地与开敞空间变化的认知

第 II-II 部分集中讨论公众对社区绿地与开敞空间变化的认知 (C)。李克特量表的“1、2、3、4、5”对应“大幅下降、略微下降、无变化、略微增加、大幅增加”。

### C 您所在社区绿地与开敞空间的变化

- |    |               |                            |                            |                            |                            |                            |
|----|---------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| 17 | 城市绿地面积的变化     | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 18 | 城市绿地植被丰度的变化   | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 19 | 城市绿地分布分散程度的变化 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 20 | 水体面积的变化       | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 21 | 水体质量的变化       | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 22 | 水体分布的分散程度的变化  | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |

## II-III. 了解改善社区绿地与开敞空间的方法的重要性

你在多大程度上同意从以下方面改善您社区或邻近城市绿地与开敞空间的自然要素和辅助设施非常必要 (D)? 李克特量表“1、2、3、4、5”分别对应“非常不同意、有点不同意、中立、有点同意、非常同意”。

### D 改善社区绿地与开敞空间的对策的重要性

- |    |             |                            |                            |                            |                            |                            |
|----|-------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| 23 | 发展新的绿地      | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 24 | 提高绿地植被丰度    | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 25 | 提高绿地分布的分散程度 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 26 | 发展或修复湿地     | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 27 | 改善水体质量      | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| 28 | 提高湿地分布的分散程度 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |

29	改善步行道网络	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
30	改善自行车道网络	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
31	增加运动锻炼的设施	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
32	增加孩童游乐场地	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**II-IV. 您对所在社区的自然景观-生态关系的看法**

你在多大程度上同意绿色开敞空间为居民提供以下自然和社会生态服务（E）？请在 1 到 5 的范围内指出你同意的程度，其中“1、2、3、4、5”分别对应“非常不同意、有点不同意、中立、有点同意、非常同意”。

<b>E 社区绿地与开敞空间生态系统服务的重要性</b>						
33	供应农业产品	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
34	改善空气质量	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
35	缓解城市热岛效应	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
36	降噪	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
37	调节水文	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
38	减少土壤侵蚀	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
39	降低城市暴雨洪水风险	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
40	生物多样性保护	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
41	有利于居民的日常休闲娱乐	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
42	有利于居民的身心健康	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
43	有利于社区安全	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
44	提高房地产的价值	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

请添加您认为与在本部分问卷相关的任何评论。

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### 第三部分:您对城市不透水面扩张及其社会生态影响的感知

本节重点关注您对城市不透水面扩张及其社会生态影响的感知。

#### III-I. 您对城市不透水面扩张的生态影响的认知

您在多大程度上同意城市 ISA 扩张会导致自然资源的严重损失和城市污染和脆弱性的显著增加 (F, G)。李克特量表的“1, 2, 3, 4, 5”分别对应于“非常不同意、有点不同意、中立、有点同意、非常同意”五级。

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<b>F 自然资源的损失</b>						
45	城市绿地流失	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3		
		<input type="checkbox"/> 4	<input type="checkbox"/> 5			
46	水体面积损失	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3		
		<input type="checkbox"/> 4	<input type="checkbox"/> 5			
47	优质农用地流失	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3		
		<input type="checkbox"/> 4	<input type="checkbox"/> 5			
48	生物多样性丧失	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3		
		<input type="checkbox"/> 4	<input type="checkbox"/> 5			

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<b>G 城市污染和脆弱性增加</b>						
49	空气污染增加	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
50	水污染增加	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
51	土壤污染增加	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
52	土壤侵蚀增加	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
53	温室气体排放增加(如 CO <sub>2</sub> 排放)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
54	城市噪音增加	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
55	城市暴雨洪涝风险增加	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

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#### III-II. 您对城市不透水面扩张的社会经济影响的认知

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您在多大程度上同意城市 ISA 扩张导致社会生态互动的显著减少和社会经济成本的显著增加 (H, I)。李克特量表的“1, 2, 3, 4, 5”分别对应于“非常不同意、有点不同意、中立、有点同意、非常同意”。

<b>H 社会和自然的关联</b>						
56	降低通往绿地的可达性	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
57	降低水体景观的可达性	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
58	降低访问绿地空间的频率	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
59	降低临水的频率	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
60	减少社会自然互动	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>I 社会经济成本</b>						
61	增加居住隔离	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
62	损失社会互动	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
63	增加工作和住所之间的通勤时间	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
64	增加交通堵塞	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
65	增加用水量	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
66	增加能源消耗	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
67	增加身心健康关注	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
68	增加犯罪治安关注	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
69	增加社区安全关注	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

### II-III. 您对改善社会-生态互动的举措的重要性的认知

您在多大程度上同意以下措施对促进人与自然的互动、减弱 ISA 扩张的负面生态效应非常重要 (J, K)?。李克特量表的“1, 2, 3, 4, 5”分别对应于“非常不同意、有点不同意、中立、有点同意、非常同意”。

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**J 改善社会-生态关系的举措的重要性**

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- |    |               |                          |                          |                          |                          |                          |
|----|---------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 70 | 改善公共交通系统      | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 71 | 改善访问公共空间的步行系统 | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 72 | 增加植被和水面的物理面积  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 73 | 提高植被和水面的破碎化程度 | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
- 

**K 保护城市绿地与开敞空间的举措的重要性**

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- |    |               |                          |                          |                          |                          |                          |
|----|---------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 74 | 城市不透水面扩张的红线控制 | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 75 | 城市森林公园保护与建设   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 76 | 城市河湖岸线蓝线控制    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 77 | 城市湿地恢复        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 78 | 优质耕地保护红线控制    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
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请添加您认为与在本部分问卷相关的任何评论。

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**IV. 访谈招募**

我们正在寻找参访者，讨论您所在社区的城市绿地或水面的发展。您的参与完全是自愿的，仅用于研究目的。如果您愿意参加，请在提供您的联系信息，或者直接通过邮件、电话、短信与我们联系。收到您的信息，我们会联系您预约访谈时间。谢谢！

## 访谈问卷

受访者：

访问者：

日期：

时间：

[感谢参与者同意接受访谈。解释调查的保密性并获得被调查人的口头同意。]

1. 你的社区附近有绿地吗？你经常去那里吗？
2. 你认为改善周边的自然空间和辅助设施必要吗？为什么？
3. 您如何评价社区绿色开敞空间对您日常放松和健康的重要性？
4. 你认为居民参与社区绿地开敞空间的维护与管理有必要吗？您对社区绿地开敞空间配置方面有何考虑？
5. 你觉得社区中的绿色开敞空间有哪些负面影响？你对改进有什么建议吗？
6. 您认为居民参与绿色开敞空间的配置和维护有必要吗？你愿意参与吗？为什么？
7. 自从您第一次搬到这里以来，您注意到绿地和水体有哪些变化？在您看来，这些变化是积极的还是消极的？
8. 您认为随着城市不透水面的扩张，社会与自然的互动是改善了还是降低了？从哪些方面？
9. 您认为城市绿地与水体的配置是否影响了居民的居住和日常休闲选择？这些影响具体体现在哪些方面？
10. 您认为社区居民参与城市开敞空间的规划是否有必要？当前社区居民在开敞空间配置方面关注的重点有哪些？
11. 您认为社区开敞空间配置对房地产价值和居民的居住选择产生哪些影响？
12. 您认为伴随着城市不透水面的扩张，政府应从哪些方面采取短期或长期政策保护城市自然资源？为什么？

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