

Issues with Spatial Scale in Urban Research

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Abstract: Scale is the range or measurement unit of the characteristics of natural or human ontology in the temporal or spatial dimension and is widely used in daily life and the study of various disciplines. Scale effect pertains to certain laws and characteristics that can only be reflected on a specific scale, so choosing the appropriate scale remains the basic premise of scientific research. The concept of the urban spatial system is complex and has the characteristics of scale dependence, and the selection of an appropriate spatial scale is important for the accurate estimation and description of urban issues. In this paper, we discuss spatial scale in urban research using cases that primarily come from the Chinese experience, provide some examples that demonstrate the importance of appropriate scale in urban research, including urban shrinkage, and highlight problems in spatial research. Ultimately, we suggest that scale consciousness should be the basic consciousness required in empirical research.

Keywords: scale; scale effect; spatial scale; urban research; shrinking city

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1 Introduction

The concept of scale is widely used in various disciplines and fields. Everything in existence has a specific spatiotemporal range and measurement standard. The description of temporal and spatial scales is indispensable for scientific research. The scale effect is a universal philosophical law, and the role of most things can be accurately expressed only when they are described on an appropriate spatiotemporal scale. Ignoring the scale background conditions or cataloging things under inappropriate scale conditions will lead to errors in the description process or the results of the study.

Geography is the study of the spatiotemporal distribution and variation in regularities of natural properties

and the relationships between people and their environments on Earth's surface (Johnston and Sidaway, 2016; Fu, 2017). Research in geography requires a rigorous description of spatiotemporal scales. Scale is one of the most important concepts in geography research (Clifford et al., 2009). It is easy, however, to misrepresent and draw false conclusions based on an incorrect perception of spatiotemporal scales in geography research. Scale issues have always been used as a background (Imhoff et al., 2010; Long and Wu, 2016; Shaban et al., 2020) or as conditions (Ichiba et al., 2018; Feng et al., 2020; Tu et al., 2021) in urban research. The discussion of scale as an individual study subject is based on geography (Sheppard and McMaster, 2004; Clifford et al., 2009) as well as its major branches, such as physical

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geography (Schulze, 2000; Li and Cai, 2005), human geography (Howitt, 2002; Wang and Liu, 2015), and geographic information science (Quattrochi and Goodchild, 1997; Lam, 2004). Specialized research that focuses on the scale issues of urban space is rare.

Cities have complex spatial systems and diverse definitions, and it is easy to erroneously conclude research results due to improper scale selection in urban studies. Attention to scale problems in urban research is thus crucial. In this paper, we first review the scale problems in several disciplines to determine the significance of scale, define the concept and division of spatial scale, emphasize the importance of appropriate scale in spatial research, and summarize scale-related problems that are prevalent in spatial research. We focus on the spatial scale effect in urban research and provide examples from China that demonstrate the importance of appropriate scale selection in urban research from the aspects of research extent (ratio) and research precision (resolution). We also discuss the use of scale transformation to solve the problem of selecting an appropriate scale and emphasize that scale consciousness is the basic consciousness required in urban empirical research.

2 Scale and Scale Effect

2.1 Scale

The concept of scale is widely used in daily life and the study of various disciplines. It is nearly impossible to find any discipline that has no relationship with scale (McMaster and Sheppard, 2004). Particular fields have different definitions of scale based on differences in their subject of research; however, they are all based on the dimensions of temporal scale, spatial scale, and spatiotemporal scale superimposed over each other (Li, 2005a). One example of this is the expression of grain and extent in landscape ecology (Wu, 2001). Grain is the characteristic length, area, and volume of the smallest identifiable unit in the landscape, and time grain refers to the frequency or time interval of a phenomenon or event. Extent denotes the spatial scope or time length of the subject. In the field of geography, scale is the unit of space or time used to study an object or phenomenon and refers to the extent or frequency of the space and time involved in a phenomenon or process. It is the window to observe objects, patterns, or processes

of things and can be a description of the relative size of the object in its ‘container’ (Qi and Wu, 1996; Su et al., 2001; McMaster and Sheppard, 2004; Li, 2005b). It is also the connection between the observer and actual objects, which are distributed over time and space and constructed by humans (Easterling and Polsky, 2004). Scale can denote one or more spatial hierarchies that represent, experience, and organize geographic events and processes (Johnston et al., 2000). In general, scale can be thought of as a range or a measurement unit of natural or human ontology in terms of temporal or spatial dimensions.

In natural science, the spatial scale can be as small as the size of quarks, atoms, neutrons, and other microstructures in quantum physics, the size of genomes in biology, or as large as the size of celestial bodies in astrophysics. The temporal scale can be as small as microseconds or as large as the time range of astronomical or geological periods. Scale spectrum refers to the range from micro-scale, measured in nanometers or nanoseconds, to macro-scale measured in light years or 10 000 yr. Geosciences, such as earth information science, geography, topography, and geophysics, treat the Earth as the subject of research wherein the scale is the geoscience scale—a small segment of the scale spectrum (Li, 2005). Scale is one of the core concepts of geography (Clifford et al., 2009), and the focus on scale issues has a long history in this discipline (Harvey, 1968; Stone, 1972). Scale is the essence of nearly all geographical issues (McMaster and Sheppard, 2004). It is one of the fundamental tools for geospatial analysis, a major feature of spatial data, and one of the main factors in spatial analysis and management (Peterson et al., 1998).

2.2 Scale effect

Scale effect is a limit of objective existence expressed by a scale and in many studies or daily expressions refers to scale dependence. The scale effect is the philosophical root of many theoretical paradoxes. Certain regular patterns or characteristics can only be reflected on a specific scale. Conclusions obtained using a certain scale apply only to that scale, and changing the analytical scale will lead to a different conclusion (Sheppard and McMaster, 2004). It is not possible to infinitely extend reasoning without considering scale conditions. The scale size of statistical samples has different

effects on mean, variance, coefficient of variation, *etc.* (Bolin and Wallin, 2019). The scale effect exists in the study of various disciplines in the temporal and spatial dimensions.

The temporal scale effect can be described in the following way. As the development of things is periodic and functions as a stage from quantitative change to qualitative change, the historical time node and evolutionary time process may affect the development of things. Blurring the time background may lead to an expression error when describing the states of things states. For example, in economics, a certain economic law makes sense in a particular historical period; in meteorology, weather and climate reflect contrasting temporal scale characteristics (Ziegler et al., 2004), and in biology, the network of species interactions is temporal scale-dependent (Schwarz et al., 2020).

The spatial scale effect manifests in the spatial matching between things and their carrier or service object. For example, explaining macro laws with results from micro experiments leads to misconceptions. All space-related disciplines are scale-dependent. For instance, in ecology, which deals with the diversity trends of different communities on different scales, biodiversity is spatial scale-dependent (Crawley and Harral, 2001; Chase et al., 2018). In physics, the macro-world and micro-world follow different laws, such as certainty in classical physics and uncertainty (probability) in quantum mechanics, which makes it difficult to hypothesize a unified theory. In economics, macroeconomics and microeconomics follow different laws. The economics of manufacturers, individuals, and households will help increase wealth, while the economics of a whole society will reduce social demand and affect production. In landscape ecology, the landscape pattern index (patch density, diversity, shape index, *etc.*) decreases as the scale increases. Some phenomena are unbalanced on smaller scales but show balance on a large scale (Wu, 2001). In landscape ecology research, the human-perceptible and recognizable scale is the most appropriate scale for research (Xiao, 1999). In soil science, the distribution characteristics of water salt can be revealed by using a certain sampling scale. In geophysics, the scale of the world map is the basis of Alfred Wegener's hypothesis of continental drift, which would be difficult to discover on a national or local scale. The scale effect is particularly important in geosciences. Geographical re-

search objects have spatiotemporal scale characteristics, and their properties of patterns and processes, spatiotemporal distribution, and mutual coupling are scale-dependent (Li, 2005).

3 Spatial Scale and Main Problems in Its Research

3.1 Division of spatial scale

Schulze (2000) divided the spatial scale into process scale, observation scale, and operational scale. Process scale refers to the scale of natural phenomena. Due to the overlap of process and scale, there is no constraint of time and space, and the scale is not fixed but rather changes with the process. The process scale includes intermittent processes, periodic processes, stochastic processes, spatial extent, space period, correlation space, *etc.* Observation scales are samples or research phenomena that depend on logical objects, technical levels, and cognitive altitudes. Observation scales are not easy to alter and include resolution and grain. Frequently, the observation scale and the process scale do not match up. The observation scale should be based on the process scale and have a wide range, high precision, and tiny grids, but this can be difficult to implement. Operational scale refers to the scale that focuses on management and operation and often does not coincide with the process scale because it is not centered on natural science but on the convenience and functionality of management, such as the scope of administrative regions.

Lam and Quattrochi (1992) and Lam proposed four types of spatial scales based on remote sensing and Geographic Information System (GIS) (Fig. 1). This division can be applied to physical and human geography research. Measurement scale refers to spatial resolution, which is the smallest discernible part of an image, such as pixels in remote sensing images and grids in ecology. Zooming in or out of the resolution or range of data may make things that originally appeared heterogeneous seem uniform (Wiegand and Bröning, 1996). Operational scale refers to the spatial range in which natural phenomena occur. It is the logical scale of the occurrence of geographical processes and takes up hundreds of pixels ranging from a few meters to 100 m. Operational scale is linked to action that takes place during natural, political, or social processes, such as mountainous tectonic processes, that often require a larger scale than the pro-

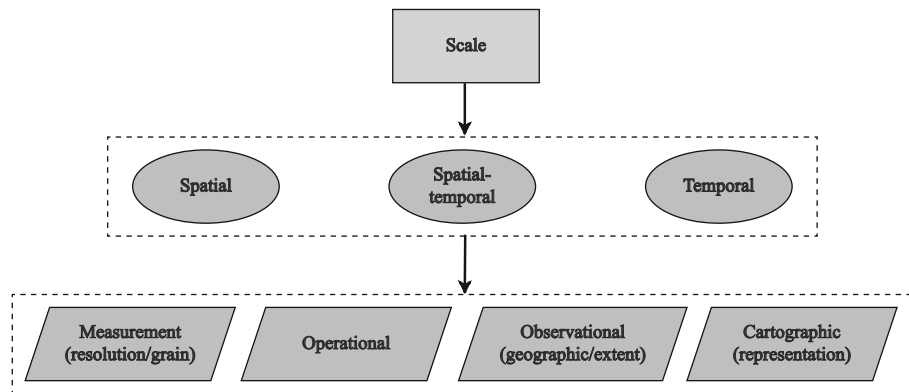


Fig. 1 Division of spatial scales (Lam, 2004)

cesses produced by river pits. Determining the operational scale is essential to assessing the changing characteristics of the study area and accurate discovery of the intrinsic nature of geographical phenomena. Observational or geographic scale refers to the spatial extent of the study area, such as global climate change on earth, while the scale of the urban heat island effect is the city. Large and small scales are relative. Cartographic or map scale refers to the ratio between map measurement and actual measurement. A large-scale map depicts small areas with more prominent details, while the opposite occurs on a small-scale map. Not all disciplines pay attention to scale when mapping (e.g., DNA mapping), but scale is important in geography, especially in cartography.

Li (2005) categorized scales into intrinsic and non-intrinsic scales. The intrinsic scale refers to the natural scale, which exists in an entity, unit, pattern, or process. Different classification units or natural entities can be classified under different spatial scales, such as temporal scale, organizational scale, and functional scale, which can be summed up as the intrinsic scale. The non-intrinsic scale is an artificial scale that does not exist in nature, such as the research (observation) scale and the operational scale. The research scale includes the extent of the object's scope and space, such as extent, the smallest distinguishable part of the data set (namely resolution), and the characteristic length, area, and volume of the smallest identifiable unit (namely grain). The operational scale refers to administrative or non-administrative units such as watersheds.

Compared with the scale dependence of phenomena and processes that are of concern in physical geography, in human geography, the focus is on the social construction of scale (McMaster and Sheppard, 2004). Howitt

(2002) divided scale into three dimensions: scale as size, scale as level, and scale as a relationship. Scale as size refers to the spatial scope and structure, which is measured objectively by scale (ratio). Scale as level refers to the hierarchical ranking of space in different spatial categories, such as in urban geography, where it is divided into global, national, regional, and local levels. Scale as a relation is the relationship between scales, which is used to analyze the interaction of rights in political economy. Wang et al. (2015) emphasized the description of relationships by scale, which can be understood as a secondary abstraction of geographic feature dimensions (local, network, territorial). In other words, scales are always used to describe the structure or the relationship between two objects on a particular dimension (or attribute). For example, territory mainly involves covering the area, combination form, and power hierarchy as well as other attributes. Accordingly, scales include size relationships, nested structures, hierarchical altitudes, and other scale structures/relationships between territories.

Although there are naming conflicts and different emphases in the above divisions of spatial scale, these divisions share division standards and are interoperable. Based on the understanding and summary of the above scale divisions, we created a spatial scale type interpretation diagram, as shown in Fig. 2. In general, spatial scales can be understood from five perspectives: 'process scale/operational scale, geographic scale/observational scale, management scale, measure scale, and cartographic scale/map scale'. Of these five scales, only the 'process scale' is the intrinsic scale that occurs in nature (distinguished by the circle in the figure), and the others are human-perceived, non-intrinsic scales (distinguished by quares in the figure). We can review the interpretation and analysis aspects separately. In the inter-

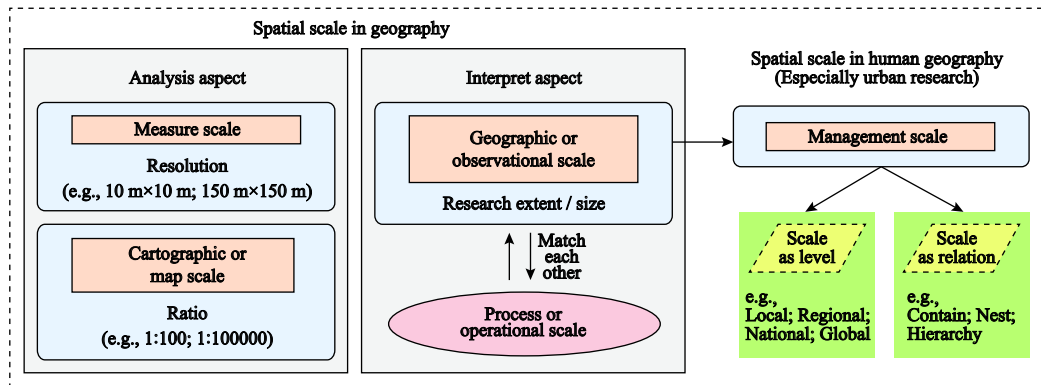


Fig. 2 Type interpretation of the spatial scale

pretation aspect, the researchers study the relationship between the logical scales, which center on the processes of natural or human phenomena (i.e., the process scale) and the human observation, definition, and interpretation of natural or human phenomena (i.e., observational scale, the spatial extent of the study area). Matching them is the key objective of this type of research (Fu, 2014). In the analysis aspect, considering the requirements of geography research for map drawing, the minimum spatial units (resolution) of study scale, and the actual matching rules (ratio) of maps become two important aspects of the geospatial scale expression, respectively expressed as *measure scale* and *map scale*. In human geography research, especially in urban studies, there is a special extension of the operational scale. That is, Schulze (2000) refers to the working scale concerned with management and operation (e.g., administrative divisions) as the *management scale* in order to distinguish it in this article. As is the case in human geography, urban research can treat scale as levels in order to build a study system from the perspective of management scale, such as multi-scale research that examines local, regional, national and global levels (or cities, metropolitan areas, urban agglomerations, provinces /states, countries, global, etc.). These scales can also be arranged in contain, nest, hierarchy and other relationships. The hierarchical division and relationship analysis of scale in human geography can be regarded as a process of in-depth analysis of scale research. A diagram explaining the spatial scale types mentioned above is shown below.

3.2 Scaling and appropriate scale

Choosing the appropriate scale is the basis of most studies. A finer scale is not necessarily the best. Human geo-

graphy research focuses on the research framework of multi-spatial scales, such as global, national, regional and local scales (Herod, 2003). We can uncover the objective laws expressed in the spatial distribution of various geographical objects or phenomena by studying spatial problems with appropriate scales. Scaling is the process of connecting time and space at different coordinates (De Coursey, 1996). Upscaling (expansion) and downscaling (shrinking) are used to solve the problem of scale mismatch in different scaling directions.

Upscaling is the process of extrapolating the results of observations and simulations from fine microscales to larger scales, while downscaling is the process of inferring the results of observations from larger scales to microscales (Li, 2018). Scaling in research requires an array of techniques and algorithms to solve problems. Methods for upscaling include the wavelet representation (Mallat et al., 1989), the Nyquist aperture (Lee et al., 2011), the empirical mode decomposition (EMD) (Chen et al., 2009), and the aggregation effect (Tan et al., 2018). Downscaling based on the resampling theory uses methods such as the fractal interpolation method (Kim and Barros, 2002), kriging (Wang et al., 2015), and high or low-resolution mapping (Wu and Li, 2009), amongst others. In recent years, machine learning methods of scaling have become popular (Agrawal, 2018). Researchers should choose appropriate scaling method based on their research requirements to avoid incorrect conclusions.

3.3 Key questions and common problems in spatial scale research

In the scientific research on scale, many questions still need to be solved. Scholars have identified core questions that pose a challenge in the study of geographical

scales. For instance, Goodchild (1997) raised five key questions about scales:

(1) Invariants of scale: which scale measurement is the invariant characteristic of geographic detail in data and can be preserved in routine manipulations (e.g., from analog to digital conversion, or coordinate transformation), and what geographical characteristics are scale-invariant?

(2) The ability to change the scale: what types of scale transformations can be used to aggregate or fragment geographic data in a logical, rigorous, and theoretically solid manner. Is it possible to develop a common method for disaggregating the coarse-grained data and the aggregating fine-grained data in a way that is consistent with how people understand the processes of the Earth's systems?

(3) Measure of the impact of scale: is it possible to implement methods to assess the impact of change? How is the observation of processes affected by scale changes? How do we measure the performance of processes on different scales?

(4) Scale as a parameter in process models: how is the scale represented in the parametric process model, and how is the influence of scale parameters on the model evaluated?

(5) The implementation of multi-scale approaches: what is the potential for integrated tools to support multiscale databases and related modeling and analysis? Can tools provide a compatible framework for multiscale data? What problems must be overcome when integrating data into different scales?

Li and Cai (2005) also put forward 10 challenging questions that should be solved by geo-scale research: 1) How does spatial heterogeneity change with scaling? 2) How do the rate variables change with scale in-process research? 3) How does the advantage or lead process vary with scale? 4) How do process properties change with scale? 5) What are the sensitivity changes with scale? 6) How does predictability change with scale? 7) What are the conditions for simple aggregation and disaggregation in scaling? 8) How is the scale effect of interference factors expressed? 9) Can the scale conversion span multiple scales or scale domains? 10) Can noise composition change with scale.

On the basis of the questions outlined above, other scholars found that in the study of geography, the definition of scale, the choice of scale, and the transforma-

tion of scale are prone to some ambiguity and one-sided understanding. They then summarized the common problems that emerge in scale research as follows. Li et al. (2018) compared the key questions raised by Goodchild and identified the scale problems that still exist today: 1) The understanding of scale and the properties of scale problems are still not comprehensive; 2) Although the scale effect has been well studied in past research—primarily data scale—the combined research of various scales (such as data scale and analytical scale) is still poor, and the lack of systematic research on the change in the amount of information caused by scale transformation needs to be given more attention; 3) There are many scaling models available, but taking the scale as an explicit parameter in the model is still insufficient, and the theoretical basis of some methods are not perfect; 4) There are various multi-scale analytical methods, but many of them still lack a theoretical basis. Li and Cai (2005) stated that the common scale problems in geographical research include the following:

(1) The improper choice of scale leads to incorrect evaluation of the scientific nature of the research object. If the research scale is too large, several details will be omitted, and the study will become a 'biased estimate'. If the research scale is too small, the study will focus on a local feature without seeing characteristics as a whole.

(2) Blindly carrying out scaling leads to the subjective presumption of cross-scale research results or arbitrary scaling of research results regardless of the condition limit.

(3) With respect to the improper use of scaling technology, the applied conceptual model, the mechanism model, and the statistical model fail to adopt different appropriate strategies when scaling but casually apply some kind of regression technology.

(4) Ignoring the scale on which the results are produced or effective.

(5) Using many types of scales and making it more difficult to integrate results.

4 Spatial Scales in Urban Research

4.1 Types of spatial scales in urban research

In the field of geography, it is believed that the scale size of the research area is relative and that the scale is classified according to the scope of the study area. McMaster and Sheppard (2004) divided the human geospa-

tial scale into the levels of the human body, household, neighborhood, city, metropolitan area, province/state, nation-state, continent, globe, *etc.* According to Sexton et al. (2002), the spatial scale of human geography in the context of environmental health and policy research is divided into personal exposure, city block/factory, city, state, country/continent, and earth. Herod (2003) described the complex relationship between the four scales of the globe, nation, region, and local, including scale as a ladder, scale as concentric circles, scale as matryoshka (nesting) dolls, scale as earthworm burrows, and scale as roots.

Urban geography or urban development research is an important branch of human geography. In recent years, the relevant research has paid more attention to the urbanization development driving mechanism and basic regularity, spatial pattern differences, the coupling relationship of urbanization development and resource environment, urbanization development scenario simulation, and risk warning under multi-scales, such as the global-national-regional framework (Lu et al., 2020). The research object of urban geography is a complex urban system, which is a diverse concept but can be summarized into the physical area, administrative area, and functional area.

Physical area refers to the distribution range of the urban landscape with non-agricultural land and non-agricultural activities as the main body, which agglomerates urban facilities and is different from rural areas. Physical area is the built-up area and built-up environment of the city. In China, the physical area coincides with the statistical urban area and is referred to as the actual urban construction of the municipal and district government residences. In the United States, the physical area is called the urbanized area.

The urban administrative area is the jurisdiction of a city defined according to administrative divisions. In China, this includes the urban district, city-region (municipal), and so on. The urban district refers to the administrative part of the urban area with the exclusion of the administrative counties and is generally slightly larger than the urban physical area (as shown in Fig. 3a, the scope of general urban district areas in China is often slightly larger than that of urban entities). The city-region refers to the whole city inclusive of all administrative areas. It encompasses urban districts and surrounding counties or county-level cities, which are actually a mix of urban entities and rural areas. In western countries, the administrative area is called the city proper. Due to the expansion that occurs during the process of urban development and the unadjusted administrative region, in western countries, the administrative area is often smaller than the urban physical area (as shown in Fig. 3b).

Urban functional area refers to the area in which the city and its surrounding marginal groups have close economic and social ties. The urban functional area is the daily life circle and commuting area of city residents, which is the area of urban functional integration. As shown in Fig. 3a, in China, the urban functional areas often encompass urban districts, including urban physical areas, and towns of counties that are closely connected with the urban districts, which are bonded due to the intimate functional relationship of residence, work, shopping, medical treatment, and recreation. As shown in Fig. 3b, in the west, the urban functional area is often similar to the concept of the metropolitan area. It is commonly used as an urban regional concept and a statistical concept with more emphasis on coordination organizations. The infrastructures of urban sectors and

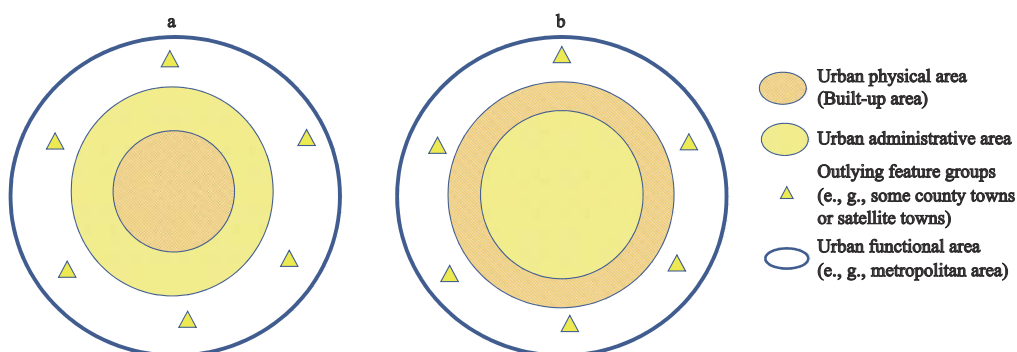


Fig. 3 A schematic diagram of the urban area system

counties in the metropolitan area are planned and constructed in coordination. The metropolitan area often includes the central city and the outlying counties or satellite towns that are closely connected with it and fulfill standards linked to the non-agricultural level, the numbers of non-agricultural labor sources, and commuting connections.

4.2 Scale effects in urban studies

As a space discipline, the characteristics of research phenomena and research objects in urban studies require suitable space, have scale dependency, and conform to the scale effect. To describe urban phenomena and conduct urban research, we need to choose the appropriate spatial scale to collect scientific research results and explanations. For spatial scale division, the mechanism of selecting the appropriate urban research spatial scale is the mechanism that effectively matches the process or the operational scale of natural or social phenomena in urban research and the geographic or observational scale understood in urban research. It requires the selection of the appropriate resolution and ratio and the selection of appropriate measurement scale and cartographic scale for research because these factors are linked to research precision and research extent, respectively. Researchers have long understood that the choice of ratio and resolution affects the empirical analysis results of human geography studies (McMaster and Sheppard, 2004). The scale effect in urban research is reflected in the selection of the correct ratio (study extent) and resolution (study fineness).

We have described the scale effect of urban research using two characteristics: ratio and resolution. In chapter 4.2.1–4.2.4, using aspects such as urbanization and urban law, the spatial scale extent of daily life circle, the relationship between urban problems and urban scale, and the appropriate spatial scale choice in shrinking urban research, we provide examples that show why choosing the correct research area (ratio) for urban research is important. We also explain how the choice of grain (resolution) of urban research affects the results of urban research in chapter 4.2.5.

4.2.1 Urbanization and the laws of the urban system

Urbanization and urban system law are used to summarize and reveal the spatial characteristics on a larger regional scale. If it is blindly applied to urban units, such as the scale of the city-region, it may not be applicable.

The law of urbanization ‘S’ type curve proposed by Northam (1979) that there are three stages in the urbanization process. The primary stage of urbanization rate is about 25%, and during this period, agriculture accounts for a large proportion of the national economy and the dispersed distribution of the agricultural population, whereas the urban population only accounts for a very small proportion. In the next stage, there is accelerated urbanization, with the rate varying from 25% to 50% and even going up to 70%, wherein the growth rate of the secondary and tertiary industries exceeds agriculture and sustained rapid growth occurs. Lastly, in the mature stage, the urban population proportion reaches 70%–80% and gradually declines. The urbanization S-curve is cited widely to prove the evolution of urbanization over decades, hundreds of years, or longer periods within the large-scale of countries or regions (Zhao and Zhang, 1995; Treivish et al., 1999; Antrop, 2000; Pannell, 2002; Meng, 2004; Li and Tong, 2007; Chen et al., 2011; Niu, 2017). While the urban development process within a city-region is dependent on political, economic, and transportation development as well as historical environment, natural conditions, war, natural disasters, and other factors, the trends of urbanization development are different, as it is difficult to find a growth law applicable to each city that matches the S-curve.

Another example is the urban ‘rank-size rule’, which reveals the distribution law of the urban system and refers to the relationship between urban size and urban rank by size (Batty, 2006). It was first discovered by Auerbach in 1913 while he was studying the city population data of five European and American countries (Soo, 2005). Later, Zipf (1949) stated that the rank and size of cities maintained a stable relationship while obeying the power-law distribution in the integrated urban system. The rank-size rule is mostly used in the study of large-scale urban systems, such as in national, regional, and urban agglomerations (Lanmandjèkpogni et al., 2019; Wei et al., 2019; Shaban et al., 2020; Bajracharya and Sultana, 2020; Han et al., 2020), and is not suitable for the urban-town systems in city-regions. Within a municipal area, the population is agglomerated in the urban center district, and the population of townships is small and scattered and cannot follow the ‘rank-size rule’ model. Fig. 4 shows the rank-size rule comparison chart of the city-county system in Liaoning

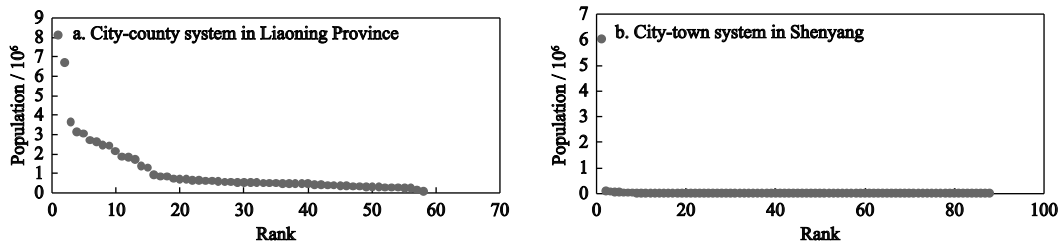


Fig. 4 The rank-size charts of different scales based on the sixth national population census data of China. a) City-county system in Liaoning Province; b) City-town system in Shenyang

Province, China and the city-town system in Shenyang, China based on census data. As depicted in the figure, the counties and cities in Liaoning Province are in line with the rank-size rule, but this does not apply to the Shenyang City region.

4.2.2 Spatial scale of daily life circles

Life circle is a geospatial concept of the daily life extent of people and includes the commuting distance and service radius. It delineates a certain range of circles as a boundary and has a spatiotemporal scale and circle spatial characteristics (Zhao et al., 2019). With the development of science and technology and changes in the mode of transportation, the spatial scale of the human daily life circle has expanded. At the same time, the scale of the city is also expanding, affected by the evolution of transportation modes.

In ancient times, people usually traveled on foot or used horse-drawn carriages. The average walking speed is about 4 km/h, and horses run at an average speed of 20 km/h. Considering the poor road conditions during this period, the speed of a horse-drawn carriage was generally about 5 to 10 km/h, which is slightly faster than walking. For half an hour traveling distance, by walking and a horse-drawn carriage, a person can cover

between 12.6 km² to 78.5 km². From the 1850s to the early 1900s, the emergence of railways, trams, and underground railways expanded the size of human life circles, and the suburbs near the urban centers of western cities were gradually built and expanded. The popularity of automobiles has greatly increased the scope of the human life circle as well. During the expansion of cities in the railway era, suburban development was limited to the range of railway stations and walking distance, but the automobile era changed this limit, and the urban scope spread further (Mumford, 1961). The average speed of an automobile is generally 40 km/h. Therefore, the half an hour life circle covered a maximum of approximately 1256 km² in the automobile era.

The evolution of the built-up area of Xi'an, China can be used as an example (Fig. 5). During the golden age of the Tang dynasty (618 CE–907 CE), Xi'an was the capital. In ancient times, it was known as Chang'an, and it welcomed people from all over the world with its inclusive culture. The city had a built-up area of 84 km² and served a brilliant example in the development history of cities. Due to the impact of the war, Xi'an or Chang'an lost its status as the capital, and its built-up area fell sharply to 5.2 km² in the late Tang dynasty.

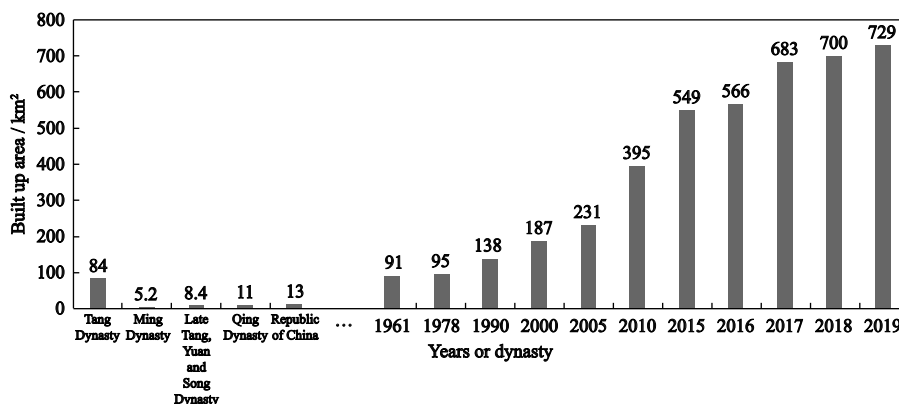


Fig. 5 Historical evolution of the scale of the built-up area in Xi'an City. In this figure, data after 1978 from Xi'an Bureau of Statistics, data before 1978 from literature (Zhao, 1998)

There was little change in the built-up area during the Yuan and Song dynasties, and it gradually increased to 8.4 km² in the Ming dynasty. In the era of horse-drawn carriages and walking, Xi'an's scale maintained the daily life circle scale based on the distance covered by these modes of transportation. In the modern era, during the period of the late Qing dynasty and the Republic of China, with the development of technology, the opening of railways, the 'alternate capital' development plan of the Republic of China government, and other economic and political factors, the scale of Xi'an increased to 13 km². The scale of Xi'an further expanded after the founding of the People's Republic of China and reached 91 km² in 1961. In the past 40 yr, especially in the last decade, the scale of Xi'an has rapidly expanded, and the built-up area reached 729 km² in 2019. This is the half-hour range that automobiles can cover. Thus, the scale of the human life circle has gradually grown larger with the development of traffic.

4.2.3 *Big city problems and spatial scales*

Many urban problems only occur in cities with enough scale and are unique to big cities. The same problems may not be obvious or require a different solution in small cities.

For example, the problem of urban heat islands is only evident in big cities. The urban heat island effect is the phenomenon in which the urban temperatures are significantly higher than the surrounding suburbs or villages. It is caused by urbanization, where natural surfaces are replaced by impermeable surfaces, such as asphalt, cement, and metals, which increase anthropogenic heat emissions (Oke, 1982). Most of the studies on urban heat islands have been conducted in large cities. For example, Hung et al. (2006) studied the urban heat island effect in 18 mega Asian cities; Imhoff et al. (2010) studied the urban heat island effect in 38 of the most populated urban areas in the continental United States; Peng et al. (2012) studied the urban heat island effect in 419 global big cities; Zhou et al. (2014) studied the heat island effect in 32 major cities in China; and Li et al. (2021) studied it in 84 cities with a population of over a million. The urban heat island effect in large cities is stronger and larger than that it is in smaller cities (Dong et al., 2011). Many studies have proved that urban green land can help cool down the urban heat island effect, but the cooling range does not change linearly with the area of green patches. The larger the area

of green patches, the more obvious the cooling effect. The cooling effect depends on the area, spatial form, shape complexity, landscape composition, landscape configuration, and vegetation growth conditions of the urban green space (Yu et al., 2019; Ke et al., 2021).

Urban problems, such as haze, traffic congestion, and urban flooding, are more pronounced in big cities than in smaller cities. For example, if we consider urban flooding, the different settlement scales lead to different drainage modes. In the village, sewage is discharged directly into the soil, which penetrates the soil and is purified by the self-purification function of the soil. Small cities and towns can achieve a certain degree of separation of rainwater and sewage when the sewage is collected for centralized treatment and the rainwater flows directly into the water body. When the impermeable road surface in large urban areas is larger, the urban drainage system is more complex, the pressure is greater on the system, and storms may lead to serious flooding. On July 21st 2012, a torrential rainstorm in Beijing triggered a severe flooding disaster, resulting in 79 deaths and the collapse of 10 660 houses, which affected 1.602 million people and led to an economic loss of RMB 11.64 billion. More attention thus needs to be paid to big city problems with investment in scientific research and management as well as governance efforts. In response to urban flooding, big cities must pay more attention to rainwater utilization and construction of drainage network systems, improve the standard of rainwater harvesting, and stress developing sponge cities.

Compared with smaller cities, large cities are more vulnerable to problems and disasters, such as industrial accidents, extreme weather, terrorist attacks, and epidemics. On one hand, large cities are densely populated with high building volume and rich economic and social resources, which make them vulnerable to attacks. Once attacked, they are more likely to incur larger losses than smaller cities, as was the case in the 911 attack in the United States. On the other hand, in a large city, there is a floating population, a large and complex transportation system, complex social relationships, and faster information/material exchange. When there is a disaster, it spreads rapidly through the city's internal system network. The disaster thus spreads in a shorter time and cumulatively forms a larger disaster. For example, infectious diseases in large cities spread and cause more serious harm due to the extensive move-

ment of people and rapid traffic flow. Because of the potential impact of these issues, it would be improper to analyze the city's problems while ignoring the scale background of the city.

At the operational level of urban planning, small and medium-sized cities need to determine the direction of space development. As long as there are no natural obstacles and administrative restrictions, any direction may become the development direction of big cities. Some big cities develop on the principle of 'expansion' or 'control' of the space strategy and spread in all four cardinal directions (north, south, east, and west), while some cities adopt the 'industry in the north, central business district, and homes in the south' minimalist space layout strategy. The root cause of this type of development is the impact of small urban thinking. Also related to the city scale, the urban planning structure should have a multi-centric approach for large cities and a single-centric approach for small cities. If big cities continue to follow the single-center approach with the construction of multi-circle ring-main roads, they are bound to decrease the optimization of the urban structure.

4.2.4 Scale effect and shrinking cities study

Research on shrinking cities stems from problems related to loss of urban population and urban decline (Häußermann et al., 1988), which are characterized by three criteria: urban population decline or loss, economic recession (including industrial decline, unemployment, population aging, etc.), and fading of the urban landscape (e.g., declining urban space quality, abandonment of houses, etc.) (Wu and Qi, 2021). Among them, the decrease of the urban resident population is the most significant cause of shrinking cities according to most scholars (Delken, 2008; Schilling and Logan, 2008; Hollander and Németh, 2011).

Shrinking cities face numerous problems, such as idle public spaces and facilities that result from population

loss, lack of economic and social vitality, and depreciation of personal and family assets. These issues lead to financial difficulties for the urban government and governance crises. The urban landscape becomes dilapidated due to adverse maintenance, which leads to new social problems. These problems are a global characteristic of specific entity city, so that the study of shrinking cities must also attach great importance to the scale problems.

Martinez-Fernandez et al. (2012) summarized the scale of shrinking cities into several scales, including the whole city, a part of the city, the metropolitan area, and the town. Numerous scales of shrinking urban concerns have been proposed in past studies, such as street and township scales (Li et al., 2015), county scales (Zhou et al., 2017; Guan et al., 2021), and the city-scale (Long and Wu, 2016; Haase et al., 2021).

In the study of urban shrinkage, it is important to define the scale background of the research problem. Otherwise, it is easy to produce errors, such as generalization or a mismatch. As shown in Fig. 6, in terms of the shrinking of the street scale, the number of people in the streets of the old town decreased due to older living facilities, the migration of the industrial sector, and the reduction of employment opportunities, among other issues, resulting in the decline of some streets. However, this does not necessarily represent the shrinkage or decline of the entire city. The other streets of the city may continue to develop and attract people. Issues such as idle facilities, lack of vitality, asset depreciation, governance crisis, and landscape dilapidation do not affect all areas of the city, so the city as a whole is not shrinking. Due to the establishment of district-level government within big cities, urban local growth or decline may impact the financial situation at the district level, affecting the construction and maintenance of facilities in that part of the urban area. However, most of these

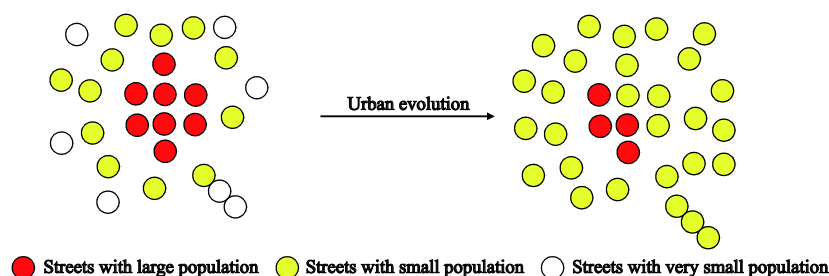


Fig. 6 Street scale shrinkage does not represent whole city shrinkage

characteristics of shrinking cities are not obvious.

Population decline in one urban district does not necessarily affect the population growth trend of the entire city. The shrinkage of individual municipal districts may lead to a change in the internal structure of the city, but the population of the entire city may still grow. For county-level cities, there may be an outflow of rural population from townships in the county region, but the county center population increases. In these cases, the entire county (county-level city) population may increase or decrease. Urban areas (built-up areas), urban districts, and urban functional areas can be the appropriate scale for shrinking urban research, but the city region, including the urban center and surrounding counties, is a broad 'region' concept that is not suitable when the research object is shrinking cities.

4.2.5 Influence of resolution on scale effect in urban research

In urban research, it is important to choose the appropriate resolution, as it is a reflection of the scale effect. With appropriate resolution (measure scale), research objects such as urban roads and land cover can be expressed, and the actual problem can be solved (Ichiba et al., 2018).

The study of urban scale effect based on resolution selection can be observed in research on urban roads, land use, urban function, urban resilience, etc. (Ichiba et al., 2018; Feng et al., 2020; Tu et al., 2021). For example, remote sensing data reflects the different urban functional characteristics at different spatial scales (Tu et al., 2021). The smaller the grid, the more it shows the physical characteristics of the land type of the city. With an increase in the size of the grid, urban functions, such as residential, commercial services, industrial, and other urban land use attributes, are shown. If the grid is too large, however, the functional features can not be distinguished, which may lead to a mixed expression of functions and a failure to display the functional classification of urban land use. In urban spatial measurement, the same index may have different measurement results at different parameters. By selecting the appropriate resolution, the pattern and characteristics of urban problems can be clearly described.

4.3 Scaling in urban studies

In urban research, the choice of appropriate scale is the key to evaluating the research problem accurately. The

selection of appropriate scale for urban research can be achieved with upscaling and downscaling. In Fig. 7 and Fig. 8, Shenyang, China is used as an example to describe several possibilities of scaling in urban research.

In urban research, upscaling is used to aggregate smaller urban space research units into larger ones. The upscaling of street scales is completed for the aggregation of the data of street scale into the urban entity. As shown in Fig. 7a, there are about 94 streets in the central urban area of Shenyang. The street data is aggregated to form the core of the central urban area of Shenyang, which coincides with the spatial built-up area. Although there is not an enough conclusion about the shrinking or

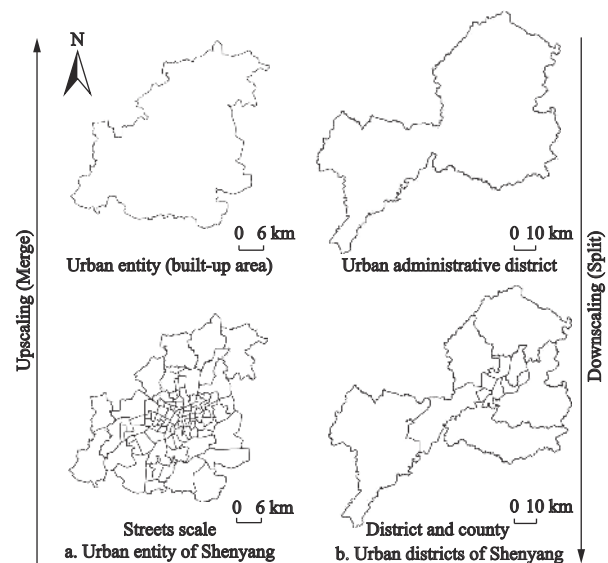


Fig. 7 Scaling in urban studies of Shenyang, China

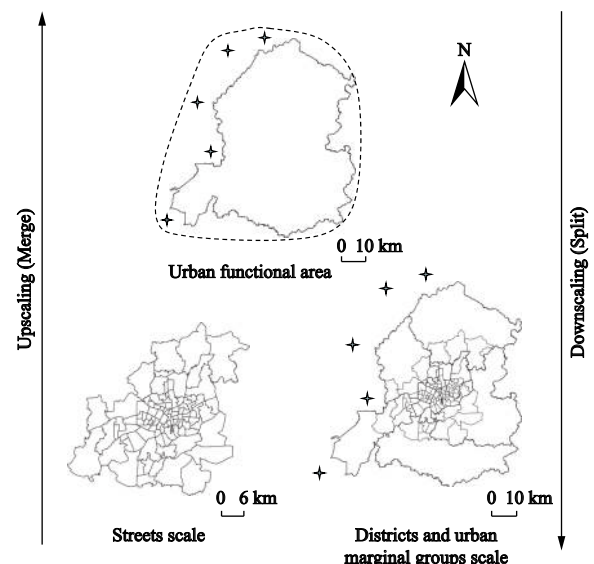


Fig. 8 Mixed scaling in urban studies of Shenyang, China

growth of a city at the street scale, it is possible to accurately judge whether a city is growing or shrinking by aggregating scattered and messy street data into the data of the central urban area. The upscaling of district and county scale is embodied in the merging of municipal districts into the whole urban district. As shown in Fig.7b, there are 10 districts in Shenyang, and the combination of municipal districts can form the entire urban district of the city. In urban research, downscaling is the opposite of upscaling. For example, problems that cannot be studied on the urban scale can be studied at the street scale. When the urban scale is too large to clarify the internal differences, it can be downscaled to the district/county scale for research. To study the situation of urban clusters, downscaling of the district-county scale to the urban marginal group's scale should be completed.

The scale transformation in urban research can be realized through the conversion of mixed scale in addition to the realization of upscaling and downscaling through the aggregation and splitting of a single scale. For example, mixed upscaling occurs in the comprehensive upscaling of street, district, and county scales and marginal group scale to the scale of the urban functional area (metropolitan area). Some counties and districts under the jurisdiction of Shenyang are far from the central urban area, and they have not formed a strong functional connection to the central urban area. Even though some townships within the districts and counties that are adjacent to the central urban area are not directly connected to the built environment, they are linked to the urban area by transportation and therefore form an integral part of the urban area in function (Fig. 8). The urban district and the surrounding townships of districts and counties can be divided into a general scale of the urban functional area of Shenyang.

5 Discussion and Conclusions

As the range and measurement unit of natural or human ontology characteristics in the temporal or spatial dimension, the concept of scale is widely used in various disciplines. Scales are important for the expression of anything that exists in time and space. The scale effect is reflected in both time and space, and can be manifested in scale dependence, in research. Geographical research also has scale dependence. Since the core of geo-

graphical research is the issue with space, it is important to choose the appropriate spatial scale and treat scale effect with caution. In geographical research, it is necessary to find the intrinsic process scale of geographical phenomena and match it with the geographical observation scale.

Choosing the appropriate scale is the key to research. Scale conversion using upscaling and downscaling is an effective method to choose the appropriate scale. In scientific research, common scale problems include improper scale selection, blind scale conversion, improper use of scaling technology, disregard for the results of the study of scale, the use of different scales which increase the difficulty of integration, and so on. Scale consciousness should become the basic consciousness in carrying out empirical research.

Urban research development is based on spatial scale and is scale-dependent. The macro law of large scale is not suitable for micro-small-scale studies. Problems encountered in big cities do not necessarily occur in small cities. Changes in the metrics at the street- and county-scale do not represent the functional changes across the entire city.

In many urban empirical studies from the past to present, neglecting of scale problems or conducting research in inappropriate scale contexts often occurs. It is easy to draw wrong conclusions, make misjudgments, and even push them into practical applications to make bad decisions. For example, in the study of shrinking cities, there is a common error that discussing the phenomenon of the shrinkage of only a street, an administrative district, or a county, but ignoring the fact that the population of the whole city or central urban area increases, thus forming the city is a 'shrink city' misjudgment. As another example, when some big city problems or planning techniques are directly used in small city research or planning, it may result in the waste of resources that do not match the actual development needs of small cities. It is important to judiciously use upscaling, downscaling, and other scaling methods, in choosing the appropriate scale for urban research for the accurate assessment and correct description of urban research.

In this study, based on combing through the concepts, divisions, key questions, and common problems of scale in geography, we focus on the scale in urban research, illustrate that the spatial scale is an indispensable prob-

lem in urban research through a series of examples, interpret some common scale fallacies in urban studies, and emphasize that it is necessary prerequisite to determine a reasonable scale background and establish scale consciousness in the study. The research results not only play a positive role in suggesting the importance of scale consciousness in urban research but also provide a lot of valuable references on choosing appropriate scales in the field of urban research.

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