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Spatial Equity Evaluation of Rural Eldercare Service Resources Based on Accessibility: A Case Study of Huanxian County of Gansu Province, China

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Abstract: Safeguarding the elderly population in the countryside is an inherent requirement for alleviating social conflicts in rural areas and effectively carrying out China's Rural Revitalization. The existing spatial mismatch between rural elderly service facilities and population distribution in China aggravates the imbalance of facility resource space, how to improve the accuracy of demand and supply results and better measuring the spatial fairness of elderly service is significant to realize the optimal allocation of rural elderly service. Based on the above, this study pays attention to the refined needs of the elderly population, and focuses on the spatial equity of the rural elderly facilities, to make up for the short boards of the basic public services in the countryside and realize the all-round rural revitalization. This study takes Huanxian County in the hilly loess area of Longdong, China as an example and explores the spatial equity of rural elderly services by using the Urban Spatial Network Analysis (UNA) to measure the accessible quantity and supply capacity of elderly services. The results found that there were 553 rural eldercare service facilities in Huanxian County, including 285 eldercare facilities and 268 medical and health facilities, and the spatial distribution is characterized by a southward shift in the east and uneven regional distribution. Overall, the supply capacity of rural pension services was generally good, with the township center as the gathering point and spreading out in a faceted manner, with nearby townships forming a contiguous area; however, there were strong contrasts and obvious differences in the strength of supply capacity. However, the spatial equity of rural eldercare service was poor. In 42.05% of the elderly population grid cells, eldercare service spatial equity was extremely low. The spatial distribution also presented a northern preference over the southern, a western preference over the eastern, and a concentration along the highway. The study explored the realization of spatial equity in the optimal allocation of rural elderly services based on paying attention to the refined needs of the rural elderly population, a vulnerable group, to provide a reference for solving the shortcomings of basic public services in rural areas. The fair allocation of rural elderly services demands that the spatial optimization of facility layout be organically coordinated with policy, management, and post-maintenance, and all elements in the rural territorial system be fully mobilized to achieve the basic guarantee of China's rural elderly problems.

Keywords: rural eldercare service; spatial equity; hilly loess region of Longdong; Huanxian County; China

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1 Introduction

The 2019 World Population Prospects Report published by the United Nations highlights that global population aging will continue to increase in the future (UN, 2020). The population aged 60 and over in China now stands at 264 million, accounting for 18.70% of the total population. There are 191 million people aged 65 and over, representing 13.50% of the total population, and the problem of population aging is prominent. In rural China, there are 90 million elderly people aged 65 and over, constituting 17.72 % of the total rural population, and the degree of population aging in rural areas is much higher than in towns and cities (Bai and Lei.,2020; Jun., 2021). The increase in aging and the long-term mismatch of services for the elderly in rural China will have far-reaching economic, social, cultural, and political implications and is a huge challenge for sustainable development in the new era (Wang and Wu, 2016). In this special period of urban-rural integration, rural areas are facing many challenges, such as the widening gap between urban and rural areas and 'aging before getting rich'. A scientific and reasonable response to the aging population and the allocation of services for the elderly in rural areas is related not only to the realization of the rural revitalization strategy but also to overall social and economic development in China (Gao et al., 2015; Guo et al., 2019).

Living in one's own home and familiar community is still the dominant choice for elderly population in rural areas, despite the increasing diversity of aging patterns. Aging in place, supporting elderly people to age in familiar communities is therefore widely accepted. Researchers have explored the factors and ways in which aging in place can be achieved and have suggested that transport, leisure, facilities, interaction, and culture should be considered in planning (Wahl and Lang, 2003; Davey et al., 2006; Dye et al., 2010). With the rapid development of industrialization and urbanization in China, the elderly have undergone profound changes in their lifestyles, quality of life, and concepts of life: the model of eldercare has changed from traditional family-based eldercare to institutional and community-based eldercare; the pursuit of health has changed from focusing on disease treatment to strengthening health management and emphasizing the integration of medical care; material and cultural needs have changed from basic material need to spiritual and social needs for self-respect and self-fulfillment. The shift in material and cultural needs from basic material needs to spiritual, self-respecting, and self-fulfilling social participation needs has posed new challenges to the elderly system and the allocation of elderly services in the new era. Researchers conducted surveys and analyses of service needs for the rural elderly and related factors based on open data or regional case studies (Guo, 2012). They have also indicated that the basic personal characteristics of the elderly, the situation of the family and children, the level of social security, the stability of economic resources, and the level of local economic development all influence the choice of retirement model by the rural elderly (Wang, 2016; Li and Zheng, 2016). However, due to the long-standing urban-rural dichotomy, most rural areas lack economic capacity and public services, there is a clear contradiction between supply and demand for various facilities, and the spatial equity of eldercare services needs to be improved (Ding and Wang, 2011).

In the 1960s, Hansen (1959) introduced the concept of spatial accessibility and defined it as 'potential opportunities for interaction' or 'the ease of getting from a place to a destination based on some mode of transport' (Järv et al., 2018). Accessibility measures consider the spatial distribution of potential services, the ease of reaching a destination, and the attractiveness and value of the destination. Research methods include the buffer zone method, Huff model, nearest distance model, potential model and improved potential model, the two-step movement search method (2SFCA) and improved 2SFCA, and the three-step movement search method (3SFCA) and improved 3SFCA (Tao et al., 2014). In recent years, the combination of Geographic Information System (GIS), statistical surveys, and other methods to link public service facilities and residents' daily behavior has been applied with wider perspectives and increased methodological rigor. It is an important baseline for measuring equity in the provision of public service facilities and is widely used in studies of spatial equity and spatial layout of health facilities, education, transport facilities, facilities for the elderly, and public green spaces (Delamater, 2013; Cho et al., 2021; Gaglione et al., 2021). Chinese researchers believe that the spatial equity of public service facilities includes both spatial accessibility equity and spatial availability equity, of which spatial accessibility is an important indicator to

assess whether service allocation for the elderly is fair and reasonable and can reflect the inefficient allocation and unfair distribution of service facilities for the elderly in traditional planning (Lin et al., 2009). With the achievement of a moderately prosperous society by 2020 and the orderly implementation of rural revitalization, rural eldercare services can now be greatly improved, but in the current situation of rural eldercare services, especially when compared with the urban case, there is still a large gap between supply and demand. At present, the supply of services for the rural elderly still can not fully meet their diverse needs in the new era. Most existing accessibility research methods ignore the internal structure of the countryside, scarcely consider its complex natural environment, and use relatively crude measures of public resource accessibility. In terms of research regions, most studies focus on the areas surrounding large cities, which have good socio-economic conditions. Few studies have been conducted in the hilly areas of the Loess Plateau of China, where natural conditions are poor and socio-economic conditions are backward, and even fewer studies have been conducted on the villages in this area (You and Niño-Zarazúa, 2019; Huang and Zhang, 2021). In terms of research objects, most studies have focused on public service resources as a whole; most studies of single public-service resources have focused on medical facilities, educational resources, and public green spaces (Chías and Abad, 2017), with few studies on the supply and demand of services for the rural elderly and spatial equity. In terms of research scale, most studies have taken administrative units such as towns and villages as the units of study, which do not truly reflect the spatially distributed demand of the elderly population and the supply capacity of services for the elderly (Shen and Williamson, 2010; Zhao et al., 2016).

The hilly loess area of Longdong, China is characterized by terrain fragmentation, poor natural environment, numerous rural settlements, scattered population, and difficulty of public service facility configuration. These factors seriously affect the supply of services for the rural elderly. This study was carried out from the perspective of spatial equity and optimal configuration. The example of Huanxian County in the loess hills region of Longdong was used. The study began with the spatial distribution of the rural elderly population and the spatial layout of services for the rural elderly. Then, in the context of comprehensive rural revitalization, it clarified the supply capacity of rural elderly care services, explored their degree of spatial equity. The aim was to address the shortcomings of basic rural public services and provide ideas for building a better system.

2 Materials and Methods

2.1 Study area

Huanxian County (106°21′E−107°44′E, 36°01′N−37°09′N) is located in the eastern part of Gansu Province and the northwestern part of Qingyang City (Fig. 1). Huanxian County is located at the edge of the Mu Us Desert, in the hill and gully area of the hilly loess area of Longdong, with many mountains, gullies, and ravines, and is a transition zone from the residual plateau and gully area to the desert area. Its geomorphology can be divided into the western palm hills and gullies, the northern part of the hill and gully area, the southern part of the residual loess hills and gullies, and the central ring river valley area. More than 90% of the territory is covered by loess, with undulating hills and gullies. The county's topography is northwest high and southeast low, with the highest altitude reaching 2089 m and the lowest at 1136 m. It has a temperate continental semi-arid climate, with an average annual temperature of 9.2°C, a frost-free period of 200 d, a sunshine period of 2600 h, an average annual precipitation of about 300 mm, and a high evaporation rate of 2000 mm (Qingyang Statistics Yearbook, 2023).

Huanxian County has 10 towns and 10 townships, 251 administrative villages, 11 communities, and 1487 village groups. The population consists of 3.649×10^5 people in total, 1.027×10^5 households in total, and 3.046×10^5 permanent residents at the end of 2020, including 1.103×10^5 people in towns and cities, accounting for 36.21% of the permanent population, and 1.944×10^5 people in villages, accounting for 63.79% of the resident population. Among the county's resident population, 0.637×10^5 people (20.92%) are aged 0–14; 1.887×10^5 people (61.92%) are aged 15–59; 5.230×10^4 people (17.16%) are aged 60 and above; and 0.365×10^5 people (11.98%) are aged 65 and above. The annual per capita disposable income of urban residents is 3.3128×10^4 yuan (RMB), and that of rural residents is 1.0032×10^4 yuan (RMB) (Qingyang Statistics Yearbook, 2023).

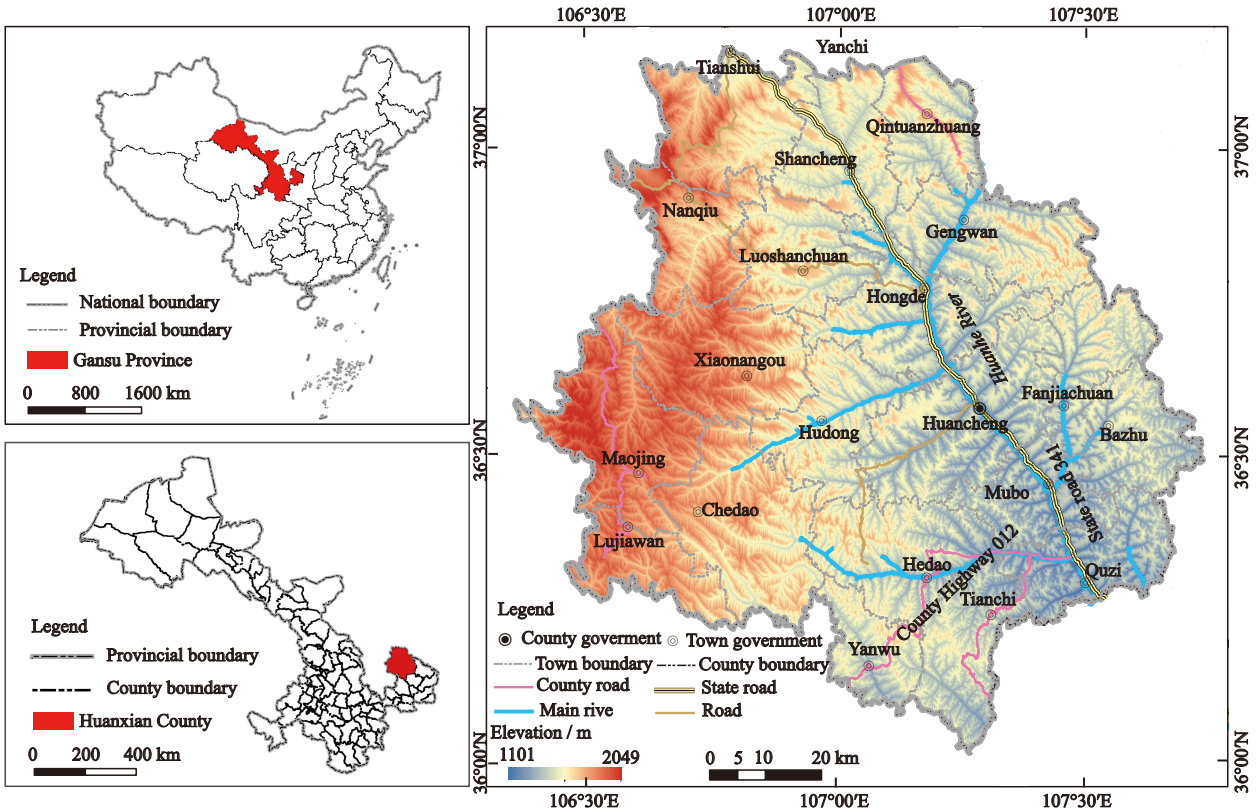

Fig. 1 Location of the Huanxian County of Gansu Province, China. Based on the standard map service website of the Ministry of Natural Resources (http://bzdt.ch.mnr.gov.cn) with the approval number GS(2020)4619, and the boundary of the base map has not been revised

2.2 Theoretical framework

The long-term dual urban-rural structure will have difficulty adapting to the new trend of rapid industrialization and urbanization, which makes it difficult for many rural resources to function and hinders the sound operation of the rural territorial system (Liu, 2019). With the increasing number of urban jobs and the more convenient infrastructure and public service facilities of cities, the attractiveness of cities for the rural population increases, and socio-economic development intensifies the contradiction between urban and rural development. However, due to the huge differences in rural resource endowments and location conditions, the development of areas with poorer rural resource endowments lags, the endogenous development momentum of rural areas is insufficient, and the loss of high-quality resource elements is serious. Advanced industrial technology is provided by industrialization while improving agricultural productivity, promoting the emergence of surplus labor, leading large numbers of rural people to depart for the cities. The surrounding environment has significantly disturbed the rural territorial system, and the failure of the rural territorial system to adjust to the disturbance promptly has eventually led to a disruption of the balance of the rural territorial system, resulting in 'rural disease' (Zheng and Liu, 2018; Fang, 2022).

'Rural disease' refers to the loss of self-regulation and self-adaptation of the rural territorial system in the process of development and of the interaction between the various subsystems and the surrounding environment, which eventually leads to the decline of the rural territorial system. The main manifestations of the disease are the rapid deagrarianization of rural production factors, the rapid aging and weakening of social agents, emptying of land for construction, serious pollution of the environment, and hollowing-out of infrastructure and public service facilities (Liu et al., 2019).

Due to the departure of the rural young and middle-aged labor force, a series of problems emerged including leaving the elderly behind in the countryside, and Chinese society is already entering a period of aging with fewer children (Ma et al., 2022a). With an improved living environment and quality of life in the countryside, the elderly population is seeking a more

convenient lifestyle and a higher quality of life, and their needs are gradually diversifying (Ma et al., 2022b). However, due to large-scale relocation and eviction and the crude use of rural land elements, there is a significant shortage of rural public services and infrastructure. The demand for services for the rural elderly (healthcare facilities and services for the elderly) has changed significantly, and the supply of these services has fallen short of demand. This spatial imbalance has greatly affected the living environment and quality of life of the elderly population (Ma et al., 2021).

Although the administrative unit-based allocation of public service facilities in China is administratively equitable, it does not consider the actual distribution of the rural population, which to some extent reduces the number of demand points and exacerbates the spatial imbalance of facilities and resources, especially for services for the rural elderly. The rural population grid, on the other hand, refines population demand, improves the accuracy of supply and demand results, and better measures the spatial equity of eldercare services, thus realizing an optimal allocation of rural eldercare services on the existing basis, solving the existing problem of 'seeing people, but not things', and better bridging to the 'bottom-up' concept of 'people-centered' allocation (Fig. 2).

2.3 Data sources and processing

The research data used in this paper came from four main sources: 1) data on the elderly population. The data on the elderly population in each administrative village in Huanxian County in 2021 came from the annual statistical reports of each township in Huanxian County (https://www.huanxian.gov.cn/tjj/fdgk/gzdt); the subject group, based on the Participatory Rural Appraisal (PRA) method, conducted two surveys in August 2020 and September 2021. This paper covers three aspects (demographic characteristics, social security, and public service facilities). 2) Data on services for the elderly. First, 860 POI (Point of Interest) data points were obtained through the Gaode Map API (https://amap.apifox.cn/) using a Python crawler (https://python.belacad.cn/?bd_vid), including the names, addresses, latitude, longitude, category codes, and other attribute information of POI data points such as healthcare services and public facilities. Spatial matching and spatial projection were carried out with the help of ArcGIS 10.4 (https://

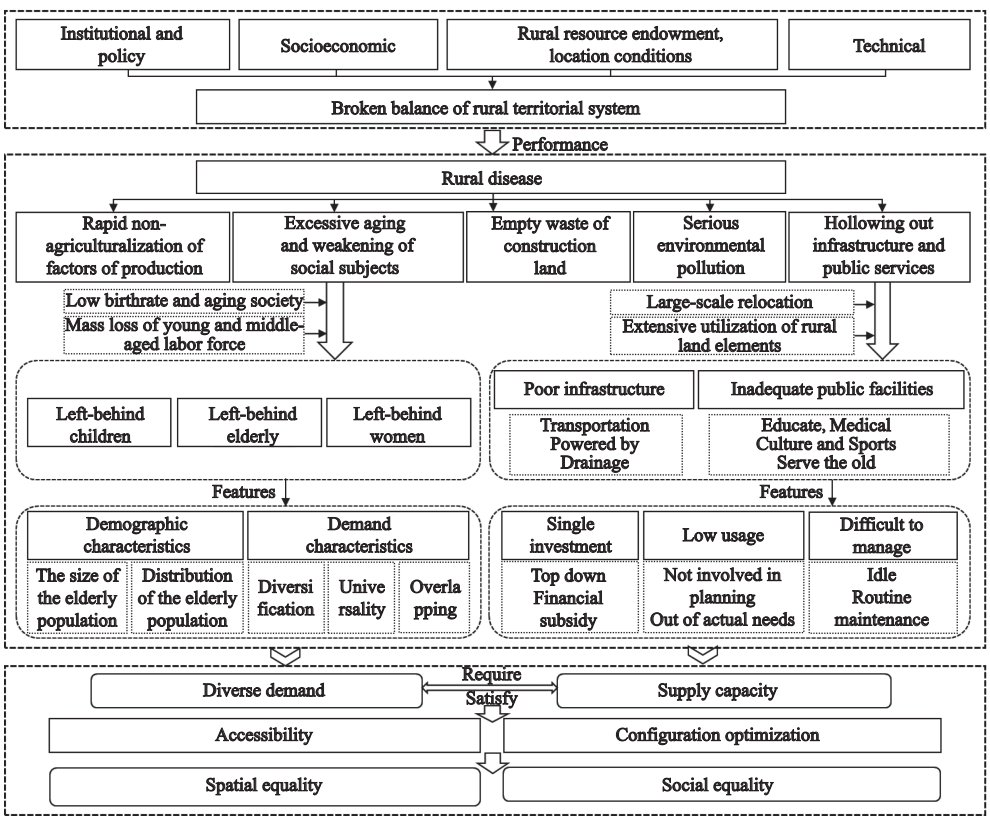

Fig. 2 Theoretical framework of equity evaluation of rural elderly services

soft.wxqilinz.cn/gis-jb61d/?plan). The data extracted from the 'Third Land-Use Survey' database were used for the research (https://www.huanxian.gov.cn/Upload/main/pdf/2021/11/10/). 3) Road data. Including vector data for national, provincial, county, and township roads in the county, were downloaded from the Geospatial Data Cloud (http://www.gscloud.cn/), and data for internal road networks in villages were extracted from the 'Third Land-Use Survey' database of Huanxian County. 4) Vector administrative village boundaries (1 : 250 000) and land-use data for Huanxian County were extracted from the 'Third Land-Use Survey' database of the Huanxian County Natural Resources Bureau in 2020 (https://www.huanxian.gov.cn/Upload/main/pdf/2021/11/10/).

2.4 Methods

2.4.1 Spatial distribution and testing of the elderly population

The administrative village unit is the smallest geographic unit in China's rural demographics, and due to constraints such as the elderly population's difficulty in traveling and the sparsely populated nature of rural areas, a supply source located at an administrative center can not always fall within the accessible radius of services for the elderly, resulting in huge differences in the ratio of supply to demand for services for the elderly in some administrative villages. Using a smaller geographical unit, the grid cell, as the demand point for services for the elderly, the land-use impact model was used to estimate the population of each grid cell (Wu et al., 2018; Luo et al., 2020).

First, a 500 m × 500 m grid was created based on ArcGIS; the number of grid cells within the study area was 37 823, and the land-use impact model was used to represent the spatial distribution of the population. The regression coefficients of the rural elderly population density (independent variable) and the rural land-use type index (independent variable) were found by stepwise regression. Because the test data needed to be no less than 20% of the total sample, the 251 rural units were randomly divided into two groups, 200 data points for constructing the grid cell regression model, and 51 data points for testing the model. The village land-use coefficients of 37 secondary categories under 12 primary categories in the 'Third Land-Use Survey' were selected as the independent variables, and the elderly population density of 251 villages was used as the dependent variable for stepwise regression. Therefore, the constant term of the regression model was set to zero to ensure the non-negativity of the simulated elderly population density, and the regression coefficients of elderly population density and rural land-use type index were found, as shown in Eq. (1):

$$Y = 187.48X_{702} - 6729.61X_{0810} + 550.96X_{508} + 128.16X_{201} + 751.13X_{801} \quad (1)$$

where Y denotes the elderly population density, and Eq. (1) passed the $P = 0.01$ significance test in the stepwise regression analysis, with an R^2 of 0.91. The independent variables of the rural land-use impact model were the five indicators, including: (1) X_{702} (rural residential land) is the carrier of the residence and life of the elderly in the countryside, and the main place of activities for the elderly, so the variable can effectively measure the density of the spatial distribution of the elderly's living space. X_{0810} (building lots) is a place for the elderly to spend their old age and leisure activities, and it is a variable that directly reflects the spatial distribution of the elderly in the countryside in terms of leisure agglomeration. X_{508} (logistics and storage land) could reflect express places such as online shopping for seniors, while potentially increasing employment for some seniors. Therefore, this indicator can measure the spatial distribution of older persons from a business perspective. X_{201} (orchards) is an important place for rural older people to work, and the orchard indicator can demonstrate the spatial distribution of older people in terms of farming. X_{801} (parks and green spaces) also measures the spatial distribution of older people in the countryside from a recreational aging perspective, as a measure of the density of the older population.

Next, the population density of each grid cell was calculated. The grid cells were overlaid with the land-use types to determine the rural land-use type index for each grid cell. The regression coefficients of the various rural land-use types in Eq. (1) were assigned to the corresponding land-use types of the grid cells to fit the elderly population densities of the various rural land-use types in the grid cells, and finally, the simulated values of each land-use type were fused to obtain the elderly population density of individual grid cells. This resulted in 15 974 grid cells with reasonable elderly population densities and a spatially distributed elderly population.

Finally, the study tested the reliability and accuracy

of the model using a second set of 51 test data. We found that the R^2 values of the statistical values of elderly population density fitted to the simulated values were all 0.97, giving a good fit. The county's total statistical elderly population is 52 285 and the total number of simulated elderly population is 58 351. The average density of the statistical elderly population is 5 person/km^2 and the simulated average density is 6 person/km^2. Overall, the average relative error for the total simulated elderly population was 11.61%. This study employed rural elderly population and land use data to obtain an overall 500 m × 500 m grid population density that could reflect the distribution of the elderly population in Huanxian County.

2.4.2 Spatial accessibility of eldercare services

Villages in rural areas are scattered, and in the hilly loess region of Longdong, roads consist mostly of steep and winding hill climbs and descents, meaning that elderly people are greatly restricted in their travel. The accessibility of services for the rural elderly is greatly limited by the locations of the elderly and the transport network, and there is a significant difference between the elderly living in the Loess Plateau area and those living in the mountainous areas, who travel the same distance to access facilities for the elderly. Previous facility-centered spatial coverage calculations ignored the population's demand for facilities; using the center of an administrative village as a starting point to search for facility provision within a certain radius resulted in most demand points in the area not being involved in the calculation, making the supply/demand ratio and the accessibility calculations less accurate. According to existing research, a more microscopic spatial representation of the elderly population's demand points and eldercare facilities could effectively improve the accuracy of the accessibility calculation. In this study, the spatial accessibility of services for the rural elderly was quantified using the Urban Spatial Network Analysis (UNA) environment developed by the Urban Form Lab, which was a joint project of the Massachusetts Institute of Technology (MIT) and the Singapore University of Technology and Design (SUTD) (Sevtsuk and Mekonnen, 2011; 2012).

UNA is based on the theory of behavioral geography, where points are used to represent a spatial location when assigning values to points in space (Gan et al., 2021), calculating network paths to assign values to points in a given target, and combining this with weight analysis to calculate the total score obtained for each target point:

$$\text{Gravity}[i]^r = \sum_{j \in G-\{i\}, d[i,j] \le r} \frac{W[j]^\alpha}{e^{\beta \cdot d[i,j]}} \tag{2}$$

where Gravity$[i]^r$ is the accessibility index of starting point i within search radius r; G denotes the distribution point of the elderly population; $W[j]$ is the weight of endpoint j; $d[i, j]$is the shortest path between starting point i and endpoint j, also known as the network distance; α is an index to control the weight of endpoints or the attraction effect of endpoints; β is an index to control the distance decay effect; α takes on a constant value of 1, and β takes on a value of 0.02.

Eq. (2) is based on two objects: the starting point and the focal point. First, a value is assigned to the endpoint (a service facility for the elderly), and the distance traveled is also given. Second, it is determined whether the starting point (the center of the elderly population distribution grid cell) can reach the endpoint within the distance traveled according to the actual road network. Finally, the values of all the endpoints reached are aggregated as the total score of the starting point, i.e., the accessibility of the starting point. The higher the value of the indicator, the more convenient it is for the starting point to enjoy the services of multiple endpoints and the higher the accessibility of the starting point.

With the development of mutual integration of resources among medical institutions and eldercare institutions, the combined medical and eldercare service model, which integrates medical care, rehabilitation, eldercare, and nursing care, with medical support and eldercare at its core, is gradually becoming a trend. Therefore, services for the elderly in this paper included facilities specifically for the elderly and primary medical and health facilities, effectively integrating service resources for the rural elderly and better adapting to their diverse needs (Table 1). Based on the actual situation of service facilities for the elderly in Huanxian County and on information obtained from interviews, different service weights $W[j]$ were assigned. Based on fieldwork in the rural areas of Huanxian County, the elderly travel widely, mostly on foot when their activities are confined to their village, outside the village, or further afield by motorbike or car accompanied by family members. Based on the concept of a village community life circle, the travel modes were categorized as

Table 1 Eldercare service-related weights and travel network distance

Sort	Eldercare facilities			Medical and health facilities		
	Nursing homes	Aged day care center	Elderly activity room	Township health center	Village health room	Small clinic
Weights $W[j]$	1	1.5	2	2	1	1.5
Travel mode	Motorcycle	Motorcycle	Walking	Motorcycle	Walking	Walking
Network distance $d[i, j]$/km	5	5	1.25	5	1.25	1.25

walking, motorbike, and car, with the network distance $d[i, j]$ being 1.25 km in 15 min for walking, 5 km in 20 min for motorbike, and 12.5 km in 30 min for car (Cao et al., 2022).

2.4.3 Spatial equity assessment model

The location quotient model proposed by Peter Haggett and applied in location analysis can reflect the equity of the spatial distribution of factors and measure the relative difficulty of the elderly population in accessing services for the elderly in rural areas (Mishra et al., 2019). The equity assessment indicator E_i was constructed based on the location quotient:

$$E_i = \frac{\text{Gravity}[i]^s}{\overline{\text{Gravity}[i]^s}} = \frac{\text{Gravity}[i]^s}{\frac{1}{n}\sum_{i=1}^{n}\text{Gravity}[i]^s} \tag{3}$$

where E_i denotes the location quotient of demand point i of the elderly population, i.e., the equity index, and n is the total number of demand points in the elderly population. s denotes the distance between the distribution of the elderly population and the elderly facilities. When $E_i > 1$, demand point i has access to service facilities for the elderly at a higher than average level in the study area; when $0 < E_i \leq 1$, the level of services for the elderly available to i is less than or equal to the average level in the study area; $E_i = 0$ means that services for the elderly are not available from demand point i within the search threshold, at which point equity is the worst. To better express differences in fairness among population demand points, and considering actual medical facility allocation in rural areas, the value of the fairness level E_i was further divided into five levels concerning existing studies. The grading criteria and the meaning of each level are shown in Table 2.

Table 2 Spatial equity evaluation of senior services facilities in Huanxian County of Gansu Province, China

Fairness level	Range	Meaning
I	$E_i > 10$	High accessibility, high level of fairness
II	$1.5 < E_i \leq 10$	Better accessibility, higher level of fairness
III	$1.0 < E_i \leq 1.5$	Average accessibility, moderate fairness
IV	$0.5 < E_i \leq 1.0$	Poor accessibility, low fairness
V	$0 \leq E_i \leq 0.5$	Very poor accessibility, very low fairness

3 Results

3.1 Spatial patterns of the rural elderly population

The spatialization methodology of the elderly population shows that the overall distribution of the elderly population in Huanxian County is dispersed, varying widely in density (Fig. 3). Spatially, there is an uneven distribution between north and south, with the southern part of the county being more dense than the northern area. In the central part of the country, a north-south high-density distribution belt of the elderly population is formed along the Huanhe River, connecting the three higher-density distribution belts of the elderly population formed by National Highway 341, County High-

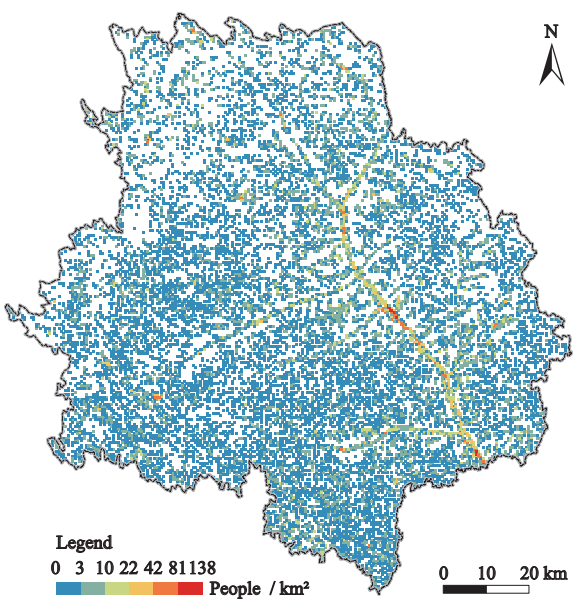

Fig. 3 Spatialization of the elderly population of Huanxian County of Gansu Province, China

way 008 and County Highway 012 at the same time. The method section divides the density of the elderly population into six categories (0−3, 4−10, 11−22, 23−42, 43−81, 82−138) using the natural breakpoint method. We found that Huanxian County's elderly population density is dominated by 0−3 and 4−10, with 15 160 grids, or 94.90% of the total number of grids. The largest number of grids (11 190) are in the 0−3 category, accounting for 70.05% of the total. The number of grids with an elderly population density greater than 11 is 814, constituting 5.10% of the total number of grids.

Overall, the spatial distribution of the elderly population density in Huanxian County shows that the density is higher in the central Huanhe River valley area and the southern residual loess hill and gully area than in the western palm land hill and gully area and the northern Liangxuan hill and gully area. In particular, a clear north-south belt of high-density distribution of the elderly population is formed along the Huanhe River. The reasons for the above spatial distribution are mainly related to topographic and hydrological reasons, with the lower altitude in the south providing a relatively large living space. In addition, the Huanhe River provides a rich source of water, guaranteeing the basic resources needed for the elderly to live.

3.2 Supply capacity of rural eldercare services

3.2.1 Spatial pattern of rural elderly care services

The spatial distribution of rural eldercare services showed an eastern-southern bias, which was closely related to the natural environmental background of Huanxian County, the socio-economic development of the township, and the population distribution. There were 553 service facilities for the rural elderly (Fig. 4), including 285 eldercare facilities (11 nursing homes, 20 day-care centers for the elderly, and 254 activity rooms for the elderly); 268 medical and health facilities (20 township health centers, 211 village health rooms, and 37 small clinics).

In the UNA tool, the 15 974 rural elderly population distribution grid cells were set as starting points, and the service facilities for the elderly were set as endpoints. The rural road network data were then imported to search for the number of service facilities for the elderly that could be reached from each elderly population distribution grid cell under a certain travel mode and to explore the quantity and capacity of the spatially distributed supply of eldercare services.

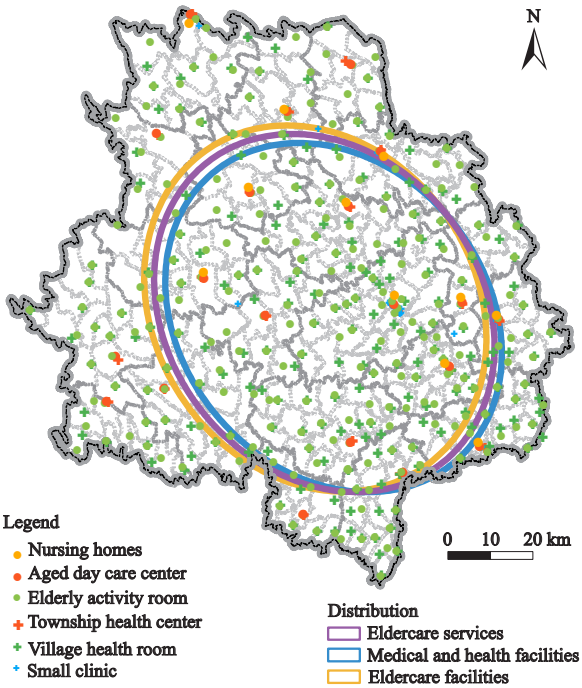

Fig. 4 Distribution map of eldercare services in Huanxian County of Gansu Province, China

3.2.2 Number of rural eldercare facilities accessible

There are significant differences in the number of rural elderly people arriving at the various types of rural aged care facilities. Table 3 shows that daycare centres for the elderly are higher than nursing homes and senior activity rooms. The elderly population has access to a maximum of four senior activity rooms at a time and a maximum of three inter-age care centers, but only a maximum of two nursing homes. Besides, there is also a large gap in the number of accessible within the elderly facilities. The number of grids with access to one or more activity rooms for the elderly is only 1676, accounting for 10.48% of the total number of grids, and the accessibility of activity rooms for the elderly is low. The 62.65% grid method to reach nursing homes also shows lower accessibility of nursing homes. In contrast, the accessibility of daycare centres for the elderly is relatively high, with 57.94% of the grid being accessible.

Fig. 5 shows the number of different aged care facilities accessible, and we found that the distribution of the number of rural aged care facilities supply presents a branching and dispersed character, with polycentric clustering found on a local scale. The distribution of the elderly population in the central part of the county is concentrated and easily accessible by road, therefore

Table 3 Accessible number of eldercare facilities in Huanxian County of Gansu Province, China

Reachable quantities	0		1		2		3		4	
	Number of grids	Ratio / %	Number of grids	Ratio / %	Number of grids	Ratio / %	Number of grids	Ratio / %	Number of grids	Ratio / %
Elderly activity room	14298	89.51	1069	6.69	563	3.52	31	0.19	13	0.08
Aged day care center	6718	42.06	3150	19.72	5631	35.25	475	2.97	0	0
Nursing homes	10008	62.65	2344	14.67	3622	22.67	0	0	0	0

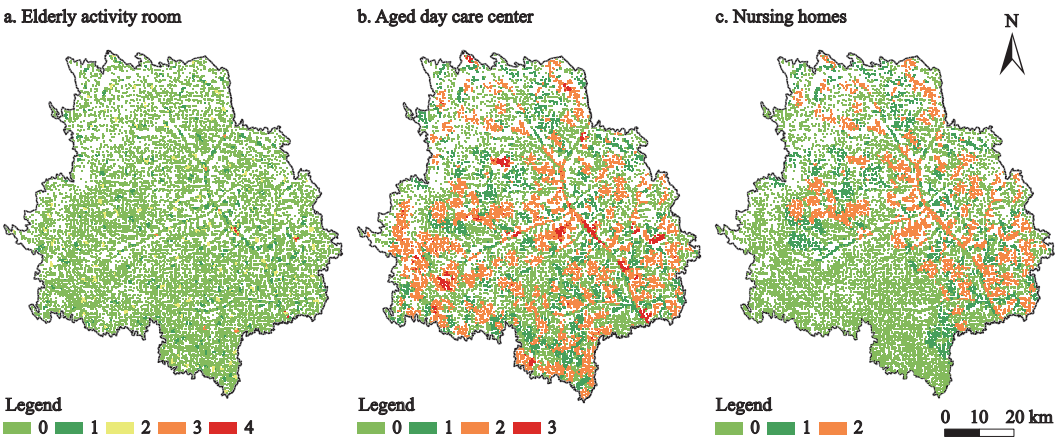

Fig. 5 Accessible number of eldercare facilities in Huanxian County of Gansu Province, China

senior rooms form a smaller highly accessible cluster center in the area. Elderly day care center accessibility is spatially formed in seven high accessibility agglomeration centers, decreasing in circles from the center of the county to the periphery. Nursing home accessibility is unevenly distributed geographically, and the east is a relatively high area.

3.2.3 Number of rural health facilities accessible

The number of accessible rural health facilities v aried widely, with township health centers being more accessible than village health offices, which were in turn more accessible than small clinics. There were also significant differences in the number of accessible health facilities (Table 4). An elderly population distribution grid cell could reach up to three township health centers, up to four village health offices, and up to nine clinics. Small clinics were a stronger focus of interest and were more concentrated, resulting in more small clinics being reachable from a few grid cells.

In terms of spatial layout (Fig. 6), the number of accessible rural health facilities in the central part of the county was higher than in other areas, with an overall scattered and star-shaped distribution. The number of small clinics with high accessibility was mainly concentrated around the periphery of the county, with strong agglomeration; the number of village health offices with accessibility was scattered in a stellar pattern, with weak agglomeration; the number of township health centers with accessibility covered a wider area, forming two large agglomeration centers in the central part of the county, with the rest mostly spread out over a large area in a stellar pattern.

Table 4 Accessible number of health care facilities in Huanxian County of Gansu Province, China

Reachable quantities	0		1		2		3		4		5–9	
	Number of grids	Ratio / %	Number of grids	Ratio / %	Number of grids	Ratio / %	Number of grids	Ratio / %	Number of grids	Ratio / %	Number of grids	Ratio / %
Small clinic	14882	93.16	1028	6.44	22	0.14	14	0.09	10	0.06	18	0.13
Village health room	14282	89.41	1081	6.77	546	3.42	45	0.28	20	0.13	0	0
Township health center	8811	55.16	6103	38.21	971	6.08	89	0.56	0	0	0	0

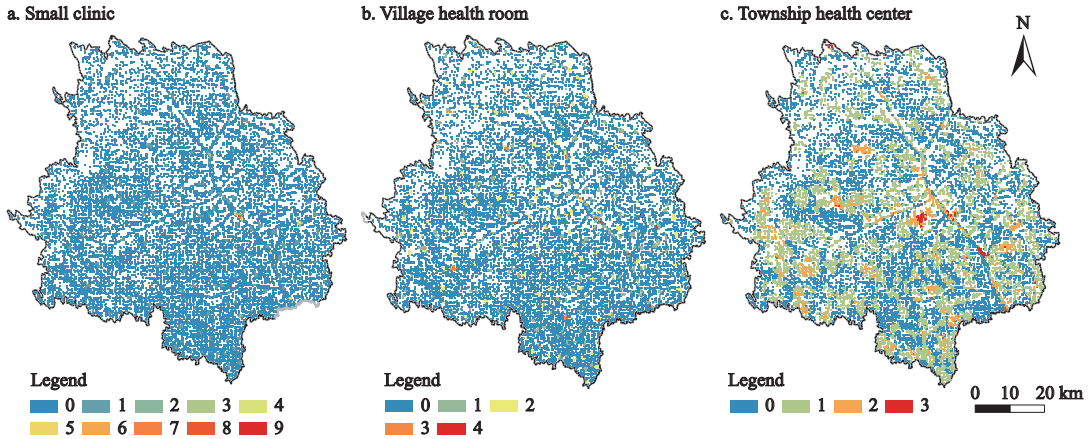

Fig. 6 Accessible number of rural medical and health facilities in Huanxian County of Gansu Province, China

3.2.4 Accessibility of services for the rural elderly

From a comprehensive consideration of the accessibility of eldercare services, the three types of eldercare facilities and three types of healthcare facilities were combined and divided into four categories, with category I (inaccessible) meaning that all three types of facility were inaccessible, category II (low accessibility) meaning that only one of the three types was accessible, and so on, with category IV (high accessibility) meaning that all three types of facility were accessible and representing the highest accessibility.

The accessibility of facilities offering services to the rural elderly was higher than that of health facilities overall, but the proportion of low accessibility for elderly facilities was higher than that for health facilities, and within individual facilities, the accessibility differences diverged significantly (Table 5).

In terms of the spatial distribution of integrated accessibility of services for the rural elderly (Fig.7), the coverage of facilities for the elderly with integrated accessibility was significantly higher than that of healthcare facilities with integrated accessibility, and the coverage of the county was also better. Comprehensive accessibility of eldercare services spread out in a faceted

Table 5 Accessibility statistics for rural eldercare services in Huanxian County of Gansu Province, China

Accessibility rating	I		II		III		IV	
	No. of grids	Ratio / %	No. of grids	Ratio / %	No. of grids	Ratio / %	No. of grids	Ratio / %
Eldercare facilities	6717	42.05	2697	16.88	5479	34.30	1081	6.77
Medical and health facilities	8525	53.37	6035	37.78	330	2.07	1084	6.79

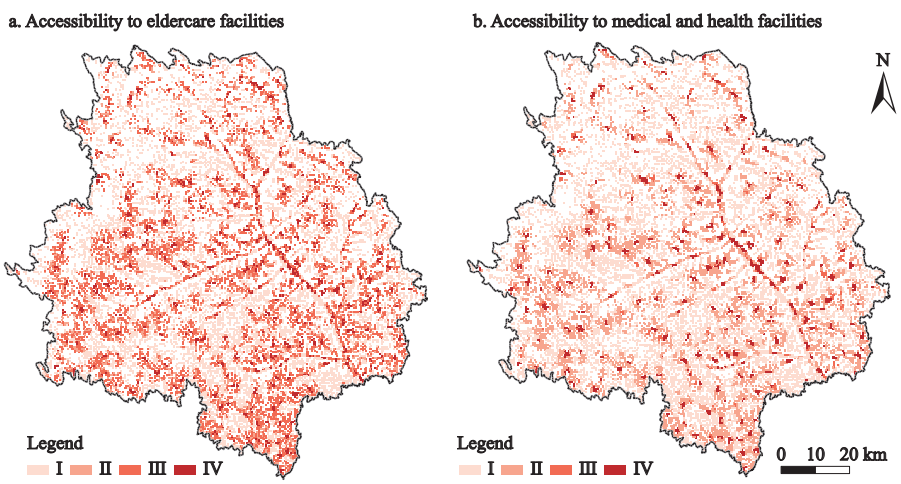

Fig. 7 The number of rural eldercare services in Huanxian County of Gansu Province, China

manner within the county, with a gradual progression of hierarchical levels and smaller differences between levels. Healthcare facilities formed small aggregation points, with obvious differences in levels.

3.2.5 Supply capacity of services for the rural elderly

To better illustrate the supply capacity of services for the rural elderly, the supply capacities of the covered eldercare facilities and medical and health facilities were measured comprehensively and divided into three categories. The supply capacity where neither facility for the elderly nor medical and health facilities were accessible was category I, the weakest supply capacity; the supply capacity where one, but not the other could be reached was category II; and the supply capacity where both could be reached was category III, the strongest supply capacity.

The overall supply capacity of services for the rural elderly tended to be good, with the township center as the gathering point, spreading out in a faceted manner, with the nearby townships forming a contiguous area; however, there was a strong contrast between strong and weak supply capacities, and the differences are obvious (Fig. 8).

3.3 Spatial equity in services for the rural elderly

Using the spatial equity assessment model, the spatial equity of access to eldercare and healthcare facilities was measured to capture the spatial equity of rural eldercare services (Table 6, Fig. 9 and Fig. 10). The over-

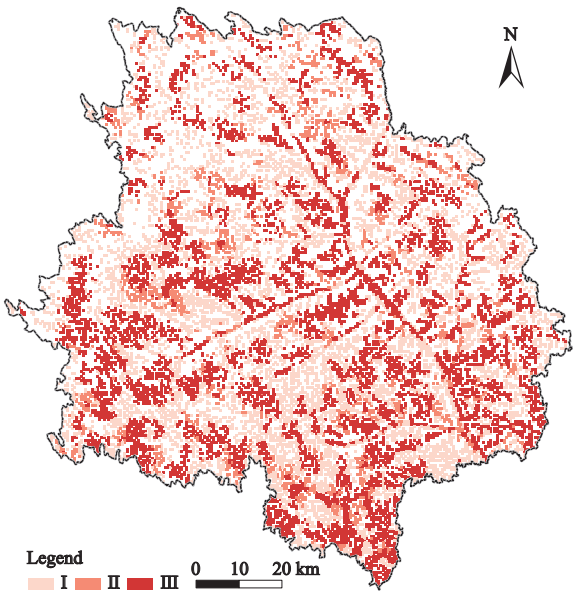

Fig. 8 The supply capacity of rural eldercare services of Huanxian County of Gansu Province, China

Table 6 Spatial equity statistics for rural eldercare services in Huanxian County of Gansu Province, China

Space fairness rating	II		III		IV		V	
	No. of grids	Ratio / %	No. of grids	Ratio / %	No. of grids	Ratio / %	No. of grids	Ratio / %
Eldercare facilities	6560	41.07	0	0	2697	16.88	6717	42.05
Medical and health facilities	1414	8.85	6035	37.78	0	0	8525	53.37
Eldercare service	7449	46.63	1808	11.32	0	0	6717	42.05

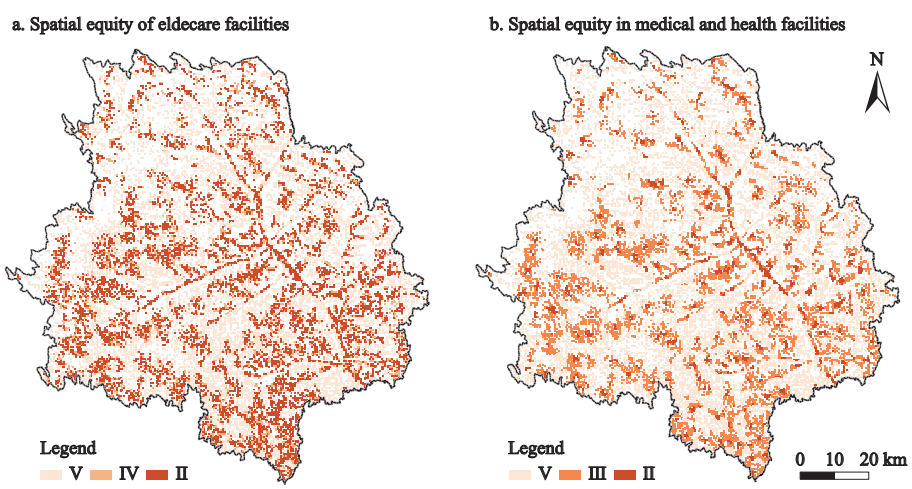

Fig. 9 Spatial equity of rural eldercare facilities (a) and medical and health facilities (b) in Huanxian County of Gansu Province, China

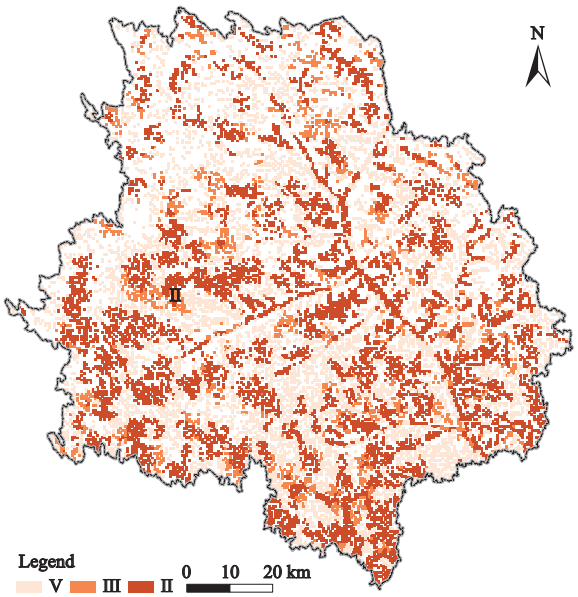

Fig. 10 Spatial equity of rural eldercare services in Huanxian County of Gansu Province, China

all spatial equity of access to rural eldercare services is poor, but there are some differences in the spatial equity of eldercare and healthcare facilities.

The equity of facilities for the rural elderly in the county was unevenly spatially distributed (Fig. 9), with the north being better than the south and the west better than the east, and with facilities distributed along roads. Class II (higher equity grade) areas mainly extended outwards from the center of each township, with Tianchi, Hedao, and Muzha Townships in the south having the most facilities. However, the elderly population in the north was sparsely distributed, and equity was higher than in the south. Class IV (lower equity grade) areas were few and dotted around Class II areas; Class V (very low equity grade) areas were scattered all over the county. Medical and health facilities were more widely distributed in the southern part of the county, but the distribution of existing facilities in the south still has difficulty meeting demand due to the wide distribution of the population. Class II areas were scattered in and around the central part of the county, whereas Class III areas (medium equity grade) were distributed around Class II areas in an encircling pattern. There were no Class IV areas, but Class V areas were numerous and widely distributed. The equity of rural eldercare services varied widely (Fig. 10), with Grades II and V areas dominating and being more widespread; Grade III areas were dotted in the middle of Grade II and V areas and were few in number, mostly in the central part of the county.

4 Discussion

4.1 Spatial heterogeneity of equity in rural elderly services

The long-standing individual and family model of rural old-age care in the countryside is gradually weakening. The diversification of social old-age care models has become an inevitable requirement (Zhao et al., 2022; Zhang et al., 2022). To pursue a better material foundation, the long-established traditional model of support for the elderly, including ‘raising children for the sake of old age’ and ‘not traveling far away from parents’, are gradually being broken. Due to the impact of eugenics and other concepts, there is a significant miniaturization of rural families. The impact of foreign socio-economics has faded the traditional social order maintained by clans, and economic interests instead of ethical constraints. Older people in the countryside are faced with multiple pressures on agricultural production, aging, and many other problems, which have led to more diversified demands on the social provision of old age care.

As a basic prerequisite, it is necessary to understand the pattern of distribution of demand and supply of elderly services for the elderly. However, there is a lack of empirical scientific analyses to examine the spatial accessibility of multilevel elderly care services for the elderly in China. We assessed inequalities in accessibility within the study area to identify areas experiencing better or worse conditions. This inequality could be addressed through localized interventions and integrated spatial planning strategies. To address intra-regional disparities, interventions could be tailored to local realities in specific areas. These findings are relevant for policymakers in prioritizing future pension investments to reduce disparities in pension development. More importantly, we use the grid scale to study the spatial equity of elderly service resources in rural China, disrupting administrative boundaries. The studies allowed for optimization and coordination across administrative districts at the boundaries of some of the region's underserved areas for the elderly. Therefore, resource equity in elderly care services between and within regions should be considered in a coordinated manner to find out the optimal layout of elderly care facilities (Agbenyo et al.,

2017; Yin et al., 2018).

Government policy of 'top-down coordination' is an external regulating force in the allocation of rural elderly services (Humer and Granqvist, 2020; Wei et al., 2021). Despite China's current deep integration of urban and rural areas, the urban-rural gap persists. In particular, the degree of equalization of basic public services between urban and rural areas remains low, and the configuration of rural elderly services is seriously lagging. Government departments continue to meet the growing multi-level, high-quality demand for healthy aging among the elderly and to narrow regional and urban-rural disparities by building and improving an integrated urban-rural pension service system based on a bottom-up, inclusive, and diversified approach.

4.2 Influencing factors of spatial equity in rural elderly services

In this study, the hilly loess region of Longdong and gullies area was selected. The special natural environment of the region is the primary condition for rural resource allocation consideration. Facing the diversified demand for rural elderly services, the natural background is the internal basis for allocation (Hou et al., 2021; Cui et al., 2022). Huanxian County is located in the transition zone between the Mu Us Desert and the loess hills, with complex and varied terrain. The spatial pattern of rural settlements is dispersed, the distribution of the rural elderly population is fragmented, and rugged transportation conditions hinder the accessibility of rural elderly services (Fig.11). However, the current limited labor force and the closed development environment restrict the flow of information and the conversion of resources between rural and urban areas. There are high construction costs required to guarantee equity in the allocation of rural elderly services. The difficulty of spatial equity due to natural background is a major reason for the imbalance in the allocation of supply and demand for rural elderly services. Therefore, the establishment of elderly service facilities that are appropriate to the natural local conditions of the area is an important step in realizing spatial equity.

The level of socio-economic development of villages is a fundamental influence on the allocation of elderly services. The level of economic development within regions also showed significant differences. The differences manifest themselves in the fact that equity in elderly care is closer to areas with higher economic levels. The economic standard is the foundation for investment in senior care facilities, and with the diversification of economic activities in the primary, secondary, and tertiary sectors in rural China, villages in the loess hills and gullies are seeing important opportunities for economic development. As the level of economic development rises, the government's ability to pay will be greatly enhanced, and the ability to provide public service facilities in villages will also increase. Rural villages prefer to prioritize the development of medical and health facilities, creating an imbalance in the development of rural elderly care services. Access to old age services is multidimensional, and this study focuses more on spatial factors (i.e., geographic equity) like gender, income, employment, and social status, potentially exerting a significant influence on individual resources for old age services (Guagliardo, 2004; Tao et al., 2014) are not included in the consideration. The barriers arising from these factors could be mitigated through policy interventions, such as more robust health insurance systems and the provision of health resources to socially disadvantaged and minority groups. The equitable allocation of rural elderly services is not just a supplement to the hardware of a particular facility but requires the full mobilization of all elements of the rural territorial system.

4.3 Limitations and innovations

The elderly population has complex characteristics and varies greatly in terms of physical condition. Rural empty nesters, poor elderly, elderly without descendants, and disabled elderly have different degrees of mobility and different requirements for services. Finally, as part of intensive development, facilities for the elderly are usually built and shared with other public service facilities. This paper did not consider the presence of additional facilities, ignoring their possible agglomeration attraction, although their supply capacity may be weakened. A reality that has to be recognized is that the hilly loess region of Longdong can access care services across administrative boundaries due to the distance between rural settlements, the accessibility of transportation, and the health status of the elderly. More elderly people are close to realizing the nursing care services in the nursing facilities. Besides, this paper is limited in the use of methods, including both 2SFCA and 3SFCA, the more widely researched and applied ones at present.

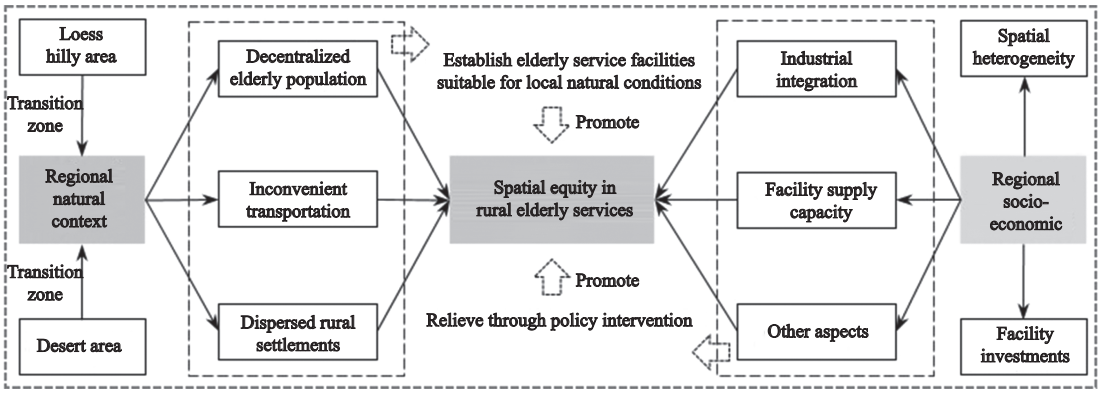

Fig. 11 A framework of factors influencing spatial equity in rural elderly services

However, to capture the concept of 'physical distance' in our study, we used urban network analysis. In the next step of the study, we will compare the calculation results under different methods and provide the optimal configuration of rural elderly facilities.

The study considered the supply capacity on the scale level of services for the elderly based on paying attention to the refined demands of a specific rural disadvantaged group-the elderly population. This model of spatially fair distribution of services for the elderly based on supply and demand differences will help improve the fairness of rural elderly care service distribution.

5 Conclusions

Based on the spatial distributions of the rural elderly population and services for the rural elderly, this study measured the spatial supply capacity of services for this group, assessed the spatial equity of service provision for them, optimized services for them on this basis, and conducted an empirical analysis using Huanxian County in the Loess Hills area as an example. The study has shown that: the elderly population in Huanxian County was scattered, and its density varied greatly. There were 553 service points for the rural elderly in Huanxian County and spatial distribution showed a southward bias in the east and an uneven regional distribution. Forming a distinct north-south belt of high-density distribution of the elderly population along the Huanhe River, and a high-density agglomeration area in the Towns. The overall supply capacity of services for the rural elderly was good, with the township center as the gathering point and spreading out in a faceted manner, with nearby townships forming a contiguous area. However, there were strong contrasts and obvious differences between strong and weak supply capacities. The overall spatial equity of services for the rural elderly was poor. The spatial distribution is better in the north than in the south and in the west than in the east, with a clear road convergence. Based on the above facts, the spatial fairness in Huanxian County needs to be enhanced, and the improvement of senior care service allocation requires: 1) further promoting the economic development of the study area and realizing the economic basis of senior care facility allocation; and 2) leveraging the external regulatory power of governmental coordination. In addition, this study found that there is also a need for equitable allocation of senior living facilities in the western counties of China at both the economic and policy levels.

Conflict of Interest

The authors declare that they have no known financial interests or personal relationships that may affect this paper.

Author Contributions

Data processing: CHANG Xiaoyan; Funding acquisition, MA Libang; Investigation: CHANG Xiaoyan, CUI Xijuan, TAO Tianmin and ZHAO Shoucun; Methodology: CHANG Xiaoyan and MA Libang; Software: CHANG Xiaoyan and CUI Xijua; Supervision: MA Libang; Writing-original draft: CHANG Xiaoyan; Writingreview & editing: CHANG Xiaoyan and MA Libang. All authors contributed to manuscript revision, read and approved the submitted version.

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