sustainability

MDPI

Article

How Does the Spatial Structure of Urban Agglomerations Affect the Spatiotemporal Evolution of Population Aging?

Miao Fu [1], Lucang Wang [1,2,*] and Qianguo Li [3]

[1] College of Geography and Environmental Science, Northwest Normal University, Lanzhou 730070, China; fmiao2022@163.com
[2] Key Laboratory of Resource Environment and Sustainable Development of Oasis, Lanzhou 730070, China
[3] College of Agricultural and Forestry Economics and Management, Lanzhou University of Finance and Economics, Lanzhou 730020, China; xsdlqg@126.com
* Correspondence: wanglc007@nwnu.edu.cn

Abstract: China has fully become an aging society, and the scientific response to population aging has become a major task that the country must face in the future. Research on population aging in the Chengdu-Chongqing urban agglomeration (CCUA) can provide a scientific basis for future population management in the CCUA. This paper applies spatial autocorrelation, geodetection, and other methods to analyze the temporal and spatial pattern of population aging and its driving factors in the CCUA from 2000 to 2020, taking districts (counties) as the basic unit and combining them with the spatial structure of the urban agglomeration. The results show that: ① in the time dimension, the population aging in CCUA has gone through the evolution process of "mild–moderate–heavy"; in the spatial dimension, the influence of the urban agglomeration's development planning axes on the spatial differentiation of the aging population has become more and more prominent. ② The aging level has a strong spatial correlation, and with time, the spatial correlation has changed from weak to strong, and the spatial difference has increased. The dual core city shows a typical spatial pattern of a decreasing aging level in the core area and an increasing aging level in the peripheral area, and the heavily aging area is spreading along the axis. ③ The overall aging speed is high, and the aging speeds of the core cities and node cities are lower than those of other regions. There is a clearer positive correlation between the aging level and the speed of aging, showing the characteristic of "the older the faster". ④ Endogenous factors such as the aging level and fertility level at the beginning of the period have a significant determining power on the change in the aging level, while exogenous factors such as the in-migration rate and the out-migration rate have a persistent determining power on the urban agglomerations and key areas (core cities, central cities, main axes of development, city belts, and dense urban areas).

Keywords: population aging; spatial and temporal changes; influencing factors; urban agglomeration; spatial differentiation

Citation: Fu, M.; Wang, L.; Li, Q. How Does the Spatial Structure of Urban Agglomerations Affect the Spatiotemporal Evolution of Population Aging? *Sustainability* **2024**, *16*, 3710. https://doi.org/10.3390/su16093710

Academic Editors: Jian Feng and Ming Tian

Received: 18 March 2024
Revised: 20 April 2024
Accepted: 26 April 2024
Published: 28 April 2024

1. Introduction

The world is currently undergoing two demographic transitions: urbanization and aging, and these two trends will soon converge (United Nations Population Division). Urbanization acts as a "converter" and "catalyst" for aging [1], and eventually, people will grow old in cities. Population aging is expected to pose significant headwinds against the region's future economic growth [2]. According to the United Nations, 56.5% of the global population lives in cities, which is expected to reach around 68% by 2050 (UN, 2022a [3], UN, 2022 2b [4]). The World Population Ageing Report (UN, 2017) states that the proportion of the global population aged 60 and over will increase from 12% to 23% by 2050. This trend in population aging is even more obvious in China, where residents ≥ 60 are expected to account for 35% of the total population by 2050 (UN, 2017) [5]. Since the reform and opening up of China, the trends in urbanization and aging have both accelerated, with the level of urbanization increasing from 36.91 percent to 50.27 percent during the period from 2000 to 2010, at an average annual rate of 1.4 percent. The average annual growth rate of the elderly population was as high as 3.5%, with the rate of aging being far faster than the rate of urbanization. Since 1996, however, the growth rate of China's urbanization rate has begun to decline, with the growth rate falling below 1% for the first time in 2021 and being only 0.5% in 2022. However, the aging process is still accelerating, with the average annual aging rate rising by 0.18 and 0.45 in 2002–2012 and 2012–2022, respectively, creating a fast and old trend. Moreover, as China's demographic structure transforms, it will shift from "longevity-type aging" to "childless aging".

Urban agglomeration is the main form of China's new urbanization, and in the future, more than 80% of China's population will be distributed across 19 urban agglomeration areas [6]. Relative to individual cities, urban agglomeration can allocate resources from a wider area, thus attracting a large number of people to gather there [7–9]. The result is that the population aging process and its outcomes in urban agglomerations are significantly different to those in the general area. The urbanization of the Chengdu–Chongqing urban agglomeration (CCUA) is advancing rapidly. However, the aging process and pattern resulting from population migration and aggregation deviate from the typical trend observed in the country and other established urban agglomerations. At the same time, within the urban agglomeration, the siphoning effect of the core cities has led to the uneven and unequal development of the core and peripheral areas. While the core area attracts an inflow of young people which causes a dilution of the aging level, the peripheral area experiences a residual aggregation effect of the elderly population due to the outflow of young people. Therefore, studying the unique process of population aging in urban agglomerations, particularly the differences in the level, speed, and type of aging across various regions within the agglomeration, is crucial for developing tailored policies. This research has significant practical and theoretical implications. The purpose of this paper is to reveal how the internal structure of urban agglomeration affects the spatio-temporal evolution of population aging.

Literature Review

By combing through previous studies, it has been found that population aging is an irreversible change in the urban population age structure at present and for a long time in the future, and this tendency for change inevitably has significant and continuous influence on the urban economy in the future [10]. The study of urban agglomeration aging is carried out alongside the study of the processes of urbanization and aging [11]. In foreign countries, due to the lack of the concept of urban agglomeration, the study of population aging is gathered in metropolitan areas. In the United States, 75% of the elderly population lives in metropolitan areas, half of which are concentrated in the center of the city, forming a typical "retirement" center [12]. According to the American Community Survey, 12% of older Americans ($\geq$65 years of age) lived in nonmetropolitan areas from 2005 to 2009 [13]. "The Rust Belt metropolitan areas" all have older populations that are over 14% of the total population. The rise in population aging in metropolitan areas has been accompanied by changes in their internal structure, with older adults in the urban core moving to the periphery. Between 2000 and 2010, the proportion of older adults living in the metropolitan core decreased from 15% to 13%. Over the same period, 97% of the increase in the number of older adults occurred in the suburbs and far-flung suburbs [14]. Similar trends have been observed in other countries and regions as well [15,16]. Suburbanization and migration of the elderly population are the main influencing factors.

China is a major research center for urban agglomerations. However, the research mainly focuses on issues such as spatial structure and the synergistic development of urban agglomerations, with relatively little research on aging. Existing studies have found that population aging in China's urban agglomeration as a whole showed an accelerated deepening trend from 2000 to 2020 [17,18]. However, there are significant differences in the increasing speed of different urban agglomerations, and the discrete degree of population aging in the cities under the jurisdiction of urban agglomerations has a significant tendency to widen over time. The average aging level of China's 20 urban agglomerations in 2000 was 7.32%, of which 12 urban agglomerations were of the adult type. By 2010, the average level of population aging had risen to 9.00%; except for the Pearl River Delta and the Ningxia Along the Yellow River urban agglomeration, the other 18 urban agglomerations have all entered the old-age population stage, showing a clear trend of escalation and type substitution [19]. The aging rate of the Ha-Chang and Liao-Zhongnan urban agglomerations, which have a serious population outflow, is relatively fast, and aging is becoming more and more serious, while the aging rate of the Pearl River Delta, the Yangtze River Delta, the West Coast of the Taiwan Strait, and the Beibu Gulf urban agglomerations, which have a large population inflow, is relatively slow [17].

Urban agglomerations at different levels of development have different processes and levels of population aging. In general, the speed of population aging in urban agglomerations in the primary stage is significantly accelerated, and the starting point of population aging in urban agglomerations in the intermediate and advanced stages is relatively high [20]. The mature urban agglomeration of the Yangtze River Delta has experienced three stages of population aging. These are longevity (healthy) aging, childless aging, and migration (mobility) aging. The level of population aging varies along the development axes of Shanghai–Nanjing and Shanghai–Hangzhou–Ningbo, showing an inverse core–edge structure. The regional center city becomes the wave valley of the region's core–edge structure. The growing urban agglomeration (Guanzhong Plain Urban Agglomeration) has gradually formed a circle distribution pattern of "low in each district of the city and high in the surrounding counties", and is characterized by a low starting point and accelerated growth [21]. The different population aging type areas in the Central Plains urban agglomeration can be divided into four major categories, six subcategories, and ten subcategories. Among them, the agglomeration aging type and residual aging type account for the vast majority [22], aging is also in an accelerated state [23], and the high level of aging is expanding from a local area to the whole region [24]. In different urban agglomerations, the unevenness of population aging and its evolution trajectory are different. The overall difference in aging in the Pearl River Delta (PRD) shows a shrinking trend, while the overall difference in aging in the Yangtze River Delta (YRD) shows a fluctuating development [25], the degree of aging has deepened, forming four-county clusters of areas in the heavy aging stage [26]. The aging population in counties in the twin-city economic circle of the Chengdu–Chongqing region mainly exhibits the spatial distribution characteristics of similar types of agglomeration [27].

Urban agglomeration is a form of spatial organization in which cities have developed to a mature stage [28] with a complex internal structure, which affects the spatial and temporal evolution pattern of population aging in urban agglomerations. There is evidence that, within an urban agglomeration, the distribution pattern of aging exhibits the coexistence of uplift–collapse [19]. The process, pattern, and mechanism of population aging are not only reflected among urban agglomerations but also within urban agglomerations. Specifically, there are differences in the speed, type, and mechanism of aging between the core area and the peripheral area. These differences also exist between the core city and the node city, as well as between the general city and the hinterland. The existing research takes urban agglomeration as a whole and does not consider the fundamental influence of the internal spatial structure of urban agglomeration and its heterogeneity on the spatiotemporal pattern of aging. Some research has studied the spatial and temporal differences in aging in urban agglomerations based on the city or county scale. On the surface, it seems to reflect the spatial heterogeneity within the urban agglomeration, but the city and county scales do not reflect the spatial differences within the urban agglomeration and homogenize the spatial units (city or county) within the urban agglomeration. Secondly, in the analysis of drivers, the mechanism of the influence of each factor on population aging in an urban agglomeration is emphasized, but the urban agglomeration is taken as a whole. No attention is paid to the fact that, since there is spatial heterogeneity in population aging within an urban agglomeration, there is also heterogeneity in the contribution of each influencing factor to population aging within the urban agglomeration. Therefore, the main purpose of this thesis is to deconstruct how the internal structure of an urban agglomeration (core–axial belt district) influences the spatial and temporal heterogeneity of population aging. Are the drivers of population aging heterogeneous in the spatial structure of urban agglomeration?

The Chengdu–Chongqing urban agglomeration (CCUA) is a national urban agglomeration leading the development and opening up of western China, an important platform for the development of western China, an inland open economy, and a strategic highland, as well as strategic support for the Yangtze River Economic Belt. Between 2000 and 2010, both the increase in the rate of aging and the rate of increase were much higher than those of the Yangtze River Delta, which is also a "national urban agglomeration ", facing greater pressure from "aging fast". Compared with mature urban agglomerations, the CCUA is still in the growth stage, and population aging is also in the process of undergoing dramatic changes. As a typical dual-core urban agglomeration, the CCUA experiences unbalanced development between Chengdu and Chongqing. This imbalance not only attracts a mobile foreign population but also creates competition for both the population (especially young and middle-aged individuals) and resources within the region. Consequently, the flow of the population between different spatial units within the urban agglomeration varies significantly, leading to more prominent residual and aggregated heterogeneity among the elderly population. To cope with aging scientifically, it is necessary to answer the question of what special spatial and temporal processes the aging population of the CCUA has gone through. Is it the result of "local aging" or "migration and dilution"? What are the driving factors? Based on this, this paper takes the 145 districts (counties) of the CCUA as the basic unit, and decomposes and corresponds them to the spatial structure of the urban agglomeration (core, axial belt, and urban agglomeration), and seeks to portray the spatial heterogeneity of the level, speed, type, and driving factors of aging, based on the data from the three population censuses to explore how the spatial structure of the CCUA urban agglomeration affects the spatio-temporal pattern of population aging.

2. Materials and Methods

2.1. Study Area

The Chengdu–Chongqing urban agglomeration (CCUA) is a key development area in central and western China. It is one of the five national urban agglomerations in China and plays a pivotal role in the economic development of the central region and the entire country. Additionally, it serves as an important platform for the development of the western part of the country, provides strategic support for the Yangtze River Economic Belt, and serves as a significant demonstration area for promoting new types of urbanization in China. According to the CCUA Development Plan approved by the State Council, the specific scope of the area includes 27 districts (counties) in Chongqing, including Yuzhong, Wanzhou, Qianjiang, Fuling, Dadukou, Jiangbei, Shapingba, Jiulongpo, Nan'an, and Beiqiang, as well as part of Kaizhou and Yunyang; and Zigong, Luzhou, Deyang, Mianyang (in addition to Beichuan and Pingwu counties), Suining, Dazhou (in addition to Wanyuan), Ya'an (in addition to Tianquan and Baoxing counties), and Chengdu, Zigong, Luzhou, Deyang, and Mianyang in Chengdu (in addition to Beichuan and Pingwu counties). According to the plan, the CCUA will build a "one axis, two belts, two cores, three districts" spatial development pattern (Figure 1). One axis refers to the Chengdu–Chongqing Development Axis (CC_{DA}). The two belts include the Urban Belt along the Yangtze River (YZ_{UB}) and the Chengdu–Deyang–Mianyang–Leshan Urban Belt ($CDML_{UB}$). The two cores refer to the two core cities (Chengdu and Chongqing). Three districts include the Southern Sichuan Urban Agglomeration Area (SS_{UAA}), Nanchong–Suining–Guang'an Urban Agglomeration Area (NSG_{UAA}), and the Dazhou–Wanzhou Urban Agglomeration Area (DW_{UAA}). There are also two other metropolitan areas involved around the core city, the Chengdu metropolitan area (CD_{MA}) and the Chongqing metropolitan area (CQ_{MA}).

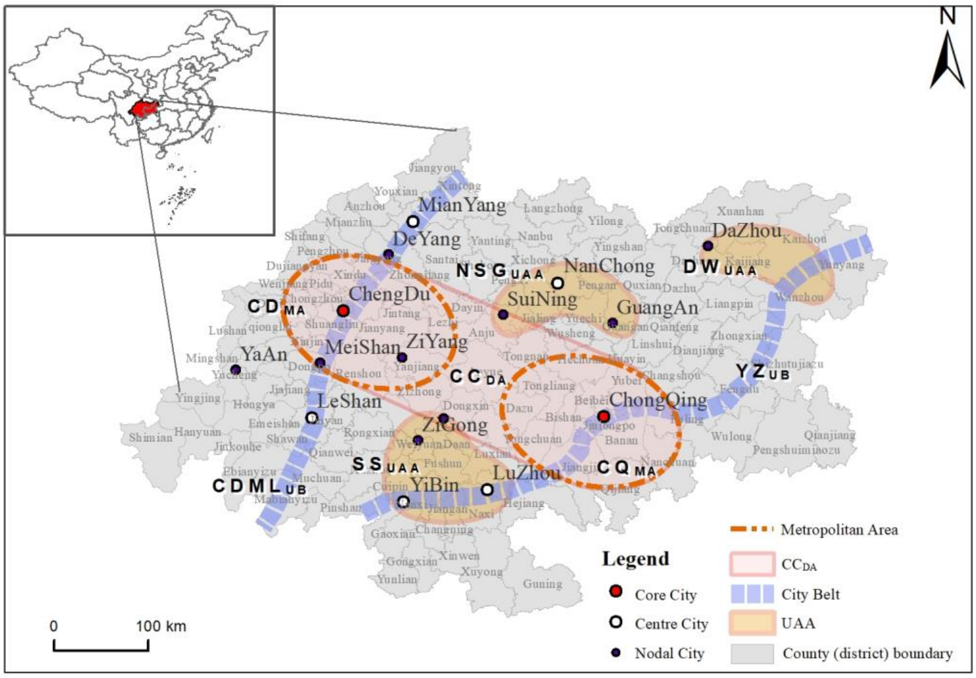


Figure 1. Spatial pattern of CCUA.

2.2. Data Sources

In this paper, the demographic data related to the resident population and the elderly population are all from China Census Subcounty Data (2000, 2010, 2020). Due to the more frequent adjustment of administrative divisions within the CCUA, this paper takes the districts (counties) in 2000 as the benchmark and adjusts some of the districts (counties) that have changed between 2010 and 2020 to reach a total of 145 districts (counties).

2.3. Research Methods

2.3.1. Spatial Correlation Analysis

This method mainly uses GeoDa software 1.18.0.0 to calculate Moran's I index of the population aging coefficient in CCUA and analyze its spatial autocorrelation degree. There are two specific types of spatial autocorrelation analysis: overall spatial autocorrelation and local spatial autocorrelation. The first is the overall spatial autocorrelation analysis, which studies the geographic attribute values as a whole to determine whether they have spatial clustering characteristics [29–31]. The calculation formula is:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)}{\sigma^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{1}$$

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2, \overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \tag{2}$$

$$Z(I) = \frac{I - E(I)}{\sqrt{VAR(I)}} \tag{3}$$

In the formula, n is the number of spatial units; X_i is the observed value of unit i; X_j is the observed value of unit j; W_{ij} is the spatial weight matrix; σ^2 is the variance of the attribute value. $Z(I)$ is the significance test value of Moran's I index; $E(I)$ is the mathematical expectation; and $Var(I)$ is the variance. Theoretically, $Z > 1.96$ indicates positive correlation; $Z < -1.96$ indicates negative correlation.

On this basis, local spatial autocorrelation analysis was carried out at the district (county) scale of the CCUA, and the local spatial autocorrelation of the CCUA was calculated to reveal local spatial correlation characteristics and spatial agglomeration area location. The specific calculation formula is:

$$I_i = \frac{(X_i - \overline{X})}{\sigma^2} \sum_{j=1}^{n} W_{ij}(X_j - \overline{X}) \tag{4}$$

The I coefficient takes values between [–1 and 1] where less than 0 indicates negative correlation, equal to 0 indicates no correlation, and greater than 0 indicates positive correlation.

2.3.2. Model for Calculating the Rate of Aging

The average annual growth rate of the aging coefficient of each county in CCUA was calculated by using the "exponential growth model" measurement method, and graded and visualized by using the ArcGIS natural discontinuity method [32].

$$\begin{aligned} TA_i(65+) &= \frac{1}{n}\ln\left[\frac{p_i^{t+n}(65+)}{p_i^t(65+)}\right] - \frac{1}{n}\ln\left[\frac{p_i^{t+n}(0+)}{p_i^t(0+)}\right] \\ &= r_i(65+) - r_i(0+) \end{aligned} \tag{5}$$

In the formula, $p^t{}_i(65+)$ and $p^t{}_i(0+)$ are the number of elderly people and total population in each county unit; $p_i{}^{t+n}(65+)$, and $p_i{}^{t+n}(0+)$ are the number of elderly people and total population in each county unit after n years; and $r_i(65+)$ and $r_i(0+)$ are the average annual growth rate of elderly people and total population in each county unit.

2.3.3. Geodetector Analysis Methodology

GeoDetector is a spatial analysis method for detecting spatial dissimilarities as well as revealing the driving forces behind them, and it is widely used to perform driver analysis and factor analysis [33,34].

$$PD = 1 - \frac{\sigma_{D,P}^2}{\sigma_{D,Z}^2} \tag{6}$$

$$\sigma_{D,P}^2 = \frac{1}{n_{D,P}} \sum_{P=1}^{n_{D,P}} (y_{D,P} - \overline{y_D})^2 \tag{7}$$

$$\sigma_{D,Z}^2 = \frac{1}{n_{D,P}} \sum_{Z=1}^{n_{D,Z}} \sum_{P=1}^{n_{Z,P}} (y_{Z,P} - \overline{y_Z})^2 \tag{8}$$

PD denotes the effect of factor D on the dependent variable, $\sigma^2{}_{D,P}$ denotes the sum of the variances of each categorical region, and $\sigma^2{}_{D,Z}$ denotes the overall discrete variance in aging in the study area. $n_{D,P}$ denotes the number of sample sizes included in the categorical region, $n_{D,Z}$ denotes the number of categorical regions, $y_{Z,P}$ denotes the value of the attribute of all samples, $\overline{y_Z}$ denotes the mean value of all samples, $y_{D,P}$ denotes the value of the attribute of samples included in the categorical region, and $\overline{y_D}$ denotes the mean value of the classification region.

3. Results

3.1. Spatial and Temporal Evolution of Population Aging

3.1.1. Overall Rise in the Level of Population Aging and the Type of Shift

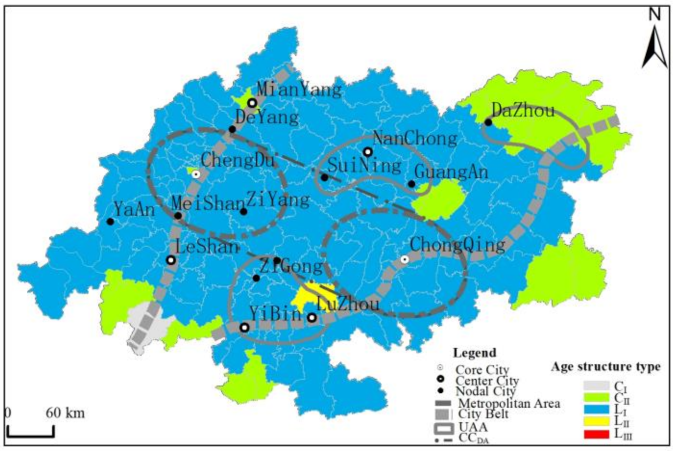
There are many indicators that can be used to measure the degree of aging, such as the coefficient of aging and the ratio of old to young. Among them, the coefficient of aging is an internationally and nationally recognized indicator. The coefficient of aging is the most direct indicator used to reflect the phenomenon of regional population aging, and it is an important symbol that reflects the degree and level of population aging. Therefore, this paper chooses the coefficient of aging (the proportion of the population over 65 years old to the total population) as the indicator of the degree of aging. We classify the population into six types based on the coefficient of aging, i.e., those with LD < 4.0% are in the young age group (Type N), those with LD between 4.0% and 5.5% are in the adult type I stage (Type C_I), those with LD between 5.5% and 7.0% are in the adult type II stage (Type C_{II}), those with LD between 7.0% and 10% are in the old age type stage I (Type L_I, mild aging), those with 10% to 14% were stage II aged (Type L_{II}, moderate aging), and those with more than 14% were stage III aged (Type L_{III}, severe aging) [35].

In 2000, the CCUA had already entered a state of mild aging, with the largest proportion (86.9%) of Type L_I people living 126 counties (districts) (Table 1, Figure 2a) with a contiguous distribution. During that period, the spatial structure of urban agglomeration did not affect the spatial pattern of population aging, and differences in the age structure of individual districts and counties were prominent. There are obvious differences in the age structure of individual regions due to the level of development and the concept of fertility. The central areas of dual-core cities and individual central cities have a young age structure. Specifically, only the southwest and northeast (both marginal areas of CCUA) still have adult populations, and the core city (Chengdu) and the central area of the important node city (Mianyang City) are Type L_{II}. Lu County and Chongqing Yuzhong District are Type L_{II} and are the only two moderately aging districts (counties) within the CCUA. The aging coefficients in Yuzhong District are as high as 10.56%, and Lu County is at 10.11%. Lu County has a slow natural population growth while the number of women of childbearing age continues to decrease. Yuzhong *District is typical of low births, low deaths, and low growth.* This can be attributed to the fact that the combination of a large elderly population base and relatively low natural increase has led to the development of a typical aging state in the two districts (counties). Mabian Yi Autonomous County has the lowest level of aging and is the only Type C_I county, where the fertility rate is as high as 18.3% due to the influence of ethnic minorities' fertility policies and concepts, diluting the level of aging from the bottom up.

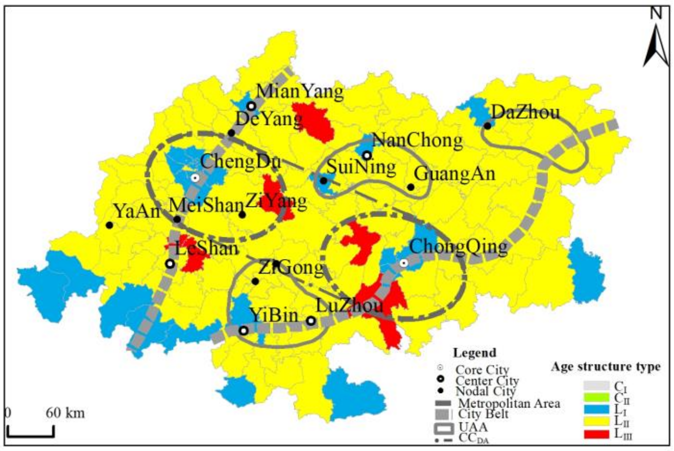
In 2010, the CCUA had fully entered a state of moderate aging, with the vast majority of the area being Type L_{II} and only a small number of counties in the southern fringe area still being Type L_I (Figure 2b). During this period, the spatial structure of the urban agglomeration began to influence the spatial pattern of population aging, which was evident in the metropolitan area and within the dense urban areas. The aging of the population in the metropolitan area gradually deepened from the center to the periphery. The dual-core cities (Chengdu and Chongqing) have formed a typical core–high/periphery–low circle of differentiation. The Qingyang district of Chengdu City and the Yuzhong district of Chongqing City are Type L_{II}, while the remaining peripheral districts are Type L_I. The increase in the aging level in the core area is the result of "aging in place", while the decrease in the low peripheral area is due to the inflow of a large number of young adults. The fringe areas of the metropolitan area are Type L_{III}. Within the three urban agglomeration zones, under the guidance of the urban agglomeration planning policy, the development of the key areas has accelerated, and the population has been attracted to flow into the better-developed central cities and nodal cities within the urban agglomeration zones. Within the three dense urban areas, the Cuiping District of Yibin City, the Chuanshan District of Suining City, the Shunqing District of Nanchong City, and the Tongchuan District of Dazhou City, the level of aging did not change compared to 2000, and it was Type L_I. The main reason for this was the increase in the total population from 2000 to 2010, which has had a diluting effect on the old-age population. Serious aging has occurred in the fringe areas of the "one axis, two belts, two cores and three districts" of CCUA. Six counties (districts), namely Lezhi in Ziyang City, Jingyan in Leshan City, Qingshen in Meishan City, Yanting in Mianyang City, Tongliang County in Chongqing Municipality, and the Jiangjin District, transitioned directly from mild aging in 2000 to severe aging in 2010. These counties (districts) are all located in the fringe area of the CCUA's "one axis, two belts, two cores, and three districts". Attracted to the core area and the axis, the populations have been in a state of loss or contraction between 2000 and 2010. Population contraction refers to a decrease in the total number of people in an area as a result of low birth rates, high death rates, and migration. Population loss refers to the phenomenon of population movement from one region to another. The natural population growth rates in Lezhi County, Jingyan County, and the Jiangjin District, of −1.17‰, −4.69‰, −4.0‰ (2020), are of typical population contraction in the county. Severe population contraction leads to deepening aging. Yanting County, with a household population of 537,200 and a resident population of 457,000 (2020), is a population loss county. Population loss, especially the outflow of young adults, can exacerbate the level of regional aging. Population contraction and loss form the "residual aging" effect (i.e., the loss of young adults and the residual elderly population, raising the level of aging).

In 2020, the degree of aging continued to deepen. Except for a few areas, the majority of districts (counties) reached the advanced stage of heavy aging, with Type L_{III} accounting for the largest proportion in 123 districts (counties) and Type L_{II} in 20 districts (counties). The spatial structure of an urban agglomeration has no significant spatial distributional impact on population aging. Specifically, it has no impact on dense urban areas and CC_{DA} but has a certain degree of impact on metropolitan areas and core cities. Compared with in 2010, the spatial structure of an urban agglomeration now has a weaker impact on the spatial pattern of population aging. It is possible that the aging base of the population in previous periods was too large or the number of people who were about to become elderly people was too large, which exceeded the attractiveness of the spatial structure of the urban agglomeration for the development of the population. Specifically, the metropolitan area still has an impact, characterized by a low core and a high periphery. The twin core cities within the metropolitan area still show a high core and low periphery. Compared with the overall rise in the regional aging level, the ageing levels of the two core cities declined, forming a strong contrast. On the one hand, the heavily aging region forms a contiguous distribution situation; on the other hand, a typical low center–high periphery circle structure has formed around the core of the two cities. The Chengdu Qingyang District and the Chongqing Yuzhong District are the Type L_{III}, and the surrounding districts (counties) are all Type L_{II}. Among them, the core city, the Chengdu Pidu District, shows a prominent difference compared to the surrounding areas, which are Type L_{I}. The main reason for not aging further is the dilution effect of aging due to the inflow of a young population. In 2010, the Pidu District had a resident population of 756,100 people, a household population of 508,600 people, and a net inflow of 247,500 people; in 2010, the resident population was 1,390,900 people, the household population was 673,500 people, and there was a net inflow of 717,400 people. The growth rate of the resident population is much larger than that of the household population, and the population inflow is prominent, leading to a declining level of aging. The impact on spatial differences in population aging is not obvious within the boundaries of dense areas and urban belts, with differences occurring only in individual central and nodal cities within their boundaries. The important node cities are the Cuiping District of Yibin City, the Shunqing District of Nanchong City, the Funshan District of Suining City, and the Hanyuan County of Ya'an City, which belong to the mutation type, directly transforming from the Type L_{I} in 2010 to the Type L_{III} in 2020. Combined with the changes in total population, these districts (counties) are experiencing an increase in total population and a concurrent increase in population aging, which is the result of "aging in place" (Figure 2c).

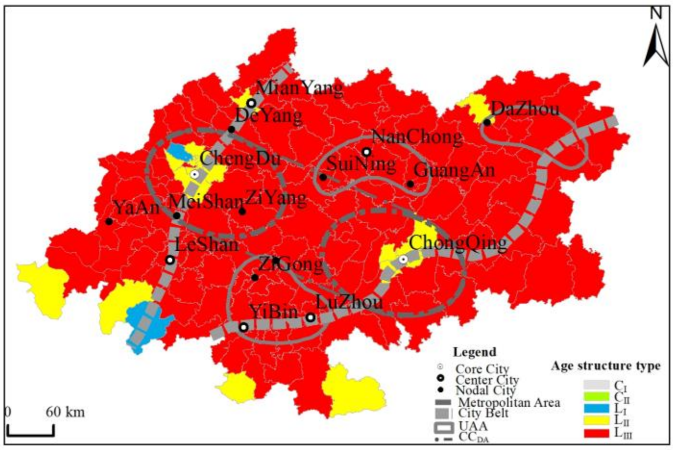
McCarthy proposed "spatial agglomeration of aging population", and divided the process of aging area change into three categories: accumulation, recomposition, and congregation [36]. With the help of the conceptual model of the population aging matrix, the type of population aging within the urban agglomeration can be decomposed into unchanged type, elevated type, leaping type, and conversion type. The unchanged type implies that the population type is stable, while the rising, leaping, and transitioning types indicate that the population type has changed and the degree of aging has increased.



(**a**)



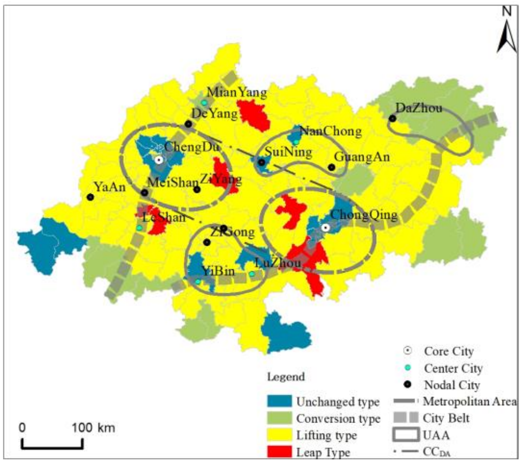
(**b**)



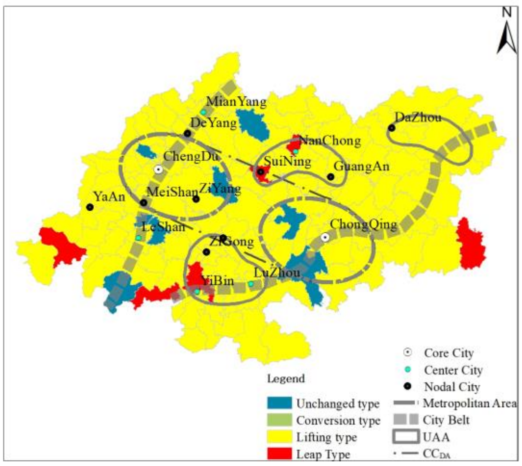
(**c**)

Figure 2. Distribution of population aging level in CCUA: (**a**) 2000; (**b**) 2010; (**c**) 2020.

Overall, the lifting type accounted for the largest proportion of counties (districts) in the 2000–2010 and 2010–2020 time periods, and the number of counties (districts) increased significantly (Figure 3), indicating that aging is continuing to increase. Conversion types are mainly located at the edge of the CCUA and the periphery of major development areas. The conversion type decreased from 17 counties (districts) in 2000–2010 to 0 counties (districts) in 2010–2020, and the general trend is to convert from young-type to adult-type (N-C) from adult-type to old-age-type or (C-L), which indicates that these regions are completely moving into having an aging society. The leapfrog type was distributed on the periphery of the main development planning areas in 2000–2010, and mainly on the edge of urban agglomerations and in some counties (districts) in the densely populated urban areas in 2010–2020. Leaping-type counties (districts) directly leap from young-type to adult-type II (N-C_{II}) or old-age-type I phase leaping into the Aging Type III (L_I-L_{III}). Such as Shunqing, Chuanshan, Hanyuan, Cuiping, Pingshan, and Qianjiang, all of which jumped directly from Aging Type I to Aging Type III. These districts all have net population outflows, and the loss of a large number of young and strong people has led to sudden changes in the aging process of the population and the aging level has been passively raised over and above the level of the aging process. The unchanged type of districts (counties) mainly appeared in the periphery of the two major core cities and the two major dense urban areas (NSG_{UAA}, SS_{UAA}) during the period of 2000–2010, but were displaced from 2010 to 2020 when they mainly appeared in the periphery of the main axis of development.



(**a**)



(**b**)

Figure 3. Transformation of population aging types in CCUA: (**a**) 2000−2010; (**b**) 2010−2020.

Table 1. Changes in population aging level in CCUA in different periods.

	2000		**2010**		**2020**	
	Average Level (%)	**Number of Counties (Districts) Involved**	**Average Level (%)**	**Number of Counties (Districts) Involved**	**Average Level (%)**	**Number of Counties (Districts) Involved**
N	0	0	0	0	0	0
C_I	5.44	1	0	0	0	0
C_{II}	6.48	16	0	0	0	0
L_I	8.18	126	8.93	28	9.77	2
L_{II}	10.34	2	12.09	111	12.46	20
L_{III}	0	0	15.26	6	19.36	123

3.1.2. The Level of Population Aging Is Characterized by a Clear Spatial Correlation

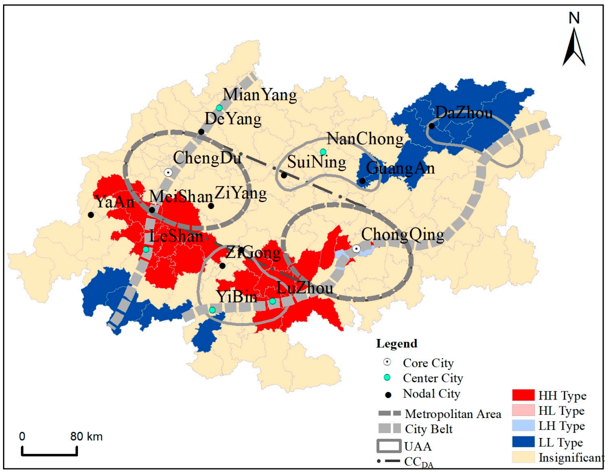
Using GeoDa software, the global Moran's I values of the aging coefficients of the CCUA in 2000, 2010, and 2020 were calculated to analyze the spatial correlation characteristics of the aging level, the location of the agglomeration area, and its changes in the CCUA. The *p*-test value is less than 1% and the Moran's I index is positive, indicating that there is a spatial correlation of the population aging level in the CCUA. With time, the Moran's I index shows a "high–low–high" trend, decreasing from 0.370 in 2000 to 0.332 in 2010 and increasing to 0.424 in 2020, indicating that the spatial agglomeration of the population aging level is moving from weakening to strengthening, and the spatial difference is increasing (Table 2). The level of population aging in the past has been increasing. That is to say, it has gradually evolved from continuous aging in the previous period to differential aging.

Table 2. Global Moran's I estimate.

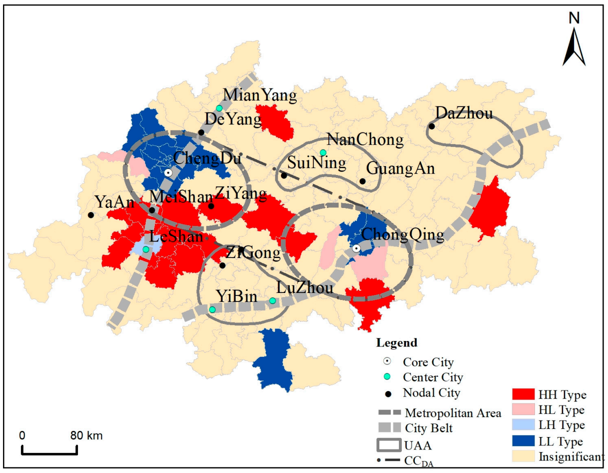
Year	Moran's I	*p*-Test Value	Z-Statistic Value
2000	0.370	0.001	7.7
2010	0.332	0.001	7.202
2020	0.424	0.001	8.851

From the local spatial autocorrelation LISA agglomeration map (Figure 4), the spatial agglomeration types can be classified into four types: high–high agglomeration (HH type), low–low agglomeration (LL type), high–low agglomeration (HL type) and low–high agglomeration (LH type). The local spatial agglomeration characteristics of the population aging level in the CCUA are clear, dominated by high-value agglomeration and low-value agglomeration, indicating that aging has a typical spatial correlation. In 2000, the HH type mainly appeared in the southwestern part of the CCUA in the northern districts (counties) of Leshan City, Meishan City, Luzhou City, and the Chongqing Municipality, forming two high-value agglomerations. The region is both a penetration area of the two city belts and also a strong radiation area of the two cores. The LL type mainly appears in the southwest and northeast, Dazhou City, Guang'an City, and the southern district (county) of Leshan City, forming two low-value aggregation zones in the south and north, which are the edge zones of the whole urban agglomeration.

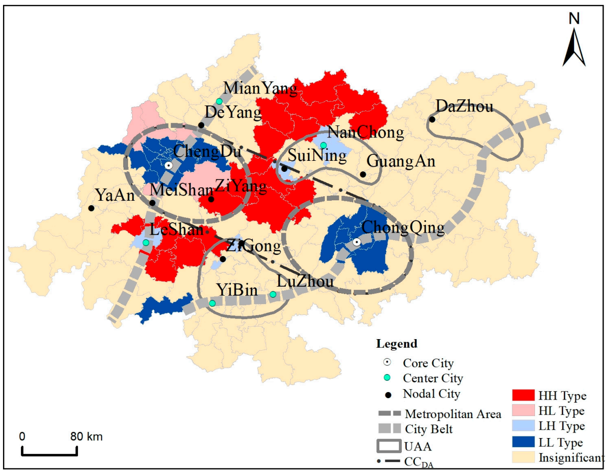
In 2010, the LL type began to shift from the fringe areas of the urban agglomeration to the double core, forming two major low-value agglomerations that are closely related to the two core cities of the urban agglomeration. The HH type is moving closer to the main axis of urban agglomeration development and is fragmented. Part of it spreads into a semi-surrounding shape around Leshan City, moving closer to Chengdu City. Another part is mainly in Ziyang City and the Dazu District of the Chongqing Municipality in the middle of the Chengdu–Chongqing main axis of development. The rest are scattered in Yanting County of Mianyang City, the Qijiang District, and the Shizhu Tujia Autonomous County of Chongqing.



(**a**)



(**b**)



(**c**)

Figure 4. LISA agglomeration map of population aging coefficient in CCUA: (**a**) 2000; (**b**) 2010; (**c**) 2020.

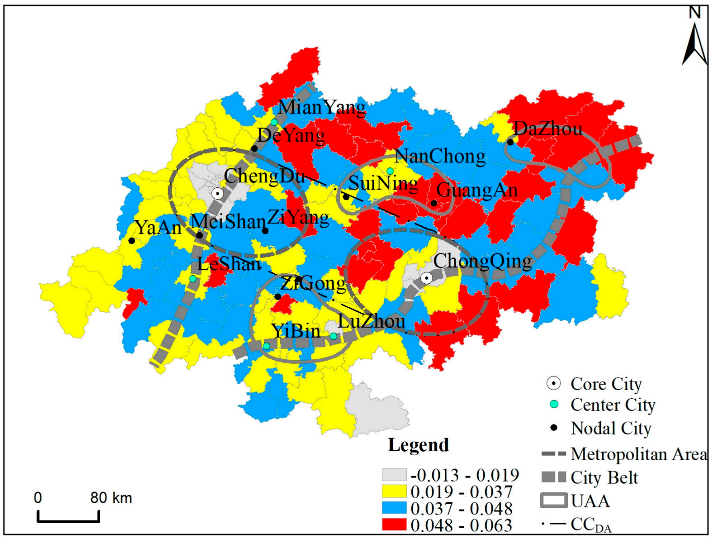
In 2020, the HH pattern further converged in space and evolved from the original east–west spread to a north–south spread, with three main regions: the central part of the CC_{DA}, the periphery of Leshan City in the south, and Nanchong City in the north. It can be seen that the CC_{DA}, metropolitan areas and urban belts have a guiding and controlling effect on the pattern of population aging. It can be seen that, under the influence of the major development axes of the CCUA, the high and high-value zones mainly appear in the areas outside or on the edge of the axes. Relative to 2010, the scope of the semi-ring-shaped area centered on the low–high values in the city center of Leshan is shrinking, while the scope of the high–high values in the central part of the Chengdu–Chongqing development axis is expanding. The LL type occurs in the two core cities, and relative to the scope of 2010, Chengdu is slightly shrinking, while Chongqing is expanding with a clear trend. This is fully consistent with the overall decline in the population aging levels in the two core cities.

3.1.3. Accelerating Population Aging and Increasing Spatial Variability

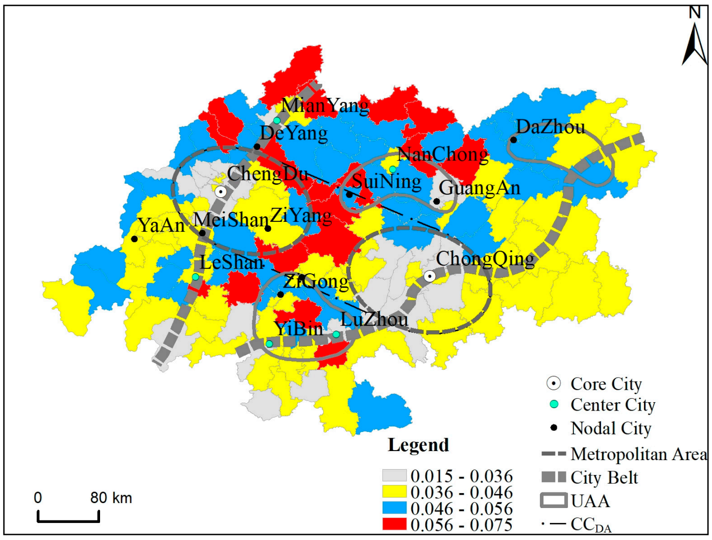
The range of the aging speed is selected as the range of intervals with the largest and smallest values of aging speed in the districts and counties of the CCUA. The low, medium, and high categories of the aging speed thresholds are utilized by the natural breakpoint method in the GIS software 10.2. Between 2000 and 2010, the range of the population aging speed in the CCUA was [−1.3%~6.3%], with an average growth rate of 3.7%, of which the maximum value of 6.3% appeared in Yuechi County of Guang'an City and Yanyang County of Chongqing Municipality, and the minimum value of −1.3% appeared in the Pidu District of Chengdu Municipality. The spatial variation in the aging growth rate shows that the trends in the northeast and central and the south of the eastern area are greater than those in the northwest and southwest. The variability in speed directly affects the spatial variability of the aging level. Chongqing Municipality, Leshan City, Meishan City, and Mianyang City have the most districts (counties) in which the aging speed greater is than 3.8%; Chongqing Municipality has as many as eighteen districts (counties), in Leshan City, there are eight, and in Chengdu Municipality, there is only one. Overall, the high-speed areas are distributed in the peripheral areas of the two major cores and axes of the urban agglomeration. The Chengde–Mianle city belt is a north–south low-speed zone. The aging speeds in the dense urban area of South Sichuan and the dense urban area of South Suiguang are also lower than those of other surrounding areas. The Pidu District, Yuzhong District, and Jinjiang District have even become negative growth areas. It can be seen that the main development axes and dense urban areas in the CCUA development plan have an impact on the regional aging speed (Figure 5a).

Between 2010 and 2020, the range of the population aging speed in the CCUA was [1.5%~7.5%], with an average growth rate of 4.4%, with the maximum value of 7.5% occurring in the Anju District of Suining City, and the minimum value of 1.5% occurring in the Shuangliu District of Chengdu City. The aging speed is high overall, with medium- and high-speed growth dominating, and there are fewer counties with low-speed growth. Spatially, the high-speed growth area has a tendency to move towards the west and center, and the central and northwestern part of the urban agglomeration has the fastest aging speed; the two core cities form a typical low-speed growth area, and the scope of the area has further been enlarged compared with that between 2000 and 2010. The districts (counties) within the main axis of Chengdu–Chongqing development are aging faster the farther they are from the twin cores, with the Anju District, Anyue County, and Zizhong County aging the fastest (Figure 5b).

Between 2000 and 2020, the range of the population aging speed in the CCUA was [0.8–5.8%], and the average growth rate was 4%, with the minimum value (0.8%) appearing in Pidu District, Chengdu City, and the maximum value (5.8%) appearing in Nanchong City, Nanfang County. The spatial distribution in this period is similar to that during 2000–2010, indicating that the inertia of the population aging speed in the previous period (2000–2010) is more prominent. The northeastern and central parts of the city are dominated by high-speed growth, the two core cities are dominated by low-speed growth, and the regions along the two major city belts are dominated by low- and medium-speed growth. Seven districts in Chengdu, such as Pidu and Shuangliu, six districts in Chongqing, such as Yuzhong and Shapingba, and Longmatan district in Luzhou all have aging speeds lower than 2.4%, making them typical low-speed growth areas (Figure 5c).

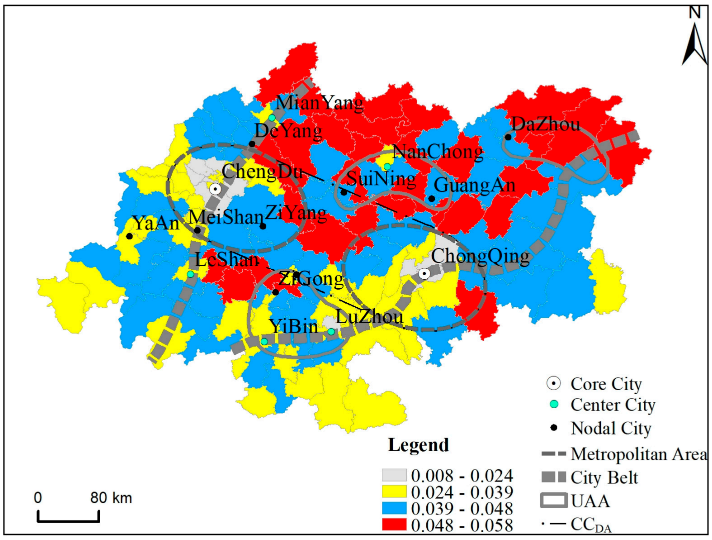


(**a**)



(**b**)

Figure 5. *Cont.*



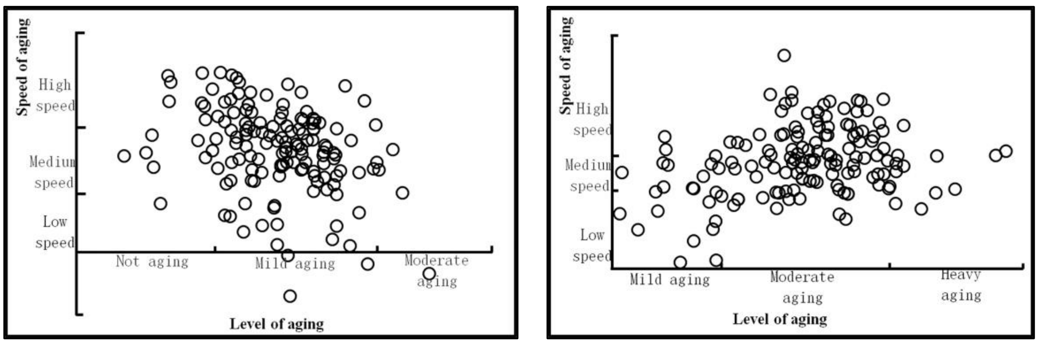
(**c**)

Figure 5. Spatial distribution of the average annual growth rate of the aging level: (**a**) 2000−2010; (**b**) 2010−2020; (**c**) 2000−2020.

3.1.4. "Old and Fast" Growth Characterized by the Predominance of the "Double Growth" Model

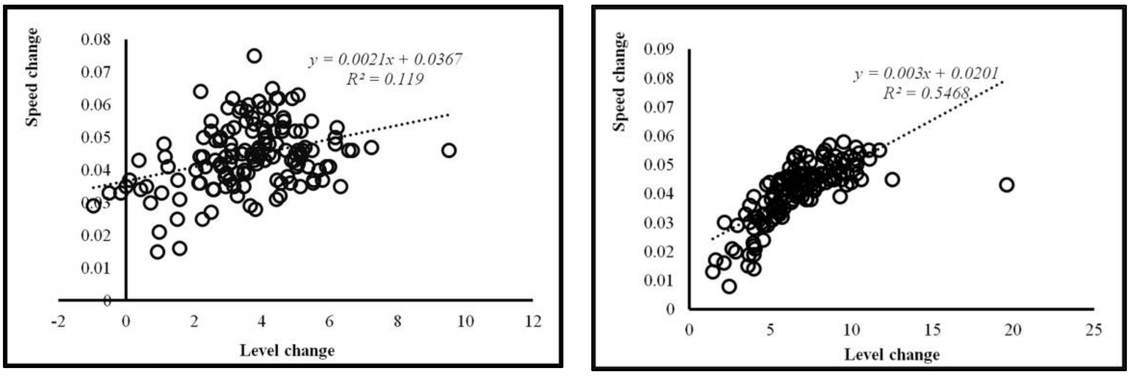
Selecting the increase and growth rate of population aging level and establishing the relationship mapping between population aging level and aging speed, we analyze the matching relationship between the level and speed of population aging in the CCUA and find that "old and fast" features are prominent, and the "double increase" type gradually dominates.

Between 2000 and 2010, the vast majority of districts (counties) in the CCUA were in a state of mild aging accompanied by medium and high speeds, there was a lack of "high and fast" type, and the growth rate of the non-aging areas was generally higher, being medium- or high-speed-based (Figure 6a). The vast majority of counties (districts) were of the "double increase type" (i.e., the aging level increases, speed increases). Only in Jinjiang District and Pidu District, Chongqing Yuzhong District did the speed increase while the level decreased (Figure 7a). In 2010–2020, the vast majority of districts (counties) in the CCUA had a middle aging/moderate or high-speed status, with very few light aging/high-speed types and heavy aging/low-speed types (Figure 6b). The characteristics of the "double-increasing type" are more obvious, indicating that the "old and fast" trend was further strengthened (Figure 7b).



(**a**) (**b**)

Figure 6. Level−rate relationship of aging in CCUA during 2000−2010 (**a**) and 2010−2020 (**b**).



(**a**) (**b**)

Figure 7. Change in the level of aging−speed relationship in CCUA during 2000−2010 (**a**) and 2010−2020 (**b**).

3.2. Factors Affecting Spatial and Temporal Changes in Population Aging

3.2.1. Selection of Indicators

Aging is the result of the combined effect of natural aging in place and external population migration. Examining the internal factors, the population age structure, the elderly population base, the fertility rate, and other factors have an endogenous influence on population aging, which determines the features of aging in place and the residual aggregation of the elderly [37–40]. Examined from the point of view of the externality factor, urban agglomerations, as the center of population migration and aggregation, are the main destination of the young and strong population, and the migration of the young population has a significant dilution effect on the aging level [40–44]. Therefore, this paper selects indicators such as the initial aging level, the proportion of the population aged 55–64, the fertility level, the in-migration rate, etc., to explore exactly how the population development inertia and population mobility factors have influenced the spatial and temporal changes in the CCUA urban agglomeration's aging. At the same time, considering the spatial heterogeneity within the urban agglomeration (one axis, two belts, two cores, and three districts), the influencing factors are concretized onto specific spatial units and subdivided into subdivided studies to analyze the spatial heterogeneity of the driving factors.

The increase in the aging level during 2000–2010 ($\Delta L_{2000\text{–}2010}$) and the increase in the aging level during 2010–2020 ($\Delta L_{2010\text{–}2020}$) are taken as the dependent variable, and the aging level (L_{2000}, L_{2010}), the proportion of the population aged 55–64 ($\Delta C_{55\text{–}64}$), the fertility level (ΔF), the in-migration rate (ΔINr), and emigration rate (ΔEMr) are talen as independent variables (Table 3).

Table 3. Selection and description of indicators.

Type of Indicator	Specific Indicator	Symbol	Indicator Description
Endogenous factors	Initial aging level	L_{2000}, L_{2010}	The share of the population over 65 years of age in the total population at the beginning of the study period indicates the elderly population base and largely influences the basic direction of aging.
	the proportion of the population aged 55–64	$\Delta C_{55\text{–}64}$	The higher the proportion of older persons to the total population that will step in 10 years, the greater the impact on the degree of population aging in 10 years.
	the fertility level	ΔF	The average number of surviving children of women of childbearing age between 15 and 60 years was chosen as a proxy variable for fertility level, with a larger number indicating a larger young population.

Table 3. *Cont.*

Type of Indicator	Specific Indicator	Symbol	Indicator Description
Exogenous factors	the in-migration rate	ΔINr	Inflows as a proportion of the total population, with implications for population aging in both in-migrating and out-migrating areas
	emigration rate	ΔEMr	The share of the outflow population in the total population, characterizes the outflow of the population.

3.2.2. Analysis of Results

In this study, we used the geodetector method to detect the influencing factors, and closely combine the special characteristics of the spatial structure of urban agglomerations to subdivide the influencing factors of population aging in core cities, node cities, central cities, and key development areas (city belts and dense urban areas).

The influence of each factor on the spatial and temporal changes in the aging level is different for different regions. And the factors have been deflected over time. However, in general, external factors such as the in-migration rate and the out-migration rate have a significant determining power on the urban agglomerations and their key regions (core cities, nodal cities, main axes of development, city belts, and dense urban areas), and are persistent. Endogenous factors such as the initial aging level, the proportion of the population aged 55–64 years old, and the fertility level had a significant determining power on the changes in the aging level between 2010 and 2020 (Table 4).

Table 4. Detection results of population aging factors in CCUA (2000–2010, 2010–2020).

		L_{2000}		$\Delta C_{55\text{–}64}$		ΔF		ΔINr		ΔEmr	
		2000–2010	2010–2020	2000–2010	2010–2020	2000–2010	2010–2020	2000–2010	2010–2020	2000–2010	2010–2020
CCUA	* D	0.04	0.42	0.27	0.06	0.09	0.24	0.32	0.12	0.19	0.15
	S	0.42	0.00	0.00	0.60	0.13	0.00	0.00	0.00	0.00	0.00
Core City	D	0.23	0.64	0.28	0.07	0.27	0.37	0.39	0.09	0.15	0.21
	S	0.02	0.00	0.05	0.62	0.11	0.00	0.00	0.39	0.15	0.05
Center City	D	0.09	0.62	0.54	0.21	0.10	0.25	0.12	0.18	0.36	0.13
	S	0.62	0.00	0.00	0.54	0.73	0.11	0.17	0.21	0.24	0.44
Nodal City	D	0.03	0.10	0.20	0.08	0.11	0.10	0.12	0.24	0.43	0.50
	S	0.98	0.51	0.07	0.83	0.51	0.30	0.14	0.01	0.00	0.00
Chengdu-Chongqing Development Axis	D	0.19	0.50	0.31	0.05	0.29	0.28	0.41	0.11	0.16	0.13
	S	0.02	0.00	0.01	0.56	0.03	0.00	0.00	0.25	0.07	0.27
Chengde-Mianle City Belt	D	0.08	0.67	0.48	0.13	0.22	0.39	0.48	0.22	0.22	0.18
	S	0.54	0.00	0.00	0.54	0.60	0.02	0.00	0.04	0.16	0.32
Riverside City Belt	D	0.03	0.27	0.11	0.17	0.22	0.27	0.19	0.04	0.52	0.16
	S	0.93	0.71	0.58	0.87	0.99	0.14	0.29	0.99	0.13	0.94

* D: Determinacy; S: Significance level.

Between 2000 and 2010, analyzed from the perspective of the CCUA as a whole, the determining power of the influencing factors, in descending order, was the migration rate, the proportion of population aged 55–64, and the out-migration rate. This indicates that the roles of population mobility (especially the in-migration rate) and population development inertia are prominent. The most influencing factor of the population aging level in the areas along the CC_{DA}, migration rate, is still the most determining factor (D = 0.41), followed by the proportion of the population aged 55–64 (D = 0.31) and the fertility level (D = 0.29). This indicates that population mobility and age structure turnover have a prominent impact on the change in the aging level, and at the same time implies that frequent population mobility exists. Compared with the 2010–2020 period, the determining power of the initial aging level increased sharply from 0.19 to 0.50, indicating that the base effect of aging appears; the determining power of the proportion of the population aged 55–64 decreased drastically from 0.31 to 0.05, and the effect of the turnover of the population structure weakened. Among the two major city belts, only the $CDML_{UB}$ has been well developed, and the determining power of the migration rate (D = 0.48) and the proportion of the population aged 55–64 (D = 0.48) on the change in the aging level is obvious.

Only the fertility level and emigration rates of the two core cities did not pass the significance test, and the rest of the factors have an impact on the change in the population aging level, among which the highest determining power is the emigration rate (D = 0.39), followed by the proportion of population aged 55–64 (D = 0.28), indicating that the core cities, as the best-developed regions in CCUA, have attracted a large number of young and strong people which has had a significant dilution effect on the aging level, and is the fundamental reason for the decline in the two core cities. Compared with the period of 2010–2020, the determining power of both the in-migration rate and out-migration rate have changed. The determining power of the out-migration rate has increased slightly, but the determining power of the initial aging level and the fertility level has increased sharply. This means that the factors influencing changes in the level of population aging have shifted over time. In particular, the determining power of the proportion of the population aged 55–64 years has changed drastically from 0.28 to 0.07, which indicates that the core cities have a significant dilution effect on aging due to a large number of population flows. The role of age structure substitution on the change in the aging level tends to weaken in the core cities due to the movement of a large number of people. In comparison, the proportion of the population aged 55–64 (D = 0.54) has a stronger determining power on the change in the aging level of the population in the central city. The proportion of the population aged 55–64 characterizes the replacement of the age structure of the population, i.e., the larger the base of the population that will move into the elderly population in 10 years, the stronger the inertia of aging. Compared with the period of 2010–2020, the determining power of the initial aging level in the central city have sharply increased from 0.09 to 0.62, while the proportion of the population aged 55–64 decreased from 0.54 to 0.21, indicating that the role of the influencing factors has also undergone a metamorphosis and that the inertia of aging has been enhanced, while the influence of age structure replacement on aging has weakened. The nodal cities are mainly affected by the out-migration rate (D = 0.43), and it is reasonable to argue that the nodal cities also play a key role in the urban agglomeration and represent the net inflow of population. However, due to the low level of development in the CCUA as a whole, the efficacy of the nodal cities has not yet been brought into full effect or has been replaced or covered up by the core's siphoning effect. Therefore, young people favor the core cities that have more opportunities, resulting in the nodal cities becoming the net outflow of the population instead. The result is the residual gathering of the elderly population, which raises the level of aging. Compared with the period of 2010–2020, the determinants of the in-migration rate and the out-migration rate are both rising. This shows that as the level of urban agglomeration construction in the nodal cities continues to rise and the pattern of population mobility is undergoing subtle changes, which in turn affects the changes in the level of aging.

During the period 2010–2020, only the proportion of people aged 55–64 in the CCUA as a whole failed the significance test, and the initial aging level, fertility level, and population mobility all had a positive impact on population aging. Different regions within the CCUA are similarly affected by the initial aging level, fertility level, and population mobility. Specifically, the initial level of aging plays a decisive role in the core cities, central cities, the CC_{DA}, and the $CDML_{UB}$. This indicates that aging has a fundamental impact and that past levels of aging influence the trend and direction of future changes in aging. Additionally, fertility levels have a significant influence on the core cities, CCDA, and $CDML_{UB}$. A decrease in fertility rates in more developed regions leads to a decrease in the young population and an increase in the proportion of the elderly population. Furthermore, population mobility factors also have a strong impact on the core cities, node cities, and $CDML_{UB}$ within the urban agglomeration. The migration of populations within key areas results in noticeable dilution effects on aging levels (especially declining). The CCUA is the most economically developed and highest-status urban agglomeration in western China; particularly after the cross-provincial population migration, it will reshape the age structure of the regional population, thus affecting the aging level of the population. Within the CCUA, those in relatively underdeveloped regions (particularly those on the fringes of urban agglomerations) are attracted to core cities, central cities, dense urban areas, and other key regions. This cross-city population migration also affects levels of population aging.

From the perspective of the dynamic change in the determining power of each factor in the two periods of 2000–2010 and 2010–2020, the CCUA as a whole, the core city, the CC_{DA}, and the $CDML_{UB}$ have experienced changes in the migration rate and the initial aging level in the two time periods. The determining power of the initial aging level grows significantly faster than the migration rate, which is the factor with the greatest determining power. This shows that, based on the influence of the mobile population, the influence of the level of initial aging on the level of population aging increased in the period 2010–2020 and has had a direct impact on population aging. The main influencing factor in the central city has changed from the proportion of the population aged 55–64 to the initial aging level, indicating that the aging level of the central city is mainly affected by the further aging of the population over time. In the period of 2010–2020, the population aging level was influenced by the aging level of the previous period, i.e., the population that became old in 2010, and the degree of aging further deepened. Nodal cities are affected by a single factor, namely, population mobility.

4. Discussion and Conclusions

4.1. Discussion

Urban agglomeration is the outcome of urbanization reaching an advanced stage, typically progressing through the phases of isolated and dispersed development, inter-city (strong) weak linkage, prototype formation of a metropolitan belt, and finally maturation of the metropolitan belt [45]. Alternatively, it can be described as undergoing stages from prototype development to rapid development, tending towards maturity and ultimately achieving mature development [46]. This process encompasses both the phenomenon of population aging in place and the accompanying migration dilution that arises from increased mobility. In Western developed countries, particularly in metropolitan areas, the process of urbanization has transitioned towards suburbanization and reverse urbanization. Consequently, there is a notable migration and concentration of elderly individuals from the core area to the suburbs or edge areas [14] (Johnson K M, 1989). China is still in the middle and late stages of industrialization and urbanization, but like the general trend in the country, population aging in urban agglomerations continues to be serious [17,19]. However, the spatial and temporal patterns of population aging in urban agglomerations with varying levels of development and geographical locations exhibit some degree of heterogeneity. Specifically, coastal city agglomerations experiencing a significant influx of people are undergoing aging at a relatively slower pace [17]. Conversely, the Ha-Chang and Liao-Zhong-South city agglomerations, characterized by substantial population loss, are witnessing a comparatively accelerated aging process that is progressively worsening [17]. In addition to the mature city agglomerations of the Yangtze River Delta, Pearl River Delta, and Beijing–Tianjin–Hebei, the remaining city agglomerations (like the CCUA) are currently in a stage of growth or cultivation. These agglomerations exhibit centripetal migration patterns and have become primary destinations for external populations. The significant influx of young and middle-aged individuals has varying degrees of influence on the aging process and level of urban agglomeration, either diluting its effects [19] or contributing to residual aggregation. This study has a similar pattern, finding that the CCUA is in the growth stage, and the population flows into the core area of the twin city cluster. The different spatial structures within the city cluster lead to different development dynamics between the core and the edge. Core cities and node cities have different attractions due to population and economic factors. Therefore, core areas and core cities tend to slow down the aging rate and degree by attracting foreign populations. However, the marginal areas, under the strong siphoning effect of the core areas and core cities, often lead to the formation of residual aggregation dynamics of the elderly population, superimposing residual aggregation on aging in place. This makes aging fast and old [25], leading to a more complex pattern of aging within urban agglomerations. Despite the slowing down of population mobility in China, urban agglomerations (especially the CCUA) are still the preferred location for migrating populations, implying that mobility factors will still produce a lasting influence on the evolution of population aging. On the other hand, from 2022 onwards, China's population development has reached an inflection point, creating negative growth, a reduction, and the oligomerization a foregone conclusion. This means that the logic of urbanization and aging in China has changed and that low fertility and longevity will lead to a greater likelihood of "aging in place", while the influence of the mobility factor on aging will weaken.

Through in-depth study of the causes, characteristics, and trends in population aging within the CCUA, it can enable the CCUA and other similar urban spaces to more accurately grasp the impact of the differences in spatial structure development within the CCUA on population aging. It provides an important reference basis for the formulation of urban spatial development planning, which can respond to the challenges of aging in a timely and targeted manner, promote social harmony and stability, and achieve sustainable urban development.

4.2. Conclusions

Based on 2000, 2010, and 2020 population census sub-county data, this study utilized geodetector analysis, spatial correlation analysis, and other methods to study and analyze the causes of population aging in the districts (counties) within the CCUA, and draws the following conclusions:

Firstly, from 2000 to 2020, the CCUA has gone through the process of "light–medium–heavy" change and the aging level of the population continues to increase. With the changes in the development level of different levels of cities and planning axes within the urban agglomeration, the spatial differentiation of the aging level has appeared and become obvious. Specifically present in 2000, in addition to some better-developed areas for adult type, most of the rest of the continuous light aging area. The 2010 population aging level of the CCUA development axis gradually appeared, the core city formed the core area of the high–low periphery of the circle structure, and the two city belts radiated out towards the peripheral districts (counties) to take the lead in the heavy aging. By 2020, the entire urban agglomeration area, except for remote areas, had completely moved towards a deeper type of aging, which was focused around the double core city to form a typical aging level "collapse zone"; in the rest of the districts (counties), the trend of heavy continued.

Secondly, there is a strong spatial correlation within the aging level of the population in the CCUA; the spatial agglomeration moved from weak to strong and the spatial difference increased with time. Spatial agglomeration is dominated by high-value agglomeration and low-value agglomeration, and high-value agglomeration and low-value agglomeration are influenced by the development axis of the CCUA, with low-value agglomeration areas approaching the core cities, and the high-value agglomeration areas moving to the areas outside the axis or the poorly developed axes and belts.

Thirdly, the aging rate of the population in the CCUA is on the high side as a whole, with medium- and high-speed growth, and the spatial differentiation is influenced by the development axes and dense urban areas. Between 2010 and 2020, the central and northern parts of the cluster had the fastest growth rates, and the aging rates of the areas passing through the urban zones and some of the dense urban areas were lower than those of the surrounding areas. Between 2000 and 2020, the northeastern and central parts of the cluster had a faster growth rate. Some of the better-developed city districts had a lower rate of population aging than other counties and they can be seen to be spatially clustered.

The further away from the dual-core region within the Chengdu–Chongqing development axis, the faster the aging rate. Analyzing the relationship between the population aging level and aging speed, it was found that the "old and fast" feature is prominent, and the "double-growth" type has gradually dominated.

Fourthly, the geodetector analysis shows that population aging in the CCUA is the result of both endogenous and exogenous factors. There is heterogeneity in the drivers of population aging in different spatial units of urban agglomerations (core, axis, and densely populated urban areas). In terms of the internal spatial structure of the CCUA, the changes in population aging level in the core cities, central cities, the CCUA development spine, and $CDML_{UB}$ were mainly affected by the migration rate in the early stage, and by the initial aging level in the late stage. The YZ_{UB} city belt had a smaller overall impact, which was mainly affected by the migration rate in the early stage and the fertility level in the later stage. Due to the limitation of development conditions, the nodal cities are mainly affected by the population flow, with more serious population loss. And affected by the proportion of the soon-to-be-elderly population in the later stage.

The research led to some new findings. Urban agglomeration is a form of spatial organization that allows cities to develop to a mature stage, and the spatio-temporal process of population aging in urban agglomerations is more specific than that in individual cities. The spatial structure (core, axis, and densely populated urban areas) of the CCUA profoundly affects the level, speed, and type of population aging. The CCUA is a typical dual-core urban agglomeration; while jointly attracting migrant populations, due to the uneven development of the two cities, Chengdu and Chongqing are also competing for the population (especially young and middle-aged people) and resources within the region, resulting in completely different population flows in different spatial units within the urban agglomeration. The heterogeneity of the residual and aggregated elderly population is more prominent, and there is heterogeneity in the factors driving population aging across different spatial units (core, axis, and densely populated urban areas).

Author Contributions: Conceptualization, M.F. and L.W.; methodology, M.F. and L.W.; software, M.F.; formal analysis, M.F. and Q.L.; writing—original draft preparation, M.F.; writing—review and editing, M.F. and L.W.; visualization, M.F.; supervision, L.W. and Q.L.; project administration, L.W.; funding acquisition, L.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China (42371219). The Action Plan for Breakthrough in Oasis Scientific Research Achievements (NWNU-LZKX-202302).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Grafeneder-Weissteiner, T.; Prettner, K. Agglomeration and demographic change. *J. Urban. Econ.* **2013**, *74*, 1–11. [CrossRef]
2. Park, D.; Shin, K. Impact of Population Aging on Asia's Future Economic Growth, 2021–2050. *Asian Dev. Rev.* **2023**, *40*, 49–78. [CrossRef]
3. Gaigbe-Togbe, V.; Bassarsky, L.; Gu, D.; Spoorenberg, T.; Zeifman, L.; Gerland, P.; Bay, G.; Castanheira, H.C.; Gonnella, G.; Hertog, S.; et al. *World Population Prospects 2022: Summary of Results*; United Nations Department of Economic and Social Affairs: New York, NY, USA, 2022.
4. United Nations, Department of Economic and Social Affairs, Population Division (2022). *World Population Prospects 2022: Methodology of the United Nations Population Estimates and Projections*. UN DESA/POP/2022/TR/NO. 4. New York. Available online: https://population.un.org/wpp/Publications/Files/WPP2022_Methodology.pdf (accessed on 17 March 2024).
5. United Nations. *World Population Aging 2017*; United Nation Publication: New York, NY, USA, 2017.
6. Fan, C.L. The construction of city clusters and metropolitan areas in China under the new development pattern. *J. Econ. Geogr.* **2021**, *41*, 1–7.

7. Buffel, T.; Phillipson, C. Can global cities be'age-friendly cities'? Urban development and ageing populations. *J. Cities* **2016**, *55*, 94–100. [CrossRef]
8. Ji, S.; Zhu, Z.S. Study on the balance of population mobility and regional economic development in Chinese urban agglomerations—An analysis based on the long form data of the sixth national population census. *J. Econ. Theory Econ. Manag.* **2014**, *2*, 5–16.
9. Xu, Q.M.; Hu, C.G.; Liu, D.X. Population agglomeration gradient and industrial structure optimization and upgrading in urban agglomerations-A comparison between China's Yangtze River Delta region and Japan and South Korea. *Chin. J. Popul. Sci.* **2015**, *1*, 29–37+126.
10. Shi, Y.; Xu, N. Analysis of Influence of Population Aging on Urban Economic Growth. *Open Cybern. Syst. J.* **2015**, *9*, 2847–2852. [CrossRef]
11. Van Hoof, J.; Kazak, J.K.; Perek-Białas, J.M.; Peek, S.T. The Challenges of Urban Ageing: Making Cities Age-Friendly in Europe. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2473. [CrossRef] [PubMed]
12. Fuguitt, G.V.; Tordella, S.J. Elderly Net Migration: The New Trend of Nonmetropolitan Population Change. *Res. Aging* **1980**, *2*, 191–204. [CrossRef]
13. Bryant, E.S.; El-Attar, M. Migration and Redistribution of the Elderly: A Challenge to Community Services1. *Gerontologist* **1984**, *24*, 634–640. [CrossRef]
14. Johnson, K.M. Recent Population Redistribution Trends in Nonmetropolitan America. *Rural. Sociol.* **1989**, *54*, 301–326.
15. Ito, K. Changes in determinants of long-distance elderly migration in Japan. *Stud. Reg. Sci.* **2011**, *41*, 179–194. [CrossRef]
16. Lundholm, E. Return to where? The geography of elderly return migration in Sweden. *SAGE Publ.* **2015**, *22*, 92–103. [CrossRef]
17. Liu, Y.-P.; Wang, R.-X. Spatio-temporal Evolution of Population Aging in China from the Perspective of Urban Agglomeration: An Analysis Based on Census and Sample Survey Data. *J. China West Norm. Univ. Nat. Sci.* **2023**, 1–12. [CrossRef]
18. Guo, X.X. Spatial and temporal evolution of population aging in Chinese urban agglomerations and the factors affecting it: An analysis based on national census data. *J. Yunnan Univ. Natl. Philos. Soc. Sci. Ed.* **2023**, *40*, 84–94.
19. Wang, L.C.; Wu, R.W.; Li, W. Spatial and temporal patterns of population aging in Chinese urban agglomerations. *J. Geogr.* **2017**, *72*, 1001–1016.
20. Li, H.M.; Wang, Z.B.; Zhao, N.N.; Gao, W. Characteristics of geographical differentiation of population aging in the process of urban agglomeration evolution. *J. Reg. Res. Dev.* **2021**, *40*, 164–170.
21. Li, Y.H. Study on Spatiotemporal Change of Population Aging in the Guanzhong Plain Megalopolis Based on County-scale. *J. Xi'an Shiyou Univ. Soc. Sci. Ed.* **2023**, *32*, 52–59.
22. Liu, J.Y.; Shi, M.H.; Huang, Q.K.; Zhang, F.F.; Jia, Y.F.; Zhang, Q.; Wang, X.M. Spatial differentiation of population aging and coping strategies in the Central Plains urban agglomeration. *J. Henan Univ. Nat. Sci. Ed.* **2023**, *53*, 140–150.
23. Hu, M. Research on the Spatio-Temporal Pattern of Population Aging and Influencing Factors in Counties of Central Plains Urban Agglomeration. Master's Thesis, Henan University, Kaifeng, China, 2019.
24. Kang, J.J.; Ding, Z.W.; Zhang, G.S.; Wang, F.Z.; Wu, R.W. Multi-scale spatio-temporal pattern of population aging in the Central Plains. *J. Econ. Geogr.* **2016**, *36*, 29–37.
25. Xie, T.; Li, Y.D.; Zhang, J. A Comparative Study on Spatiotemporal Changes of Population Aging in the Yangtze River Delta and the Pearl River Delt. *Popul. Dev.* **2021**, *27*, 111–120.
26. Zhou, Z.X.; Han, H.R.; Yang, C.F. Spatio-temporal Evolution Characteristics and Impact Mechanism of Population Aging in the Yangtze River Delta Urban Agglomeration at the County Level. *J. Econ. Geogr.* **2024**, *44*, 90–101. [CrossRef]
27. Guo, J.J.; Liu, Y.P. Spatio-Temporal Evolution and Influencing Factors of Population Aging in the Chengdu-Chongqing Economic Circle at the County Level in China Using the Latest Three National Census Data. *Tropical. Geogr.* **2023**, *43*, 2087–2101. [CrossRef]
28. Fang, C.L.; Song, J.T.; Zhang, Q.; Li, M. The formation, development and spatial heterogeneity patterns for the structures system of urban agglomerations in China. *Acta Geogr. Sin.* **2005**, *60*, 827–840.
29. Wu, Y.; Song, Y.X.; Yu, T.T. Spatial Differences in China's Population Aging and Influencing Factors: The Perspectives of Spatial Dependence and Spatial Heterogeneity. *J. Sustain.* **2019**, *11*, 5959. [CrossRef]
30. Shiode, N.; Morita, M.; Shiode, S.; Okunuki, K.I. Urban and rural geographies of aging: A local spatial correlation analysis of aging population measures. *J. Urban Geogr.* **2014**, *35*, 608–628. [CrossRef]
31. Zhang, K.; Sun, H.; Li, X.Y. Aging Population Spatial Distribution Discrepancy and Impacting Factor. *J. Sustain.* **2022**, *14*, 9528. [CrossRef]
32. Rogers, A.; Woodward, J.A. Tempos of Elderly Age and Geographical Concentration. *J. Prof. Geogr.* **1992**, *44*, 72–83. [CrossRef]
33. Xu, X.; Zhao, Y.; Zhang, X.; Xia, S. Identifying the Impacts of Social, Economic, and Environmental Factors on Population Aging in the Yangtze River Delta Using the Geographical Detector Technique. *J. Sustain.* **2018**, *10*, 1528. [CrossRef]
34. Wang, J.F.; Xu, C.D. Geoprobes: Principles and Prospects. *J. Geogr.* **2017**, *72*, 116–134.
35. Wang, L.C.; Wu, R.W.; Liu, H.M.; Zhou, P.; Kang, J.J. Spatial pattern and regional differences of population aging in China at county scale. *J. Prog. Geogr. Sci.* **2016**, *35*, 921–931.
36. McCarthy, K.F. *The Elderly Population Changing Spatial Distribution: Patterns of Change Since 1960*; Rand Corp.: St. Monica, LA, USA, 1983.
37. Wu, L.G.; Wu, R.W.; Yang, D.G. Spatial and Temporal Evolution of Population Aging and Influencing Factors in China, 2000-2020. *J. World Geogr. Res.* **2023**, 1–16.

38. Wang, M.; Wang, S.B.; Yang, H. Exploring the spatial-temporal distribution and evolution of population aging and social-economic indicators in China. *J. BMC Public Health* **2021**, *21*, 966.
39. Wang, S.B. Spatial patterns and social-economic influential factors of aging indexes: A global assessment from 1990 to 2010 using spatial regressive modeling. *J. Soc. Sci. Med.* **2020**, *253*, 112963. [CrossRef] [PubMed]
40. Chen, Q.H.; Han, H.R. Spatial Characteristics and Influencing Factors of Population Aging in the Yangtze River Economic Belt. *J. Resour. Dev. Mark* **2022**, *38*, 443–450.
41. Cao, H.Q.; Chen, S.Y.; Xi, X.C. Aging, migration, and structural transformation in China. *J. Econ. Model* **2023**, *126*, 106430. [CrossRef]
42. Yang, C.; Ma, C.Y.; Wang, J.; Zhou, Y.Q. Cross-border aging in China's Greater Bay Area in the digital age: A comparative study of mobile application adoption by Hong Kong older migrants and local older adults in Shenzhen. *J. Trans. Plan. Urban. Res.* **2023**, *2*, 149–166. [CrossRef]
43. Prenzel, P. Are old regions less attractive? Interregional labor migration in a context of population aging. *J. Pap. Reg. Sci.* **2021**, *100*, 1429–1447. [CrossRef]
44. Sampaio, D.; King, R.; Walsh, K. Geographies of the aging–migration nexus: An introduction. *J. Area* **2018**, *50*, 440–443. [CrossRef]
45. Gottman, J. *Megalopolis: The Urbanization of the Northeastern Seaboard of the United States*; The M L T Press: Cambridge, UK, 1961.
46. Hen, O.; Yu, D. Stages, characters and exploitation modes of urban agglomerations development in China. *Mod. Urban Res.* **2009**, *24*, 77–82.