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Research article

Evaluation of the suitability of elderly care in prefecture-level cities in China based on GIS

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ABSTRACT

The population of China is aging, and the demand for healthy elderly care is expanding. There is an urgent need to develop a market-oriented elderly care industry and cultivate a number of high-quality elderly care bases. The geographical environment is an important condition affecting the health of elderly individuals and the suitability of elderly care. Research on this topic has important guiding significance for the layout of elderly care bases and the choice of elderly care locations. In this study, a spatial fuzzy comprehensive evaluation was conducted to construct an evaluation index system based on the following standard layers: climatic conditions, topography, surface vegetation, atmospheric environment, traffic conditions, economy and population, elderly-friendly urban environments, elderly care service capabilities, and wellness and recreation resources. The index system analyzes the suitability of elderly care in 4 municipalities and 333 prefecture-level administrative regions in China, and development and layout suggestions are proposed. The results show the following: (1) The three concentrated areas with a highly suitable geographical environment for elderly care in China are the Yangtze River Delta, the Yunnan-Guizhou-Sichuan region and the Pearl River Delta. The areas with the most concentrated unsuitable areas are the southern Xinjiang and Qinghai-Tibet areas. (2) In areas with a geographical environment that is highly suitable for elderly care, high-end elderly care industries can be deployed, and national-level elderly care demonstration bases can be built. Areas with a highly suitable temperature in Central and Southwest China can develop characteristic elderly care bases for people with cardiovascular and cerebrovascular diseases. Scattered areas with a highly suitable temperature and humidity can develop characteristic elderly care bases for people with rheumatic and respiratory diseases.

1. Introduction

According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), when the proportion of a population over the age of 60 exceeds 10% or the proportion of the population over the age of 65 exceeds 7%, the population is considered to be aging [1]. At present, 18.70% of China's population has reached or exceeded the age of 60, and 13.50% of the population has reached the age of 65 [2]. Except for Tibet, the proportion of the elderly population aged 65 and over in the other 30 provinces exceeds 7%. Clearly, China and all of its domestic provinces and cities are already aging societies. However, China's current aging has not yet

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reached its peak. It is expected that China will face a more severe aging trend in the next 10–20 years [3], and the market demand for elderly care services will expand rapidly [4,5]. It is predicted that by 2053, the output value of China's pension industry will exceed 106 trillion yuan [5]. Aging and the low birthrate phenomenon coexist in China; in addition, the traditional model in which elderly care is provided by the family has changed, and the demand for market-oriented elderly care has increased sharply. China's existing medical service supply capacity does not match the large-scale demand for healthy elderly care. There is an urgent need to carry out supply-side structural reforms, develop a market-oriented elderly care industry, and build national-level elderly care demonstration bases. A good geographical environment is an important material basis for elderly care. The construction of elderly care bases must consider regional suitability and the impact of the geographical environment on the health of the elderly because elderly care is closely related to the health of elderly individuals, which is affected by the geographical environment to a certain extent. Elderly care bases built in areas where the geographical environment is conducive to the physical and mental health of elderly individuals and where such individuals will feel comfortable will have a strong appeal to elderly people.

Among geographical and environmental factors, climatic conditions have the greatest impact on the health of elderly individuals [6]. Medical geographers have paid attention to the relationship between the medical reference value of geriatric health and the geographical environment. For example, Ge et al. found that the reference value of hemoglobin in the elderly is positively correlated with the number of sunshine hours and negatively correlated with altitude, annual humidity, temperature and precipitation [7–10]. Some scholars have summarized the geographical environmental conditions that affect health and longevity by studying the spatial distribution of typical longevity areas. Li and Zou found that centenarians mostly live in high mountain areas [11,12]. Gong proposed that suitable climatic conditions, including a mild climate, no extreme heat in summer, no severe cold in winter, moderate rainfall, and sufficient sunshine, are conducive to longevity [13,14]. Ao pointed out the heterogeneous impact of environmental factors, such as the average temperature in January, the average temperature in July, and the average annual precipitation, on the health of the elderly [15]. Wang showed that a beautiful natural environment, a moderate altitude, fresh air, good drinking water quality, a developed economy, food containing trace elements necessary for the human body, a peaceful humanistic environment and other environmental conditions are conducive to health and longevity [16]. Frankovic stated that the level of access to health care and income-related differences are the driving factors of inequality in health and longevity [17].

The suitability of elderly care is mainly related to the suitability of human settlements and the correlation between the environment and health. Research on the suitability of human settlements for comfort in China and elsewhere is relatively mature, and some scholars have focused on evaluating individual indicators. The climatic suitability of human settlements has received the most attention. Hundt, Thom, and Werner constructed models of the effective temperature [18], comfort index [19], and wind efficiency index [20] using conventional meteorological data such as temperature, humidity, wind speed, and sunshine. Other scholars at home and abroad have constructed evaluation models of the temperature and humidity index, the clothing index, the comprehensive index, and the effective temperature of the human body heat perception index and analyzed the climatic suitability of different regions [21–24]. Recently, researchers have studied the influence of certain climate indicators, primarily temperature indicators, on comfort. For example, Nely compared and analyzed the ambient thermal comfort conditions of Teixeira and Patos, Brazil [25]. Negin found that as urban temperatures increased, thermal stress and thermal discomfort increased, affecting the suitability of the urban living environment [26]. Giuffrida reversely determined the temperature comfort range based on people's perception of the weather [27]. In addition, Huo took the Dianchi Lake Basin as an example to study the impact of wetlands on human settlements [28]. Zha and Shen evaluated the topographic suitability of human settlements in Nanchuan District and Anhui Province by calculating the topographic relief [29,30]. Bravo studied the correlation between urban pollution and the suitability of urban settlements [31].

Evaluations of the suitability of human settlements generally use a geographic information system (GIS), SPSS software and other technical methods to construct evaluation models based on aspects such as climate, topography, hydrology, and vegetation. These evaluations often include aspects such as climatic suitability, terrain relief, a hydrological index, and a ground cover index, and these models can be used to analyze suitability in study areas [32–40].

In recent years, scholars have realized that the human geographical environment is a significant factor affecting the level of comfort and convenience of human settlements. Therefore, economic and social factors, such as transportation [41,42], population [34,35,37,43], annual income [44], number of livestock [44], GDP [45,46], public services [47], the leisure environment [47], scientific and educational conditions [46], housing and facilities [46], are introduced. These indicators, together with the natural suitability evaluation index system, form a comprehensive suitability evaluation index system. On this basis, a comprehensive evaluation of the suitability of human settlements for comfort and convenience in different study areas can be carried out [41–45,47–51].

There are relatively few studies on the suitability of the geographical environment for the health of physically and mentally more vulnerable elderly individuals. Studies have mainly focused on the relationship between health and longevity and the geographical environment and the relationship between the subjective comfort of healthy adults of the living environment and the geographical environment. Research on the impact of the geographical environment on the health of elderly individuals mostly takes a specific area as the research area and summarizes the correlation between the two by analyzing the laws of the temporal and spatial distribution. Most researchers choose chemical environmental indicators, and research from the perspective of the physical environment and society is still insufficient. Li selected 42 indicators based on two aspects, the environment and health, to construct an evaluation index system with the average life expectancy as the core index, and they divided China's environment-health status into five types [52]. Based on the unique physiological and psychological characteristics of elderly individuals, Dai et al. selected 33 tertiary indicators subsumed under 8 secondary indicators based on two aspects of the livable environment for elderly individuals, public and special, to form an indicator system. It is the first complete index system for the livable environment for elderly individuals in China [46]. However, most of the existing livability index systems for elderly individuals take the whole country as the research unit or target specific cities or regions, and comparative spatial analysis is lacking. Therefore, an index system to determine if a geographical

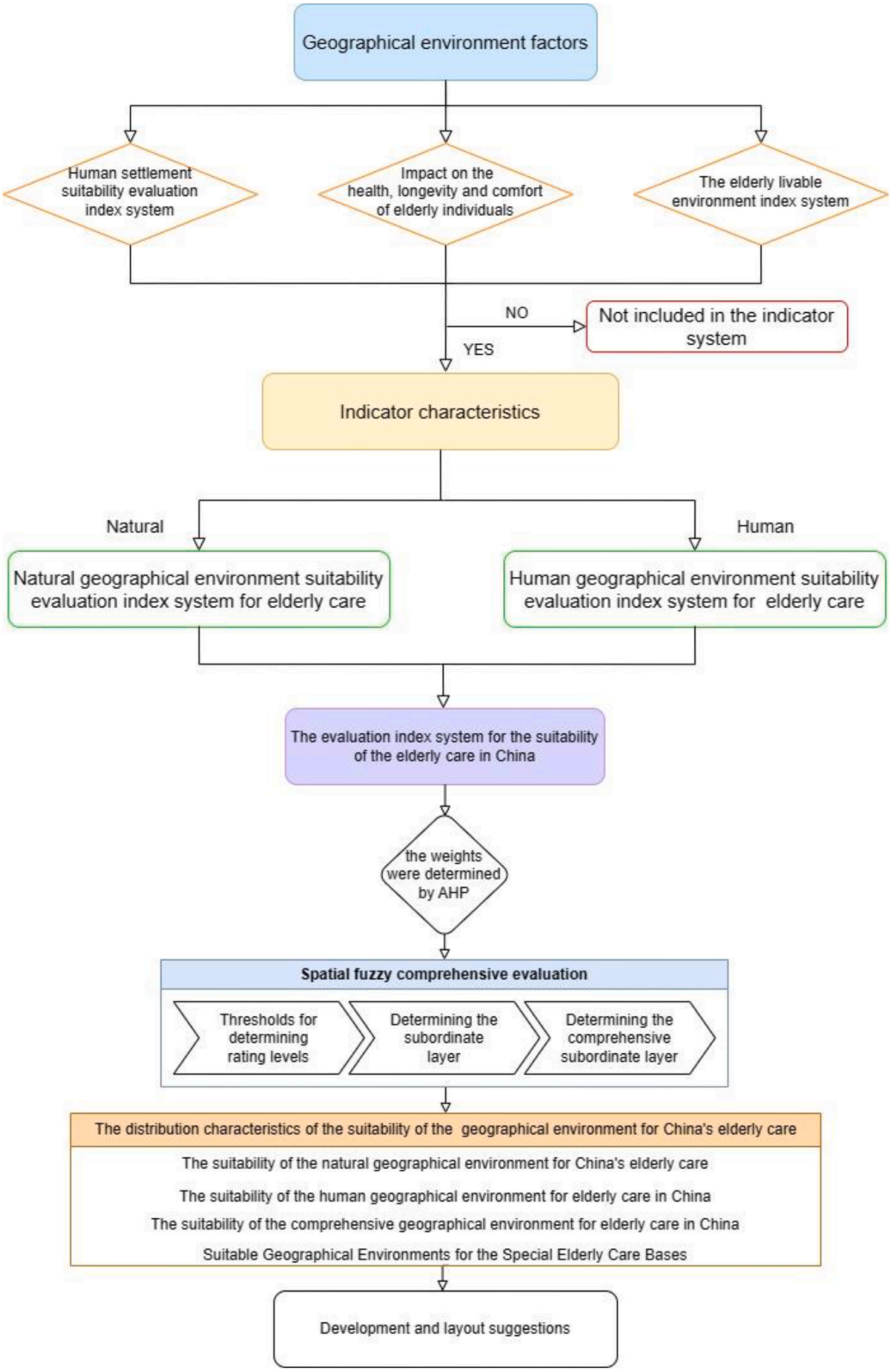


Fig. 1. Research flowchart.

environment is suitable for elderly care is needed, as are spatial analyses conducted on this basis.

2. Materials and methods

In this study, by screening the geographical environment factors, constructing an evaluation index system, calculating the weights using hierarchical analysis and adopting the spatial fuzzy comprehensive evaluation method, we obtain the evaluation results of the suitability of the geographical environment for elderly care and then propose development and layout suggestions (Fig. 1).

Table 1
The evaluation index system for the suitability of elderly care in China.

Target Layer	Subtarget Layer	Standard Layer	Substandard Layer	Index Layer	Unit	Direction	Weights
Suitability of the elderly care	Suitability of the natural geographical environment	Climatic conditions [9]	Temperature	Number of days in which the daily minimum temperature is below 5 °C	Days/year	Reverse	0.0711
				Number of days in which the highest temperature is above 30 °C	Days/year	Reverse	0.0133
				Number of days in which the average temperature difference between two adjacent days is less than 5 °C	Days/year	Reverse	0.0314
				Annual average temperature	°C	Forward/reverse	0.0711
				Average temperature in January	°C	Forward/reverse	0.0711
				Average temperature in July	°C	Forward/reverse	0.0133
				Annual temperature range	°C	Reverse	0.0133
			Humidity	Annual average relative humidity	%	Forward/reverse	0.0515
				Number of days in which the annual relative humidity changes by less than 10%	day	Forward	0.0515
			Airflow	Annual average wind speed	m/s	Reverse	0.0263
				Number of days with winds above level 3 in winter and spring	day	Reverse	0.0263
			Air pressure	Air pressure	hPa	Forward/reverse	0/1
			Sunshine	Annual average sunshine hours	h	Forward/reverse	0.0228
			Precipitation	Annual precipitation	mm	Forward/reverse	0.0228
		Topography	Topography	Altitude	m	Forward/reverse	0.0293
				Slope	°	Reverse	0.0293
		Surface vegetation	Vegetation coverage	Normalized difference vegetation index (NDVI)	–	Forward	0.0587
		Atmospheric environment	Air quality index	Air quality index (AQI)	–	Reverse	0.1472
	Suitability of the human geographical environment	Traffic conditions	Traffic conditions	Civil aviation convenience	–	Forward	0.0088
				Rail passenger accessibility	–	Forward	0.0088
				Road network density	–	Forward	0.0088
		Economy and population	Economy and population	GDP	Yuan/km^2	Forward	0.0088
				Population density	People/sq. km	Forward	0.0029
		Elderly friendly urban environment	Elderly friendly index	Housing affordability (house prices)	Yuan	Reverse	0.0197
				Level of free bus rides for elderly individuals	–	Forward	0.0066
		Medical service supply capacity	Medical service supply capacity	Density of tertiary first-class hospitals	–	Forward	0.0621
				Number of hospital beds per 10,000 people	piece	Forward	0.0621
		Wellness and recreation resources	Wellness and recreation resources	Entry-level parks and 4A-level and above scenic spots Hot springs and spa hotels, nursing homes, sanatoriums and other recreation and health centers	Density of recreation, health and wellness resources	–	Forward	0.0614

2.1. Indicator system construction

Geographical environmental factors can be classified into two categories: the natural geographical environment and the human geographical environment [16]. Among them, the natural geographical environment factors that are related to the suitability of elderly care mainly include climate, topography, vegetation, the atmospheric environment and other aspects, while the human geographical environment factors mainly include traffic conditions, economy and population, elderly friendly urban environment, elderly care service capabilities, wellness and recreation resources and other aspects [53]. These aspects contain many indicators that have an important impact on the health, longevity and comfort of the living environment of elderly individuals. Combining the existing human settlement suitability evaluation index system and the elderly livable environment index system and considering the impact of geographical environmental conditions on the health and longevity of elderly individuals, specific evaluation indicators can be selected.

In this study, 18 indicators were selected from the 4 categories of natural geographical environment factors to construct a natural geographical environment suitability evaluation index system for elderly care. Ten indicators were selected based on 5 categories of human geographical environment factors to construct a human geographical environment suitability evaluation index system for elderly care. Finally, the two systems were comprehensively superimposed to form an evaluation index system of geographical environment suitability for elderly care (Table 1), and the weights were determined by the analytic hierarchy process with Yaahp software [6]. Due to software limitations, only three levels of indicator weights can be analyzed, so a hierarchical structure model of climate suitability, natural geographical environment suitability, human geographical environment suitability, and geographical environment suitability for elderly care was constructed in turn, and AHP questionnaires were generated and distributed to a total of 10 experts from 2 clinical medicine majors, 2 Chinese medicine majors and 6 human geography majors. Majors who have more professional opinions on the relationship between elderly physical health, human comfort and geographical environment. These experts compare the indicators two by two and give 9 levels of relative importance scores, and the expert scoring results were entered into the judgment matrix. The group decision panel was used to calculate the weight of each matrix with the average expert weights, and the weights of each layer were multiplied to obtain the final index weight. Because of the special nature of the air pressure index, it is extremely unfavorable to human health when it is lower than 701 hPa, so the weight is set separately as an absolute restriction, and the weight is 1 when it is lower than 701 hPa and 0 when it is higher than 701 hPa.

2.1.1. Natural geographical environment indicators

The climate indicators were selected and graded according to research on the suitability of climatic conditions for the elderly care industry in prefecture-level cities in China, and 14 indicators were selected [6].

There is a certain relationship between topography and longevity, and there are many long-lived elderly people in mountainous areas [54]. The results of research in the medical field and the distribution characteristics of world-famous areas of longevity show that the altitude that is most beneficial for human health and longevity is 1200–1500 m [55]. Areas with an altitude of less than 500 m have high air pressure, the air is relatively hot and humid, and the burden on human body functions is heavy. An altitude higher than 2500 m affects human heart and lung function, causing altitude sickness [56–58]. For every 100 m increase in altitude, the intensity of ultraviolet radiation increases by 1.3%. Ultraviolet rays have bactericidal and immune-enhancing effects, but excessive exposure to ultraviolet rays can increase the incidence of skin cancer and cataracts [59]. The size of the slope affects the convenience of living and the construction cost of related facilities. In general, the greater the slope is, the greater the difficulty of development [60].

Surface vegetation affects people's physical and mental health to a certain extent. Areas with high forest vegetation coverage also have a higher concentration of negative oxygen ions in the air, which is conducive to health and longevity. The presence of vegetation reduces stress, promotes peace and tranquility, enhances self-esteem and a sense of control over the environment, reduces blood pressure and heart rate, and increases well-being. The normalized difference vegetation index (NDVI) is mainly used to characterize surface vegetation coverage [61,53].

The atmospheric environment affects the health and longevity of elderly people, and the air quality index (AQI) is used to characterize the quality of the atmospheric environment. According to estimates by the World Health Organization, approximately 800,000 people worldwide die from urban air pollution every year [54]. An increase in $PM_{2.5}$ and SO_2 concentrations will lead to an increase in morbidity, hospitalizations and mortality. Long-term residence in areas with high particulate matter concentrations is associated with a 2-year shorter life expectancy compared to areas with low concentrations [54,62]. The Technical Regulation on Ambient Air Quality Index indicates that an AQI of 0–50 is normal for all types of people, 51–100 has a weak impact on the health of a very small number of unusually sensitive people, 101–150 affects children, the elderly and patients with heart and respiratory diseases, and the impact on children, the elderly and patients with heart and respiratory diseases increases when it is greater than 150.

2.1.2. Human geographical environment indicators

Convenient and accessible transportation is not only conducive to the mobility of elderly individuals who need elderly care in different places but also facilitates the visits of their children and relatives and is beneficial for broadening the service scope of the elderly care industry. There are three common modes of transportation for elderly migration: civil aviation, railways, and highways. The kernel density of airports, railway stations, and highway networks is used to reflect the degree of transportation convenience of local-level cities [63].

Regional GDP reflects the level of local economic development. A higher level of economic development is usually accompanied by greater economic opportunities. It is easier for elderly individuals to realize their own value and gain social recognition, which is beneficial for their mental health [64]. If the population is too small, it will not be able to meet the labor force requirements of the

elderly care industry, and the local market-oriented demand for elderly care will be small, which is not conducive to developing elderly care bases.

A friendly urban environment for elderly individuals is a basic support for the development of elderly care bases. Housing is an important factor when considering pension costs, and housing costs directly affect the attractiveness and competitiveness of urban elderly care. Housing affordability affects the floating population's willingness to stay [65]. The average housing price is chosen to represent housing affordability. The lower the housing price is, the better the housing affordability. Elderly individuals rely heavily on urban public transportation when they go out. Reducing or exempting public transport fares for elderly individuals has a positive effect on their mood [66]. The level of free public transport for elderly individuals in various cities is scored, and an elderly-friendly bus index is built. The higher the score is, the higher the elderly friendliness. If city A's bus system is not free for seniors, the score is 0, free for seniors over 70 or discount for those over 65 is 1, free for those over 70 and discount for those over 65 is 2, free for both over 65 or discount for both over 60 is 3, and free for both over 60 is 4.

Urban geriatric medical capacity is crucial for supporting elderly care. Medical capacity is measured by the number of beds per 10,000 people and the density of tertiary first-class hospitals. The nursing capacity for elderly individuals is usually characterized by the number of beds in elderly care institutions per 1000 elderly people [67].

Wellness and recreation resources provide recreational places and wellness services for elderly individuals. The higher the density is, the higher the service level and the more conducive these conditions are to the physical and mental health of elderly individuals [68]. There is a rich variety of recreation and leisure resources, and this paper mainly considers both recreation and leisure resources and characterizes the density of recreation and leisure resources through recreation and leisure resources such as entry-level forest parks, entry-level recreation parks, entry-level wetland parks, scenic spots of grade 4A and above, and recreation and leisure resources such as hot springs and hot spring hotels, nursing homes, sanatoriums and other recreation and leisure centers.

2.2. Data sources

The prefecture-city boundary data, kilometer-grid GDP data, kilometer-grid population density data, and 250-m NDVI product data from 2009 to 2018 were obtained from the Resource and Environmental Science Data Center (Table 2). The meteorological data from 2009 to 2018 were obtained from the China Meteorological Data Network. The 30-m digital elevation model (DEM) data for 2018 were obtained from the Geospatial Data Cloud. The 2018 atmospheric environment data were obtained from the national urban air quality real-time release platform. The 2018 road network data come from OpenStreetMap. Point of interest (POI) data were crawled from the AutoNavi Map Open Platform. Statistical data were obtained from the "China City Statistical Yearbook", "China Urban Construction Statistical Yearbook", Environmental Statistical Yearbook and statistical yearbooks of local-level cities. The 2020 national urban housing price data were obtained from China's housing price market website.

2.3. Evaluation of technical routes

In this study, the method of spatial fuzzy comprehensive evaluation was adopted [6,69–71], and the spatial analysis function of ArcGIS was used to reclassify the data, conduct map algebra and an overlay analysis, and calculate regional statistics. The affiliation function of the single-factor evaluation indexes of each raster (point) in the space is determined, and multilevel fuzzy comprehensive evaluation is carried out point by point to finally obtain the fuzzy evaluation results on the space of the whole study area. The detailed process is as follows.

Table 2
Table of data sources.

Data Type	Corresponding indicators	Data source
Meteorological Data	Temperature, Humidity, Airflow, Air pressure, Sunshine, Precipitation	China Meteorological Data Network (http://data.cma.cn)
DEM Data	Altitude, Slope	Geospatial Data Cloud (http://www.gscloud.cn)
NDVI Data	NDVI	Resource and Environmental Science Data Center (http://www.resdc.cn)
Atmospheric Environment Data	AQI	national urban air quality real-time release platform (https://air.cnemc.cn/)
POI Data	Civil aviation convenience (POI data of the airport), Density of tertiary first-class hospitals (POI data of tertiary first-class hospitals), Wellness and recreation resources	AutoNavi Map Open Platform (https://lbs.amap.com/)
road network data	Rail passenger accessibility, Road network density	OpenStreetMap (http://www.openstreetmap.org)
Kilometer grid data	GDP, Population density	Resource and Environmental Science Data Center (http://www.resdc.cn)
Statistical data	Number of hospital beds per 10,000 people	"China City Statistical Yearbook", "China Urban Construction Statistical Yearbook", Environmental Statistical Yearbook and statistical yearbooks of local-level cities
Scores Data	Level of free bus rides for elderly individuals	The scores were obtained by grading the free public bus rides policies announced on each city government's public platform

Table 3
The grading standard of the geographical environment suitability evaluation index for elderly care in China.

Standard	Index	Reference	Highly Suitable	Slightly Suitable	Low Suitability	Unsuitable
Temperature	Number of days in which the daily minimum temperature is below 5 °C	Evaluation of Climatic Condition Suitability for Elderly Care Industry Development in Prefecture-Level Cities in China [6]	≤30	30–90	90–180	≥180
	Number of days in which the highest temperature is above 30 °C		≤20	20–60	60–100	≥100
	Number of days in which the average temperature difference between two adjacent days is less than 5 °C		≥345	320–345	295–320	≤295
	Annual average temperature (°C)		15–18	18-20; 13-15	8-13; 20-25	≤8; ≥25
	Average temperature in January (°C)		≥15	4–15	-5–4	≤-5
	Average temperature in July (°C)		15–18	18-23; ≤15	23–30	≥30
	Annual temperature range (°C)		≤20	20–30	30–40	>40
Humidity	Annual average relative humidity (%)		45–60	60–70	70–80	≤45; ≥80
	Number of days in which the annual relative humidity changes by less than 10%		>290	250–290	210–250	<210
Airflow	Annual average wind speed (m/s)		≤1.8	1.8–2.5	2.5–3.3	>3.3
	Number of days with winds above level 3 in winter and spring		≤10	10–20	20–40	>40
Air pressure	Air pressure (hPa)				<701	
Sunshine	Annual average sunshine hours		1400–1800	1800–2400	2400-2800; 1200-1400	<1200; >2800
Precipitation	Annual precipitation		1250–1500	800-1250; 1500-1700	400-800; 1700-1900	<400; >1900
Topography	Altitude (m)	Research results in the field of medicine and the distribution characteristics of the world longevity areas [54–57].	1200–1500	500-1200; 1500-2500	<500; 2500-3000	≥3000
	Slope	The International Geographical Union (IGU) divides the slope into 7 grades, Comprehensive Control of Soil and Water Conservation-General Rule of Planning (GB/T 15772-2008)	0–5	5–15	15–30	≥30
Vegetation coverage	NDVI		≥0.5	0.4–0.5	0.3–0.4	≤0.3
Air quality index	AQI	Ambient air quality standard (GB 3095-2012)	≤50	50–100	100–150	≥150
Traffic conditions	Civil aviation convenience	Classification by natural breakpoint method after normalization	0.537865–1	0.304538–0.537865	0.123648–0.304538	0–0.123648
	Rail passenger accessibility		0.541443–1	0.327854–0.541443	0.130401–0.327854	0–0.130401
	Road network density		0.542148–1	0.33683–0.542148	0.143735–0.33683	0–0.143735
Economy and population	GDP		0.216543–1	0.048643–0.216543	0.008714–0.048643	0–0.008714
	Population density		0.15302–1	0.039069–0.15302	0.003256–0.039069	0–0.003256
Elderly-friendly index	Housing affordability (house prices)		0–0.60	0.60–0.87	0.87–0.93	0.93–1
	Level of free bus rides for elderly individuals	Manual grading based on scoring results	4	3	2	0–1

(*continued on next page*)

Table 3 (*continued*)

Standard	Index	Reference	Highly Suitable	Slightly Suitable	Low Suitability	Unsuitable
Medical service supply capacity	Density of tertiary first-class hospitals	Classification by natural breakpoint method after normalization	0.563194–1	0.303679–0.563194	0.107703–0.303679	0–0.107703
	Number of hospital beds per 10,000 people		0.467622–1	0.380602–0.467622	0.304597–0.380602	0–0.304597
Wellness and recreation resources	Density of recreation, health and wellness resources		0.484494–1	0.249937–0.484494	0.084594–0.249937	0–0.084594

(1) Data preprocessing

All data are converted into raster data using the WGS84 coordinate system. Spatial interpolation is performed on meteorological data and calculated annual averages; preprocessing operations, such as geometric correction, are performed on 30 m_DEM data and NDVI data, and the DEM data are used to calculate the slope. The 2018 daily atmospheric environment data are used to calculate the annual average AQI and are connected to the prefecture-level city vector data. The generated national atmospheric environment AQI index raster data map is exported. Various POI data are screened and visualized, and kernel density calculations are performed to form raster data. House price data and statistical data are connected to the administrative divisions of prefecture-level city maps, generate visualization layers and are converted to raster data. Statistical data rasterization.

(2) Constructing a collection of evaluation indicators

According to the established evaluation index system for the suitability of elderly care, there are 1 target layer, 2 subtarget layers, 9 standard layers, 14 substandard layers, and 28 index layers. u is defined as the index layer; then, the set of evaluation indexes for the suitability of pension geography is formed $U = \{u_1, u_2, \ldots, u_{28}\}$.

(3) Thresholds for determining rating levels

The suitability of each geographical environmental indicator is classified into four grades: highly suitable (v_1), slightly suitable (v_2), less suitable (v_3), and unsuitable (v_4), forming the commentary class domain $V = \{v_1, v_2, v_3, v_4\}$. Different grading schemes are applied to different index data, as shown in Table 3. The division of each evaluation index of the suitability of the natural geographical environment is based on the value range of each natural environmental index when the elderly individuals are at the healthiest level (confirmed by the results of experimental research on human physiological and psychological health [6,55–59]), the geographical environment characteristics of typical areas of longevity, and the classification thresholds of the human settlement suitability indicators. The human geographical environment indicators are one-way indicators, which are normalized and then graded by the natural segment method.

(4) Determining the subordinate layer

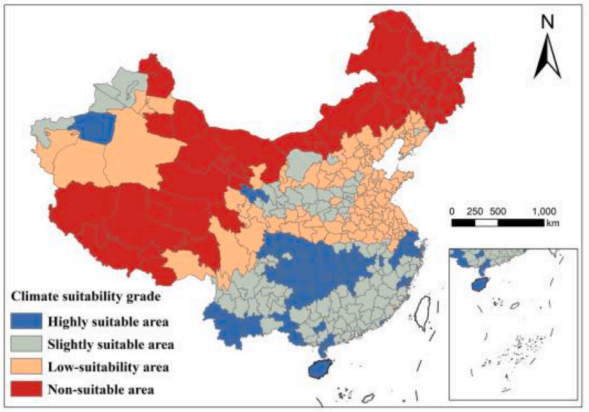
The second step is to calculate the membership degree of each level of a single indicator according to the membership function formula (formula 1). Each indicator forms 4 membership layers: $r_1 = (G_{11}, G_{12}, G_{13}, G_{14})$. Among them, due to the particularity of the air pressure index, the membership degrees of the unsuitable areas are all 1, and the membership degrees of the suitable areas, the more suitable areas, and the subsuitable areas are all 0 [6].

$$\begin{cases} G_{i1,2,3} = \dfrac{X - p_{i2,3,4}}{MAX - p_{i2,3,4}} \\ G_{i4} = \dfrac{p_{i3} - X}{p_{i4} - MIN} \end{cases} \quad \text{Eq 1}$$

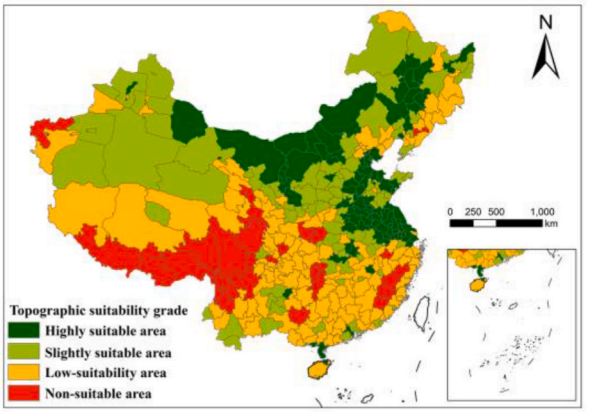
$G_{ij}(i = 1,2, \ldots,n; j = 1,2, \ldots,4)$ is the membership degree of the i-th index v_j-th evaluation level of each grid. p_{i2}, p_{i3}, and p_{i4} represent the demarcation values between the first level and the second level, the second level and the third level, and the third level and the fourth level, respectively.

(5) Determining the comprehensive subordinate layer

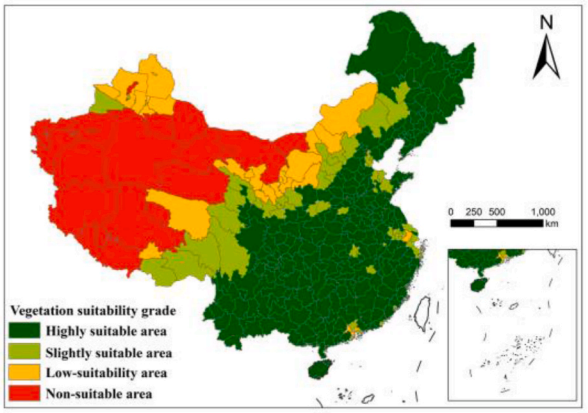
The third step is to use the weighted summation function in ArcMap to superimpose and calculate the comprehensive membership degree according to the spatial fuzzy comprehensive evaluation deformation model (formula 2) to obtain the comprehensive membership layer.



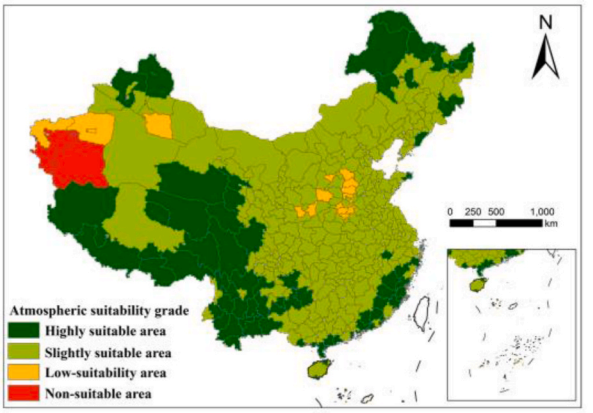
(a) Distribution map of comprehensive climatic suitability for China's elderly care



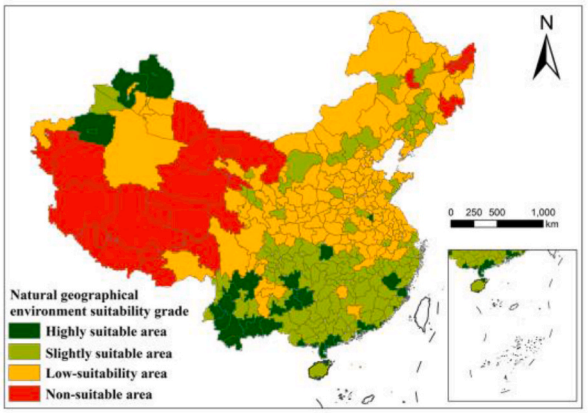
(b) Distribution map of topography suitability for China's elderly care



(c) Distribution map of vegetation coverage suitability for China's elderly care

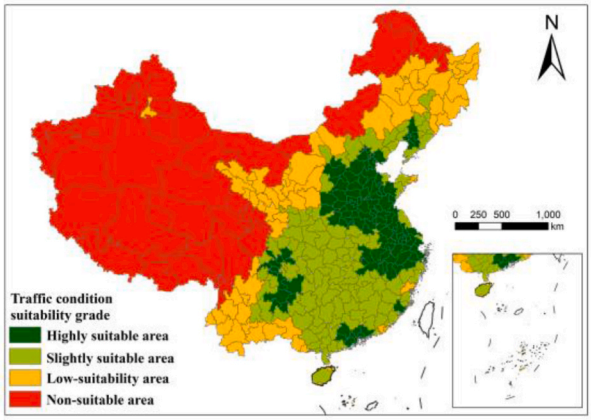


(d) Distribution map of atmospheric environment suitability for China's elderly care

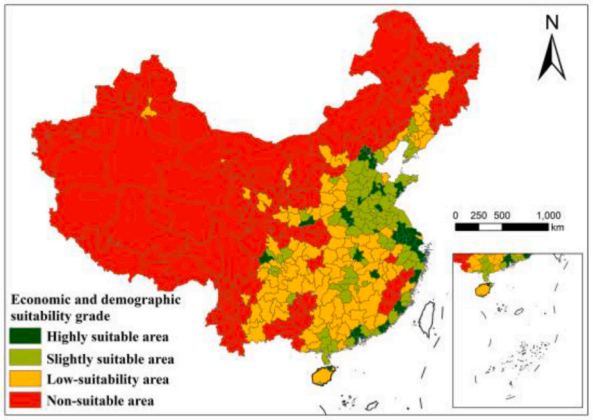


(e) Distribution map of natural geographical environment suitability for China's elderly

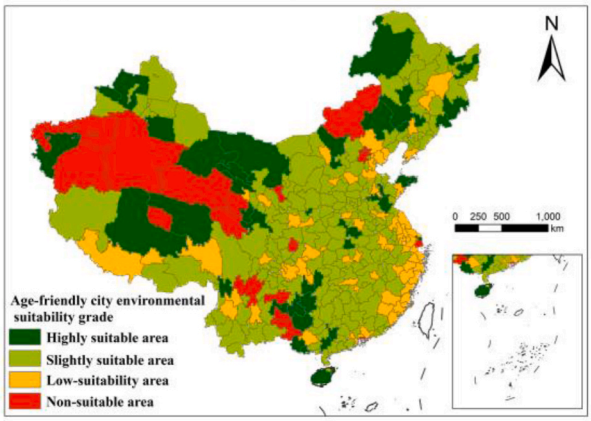
Fig. 2. Map of the distribution of the suitability of the natural geographical environment for China's elderly care.



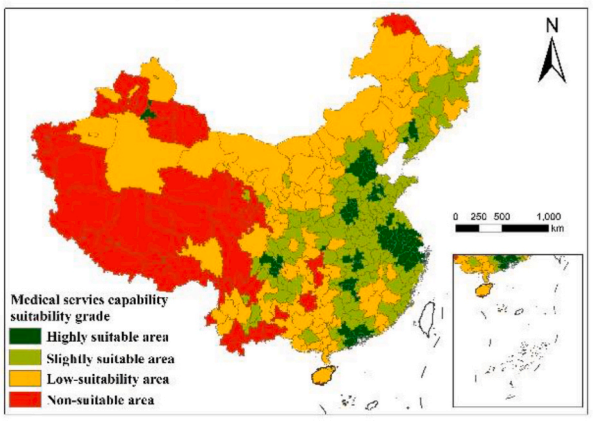
(a) Distribution map of traffic conditions suitability for China's elderly care



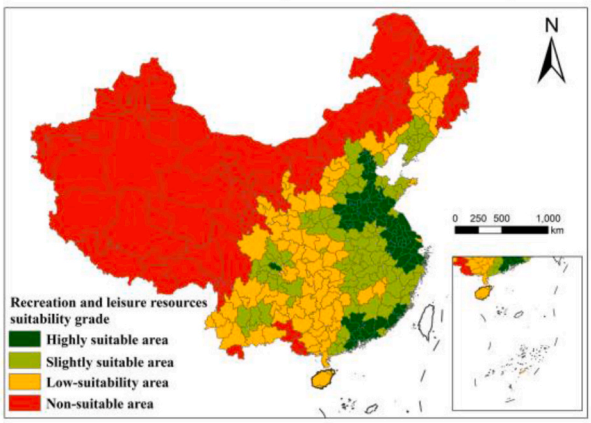
(b) Distribution map of economy and population suitability for China's elderly care



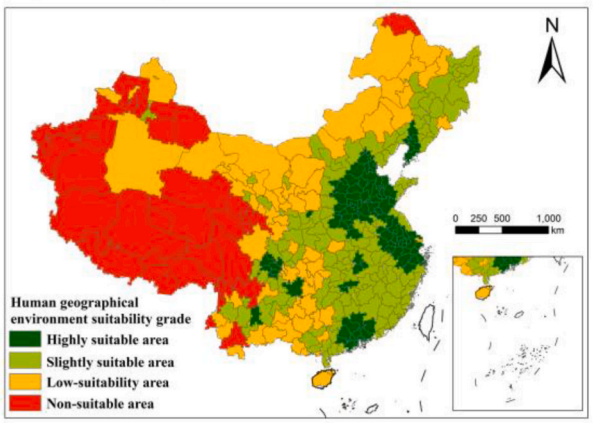
(c) Distribution map of Elderly friendly urban environment suitability for China's elderly care



(d) Distribution map of medical service capability suitability for China's elderly care



(e) Distribution map of wellness and recreation resources suitability for China's elderly care



(f) Distribution map of the human geographical environment suitability for China's elderly care

Fig. 3. Map of the distribution of the suitability of the human geographical environment for China's elderly care.

$$B = A \cdot R = (a_1, a_2, \ldots, a_n) \begin{pmatrix} G_{11} & G_{12} & \ldots & G_{14} \\ G_{21} & G_{22} & \ldots & G_{24} \\ \ldots & \ldots & \ldots & \ldots \\ G_{n1} & G_{n2} & \ldots & G_{n4} \end{pmatrix} = (b_1, b_2, \ldots, b_4) \quad \text{Eq 2}$$

B is the comprehensive membership layer, A is the weight of each factor, R is the single-factor membership layer, and $G_{ij}(i = 1,2, \ldots, n; j = 1,2, \ldots,4)$ is the membership degree of the evaluation level of the index of each grid.

Finally, the calculation results of the integrated affiliation layer are analyzed using the principle of maximum affiliation to determine the evaluation level of each raster, and then the evaluation level of each prefecture-level city is determined using the zoning statistics function of ArcGIS.

3. Results

3.1. Suitability of the natural geographical environment

The distribution characteristics of the suitability of the natural geographical environment for China's elderly care (Fig. 2(a–e)) are as follows:

The number of highly suitable areas is small, and the most concentrated areas are in Southwest China. This area has much mountainous terrain, and although many steep slopes hinder the development of the elderly care industry, the altitude range is similar to that of longevity areas (Fig. 2-b), the climatic conditions are very suitable (Fig. 2-a), the vegetation coverage is high (Fig. 2-c), the air purification ability is strong, and the quality of the atmospheric environment is high (Fig. 2-d). The Aksu, Altay, and Tacheng areas in Xinjiang are relatively suitable due to their comprehensive climatic conditions and topographic and landform conditions, and the quality of the atmospheric environment is good. Therefore, although there is a lack of surface vegetation coverage (Fig. 2-c), the comprehensive natural geographical environment (Fig. 2-e) is still conducive to the physical and mental health of elderly individuals. The comprehensive climatic conditions of Haikou, Sanya and scattered prefecture-level cities along the southeast coast are relatively suitable, the topographic and geomorphological conditions are slightly suitable and have low suitability, the vegetation coverage is high, and the quality of the atmospheric environment is good. Therefore, these areas are classified as highly suitable areas.

The areas with the most concentrated distribution of slightly suitable areas are located in Southern China, Eastern China and Southwest China. There are scattered distributions north of the Yangtze River. Among them, Northeastern China is restricted by climatic factors such as its high latitude and low temperature, and the comprehensive climate suitability is not high, but its slope is gentle, the suitability of the terrain is high, the surface vegetation is lush, the concentration of pollutants is low, and the quality of the atmospheric environment is mostly excellent. The overall natural geographical environment is slightly suitable for elderly care. The eastern part of the northwestern district has low suitability due to its climatic conditions and surface vegetation coverage, but its topography and air quality are mostly highly suitable areas. Comprehensive analysis shows that its natural geographical environment is slightly suitable. The topography, surface vegetation and atmospheric environment in the southern part of Shandong Peninsula all make it a highly suitable area, but due to the influence of low-suitability climatic conditions, the comprehensive natural geographical environment makes it only a slightly suitable area.

The low-suitability areas are mostly concentrated in the northern Yangtze River Basin and are mainly restricted by climatic suitability, which makes these areas low-suitability areas. Another concentrated area is located in Xinjiang, with a highly suitable topography and atmospheric environment; however, its climatic conditions indicate low suitability, and it has unsuitable vegetation coverage. The comprehensive natural geographical environment makes it a low-suitability area.

The unsuitable areas are concentrated in the western Inner Mongolia Plateau and the central Qinghai-Tibet Plateau. These areas have poor climate suitability and low vegetation coverage. There are also 5 unsuitable areas in the northern part of Northeastern China.

3.2. Suitability of the human geographical environment

The distribution characteristics of the suitability of the human geographical environment for elderly care in China (Fig. 3(a–f)) are as follows:

The highly suitable areas are clustered in the eastern coastal area and Southwest China (Fig. 3-f). The most concentrated area is the area composed of the Bohai Rim Economic Zone, the Central Plains City Cluster, and the Yangtze River Delta Economic Cluster. Among them, the highly suitable areas in Northern China and Central China have relatively high suitability in terms of traffic conditions (Fig. 3-a), the economy and population (Fig. 3-b), the elderly-friendly urban environment (Fig. 3-c), and the ability to provide elderly care services (Fig. 3-d). The wellness and recreation resources are rich in variety, large in number, and high in suitability (Fig. 3-e). Therefore, the comprehensive analysis results of the human geographical environment indicate suitability (Fig. 3-f). Regarding the highly suitable areas in Eastern China, although the elderly-friendly urban environment shows low suitability, its traffic conditions, economy and population, elderly care service capacity, and wellness and recreation resources all indicate suitability. Therefore, the comprehensive human geographical environment is highly suitable. The highly suitable areas in the northern part of Bohai Bay benefit from highly suitable and slightly suitable traffic conditions, an urban environment that is suitable for elderly individuals, the ability to provide elderly care services, and abundant resources for wellness and recreation. Another concentrated highly suitable area is located

in the southeastern part of Southern China. This area is highly suitable due to its traffic conditions, elderly care service capabilities, and elderly care and recreation resources. Most elderly-friendly urban environments are highly or slightly suitable areas. Thus, the comprehensive human geographical environment is highly suitable. The Chengdu-Chongqing urban agglomeration and the urban agglomeration in the middle reaches of the Yangtze River are two small and concentrated highly suitable areas, mainly due to the developed transportation system and high-level elderly care service capabilities.

The slightly suitable areas are mostly distributed in eastern and southwestern China. The most concentrated area is the meridional zone extending southward from the eastern part of Northeastern China to the eastern part of Southern China. In the eastern part of Northeastern China, the suitability of the elderly-friendly urban environment is high, the traffic conditions, elderly care service capabilities, wellness and recreation resources are slightly suitable and subsuitable, and the suitability of the economy and population is low. Thus, the comprehensive human geographical environment is slightly suitable. Regarding the slightly suitable areas in Central China, except for the low suitability of the economy and population, the suitability levels of other human geographical environment conditions are relatively high. The slightly suitable areas in Southwest China and Northern China have better suitability in terms of various human geographical environmental conditions. The slightly suitable areas in Eastern China and Southern China mainly benefit from the suitability of their traffic conditions and the suitability of their wellness and recreation resources. Urumqi in Xinjiang is also a slightly suitable area.

The low-suitability areas are roughly distributed along a “Y" line, extending from Northeastern China to Southwest China and the northwestern district. Although these areas are more elderly friendly, they have poor traffic conditions, sparsely populated areas, low levels of economic development, limited elderly care service capabilities, and fewer wellness and recreation resources. Thus, the comprehensive human geographical environment conditions are not suitable.

The unsuitable areas are concentrated in Western China, except for the Greater Khingan Mountains. These areas are geographically remote, vast and sparsely populated, and they have a limited economic level, low transportation accessibility, few wellness and recreation resources, and poor comprehensive human geographical environment suitability.

3.3. Suitability of the comprehensive geographical environment

The distribution characteristics of the suitability of the comprehensive geographical environment for elderly care in China (Fig. 4) are as follows:

The number of highly suitable areas is small, and they are mostly concentrated in the agglomerated area in the Yangtze River Delta. Although the natural geographical environment of this area indicates a slightly suitable and low-suitability area, due to the high level of economic development and the high suitability of the human geographical environment, its comprehensive geographical environment is suitable for elderly care. The second relatively concentrated area is located in the Yunnan-Guizhou-Sichuan region, which is suitable for elderly care, primarily due to its unique natural geographical environment. The southern part of Southern China and the central part of Central China are suitable for elderly care due to the high suitability of the human geographical environment and the good suitability of the natural geographical environment. The Aksu and Tacheng areas in Xinjiang are also highly suitable areas. The reason is that the comprehensive natural geographical environment of these two areas indicates that they are highly suitable areas, housing prices are low, and the elderly-friendly public transport index is high. Thus, the level of comprehensive geographical

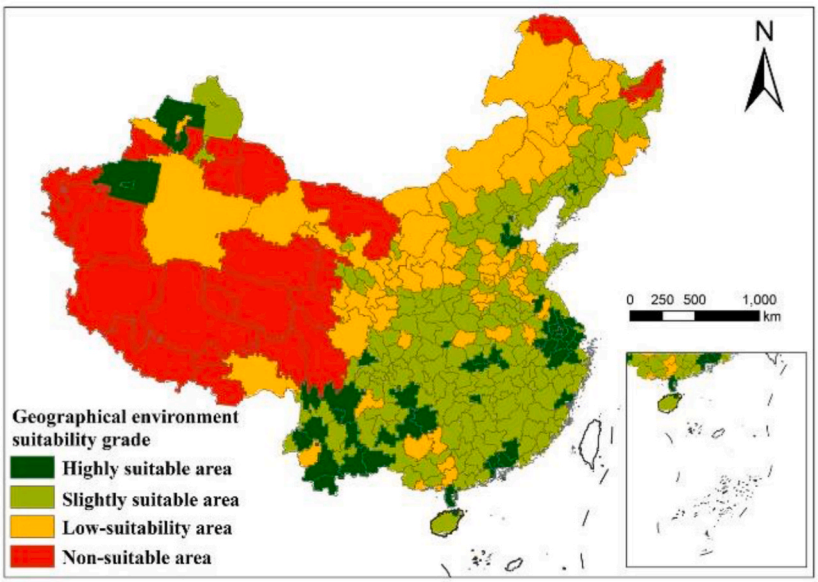


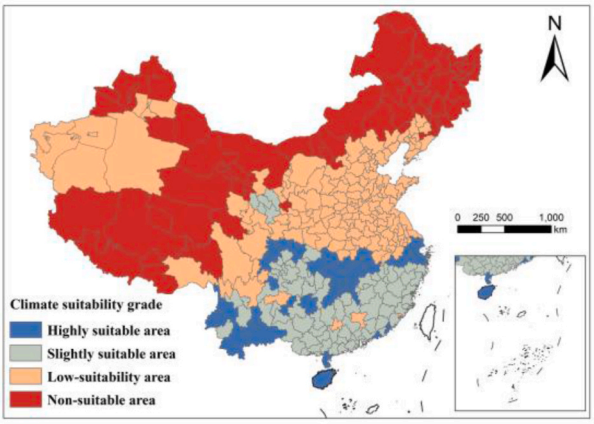
Fig. 4. Map of the distribution of the suitability of the comprehensive geographical environment for China’s elderly care.

environment suitability is high, which is favorable to developing elderly care bases.

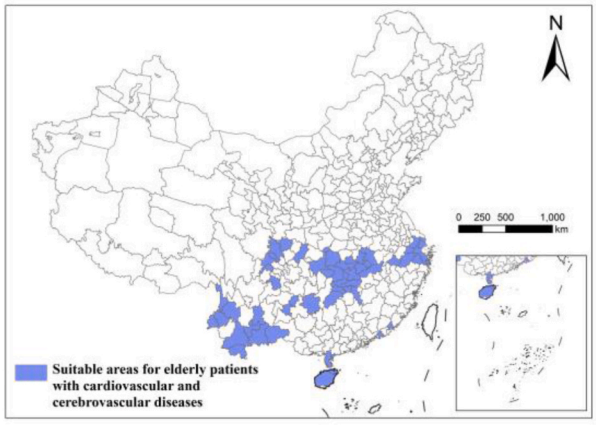
There are a large number and a wide range of slightly suitable areas, which are concentrated and contiguous in Eastern China. Among them, the southern part of Eastern China and the eastern part of Southern China have a natural geographical environment and human geographical environment that indicate that they are slightly suitable. The suitability of the human geographical environment in Southwest China is poor, but the suitability of the natural geographical environment is good, so the comprehensive conditions are slightly suitable for elderly care. The slightly suitable areas in the north benefit more from a favorable human geographical environment. The southeastern part of the northwestern district is also a slightly suitable area.

The low-suitability areas are mostly distributed in Northeastern China, Northern China and the north of the northwestern district, extending from the northeast to the southwest and northwest to form a continuous low-suitability zone. The northwest corner of Eastern China, the southeast corner of Northern China and the northeast corner of Central China form a small-scale and relatively concentrated area. In addition, there are scattered distributions in Southern China. The suitability level of the natural and human geographical environments in these areas is relatively low.

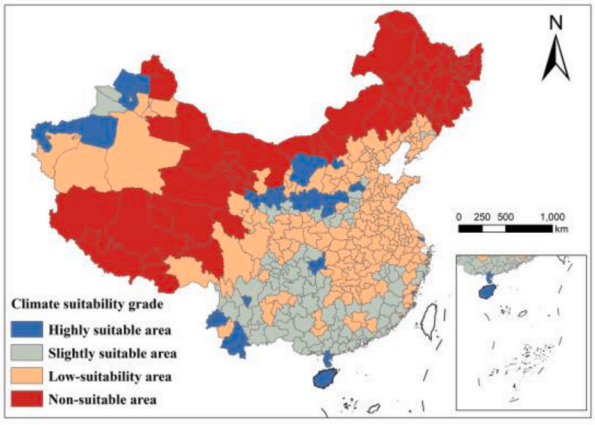
The areas with the most concentrated unsuitable areas are the southern Xinjiang and Qinghai-Tibet areas. In addition, the four prefecture-level administrative units in northern Xinjiang and the Greater Khingan Mountains have harsh natural geographical conditions, and the human geographical environment conditions are also unsuitable, which means that they are not conducive to developing elderly care bases. The northeastern corner of northeastern China is also an unsuitable area due to its harsh natural environment.



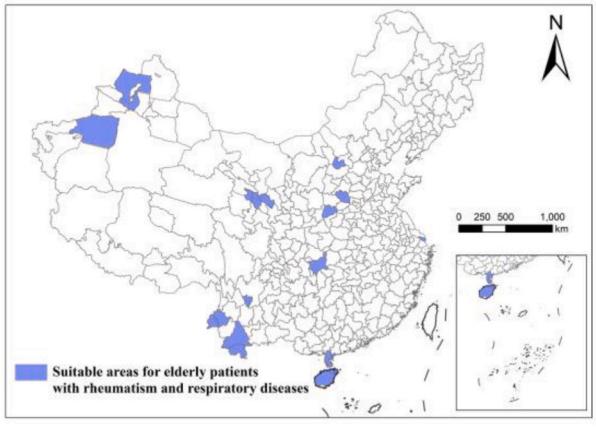
(a) Climate suitability for patients with cardiovascular and cerebrovascular diseases



(b) Special elderly care bases for individuals with cardiovascular and cerebrovascular diseases



(c) Climate suitability for patients with rheumatism and respiratory diseases



(d) Special elderly care bases for individuals with rheumatism and respiratory diseases

Fig. 5. Map of the distribution of suitable areas for elderly care for special elderly care bases.

3.4. Suitable geographical environments for special elderly care bases

(1) Special elderly care bases for elderly individuals with cardiovascular and cerebrovascular diseases:

Studies have found that under low temperature conditions, the incidence of various cardiovascular and cerebrovascular diseases is significantly increased, and temperatures higher than 37 °C can easily lead to ischemic stroke [6,59,72–80]. Therefore, the suitability of temperature conditions should be fully considered when developing special elderly care industry bases for elderly individuals with these diseases. According to the suitability index system of climatic conditions in the existing index system, to highlight the importance of temperature conditions, the comprehensive weight of the temperature index was set to 1, and the distribution of climatic suitability levels for elderly patients with cardiovascular diseases was obtained (Fig. 5-(a)). After that, we extracted the comprehensive geographical environment highly suitable areas and slightly suitable areas and at the same time extracted the climate highly suitable areas for elderly patients with cardiovascular diseases and intersected the two extraction results to obtain the suitable area for elderly patients with cardiovascular diseases (Fig. 5-(b)). In addition, given that the high temperature in the southern area may lead to discomfort among elderly individuals with a weak constitution, special elderly care bases for individuals with these diseases should be located in the central and southwestern regions.

(2) Special elderly care bases for elderly individuals with rheumatic and respiratory diseases:

Changes in temperature, humidity, and air pressure have been shown to significantly affect patients with rheumatic and respiratory diseases [9,81–83]. Therefore, the suitability of temperature and humidity conditions should be fully considered when developing special elderly care bases for elderly individuals with these diseases. According to the suitability index system of climatic conditions in the existing index system, to highlight the importance of temperature, humidity and air pressure conditions, the comprehensive weight of its temperature index, the comprehensive weight of the humidity index and the weight of the air pressure index were set to 1, the distribution of climatic suitability levels for elderly patients with rheumatic diseases and respiratory diseases (Fig. 5-(c)) was obtained, and the highly suitable areas were extracted. Then, they intersected with the previously extracted integrated geographical environment highly suitable and slightly suitable areas, and these intersecting areas can serve as the locations for the development of special elderly care bases for individuals with these diseases (Fig. 5-(d)).

4. Discussion

The results of this study were compared with those of previous studies. The results of this paper were analyzed in comparison with previous studies. The results of this study are highly consistent with the overall characteristics of the Chinese living environment proposed by Zhang [84], and the overall suitability decreases from southeast to northwest. Comparing these results with the evaluation results of the existing Chinese Habitat Environment Index (Feng) [31] shows that the spatial locations of the highly suitable and slightly suitable areas are consistent with the overall law of the distribution of the high-high Chinese Habitat Environment Index. The area east of the line from eastern Northeast China to Southwest China is mostly suitable and more suitable. There is also consistency with the concentration areas in the spatial distribution characteristics of urban nursing homes in China made by Zhu Hong's team [3]. The Aksu area in Xinjiang is a highly suitable area for the comprehensive geographical environment of elderly care, which is the same as the results of the five areas of longevity in the world [55], while the slightly suitable area in the Altay area and the highly suitable areas in the Tacheng area include areas of longevity in China [85]. The suitability of elderly care and the distribution of population density are both affected by geographical environmental conditions. Regarding elderly care, the boundary between the slightly suitable and low-suitability areas is also very close to the Hu Huanyong line, and the basis of the Hu Huanyong line is the suitability and limitations of the Chinese living environment [86]. These findings validate the reliability of the results of this study. The spatial range of the highly suitable geographical environment for elderly care is less than the comfort zone of the human settlement environment, which is also in line with the fact that elderly individuals with relatively fragile constitutions have higher requirements in terms of the geographical environment.

Compared with research on the suitability of the environment of human settlements in China, this study considered the influence of the geographical environment on the comfort of ordinary people and referred to the relevant results of medical geography research in terms of the impact of the geographical environment on health and longevity when selecting indicators and determining the evaluation standards of the indicators. More emphasis is placed on the impact of geographical environmental conditions on the health of elderly individuals while considering the factors that affect the construction and layout of elderly care bases. Certain differences were observed in the distribution of highly suitable areas found in this study and those identified by the Chinese Human Settlements Environment Index. The main difference is that the latitude was slightly higher overall, and a large number of areas with a poor elderly-friendly urban environment were not included. Although the Inner Mongolia Plateau and the northern part of Northeast China are generally suitable areas for human settlements, these areas are often too cold in winter, which can lead to high morbidity and mortality among elderly individuals, and are not suitable for the layout of market-oriented elderly care bases. The suitability of the geographical environment of Xinjiang's Urumqi, Altay, Aksu and Tacheng areas is better overall due to the better environmental suitability of these areas and the influence of factors such as low housing prices and the high degree of public transport.

It is important to acknowledge the limitations of this study. Since the purpose of this paper is to provide a scientific basis for the preliminary selection of cities for elderly individuals to retire at the macroscopic scale as well as the preliminary location of the retirement base, the results of the study are chosen to fall on the scale of prefecture-level cities. If the elderly care suitability analysis is conducted later on for small-scale study areas such as local areas, inner cities or communities, further refinement to raster-scale study

units is still needed. There are many factors that affect the suitability of elderly care, and more direct and scientific indicators, such as per capita GDP, labor force ratio, per capita park area, number of elderly beds per 1000 elderly, and per capita life expectancy, can be added when conducting relevant studies in the future. There are many kinds of diseases that are highly prevalent in the elderly population, and this paper only proposes the layout of special elderly bases for patients with cardiovascular and cerebrovascular diseases and rheumatic diseases and respiratory diseases. The suitability of elderly care can be evaluated for different types of diseases at a later stage. In addition, the occurrence of diseases is influenced by a variety of factors, and this paper only highlights the role of climatic conditions, which have been shown to have a high correlation by previous authors. In subsequent studies, we can further highlight air quality, vegetation cover, drinking water quality, and health care conditions through in-depth study of existing knowledge of disease science. In addition, the coupling analysis of the distribution of the elderly population, elderly care institutions and geographical environment areas suitable for elderly care can be added in subsequent research to find areas with a large elderly population and geographical environment suitable for elderly care but relatively insufficient elderly care institutions, which is significant for providing elderly care services for each region in a more targeted manner.

5. Conclusions

This study considered the requirements of the elderly care industry in terms of the geographical environment. Based on the effect of the environment on the health of elderly individuals and the suitability of the living environment, a good geographical environment has an important supporting role in the selection of elderly care areas and the construction of elderly care bases. Based on this perspective, the logical relationship between the geographical environment and its suitability for elderly care is established, and spatial fuzzy comprehensive evaluation is used to conduct an evaluation of the suitability of the geographical environment for elderly care in China. A natural geographical environment suitability evaluation index system composed of 18 natural geographical environment indicators and a human geographical environment suitability evaluation index system composed of 10 human geographical environment indicators are constructed. Based on the evaluation criteria for the suitability for health of elderly individuals and the suitability of human settlements for each index, classification is carried out. By analyzing China's natural geographical environment data and human geographical environment data, this paper evaluates the suitability of the natural geographical environment, human geographical environment and comprehensive geographical environment of 333 prefecture-level administrative units and 4 municipalities directly under the central government for elderly care in mainland China (data from Macao, Hong Kong and Taiwan are lacking and are not considered). Spatial layout and development suggestions for the level of suitability of the comprehensive geographical environment for elderly care bases are proposed. Finally, the conclusions are as follows:

(1) The results of the suitability of the natural geographical environment show that the number of areas that are highly suitable is relatively small, and the most concentrated areas are in Southwest China, scattered in Xinjiang and Haikou and along the southeast coast. The regions with the most concentrated distribution of slightly suitable areas are Southern China, Eastern China and Southwest China, with a scattered distribution north of the Yangtze River. The most concentrated distribution of low-suitability areas is most of the area north of the Yangtze River Basin. The unsuitable areas are concentrated in the western Inner Mongolia Plateau, the central Qinghai-Tibet Plateau and Northeastern China.
(2) From the perspective of the suitability of the human geographical environment, the highly suitable areas are concentrated in the eastern coastal areas and Southwest China. The slightly suitable areas are mostly distributed in Eastern China and Southwest China. The low-suitability areas are roughly distributed in a "Y" shape. The unsuitable areas are concentrated in the western part of China, except for the Daxing'anling area.
(3) The results show that the highly suitable areas are concentrated in the Yangtze River Delta, the Yunnan-Guizhou-Sichuan region and the southern region of Southern China and scattered in Central China, Northern China and Xinjiang. The slightly suitable areas are concentrated and contiguously distributed in a large area in Eastern China and in the northwest corner of the northwestern district. The low-suitability areas mainly extend from the Northeastern China to Southwest China and the northwestern district and are distributed in a "Y"-shaped belt. The areas with the most concentrated unsuitable areas are the southern Xinjiang and Qinghai-Tibet areas.
(4) The highly suitable areas for elderly care in China include Shanghai and 52 prefecture-level administrative units. The natural and human geographical environments in these areas are highly suitable, which is favorable for the health of elderly individuals. Areas with great market potential can be selected to build national elderly care demonstration bases. Areas with a slightly suitable comprehensive geographical environment should mainly focus on meeting the needs of local elderly care. At the same time, appropriate development space can be reserved to provide elderly care services for the surrounding low-suitability and unsuitable areas. Low-suitability areas should focus on addressing environmental constraints to ensure that the elderly care needs of the local elderly population are met and strive to improve the level of suitability. Under the premise of satisfying basic public elderly care services, unsuitable areas should strive to avoid developing too many market-oriented elderly care bases and encourage elderly individuals with conditions to seek elderly care in different locations. Regarding the comprehensive geographical environment, in highly and slightly suitable areas, further selecting the highly suitable temperature zone in the central region and the highly suitable temperature region in the southwest can develop special elderly care bases for individuals with cardiovascular and cerebrovascular diseases. In areas with a high suitability of the comprehensive geographical environment, areas with comprehensive suitability in terms of humidity and temperature can be selected to build special elderly care bases for individuals with rheumatism and respiratory diseases.

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Institutional review board statement

Not applicable.

Informed consent statement

Not applicable.

Author contribution statement

Mengyuan Wang: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Xiaoming Qi: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Zehong Li: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Jingnan Li: Analyzed and interpreted the data; Wrote the paper.

Suocheng Dong: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16539.

References

[1] H. Liu, The development trend of population aging in the world and China, Sci. Res. Aging 9 (2021) 1–16 (Chinese).
[2] The Communist Party of China Central Committee and the State, Opinions of the communist party of China central committee and the state council on strengthening the work on aging in the new era, Chin. Practical. J. Rural Doctor 29 (2022) 5–9 (Chinese).
[3] L. Jiang, X.Y. Chen, H. Zhu, The spatial heterogeneity distribution of Chinese urban homes and socio-economic driving factors, Acta Geogr. Sci 76 (2021) 1951–1964 (Chinese).
[4] Office of the national committee on aging. China population aging tendency forecasts, Chin. Women's Mov 2 (2007) 15–18 (Chinese).
[5] W. Wang, J. Ma, H.Y. Li, Analysis and evaluation on the regional environment of China's pension industry, Estate Observation 15 (2018) 185–189 (Chinese).
[6] M.Y. Wang, X.M. Qi, Z.H. Li, M.G. Hu, Evaluation of climatic condition suitability for elderly care industry development in prefecture-level cities in China, Sustainability 12 (2020) 9308.
[7] Z.K. Wang, Q. Liu, M. Ge, Curvilinear model analysis between reference values of Chinese presenile men's hematocrit and altitude, J. Southwest China Norm. Univ. (Nat. Sci. Ed.) 3 (2004) 429–433 (Chinese).
[8] X.Y. Chen, Y.M. Liang, M. Ge, Y.F. Xiao, X.X. Chen, X.X. Wu, Curvilinear model analysis between reference of Chinese old women's erythrocyte sedimentation rate and altitude, J. Xi'an Jiaotong Univ., Med. Sci. 3 (2003) 227–228 (Chinese).

[9] M. Ge, Y.F. Xiao, K. Liu, X.Y. Li, W. Liang, H.F. Chen, Reference value of presenile men's hemoglobin and geographical factors in China, Geogr. Sci. 24 (2004) 767–770 (Chinese).
[10] Q.S. Yang, H.X. Zhang, M. Ge, Y. Liu, H.Y. Jiang, B.W. Ge, Relationship between reference value (Wintrobe) of Chinese old men's erythrocyte sedimentation rate (ESR) and geographical factors based on NN, Geogr. Sci. 26 (2006) 749–754 (Chinese).
[11] R.B. Li, W.Y. Wang, J.N. Tan, etc. Chinese national health index and its regional differences, Hum. Geogr. 19 (2004) 64–68 (Chinese).
[12] X.Y. Zou, Y.H. Li, W.Y. Wang, J.M. Lv, H.R. Li, L.S. Yang, The Hometown of Longevity in China—A Survey of Geographical Environment in Xiayi County, Henan Province, Centennial Celebration of Chinese Geographical Society, Beijing, China, 2009 (Chinese).
[13] S.S. Gong, The geographical distribution of centenarians and formative causes of longevity areas in sichan and chongqing districts, J. Cent. China Norm. Univ., Nat. Sci. 37 (1998) 121–126 (Chinese).
[14] S.S. Gong, L.L. Ge, T. Zhang, Geographic distribution of centenarians and environmental backgrounds of longevity regions in Hubei province, Trop. Geogr. 36 (2016) 727–735 (Chinese).
[15] R.J. Ao, H.C. Li, Z. Yang, T. Zhang, Spatial differentiation and influencing factors of health level of the elderly population: a case study of Hubei Province, Prog. Geogr. 36 (2017) 1218–1228 (Chinese).
[16] W.Y. Wang, L.S. Yang, J.A. Tan, R.B. Li, H.R. Li, The Relationship between Geographical Environment and Longevity and Health, The 2007 Academic Annual Meeting of the Chinese Geographical Society, Nanjing, China, 3 November 2007.
[17] I. Frankovic, M. Kuhn, Access to health care, medical progress and the emergence of the longevity gap: a general equilibrium analysis, J Econ Ageing 14 (2019), 100188.
[18] J. Wu, X.J. Gao, Z.Y. Han, Y. Xu, Analysis of the change of comfort index over Yunnan province based on effective temperature, Adv. Earth Sci. 32 (2017) 174–186 (Chinese).
[19] H.T. Werner, Physiologic climates of the conterminous United States: a bioclimatic classification based on man, Ann. Assoc. Am. Geogr. 56 (1966) 141–179.
[20] N. Negin, S. Tiffany, N. Leslie, Numerical modeling of outdoor thermal comfort in 3D, Urban Clim. 26 (2018) 212–230.
[21] Z.M. Feng, Y. Tang, Y.Z. Yang, Evaluation of climate suitability for human settlement in China, Resour. Science 30 (2008) 648–653 (Chinese).
[22] W.J. Yin, Z.H. Pan, Y.Y. Pan, G.L. Han, J.L. Wang, N. Huang, Z.Y. Zhang, J.L. Zhang, The temporal and spatial characteristics of climate comfortability on human settlement in mainland China, Chin. Popul. Resour. and Environ. 28 (2018) 5–8 (Chinese).
[23] B.M. Zhu, Q. Zhou, H.Q. Zhu, W.Z. Sun, Y.F. Guo, X.F. Wang, Climate suitability and variation characteristics of human settlement in Dezhou, Chin. Agric. Sci. Bull. 35 (2019) 95–100 (Chinese).
[24] X.J. Gao, J. Wu, Y. Shi, J. Wu, Z.Y. Han, D.F. Zhang, Y. Tong, R.K. Li, Y. Xu, F. Giorgi, Future changes in thermal comfort conditions over China based on multi-RegCM4 simulations, Atmos. Ocean. Sci. Lett. 11 (2018) 291–299.
[25] A.M. Nely, M.S. Richarde, A.G. Celso, S.S. Joel, Analysis of the environmental thermal comfort conditions in public squares in the semiarid region of northeastern Brazil, Build. Environ. 152 (2019) 145–159.
[26] L. Giuffrida, H. Lokys, O. Klemm, Assessing the effect of weather on human outdoor perception using Twitter, Int. J. Biometeorol. 64 (2020) 205–216.
[27] Z. Huo, Y.G. Li, Study on the suitability evaluation of the human settlements environment in Dianchi Lake Basin based on GIS, Res. Soil Water Conserv. 17 (2010) 159–162 (Chinese).
[28] R.S. Zha, M.L. Chen, X.X. Zhao, An RDLS-Based evaluation of natural environment suitability for human settlement in Nanchuan, J. Southwest. Univ., Nat. Sci. Ed. 36 (2014) 150–156 (Chinese).
[29] S. Nandy, Assessment of terrain stability zones for human habitation in Himalayan Upper Pindar River Basin, Uttarakhand using AHP and GIS, Environ. Earth Sci. 80 (2021) 356.
[30] M. Bravo, J. Rio, R. Lopez, Trade-offs among urban sustainability, pollution and livability in European cities, J. Clean. Prod. 224 (2019) 651–660.
[31] Z.M. Feng, Y. Tang, Y.Z. Yang, D. Zhang, Establishment and application of human settlements environment index model (HEI) based on GIS, Acta Geogr. Sci 63 (2008) 1327–1336 (Chinese).
[32] Q. Yu, T. Shen, S. Wang, Y.H. Zhang, Natural suitability evaluation of human settlement environment in the town of Huangshan City based on GIS, Environ. Pollut. Control 43 (2021) 880–885 (Chinese).
[33] C.J. Xu, S.M. Jin, Y. Wang, Natural suitability evaluation of human settlements in Qinghai-Tibet Plateau based on GIS, Ecol. Sci. 39 (2021) 93–103 (Chinese).
[34] X.K. Yin, Research on Suitability of Human Settlements in Hunan Province Based on GIS, Master, Hunan Normal University, Hunan, China, 2010 (Chinese).
[35] J. He, Y.Z. Tian, Y.H. Gao, X.H. Ming, Z.J. Chen, S.Q. Yang, Assessment of climate suitability for human settlement environment in mountain areas of chongqing, J. Southwest. Univ., Nat. Sci. Ed. 32 (2010) 100–106 (Chinese).
[36] B.Y. Zhu, G.Z. Li, C.Y. Liu, J.F. Liu, C.H. Xu, Evaluation of the natural suitability of human settlements environment in Jilin Province based on RS and GIS, Remote. Sens. Land. Resour. 25 (2013) 138–142 (Chinese).
[37] J.Q. Luo, Dynamic Evaluation of Natural Suitability of Mountain Human Settlements in the Three Gorges Reservoir Area Based on GIS. Master, Southwest University, Chongqing, China, 25 April 2013 (Chinese).
[38] J. Wang, Research on the Impact of Natural Elements on the Urban Human Settlement Environment in Dalian. Master, Liaoning Normal University, Dalian, China, 2013 (Chinese).
[39] X.Y. Xie, X. Zeng, J. Li, Evaluation of natural suitability of human settlements in Chongqing based on moving window method and grid data, Resour. Environ. Yangtze Basin 23 (2014) 1351–1359 (Chinese).
[40] Z.F. Sun, Evaluation and Analysis of the Suitability of Urban Human Settlements in Hohhot. Master, Inner Mongolia Normal University, Hohhot, China, 5 June 2005 (Chinese).
[41] W. Wei, P.J. Shi, H.C. Feng, X.F. Wang, Study on the suitability evaluation of the human settlements environment in arid inland River Basin——a case study on the shiyang River Basin, J. Nat. Resour. 27 (2012) 1940–1950 (Chinese).
[42] B.H. Li, S.N. Zheng, The suitability evaluation and spatial differentiation of human settlements in the Fenhe River Basin, J. Arid Land Resour. Environ. 32 (2018) 87–92 (Chinese).
[43] A. Asmguli, Spatial Characteristics and Environmental Suitability Analysis of the Living Environment of Dali Yaboyi Aborigines in the Desert Hinterland Oasis. Master, Xinjiang University, Xingjiang, China, 24 May 2014 (Chinese).
[44] M. Wang, X.M. Li, Urban human settlement environment suitability assessment—a case study of four districts in dalian city, J. Human Settlements in West China 33 (2018) 48–53 (Chinese).
[45] Y.M. Han, Analysis of the Suitability Evaluation and Spatial Change of Human Settlements in the County Area of Gansu Province. Master, Lanzhou University, Lanzhou, China, 2018 (Chinese).
[46] J.C. Dai, S.Y. Zhou, B.H. Zhao, X. Liu, Discussion on the evaluation index system of livable cities for the elderly in China, Chin. J. Gerontol. 31 (2011) 4008–4013 (Chinese).
[47] S. Gao, H. Sun, W.Y. Xu, S.B. Sun, Grid-based evaluation of the suitability of human settlements in Xi'an, J. Ningxia Univ., Nat. Sci. Ed. 43 (2022) 115–120 (Chinese).
[48] J. Zheng, Z.X. Chen, Y. Wang, M. Qiu, Evaluation of urban human settlements development in northwest China, J. Ningxia Univ., Nat. Sci. Ed. 2 (2005) 171–175 (Chinese).
[49] M. Ainur, K. Wahav, H. Gurigna, R.M. Maimaiti, GIS-based evaluation of the suitability of human settlements in southern Xinjiang, J. Arid Land Resour. Environ. 26 (2012) 11–17 (Chinese).
[50] Q.Q. Yang, J. Chen, B.H. Li, Y.Y. Zhu, Evolution and driving force detection of urban human settlement environment at urban agglomeration in the middle reaches of the Yangtze River, Scientia Geogr. Sci 38 (2018) 195–205 (Chinese).
[51] C. Zheng, Research on Comprehensive Evaluation of Suitability of Urban Living Environment Based on Remote Sensing, Master, Chongqing Normal University, Chongqing, China, 2019 (Chinese).

[52] R.B. Li, J.N. Tan, W.Y. Wang, Y. He, L.S. Yang, W.Y. Zhu, H.Y. Li, Comprehensive evaluation of China's environment-health region, J. Environ. Sci. (China) (S1) (2000) 157–163 (Chinese).
[53] X.X. Pang, G.S. Sang, Y. Yu, GIS-based evaluation of the suitability of the destination for living and elderly care: taking Jinhua City as an example, Yunnan Geogr. Environ. Res. 28 (2016) 15–21+36 (Chinese).
[54] Z. Hao, Y.H. Li, H.R. Li, L.S. Yang, W.Y. Wang, The coupling relationship between regional longevity and geographical environment in China, Chin. J. Gerontol. 35 (2015) 1422–1423 (Chinese).
[55] H. Cai, X.Z. Fu, M. Ge, The relationship between centenarians and natural geographical environment, Foreign Med. Sci., Sect. Medgeogr. 2 (2006) 88–92 (Chinese).
[56] Z.A. Tang, S.Y. Guo, J.B. Huang, Health examination results and influencing factors of cardiovascular system of military personnel in plateau area, Occupational and Health 36 (2020) 1655–1658+1663 (Chinese).
[57] P. Peng, Research on the Identification of Health Tourism Resource Areas in the Gas-Biological System, Master, Yunnan Normal University, Kunming, China, 26 May 2020 (Chinese).
[58] F.C. Villafuerte, N. Corante, Chronic Mountain sickness: clinical aspects, etiology, management, and treatment, High Alt. Med. Biol. 17 (2) (2016).
[59] G.F. Lian, Y. Chen, X.Y. Liu, R. Wang, Y.J. Luo, X.S. Chen, A series of studies on geographical environment and military health (2) Medical geographical features and protection of solar radiation in the Qinghai-Tibet Plateau, High Alt. Med. Biol. 62 (2019) 830–835 (Chinese).
[60] Y.X. Xia, Evaluation of Suitability of Forest Health Care Base Construction, Master, Anhui Agricultural University, Hefei, China, 2020 (Chinese).
[61] K.G. Yuan, L. Liu, Y.B. Xiang, J.H. Zou, GIS-based evaluation of the suitability of interactive tourism pension destination in different places, Econ. Geogr. 33 (2013) 163–168 (Chinese).
[62] H.P. Li, Major air pollutants and their relationship with human health, Jiangsu J. Prev. Med. 31 (2020) 635–636+647 (Chinese).
[63] J.Z. Li, N. Yuan, B.Y. Zhao, X. Xiao, X. Xie, B. Xue, Research on accessibility rating analysis of traffic network in Henan Province based on GIS, J. Xuchang Univ. 38 (2019) 25–29 (Chinese).
[64] X.X. Pang, Tourism Endowment Destination Site Selection Research, Master, Zhejiang Normal University, Jinhua, China, 2015 (Chinese).
[65] X. Yu, Y.D. Xu, Impact of destination city on settlement intention of floating Population : Based on the family life cycle theory, Popul. Res. 45 (2021) 50–67 (Chinese).
[66] L.Y. Liu, Research of Influence of Elderly Preferential Projects on Elderly Subjective Sense of Happiness-Taking the Example of Beijing. Master, Capital University of Economics and Business, Beijing, China, 30 June 2019 (Chinese).
[67] C. Bai, X. Gu, Horizontal inequality in the capacity building of basic elderly care services in China: from the perspective of multi-dimensional well-being measurement, Soc. Sci. Res. 2 (2018) 105–113 (Chinese).
[68] Z.X. Cheng, Research on the Construction and Application of the Service Intervention Model of Therapeutic Recreation, Master, Fujian Normal University, Fuzhou, China, 3 March 2014 (Chinese).
[69] L.L. Wang, Z.Q. Hu, Spatial fuzzy comprehensive evaluation method and practice based on GIS raster data, Geogr. Geo-Inf. Sci. 25 (2009) 38–41 (Chinese).
[70] Z. Fu, Y.X. Zhou, D.W. Liu, et al., Spatial fuzzy comprehensive evaluation of ecological environment quality - taking western jilin province as an example, J. Arid Land Resour. Environ. 5 (2005) 97–102 (Chinese).
[71] F.L. Xu, X.Y. Lu, J.G. Zhou, et al., Environmental impact evaluation index system and fuzzy comprehensive evaluation of large water conservancy projects–Take the "two rivers and two stations" project of Chaohu Lake as an example, Bull. Soil Water Conserv. 4 (2001) 10–14, https://doi.org/10.13961/j.cnki.stbctb.2001.04.003 (Chinese).
[72] Y.C.A. Wang, Study on the Pension Industry from the Perspective of Building Moderately Prosperous Society, Master, Tianjin University, Tianjin, China, 2017 (Chinese).
[73] R.J. Chen, P. Yin, L.J. Wang, et al., Association between ambient temperature and risk mortality and burden: time series study in 272 main Chinese cities, BMJ 363 (2018) k4306.
[74] W.J. Ma, R.J. Chen, H.D. Kan, Temperature-related mortality in 17 large Chinese cities: How heat and cold affect mortality in China, Environ. Res. 134 (2014) 127–133.
[75] A. Bunker, J. Wildenhain, A. Vandenbergh, N. Henschke, J. Rocklov, S. Hajat, R. Sauerborn, Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly; a systematic review and meta-analysis of epidemiological evidence, EBioMedicine 6 (2016) 258–268.
[76] Cui, B.Q. *Environment* and Health, Chemical Industry Press, Beijing, China, 2012, pp. 11–13 (Chinese).
[77] F. Monacelli, I. Aramini, P. Odetti, For debate: the August sun and the December snow, J. Am. Med. Dir. Assoc. 11 (2010) 449–452.
[78] Y. Gerber, S.J. Jacobsen, J.M. Killian, S.A. Weston, V.L. Roger, Seasonality and daily weather conditions in relation to myocardial infarction and sudden cardiac death in olmsted county, Minnesota, 1979 to 2002, J. Am. Coll. Cardiol. 48 (2006) 287–292.
[79] X.S. Huang, X.P. Liao, M. Xie, S.X. Xu, Q.Y. Zhu, Effects of weather and climate on human health in Guangxi, J. Meteorol. Res. and App 40 (2019) 42–45 (Chinese).
[80] X.P. Song, S.G. Wang, Y.L. Hu, M. Le, T.T. Zhang, Y. Liu, J.H. Tian, K.Z. Shang, The Effect of Temperature on Disease Morbidity and Mortality. Chinese Meteorological Society. Proceedings of the 34th China Meteorological Society Annual Meeting S15 Climate Environment Change and Human Health Branch, *China Meteorol. Soc* Beijing, China, 27 September 2017, p. 6. Available online: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=ZGQX201709015035&DbName=CPFD2017. (Accessed 5 November 2020) (Chinese).
[81] Z.Q. Li, Z.H. He, Z.M. Hu, Review of the research on relationship between climate and healthcare, J. Mar. Meteorol 40 (2020) 107–116 (Chinese).
[82] L. Cheng, Relation between RA Morbidity and Meteorological Factors in Beijing Area, Master, China Academy of Chinese Medical Sciences, Beijing, China, 2010 (Chinese).
[83] W. Patberg, J.J. Rasker, Weather effects in rheumatoid arthritis: from controversy to consensus. A review, J. Rheumatol. 31 (2004) 1327–1334.
[84] W.Z. Zhang, The basic pattern and optimization countermeasures of human settlement in China, Think Tank: Theory & Practice 4 (2019) 68–70+74 (Chinese).
[85] J.J. Ma, Study on the Chinese Rural Longevity Phenomena and Human Settlement, PhD, Central China Normal University, Wuhan, China, 2012 (Chinese).
[86] D.D. Lu, Z. Wang, Z.M. Feng, et al., Academic debates on Hu Huanyong population line, Geogr. Res. 35 (2016) 805–824 (Chinese).