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What Affects the Level of Rural Human Settlement? A Case Study of Tibet, China

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Abstract: Rural human settlement is an important factor in the sustainable development of the rural economy and society, and improving rural human settlement is an important task for China's rural revitalization strategy. Based on the human settlement framework, this study constructed a comprehensive evaluation index system to evaluate the rural human settlement by calculating the rural human settlement index (*RHSI*) in Tibet. The results showed that: (1) The natural subsystem is extremely vulnerable. In recent years, the anti-interference ability and natural restoration ability of the ecosystem have gradually increased. Changes in population size, structure, and scale have made the level of the human subsystem lower. From the perspective of drinking water, communication and housing, the human settlement level of the residential subsystem was gradually improved. The construction of rural infrastructure was increasingly improved, driving the level of the supporting subsystem to improve. Furthermore, income and livelihood diversity were the key to improving the social subsystem; (2) From the perspective of the comprehensive index, the level of rural human settlement in Tibet showed a trend of significant improvement; (3) In terms of the explanatory power, the explanatory power of the five subsystems were quite different. The basic dimensions (natural subsystem, human subsystem, residential subsystem) lagged behind the development of the dominant dimensions (supporting subsystem, social subsystem). There were inconsistencies and mismatches. The recommended measures involve strengthening the top-level design of the planning of rural human settlement in farming and pastoral areas, and improving and strengthening the construction of rural infrastructure to improve the responsiveness of rural human settlement in Tibet.

Keywords: rural human settlement; Tibet; Qinghai-Tibet Plateau; China

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1. Introduction

Human settlements refer to the sum of everything that serves residents and uses residents' behaviors as the carrier, which is an important determinant of regional social and economic sustainable development [1]. Human settlement science was founded by Doxiadis, who stressed that human settlement science takes all human settlements as research objects, including villages, market towns and cities [2]. Furthermore, related studies on human settlement originated in urban research [3]. Urban planners such as Mumford, Geddes and Howard put forward the theoretical basis of urban research [4]. Mumford suggested that the vision of urban planning should shift from cities to villages [5]. Geddes stressed that urban planning is people-oriented, taking into account urban and rural development [6]. Howard proposed that the balance between urban and rural areas is conducive to solving the problems of urban human settlements [7]. In China, the research framework of human settlements, which was first presented by Wu, involved comprehensive research on 'systems' (nature, human, residence, society and supporting network) [8].

Generally, human settlements can be divided into urban and rural human settlements [9]. Research on urban human settlements has provided rich insights, mostly

focused on the livability of cities [10,11], sustainable development [12], urban spatial structure [13,14] and urban planning [15], etc. Comparatively speaking, there is little empirical research focused on rural human settlements. Rural human settlements are an organic combination of material and non-material needs for the production and life of rural residents, which is also an essential determinant of the sustainable social and economic development in rural areas [16–18]. On the one hand, some scholars have conducted research on land utilization [19], hydrological conditions [20], air quality [21], and biodiversity [22]. On the other hand, some studies have discussed rural migration [23], rural residents' satisfaction [24,25], and payment willingness within rural residents' participation [26]. These studies sharply deepened and expanded the concept and content of rural human settlements and gradually attracted the attention of the academic community and social circles. The second United Nations conference on human settlements regarded the improvement of human settlements as a global agenda [27]. The theme 'Cities-Engines of Rural Development', which was proposed on World Habitat Day in 2004, indicated that the coordinated development of urban human settlements and rural human settlements is essential, which has been highly concerning for the international community [28].

The United Nations statistics show that the development gap between countries in the world has significantly narrowed, but the gap between regions within countries has widened. Inequality within developing countries is largely caused by the urban-rural gap. The contradiction of inequality and inadequacy in China is most prominent in rural areas [29]. In 2020, China's poverty elimination achieved a sweeping victory. China has completely eliminated absolute poverty and increased residents' income. However, problems such as pollution in the rural environment, the lagging development of public service facilities and disorganized village constructions still remain. To overcome these difficulties, China has released a five-year action plan on improving rural human settlement, setting the improvement of rural human settlement as an important task for the implementation of the rural revitalization strategy, including rural domestic waste treatment, toilet manure treatment, domestic sewage treatment, village appearance improvement and village planning reinforcement [30]. Existing studies on the evaluation of rural human settlements have concentrated on the natural ecosystem, and research areas are mainly regions with well-developed rural tourism [31,32]. Few studies have made a comprehensive assessment of rural human settlements in areas with weak ecosystems and poor economies. A comprehensive understanding of rural human settlements is the basis for governance strategies. The evaluation of rural human settlements should cover multiple regions, especially in rural areas with poor foundation.

The Qinghai-Tibet Plateau is a crucial ecological security barrier area in China and the world, which is also one of the economically impoverished areas with the most fragile ecosystems in China [33–35]. More than 80% of the area of the Qinghai-Tibet Plateau is 4000 m above sea level, and the temperature is significantly lower than that of the same latitude region, forming the "third pole of the earth". The natural conditions of being highly cold and having a high altitude lead to the weak anti-interference ability of the Qinghai-Tibet Plateau and its vulnerability to global environmental changes. Limited by natural factors, the population over the Qinghai-Tibet Plateau is much smaller than its surrounding regions, and the population and family structure are also different from other regions. Due to the influence of terrain, the population density of the Qinghai-Tibet Plateau is low, the residence is scattered, and the overall level of the residential system is low. To sum up, natural factors lead to the low level of natural systems, human systems and residential systems of rural human settlements in the Qinghai-Tibet Plateau. The social system and supporting system are based on the natural system, human system and residential system. Thus, infrastructure and public services on the Qinghai-Tibet Plateau are lower than the national average. The Tibet Autonomous Region was once the only provincial-level-concentrated and contiguous poverty-stricken area and the overall deep poverty-stricken area in China [36]. It integrates border areas, ethnic minority areas and underdeveloped areas. Its economic and social development is relatively lagging behind. It

is a key practice area for China's poverty elimination and Rural Revitalization. Tibet not only has the common characteristics of the Qinghai-Tibet Plateau, such as high cold, high altitude and frequent natural disasters, but it also has typical human settlement problems. In addition, Tibet is a key area of concern for the international community, and local statistics and first-hand information are difficult to obtain [37]. In this context, taking Tibet as a case area has a certain typicality and representativeness for discussing the evolution of rural human settlements on the Qinghai-Tibet Plateau.

Therefore, this paper deeply discusses the evolution of the rural human settlement environment system on the Qinghai-Tibet Plateau, and attempts to analyze the mechanism of the evolution of the rural human settlement environment system. It will provide a theoretical reference and decision-making basis for improving the rural human settlements on the Qinghai-Tibet Plateau, enrich the perspective of rural regions and areas with weak ecosystems and poor economies of human settlement research, and expand the rural human settlement evaluation index system with comprehensive understanding.

2. Materials and Methods

2.1. Study Area

Tibet Autonomous Region is located in the southwest of China, between 26–36° N and 78–99° E (Figure 1). The total area of this district is 1,228,400 km^2, accounting for 12.5% of China's land area. The total population of Tibet is 363,810,000, with an average altitude of over 4000 m. Tibet Autonomous Region governs six prefecture level cities and one region (eight municipal districts and sixty-six counties). Influenced by the geological environment and human activities, Tibet represents one of the most typical alpine pastoral areas within the Qinghai-Tibetan Plateau.

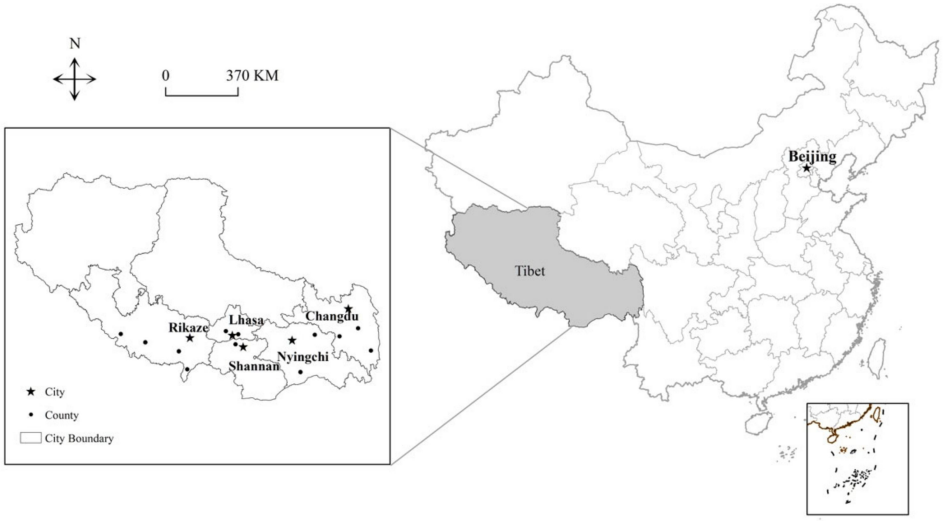

Figure 1. Location of the study area.

2.2. Sampling and Data Collection

In this paper, the data used mainly included statistical information and semi-structured interview data. The statistical data are mainly divided into socioeconomic and ecological environment data. Among them, the socioeconomic data were directly or indirectly derived from Tibet Autonomous Regions Statistical Yearbook, Statistical Bulletin of Tibet's National Economic and Social Development, China Rural Statistical Yearbook, as well as provincial annual data of the National Bureau of Statistics. The ecological environmental data, such as the amount of water resources, the area of national nature reserves, and the forest coverage, were obtained from Tibet Autonomous Region Water Resources Bulletin, Bulletin of Soil and Water Conservation of the Tibet Autonomous Region, and Bulletin on the ecological environment of the Tibet Autonomous Region. In addition, to fully consider the "human feeling" in the evaluation of rural human settlements, researchers conducted three rounds

of face-to-face, semi-structured interviews with people from governments and related departments across Tibet, heads of rural cooperatives, employees of rural enterprises, farmers and herdsmen from 1 to 14 August in 2019, 3 to 15 August in 2020, 23 June to 9 July, and 1 to 14 August in 2021. The interview lasted 58 days, with a total of 248 people interviewed, forming 248 valid records (Table 1). Some interviews were conducted in both Tibetan and Chinese to ensure that each interviewee could understand the questions well. The contents centered on the sources of livelihood, infrastructure, and human settlement. Key interview questions included: (1) What changes have occurred in various areas of residence since 2000? (2) What are the reasons for the above changes? What is the role of the farmers, the state and the local government in these changes? (3) Are you satisfied with the changes in human settlement? What other areas would you like to be improved?

Table 1. Interview time, place and main object.

	Time	Place	Main Object
first round of interviews	August 2019	Lhasa City	Tibet Autonomous Region Development and Reform Comission, Department of Industry and Information Technology, Lhasa Natural Resources Bureau, Development and Reform Comission, Agricultural and Sideline Products Company in Lhasa, etc.
second round of interviews	August 2020	Jilong County, Yadong County, Dingjie County, Nyalam County, Shigatse City; Duilong Deqing District and Dazi District, Lhasa City; Milin County, Nyingchi City	Shigatse Development and Reform Comission, Science and Technology Bureau, Agriculture and Rural Affairs Bureau, Tourism Development Bureau, Statistics Bureau, Poverty Alleviation Bureau, Education Bureau, and Transportation Bureau; Jilong County Development and Reform Comission, Human Resources and Social Security Bureau, Poverty Alleviation Office; Jilong Town, Zongga Town, Zheba Township in Jilong County, Chaina Township, Gongdang Township Government; Dingjie County Chentang Town Government; Nyalam County Government, villagers of Zongta Village, Nyalam Town; Tibet Autonomous Region Planning Office, Energy Bureau, Industry Office, Regional Office, Agricultural Economics Office, Resource Research Center, Science and Technology Entrepreneurship Service Center, Science and Technology Department, Natural Resources Department, Ecological Environment Department, Agriculture and Rural Affairs Department, Poverty Alleviation Office, Commerce Department, Tourism Development Department; Baga Village and Qionglin Village, Milin County, Nyingchi City Villager, etc.
third round of interviews	July and August 2021	Chaya County, Batang County, Qamdo City; Bomi County, Nyingchi City; Shannan City	Qamdo Science and Technology Bureau, Economic and Information Bureau, Development and Reform Comission, Natural Resources Bureau, Statistics Bureau, Tourism Development Bureau, Agriculture and Rural Affairs Bureau, Rural Revitalization Bureau; Publicity Comittee of Jitang Characteristic Town in Chaya County; Head of Copper Company a; Hydropower Station b Person in charge; Person in charge of C Village Agricultural Ecological Experience Park; Bomi County Rural Revitalization Bureau, Agriculture and Rural Affairs Bureau, Culture and Tourism Bureau, Housing and Urban-rural Development Bureau; Tibet Autonomous Region Regional Office, Planning Office, System Reform Office, Railway Shipping Office, Investment Promotion Office, Department of Agricultural Economics, Statistics Bureau, Department of Commerce, Department of Economic and Information Technology, Department of Industry, and Department of Basic Affairs; Shannan Agriculture and Rural Bureau, Rural Revitalization Bureau, etc.

2.3. Indicator Selection of Rural Human Settlement

The Chinese view of human settlements inherited proposed that the human settlements system should include five subsystems: natural subsystems, human subsystems, residential subsystems, supporting subsystems and social subsystems. It is instructive to evaluate the human settlement level based on China's experience. On the basis of the theoretical analysis framework presented above and the complex situations of rural Tibet Autonomous Region, this paper constructed the rural human settlement index (*RHSI*), which includes 26 indicators from the five major subsystems (Table 2). The natural subsystem emphasizes the characteristics of the natural environment, which is the basis of the rural human settlement and the prerequisite for its existence and stable development. Although human settlements are influenced by many natural factors, the most fundamental factors are hydrological conditions [20], land use [19], climate [36], etc. Water resources reflect hydrological conditions, whereas agriculture and forestry are the way of land use. Therefore, six indicators are selected to characterize the natural subsystem: forest coverage, water resources, natural disasters, fertilizer application, protection measures, and agricultural development. The human subsystem emphasizes the residents in the human settlement environment, which is the internal driving force for the evolution and development of the rural human settlement system. Therefore, the attributes of rural residents such as population gender, quantity and burden can be used to measure the level of human subsystems [38], and four indicators are selected to characterize the human subsystem: gender balance, population growth, family size, and population burden. The residential subsystem is the living material environment that is utilized by human subsystems and social subsystems; it is a powerful tool to promote rural social development, mainly including residential conditions (including home appliances), and social public facilities (including hospitals, schools) [39]. Therefore, it is characterized by four indicators: drinking water safety, communication conditions, home appliances, and housing area. The natural subsystems, human subsystems, and residential subsystems are the basic guarantees for the production and life of residents. They have sensitive-exposure-adaptive properties [40], which are identified as the basic dimensions in this paper. Among them, natural disasters, fertilizer applications, and population burden have negative impacts on the level of human subsystems. The larger the affected area of crops, the larger the amount of chemical fertilizer applied per unit area, and the heavier the population burden, the higher the sensitivity of the human settlement, and the weaker the risk response capability.

The supporting subsystem refers to the guaranteed system that provides support and services for human activities and social interactions, which connects rural settlements through a whole infrastructure network, thereby generating huge influences on other subsystems. The supporting subsystem mainly includes education, medical facilities, electricity [41], etc. Considering the availability of data, six indicators were selected to characterize the supporting subsystem: educational investment, medical services, electricity supply, cultural construction, road network construction and express delivery. The social subsystem also serves higher-level demands, such as economic development, residents' welfare and equity, which provides the impetus for the rural human settlement system to reduce risks and cultivate system robustness. The degree of agricultural mechanization [42], sources of livelihood [43], and social security [44] are all related to risks. It is characterized through six indicators: agricultural mechanization, social security, urban-rural gap, livelihood diversity, resident income, and wealth building. The support and social subsystems serve the high-level demands, such as residents' social interaction and welfare and equity, providing sustainable development momentum for the improvement of the rural human settlement system and the cultivation of robustness. They are the dominant dimensions in the human settlement system. Among them, the urban-rural gap has a negative impact on the human settlement level. The greater the urban-rural gap, the higher the human settlement sensitivity, and so the weaker the risk response capability [45].

Table 2. Rural human settlement system level measurement index.

Layers	Subsystem Level	Index	Indicators	Meaning (in Units)	Expected Direction
Basic dimensions	Natural Subsystems	x_1	Forest cover	Forest cover (%)	+
		x_2	Water resources	Total water resources (billion cubic meters)	+
		x_3	Natural disasters	Area of crops affected (thousands of hectares)	−
		x_4	Fertilizer application	Fertilizer application per unit area for agricultural use (kg/ha)	−
		x_5	Protection measures	Area of national-level nature reserves (million hectares)	+
		x_6	Agricultural development	Total crop area sown (thousands of hectares)	+
	Human Subsystems	x_7	Gender Balance	Gender balance of rural practitioners	+
		x_8	Population growth	Rural population growth rate (%)	+
		x_9	Family size	Household size (persons/households)	+
		x_{10}	Population burden	Average population per workforce	−
	Residential subsystems	x_{11}	Drinking water safety	Drinking water safety	+
		x_{12}	Communication conditions	Telephone penetration rate (units per 100 people)	+
		x_{13}	Home appliances	TV ownership among rural residents (units per 100 people)	+
		x_{14}	Housing area	Housing area per capita in rural areas (m^2)	+
Dominant dimensions	Supporting subsystems	x_{15}	Education input	Education expenses (RMB million)	+
		x_{16}	Medical Services	Number of township health personnel (persons)	+
		x_{17}	Electricity supply	Rural electricity consumption (billion kWh)	+
		x_{18}	Culture building	Township cultural stations (pcs)	+
		x_{19}	Road network construction	Road mileage (million km)	+
		x_{20}	Express delivery	Rural delivery routes (km)	+
		x_{21}	Agricultural mechanization	Agricultural machinery power per unit area (kW/hm^2)	+
	Social subsystems level	x_{22}	Social Security	Number of participants in unemployment insurance (10,000)	+
		x_{23}	Urban-rural gap	Urban-rural income disparity ratio	−
		x_{24}	Livelihood diversity	Share of non-agricultural output (%)	+
		x_{25}	Resident income	Disposable income per rural resident (yuan)	+
		x_{26}	Wealth building	Savings balance per rural resident (yuan)	+

2.4. Model Formulation and Data Processing

The extreme value normalization method was used in this paper, which considered the difference between the positive and negative indexes on the index calculation, to eliminate the influences of different index dimensions on the calculation results, thus ensuring that the processed dimensionless values can truly reflect the relationship between the original index values. Formulas (1) and (2) were used to process the data for the positive and negative indicators, and the final standardized values were normalized to [0, 1]. In the following equations, x_{ij} represents the value of the j-th indicator in the i-th year.

$$y_{ij} = \frac{x_{ij} - min(x_j)}{max(x_j) - min(x_j)} \quad (1)$$

$$y_{ij} = \frac{max(x_j) - x_{ij}}{max(x_j) - min(x_j)} \quad (2)$$

The indexes of each subsystem are aggregated by the unweighted summation method, see Formula (3). $y_{ij,s}$ represents the standardized value of the j-th index in the i-th year of the s subsystem; V_{is} represents the s system level of the s subsystem in the i-th year. Considering the difference in properties and functions between basic dimensions and dominant dimensions, the basic dimensions aggregate subsystems in accordance with the "bucket effect" because of its exposure-sensitive adaptive properties. In other words, the level of the basic dimensions in this period is represented by the minimum value of the subsystem, see Formula (4). V_{iB} refers to the level of the basic dimensions in the i-th year. The supporting subsystems and the social subsystems can interact with each other and have the ability to correspond to the level of basic dimensions. Therefore, the level of dominant dimensions and the comprehensive level are still aggregated by the unweighted summation method, see Formulas (5) and (6). V_{iD} refers to the dominant dimension level in the i-th year. $RHSI_i$ refers to the comprehensive level of the five subsystems in the i-th year. The values of each subsystem are in the range of [0, 1]. The human settlement level is divided by the quadratic method from low to high. The range of (0, 0.25) refers to the

very low level. The range of (0.25, 0.5) refers to the low level. The range of (0.5, 0.75) refers to the moderate level. The range of (0.75, 1) refers to the high level. The comprehensive human settlement level can be calculated based on the unweighted summation method. The weight of the basic dimension is calculated to be 1/2 through Formulas (4)–(6), and the weight of the supporting subsystem and the social subsystem is 1/4, respectively. The system explanatory power mainly measures the explanation degree of the human settlement suitability by different subsystems, as shown in Formula (7).

$$V_{is} = \frac{1}{n}\sum_{j=1}^{n} y_{ij,s}\ (i = 1,2,\ldots,m; j = 1,2,\ldots,n; s = 1,2,\ldots,l). \quad (3)$$

$$V_{iB} = min(V_{is})\ (i = 1,2,\ldots,m; s = 1,2,\ldots,l) \quad (4)$$

$$V_{iD} = \frac{1}{l}\sum_{s=1}^{l} V_{is}\ (i = 1,2,\ldots,m; s = 12,\ldots,l). \quad (5)$$

$$RHSI_i = \frac{1}{2}\left(V_{iB} + V_{iL}\right)\ (i = 1,2,\ldots,m). \quad (6)$$

$$SEP = \frac{\omega_{is}V_{is}}{\sum \omega_{is}V_{is}}\ (if\ V_{is} = V_{iB},\ \omega_{is} = \frac{1}{2};\ V_{is} = V_{iL},\ \omega_{is} = \frac{1}{4}) \quad (7)$$

The development process and influencing factors of the rural human settlement system were explored based on the semi-structured interviews [46]. First, the outline questions were designed, focusing on farmers' perceptions of changes and causes in areas such as livelihood sources, infrastructure, and human settlement. Secondly, the contents of the 248 valid recordings were processed into texts for analysis. Finally, the staged characteristics were extracted to identify the root causes of the level change of the rural human settlement system.

3. Results

3.1. Natural Subsystem Level

The level of the natural subsystem is relatively low. In recent years, the anti-interference abilities and the natural restoration abilities of ecosystems have gradually increased. As the largest ecologically vulnerable area in China, the high altitude of the Qinghai-Tibet Plateau makes the relatively low temperature and coldness prominent, resulting in the frequent occurrence of natural disasters such as blizzards, hails, droughts, as well as biological disasters such as locust plagues and rodent damage. The natural subsystem has characteristics such as a simple ecosystem structure, weak anti-interference ability, vulnerability to damage and difficulty in repairing [35]. From 2000 to 2020, the sown area of crops in Tibet increased from 231,050 hectares to 272,080 hectares (Figure 2). Although the sown area increased, since the land type in Tibet was mainly alpine and arid land with low production capacities, the area of land suitable for farming was limited, accounting for only 0.19% and 0.22% of the total area, and the land reclamation index still ranked the lowest in China, only higher than that of Beijing and Shanghai. In recent years, the affected area of crops has shown a decreasing trend. From 2000 to 2020, the affected area decreased from 32,000 hectares to 9200 hectares, and the affected ratio decreased from 13.8% to 2.4%, which was lower than the national average of 11.9%. The impacts of natural disasters and biological hazards on rural Tibet have been alleviated. With the reduction in the affected area of crops, farmers' demand for chemical fertilizers has also decreased. From 2000 to 2020, the application amount of agricultural chemical fertilizer per unit area decreased from 200.96 kg/ha to 155.58 kg/ha. In 2020, the average amount of agricultural chemical fertilizer applied per unit area in China reached 506.11 kg/ha, whereas the application amount in Tibet was about one third of China's average level. Due to the ecological vulnerability of Tibet, the use of chemical fertilizers and pesticides in Tibet is more stringent. For example, a person in charge of an agricultural ecological park said in an interview, "In Tibet, the

use of chemical fertilizers and pesticides is contrary to traditional religious beliefs. Most villagers do not use them spontaneously. Chemical fertilizers and pesticides used by a few people to prevent biological disasters should have special approvals, and be purchased in unified orders. They are prohibited in nature reserves.". The effective control of chemical fertilizers and the establishment of nature reserves aim to protect the natural subsystem of the Qinghai-Tibet Plateau, and enhance the anti-interference ability and natural restoration ability of the ecosystems.

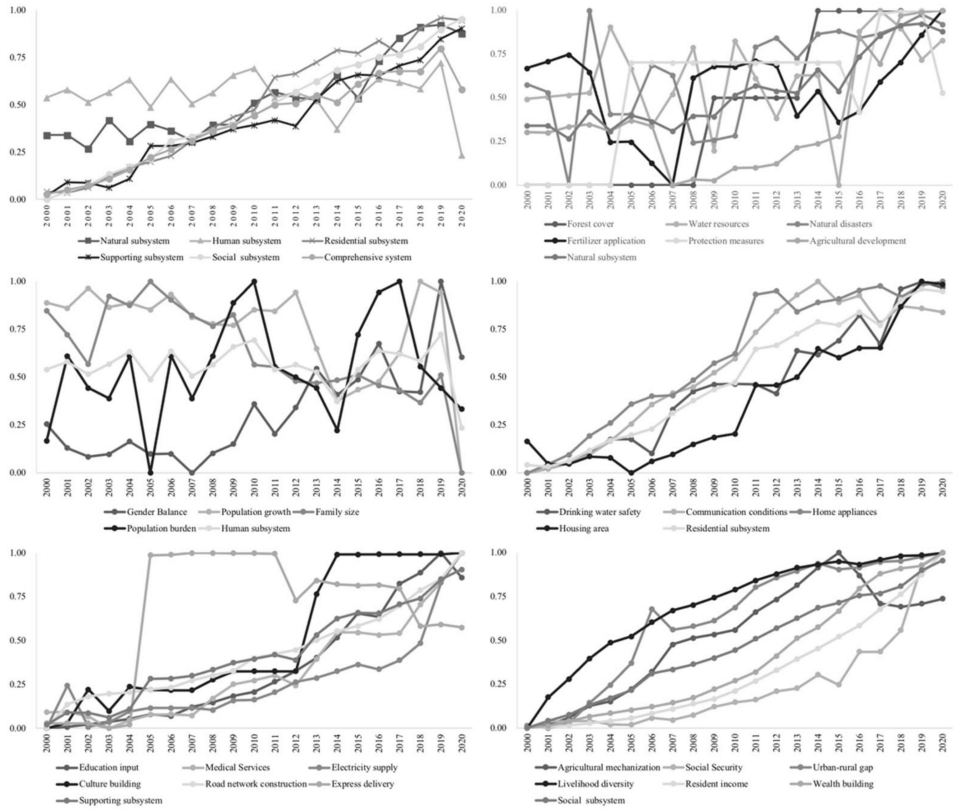

Figure 2. Factor changes of five subsystems from 2000 to 2020.

3.2. Human Subsystem Level

Changes in population size, structure and scale have made the human subsystem level lower. Tibet is the main settlement where Tibetans live. The fertility rate in the ethnic minority areas is relatively high, and the population growth rate is relatively fast. From 2000 to 2020, the birth rate of the rural population in Tibet decreased, and the population growth rate slowed down, decreasing from 1.16% to −2.5% (Figure 2). The decline in the birth rate led to the continuous shrinking in family size. The development of families showed a trend of miniaturization. The number of people per household dropped from 4.75 to 3.19. The negative growth of the rural population and the reduction in family size are not conducive to the development of the human subsystem. With the intensification of the gender imbalance of rural employees, the single gender of family labor forces does not match the size of small families, and the labor burden increases. Although Tibet shows a slowdown in rural population growth, a contraction in household size and an increase in the labor burden population, the indicators are still better than the national average, with a negative growth rate of −2.5% in 2020, which is still higher than the national rural average (−3.1%). Furthermore, the average household size is still the highest in the country, 1.2 times the national average household size, and in 2020, the labor burden population was 1.71 person, slightly lower than the national average of 1.77 person. The slowing population growth, shrinking family size and increasing labor burden are not conducive to the sustainable development of the human subsystem, which are also directly related to

the concept of population fertility caused by rapid economic development and improved living standards. It is necessary to consider from a dialectical perspective.

3.3. Residential Subsystem Level

From the perspective of drinking water, communication, and housing, the human settlement level of the residential subsystem is gradually improving. Rural residents on the Qinghai-Tibet Plateau have become increasingly rich in material capitals. The durable consumer goods have grown exponentially. Basic durable goods such as landline phones and TV sets have been fully popularized. In 2011, the telephone penetration rate and the number of TV sets decreased due to the adjustment of data statistics. The content of "the number of TV sets owned by rural residents" was changed from black-and-white TV sets to color TV sets, and the content of "the telephone penetration rate" was expanded from landline phones to landline phones and mobile phones. The policy of "two assurances and three guarantees" is the basic requirement and the core index for the rural poor to eliminate poverty. It refers to no worries over food and clothing and available access to compulsory education, basic medical services and safe housing. Housing is the core element of the human settlement system. The satisfaction of housing demands and the quality of housing are also significant manifestations of rural livability. The proposal of the policy of "being free from worries over food and clothing and having access to compulsory education, basic medical services and safe housing" helps continuously improve the living conditions in Tibet's rural areas, which makes significant contributions to the improvement of the human settlement. From 2000 to 2020, the per capita housing area in Tibet grew rapidly, rising from 23.16 m^2 to 41.15 m^2, which was higher than the per capita housing area of 26.85 m^2 in Xinjiang, but it was still lower than the national rural per capita housing area of 48.9 m^2 (Figure 2). Tibet is a deeply impoverished area with the highest incidence of poverty and the deepest degree of poverty in China. The safety of rural drinking water is the most concerned, direct and realistic issue for farmers and herdsmen. The whole region is located in a high-cold and high-altitude area, with harsh natural conditions, complex topographies, and scattered settlements. The rural drinking water projects mainly use the small, decentralized water supply, and the per capita construction cost is high; at the same time, the temperature in winter is low, and the water supply is unstable. By 2020, the penetration rate of safe drinking water in Tibet's rural areas reached 100%, creating a miracle of water supply in Tibet's agricultural and pastoral areas and greatly improving the residential subsystem level.

3.4. Supporting Subsystem Level

The construction of rural infrastructures is increasingly improving, driving the improvement of the level of the supporting subsystem. The road system in Tibet has been gradually perfected. The mileage of highways has increased from 22,500 km to 104,000 km. A total of 4075 km of highways are built on average every year. The annual mileage of newly added highways is higher than the sum of the Sichuan-Tibet Highway and the Qinghai-Tibet Highway. The development of road transportation in Tibet has led to the improvement of agricultural and animal husbandry life. Electricity is the driving force for economic and social development. Due to the scarcity of coal resources in Tibetan areas and the inconvenient geographical conditions for the long-distance transportation of electricity, the construction and improvement of rural electric power systems is a rigid need for residents in Tibet. With the changes in road transportation in Tibet, the construction of power grids in the "three districts and three prefectures" as the deeply impoverished areas has been completed one after another, making rural electricity consumption rise rapidly. From 2000 to 2020, the electricity consumption increased from 34 million kWh to 292 million kWh, with an average annual growth of 11.4% (Figure 2). In addition to electricity, the education, medical care, sanitation, and postal services of villages have been upgraded. The infrastructure conditions of the villages have also been significantly enhanced. The production and living standards of the people have been obviously strength-

ened, and the level of the supporting subsystem has been promoted. For example, a farmer in Xuewaka Village, Guxiang, Bomi County said in an interview, "It is very convenient for us to have domestic water and electricity now. The lighting facilities, streets and alleys have been improved to a certain extent. I also hope that the drainage facilities, public toilets and logistics stations in our village can be improved.". It can be seen that residents are satisfied with the existing basic infrastructure, such as water supply, power supply, lighting facilities, streets and alleys. They believe that some improved infrastructures need further enhancement, such as drainage facilities, public toilets, farmland irrigation and logistics stations.

3.5. Social Subsystem Level

Income and livelihood diversity are the key to improving the social subsystem. Since the Qinghai-Tibet Plateau won the poverty elimination battle, the incomes of rural residents have increased significantly. Although the per capita disposable income in rural areas is still relatively low, the growth rate is fast. From 2000 to 2020, it rose from 1326 to 14,598 yuan, with an average annual growth rate of 12.7%, which was two percentage points higher than the national average growth rate (Figure 2). With the steady growth of residents' incomes, the per capita savings balances of rural residents have increased significantly from CNY 1558 to CNY 29,746. The gap with that of urban areas is gradually narrowing. Meanwhile, the livelihood strategies of Tibetan farmers and herdsmen have undergone great changes. On one hand, with the development of the planting industry, the degree of agricultural mechanization in Tibet has increased rapidly, from 5.0% to 21.2%. However, due to the scattered land resources, the family farming scale is small, and the price of rural machinery and equipment is high, making the per capita use cost high. It is difficult to achieve the large-scale use of machinery. The level of agricultural mechanization in Tibet is still far below the average level of 71% in China; on the other hand, due to the unique geographical location and climatic conditions of the Qinghai-Tibet Plateau, most rural residents relied on planting and animal husbandry to maintain their livelihoods in the past. In recent years, the proportion of traditional agriculture has gradually decreased. Farmers and herdsmen have more diverse choices of livelihood, which has led to a significant increase in incomes. The proportion of non-agricultural industry output value has risen from 69.9% to 92.1%. For example, a staff member of a certain agricultural science and technology company said in an interview, "The tea garden project transfers a total of 1020 mu of farmers and herdsmen's land, which encourages 175 people from 35 households in Xuewaka Village to be employed locally for a long time. The monthly salary of each farmer and herdsman is 6000 yuan. To allow farmers and herdsmen to adapt to the modern tea industry as soon as possible, a series of professional trainings have also been arranged." The tea industry is of great value to people's livelihood in Tibet, which has a strong ability to drive related industries. The implementation of the tea garden project provides farmers and herdsmen with a variety of livelihood options, not only increasing their incomes, but also further improving the human settlement level of the social subsystem.

3.6. Comprehensive System Level

The comprehensive index shows that the growth trend of Tibet's rural human settlement level is obvious. From 2000 to 2020, the composite index rose from 0.03 to 0.58, with an average annual growth of 16.0%. Among them, the rural human settlement level grew rapidly from 2000 to 2013, with an average annual growth rate of 25.1%. From 2013 to 2020, the growth rate slowed down, with an average annual growth rate of 0.8%. Due to the outbreak of COVID-19, the indexes of living, human, and natural subsystems decreased from 2019 to 2020, resulting in a decrease in the comprehensive human settlement level. For example, a staff member of an e-commerce business in Jilong County, Shigatse City, said in an interview, "Due to the epidemic, the number of tourists visiting Tibet has dropped significantly, making it difficult for local brands to gain popularity through the tourist population. The number of online and offline sales of agricultural and sideline products

with Tibetan characteristics is not ideal, such as Ganoderma Lucidum, rapeseed oil, Tibetan perfumes." Uncertain factors such as COVID-19 still bring instability to Tibet's human settlement level.

From the perspective of explanatory power, there are great differences in the explanatory power level of the five subsystems, which is consistent with previous studies showing that there is an imbalance in the sustainable development of the Qinghai-Tibet Plateau [47]. The residential subsystem and the human subsystem have strong explanatory powers for basic dimensions. From 2000 to 2010, the residential subsystem was one basic dimension, serving as the main explanatory power for the comprehensive human settlement level. The explanatory power level showed a downward trend, falling from 78.7% to 53%, but it was still higher than 50%, indicating the explanatory power of the basic dimensions at this time was greater than that of the dominant dimensions. From 2000 to 2010, the human subsystem was one basic dimension, serving as the main explanatory power of the comprehensive human settlement level, indicating that in basic dimensions, the human subsystem level was relatively backward. Measures should be taken for improvement.

The natural subsystem is relatively fluctuating, and the explanation of the comprehensive human environment level only appeared in 2007, 2009, 2012, and 2015 (Figure 3). This is because there are many uncertain factors in the ecological environment, such as natural disasters and biological hazards, which will result in the instability of the explanatory power of the natural subsystem. The explanatory power of the dominant dimensions for the comprehensive human settlement level gradually increases. From 2000 to 2020, the proportion of dominant dimensions in the comprehensive human settlement level gradually increased from 21% to 80% (Figure 4). This is due to the fact that, on one hand, the supporting subsystem and the social subsystem have improved more significantly; on the other hand, the development of the basic dimensions lag behind that of the dominant dimensions. There are inconsistencies and mismatches. For a long time, Tibet's special plateau geographical environment has restricted its infrastructure construction and large-scale economic development. Therefore, it is urgent to improve the policies and measures related to the human settlement, coordinate various systems, and solve the imbalance problem.

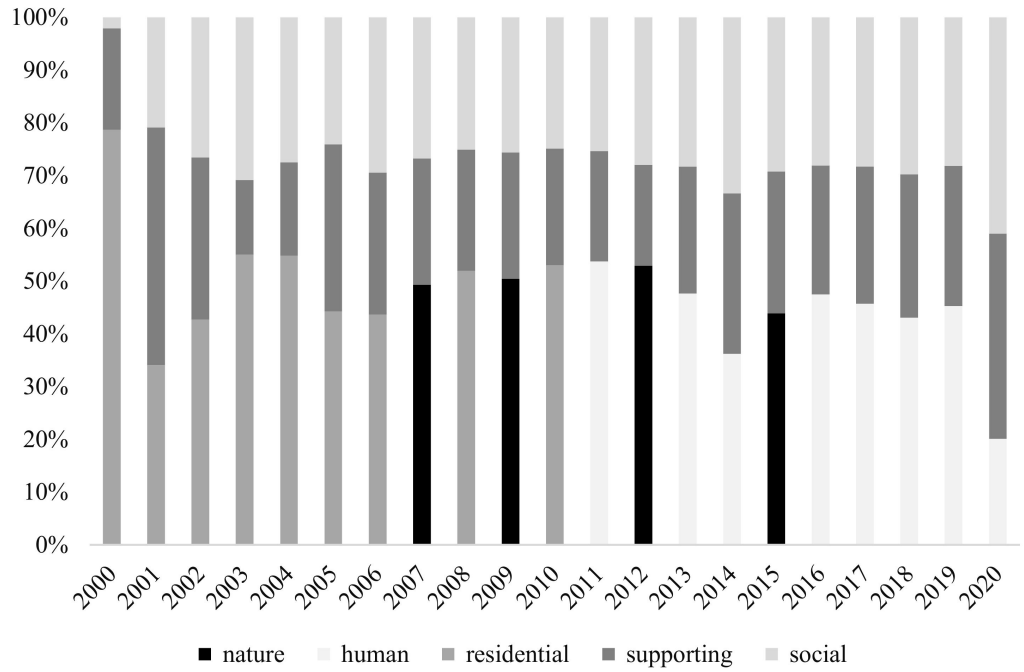

Figure 3. Changes in explanatory power of five subsystem factors from 2000 to 2020.

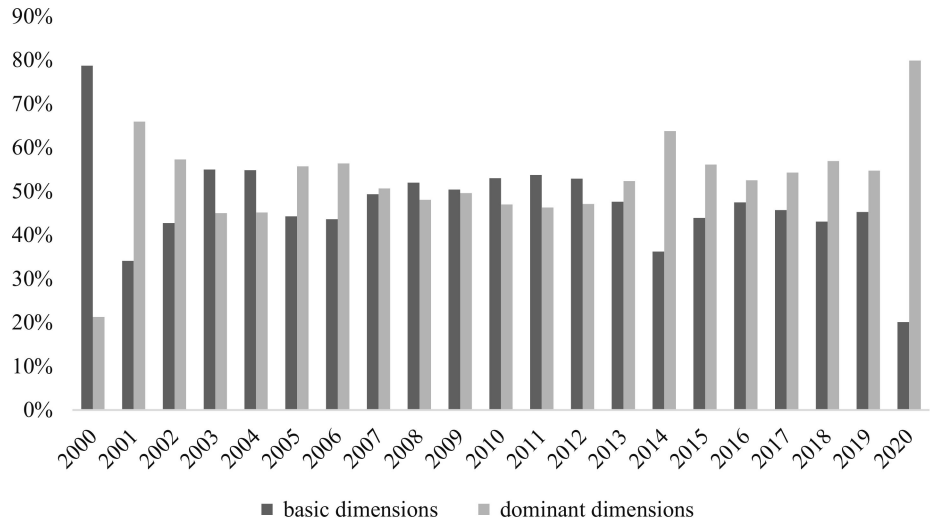

Figure 4. Changes in explanatory power of basic and dominant dimensions from 2000 to 2020.

4. Discussion

In order to solve the problems of rural human settlements in a wide range of development organizations, five systems are receiving attention. The five-systems framework mainly introduces the main factors affecting the human settlement environment and their relationships. Based on the framework, this study constructed a comprehensive evaluation index system to evaluate the rural human settlement by calculating the rural human settlement index in Tibet. The rural human settlement level in Tibet was evaluated based on statistical data. The results showed that:

(1) From the basic dimension, the natural subsystem in Tibet is extremely vulnerable [48]. In recent years, the anti-interference ability and natural restoration ability of the ecosystem have gradually increased. Although the sown area increased, since the land type in Tibet was mainly alpine and arid land with low production capacities [49], the impacts of natural disasters and biological hazards on rural Tibet have been alleviated. Changes in population size, structure, and scale made the level of the human subsystem lower. Although Tibet shows a slowdown in rural population growth, a contraction in household size and an increase in the labor burden population, the indicators are still better than the national average [50]. From the perspective of drinking water, communication, and housing, the human settlement level of the residential subsystem was gradually improving [51,52]. From 2000 to 2020, the per capita housing area in Tibet grew rapidly, but it was still lower than the national rural per capita housing area. Because the three systems in the basic dimension have been improved to a certain extent, the social subsystem and supporting subsystem in the dominant dimension have also made progress. The construction of rural infrastructure was increasingly improving, driving the level of the supporting subsystem to improve. Income and livelihood diversity were the key to improving the social subsystem. Livelihood diversity and off-farm livelihoods are two important livelihood strategies in developing countries, helping to improve rural settlements, ensure food security and reduce the threat of famine [53,54].

(2) From the perspective of the comprehensive index, the level of rural human settlement in Tibet showed a trend of significant improvement, which is inconsistent with earlier studies [55,56], possibly because the government has launched a series of ecological restoration projects and improvement of human settlements policies [57]. The government work report also confirms this view. During the 13th Five Year Plan period, a total of 270,000 rural household sanitary toilets were renovated in Tibet, more than 90% of the domestic garbage in villages was treated, more than 30% of the domestic sewage in villages was controlled, 40% of the villages basically realized the separation

of human beings and livestock, and farmers and herdsmen gradually developed good hygienic living habits.

(3) In terms of the explanatory power, the explanatory power of the five subsystems were quite different. The basic dimensions (natural subsystem, human subsystem, residential subsystem) lagged behind the development of the dominant dimensions (supporting subsystem, social subsystem). There were inconsistencies and mismatches. In other words, rural human settlements depend on the basic dimensions that they have, which is consistent with previous studies showing that residents in Tibet focus more on meeting the basic needs of life, and they are not able to improve their dominant dimensions [47]. Under the premise of obtaining the development of the social subsystem and supporting subsystem, rural residents develop dominant dimensions, especially the natural subsystem, human subsystem and residential subsystem, which have a significant positive impact on rural human settlements. The balanced system combination is one of the main goals of rural human settlements.

5. Conclusions

Taking Tibet as the research area, this paper comprehensively evaluates the quality of rural human settlements from five aspects: natural subsystem, human subsystem, residential subsystem, social subsystem and supporting subsystem, and then discusses the influencing factors of rural human settlements on the Qinghai-Tibet Plateau. It enriches the evaluation index system of rural human settlements and provides new ideas for the governance of rural human settlements on the Qinghai-Tibet Plateau.

This paper makes two empirical contributions. On the one hand, the coordinated development of various systems is an important condition for the realization of rural human settlements and sustainable development. It is necessary to establish a whole concept. We will strengthen cooperation and governance in areas such as the ecological environment, housing construction, infrastructure, public services, and social networks. On the other hand, the human subsystem is the basis and key to affecting the quality of rural human settlements in Tibet. In promoting the development of rural human settlements, we should clarify the population distribution pattern, its influencing factors, and regional differences. The theoretical contribution of this paper is to provide theoretical reference and a decision-making basis for improving rural human settlements on the Qinghai-Tibet Plateau, enriching the perspective of rural regional human settlements research and expanding the rural human settlements evaluation index system. In addition, the research results can provide reference for rural areas in developing countries with similar natural conditions and human activity levels.

This study also has some deficiencies. Firstly, due to the availability of data, geographical factors are not considered in this paper. The evaluation indicators of human settlements quality need to be further improved. Secondly, the empirical data mainly come from statistical data, and the research data sources need to be further enriched. Lastly, the research object of this paper is only one city, but the characteristics of rural human settlements may vary from region to region on the Qinghai-Tibet Plateau. Future research should further consider a comparative analysis of multiple cities on the Qinghai-Tibet Plateau to explore the influences of five subsystems on the level of rural human settlement.

Based on the findings, it is recommended that the following policy measures should be taken to improve the human settlement of the Qinghai-Tibet Plateau. First, it is necessary to strengthen the top-level design of the human settlement improvement planning in farming and pastoral areas. Secondly, it is essential to improve and strengthen the construction of rural infrastructure, organically combine the rural revitalization with the improvement of the rural human settlement to further strengthen the construction of road transportation, water supplies, power supplies and logistics stations. Thirdly, the formulation of policies should adopt an inclusive approach, and emphasize the coordination and adaptation. The coordination of the five subsystems of the human settlement is crucial. Attention should be paid to the "bucket effect" of the relatively low-level subsystems. In recent years, the

process of urbanization and industrialization in Tibet has been accelerating. The scale of development has become larger, bringing enormous pressure to the natural environment of the Qinghai-Tibet Plateau. The self-regulation and repair abilities of the natural ecosystem in the Qinghai-Tibet Plateau are weak. After the ecological environment is damaged by humans, it is quite easy to cause the rapid deterioration of the ecological environment. Therefore, on the premise of protecting the Qinghai-Tibet Plateau's lucid waters and lush mountains, it is vital to improve the human settlement level and enhance the ability of the low-income population to resist risks.

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