

Article

Spatial Coupling Characteristics and Driving Mechanisms of Population–Land–Housing Based on Multi-Source Data: A Case Study of Guangzhou, China

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Abstract

Against the backdrop of the transition of new-type urbanization towards high-quality development, the triple contradictions of population agglomeration, land constraints, and housing supply-demand imbalance have become increasingly prominent. The conventional binary framework of human–land relations can no longer meet the requirements of coordinated development within human settlement systems, creating an urgent need to examine the multi-system interactions among population, land, and housing in order to resolve spatial mismatch. Taking Guangzhou as a case study, this research integrates 2020 population census data, land-use data from the European Space Agency (ESA), housing-price data from the Anjuke platform, and multi-source data on related influencing factors, and conducts a systematic empirical analysis by combining coupling coordination analysis, a relative development model, and the geographical detector. The findings reveal that the coupling coordination level of population, land and housing in Guangzhou exhibits a concentric, ring-shaped distribution pattern with central agglomeration and peripheral decline. The relative development among the three systems can be classified into matching types including the core-differentiated type, the peripheral-imbalanced type, and the surrounding-equilibrium type. With respect to influencing factors, all pairwise interactions are of the bi-factor enhancement type, and the driving mechanism displays a three-stage dynamic evolution. This study enriches research on human–land relations, provides precise guidance for optimizing spatial allocation and alleviating housing mismatch conflicts in Guangzhou, and offers transferable practical experience for comparable cities in China seeking to advance the high-quality development of new-type urbanization.

Keywords: new-type urbanization; spatial mismatch; coupling coordination; driving mechanism; Guangzhou



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1. Introduction

1.1. Theoretical Foundations

Grounded in the context of new-type urbanization and high-quality development, this study draws on three core theoretical frameworks: human–land areal system theory, coupling coordination theory, and spatial mismatch theory, and incorporates housing as an independent subsystem into the urban human settlement system analytical framework. By integrating domestic and international scholarship on housing market evolution, land

spatial governance, and urban spatial structure differentiation, this study further constructs a human–land–housing ternary coupling framework. The following sections examine the theoretical content and scholarly applications of each framework in turn, explain how incorporating the housing dimension expands the understanding of urban development patterns, and identify the corresponding theoretical contributions of this study.

Human–land areal system theory stands as a foundational pillar in both human geography and urban studies. Academician Wu Chuanjun systematically defined this theory, whose core proposition is that human social activities and geographical environmental elements within a specific territory interact with and constrain each other, forming a dynamically evolving composite areal system, and that the combinatory relations and interaction intensity among internal elements directly determine regional development outcomes [1]. Building on this foundation, early domestic and international research long operated within the human–land binary analytical paradigm [2,3]. International scholars focused on how urban population agglomeration and spatial expansion shape land-use patterns and land development modes, while also examining the constraining role of land carrying capacity on population distribution. While domestic research, informed by China’s national conditions of urbanization, concentrated on land governance issues, including construction land expansion, cultivated land protection, and human–land conflict regulation, with particular emphasis on the matching relationship between population growth and land supply [4]. A survey of the existing literature, however, shows that the traditional framework consistently treats land as the core medium of human–land relations, attending only to human–land interactions and thus overlooking the direct spatial carrier of human settlement activities [5]. In urban studies, housing serves as the intermediary through which population settles and land value materializes. Land governs the spatial supply scale and locational layout of housing, population determines genuine housing demand and market trajectory, and together the three form an inseparable organic whole [6]. In recent years, some international scholars have begun to examine how residential space reshapes human–land relations, and domestic researchers have gradually recognized the limitations of the binary framework, yet most existing studies still treat housing as a supplementary indicator rather than elevating it to an independent subsystem within the human–land areal system for systematic analysis [7,8].

The traditional human–land binary framework can only explain one basic question, namely whether land can carry the population. It cannot address the real-world paradoxes that appear during urbanization, for instance, land supply stays sufficient yet housing sits vacant, and population grows dense yet housing runs short [9]. Once housing enters the human–land areal system as its third core dimension, understanding deepens in three respects. First, this framework improves the transmission logic of the human–land relationship. It clarifies the complete path that runs from population demand to the housing market response and then to land development and supply. With this path in view, the direct opposition between population and land breaks down, and housing instead becomes the key intermediary that links population behavior with land use. This in turn restores the true operating logic of the urban human settlement system [10,11]. Second, the housing dimension extends the research boundary of land governance. Traditional land governance mainly controls the scale and type of land use, but after housing joins in, it no longer stays within simple land-use quota management. It reaches into the coordinated governance of land supply, housing supply and demand, housing prices, and living quality. Land governance then turns from total-volume control toward spatial adaptation and supply-demand matching [12–14]. Third, housing also leads to a new interpretation of how urban human settlement develops. The spatial flow of the urban population no longer drives land expansion alone. Through the location choice of housing, the divergence of prices,

and the turnover of the existing stock, this flow works in the opposite direction. It pushes the land-use structure toward optimization and urban space toward restructuring. The understanding of urban human–land interaction therefore shifts from macro totals down to the micro level of residential behavior and spatial structure [15,16].

1.2. Research Background

New-type urbanization is a national medium- and long-term development strategy that China has put forward based on its basic national conditions. It also serves as the core lever for advancing urban-rural integration and high-quality urban development. In terms of its policy substance and implementation requirements, this strategy sets out three core orientations. First, it guides the agricultural transfer population toward citizenization in an orderly way and reasonably regulates the spatial agglomeration pattern of the population. Second, it enforces the strictest land management system, promotes the intensive and economical use of urban land, and strictly controls the disorderly expansion of construction land. Third, it improves the housing supply system, achieves a precise spatial and structural match between housing supply and demand, and works to resolve the housing conflicts in large cities [17–19]. As this strategy advances, the coordinated spatial development of the three major elements of population, land, and housing becomes a key yardstick for measuring the quality of urbanization. Therefore, solving the problem of spatial mismatch among these three elements and keeping the human settlement system running soundly is also an inevitable requirement for implementing the national urbanization strategy [20].

Around the world, urbanization is a necessary stage in the modernization of every country. Developed countries in Europe and America, together with Japan and South Korea, all completed a phase of rapid urbanization. After that, they introduced transformation policies that come close to China's goals for new-type urbanization. These policies focus on optimizing the human settlement system and on the coordinated governance of spatial elements [21,22]. Among them, the developed countries in Europe and America entered the post-urbanization stage fairly early. These countries faced problems such as the excessive concentration of population in large cities, inefficient land use, and the differentiation of residential space. In response, they launched planning policies such as smart growth, compact cities, and metropolitan integration. The aim of these policies is to curb the disorderly outward expansion of cities, to revitalize the existing land stock, and to balance the supply of residential support facilities across different regions. In this way, these countries coordinate population distribution, land development, and the housing needs of residents [23,24]. As for East Asia, Japan and South Korea face a prominent human–land conflict. Their national conditions include a small national territory and a population heavily concentrated in large cities. With this in mind, they successively introduced comprehensive national land planning, housing security policies, and balanced regional development policies. These measures mainly regulate the spatial layout of population, land, and housing inside the major metropolitan areas. As a result, they relieve problems such as the housing pressure in core cities and the hollowing-out of development in peripheral regions [25,26]. On the whole, the urbanization transition policies of different countries differ because of their national conditions and stages of development. Yet their core logic tends to converge. In the middle and later stages of urbanization, these countries all turn toward quality improvement, the coordination of elements, and spatial balance. This direction aligns closely with the development philosophy behind China's new-type urbanization.

As new-type urbanization in China continues to accelerate, the rapid population concentration in urban areas has become increasingly pronounced, while the scarcity and non-renewable nature of land resources have placed the human–land relationship under mounting strain [27]. The sustained growth of the urban population, together with the sharp

differentiation in its spatial distribution, has continually intensified the demand for urban land, particularly the inelastic demand for residential land, which has surged markedly. Consequently, a spatial mismatch has emerged between housing supply and population demand: regions with high population density experience inadequate housing availability and elevated prices [28], whereas areas with low population inflow face housing vacancies and inefficient resource utilization. This further aggravates the supply–demand imbalance in the housing sector, so that the strained human–land relationship is concentrated and expressed through housing problems [29].

The current discussions of the interrelationship among population, land, and housing primarily address two key issues. First, there is a contradiction between the uncertainty of population mobility and the rigid constraints of land supply. The dynamic nature of population movement makes it difficult to accurately predict housing demand, while the planned and lagging nature of land supply prevents housing provision from adapting in time to shifts in the spatial distribution of the population [30,31]. Second, a disparity is evident between the efficiency of land use and that of housing provision. In some areas, idle and underused land resources coexist with a shortage of housing supply, indicating insufficient coordination between land development and housing construction [32,33]. Achieving spatial coupling among population, land, and housing is crucial for the high-quality advancement of new-type urbanization. Such integration addresses critical challenges, including the conflict between population growth and land availability, as well as the imbalance between housing supply and demand. It facilitates the efficient utilization of land resources, the precise alignment of housing supply with demand, and the rational concentration of population, thereby fostering a transition in new urbanization from mere quantitative expansion to qualitative enhancement [34].

1.3. Literature Review

Traditional research on human–land relationships has mainly focused on the interactive relationship between the two major systems of population and land [35], centering on aspects such as the coupling coordination between population scale changes and land use expansion, the matching of land carrying capacity and population capacity, and the formation mechanisms and regulatory pathways of human–land conflicts [36], while the focus has largely been on examining the driving influence of population growth on land utilization and the constraining effects of land resource limitations on population development [37]. The research perspective has mostly concentrated on macro-scale aggregate analysis, lacking in-depth exploration of the concrete carriers of human–land relationships [38]. With the advancement of new-type urbanization and the continual enhancement of residents' living standards, the conceptualization of human–land relationships has been progressively enriched [7], as the scope of these relationships has expanded beyond the traditional binary interaction between population and land to encompass multiple domains closely linked to human production and daily life [20]. Housing, as the basic material carrier on which human survival depends, has become an important concrete manifestation of human–land relationships [39]. The limitations of traditional human–land relationship research have become increasingly prominent [31], underscoring the urgent need to incorporate the housing system into the human–land relationship research framework. This integration aims to investigate the synergistic interactions among population, land, and housing systems, thereby broadening the conceptual and practical dimensions of human–land relationship studies.

New-type urbanization adopts a people-centered approach, distinguishing itself from traditional urbanization models that prioritize scale expansion [40]. It emphasizes enhancing urban quality, improving the living environment, equalizing public services, and fostering coordinated adaptation between population dynamics and urban development.

Its central objective is to achieve sustainable urban growth and elevate residents' quality of life [17–19]. Within the context of new-type urbanization, the human settlement system is no longer a single population or land system but a complex organic whole composed of multiple subsystems such as population, land, housing, ecology, and public services. These subsystems are interrelated and interact with each other, jointly supporting the optimization of the living environment and high-quality urban development [9,41,42]. Key issues in the evolution of the human settlement system under new-type urbanization include spatial population mobility, functional transformation of land, and optimization of housing supply [43–46]. Addressing these challenges through the development of isolated systems is insufficient; instead, exploring the coordinated development and adaptive interactions among multiple subsystems has become a critical research direction to overcome developmental bottlenecks and promote high-quality urbanization [47,48].

On the interaction among the population, land, and housing systems, scholars have already developed diverse analytical frameworks, research methods, and data systems [49]. Early studies in this area mainly relied on binary system analysis. These studies often used simple tools such as qualitative description and correlation analysis, and they focused on the one-way effect between two systems. Their data also came mainly from macro statistical yearbooks and census records, so the spatial precision remained low and could hardly capture the spatial differentiation at the micro scale [50–53]. As the research system kept improving, quantitative methods such as the coupling coordination degree model, spatial econometric models, and system dynamics models gradually became common [37,54]. Among these, the coupling coordination degree model can effectively measure how several systems develop together and how they evolve, and it has now become the mainstream tool in studies of multi-system coupling [55]. At the same time, scholars widely apply multi-source data such as remote sensing imagery, geographic information system (GIS) spatial data, and large-scale internet data. This kind of data effectively makes up for the shortcomings of traditional statistics, and it clearly raises the level of refinement and the empirical reliability of the research [56–58]. In this way, it lays a foundation in data and methods for the coupling study of complex human settlement systems with three or more elements.

In terms of research objects and frameworks, the existing studies fall into three categories. The first category is traditional human–land binary coupling research, and it remains the mainstream paradigm in the field of human–land relations. This research focuses on the interaction patterns between population size and land use, but it completely ignores housing, which is a core carrier of human settlement. As a result, it cannot explain the real problem of human–land–housing spatial mismatch during urbanization [4,59,60]. The second category is pairwise binary coupling research on human–housing and land–housing. It focuses on the relations of supply and demand, price, and spatial distribution between housing and a single system. Yet it breaks the overall integrity of the three major systems, so it can hardly reveal the complex mechanism by which the three systems interact [31,61]. The third category is human–land–housing ternary coupling research. Although this research breaks through the binary framework, the existing studies still have obvious shortcomings. In theoretical terms, most studies merely apply generic coupling models. They do not build targeted analytical logic that fits the development features of new-type urbanization in megacities, so they explain the internal mechanism of system imbalance insufficiently [62,63]. As for the research perspective, most studies remain at macro scales such as the municipal area and the districts and counties. Few of them conduct empirical work with fine-grained spatial units at the subdistrict level, so they can hardly identify the mismatch features in local areas [6,20]. In methodological terms, most existing ternary coupling studies rely on the coupling coordination model alone. They only judge the

overall level of coordination and lack a breakdown of the relative development state of each subsystem [9,30]. In addition, their analysis of driving factors mostly uses traditional regression models, so it can hardly identify the nonlinear interactions among factors and the spatial heterogeneity.

In the system of multi-system coupling research, two core tasks stand out, namely the analysis of coupling spatial features and evolution patterns, and the identification of driving mechanisms [64]. Among them, scholars use the coupling features to judge the current state of coordinated development among systems, while they use the driving mechanism to reveal the internal reasons behind a given coupling state, which serves as the key basis for designing regulation strategies [65,66]. At present, when scholars study the driving mechanism of human–land–housing coupling, they mostly select influencing factors from such dimensions as population, economy, industry, and policy [6,9,59]. However, most existing studies adopt traditional statistical regression methods, and they assume by default that the factors relate to one another in a linear way, so they ignore spatial heterogeneity and the interaction among factors. For this reason, their analytical results carry certain limitations [20]. To address this gap, the present study chooses the geographical detector model for the analysis of driving mechanisms. This method needs no linear assumption, and it can measure the influence of each factor and identify their interactions at the same time, so it fits the study of driving mechanisms in complex human settlement systems better. It therefore supplements and improves the existing methods of driving analysis. Moreover, this direction still remains a research focus and a hot topic in the field of human settlement coupling [67]. The classification, core content and main limitations of the above four strands of existing literature are summarized in Table 1.

Building on the research gaps in theory, perspective, and method that the previous part has reviewed, this study takes the subdistricts of Guangzhou as the basic unit and carries out an empirical analysis around the human–land–housing ternary system. The whole study falls into two core modules, and their research goals and specific content are as follows. The first module analyzes the spatial coupling features of population, land, and housing. To begin with, this study uses the coupling coordination model to calculate the coupling coordination degree of the three systems in each subdistrict, and it then identifies the spatial differentiation pattern and the concentric distribution of the coupling coordination level. On this basis, this study integrates the various coupling coordination results and further divides them into three matching patterns, namely the core differentiation type, the peripheral imbalance type, and the surrounding equilibrium type. After that, it draws on the relative development model to dissect the imbalance features of different types of areas, so it clarifies the overall form of spatial mismatch across the whole region. The second module analyzes the driving mechanism behind coupling mismatch. Here this study applies the geographical detector model and selects influencing factors from multiple dimensions such as location, transportation, public services, industry, and ecology. It then quantifies the driving strength of a single factor and the synergistic interaction among factors, and it builds a theoretical conceptual framework in light of the laws of urban development, so it explains how coupling differentiation and spatial mismatch take shape.

Overall, this study aims to make up for the shortcomings of existing ternary coupling research. At the same time, it provides an empirical basis for Guangzhou to resolve the human–land–housing spatial mismatch and to advance the high-quality development of new-type urbanization. Moreover, it offers comparable research ideas and practical solutions for other megacities of the same kind in China.

Table 1. Review of domestic and international research.

Research Category	Main Research Subjects and Content	Main Existing Achievements	Existing Limitations
Traditional binary research on human–land relations (population + land)	It focuses on the interaction between population size and distribution on one side and land use and land carrying capacity on the other. It relies mainly on qualitative description and basic statistical analysis, and its research scale is mostly the municipal area and macro regions [50–53].	<ol style="list-style-type: none"> 1. It lays the theoretical foundation for human–land relations and clarifies the basic law by which population and land restrict and influence each other. 2. It summarizes the synergy and conflict between land expansion and population growth during urbanization. 3. It puts forward basic governance ideas such as land control and population regulation [4,5,37]. 	<ol style="list-style-type: none"> 1. It sticks to the binary analytical framework and leaves out housing, which is a core carrier of human settlement. 2. It emphasizes macro aggregate analysis and lacks investigation at the micro spatial scale. 3. It can hardly explain the comprehensive human–land–housing spatial mismatch [38,59,60].
Pairwise binary coupling research (population + housing/land + housing)	It separately analyzes the relationship between population and housing supply, demand, or prices, or the matching between land use and housing construction. It gradually introduces coupling models and spatial analysis methods [37,54].	<ol style="list-style-type: none"> 1. It clarifies how population mobility affects housing prices and the balance of supply and demand. 2. It identifies how the scale of land supply and the land-use type constrain housing construction. 3. It verifies that big data and spatial models apply to housing-related research [31,39]. 	<ol style="list-style-type: none"> 1. It artificially breaks the integrity of the three major systems and cannot reveal how they interact. 2. It often uses a single indicator such as housing price alone and does not define where that indicator applies. 3. It interprets the causes of spatial differentiation rather superficially [31,61].
Human–land–housing ternary coupling research (existing comparable studies)	It uses the coupling coordination model to evaluate the synergy among the three elements. Some studies also add regression models to analyze driving factors, and their data come mainly from traditional statistics [6,9].	<ol style="list-style-type: none"> 1. It confirms that large cities generally show a concentric spatial differentiation of population, land, and housing. 2. It preliminarily identifies transportation, public services, and industry as the main influencing factors. 3. It proves that the coupling coordination model suits the evaluation of human settlement systems [20,30]. 	<ol style="list-style-type: none"> 1. Most studies force a temporal evolution pattern out of single-period cross-sectional data, which leaves a logical flaw. 2. They divide coupling types in a broad way and lack a fine-grained classification. 3. Their driving analysis mostly targets a single factor and ignores the interaction among factors. 4. They assign equal weights without a supporting argument [62,63].
Research on comparable cities worldwide	It focuses on land control, the governance of idle land, the layout of residential land, and housing security policies in overseas cities. It relies mainly on case analysis and policy evaluation. [21,22]	<ol style="list-style-type: none"> 1. It summarizes mature international policies such as the strict control of urban sprawl, the renewal of existing stock, and transit-oriented development. 2. It reveals the common pattern of human–land–housing mismatch that megacities around the world generally share [23–26]. 	Domestic review studies seldom use international land policies as a horizontal reference, so the comparison between China and other countries and the borrowing of their experience remain insufficient [68].

2. Materials and Methods

2.1. Study Area

This study takes Guangzhou as its study area (Figure 1), and it uses the subdistrict as the basic spatial analysis unit. Guangzhou has 176 subdistricts in total, and the sample covers all 11 municipal districts of the city, so the spatial coverage is complete. According to the latest statistical data, Guangzhou's resident population in 2024 has reached 18.978 million, representing a sustained increase from 18.7403 million in 2020. With an urbanization rate maintained above 86%, the city exhibits a significant spatial imbalance: the central urban area has a high population density and excessive concentration, whereas the peripheral new towns suffer from insufficient population inflow. This uneven spatial distribution is further exacerbated by the dynamic nature of population mobility. In terms of land use, the urban built-up area has expanded to 1431.83 square kilometers as of October 2025. However, there are significant regional differences in land use efficiency, with saturated land development in the central urban area coexisting with inefficient land use in peripheral areas. The transformation of land functions and spatial allocation have not adequately adapted to the spatial patterns of population distribution and housing demand. Regarding the housing market, Guangzhou demonstrates a distinct supply-demand imbalance and structural differentiation. The central districts face supply shortages and inflated prices—particularly for entry-level housing—while peripheral areas grapple with high inventories and significant vacancy rates. As one of China's premier megacities, the developmental characteristics and population-land-housing mismatches in Guangzhou are highly representative among similar hub cities [69]. Therefore, conducting an empirical study on Guangzhou provides critical practical insights for advancing high-quality new-type urbanization.

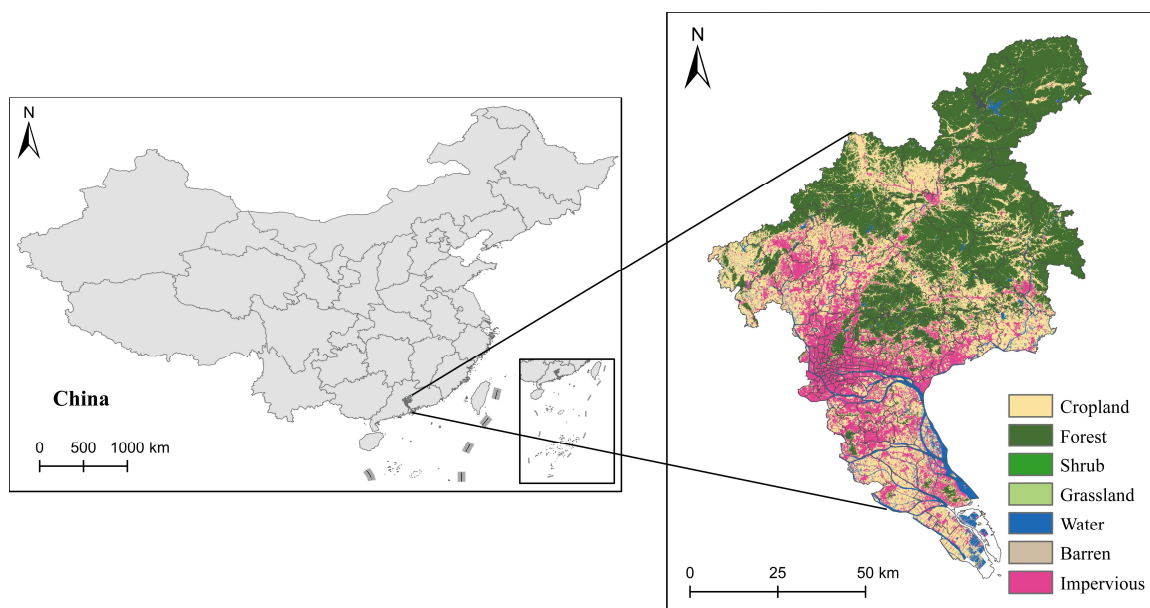


Figure 1. Study Area.

2.2. Research Data

The data selection in this study follows three core principles, namely scientific soundness, relevance, and accessibility. Around the research needs on the coupling features and driving mechanism of the population, land, and housing systems, this study builds a comprehensive data system of multiple types and multiple sources, which ensures that the conclusions stay reliable and precise. For the core population data, this study adopts the data of the year 2020, and the main reason lies in the standard reference time of China's

seventh national population census. China organizes the national population census once every ten years, and the year 2020 provides the most recent and the only fine-grained official population data source that the public can access and that covers all subdistrict units of Guangzhou. Up to now, no census subdivision data of the same scale exist for 2025 or later, and the regular annual statistics only reach the level of districts and counties, so they cannot match the subdistrict-level units in this study. For this reason, this study uniformly takes 2020 as the baseline year for all the data.

Among these data, the population system data come mainly from the subdistrict-level subdivision data of Guangzhou in the seventh national population census of 2020. The built-up area data in the land system come from the ESA land-use data of the same period. The housing system data come from the second-hand housing data on the Anjuke platform in 2020. In this way, the time points of the multi-source data stay completely consistent, and this avoids the analytical bias that a temporal mismatch would bring.

To thoroughly investigate the driving mechanisms of this spatial coupling, the study integrated multi-source data on influencing factors, encompassing statistical yearbooks, remote sensing imagery, and web-scraped big data. The data processing procedures in this study were implemented via ArcGIS 10.7 software.

2.2.1. Population Data

All population data used for analysis in this study were drawn from the sub-district data of the 2020 Seventh National Population Census of Guangzhou. Officially released by the Guangzhou Municipal Statistics Bureau, this data serves as the most authoritative and comprehensive foundational data reflecting the spatial distribution and structural characteristics of the city's population. As a centrally organized national census, the data were collected through door-to-door registration by professionals and subjected to multi-tiered verification and strict quality control. This process effectively eliminates the random bias inherent in sampling surveys and ensures very high authenticity and reliability. Moreover, the high spatial resolution—refined to the sub-district level—accurately aligns with the spatial analytical scale of this study, clearly illustrating the regional disparities in population distribution and fulfilling the specific requirements for population spatial coupling research [70]. To ensure data quality, the census data were cleaned systematically. First, missing values were addressed by supplementing missing indicators for individual sub-districts using statistical bulletins to avoid impacts on analysis results. Second, outliers were removed by identifying extreme values in each indicator using boxplot methods, cross-checked against the actual population situation in Guangzhou, and removed once confirmed. Third, the data standardization and unification were conducted. Spatial matching corrections were also applied by aligning the sub-district level census data with the administrative boundary map of Guangzhou's subdistricts to ensure the accuracy of spatial attributes. The resulting data are shown in Figure 2.

2.2.2. Built-Up Area Data

The core land-system data in this study derive from the China ESA 2020 land use dataset, released by the European Space Agency (ESA). This dataset is a global land-cover dataset derived from Sentinel satellite remote sensing imagery. This study focuses on extracted land-use data within Guangzhou's administrative boundaries for subsequent analysis [71,72]. The data are categorized into primary categories such as cropland, forest, grassland, water bodies, built-up land, and unused land, with further secondary subdivisions. Built-up land data are used to delineate built-up areas. With a spatial resolution of 10 m, far higher than that of conventional statistical land data, the ESA 2020 land-use data can precisely capture subtle differences in land use across Guangzhou and clearly

delineate the boundaries between built-up and non-built-up areas, thereby meeting the spatial analysis precision requirements at the sub-district level for this study. The data are also timely and synchronous, collected and processed in 2020, consistent with the population census and housing data time points used in this study, avoiding analysis bias caused by temporal mismatches.

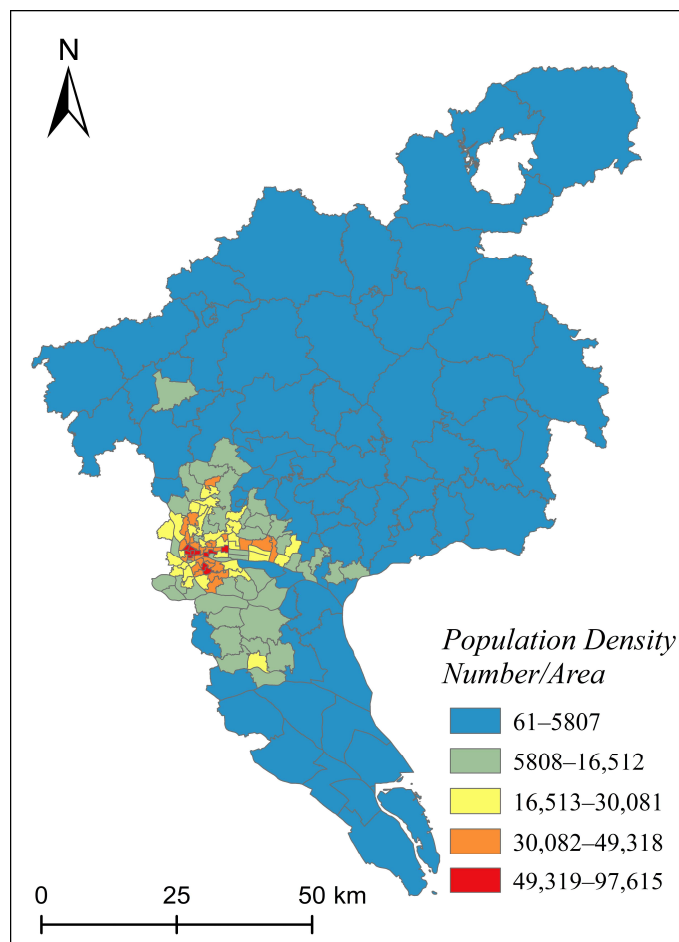


Figure 2. Population Distribution of Guangzhou City.

To adapt to the analytical requirements of this research and ensure data quality and spatial consistency the China ESA 2020 land-use data were systematically preprocessed and cleaned. First, clipping and masking were performed using Guangzhou’s administrative boundary vector map as a mask to clip the national ESA 2020 land use data, removing redundant data outside Guangzhou’s administrative area and retaining core data for the study area. Second, resampling and resolution unification were done using bilinear interpolation to resample data to a uniform resolution, ensuring consistency with the spatial resolution of population and housing data and avoiding resolution differences affecting coupling analysis results. Third, classification correction and accuracy verification were conducted by referencing Guangzhou’s overall land use planning data and actual land use conditions to manually correct classification bias areas, followed by statistics to obtain the sub-district level built-up area proportion results shown in Figure 3.

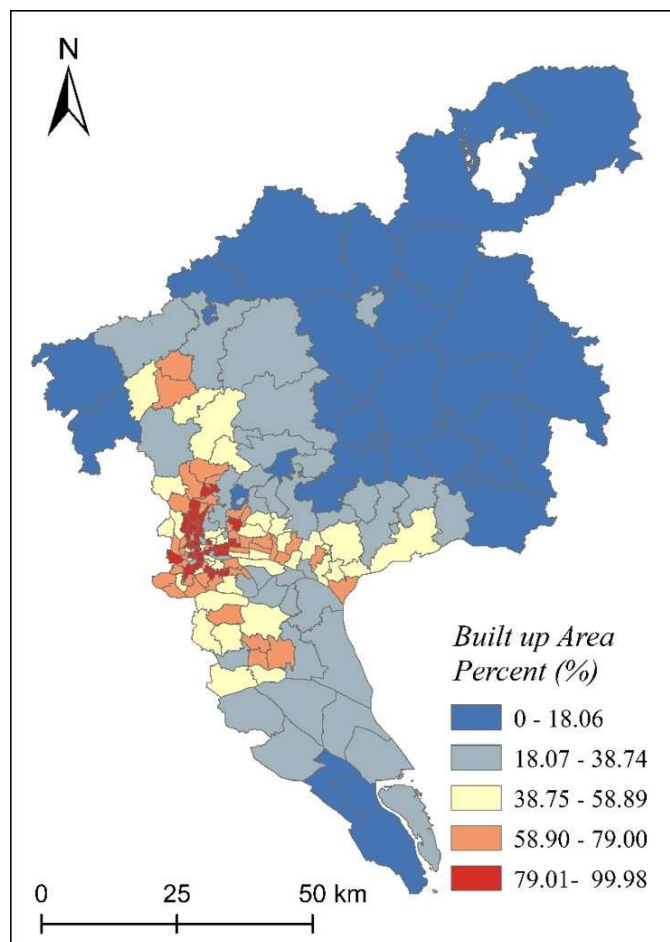


Figure 3. Built-up Area Distribution of Guangzhou City.

2.2.3. Housing Price Data

The housing price data in this study all come from the subdistrict-level second-hand housing data of Guangzhou on the Anjuke platform in 2020. This study chooses the second-hand housing price as the evaluation indicator of the housing subsystem, and this choice rests on sufficient practical grounds and academic soundness. In terms of the urban development stage, Guangzhou is a first-tier megacity, and its urban development has matured, so the existing housing stock has become the main body of the city's housing. The second-hand market shows far higher transaction activity and a far wider listing coverage than the new-house market, and it covers all subdistrict units across the central districts, the near suburbs, and the outer suburbs, so it matches the subdistrict-level spatial scale of this study well. In terms of market attributes, government price caps, project pricing strategies, and developer marketing generally intervene in new-house prices, so the new-house market shows a weak degree of marketization. By contrast, individual buyers and sellers carry out most second-hand transactions, and the relationship between market supply and demand decides the price on its own, so the second-hand price reflects the intrinsic value, the locational advantage, and the residential appeal of regional housing more truly, which fits the research goal of this study in measuring the comprehensive development level of regional housing. In terms of data features, Anjuke is a mainstream property information platform in China, and it offers a large sample of listings and a fine spatial granularity, so the data can sink accurately to the subdistrict scale. Therefore, the field of urban geography and human settlement coupling commonly uses it as a data source for studying housing spatial differentiation, and many empirical studies have already verified its reliability. Taking all these factors together, this study finally decides to use

the subdistrict-level second-hand housing price of Guangzhou in 2020 to represent the development level of the housing subsystem. Taking all these factors together, this study finally decides to use the subdistrict-level second-hand housing price of Guangzhou in 2020 to represent the development level of the housing subsystem.

This study does not include the data of the new-house market and the housing rental market. In light of the research goal and the features of these two markets, the specific reasons and the potential data bias run as follows. First, the supply of new houses shows clear regional concentration, and it mostly spreads across the outer areas of the city, while new-house listings stay scarce in the central districts. Therefore, the new-house data cannot cover all subdistricts evenly, and once this study includes them, they would break the integrity of the spatial analysis. At the same time, policy control and product positioning affect new-house prices to a large extent, so these prices can hardly reflect the long-term human settlement value of a region in an objective way. Second, the housing rental market mainly serves short-term living needs, and commuting distance and temporary residence demand affect the rent more, so this market matches poorly with the core orientation of this study, which focuses on the long-term agglomeration of population and the long-term use of land.

This study mainly extracts core indicators from the platform, such as the listing price, the transaction price, the housing layout structure, the listing volume, and the transaction volume of second-hand housing. In addition, it supplements auxiliary information such as the construction year of the housing and the supporting facilities of the residential community. The data cover all administrative districts of Guangzhou, so they accurately reflect the spatial distribution, the supply and demand pattern, and the differentiation of the existing housing prices across different subdistricts. Compared with other types of data, the data on the Anjuke platform offer higher spatial precision, and they can refine down to the subdistrict level, so they accurately match the spatial analysis scale of this study and clearly present the spatial differentiation of housing prices in Guangzhou. Moreover, these data cover a wide range and contain rich indicators. They include not only the core indicators of housing price but also auxiliary information such as the housing supply volume, the layout structure, and the supporting facilities, so they fully reflect the supply and demand features of the existing housing market. In addition, the platform updates the data in real time and provides a large sample, so the data effectively reflect the real operating state of the existing housing market in Guangzhou [73,74].

Given that the Anjuke platform data consists of raw records obtained by web scraping, it inherently contained noise, outliers, and missing values. To ensure data quality and satisfy analytical needs, a rigorous cleaning and standardization protocol was implemented. First, redundant records of repeated listings and transactions were removed to prevent data duplication from interfering with the analysis. The focus was on resolving issues like multiple listings of the exact same property and duplicated price entries. Second, for gaps in indicators such as housing prices or unit typologies in certain sub-districts, the mean imputation method was applied, drawing on the price levels and layout characteristics of similar properties in adjacent sub-districts. These imputations were subsequently verified and calibrated against Guangzhou's official 2020 housing market statistics to ensure their validity. Third, outliers were removed by identifying extreme housing price outliers using boxplot methods. Data points strictly exceeding or falling below three times the average housing price of their respective sub-districts were rigorously screened. Confirmed abnormal listing or transaction prices were removed after being cross-checked against actual market conditions in 2020, thereby preventing outliers from compromising analytical accuracy. Finally, indicators such as housing prices, listing volumes, and transaction volumes were standardized to eliminate dimensional disparities. The cleaned housing price data was then

spatially joined with the administrative boundary shapefiles of Guangzhou's sub-districts, generating the sub-district-level housing price distribution depicted in Figure 4.

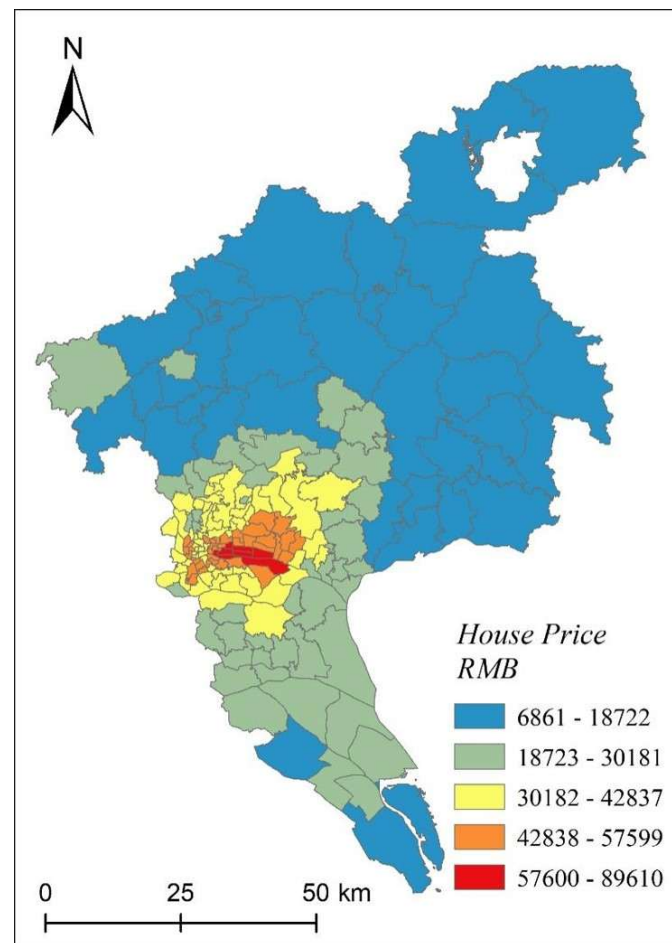


Figure 4. Housing Price Distribution of Guangzhou City.

2.2.4. Influencing Factor Data

To explore in depth how the spatial coupling differentiation and the mismatch of population, land, and housing in Guangzhou take shape, this study introduces 12 external influencing factors for the analysis of the driving mechanism. It should be noted that these 12 factors do not take part in the calculation of the comprehensive indices U_1 , U_2 , and U_3 of the population, land, and housing subsystems, nor in the calculation of the coupling coordination index. Instead, they only serve as driving variables that explain the spatial differences in the coupling coordination level, and the geographical detector model analysis in the later part uses them.

Drawing on the research achievements in urban geography and human settlement space [6,9,75], and following the principles of systematicness, representativeness, and quantifiability, this study screens the influencing factors (X1 to X12) from seven dimensions, namely locational conditions, transportation facilities, public services, the ecological environment, building form, the economic level, and industrial layout. Each kind of factor acts on the spatial flow of population, the intensity of land development, and the supply, demand, and price of housing, so it indirectly changes the coupling and matching state of the three systems. To be specific, location and transportation decide the locational choice of population agglomeration. Public services and the ecological environment affect the human settlement appeal of a region, and they thereby change the population distribution and the housing demand. The economic level and the industrial layout dominate the land-use

structure and the division of land-use functions. In the end, all these factors jointly shape the coupling coordination pattern of population, land, and housing.

The data in this part integrate sources such as the Guangzhou statistical yearbook, online POI big data, and spatial vector data. The data precision matches the subdistrict-level research unit, so it meets the requirement of the quantitative analysis of the driving mechanism. Table 2 shows the name, the category, and the data source of each factor.

Table 2. Influencing factor and data sources.

Code	Influencing Factor	Data Source
X1	distance to city center	-- [75]
X2	coverage rate of 500-metre buffer zones around metro stations	POI data extracted from Amap (2020) [9]
X3	road density	Open Street Map (2020) [9]
X4	coverage rate of 500-metre buffer zones around bus stops	POI data extracted from Amap (2020) [9]
X5	density of educational resources per square kilometre	POI data extracted from Amap (2020) [6]
X6	density of medical POIs per square kilometre	POI data extracted from Amap (2020) [6]
X7	density of shopping mall POIs per square kilometre	POI data extracted from Amap (2020) [6]
X8	park green space coverage	POI data extracted from Amap (2020) [6]
X9	average building height	ChinaUV-Roof [76]
X10	street GDP output	Spatial distribution dataset of GDP in China at 1 km resolution [77]
X11	density of factories per square kilometre	POI data extracted from Amap (2020) [6]
X12	density of office buildings per square kilometre	POI data extracted from Amap (2020) [6]

Note: The distance to the city center is calculated as the straight-line/driving distance from the sample location to the municipal government building, using the Amap API.

2.3. Research Methods

This study builds three subsystems of population, land, and housing, and they correspond to the comprehensive evaluation indices U_1 , U_2 , and U_3 respectively. In light of the data availability, the research scale, and the research goal, each subsystem adopts a single core indicator, and the definition, the calculation rule, and the selection basis of these indicators run as follows. Meanwhile, the three kinds of raw data differ greatly in dimension and value range, so this study first carries out standardization, and it only uses the data for the coupling coordination model after it removes the dimensional effect.

For the indicator of the population system index U_1 , this study selects the subdistrict-level permanent population data of Guangzhou from the seventh national population census of 2020. The scale of population agglomeration is a core sign of the regional population development state, and it is also a basic element that drives changes in land use and housing demand. These data come from the subdistrict-level subdivision data of the seventh national population census in Guangzhou, so the spatial precision fully matches the research unit. This indicator is a positive one, and a larger value means a higher degree of population agglomeration in a region.

For the indicator of the land system index U_2 , this study selects the per capita construction land area at the subdistrict scale. U_2 represents the land-use state, the land supply level, and the effectiveness of land governance in a region, and it takes the per capita construction land area as the single evaluation indicator. This indicator comprehensively reflects how the supply of land resources matches the population it carries, so it is a core indicator for measuring the operating state of the land system. Given the land resource constraints of

Guangzhou as a megacity, this indicator is a moderate one, yet this study uniformly treats it as a positive indicator in the standardization.

The composite evaluation index U_3 for the housing system characterizes regional housing market development, supply-demand patterns, and housing value distribution, and adopts the average second-hand housing price at the subdistrict level as the sole evaluation indicator. Second-hand housing prices directly reflect the regional supply-demand relationship, locational value, and residential market vitality, making them the most representative core indicator of the housing system. The underlying data consist of subdistrict-level average housing prices after cleaning, deduplication, and outlier removal. As a positive indicator, higher values indicate greater market activity and value levels in the regional housing market. This study did not separately select sub-indicators such as vacancy rate, housing affordability, residential quality, and transport accessibility, primarily due to three limitations. To begin with, continuous and authoritative fine-grained subdistrict-level data covering housing vacancy rates, resident income for affordability estimation, and residential quality scores across all subdistricts in Guangzhou prove difficult to obtain and cannot satisfy the analytical requirements of the 176 valid subdistrict samples in this study. Beyond data availability, this study concentrates on the spatial coupling and matching relationships among the three systems of population, land, and housing rather than a multidimensional evaluation of internal housing characteristics, and accordingly prioritizes comprehensive indicators that are available across the full study area and show the highest spatial compatibility. Furthermore, transport and public service factors already function as independent driving factors in the subsequent geo-detector analysis, and incorporating them again into the housing subsystem evaluation would generate indicator redundancy and multicollinearity, ultimately undermining the accuracy of model results.

The three types of raw data, namely population size, per capita construction land area, and second-hand housing price, carry different units of measurement and show markedly different numerical ranges, making their direct input into the coupling coordination model infeasible. To address this, this study applies the range standardization method to normalize all raw indicators, mapping each value uniformly to the interval [0, 1]. The calculation procedure for positive indicators is as follows.

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

where X'_{ij} denotes the standardized value, X_{ij} represents the original value of the j -th variable for the i -th subdistrict, and $\max(X_j)$ and $\min(X_j)$ refer to the maximum and minimum values of the j -th variable across all subdistrict samples in Guangzhou, respectively. After this normalization procedure, the data yield standardized values within the range from 0 to 1, and these results serve as the final composite evaluation indices U_1 , U_2 , and U_3 for the three major subsystems. All subsequent coupling coordination analyses and relative development modeling proceed on the basis of the standardized U_1 , U_2 , and U_3 .

Figure 5 illustrates the technical workflow of this study.

2.3.1. Coupling Coordination Analysis

Coupling coordination analysis (CCA) serves as the core method in this study to explore the spatial coupling characteristics of the population-land-housing systems in Guangzhou. Its primary objective is to quantitatively analyze the interactions and interdependencies among the three subsystems, accurately measure their coupling coordination level, and clarify their spatial differentiation patterns and spatio-temporal evolution. This allows for the determination of whether the three major systems are in a state of synergistic development, thereby providing foundational support for subsequent explorations of

driving mechanisms and optimization pathways. Consequently, it effectively resolves the limitation inherent in single-system analyses, which fail to reflect multi-system synergistic relationships [78].

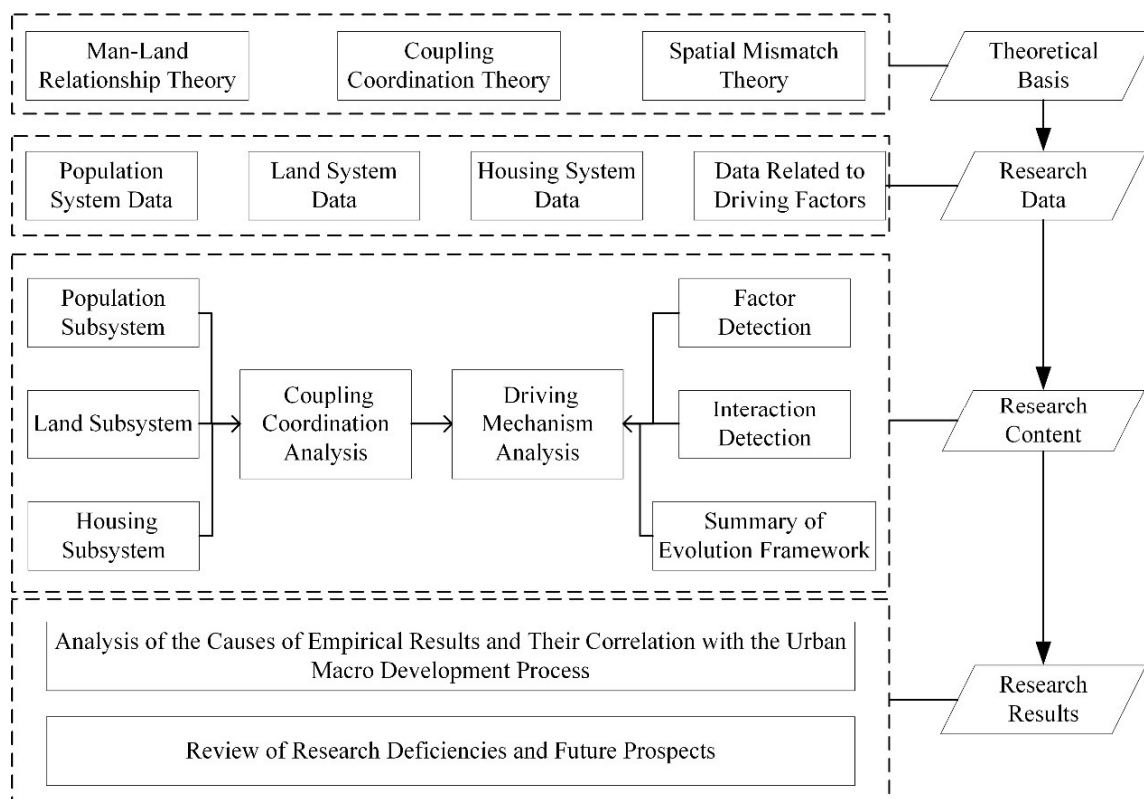


Figure 5. Workflow.

Compared to traditional methods such as correlation and regression analysis, CCA possesses significant advantages: First, it transcends the limitations of single-dimensional analysis by focusing on the bidirectional interactions among multiple systems rather than unidirectional impacts, thereby accurately depicting the dynamic relationships of mutual restriction and promotion among population, land, and housing. Second, it offers high quantitative precision. By constructing coupling degree and coordination degree models, it converts multi-system coupling relationships into specific numerical values, intuitively presenting hierarchical differences and spatial distribution characteristics, and avoiding the subjective bias of qualitative assessments. Third, it exhibits strong adaptability. It can flexibly fit research scenarios involving multiple systems and indicators—aligning perfectly with the needs of this study’s synergistic analysis—while balancing the correlations among internal system indicators and the interactions across systems, thus providing reliable methodological support for in-depth coupling analysis [6].

In this study, CCA proceeds in two core steps: calculating the coupling degree and calculating the coordination degree. The specific formulas and their variable definitions are as follow.

The formula for the coupling degree (C) is:

$$C = \sqrt[3]{\frac{U_1 \times U_2 \times U_3}{(U_1 + U_2 + U_3)^3}} \tag{1}$$

where C represents the coupling degree of the population-land-housing systems, with values in [0, 1]; U_1, U_2, U_3 are the comprehensive evaluation indices for the population,

land, and housing systems, respectively, each reflecting the development level of each subsystem. The closer C is to 1, the stronger the interaction and interdependence among the three systems and the tighter their coupling. Conversely, the closer C is to 0, the looser the coupling relationship and the weaker the interaction.

The formula for the coordination degree (D) is:

$$D = \sqrt{C \times T} \quad (2)$$

where D denotes the coordination degree of the three systems, with values in $[0, 1]$; C is the coupling degree; and T is the comprehensive development level index of the three systems, calculated as $T = \alpha U_1 + \beta U_2 + \gamma U_3$. Here, α , β , and γ represent the weights of the population, land, and housing systems, respectively. Based on the specific context of this study and relevant literature, these are all set to 0.333'. Starting from the core research objective, this study centers on the coupling coordination and spatial matching relationships among the three systems of population, land, and housing. These three systems together constitute an organic whole of the urban human settlement system, mutually constraining and supporting one another. As parallel core elements in the operation of the human settlement system, they exhibit no hierarchy in terms of primacy, superiority, or degree of importance, and there is thus no theoretical basis for assigning differentiated weights. Turning to the actual research context, Guangzhou, as a megacity, faces the intertwined urban challenges of population concentration, land constraints, and supply-demand imbalances in existing housing stock. A weakness in any single system would directly disrupt the overall coordination pattern, and the three systems contribute equally to land spatial governance and the advancement of new-type urbanization, making differentiated weighting objectively inappropriate. Furthermore, from the standpoint of academic convention, a large body of domestic empirical research on the ternary coupling of population, land, and housing has widely adopted an equal-weight assignment scheme for parallel human settlement subsystems, and this practice has gained broad recognition in the scholarly community [79]. The closer D is to 1, the better the developmental coordination on the basis of coupling interactions, indicating a state of synergistic development. The closer D is to 0, the poorer the developmental coordination, indicating significant coupling imbalances.

By combining the values of the coupling degree (C) and coordination degree (D), the coupling coordination levels of the three systems can be further classified, which defines the specific state of the population-land-housing coupling coordination across different sub-districts and provides a quantitative basis for subsequent spatial differentiation analysis.

2.3.2. Relative Development Model

The relative development model (RDM) is a vital supplementary method to CCA. Its core purpose is to quantitatively assess the differences in relative development levels among the population, land, and housing subsystems and to identify whether each subsystem is lagging or leading in its development. This explains the underlying causes of differences in coupling coordination levels and compensates for CCA's limitation, which measures only overall synergy and cannot reveal imbalances among individual subsystems. Ultimately, the RDM provides precise guidance for subsequent driving mechanism analysis and targeted optimization strategies. This method accurately pinpoints which of the three systems is lagging and which is advanced, thereby clarifying the core crux of coupling imbalances [80].

Compared to other methods for measuring systemic development differences (e.g., the range method or standard deviation method), the RDM has notable advantages: First, it is highly targeted, specifically designed for multi-subsystem coupling scenarios to precisely capture the deviations of individual subsystems relative to overall development, effectively

complementing CCA. Second, it is highly interpretable. By calculating the relative development index, it intuitively diagnoses subsystem development states and quantifies the degree of lead or lag, overcoming traditional methods' inability to define the direction of disparity. Third, it features straightforward operation and clear logical computation. It can be utilized in conjunction with CCA results to not only define the overall coordination level but also deconstruct the developmental shortcomings of single systems, enhancing the relevance and practicality of the research findings [81].

This study utilizes the RDM based on the comprehensive development level index (T) to calculate the relative development index for each subsystem. The formula and definitions are as follows:

The formula for the relative development index (K) is:

$$K_i = \frac{U_i}{T} \quad (3)$$

where K is the relative development index of the i -th subsystem ($i = 1, 2, 3$, corresponding to the population, land, and housing systems, respectively); U_i is the comprehensive evaluation index of the i -th subsystem (consistent with U_1, U_2, U_3 in the CCA); and T is the comprehensive development level index of the three systems (consistent with T in the CCA).

The implications of the K_i values are as follows: When $K_i = 1$, the subsystem's development level is synchronized with the overall development of the three systems, showing neither lag nor advance. When $K_i > 1$, the subsystem's development is ahead of the overall development, which may indicate excessive resource inputs or developmental imbalances. When $K_i < 1$, the subsystem lags behind the overall development, acting as a constraint on the synergistic coupling of the three systems. By computing K_i for all three subsystems across different sub-districts, the developmental imbalance characteristics of each region can be clearly mapped, offering precise direction for subsequent mechanism analysis.

2.3.3. Geographical Detector (Geo-Detector)

The geo-detector serves as the core analytical method for examining the driving mechanisms underlying the spatial coupling of population, land, and housing in Guangzhou. The model draws on the 176 valid subdistrict samples identified through the earlier screening process, and the sample size satisfies the data requirements of the geo-detector model. Its primary function is to quantitatively identify the impact intensity, influence direction, and spatial differentiation characteristics of various influencing factors on the coupling coordination level. This allows for the precise determination of the core factors, secondary factors, and interactive mechanisms driving the spatial coupling [82]. It overcomes the limitations of traditional analytical methods that fail to accurately capture spatial heterogeneity, thereby providing a scientific basis for formulating targeted optimization policies. This method effectively reveals the spatial associations between influencing factors and the coordination degree, clarifying the differential driving effects of various elements.

Compared with traditional methods for analyzing driving mechanisms, such as regression analysis and factor analysis, the geographical detector offers distinct advantages. First, it handles spatial heterogeneity well, capturing how driving effects vary across different areas, which suits the subdistrict-level analysis of this study and overcomes the assumption of spatial homogeneity in traditional methods. Second, it possesses strong quantitative and interpretative capabilities; by calculating the power of determinant (q -statistic), it directly quantifies the driving strength of factors without requiring linear assumptions, making it suitable for multi-type, nonlinear driving analysis. Third, it is capable of analyzing factor interactions, identifying synergistic or antagonistic relationships between

different variables, and clarifying the comprehensive impact of multiple factors acting concurrently. This closely aligns with the complex nature of the population-land-housing coupling mechanism [83].

This study primarily employs two core modules of Geo-detector: the factor detector and the interaction detector. The calculation formulas and definitions are as follows:

$$q = 1 - \frac{\sum_{h=1}^L N_h \sigma_h^2}{N \sigma^2} \quad (4)$$

where q is the power of determinant of an influencing factor, ranging from [0, 1]; L is the number of strata of the factor; N_h is the number of samples in stratum h ; σ_h^2 is the variance of the coupling coordination degree in stratum h ; N is the total number of samples; and σ^2 is the total variance of the coupling coordination degree across all samples. The closer the q value is to 1, the stronger the driving force of the factor on the coupling coordination degree, indicating it is a core factor. Conversely, the closer the q value is to 0, the weaker its driving effect.

Following factor detection, interaction detection is conducted. This module is primarily used to analyze the comprehensive impact of the interaction between two influencing factors on the coupling coordination degree. By cross-combining two factors, recalculating the combined q value, and comparing it with their individual q values, the interaction type is determined. There are five main types of interactions: synergistic enhancement (the interacted q is greater than the maximum of the individual q values); bi-factor attenuation (the interacted q is less than the minimum of the individual q values); antagonistic effect (the interacted q lies between the two individual q values and is less than their mean); nonlinear enhancement (the interacted q is greater than the sum of the individual q values); and nonlinear attenuation (the interacted q is less than the individual q values but greater than their minimum). Through interaction detection, the mutual relationships among different influencing factors can be clarified, revealing the complexity of the coupling driving mechanism.

3. Results

3.1. Spatial Characteristics Analysis of Population-Land-Housing Coupling Coordination in Guangzhou

Based on the coupling coordination analysis method, Figure 6 illustrates the population-land-housing coupling coordination degree across various sub-districts in Guangzhou. The spatial distribution of the population-land-housing coupling coordination in Guangzhou demonstrates pronounced spatial heterogeneity, predominantly exhibiting a concentric pattern characterized by central agglomeration and peripheral attenuation. Regions with higher levels of coupling coordination are primarily concentrated in the central urban areas such as Yuexiu, Haizhu, Liwan, and Tianhe districts. In contrast, the coupling coordination level gradually decreases in the peripheral areas, with certain areas experiencing coupling dysfunction. This forms a gradient pattern from the core to the periphery: coupling coordination, basic coordination, mild dysfunction, and moderate dysfunction.

Specifically, as the core central urban areas of Guangzhou, Yuexiu, Haizhu, Liwan, and Tianhe districts feature a high degree of population agglomeration, high land-use efficiency, and strong match between housing supply and population demand. Their coupling coordination degrees all exceed 0.7, categorizing them within the high coupling coordination tier and positioning them as pivotal regions for the integrated development of population, land, and housing. Benefiting from advantageous locational attributes, comprehensive public service infrastructure, and dense transportation networks, these districts have fostered a positive interaction among population scale, land utilization, and

housing provision. Population agglomeration, land development, and housing supply have formed a strong synergistic effect, resulting in a tight coupling relationship and high development coordination.

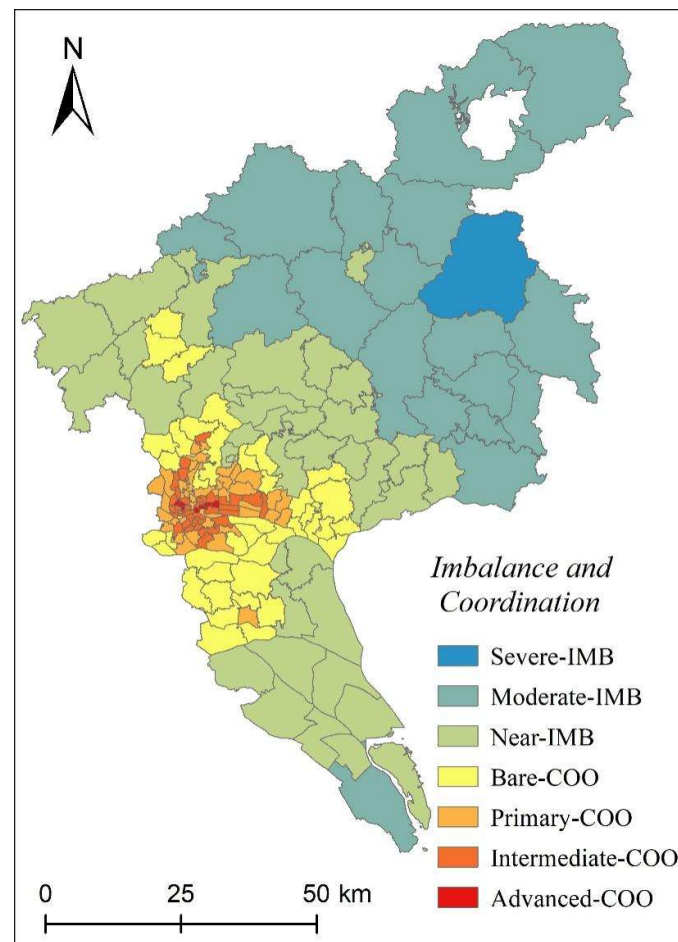


Figure 6. Coupling Coordination Results of Population-Land-Housing Prices in Guangzhou City.

Moving outward to the inner suburban districts—Baiyun, Huangpu, and Panyu district—a notable decline in coupling coordination levels is observed. These districts predominantly register values between 0.5 and 0.7, corresponding to moderate or basic coupling coordination categories. Despite experiencing rapid population influx, these areas exhibit comparatively lower land-use efficiency and a less adaptive housing supply structure relative to population demand than the central districts. Certain subdistricts face issues such as a spatial mismatch between population agglomeration and land supply, as well as a mismatch between housing supply and demographic structure, causing their coupling coordination levels to fall short of the core regions.

Conversely, the outer suburban districts—including Huadu, Nansha, Conghua, and Zengcheng—generally display low coupling coordination levels. Most subdistricts within these regions have coordination degrees below 0.5, with some falling under 0.3, placing them within the mild to moderate dysfunction categories. Although these regions possess relatively abundant land resources, they suffer from insufficient population inflow and low land-use efficiency. A pronounced spatial mismatch exists between housing supply and population demand, characterized by the simultaneous presence of vacant housing and insufficient residential demand. Consequently, the coupling among the three principal systems—population, land, and housing—is weak, and developmental coordination is suboptimal. These outer suburban districts thus represent critical bottlenecks imped-

ing the overall enhancement of the population-land-housing coupling coordination level of Guangzhou.

The preceding analysis based on the coupling coordination model yielded the spatial distribution of overall coupling coordination degree across Guangzhou, as shown in Figure 6, clearly revealing a concentric-zone gradient pattern in the population-land-housing coupling coordination levels. To further characterize the overall morphology of spatial mismatch and distinguish the developmental combination features across different areas, this study integrates and categorizes the CCA results together with the relative development status of each subsystem at the subdistrict level, thereby identifying differentiated system matching patterns, as presented in Figure 7. Drawing on the spatial pattern of coupling coordination, the composite evaluation indices of the three major systems, and the relative development model results discussed above, and grounding the analysis in the core characteristics of population concentration, land-use intensity, and housing price levels at each subdistrict, this study constructs a systematic typological classification of population-land-housing matching types in Guangzhou. The spatial distribution of population, land, and housing matching types in Guangzhou demonstrates pronounced spatial heterogeneity, which closely corresponds with the spatial pattern of coupling coordination. These typologies are delineated into three primary categories: the core-differentiated type, the peripheral-unbalanced type, and the surrounding-balanced type. The spatial distribution and defining characteristics of each category are detailed as follows:

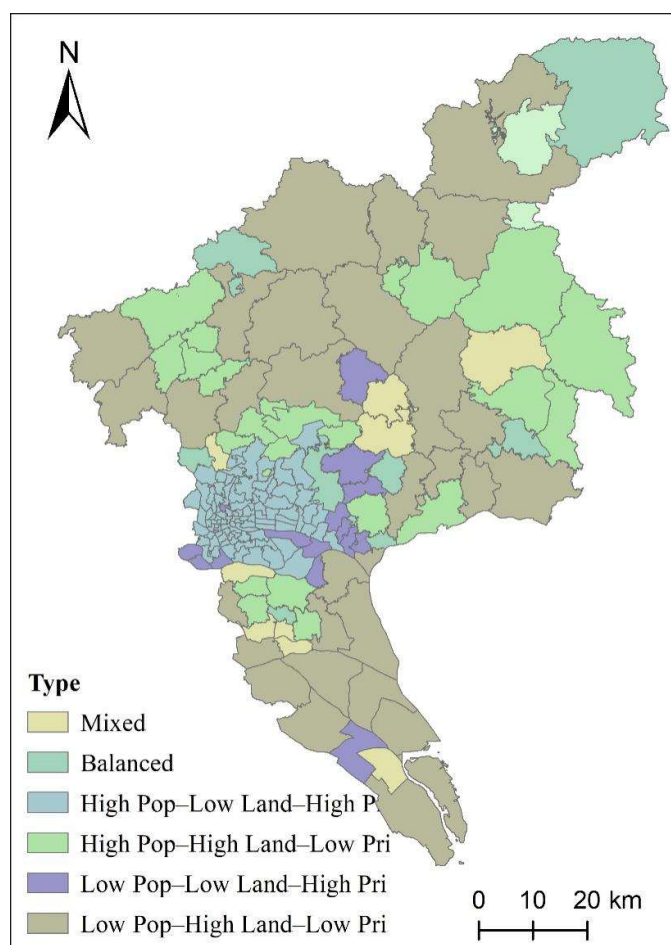


Figure 7. Population-Land-Housing Matching Types in Guangzhou City.

The predominant matching type is identified as the core-differentiated type, which is primarily concentrated in the core central urban areas such as Yuexiu, Haizhu, Liwan,

and Tianhe districts. This type is characterized by the triadic pattern of high population, low land, high housing prices. Specifically, Population agglomeration here is extremely high, with permanent resident population densities substantially surpassing the municipal average. The total population is both large and structurally heterogeneous, engendering strong rigid and improvement-driven housing demand. However, land resources are stringently constrained, resulting in high land development saturation and a scarcity of newly allocated residential land. Consequently, land development intensity remains elevated, reflecting a dynamic of limited land supply coupled with high land-use efficiency. The sharp contrast between booming housing demand and limited housing supply directly forces housing prices to remain elevated, making this the core zone for high housing prices in the city. The three systems thus form a non-equilibrium matching pattern characterized by high population and housing prices alongside limited land supply. Although the overall coupling coordination level is relatively high, latent imbalances persist, primarily attributable to insufficient land supply and excessively elevated housing prices.

In stark contrast to the core areas is the peripheral-unbalanced type, mainly distributed in the outer suburbs districts such as Huadu, Nansha, Conghua, and Zengcheng. This type is characterized by the triadic pattern of low population, high land, low housing prices. These areas possess relatively ample land resources, lower land development intensity, and a plentiful supply of residential land, albeit with comparatively low land-use efficiency. However, factors such as locational disadvantages, industrial spatial configuration, and limited public service infrastructure constrain their capacity to attract population inflows. As a result, permanent resident population densities remain low, total population figures are modest, and housing demand is correspondingly insufficient. The resultant mismatch between abundant housing supply and subdued housing demand leads to generally lower housing prices, with some areas experiencing housing vacancies. The triadic systems thus exhibit an unbalanced matching state characterized by sufficient land supply but low population density and housing prices, which fundamentally underpins the low coupling coordination levels observed in these peripheral suburban regions.

From the perspective of location and public services, the central urban districts, as the core of urban development, concentrate the city's finest educational, medical, commercial, and transportation resources. This strong residential attractiveness sustains high levels of population concentration, and the completeness of supporting infrastructure simultaneously enhances land-use efficiency and housing market value, driving the three systems toward a positive interactive relationship and thus keeping the coupling coordination degree at a high level. Moving outward toward the periphery, public service quality and transport network density decline progressively, regional residential attractiveness weakens, and population concentration gradually contracts, which directly causes land development intensity and housing market vitality to fall in tandem, so the coupling coordination level decreases accordingly. From the perspective of land resource constraints, the central urban districts carry a long development history, their construction land approaches saturation, and land use has entered a phase of stock renewal. Through prolonged mutual adjustment, land, population, and housing have formed a stable and compatible relationship. The distant suburban areas, by contrast, hold abundant land reserves, yet limited by locational disadvantages and infrastructure shortfalls, land development there lacks effective support from population and housing demand, and the advantages of land resources consequently fail to translate into systemic coordination advantages, ultimately manifesting as coupling dissonance. From the perspective of housing market dynamics, housing prices and supply-demand patterns attach closely to population distribution and land supply. In the central urban districts, robust residential demand combined with limited housing supply pushes prices upward, and the three systems maintain tight mutual

linkage. In peripheral areas, insufficient demand and elevated housing stock suppress market activity, which further widens the spatial gap in coupling coordination levels across the full study area.

3.2. Influencing Factors and Underlying Mechanisms of Population, Land, and Housing Discrepancies in Guangzhou City

Based on the factor detector module of the Geo-detector, a q-value analysis was conducted on 12 selected influencing factors. The results (Figure 8) reveal marked disparities in the extent to which these factors drive the spatial mismatch among population, land, and housing. The four most influential factors, ranked in descending order, are X12 (q = 0.8605), X4 (q = 0.8593), X5 (q = 0.8034), and X1 (q = 0.7675). Given that all their q-values exceed 0.75, they are classified as strong drivers and exert the greatest influence on the coupling coordination level of Guangzhou’s population-land-housing system, functioning as the principal determinants of the observed spatial mismatch. Specifically, X12 reflects the concentration of office buildings within the industrial layout, which has the most pronounced effect on spatial matching; regions with higher office building density tend to exhibit greater population agglomeration and enhanced land-use efficiency, thereby increasing housing demand and prices and resulting in a higher degree of coupling coordination. Closely following, X4 represents the adequacy of public transit facilities—a proxy for transportation convenience—which is critical for aligning the three elements. Denser bus coverage facilitates population aggregation, enabling land use and housing supply to better correspond to population distribution and effectively mitigating spatial mismatch. Similarly, X5 and X1 demonstrate strong driving effects, indicating that public service facilities and locational conditions serve as core guiding forces for population concentration, land development, and housing provision, directly influencing the spatial matching efficiency among the three components.

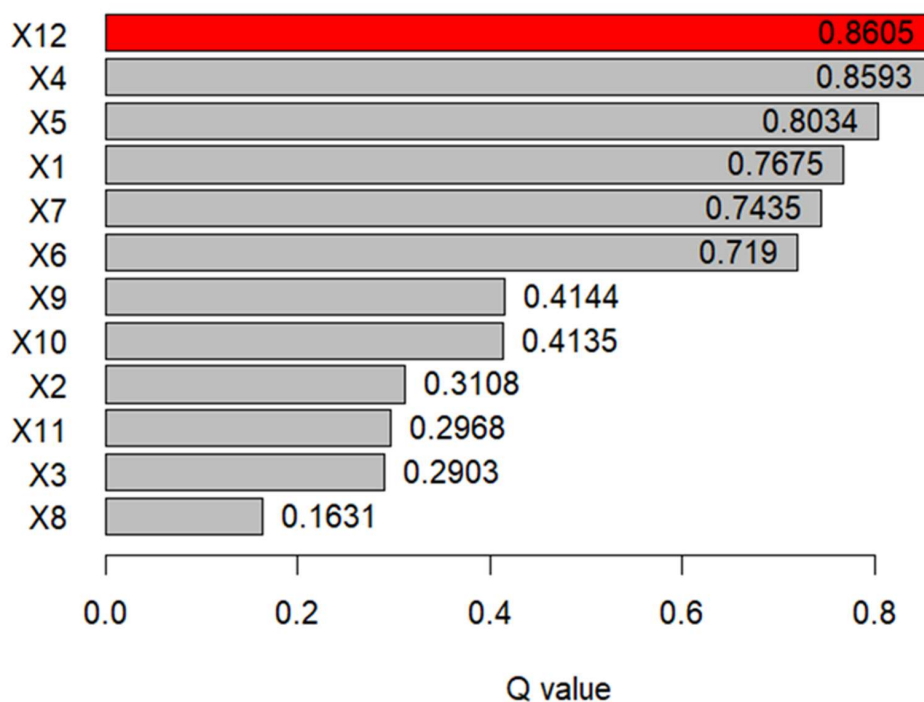


Figure 8. Detection results of q values under different influencing factors.

In stark contrast, the three weakest influencing factors are X8 (q = 0.1631), X3 (q = 0.2903), and X11 (q = 0.2968). With q-values below 0.3, these are categorized as weak drivers and exert relatively limited influence on the population-land-housing mismatch

in Guangzhou. Notably, X8, which pertains to the ecological environment, has the lowest q-value, indicating that its driving effect on the coupling coordination level is minimal compared to factors such as location, transportation, and public services. The weak driving effects of X3 and X11 suggest that overall road network density and manufacturing industrial layout have limited impact on population-land-housing matching; relative to office agglomeration and public transit facilities, their role in fostering coordinated development among the three elements is not prominent.

The q-values of the remaining factors range between 0.3 and 0.75, classifying them as moderate drivers. Their influence on the population-land-housing mismatch is intermediate, serving as a mediating force between the strong and weak drivers. Collectively, these factors constitute a multi-driver system underlying Guangzhou’s population-land-housing spatial mismatch. In summary, locational conditions, transportation convenience, public service facilities, and office layout emerge as the core determinants of the mismatch, whereas the ecological environment, manufacturing layout, and road density exert comparatively limited effects.

Based on the interaction detector module of the Geo-detector, a pairwise interaction analysis was conducted on the 12 factors to assess the comprehensive impact of dual-factor interactions on the coupling coordination level of Guangzhou’s population-land-housing system. This analysis elucidates the nature of interaction relationships among factors and further reveals the complex driving mechanisms underlying the mismatch (Figure 9). The results indicate that all dual-factor interactions exhibit a bivariate enhancement relationship. No instances of bivariate weakening, antagonistic effects, or nonlinear enhancement/weakening were observed. This finding implies that the joint driving force of any two interacting factors on the coupling coordination level surpasses that of any single factor alone. The factors demonstrate a positive, synergistic, and mutually reinforcing relationship, collectively contributing either to the improvement of coupling coordination or to the exacerbation of spatial mismatch.

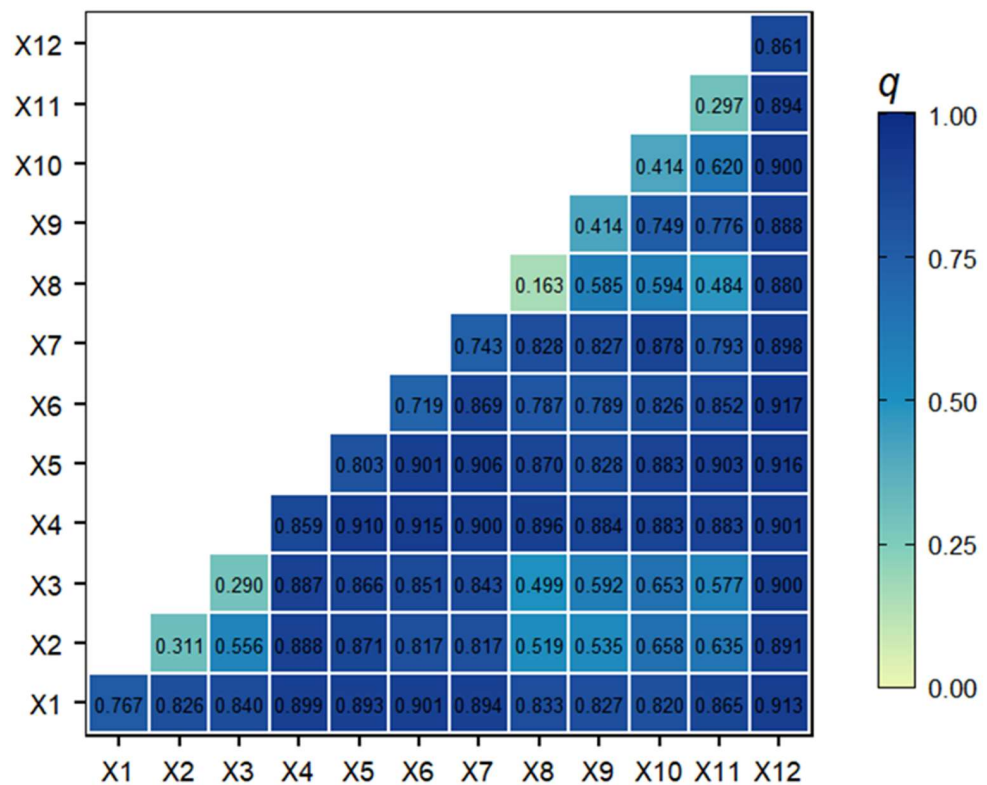


Figure 9. Interaction test results of different influencing factors.

A detailed examination of the interaction results reveals substantial variation in driving strengths when factors interact, closely aligning with the single-factor q-value findings. When strong drivers (X4, X5, X12, X1) interact with any other factor, their combined q-values exceed 0.8, indicating an exceptionally strong synergistic driving effect. This suggests that the influence of core strong drivers on population-land-housing matching is further amplified through interaction with other factors. Conversely, when weak drivers (X3, X8) interact with any other factor, their q-values remain within the range from 0.2 to 0.4, reflecting a persistently weak driving effect. Although these factors exhibit bivariate enhancement upon interaction, their combined driving strength remains substantially lower than that of the strong drivers. This indicates that the synergistic amplification effect of weak drivers is limited; even in combination with core strong drivers, they do not significantly elevate the overall driving force affecting the population-land-housing mismatch.

In conclusion, the driving mechanism underlying Guangzhou's population-land-housing mismatch is characterized by the dominance of core factors and the synergistic enhancement of multiple factors. Interactions among strong drivers generate a potent synergistic effect, serving as the primary engine that either facilitates coordinated development or intensifies the mismatch. Meanwhile, the synergistic contributions of weak drivers are limited, exerting only a minor influence on the overall driving mechanism. These findings further corroborate the conclusions derived from the single-factor q-value analysis.

Drawing on the preceding analytical results and the general developmental patterns of urban human settlement systems, and applying the geographical approach of using spatial variation as a proxy for temporal progression, this study constructs an ideal evolutionary conceptual framework that links population concentration, land constraints, and housing prices. This framework divides urban development into three theoretical stages, and the interaction characteristics among the three systems differ notably across each stage. One clarification is necessary here. This study relies solely on single-period cross-sectional spatial data from 2020 and therefore cannot capture the long-term dynamic changes in Guangzhou. The following three stages accordingly represent a theoretical model, and their respective characteristics are interpreted through analogy with the spatial differentiation features of Guangzhou's center-periphery ring structure, as illustrated in Figure 10.

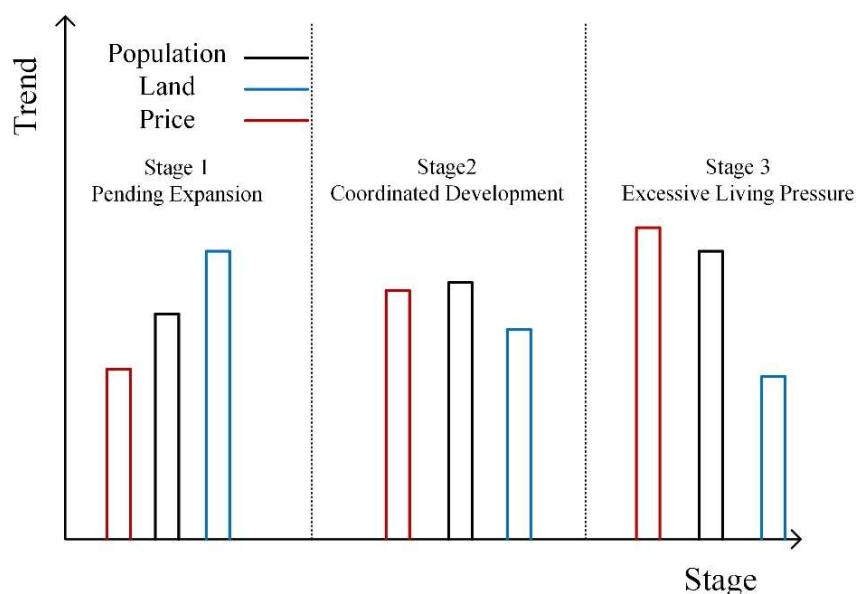


Figure 10. Ideal Evolutionary Conceptual Framework for the Coupling Relationships among Population, Land, and Housing Prices in Guangzhou.

The first stage is characterized by insufficient land development, corresponding theoretically to the early period of urban growth, and finds its spatial analogue in the current developmental conditions of distant suburban areas within the study region. In such areas, population concentration remains at an early stage, with a comparatively small total population and weak agglomeration effects, and overall housing demand stays insufficient. Meanwhile, the region holds abundant land resource reserves, yet development intensity is limited and land utilization efficiency is low, which keeps land values at a subdued level. Under this theoretical stage, the three systems have yet to form a positive interactive relationship, and the mismatch problem mainly manifests as idle land resources, with housing supply and population demand both remaining low. Core driving factors such as transportation, industry, and public services have not yet released their full effects, and the overall coupling coordination degree of the system consequently stays at a low level.

The second stage is characterized by coordinated development, corresponding theoretically to the period of rapid urban expansion, and finds its spatial analogue in the current developmental conditions of near-suburban areas within the study region. As urban construction advances, the scale of population inflow into the region expands continuously, and both rigid housing demand and improvement-oriented demand are gradually released. At the same time, the stock of developable land steadily decreases, land utilization efficiency improves markedly, and land supply progressively aligns with population scale and housing demand. At this stage, core driving factors including location, transportation, public services, and industry converge into a synergistic force, and the three systems of population, land, and housing enter a positive interactive state. The degree of coupling mismatch reaches its lowest point, and the characteristics of coordinated development become particularly prominent.

The third stage is characterized by mounting residential pressure, corresponding theoretically to the mature period of urban development, and finds its spatial analogue in the current conditions of Guangzhou's core central urban districts. Population concentration in such areas reaches a high and near-saturated level, and housing demand remains persistently elevated. Construction land approaches exhaustion, land supply forms a rigid constraint, and this scarcity further drives housing prices upward. Core driving factors continue to play a dominant role at this stage, yet the contradiction between excessive population concentration and scarce land resources intensifies steadily, and housing supply struggles to keep pace with robust residential demand. Although the overall coupling coordination level remains relatively high, latent imbalances within the system gradually become more pronounced.

Taken together, the theoretical framework reveals that the interplay among population concentration, land constraints, and housing prices constitutes the intrinsic mainline underlying systemic mismatch, and the synergistic effects of additional driving factors including location, industry, transportation, and public services collectively shape the coupling characteristics at each theoretical stage. Viewed against the actual conditions of Guangzhou, the distinct spatial rings of the city correspond precisely to the typical developmental forms identified above, and the observed spatial differentiation features align closely with the ideal evolutionary framework.

4. Discussion

Using Guangzhou as an empirical case, this study systematically examines the spatial coupling characteristics and driving mechanisms of the population-land-housing system. Responding to the need for coordinated development under new-type urbanization, and addressing the limitation of traditional human-land frameworks that omit the housing dimension, the study focuses on the spatial mismatch among these three interrelated

systems. Through comprehensive analyses, the study elucidates the spatial coupling status, typologies of matching, and the underlying drivers shaping these dynamics in Guangzhou.

When situated within the broader corpus of domestic and international scholarship, the findings align with established patterns while contributing methodological innovations. Consistent with prior research, a pronounced core-periphery gradient in coupling coordination is observed, with the urban core exhibiting higher levels of integration that diminish toward peripheral zones. [58,84]. Current literature widely recognizes locational conditions, transit accessibility, public service amenities, and industrial spatial layout as the primary determinants of population-land-housing coupling [20,62]. This mirrors our Geographical Detector findings, which identified office density, bus stop coverage, educational resource density, and distance to the city center as strong driving factors, confirming their dominant roles in synergistic urban development. Unlike conventional studies that broadly categorize matching types into simple coordinated or unbalanced classifications [20], or generic “population/land/housing-leading” types without considering specific urban development stages [33], our research provides a highly granular classification. By distinguishing specific categories—for instance, high population coupled with low land availability and elevated housing prices, as well as low population combined with abundant land and lower housing prices—this approach more accurately reflects the distinctive spatial mismatch patterns observed in Guangzhou [46]. While the majority of prior studies emphasize the static effects of spatial determinants [47], this study conceptualizes the driving mechanism as a dynamic evolutionary process: Land Underdevelopment → Synergistic Coordination → Increasing Residential Pressure. This framework elucidates the interactive relationships among population, land, and housing at various stages of development, thereby markedly differentiating our approach from static analyses [6]. Therefore, building upon the foundational conclusions of broader investigations, this study harnesses the unique regional characteristics of Guangzhou and an optimal spatial scale to generate highly specific insights. It not only validates the general principles of ternary coupling observed in large metropolitan areas but also accentuates the particular regional attributes of Guangzhou [9].

Megacities in developed regions such as Europe, North America, and East Asia have successively passed through phases of rapid urbanization and have accumulated mature policy frameworks and research findings in areas including land-use regulation, residential land allocation, coordinated governance of human–land–housing relationships, and the activation of idle land [85]. Tokyo, as a highly population-concentrated megacity in Japan, faces land resource pressures remarkably similar to those of Guangzhou and has become a key international case study for research on population–land–housing coupling [86]. At the level of land-use policy, Tokyo introduced urban growth boundaries and zoning control systems at an early stage, strictly demarcating urban expansion zones from ecological control zones, firmly curbing disorderly outward urban sprawl, and guiding the internal stock renewal of construction land. To address land development saturation in the central urban districts, Tokyo raised land utilization efficiency through vertical development and mixed land use, while to counter idle land and suburban dormitory town decline, the government gradually reduced fiscal subsidies to satellite cities, promoted the return flow of population and industry toward the main urban core, and optimized the spatial distribution of land, population, and housing accordingly [26]. New York operates a highly marketized land system, yet the central urban districts hold a low proportion of residential land, and compounded by land speculation, this produces insufficient housing supply, persistently high rents, and low vacancy rates, with the excessive financialization of land value making the human–land conflict particularly acute. Local studies have shown that market regulation alone cannot resolve the residential land shortage in the core districts, and government land banking together with mandatory proportional requirements for affordable housing

sites must serve as supplementary policy instruments [13]. Paris strictly restricts new large-scale construction land, relying primarily on old city renewal and the transformation of existing government-held land to build social housing, and law requires municipalities to guarantee a minimum proportion of social housing, balancing the residential needs of different income groups through land function restructuring [87]. Many Western European countries have pursued urban densification policies, tapping the potential of existing land within development boundaries, rejecting disorderly outward expansion, and thereby achieving both land-intensive use and residential quality improvement simultaneously [21]. Drawing on global urban policy and related research, all megacities at a mature stage of development exhibit a concentric-zone mismatch pattern of tight land supply in the center and inefficient land use in the periphery, and the land supply model directly determines population flows and housing patterns, which constitutes a universal challenge in the urbanization process [88]. The key distinction lies in the fact that China practices public land ownership, under which land planning and quota controls are more stringent and the institutional capacity to coordinate the overall spatial layout of population, land, and housing across the full territory is stronger, whereas European, American, Japanese, and Korean systems are predominantly built on private land ownership, and policies there focus more narrowly on local zoning adjustments, stock activation, and interest mediation [68].

By incorporating housing as an independent system, this study transcends the traditional population-land binary framework in human-land relationship research and integrates housing system into the research framework as a concrete embodiment of human-land interactions [30]. Consequently, this approach offers a solid theoretical foundation for future investigations into multi-system coupling and enhances our comprehension of the evolution of human settlements within the context of contemporary urbanization paradigms.

This study uses second-hand housing prices as a single indicator to represent the housing system, which constitutes a simplified approach. Although housing prices can broadly reflect multiple characteristics including housing supply and demand, vacancy levels, residential quality, and supporting infrastructure conditions, they cannot precisely decompose sub-dimensions such as housing affordability, vacancy rates, and the internal living environment, leaving the characterization of the housing system somewhat one-sided. Furthermore, the research data cover only second-hand housing transaction records and exclude new housing market and rental market information, so the conclusions apply primarily to Guangzhou's existing housing stock market and cannot fully represent the city's entire housing system. Additionally, the primary dataset is based on a 2020 cross-sectional baseline, thereby excluding dynamic changes in population mobility, land development, and housing policy adjustments that have occurred post-2020. This temporal limitation restricts the study's capacity to reflect the most recent spatio-temporal evolutionary trends. Future research should aim to refine the spatial scale to the community level and incorporate field survey data to more accurately identify micro-spatial mismatches. Moreover, the integration of longitudinal data—such as updated census information, dynamic land-use monitoring, and real-time housing transaction records—would enable a more precise tracking of the ongoing evolution of these coupling relationships. Comparative analyses across multiple cities are also recommended to enhance the generalizability and policy relevance of the findings.

Drawing on the developmental characteristics of different spatial rings in Guangzhou, this study proposes targeted refinements to land-use regulation and stock activation measures. In the central urban districts, a comprehensive investigation of existing construction land should be conducted, covering old factory areas, underperforming commercial buildings, and idle public housing. Through mixed-use functional renovation and partial

adjustments to planned land uses, inefficient parcels can be converted in an orderly fashion into housing for rigid demand and supporting land uses, thereby maximizing the value of existing spatial resources. In near-suburban areas, the authorities should strictly enforce the linkage mechanism between population, industry, and residential land allocation, releasing land supply in accordance with population inflow and industrial development progress so as to eliminate premature land approvals. In distant suburban areas, a dedicated clearance investigation of idle land should be conducted, legally compelling overdue undeveloped parcels to commence construction or reclaiming their land use rights, while the transfer scale of large-scale commercial and residential land warrants tight control. Across the entire city, a dynamic land-use supervision mechanism at the subdistrict scale should be established, integrating real-time optimization of land supply plans with changes in population and housing data, so as to achieve precise alignment among land development, stock activation, and residential demand.

5. Conclusions

This study takes Guangzhou's subdistricts as the analytical unit and draws on multi-source data including the 2020 Seventh National Population Census, employing the coupling coordination model, relative development model, and geo-detector to conduct an empirical analysis. The results indicate that the coupling coordination level between population and existing housing stock in Guangzhou displays a concentric-zone pattern of central concentration and peripheral decline, and the full study area can be classified into three spatial matching types, namely the core-differentiated type, the peripherally imbalanced type, and the surrounding-equilibrium type. Office building density, public transit provision, educational resources, and locational conditions emerge as the core driving factors, and all influencing factors exhibit a dual-factor enhancement characteristic in their interactive effects. Combined with the theoretical framework constructed through the spatial-for-temporal substitution approach, the system interactions can further be divided into three ideal developmental stages. From an academic standpoint, this study moves beyond the conventional human–land binary analytical paradigm and constructs a human–land–housing ternary coupling framework, thereby extending the application boundaries of classical theories such as human–land areal system theory and spatial mismatch theory to the domain of megacity human settlements. It additionally standardizes the analytical logic for single-period cross-sectional data, substantiates the rationale for equal-weight assignment across multiple systems and for using second-hand housing prices as a proxy indicator for the housing system, refines the typological classification of spatial matching patterns, and enriches the research methods and empirical paradigms for studying human settlement system coupling. In terms of practical contributions, this study precisely identifies the mismatch problems in land development and existing housing stock across different spatial rings of Guangzhou and puts forward targeted, actionable measures for stock activation and land-use regulation. These findings provide empirical support for Guangzhou to optimize spatial resource allocation and advance the high-quality development of new-type urbanization, while also offering a replicable case and transferable experience for comparable megacities in China to conduct similar research and spatial governance.

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