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The vision of younger-seniors-based elderly care in rural China: based on population aging predictions from 2020 to 2050

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Population aging is an irreversible and challenging global trend. Factors that worsen it in rural areas include the outflow of young adults, lack of medical resources, and uneven economic development. Based on projections of rural population aging trends in China from 2020 to 2050, this article explores the growth trends and spatial heterogeneity of elderly populations in rural areas. The results indicate that from 2020 to 2050, the aging rate in rural China will increase from 13.49% to 28.74%. Spatial disparities were observed in the East and North regions, with higher rates than in the West and South regions. Also, a turning point in rural aging is projected for 2050, with a decrease for the first time in Chongqing (−0.26%) and Gansu (−0.03%). This paper introduces the vision of younger-seniors-based elderly care, emphasizing the central role of families and the mutual assistance relationships within villages and highlighting the active role of younger elderly individuals in eldercare services. Furthermore, this paper proposes a feasible global application of this vision while identifying key issues that should be addressed in its implementation. This vision provides theoretical guidance for actively responding to rural population aging and is instrumental in advancing sustainable development goals.

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Introduction

Population aging is an irreversible global trend. Within the “2030 Agenda for Sustainable Development” framework that strives for global prosperity, the rapidly growing elderly population is a vulnerable group. The globally increasing aging trends are expected to intensify over the coming decades (UNDESA, 2022). In 2021, the global population aged 65 and above stood at 761 million, projected to reach 1.6 billion by 2050 (UNDESA, 2023; Chen et al., 2022). Due to improvements in health and healthcare, increased educational opportunities, and declining fertility rates, life expectancy is on the rise (Bai et al., 2023). Population aging is predictable, yet countries are at different stages of this transition. Many elderly individuals still lack access to essential resources, and barriers (such as intergenerational inequality and income disparities) between urban and rural areas remain during social activities (Pivodic et al., 2024; Hannah, 2024; Kriebs, 2023). Ensuring the equal participation and benefit of elderly individuals in national development and enacting sustainable development goals has become a global focus.

Contemporary global studies indicate that traditional elderly care systems confront dual structural crises under converging demographic pressures of rapid population aging and sustained fertility decline. Both state-sponsored welfare programs and family-based support mechanisms exhibit diminishing capacity to address escalating eldercare demands (Kwangyong, 2024). The concept of mutual support eldercare has gained traction as a viable response to global population aging, grounded in interdisciplinary theories such as social capital and active aging. Social capital theory posits that trust, reciprocity, and network-building within communities empower older adults to collectively address care needs, fostering resilience through shared resources and collaborative relationships (Huang et al., 2024). Concurrently, the World Health Organization’s active aging framework emphasizes sustaining autonomy and social participation in later life, aligning with mutual support models that prioritize elderly agency and intergenerational solidarity. As an emergent governance model, mutual-support eldercare harnesses social capital reconstruction to reconfigure aging societies through intergenerational reciprocity and community empowerment, manifesting culturally-adaptive implementations across welfare regimes (Wang and Yan, 2024). Western industrialized nations predominantly adopt institutionalized approaches: Germany’s Multi-Generation Houses establish statutory cohabitation communities where seniors exchange care services for subsidized housing (De Lange, 2015), while U.S. initiatives deploy market-based mechanisms through Time Banking systems that quantify care hours as tradable credits (Adarsh, 2020). Conversely, East Asian societies integrate cultural capital into their frameworks: Japan’s senior volunteer programs institutionalize cross-temporal reciprocity where pre-seniors (70–75 years) accumulate redeemable care credits (Mika et al., 2024), whereas South Korea’s state-mediated Filial Support Scheme transforms traditional obligations into subsidized intergenerational contracts (Chung et al., 2017). The rural mutual-support paradigm demonstrates particular transformative potential by converting latent community resources into self-sustaining care networks. This model repositions seniors as co-producers through social reengagement, simultaneously alleviating fiscal burdens and enhancing psychosocial well-being. Theoretically grounded in social exchange principles, such configurations operationalize Active Aging paradigms by fostering solidarity-based collectivism – proposing an alternative to individualistic care models while addressing rural service fragmentation through institutionalized reciprocity mechanisms.

As a populous nation, China is undergoing unprecedented demographic shifts and is projected to remain the country with the largest elderly population for at least the next 50 years.

Population aging implies a shift people from “producer-consumer” to “consumer-producer,” leading to the weakening and aging of rural entities such as agricultural workers and grassroots cadres (Liu et al., 2024). Aging in China is characterized by three main features: a large elderly population, rapid growth in the number and proportion of older adults, and even faster growth among those aged 80 years and above (UNPD, 2017). With the rapid socioeconomic development in China, the welfare of older adults has improved (Zhao and Li, 2024). However, inequalities persist among different elderly groups in health, safety, and social participation due to disparities in urban-rural areas, regions, genders, and generations (Kriebs, 2023; Zhang et al., 2019). In the *Global AgeWatch Index 2015 Insight* Report of 96 surveyed countries, China ranked 52nd overall, particularly low at 75th in income security (UNFPA, 2015). Moreover, China’s aging phenomenon occurred earlier in its economic development than in other countries. When China entered an aging society, its GDP was only 7% of Japan’s GDP when it crossed the same threshold. China’s proportion of the elderly population grew from 10% to 20% in just 25 years, while it took France 115 years and Sweden 85 years to experience the same (UNPD, 2017). The rapid aging of the population has sharply increased the pressure on eldercare in China (Tang et al., 2024). The pressure is more severe in rural areas due to population outflow and inadequate facilities (Rachel and Margaret, 2016; Ma et al., 2022). The preferences toward care facilities for older adults are a core factor influencing of aging societies (Kundu et al., 2022; Rawson et al., 2022). In 2020, only 0.73% of China’s elderly population lived in nursing homes, with the proportion in rural areas even lower at 0.66% (aged 65 and above); and only 3.79% of the population that was unable to live independently (aged 60 and above) lived in nursing homes. Therefore, updating the concept of elderly care and utilizing rural resources effectively are pressing issues that multiple Chinese sectors urgently need to address in response to rural aging.

Compared to developed countries, China’s elderly care development is slightly lagging, with severe deficiencies in rural care supply (Zhou and Cao, 2023; Li et al., 2012). China has gradually established a hierarchical classification system and construction standards for eldercare facilities in recent years. The layout of these facilities was based on population distribution characteristics (Li et al., 2023). However, the challenges brought by rural aging in China are complex. The main obstacles to addressing rural aging are the weakening of traditional family eldercare functions, limited opportunities to access resources, and slow development of the eldercare service market (Cheng et al., 2011; Li et al., 2024; Song, 2014). The rural elderly are not a homogeneous social group, and their demand for social eldercare services increases with age (Liu and Yi, 2023; Elena and Juan, 2020). Due to the heterogeneity of population structure and socioeconomic environment, addressing rural eldercare issues requires a regional perspective (Nidadavolu and Walston, 2021). Currently, China’s social eldercare service system is mainly led by county-level governments, with eldercare institutions as the core (Wang et al., (2023)). It overlooks township governments, village collectives, and local communities, failing to respect older adults’ personal wishes and needs adequately (Liu et al., 2020). Existing research has explored trends in nationwide aging, spatial disparities, influencing mechanisms, and the spatial layout of eldercare facilities and accessibility at the urban scale (Chen et al., 2024; Ma et al., 2022; Cui et al., 2022). Some studies have examined the preferences of older adults for eldercare methods under peculiar needs (Lee and Burns, 2022; Liu et al., 2021; Song et al., 2020). However, existing research on the prediction of rural aging trends and the construction of eldercare service systems that consider local culture in rural areas is meager. Predicting the

developmental trend of rural aging at the national and provincial levels and integrating traditional cultural values into eldercare concepts and systems to address rural aging phenomena have become urgent issues, especially for populous countries like China.

Based on data from the Seventh National Population Census of China, this study predicts the trends in rural aging in 31 provinces from 2021 to 2050, clarifying eldercare pressures and spatial heterogeneity. It analyzes the spatial layout and utilization status of eldercare resources, dissecting the phenomenon of mismatches in eldercare resources. Finally, a new vision for elderly care in rural areas is proposed to address the future aging population. The results of this study can provide the necessary theoretical basis and decision-making references for China to achieve the Sustainable Development Goals (SDGs) and experiential reference for other countries worldwide to address rural aging.

Material and methods

Data. The population data used in this study were sourced from the “Tabulation on 2020 China Population Census By County” and “China Population Census Yearbook 2020.” The book was compiled by the Office of the Leading Group of the State Council for the Seventh National Population Census and published by China Statistics Press. The rural population figures for each evaluation unit were derived from the “Tabulation on 2020 China Population Census By County”, and the age structure of the rural population for each evaluation unit was sourced from the “China Population Census Yearbook 2020”.

Population change trend prediction. This article employs the population forecasting software PADIS-INT, developed by the China Population and Development Research Center, to predict trends in China’s population development from 2021 to 2050. PADIS-INT has been vital in refining evaluation of the target population for China’s fertility policy and projecting changes in the newborn population. When conducting population forecasts, PADIS-INT requires these setting parameters: initial population, levels and patterns of mortality, levels and patterns of fertility, sex ratio (M:F) at birth, and migration levels.

- (1) Initial population: The baseline population in 2020 adopts the age distribution data from the seventh national population census of China, which divides the population by age intervals of 5 years (5-year age groups).
- (2) Mortality levels and patterns: The average life expectancy reflects the mortality level of the population. Based on the average life expectancy in China in 2020, PADIS-INT calculates the average life expectancy from 2021 to 2050, with a pattern change classified as “moderate”. The mortality pattern uses the West model of the Coale-Demeny regional model life table.
- (3) Fertility levels and patterns: Total fertility rate (TFR) indicates population fertility levels. This study first collected 2020 TFR data, then made empirical projections for 2025, 2030, 2035, 2040, 2045, and 2050. With implementation of fertility incentive policies, China’s TFR is estimated to increase by approximately 0.2 by 2025 and stabilize until 2035. Post-2035, as policy effects diminish, the TFR is projected to decrease by about 0.1. The 2020 fertility pattern is adopted for projections, assuming relative stability.
- (4) Sex ratio (M:F) at birth: The seventh national population census data shows that the sex ratio at birth in China in 2020 was 112.28. Predictions from UN DESA indicate that the sex ratio at birth in China will decrease to ≈ 107 by

Table 1 Population migration rates in Chinese provinces.

Province	Population migration rates (%)	Provinces	Population migration rates (%)
Beijing	5.84	Hubei	−1.00
Tianjin	3.71	Hunan	−2.51
Hebei	−1.05	Guangdong	4.44
Shanxi	−1.74	Guangxi	−2.49
Inner Mongolia	−0.07	Hainan	1.22
Liaoning	−0.17	Chongqing	−0.15
Jilin	−1.42	Sichun	−1.34
Heilongjiang	−3.86	Guizhou	−4.01
Shanghai	8.60	Yunnan	−1.67
Jiangsu	2.29	Tibet	1.75
Zhejiang	7.09	Shaanxi	−1.00
Anhui	−2.16	Gansu	−4.01
Fujian	2.31	Qinghai	−0.47
Jiangxi	−2.47	Ningxia	0.70
Shandong	−0.05	Xinjiang	2.23
Henan	−3.89		

around 2035 (UN DESA, 2019). Additionally, predictions from Chao-Fengqing suggest that the ratio will decrease to 106 between 2045 and 2050 (Chao et al., 2021). Assuming that the ratio in each province exhibits a similar declining trend, this is used to estimate the sex ratio at birth from 2025 to 2050.

- (5) Migration levels: The net migration rate indicates population migration levels (Table 1). This study only considers internal migration within the country and ignores international population migration. In recent years, population migration in China has gradually stabilized, so the population net migration rate in 2020 is used as the expected migration level.

Rural population aging trend prediction. The level of urbanization influences the structure and aging level of rural populations. Therefore, this paper predicts the development trend of rural population aging in China from 2020 to 2050 based on the level of urbanization. First, the urbanization level of each evaluation unit is predicted. Secondly, the rural population structure is forecasted. Finally, the level of aging in the rural population is calculated.

- (1) Prediction Method of Urbanization Level:

The urbanization rate in China exhibits strong convergence characteristics. This paper combines regional urbanization convergence characteristics and regional convergence theory to predict the urbanization level from 2020 to 2050. Considering the significant convergence characteristics of urbanization rates in various regions, the expression for modeling the urbanization rate is as follows:

$$\ln(R_{i,t+T}/R_{i,t}) = a + b \ln R_{i,t} + \delta_i \quad (1)$$

where $R_{i,t}$ represents the urbanization rate of evaluation unit i in period t , a and b are the parameters to be calculated, and δ_i signifies the random error term of each evaluation unit. Due to the slow urbanization process in Tibet, it is excluded when calculating the convergence characteristics of the model. The logarithmic model estimates the convergence characteristics of the remaining 30 evaluation units, and δ_i for each evaluation unit is calculated (Table 2).

- (2) Prediction Method of Rural Population Structure:

The population structure of rural areas is forecasted based on the population distribution by age group for evaluation units in 2020, 2030, 2040, and 2050. The calculation formula is as follows:

$$M_{i,c} = N_{i,c} \times (1 - R_i) \tag{2}$$

where $M_{i,c}$ represents the population number of age group c in evaluation unit i , $N_{i,c}$ means the total population of age group c in evaluation unit i , and R_i is the urbanization level of evaluation unit i .

(3) Calculation Method of Rural Population Aging:

Based on the standards established in the United Nations’ “Population Aging and Its Socioeconomic Consequences,” published in 1956, when the proportion of the population aged 65 and above exceeds 7% of the total population, a country or region enters an aging society. When the proportion of the population aged 65 and above exceeds 14%, it enters an aged society, and when it exceeds 20%, it becomes a super-aged society. Therefore, this paper selects the proportion of the population aged 65 and above to represent the Rural Population Aging (RPA) level. The calculation formula is as follows:

$$RPA = \frac{REP_{65}}{TRP} \times 100\% \tag{3}$$

where TRP and REP_{65} respectively represent the total rural population and the population aged 65 and above in the evaluation unit.

Results

Projection of rural population aging. The World Health Organization categorizes societies undergoing aging into aged societies, elderly societies, and super-aged societies, where the proportion of people aged ≥ 65 reaches 7%, 14%, and 20%, respectively. This article measures the degree of population aging by the proportion of people aged ≥ 65 to the total population. According to statistics, China officially entered an aging society in 1999 and an aged society in 2021. From 2020 to 2050, both the overall and rural aging in China will continue to increase. In

2020, the aging rate in China was 13.52%, and the rural aging rate was 13.49%. It is expected to enter a super-aged society after 2030. By 2050, China’s aging and rural aging rate will rise to 29.18% and 28.74%, respectively (Fig. 1).

Overall, from 2020 to 2050, regions with more rural aging in China are mainly distributed to the southeast of the Hu Line, presenting a spatial pattern of “higher in the east and lower in the west, higher in the north and lower in the south,” with significant spatial variations (Fig. 2). In 2020, Liaoning and Tibet had the highest and lowest levels of rural aging at 17.42% and 5.67%, respectively. Specifically, 58.06% of Chinese provinces entered an aging society ($>7\%$), while 38.71% entered an aged society ($>14\%$). According to this study’s predictions, by 2030, 48.39% of rural provinces will have entered a super-aged society ($>20\%$). After 2040, except for Tibet and Guizhou, all other provinces will enter a super-aged society. By 2050, all provinces except Tibet are expected to enter a super-aged society, with the aging rates of Heilongjiang, Liaoning, Jilin, and Shanghai reaching 44.06%, 40.87%, 40.74%, and 40.11% respectively. Then, 32.26% of rural provinces will have an aging rate of $>30\%$.

From 2020 to 2050, Heilongjiang and Guizhou provinces had the highest and lowest growth in rural aging rates of 28.45% and 7.50%, respectively. In 22.58% of the provinces, the growth rate of rural aging exceeded 20%, including Jilin (25.14%), Beijing (24.39%), Shanghai (23.83%), Liaoning (23.45%), Inner Mongolia (22.98%), Zhejiang (22.75%), and Tianjin (21.23%). The growth rates of rural aging in the remaining provinces ranged from 10% to 20%. However, for the first time, Chongqing and Gansu experienced a decline of 0.26% and 0.03 in 2050, respectively (Fig. 3), marking a turning point in China’s rural aging situation.

The elderly dependency ratio in rural China is expected to increase faster, exhibiting an overall spatial pattern of “higher in the east and lower in the west.” The forecasted results (Fig. 4) indicate that the elderly dependency ratio in rural China will rise from 19.85% in 2020 to 49.16% in 2050, suggesting that by 2050, ten working-age individuals will need to support nearly five elderly individuals, resulting in a continuously increasing burden of elderly care. Spatially, by 2050, Heilongjiang will have the highest elderly dependency ratio in rural areas (88.06%), while Tibet will have the lowest (28.30%).

Current status of elderly care and resource allocation in rural areas. In 2020, among the elderly (aged 65 and above) in rural areas of China, the proportion of those who were “unhealthy and unable to live independently” was 3.11%. Only 0.66% of this group resided in nursing homes, showing a significant proportion unable to live independently and posing concerns about their living conditions. Looking at the living

Table 2 Estimation formula for urbanization rate from 2030 to 2050.	
Years	The estimation formula
2030	$\text{Ln}(R_{i,2030}/R_{i,2020}) = 2.432 - 1.614 \text{Ln} R_{i,2020} + \delta_i$
2040	$\text{Ln}(R_{i,2040}/R_{i,2030}) = 2.253 - 1.489 \text{Ln} R_{i,2030} + \delta_i$
2050	$\text{Ln}(R_{i,2050}/R_{i,2040}) = 1.858 - 1.218 \text{Ln} R_{i,2040} + \delta_i$

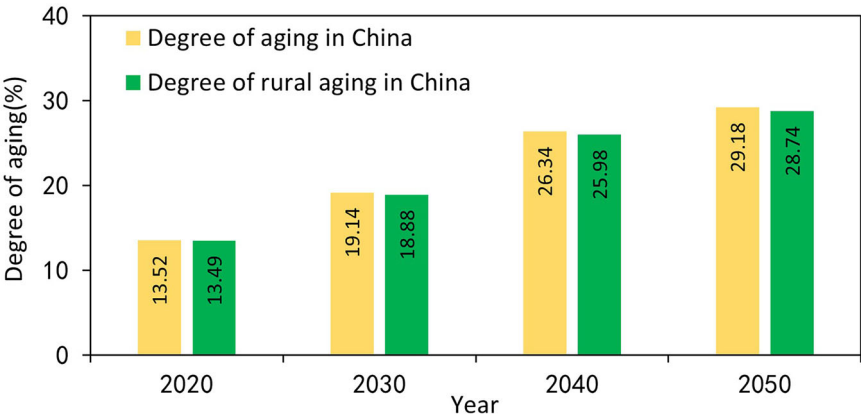


Fig. 1 The degree of aging and rural aging in mainland China from 2020 to 2050.

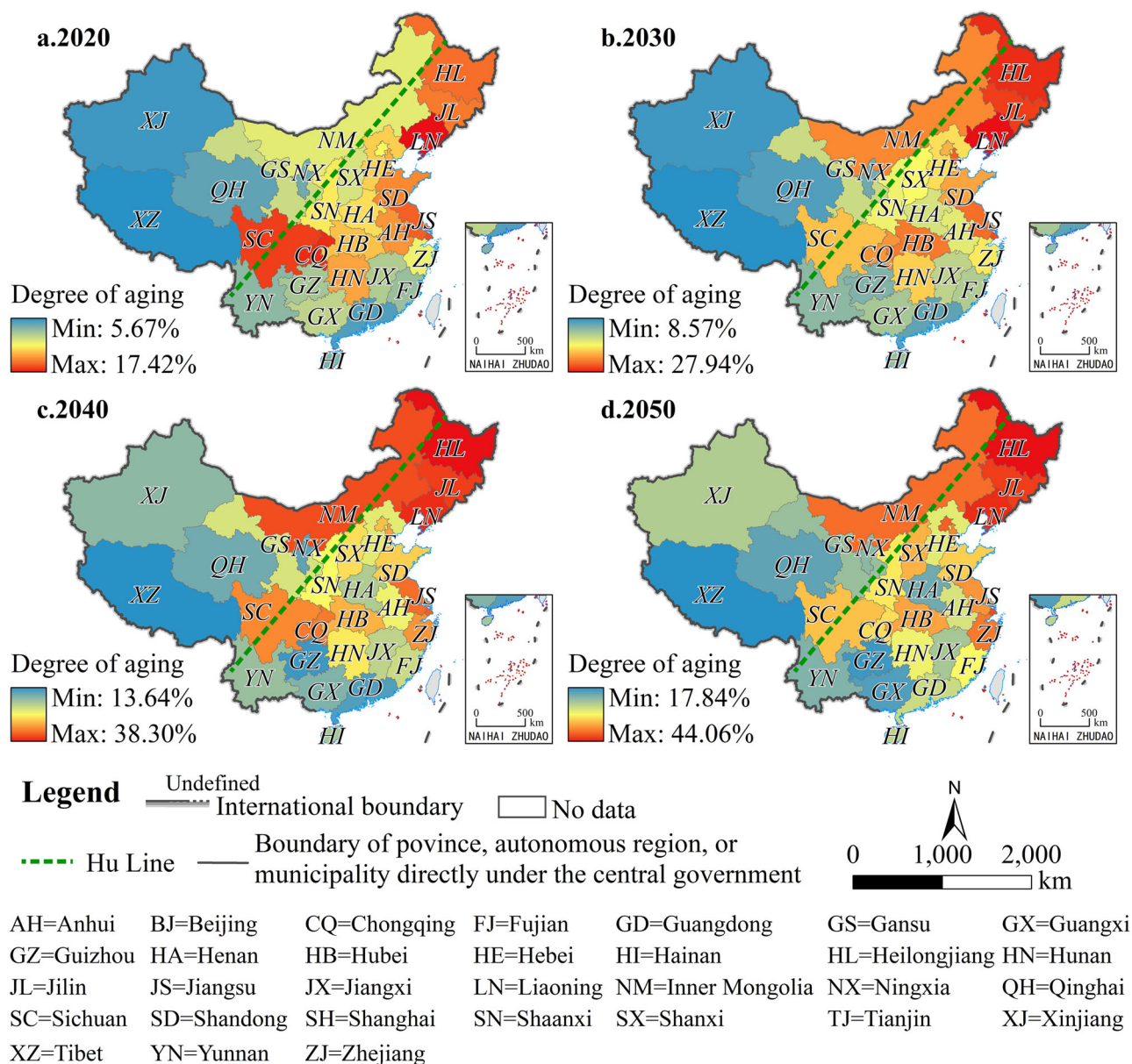


Fig. 2 Spatial distribution of rural aging in 31 provinces in mainland China from 2020 to 2050. a The degree of aging in 2020. **b** The degree of aging in 2030. **c** The degree of aging in 2040. **d** The degree of aging in 2050.

conditions in rural areas (Fig. 5), only 0.55% of the group resided in elder care institutions, while 13.50% live without caregiving assistance. Regarding regions, Shanghai had the highest proportion of elderly living in care institutions (2.02%). Only Xinjiang (1.40%) and Beijing (1.37%) had >1% of the elderly population in nursing homes in all provinces, while Yunnan had the lowest proportion (0.16%).

Most regions in China plan institutional elderly care beds based on the “9073” or “9064” targets¹. According to the “China Civil Affairs Statistical Yearbook 2021”, by the end of 2020, there were 38,158 elderly care institutions in China, equipped with 4,882,366 beds. According to the planned targets for these institutions, 7.92 million beds (calculated at 3%) or 10.56 million beds (calculated at 4%) are needed. However, only 0.73% of older adults reside in elderly care institutions, far from the 3% or 4% target. In China’s rural areas, only 3.79% of this age group cannot live independently in elderly care institutions (Table 3). However, the remaining 96.21%, unable to live independently, still live at home, with 7.78% of them

living alone without caregivers, making them the most vulnerable group.

The vision of younger-seniors-based elderly care. Due to the large and rapidly growing population of older adults in rural China, rural elderly care should be based on three principles: low cost, local residence, and mutual assistance. Nursing homes can only solve a few problems and serve very few older adults. For a long time, rural elderly care in China has mainly relied on family care, usually in the villages. Only a few rural households choose institutional care. Therefore, the future concept of rural elderly care in China should be based on community-based mutual assistance, namely “younger-seniors-based elderly care”.

- Core Concept:** The vision of younger-seniors-based elderly care is driven by rural social relationships (kinship, geographical proximity, and shared occupation), with mutual assistance and reciprocity as its core, adhering to

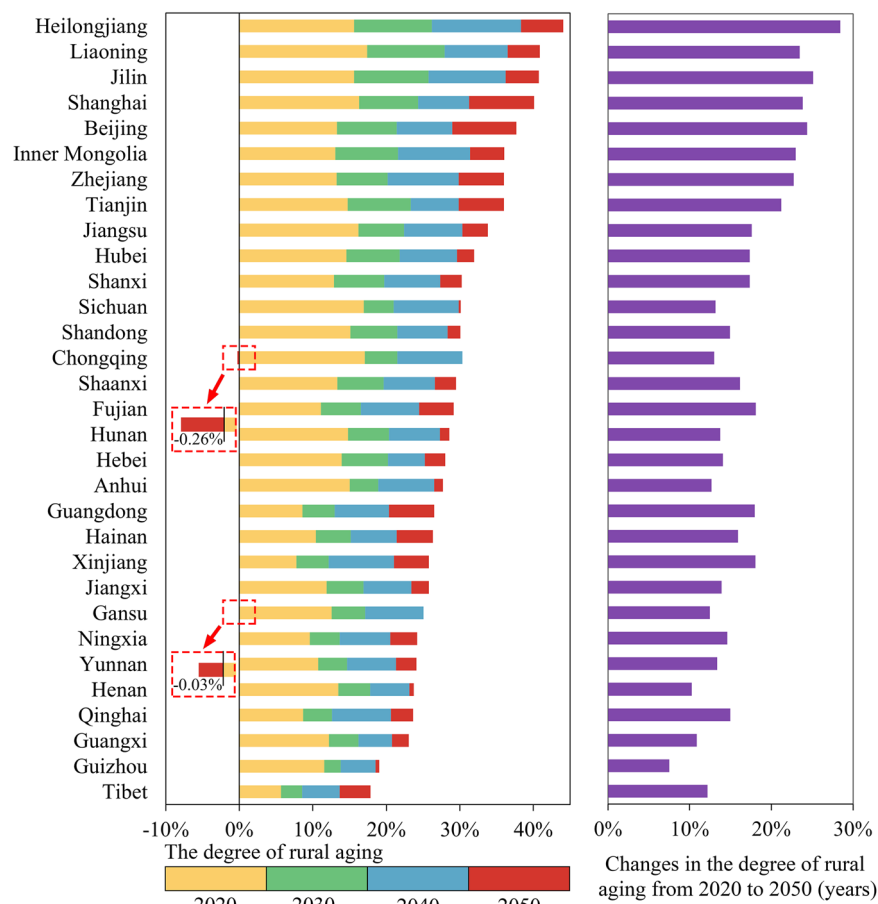


Fig. 3 Changes in rural aging in 31 provinces in mainland China from 2020 to 2050.

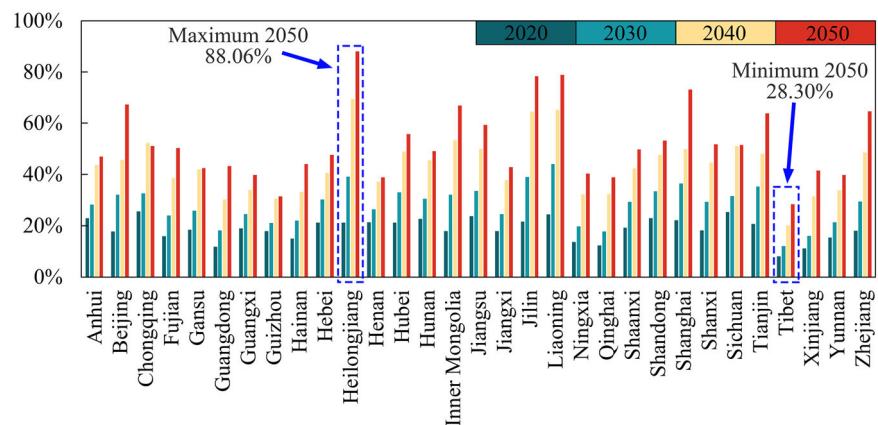


Fig. 4 The rural elderly dependency ratio in 31 provinces in mainland China from 2020 to 2050.

mutual aid among participants. Younger-seniors-based elderly care is driven by voluntary mutual assistance, with seniors as the main participants, leveraging the value of younger, healthy seniors to assist older seniors with reduced self-care abilities. This model effectively meets the basic elderly care needs of older seniors by providing them with essential life care and emotional support. Moreover, this vision emphasizes integrating and reusing rural elderly care resources, utilizing various resources to assist older adults. It also represents a diversified approach to elderly care that integrates government support, social participation, and market operation.

(2) **Feasibility Analysis:** First, traditional rural Chinese society is based on familiar relationships formed through kinship, geographical proximity, and shared occupations, often forming clan settlements based on surnames (Qiu et al., (2024)). China practices collective economic systems, especially collective land ownership, where all households have arable land and homesteads (Chen, 2022). It forms a basis for mutual assistance and cooperation in agricultural production and daily activities. Secondly, the age structure of rural elders allows younger, healthy seniors to provide services to older seniors with reduced self-care abilities. Specifically, rural older adults can be categorized into three

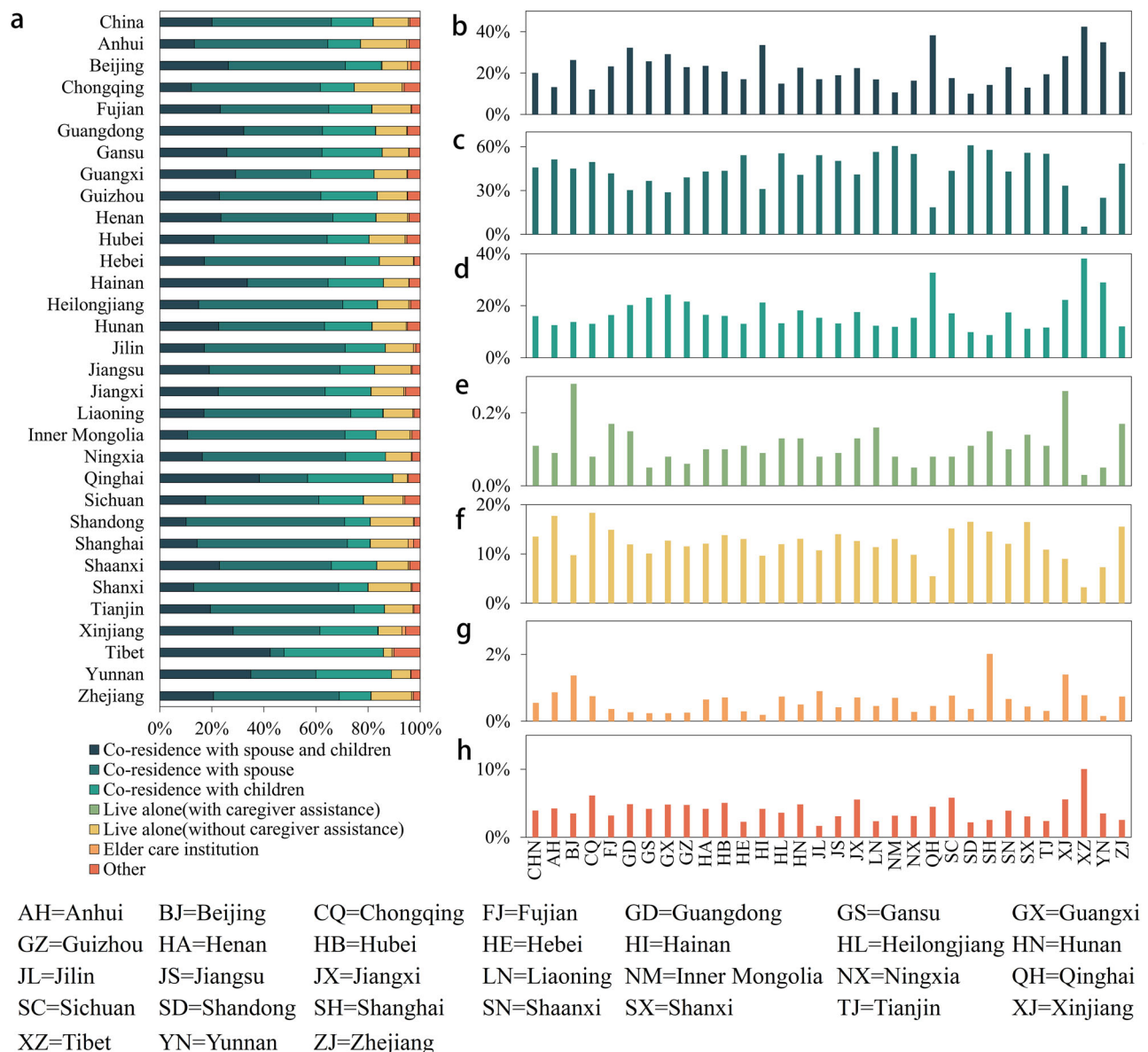


Fig. 5 Conditions of Chinese rural elderly residential homes in 2020. a Overall Situation of Various Residential Conditions. **b** Co-residence with spouse and children. **c** Co-residence with spouse only. **d** Co-residence with children only. **e** Living alone (with caregiver assistance). **f** Living alone (without caregiver assistance). **g** Elder care institution. **h** Other.

types based on their health conditions (the age classification here is estimated but generally corresponds to the overall situation): (1) physically healthy and capable of labor, aged 65–70; (2) no longer capable of labor but able to live independently, aged 70–80; (3) unable to live independently, aged 80 and above. Younger, healthy seniors provide elderly care services to older disabled seniors while saving services for their own future elderly care needs. This behavior can be called “time banking”, where “Time paid today, service earned tomorrow” is practiced (Leung et al., 2022). Thirdly, emphasizing family bonds and filial culture is one of the essences of traditional rural Chinese culture. The filial culture upheld for thousands of years in China emphasizes children’s responsibility to support their parents, known as “raising children to support oneself in old age”. It considers sending elderly family members to nursing homes as lacking filial piety and failing in one’s duty, a notion deeply ingrained as a moral judgment. At the

same time, elderly individuals often harbor strong sentiments for their hometowns and land, viewing staying within the family fold as a mark of respect and heritage preservation. They perceive nursing homes as never as comfortable as home, i.e., an “East or west, home is the best” ideology. Therefore, this study proposes the vision of younger-seniors-based elderly care centered around families and villages. Besides showing respect for the traditional understanding of elderly care in rural Chinese society, this approach also mitigates the discomfort elderly individuals may feel in unfamiliar environments, enhancing their sense of fulfillment, happiness, and security.

- (3) **Social Effects:** Rural elderly care generally begins when older adults lose their ability to work, focusing on those who can no longer live independently. In rural areas, many older adults are capable of living independently and still possess the ability to work. At the same time, few have completely lost their ability to work and are unable to live

Table 3 Residential and health conditions of rural elderly population in China in 2020.

Residential conditions	Population aged 60 and above	Health	Generally healthy	Unhealthy but able to live independently	Unhealthy and unable to live independently
Total	11,836,880	5,745,999	4,185,292	1,603,342	302,247
Co-residence with spouse and children	2,377,249	1,367,651	733,172	230,501	45,925
Co-residence with spouse	5,420,863	2,847,981	1,880,200	593,562	99,120
Co-residence with children	1,897,106	679,521	738,977	377,225	101,383
Live alone (with caregiver assistance)	12,703	3927	3918	2549	2309
Live alone (without caregiver assistance)	1,598,627	616,075	646,552	312,485	23,515
Elder care institution	65,067	10,030	22,231	21,346	11,460
Other	465,265	220,814	160,242	65,674	18,535

independently. With most younger seniors in the village taking care of the older ones, the burden on the former is relatively light. In this process, the government can also provide some financial support. The advantages of “younger-seniors-based elderly care” are as follows: First, it keeps elderly care within the family and the village, making it more acceptable to older adults. Second, it is a mutual assistance behavior among familiar individuals in the village, driven by emotional bonds rather than monetary transactions. Third, it is a form of elderly care that stores services, motivating younger seniors to participate actively. Fourth, it has low costs, optimally utilizing village assets and social relationships without requiring significant investments in funds, technology, or personnel. Lastly, the vision of younger-seniors-based elderly care alleviates the burden of elderly care on younger generations and society. Due to China’s earlier family planning policies, many young families are responsible for caring for four elderly individuals. Although China has relaxed its family planning policies by allowing for the birth of two or three children, the impact is far from the anticipated outcomes. The vision of younger-seniors-based elderly care leverages the strengths of the elderly population themselves, easing the burden of elderly care on younger generations and society.

- (4) **Differentiated Implementation Pathways in China:** Given China’s pronounced regional disparities and rich cultural diversity, promoting the vision of younger-seniors-based elderly care necessitates a differentiated implementation framework characterized by “targeted guidance, multi-dimensional integration, and dynamic adaptation.” The policy architecture should adopt a tiered approach that integrates fiscal support, resource allocation, and public mobilization—anchored in provincial-level coordination, centered on county-level customization, and grounded in village-level implementation. For economically advanced eastern regions, policy interventions may take the form of a “land reinvestment and digital empowerment” package, which leverages the strength of collective economies to support service provision. In contrast, resource-scarce central and western regions may adopt “labor-for-care” mechanisms, wherein mutual aid service time is converted into tangible resources for daily life and production, offering a practical path for service mobilization amid economic constraints. In terms of cultural adaptation, strategies should focus on modernizing traditional ethics through innovative institutional arrangements. In clan-based villages (e.g., Fujian and Guangdong), ancestral halls can be revitalized as eldercare deliberation spaces, with clan elder committees granted coordination authority for service planning and delivery. In multiethnic communities (e.g., North China Plain), a “filial piety credit point” system can be introduced to link mutual support behaviors with agricultural subsidies, thereby reinforcing informal constraints and enhancing the modern governance value of traditional virtues. To ensure sustainability, a three-tiered risk-hedging mechanism should be established: provincial governments offer designated fiscal transfers based on elderly care service density; county-level governments provide mutual aid liability insurance; and villages introduce intergenerational inheritance schemes for service hours, facilitating long-term engagement across age groups. Furthermore, a regular evaluation mechanism should be implemented to enable dynamic policy adjustments. By tracking core indicators such as the elderly population ratio and labor force outmigration rate, the prioritization of care

service items—such as shifting from agricultural support to disability or long-term care—can be recalibrated on a periodic basis, thereby ensuring that the system remains responsive to evolving demographic dynamics.

Discussion

Global feasibility of implementation. The vision of younger-seniors-based elderly care is applicable globally, especially in some developing countries and regions. First is the universality of the vision. Many countries and regions share similar social structures and cultural traditions to rural China, relying on family and community mutual assistance relationships (Spitzer and Twikirize, 2023; Davies and Reid, 2024; Mathews, 2021). In such social contexts, the vision of younger-seniors-based elderly care can better utilize internal community resources, improve the quality of life for older adults, and thereby alleviate social pressure. Moreover, the vision emphasizes the value and potential of younger, healthy seniors, considering them assets rather than burdens. Elderly individuals in different countries and regions (with different cultural backgrounds) possess life skills and experiences adapted to local conditions. Therefore, utilizing local, younger, healthy seniors to address elderly care issues is inevitably adaptable to various social and cultural environments. The second is economic feasibility. In many countries, the cost of elderly care services has become a financial burden (Shraberman and Weinreb, 2024; Cho and Lee, 2022; Bessho, 2021). The vision of younger-seniors-based elderly care emphasizes mutual assistance among elderly individuals and village resources rather than solely relying on government-provided services or the market. Since the coverage of elderly care services provided by the government and the market is limited, this vision is more feasible in some developing countries or resource-constrained areas. Particularly in countries or regions with scarce resources but strong community relationships, younger-senior-based care for older adults is more readily accepted. Third is social reciprocity. It encourages support and cooperation between generations, enhancing community cohesion and mutual assistance. While providing caregiving services, elderly individuals feel recognized and supported by their society. This social reciprocity contributes to social harmony and stability.

Considerations for implementing younger-seniors-based elderly care vision. Several issues must be addressed when implementing the vision of younger-seniors-based care for older adults. First is the integration and management of village resources. Establishing a sound mechanism for managing resource elements ensures the effective integration, rational utilization, and fair distribution of village resources, including human, material, and social relationship resources. Second is the inheritance of village mutual assistance culture. Younger-seniors-based elderly care relies on the social relationship network and mutual assistance traditions within villages. Therefore, it is necessary to strengthen such relationships and traditions, encouraging villagers to help each other, share resources, and assume responsibilities. Third is identifying and matching supply and demand for older adults. Different types of older adults must be accurately identified to determine service supply, ensuring that younger, healthy seniors can provide appropriate services to older disabled seniors (Bone et al., 2024). Fourth is the management mechanism of “time banks.” The vision of younger-seniors-based elderly care emphasizes that younger healthy seniors “save time today and exchange services tomorrow.” In this process, it is necessary to address the value measurement of mutual assistance behavior, i.e., whether the contributions of younger, healthy seniors in caring for older disabled seniors can be rewarded. Fifth is government policies and support. When promoting the

younger-seniors-based elderly care model, the government needs to provide necessary policy support and financial assistance, including formulating relevant policies and regulations, increasing fiscal investment, and establishing supervision and management mechanisms, thereby improving the quality and coverage of elderly care services. Last is social education and publicity. It helps to strengthen the publicity, promote the vision of younger-seniors-based elderly care, and enhance awareness among village residents. The relevant social education and publicity activities to improve villagers’ sense of participation and responsibility.

Contribution to sustainable development goals. The vision of younger-senior-based care for older adults is crucial for actively addressing the challenges of global population aging, making significant contributions to achieving the Sustainable Development Goals (SDGs 3, 10, 11). Currently, amidst the United Nations Decade of Healthy Ageing (2021–2030), countries worldwide are actively exploring ways to reduce health inequalities and improve the lives of older people and their families and communities. The vision of younger-seniors-based elderly care significantly enhances the well-being of older people in rural areas by leveraging rural social relationships and encouraging the active participation of younger seniors. It significantly alleviates poor living conditions, inadequate well-being, and social participation inequality among rural elderly.

- (1) Contribution to Good Health and Well-being (SDGs 3): The vision of younger-seniors-based elderly care promotes intergenerational mutual support, facilitating healthy aging. This concept advocates the formation of the health mutual-aid groups and the establishment of a support chain between younger and older seniors to ensure elderly care management (e.g., health check-ups, chronic disease management). Through social support networks, it significantly reduces elderly loneliness and enhances group belonging. Furthermore, this concept has created a talent reserve mechanism, transforming healthy rural seniors into sustainable human resources for elderly care services.
- (2) Contribution to Reduced Inequalities (SDGs 10): The vision of younger-seniors-based elderly care focuses on multi-dimensional inequalities among the rural elderly, achieving a triple-tiered mechanism through the activation of social capital: intergenerational mutual support reconstructs age-inclusive social relationships, younger seniors’ participation in caregiving services enhance self-efficacy, and the reshaping of social roles promotes the redistribution of urban-rural resources. This endogenous support system not only improves the quality of life for elderly groups but also reduces structural inequalities within the group.
- (3) Contribution to Sustainable Cities and Communities (SDGs 11): The vision of younger-seniors-based elderly care not only focuses on the well-being of elderly individuals but also serves as a core element in promoting rural sustainable development. By building age-friendly infrastructures to enhance spatial inclusiveness, utilizing intergenerational knowledge transmission to activate cultural inheritance, and through institutionalized mutual aid networks to strengthen community resilience, this integrated framework not only increases the stock of social capital but also catalyzes eco-balanced, economically circular, and socially inclusive rural ecosystems.

Research contributions and limitations. This study makes three key theoretical contributions to aging research within the SDGs framework. First, it challenges the dominant paradigm that categorizes older adults as “policy objects,” “resource consumers,” or “passive welfare recipients,” and instead redefining them as

proactive contributors to sustainable development. Second, by forecasting the spatiotemporal patterns of rural population aging, it reveals a critical window for policy intervention before the 2050 inflection point in rural demographic aging. Third, the vision of younger-seniors-based elderly care transforms informal institutions such as China's clan relationships into sustainable elderly care resources through the study of rural social networks and mutual aid traditions, contesting the individualistic assumptions prevalent in Western mainstream aging theories.

However, three key limitations merit attention. First, the spatial predictions rely on provincial-level data (31 provinces), which may obscure intra-regional disparities in rural aging patterns. Second, while the 2050 timeframe aligns with China's modernization goals, it may overlook post-2050 demographic shifts, particularly the effects of the universal three-child policy. Future research should incorporate cross-national comparative studies, extend predictive modeling to 2100 to examine intergenerational equity, and integrate micro-level case studies to evaluate the implementation efficacy of the vision of younger-seniors-based elderly care.

Conclusions

This study, based on projections of rural population aging trends in China from 2020 to 2050, has yielded the following conclusions:

Firstly, rural China grapples with significant challenges in eldercare. Analysis of the eldercare landscape in rural China in 2020 reveals that issues such as the erosion of traditional familial caregiving roles, uneven economic development, and inadequate eldercare infrastructure are major obstacles confronting rural eldercare. This underscores the urgent need for innovative eldercare models to address the burgeoning rural aging population.

Secondly, the trajectory of rural population aging in China is poised to intensify. Between 2020 and 2050, rural aging rates are set to surge markedly, exhibiting pronounced regional disparities. While eastern regions show relatively higher aging rates, their western counterparts display comparatively lower figures. Remarkably, by 2050, rural aging rates in Chongqing and Gansu are projected to experience a downturn for the first time, marking a pivotal shift in the rural aging landscape.

Thirdly, this article introduces a pioneering vision for future eldercare in rural China: younger-seniors-based elderly care. This vision underscores the central role of familial and communal support networks in rural China and advocates for the proactive involvement of younger seniors in providing essential caregiving services to their older counterparts. Aligned with the prevailing social structures and traditional cultural values in rural China, this vision is expected to alleviate the eldercare burden on younger generations and society at large.

Lastly, the vision of younger-seniors-based elderly care transcends national borders and holds relevance beyond China, particularly for developing nations with similar social frameworks. The implementation of this vision requires attention to issues such as village resource integration, the preservation of social and cultural legacies, and the alignment of eldercare supply and demand. Concurrently, this vision holds promise for advancing Sustainable Development Goals related to health, inequality mitigation, and the establishment of sustainable communities.

Ensuring the well-being of older adults has been an ideal in every era. Currently, China's population is aging before becoming affluent. By integrating the collective economy system and the familiar social networks in rural areas, Chinese villages are establishing a model of "younger-seniors-based elderly care," with subsidies and support from the state and society. In the future, rural China will be able to establish a low-cost, efficient, and emotionally connected mutual assistance eldercare system, thus realizing the ideal of ensuring the well-being of older adults.

Data availability

"Tabulation on the 2020 China Population Census by County" can be found at https://www.stats.gov.cn/zs/tjwh/tjkw/tjzl/202302/t20230220_1913738.html for a brief introduction, but the full dataset requires the purchase of the published volume. "China Population Census Yearbook 2020" is available for consultation at <https://www.stats.gov.cn/sj/pcsj/rkpc/7rp/zk/indexch.htm>.

Code availability

The population projection software, PADIS-INT V1.7.0, was used to forecast population development trends. Permission to use this software can be obtained from the China Population and Development Research Center (<https://www.cpdrc.org.cn/>). Data were analyzed using statistical software Origin and geographic information software ArcGIS 10.3.

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Note

- 1 "9073" elderly care model: 90% of the elderly choose to age at home, 7% opt for community-based care, and 3% prefer institutionalized care. "9064" elderly care model: 90% of the elderly choose to age at home, 6% opt for community-based care, and 4% prefer institutionalized care.

References

- Adarsh K-K (2020) Investigating factors that promote time banking for sustainable community based socio-economic growth and development. *Comput Hum Behav* 107:105623. <https://doi.org/10.1016/j.chb.2018.07.034>
- Bai R-H, Liu U-N, Zhang L, Dong W-Y, Bai Z-G, Zhou M-G (2023) Projections of future life expectancy in China up to 2035: a modelling study. *Lancet Public Health* 8(12):e915–e922. [https://doi.org/10.1016/S2468-2667\(22\)00338-3](https://doi.org/10.1016/S2468-2667(22)00338-3)
- Bessho S-I (2021) Local fiscal multipliers and population aging in Japan. *Jpn World Econ* 60:101099. <https://doi.org/10.1016/j.japwor.2021.101099>
- Bone J-K, Bu F, Sonke J-K, Fancourt D (2024) Leisure engagement in older age is related to objective and subjective experiences of aging. *Nat Commun* 15:1499. <https://doi.org/10.1038/s41467-024-45877-w>
- Chao F, Gerland P, Cook A-R, Guilimoto C-Z, Alkema L (2021) Projecting sex imbalances at birth at global, regional and national levels from 2021 to 2100: scenario-based Bayesian probabilistic projections of the sex ratio at birth and missing female births based on 3.26 billion birth records. *Bmj Glob Health* 6(8):e005516. <https://doi.org/10.1136/bmjgh-2021-005516>
- Chen H-R (2022) Linking institutional function with form: Distributional dynamics, disequilibrium, and rural land shareholding in China. *Land Use Policy* 120:106283. <https://doi.org/10.1016/j.landusepol.2022.106283>
- Chen S-X, Yang J, Ma B-X, Meng J, Chen Y, Ma T-T, Zhang X-J, Wang Y-L, Huang Y-Q, Zhao Y, Wang Y-G, Lu Q (2024) Understanding community-dwelling older adults' preferences for home- and community-based services: A conjoint analysis. *Int J Nurs Stud* 152:104699. <https://doi.org/10.1016/j.ijnurstu.2024.104699>
- Chen S-Y, Huang Q-X, Muttarak R, Fang J-Y, Liu T, He C-Y, Liu Z-W, Zhu L (2022) Updating global urbanization projections under the shared socioeconomic pathways. *Sci Data* 9(1):137. <https://doi.org/10.1038/s41597-022-01209-5>
- Cheng Y, Rosenberg M-W, Wang W-Y, Yang L-S, Li H-R (2011) Aging, health and place in residential care facilities in Beijing, China. *Soc Sci Med* 72(3):365–372. <https://doi.org/10.1016/j.socscimed.2010.10.008>
- Cho D, Lee K-W (2022) Population aging and fiscal sustainability: Nonlinear evidence from Europe. *J Int Money Financ* 126:102665. <https://doi.org/10.1016/j.jimonfin.2022.102665>
- Chung J, Thompson H-J, Joe J, Hall A, Demiris G (2017) Examining Korean and Korean American older adults' perceived acceptability of home-based monitoring technologies in the context of culture. *Inf Health Soc Ca* 42(1):61–76. <https://doi.org/10.3109/17538157.2016.1160244>
- Cui X-J, Ma L-B, Tao T-M, Zhang W-B (2022) Do the supply of and demand for rural public service facilities match? Assessment based on the perspective of rural residents. *Sustain Cities Soc* 82:103905. <https://doi.org/10.1016/j.scs.2022.103905>
- Davies R, Reid K (2024) Supporting each other: Older adults' experiences empowering food security and social inclusion in rural and food desert communities. *Appetite* 198:107353. <https://doi.org/10.1016/j.appet.2024.107353>
- De Lange P (2015) Mehrgenerationenhäuser: a meeting place for generations. *Geron* 17(Suppl 1):51–53. <https://doi.org/10.1007/s40718-015-0116-1>

- Elena F-L, Juan Q-L (2020) Methodology for 'reasonable adjustment' characterisation in small establishments to meet accessibility requirements: A challenge for active ageing and inclusive cities, Case study of Madrid. *Cities* 103:102749. <https://doi.org/10.1016/j.cities.2020.102749>
- Hannah M-O (2024) The global crisis of loneliness: a call for contextualised, mechanistic research. *Lancet Health Longev* 5(4):E241–E242. [https://doi.org/10.1016/S2666-7568\(24\)00030-8](https://doi.org/10.1016/S2666-7568(24)00030-8)
- Huang Y, Ma Y-R, Ou J, Ma J (2024) Capital or burden? The impact of social networks on elderly care services consumption: Evidence from China. *Int Rev Econ Financ* 94:103416. <https://doi.org/10.1016/j.iref.2024.103416>
- Kriebs A (2023) Population aging and sustainable farming in China. *Nat Aging* 3:367. <https://doi.org/10.1038/s43587-023-00406-0>
- Kwangyong P (2024) An aging population and sustainable government debt: The case of Korea. *J Asian Econ* 95:101831. <https://doi.org/10.1016/j.asieco.2024.101831>
- Kundu J, Bharadwaz M-P, Kundu S, Bansod D-W (2022) The interregional disparity in the choice of health care utilization among elderly in India. *Clin Epidemiol Glob* 13:100929. <https://doi.org/10.1016/j.cegh.2021.100929>
- Lee J-H, Burns R-C (2022) Older adults' preferences for natural environment and rural life: Intergenerational transmission of pro-environmental motivation. *J Outdoor Rec Tour* 39:100556. <https://doi.org/10.1016/j.jort.2022.100556>
- Leung W-K-S, Chang M-K, Cheung M-L, Shi S (2022) Swift trust development and prosocial behavior in time banking: A trust transfer and social support theory perspective. *Comput Hum Behav* 129:107137. <https://doi.org/10.1016/j.chb.2021.107137>
- Li L-W, Long Y, Essex E-L, Sui Y, Gao L (2012) Elderly Chinese and Their Family Caregivers' Perceptions of Good Care: A Qualitative Study in Shandong, China. *J Gerontol Soc Work* 55(7):609–625. <https://doi.org/10.1080/01634372.2012.703165>
- Li M, Ao Y, Peng P, Bahmani H, Han L, Zhou Z, Li Q (2023) Resource allocation of rural institutional elderly care in China's new era: spatial-temporal differences and adaptation development. *Public Health* 223:7–14. <https://doi.org/10.1016/j.puhe.2023.07.005>
- Li S, Wang Q, Li R (2024) How aging impacts environmental sustainability—insights from the effects of social consumption and labor supply. *Humanit Soc Sci Commun* 11:387. <https://doi.org/10.1057/s41599-024-02914-9>
- Liu C, Yi F-J (2023) Relative deprivation and health revisited: New evidence from middle-aged and older adults in rural China. *China Econ Rev* 79:101948. <https://doi.org/10.1016/j.chieco.2023.101948>
- Liu J-R, Zhong S-P, Huang Y-Q, Wang Z (2021) How does the preference heterogeneity affect the elderly's evaluation of bus accessibility? Evidence from Guangzhou, China. *J Transp Health* 22:101094. <https://doi.org/10.1016/j.jth.2021.101094>
- Liu Y-S, Li X-H, Guo Y-Z (2024) Exploring land system reform for demographic transition in rural China. *Land Use Policy* 147:107355. <https://doi.org/10.1016/j.landusepol.2024.107355>
- Liu Y-W, Duan Y-N, Xu L (2020) Volunteer service and positive attitudes toward aging among Chinese older adults: The mediating role of health. *Soc Sci Med* 265:113535. <https://doi.org/10.1016/j.socscimed.2020.113535>
- Ma L-B, Dou H-J, Wu S-S, Shi Z-H, Li Z-Y (2022) Rural development pressure and "three-stay" response: A case of Jinchang City in the Hexi Corridor, China. *J Rural Stud* 91:34–46. <https://doi.org/10.1016/j.jrurstud.2022.03.002>
- Mathews M-C (2021) How village leaders in rural Amazonia create bonding, bridging, and linking social capital configurations to achieve development goals, and why they are so difficult to maintain over time. *World Dev* 146:105541. <https://doi.org/10.1016/j.worlddev.2021.105541>
- Mika T, Shinobu I, Akiko M, Sachiko T, Shota M, Amir R, Nikil D, Mahkameh R, Adeline N (2024) Perspectives of Japanese elders and their healthcare providers on use of wearable technology to monitor their health at home: A qualitative exploration. *Int J Nurs Stud* 152:104691. <https://doi.org/10.1016/j.ijnurstu.2024.104691>
- Nidadavolu L-S, Walston J-D (2021) Underlying vulnerabilities to the cytokine storm and adverse COVID-19 outcomes in the aging immune system. *J Gerontol A Biol Sci Med Sci* 76:e13–e18. <https://doi.org/10.1093/gerona/glaa209>
- Pivodic L, Van-den-Block L, Pivodic F (2024) Social connection and end-of-life outcomes among older people in 19 countries: a population-based longitudinal study. *Lancet Health Longev* 5(4):E264–E275. [https://doi.org/10.1016/S2666-7568\(24\)00011-4](https://doi.org/10.1016/S2666-7568(24)00011-4)
- Qiu T-W, Li Y-F, Shi X-J, Peng C-Y, Luo B-L (2024) Alternative modes of governance: Clans and social instability in rural China. *China Econ Rev* 84:102136. <https://doi.org/10.1016/j.chieco.2024.102136>
- Rachel C, Margaret M-F (2016) Left behind, at-risk, and vulnerable elders in rural China. *China Econ Rev* 37:140–153. <https://doi.org/10.1016/j.chieco.2015.10.005>
- Rawson H, Rigby K, Ockerby C, Forbes H (2022) Older people's experiences of community engagement in aged care: A qualitative study. *Collegian* 29(6):828–836. <https://doi.org/10.1016/j.colegn.2022.06.010>
- Shraberman K, Weinreb A-A (2024) The fiscal consequences of changing demographic composition: Aging and differential growth across Israel's three major subpopulations. *J Econ Ageing* 27:100500. <https://doi.org/10.1016/j.jeoa.2023.100500>
- Song S, Wang D, Zhu W, Wang C (2020) Study on the spatial configuration of nursing homes for the elderly people in Shanghai: Based on their choice preference. *Technol Forecast Soc* 152:119859. <https://doi.org/10.1016/j.techfore.2019.119859>
- Song Y (2014) Losing an only child: the one-child policy and elderly care in China. *Reprod Health Matter* 22(43):113–124. [https://doi.org/10.1016/S0968-8080\(14\)43755-8](https://doi.org/10.1016/S0968-8080(14)43755-8)
- Spitzer H, Twikirize J (2023) Social innovations in rural communities in Africa's Great Lakes region. A social work perspective. *J Rural Stud* 99:262–271. <https://doi.org/10.1016/j.jrurstud.2021.10.013>
- Tang Y, Xu Q, Tian R-G (2024) Spiritual affection and support: Unique aging model of older adult Chinese who lost their only child. *Humanit Soc Sci Commun* 11:384. <https://doi.org/10.1057/s41599-024-02798-9>
- UN DESA (2019) World Population Prospects 2019 Volume I: Comprehensive Tables. <https://www.un.org/development/desa/pd/content/world-population-prospects-2019-volume-i-comprehensive-tables>
- UNDESA (2022) World Population Prospects 2022, Data Sources. <https://population.un.org/wpp/>
- UNDESA (2023) World Social Report 2023: Leaving No One Behind In An Ageing World. <https://desapublications.un.org/publications/world-social-report-2023-leaving-no-one-behind-ageing-world>
- UNFPA (2015) Global AgeWatch Index 2015 Insight Report. <http://www.globalagewatch.org/reports/global-agewatch-index-2015-insight-report-summary-and-methodology/>
- UNPD (2017) World Population Prospects: The 2017 Revision. <https://www.un.org/en/desa/world-population-prospects-2017-revision>
- Wang K, Ke Y-J, Sankaran S (2023) Social sustainability of aged care public-private partnership projects in China: Critical practices and realisation paths. *J Clean Prod* 422:138644. <https://doi.org/10.1016/j.jclepro.2023.138644>
- Wang S, and Yan B (2024) China's elderly mutual aid model: an active ageing perspective. *Qual. Ageing Older Ad. Vol. ahead-of-print No. ahead-of-print*. <https://doi.org/10.1108/QAOA-08-2024-0051>
- Zhang F, Li D-Z, Ahrentzen S, Zhang J-K (2019) Assessing spatial disparities of accessibility to community-based service resources for Chinese older adults based on travel behavior: A city-wide study of Nanjing, China. *Habitat Int* 88:101984. <https://doi.org/10.1016/j.habitatint.2019.05.003>
- Zhao Y-Y, Li J (2024) Opportunities and challenges of integrating artificial intelligence in China's elderly care services. *Sci Rep*. 14:9254. <https://doi.org/10.1038/s41598-024-60067-w>
- Zhou X-Q, Cao K (2023) Spatial multi-objective optimization of institutional elderly-care facilities: A case study in Shanghai. *Int J Appl Earth Obs* 122:103436. <https://doi.org/10.1016/j.jag.2023.103436>

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Author contributions

'Haojian Dou' and 'Cheng Wang' came up with the idea and designed the study. All authors participated in the data collection, validation, and processing processes. 'Haojian Dou' and 'Cheng Wang' organized multiple discussion meetings. 'Guishan Cheng', 'Xiaoyan Lei' and 'Shuang Xu' participated in all meetings. 'Guishan Cheng', 'Xiaoyan Lei' and 'Shuang Xu' were responsible for graphics production. 'Haojian Dou' and 'Cheng Wang' wrote, reviewed and revised the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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