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Urban Spatial Carrying Capacity and Sustainable Urbanization in the Middle-east Section of North Slope of Kunlun Mountains in Xinjiang, China

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Abstract: Urban spatial carrying capacity is the comprehensive support capacity of natural resources for urban development, which is of great significance in guaranteeing the sustainable urbanization. The middle-east section of North Slope of Kunlun Mountains in Xinjiang, China, is characterized by harsh climate and sparse population, whereas it is important for the initiative of the new Silk Road Belt because of its important location. Cities in this area have begun to take shape, and the implementation of the Silk Road Belt Initiative will inevitably stimulate the urbanization in this area. The extent to which the cities in this area will be supported by natural resources and how to fulfill the requirements of sustainable socioeconomic development needs to be investigated. In view of this, the present study evaluated the urban spatial carrying capacity and discussed feasible approaches that could support the sustainable urbanization in this area. The results show that 97.59% of the study area belongs to the low and relatively low levels of spatial carrying capacity for urban construction, and the area of medium, relatively high and high levels is 1.12×10^4 km^2, accounting for 2.41% of the total study area, mainly distributed in small clusters in the central alluvial fan oasis plains. Resource and environmental factors highly constrain urban construction, and low spatial matching of land and water resources, harsh climatic conditions and high risk of geological disasters are three major shortcomings. In addition, lagging transportation infrastructure construction and the resulting weak internal and external spatial connections also affect urban development. On this basis, the scientific arrangement of urban distribution, steady promotion of regional economic development based on local characteristics, further improvement of transportation infrastructure construction and strengthening the cooperation between the Xinjiang Production and Construction Corps and local governments are suitable approaches for sustainable urbanization in the study area.

Keywords: urban spatial carrying capacity; sustainable urbanization; development gap analysis; Kunlun Mountains

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1 Introduction

Urbanization is usually influenced by a combination of regional resource endowment, ecological environment, and industrial economy (Mega, 2000). Sustainable urbanization is the dynamic and balanced development of

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resource, environmental, and economic systems, resulting in a sustainable urban social system (Davidson et al., 2012; Huang et al., 2015). Urban spaces generally take industrial, mining and service production as their main functions, in which human activities are characterized by high density and concentrated resource consumption (Zhu et al., 2020). Therefore, in the process of forming sustainable urbanization, to achieve better economic location and obtain richer socioeconomic conditions, urban space is more obviously constrained by carrying factors such as natural resources, environmental capacity and natural disaster risk (Meng et al., 2020; Bahtebay et al., 2021).

The carrying capacity of resources and environment is the capacity of the natural environment to support human production and life under the combined effects of resources, environment conditions, disasters, and other factors, which can determine the sustainable development of the social economy (Fan, 2019). Its theoretical basis originates from demography and biology, which is believed that the land for food production, the resources available for exploitation, and the capacity of environment to treat pollution can not support the unlimited growth of social economy (Bentley, 1898; Park and Burgoss, 1921). From the research on land carrying capacity of 'how many people can be supported by land' carried out by the Food and Agriculture Organization (FAO) (Higgins et al., 1982), followed by research on the carrying capacity of resources such as water and mineral resources, and the carrying capacity of environment, to the Enhancement of Carrying Capacity Options (ECCO) model (Voigt et al., 2014) and the regional research based on ecological footprint (Rees, 2018), the research on the carrying capacity of resources and environment has gone through the process from a single factor to multiple factors.

Currently, global cities face the problem of city size exceeding the regional carrying capacity, which has aroused the attention of researchers and policymakers (Beaudoin et al., 2015). In the face of increasingly severe urban sprawl, air and water pollution, and other urban overloads, Oh et al. (2005) pioneered the establishment of a general framework for the evaluation of urban comprehensive carrying capacity based on corresponding investigations conducted in Seoul, South Korea. On this basis, the research on land carrying capacity (Smith et al., 2016), water resources carrying capacity (Ait-Aoudia and Berezowska-Azzag, 2016) and ecological carrying capacity (Daneshvar et al., 2017) in urbanized areas has also been carried out successively. In 2012, the 'Future Earth' framework was proposed to systematically solve global and regional sustainable development problems within natural carrying capacity (Future Earth, 2013). Subsequently, the natural carrying capacity has gradually evolved from a general method tool to a common decision-making tool for rational use and management of nature to achieve global and regional sustainable development (Salerno et al., 2013; United Nations, 2021). Generally, the carrying capacity of resources and environment is constrained by the different structures and functions of natural carrying elements, and it is also affected by human production and living activities of different scales and types. On the other hand, it shows a dynamic characteristic and has a good coupling with the regional sustainable process (Fan et al., 2017). This is of great significance for developing countries in the urbanization stage, especially for regions with strong resource and environmental constraints, such as arid zones (Giller et al., 2018; Du et al., 2021). Through the individual and integrated evaluation of various carrying factors, the basic pattern of development and protection in the process of urbanization can be clarified, which can provide scientific support for the sustainable urbanization.

The middle-east section of North Slope of Kunlun Mountains (NSKM) (i.e., the area from Ruoqiang County of Bayingol Mongolian Autonomous Prefecture to Qira County of Hotan Prefecture) is located in Xinjiang, China. The Taklimakan Desert and Tibetan Plateau lie in the northern and southern parts of the study area, respectively. As one of the important nodes of the Silk Road, the study area plays an irreplaceable role in safeguarding national security and opening up (Du, 2017). However, due to natural resource endowment and location conditions, the region has long been plagued by problems such as insufficient economic development momentum and lagging urbanization development. It has become a relatively underdeveloped region for socioeconomic development and urbanization in Xinjiang (Song and Yu, 2019; Du et al., 2021). Owing to the harsh natural conditions, fragile ecological environment and slow economic development, the adoption of traditional means of urbanization in this region will inevitably lead to environmental deterioration and, in turn, seriously threaten the future development. Therefore, from the perspective of sustainable urbanization, this study systematically analyzed the key factors that affected urban construction and development in the middle-east section of NSKM, evaluated the comprehensive supporting capacity of urbanization in this area based on the urban spatial carrying capacity evaluation model, determined the limiting factors and key problems faced by regional urban construction, and put forward relevant suggestions on the path of sustainable urbanization in the future. It is expected to provide guidance and a basis for the scientific layout of urban development in the middle-east section of NSKM and the realization of the goal of sustainable urbanization.

2 Materials and Methods

2.1 Study area

The study area is located in the middle-east section of NSKM (80.22°E–93.81°E, 35.23°N–41.36°N) (Fig. 1), including three counties of Qira, Yutian and Minfeng in Hotan Prefecture, and two counties of Qiemo and Ruoqiang in Bayingol Mongolian Autonomous Prefecture, with an area of 4.65 × 10^5 km^2, accounting for 27.91% of the total land area of Xinjiang. The terrain is high in the south and low in the north and the geomorphic types are mainly mountains, alluvial fan plains and desert gobi. The study area is sparsely populated, and the registered population in 2018 accounted for only 2.42% of Xinjiang. Socioeconomic development in the study area is also relatively backward. According to the statistics in the Xinjiang Statistical Yearbook (http://cnki.nbsti.net/CSYDMirror/trade/Yearbook/Single/N2020040352?z=Z018), except for Ruoqiang County, the per capita GDP of the study area has long been lower than the average level of Xinjiang, among which Yutian and Qira counties are even lower than 30%. In this context, urban development in the study area is relatively slow. In 2018, the ratio of urban population in the study area was only 30.35%, far less than 51% in Xinjiang. In addition, the remote location of the study area makes it relatively distant from the central cities, making it difficult to be influenced by the radiation of the central cities' development. Therefore, the harsh natural environment, remote geographical location, and backward socioeconomic development together make the study area a short board area of urbanization in Xinjiang.

2.2 Data sources

The data involved in this research include basic geographic data, climate observation data, hydrological and water quality data, geological disaster data, road distribution data and socioeconomic data. The basic geographic data include the administrative vector data and DEM, which were obtained from the National Earth System Science Data Center (http://www.geodata.cn/,

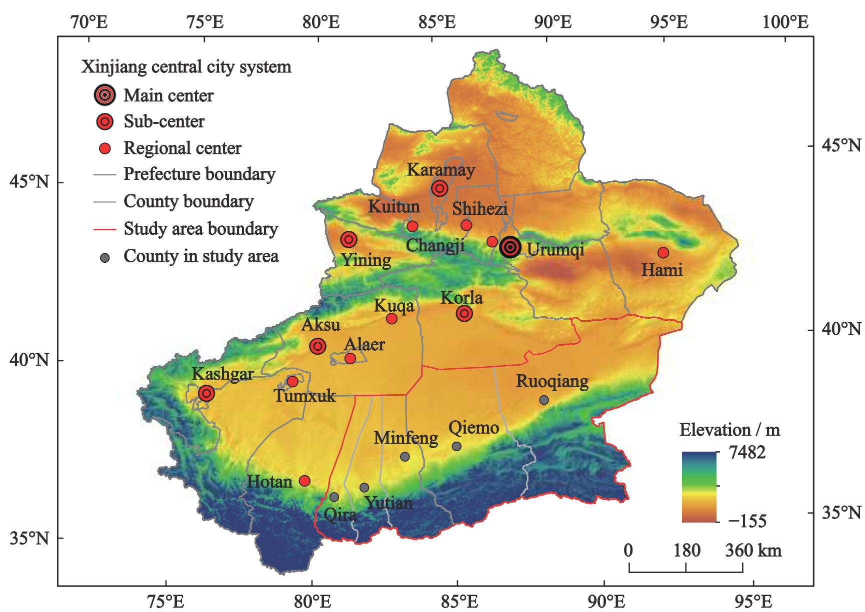

Fig. 1 Distribution of the Xinjiang central city system and location of the study area. The central city system is from 'Territorial spatial planning of Xinjiang Uygur Autonomous Region (2021–2035) (Exposure Draft)'

accessed on February 23, 2022) and National Aeronautics and Space Administration (NASA) Earth data (https://www.earthdata.nasa.gov/, accessed on July 16, 2018), respectively. Climate observations, including mean annual temperature (MAT), mean annual precipitation (MAP), mean annual humidity (MAH) and mean annual wind speed (MAWS), were downloaded from the China Meteorological Data Service Center (https://data.cma.cn/, accessed on June 13, 2022). The data on ecological service function and distribution of natural reserves were obtained from the Resource and Environmental Science and Data Center (https://www.resdc.cn/, accessed on May 20, 2022). Geological fault and disaster data were acquired from the Geological Cloud Data Center (https://geocloud.cgs.gov.cn/, accessed on May 3, 2022). Road data were downloaded from OpenStreetMap (https://www.openstreetmap.org, accessed on April 29, 2022). Hydrologic and water quality data (water quantity and quality) were obtained from regional census, and socioeconomic data were obtained from the Xinjiang Statistical Yearbook (http://cnki.nbsti.net/CSYDMirror/trade/Yearbook/Single/N2020040352?z=Z018) and China Statistical Yearbook (County-level) (http://cnki.nbsti.net/CSYDMirror/area/Yearbook/Single/N2022040099?z=D26). Missing data in some years were supplemented by interpolation. To facilitate spatial statistics, coordinate system transformation (unified to CGCS-2000 coordinate system) and spatial processing were performed for the collected data. Finally, all the data were resampled to resolution of 1 km × 1 km.

2.3 Evaluation index system of urban spatial carrying capacity

This study follows the following principles to build an evaluation index system: 1) select the main natural supporting factors for urban construction and development, including land resources, water resources, environmental conditions, and natural disasters, which were used to evaluate the suitability of construction, supply of water, capacity of environmental pollution, and possibility of geological disasters (Zhou et al., 2020). 2) Considering the important role of location conditions in urbanization, transportation dominance was added to comprehensively analyze the urban spatial carrying capacity (Gao et al, 2019). 3) Based on the current characteristics and future development of the study area, the evaluation system was determined at the county level (Table 1 for specific evaluation indicators and definitions).

2.4 Urban spatial carrying capacity evaluation

On the basis of reference to relevant research on resources and environment carrying capacity and urban sustainable development (Fan et al., 2017; Gao et al, 2019; Zhou et al., 2021), and in combination with the

Table 1 Evaluation index system of urban spatial carrying capacity in the middle-east section of North Slope of the Kunlun Mountains

Evaluation elements	Detailed indicators	Interpretation of indicators	References
Land resources	Terrain conditions	Suitability of land resources for urban construction, measured by terrain slope and elevation	Cheng et al., 2016
Water resources	Water resource abundance	The degree to which water resources can meet the needs of urban production and domestic use, measured by total water resources modulus	Liu et al., 2012
Environmental conditions	Atmospheric environmental capacity	Atmospheric capacity to hold pollutants, measured by average wind speed and static wind coefficient	Guo et al., 2018; Hasanah et al., 2020
	Water environmental capacity	Capacity of water to hold pollutants such as ammonia nitrogen and chemical oxygen demand, measured by amount of surface water resources and concentration of water pollutants	
	Climate suitability	Suitability of climatic conditions for human life, measured by temperature-humidity index	
Natural disasters	Seismic hazard	Risk level of seismic hazards, measured by distance from faults	Mejía-Navarro et al., 1994; Fedeski and Gwilliam, 2007
	Geological disaster susceptibility	The proneness of geohazard emergence, such as landslides, debris flows, and ground subsidence	
Location conditions	Transportation dominance	The proximity and convenience of transportation, measured by road network density and transportation accessibility	Ford et al., 2015

key problems and actual needs of urban construction and development in the middle-east section of NSKM, a research framework with 'individual evaluation-element integration-spatial composition' was established (Fig. 2). The specific steps were as follows:

Firstly, according to the evaluation index system, the individual evaluations of land resources, water resources, environmental conditions, natural disasters, and location conditions were carried out. In this way, the intrinsic characteristics and spatial distribution of various resources and environmental factors in the study area were understood, and the restrictive factors and key issues that affected regional urban construction and development were identified.

Subsequently, the integration evaluation was carried out based on the results of individual elements as follows. 1) Based on the terrain conditions and water resource abundance, the referential judgment matrix for water and land resources was constructed to obtain the primary classification category. 2) Considering water and atmospheric environmental capacity, the primary classification category was adjusted according to the following rule: if both the water and atmospheric environmental capacity were the lowest, the primary classification category was reduced by two levels, and if one of them was the lowest, the category was reduced by one level. The adjusted results were the preliminary evaluation result of urban spatial carrying capacity. 3) Furthermore, climate suitability, natural disasters and location conditions were considered to revise the preliminary evaluation result. The revision criteria were as follows: demote the preliminary level of evaluation units with poor climate suitability, high disaster risk or low transportation dominance, and promote the preliminary level of evaluation units with high transportation dominance. Based on this, an integrated evaluation result based on individual elements was formed, which was divided into five levels from low to high.

Thirdly, spatial composition was done in accordance with the principle of prioritizing the protection of important ecological space and cultivated land. The integrated evaluation results of important ecological spaces and cultivated land were downgraded to the relatively low level to protect these areas from urban development. The important ecological space was determined based on the ecosystem service functions and distribution of natural reserves, and the distribution of cultivated land was obtained through the classification of Landsat images in 2019. Based on the above process, the final urban spatial carrying capacity results were obtained.

2.5 Regional development gap analysis

In reference to the United Nations Sustainable Development Goals and relevant studies, and considering the urban development priorities and data availability in the study area, this study measured the socioeconomic development of the middle-east section of NSKM by comparing it with the gap between the study area and average level of Xinjiang. During the comparison, three dimensions, namely, economic development, income level, and employment status, were used as the compared parameters (Zhao et al., 2020; Fan et al., 2022). Among them, the per capita GDP was adopted for economic development. The annual disposable income of all residents, urban residents, and rural residents were adopted to represent the living standards of residents and urban-rural gaps in the region, and to indirectly re-

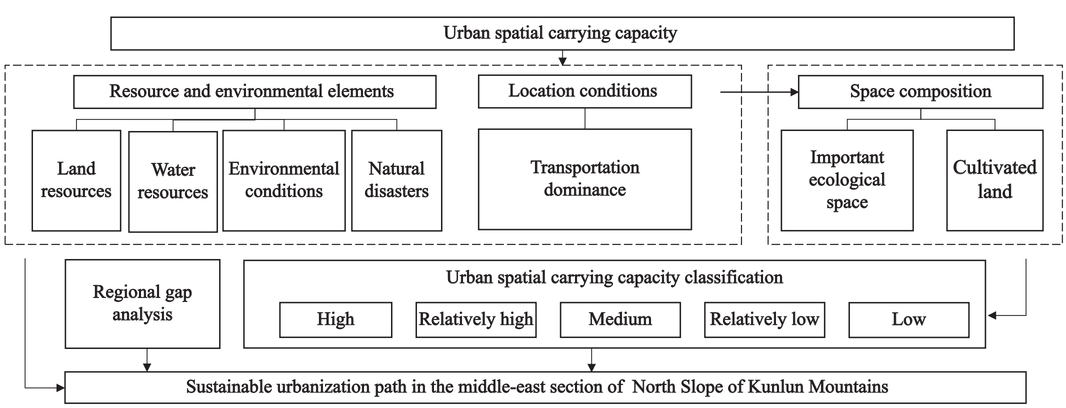

Fig. 2 Research framework of sustainable urbanization based on spatial carrying capacity

flect the regional economic development and prosperity. Employment status adopted two indicators (number of employees in the secondary and tertiary industries) to characterize the regional situation of ensuring employment and industrial development (Table 2).

3 Results

3.1 The endowment conditions of urban construction in the middle-east section of NSKM

The evaluation results of land and water resources show that, except for the middle alluvial fan and oasis plain, the matching degree of land and water resources in most study areas is low. The southern part of the study area is the Kunlun Mountains, with a large topographic relief and high altitude, where the construction conditions are poor. The altitude from the middle to the north is low, the terrain is flat, and the construction conditions gradually improve (Fig. 3a). The pattern of water resource abundance is contrary to terrain conditions. The MAP in the southern mountain area increases with elevation, and most of the rivers are distributed in the south, therefore, the water resources in southern part is better than northern part (Fig. 3b).

The assessment results show that the environmental capacity of water and atmosphere in the study area is high. The atmospheric environmental capacity increases from north to south, and low value areas are mainly distributed in the desert areas in the northwest (Fig. 3c). Influenced by the distribution of water resources, the water environment capacity presents a pattern of high in the south and low in the north. The water environment capacity level in the southeastern mountains and along the banks of major rivers is relatively high and that in the desert regions in the north is relatively low due to less surface water and groundwater resources (Fig. 3d). In terms of climate suitability, because the north is mostly desert area with dry climate and little rain, and the south is high altitude area with low temperatures year-round, the area with unsuitable climate conditions accounts for approximately 70% of the study area. The regions with suitable and acceptable climate conditions only accounts for 7.63% and 22.70% respectively, mainly distributed in the transition zone between mountains and deserts (Fig. 3e).

Natural disasters are unstable factors affecting urban construction. This study uses two indicators, namely, seismic hazard and geological disaster susceptibility to evaluate the risk of natural disasters. The results show that the overall natural disaster risk degree is relatively high in the study area, and 58.87% of the study area faces a higher or highest degree of natural disaster risk. Among these two risks, areas with relatively high seismic risk are widely distributed, extending from southwest to northeast in the study area (Fig. 3f). The areas of relatively higher geological hazard risk are mainly distributed in the central strip, which are areas with good water and land conditions and suitable climate conditions, posing a great threat to urban construction (Fig. 3g).

In addition to various natural factors, location conditions are also important for urban construction and development. Transportation dominance is used to measure the location conditions of the study area. The results show that the road accessibility in the study area is low, and the areas with medium and high accessibility only account for approximately 1% of the total study area, mainly distributed in the central oasis plain areas. In addition, accessibility in the western part of the study area is better than that in the eastern part (Fig. 3h).

3.2 Distribution pattern of urban spatial carrying capacity in the middle-east section of NSKM

The result of element integration comprehensively reflects the supporting capacity of various resource and environmental factors, and location conditions in the study area for urban construction and development (Fig. 4a).

Table 2 Indicators of regional development gap analysis

Dimension	Index	Connotation
Economic development	Per capita GDP	Represent the level of regional economic development
Income level	Annual disposable income of all residents, urban residents, and rural residents	Indicate the living standard of residents, while also reflecting the urban-rural gap
Employment status	Number of employees in the secondary and tertiary industries	Represent the state of regional employment, and indirectly reflect the regional industrial structure and development

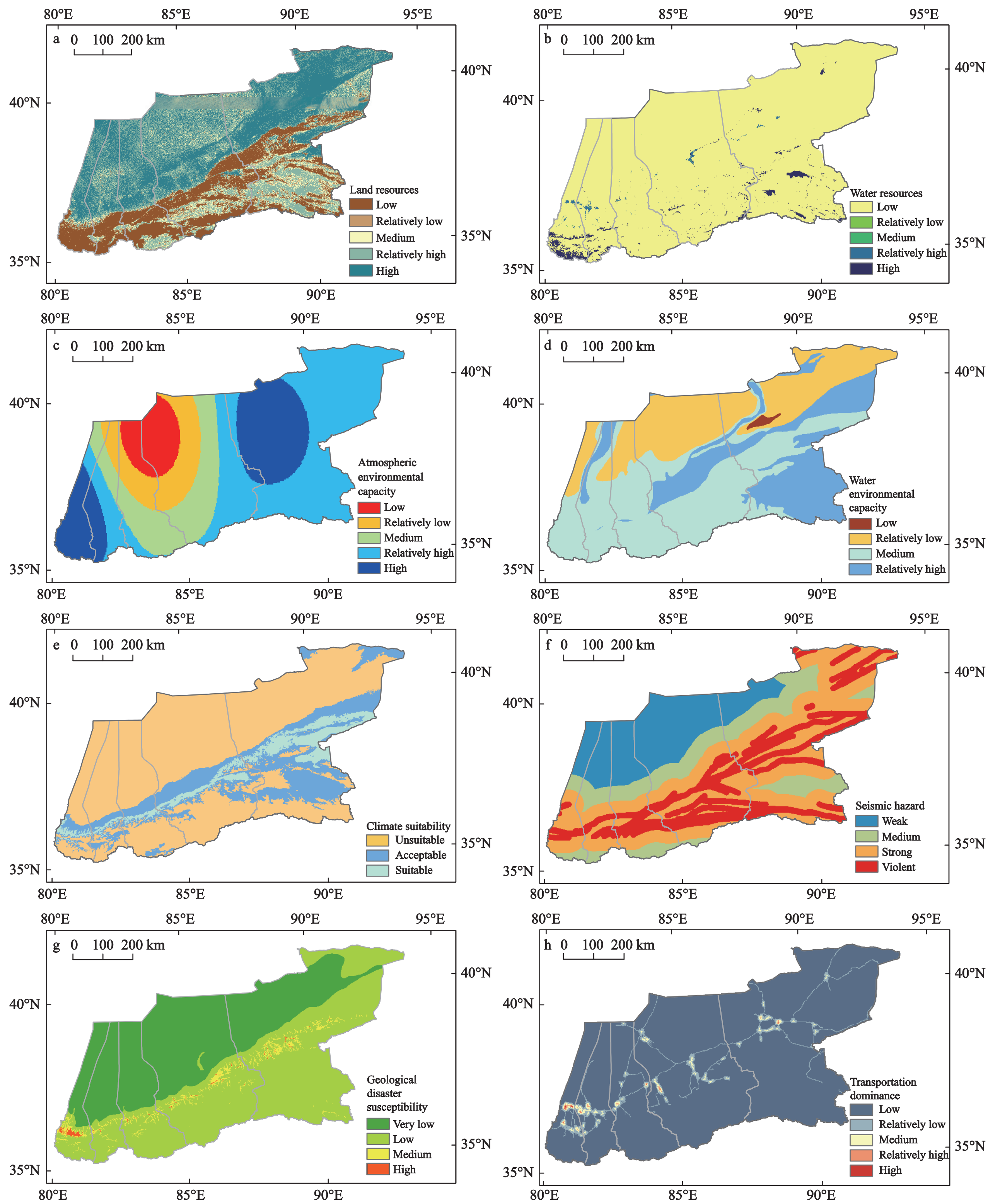

Fig. 3 Evaluation results of resource elements, environmental conditions, natural disasters, and location conditions in the middle-east section of NSKM. a to h are results for land resources (a), water resources (b), atmospheric environmental capacity (c), water environmental capacity (d), climate suitability (e), seismic hazard (f), geological disaster susceptibility (g), and transportation dominance (h), respectively

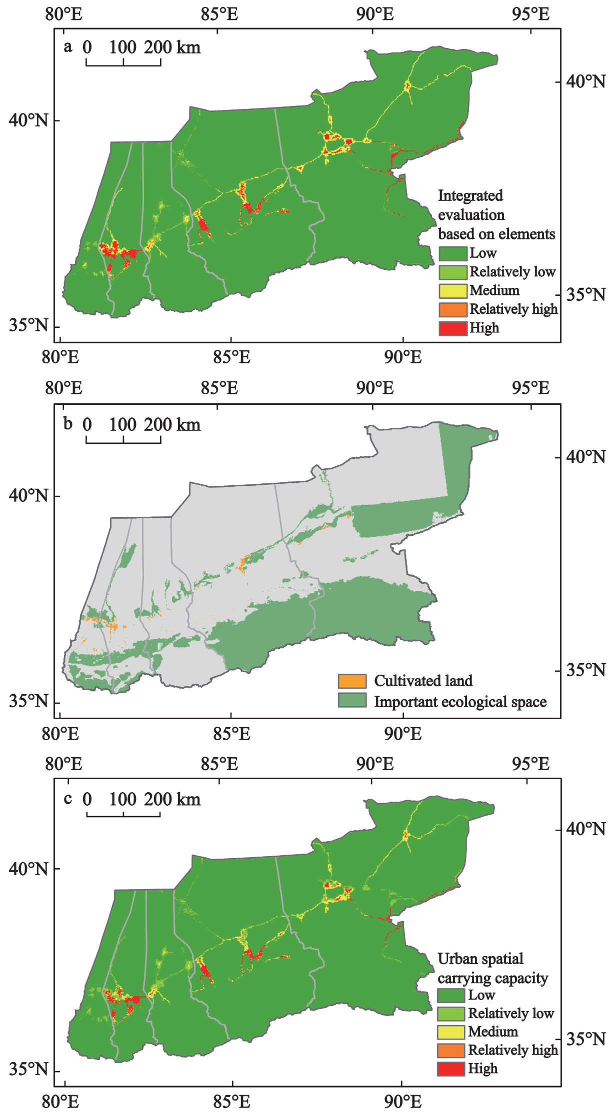

Fig. 4 Results of urban spatial carrying capacity evaluation in the middle-east section of NSKM. a to c are integrated result based on elements (a), important ecological space and existing cultivated land (b), and urban spatial carrying capacity (c), respectively

The result shows that the supporting capacity for urban construction is generally weak in the study area, and 96.61% of the study area is of low and relatively low levels. The areas of medium and higher levels only account for 3.39%, which are scattered in the transition zone between the southern mountain area and the northern desert, and mainly distributed in Ruoqiang, Qiemo and Yutian counties.

Fig. 4b shows the spatial patterns of cultivated land and important ecological spaces in the study area. There is 1767.87 km^2 of cultivated land in the study area, which is mainly distributed in the alluvial fan oasis plain in the middle part, of which 66.21% overlaps with the medium and higher grade of element integration result, and the overlapping area is mainly distributed in Yutian and Qiemo counties. The total area of important ecological space is 1.49×10^5 km^2, including biodiversity functional areas in northeastern Qiemo and southern Ruoqiang, wind prevention and sand fixation functional areas in the southern part of the Taklimakan Desert, and water and soil conservation functional areas and water source conservation functional areas across the southern part of Qira, Yutian and Minfeng counties (Fig. 4b). Spatial analysis reveals that 2.18% of the important ecological space overlaps with the regions of relatively higher integration levels, which are mainly distributed in the northeastern fringe of Ruoqiang County and scattered in Minfeng and Qiemo counties.

After spatial composition, the evaluation results of urban space carrying capacity in the study area are obtained (Fig. 4c, Table 3). The result shows that 95.78% of the study area belongs to the lowest level, and the natural conditions in these areas are relatively poor, which can not provide effective support for urban construction. The area of the relatively low level is 8394.69 km^2, accounting for 1.81% of the total study area, including areas with poor natural conditions and areas overlapping with important ecological space and cultivated land. Urban construction in these regions might threaten regional ecological security and food security and is not conducive to the long-term sustainable development of the region. The area of medium, relatively high, and high levels of carrying capacity is 11 205.50 km^2, accounting for 2.41% of the total study area. These areas have abundant water and land resources, a certain capacity for water and atmospheric pollutants, and climatic conditions that are suitable for human living. The risk of earthquake, geology and other disasters is low, and

Table 3 Urban spatial carrying capacity estimation result in the middle-east section of NSKM

Urban spatial carrying capacity	Area / km^2	Area ratio / %
Low	445067.59	95.78
Relatively low	8394.69	1.81
Medium	6465.17	1.39
Relatively high	193.75	0.04
High	4546.59	0.98
Total	464667.78	100

transportation dominance is relatively higher, which can effectively support urban construction and socioeconomic development, and will not affect regional ecological security and food security, of which can ensure the coordinated development of urban, agriculture and ecology within the region.

3.3 Regional development gap in the study area

The basic situation and main problems of socioeconomic development in the study area are analyzed from three dimensions: economic development, income level and employment status. The results show that there are significant spatial differences in socioeconomic development in the study area, mainly showing a spatial pattern of decrease from east to west. Taking Minfeng County in the middle as the boundary, Qiemo and Ruoqiang counties in the east have socioeconomic development level equal to or higher than the average levels of Xinjiang, but Yutian and Qira counties in the west have a relatively large gap from the average level of Xinjiang, and their economic development and living standard of residents are at a low level.

The per capita GDP is an important indicator of urban economic development. Fig. 5 shows the difference in economic development between the study area and Xinjiang from 2000 to 2018. In general, compared with the average value of Xinjiang, the economic development level of the study area is low, and the difference between the east and the west is large. The ratio of the per capita GDP of Qira and Yutian counties in the west to the average value of Xinjiang has remained between 0.20–0.25 for a long time. The per capita GDP of Minfeng and Qiemo counties is also lower than the average level of Xinjiang, but the gap has narrowed, especially in Minfeng County, the ratio has risen from 0.31 in 2000 to 0.65 in 2018. The economic development level of Ruoqiang County in the east is the highest. The per capita GDP exceeded the average value of Xinjiang and increased rapidly from 2005 to 2015, and decreased from 2015 to 2018.

Income is a key indicator of residents' living standards. Fig. 6 shows the change in the per capita disposable income of residents in Xinjiang and the five counties in the study area from 2011 to 2021. The income of residents in Qiemo and Ruoqiang counties in the east is significantly higher than the average level of Xinjiang. The absolute difference between the two counties and Xinjiang has been maintained at more than 7000 yuan (RMB), but the relative difference has narrowed year-by-year. The income level of residents in Yutian and Minfeng counties in the middle of the study area is at the same level as the average of Xinjiang, of which Yutian County is slightly higher than the average value of Xinjiang. The absolute and relative differences between Yutian County and Xinjiang are increasing, indicating that the living standards of residents in Yutian County are steadily improving. The income of residents in Minfeng County is slightly lower than the average of Xinjiang, and the income difference is relatively stable. The residents' income of Qira County in the west has always been at a low level, and the gap with the average of Xinjiang has increased.

Further comparison of urban and rural per capita disposable income shows that the ratio of urban to rural per capita disposable income in the study area is higher in the west than in the east (Table 4). Ruoqiang and Qiemo counties in the east have relatively stable urban-rural income ratios, which are significantly lower than the average level in Xinjiang, indicating that the urban-rural in-

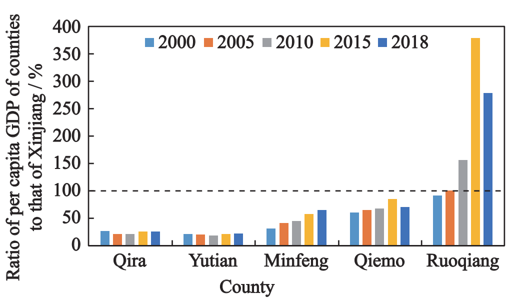

Fig. 5 Ratio of per capita GDP of five counties in the middle-east section of NSKM to that of Xinjiang from 2000 to 2018

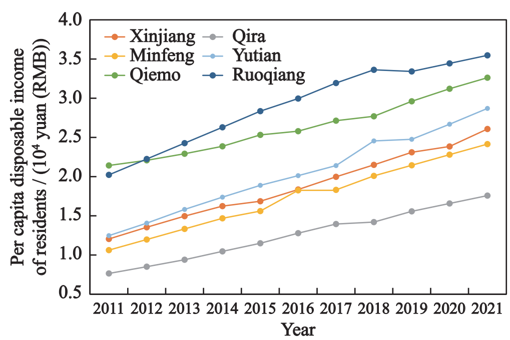

Fig. 6 Per capita disposable income of residents in Xinjiang and five counties of the middle-east section of NSKM during 2011–2021

Table 4 Ratio of urban and rural per capita disposable income in Xinjiang and five counties of the middle-east section of NSKM from 2011 to 2021

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Xinjiang	**2.81**	**2.77**	**2.69**	**2.66**	**2.79**	**2.80**	**2.79**	**2.74**	**2.64**	**2.48**	**2.42**
Qira County	4.45	4.15	3.94	3.75	3.61	3.48	3.39	3.66	3.58	3.56	3.55
Yutian County	4.06	3.81	3.64	3.49	3.50	3.15	3.15	3.20	3.39	3.33	3.12
Minfeng County	2.83	2.74	2.67	2.62	2.68	2.40	2.60	2.51	2.49	2.47	2.46
Ruoqiang County	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.10	1.10	1.16	1.20
Qiemo County	1.77	1.78	1.80	1.81	1.82	1.78	1.91	1.80	1.80	1.80	1.80

come of the two counties is relatively reasonable and stable. The urban-rural income ratio of Minfeng County is the same as Xinjiang and declined slightly in the past 11 years. The urban-rural income ratio of Qira and Yutian counties is significantly higher. Although the two counties show a downward trend and the gap between them and Xinjiang is narrowed, the income of urban residents is still more than three times that of rural residents, and the coordination between urban and rural areas needs to be improved.

Employment lays a solid foundation for livelihood security and economic development, especially for underdeveloped areas. It is also a key initiative to consolidate poverty alleviation and promote local urbanization. Table 5 shows the variation in employment in the secondary and tertiary industries in the five counties of the study area during 2013–2018. In general, the number of employees in the secondary and tertiary industries in the study area increased significantly. Except for Minfeng County, the number of employees in the secondary and tertiary industries in the remaining four counties in 2018 reached more than twice the number in 2013, with the highest being 2.84 times in Ruoqiang County. Since 2013, southern Xinjiang has vigorously promoted employment poverty alleviation by adopting various measures, such as nearby employment and transfer employment, which has not only effectively improved local people's lives but also further promoted industrial transformation and economic development in the study area (Pan, 2019; Wang and Li., 2022). However, constrained by low socioeconomic status, the development of non-agricultural industries still needs to be organized and promoted by the government, and the adjustment and optimization of the regional industrial structure must go through a long stage. Therefore, the overall employment structure in the study area is low and unstable. Taking the ratio of tertiary to secondary industry employees as an example, the ratio steadily increased from 2.0 to 3.3 for the whole Xinjiang during 2013–2018, while the ratio was around 1.0 for all five counties in the study area except for a few years.

Further comparing the distribution pattern of urban spatial carrying capacity and the current socioeconomic development of the five counties in the study area, a good correspondence can be found between the two. More than 70% of the urban spatial carrying capacity areas of medium and above levels are distributed in the eastern counties of Ruoqiang and Qiemo, accounting for 39.95% and 31.02%, respectively, while the western counties of Minfeng and Qira only account for 6.80%

Table 5 Number of employees in the secondary and tertiary industries in five counties of the middle-east section of NSKM from 2013 to 2018

County	2013			2016			2018		
	Secondary industries	Tertiary industries	Total	Secondary industries	Tertiary industries	Total	Secondary industries	Tertiary industries	Total
Qira	4621	4689	9310	5652	5775	11427	4411	20083	24494
Yutian	8016	3538	11554	7680	12010	19690	17609	7290	24899
Minfeng	1189	1544	2733	876	1303	2179	573	1281	1854
Qiemo	890	4840	5730	6875	7590	14465	5920	7421	13341
Ruoqiang	3011	2790	5801	9060	6940	16000	9043	7420	16463

and 0.13%, respectively. Correspondingly, socioeconomic development also shows a decreasing pattern from east to west in the study area. Ruoqiang County, located in the easternmost part of the study area, has the best socioeconomic development among the five counties, with per capita GDP reaching about three times the average level in Xinjiang in 2018. Minfeng and Qira, located in the west, have economic development, residents' income, and urbanization levels far below the average level of the autonomous region. The results of the carrying capacity evaluation show that the natural conditions in the study area are harsh and more than 97% of the area is not suitable for urban construction, so having certain amounts of areas with high carrying capacity levels becomes the basis for sustainable urbanization. Conversely, it is difficult to effectively support the development of local production and life activities.

4 Discussion

4.1 Constraints of natural conditions

The study area is located between the Kunlun Mountains and Taklimakan Desert and its natural environment is harsh. The evaluation results show that resource, environment, and location factors all have strong constraints on the urban spatial carrying capacity in the study area, but the impact of different factors is different. Among various factors, water and disasters have relatively stronger constraints on regional urban construction in the study area, as shown in this study. Similar results could be found elsewhere, in which the authors confirmed that efficient utilization of water resources might be the primary limiting factor for socioeconomic development in regions near our study area. As a result, the primary issue that needs to be considered is how to realize the efficient utilization of water resources for the sustainable development of urban areas in these regions (Fan et al., 2020). It should be noted that agricultural water use accounts for more than 90% of water consumption in Xinjiang (Zhang et al., 2019), therefore, optimizing agricultural water use efficiency and developing a method to efficiently utilize brackish water resources, which are widely distributed in our study area and are easily accessible, is of great significance to improve water resource utilization efficiency (Xiao et al., 2021) and ensure sustainable development of urban construction.

The low spatial matching of water and land resources is also an important factor that restricts the urban spatial carrying capacity of the study area. As a basic condition, urban construction requires relatively flat terrain and abundant water resources (Bahtebay et al., 2021; Yu et al., 2021). The lack of either of these two factors will lead to an increase in urban construction costs and pose a threat to the sustainable development of the city in the future. The distribution of water and land resources in the study area shows an obvious spatial mismatch. The land resource conditions in the north are better than those in the south, while the opposite is for water resource abundance. In the study area, the area with a mismatch of water and land resources accounts for more than 65% of the total area, mainly distributed in the desert area in the north and the valley in the south.

In addition, harsh climatic conditions and geological disasters are also the main limiting factors of urban spatial carrying capacity in the study area. A comfortable living environment is one of the basic conditions to ensure the long-term and stable development of a city (Lin et al., 2022). However, the desert climate in the north of the study area and the mountain climate in the south which are characterized by low temperatures, are not suitable for human life. The climatically unsuitable areas accounts for 69.67% of the total area. Only the central transition zone has an acceptable climate, and the area with suitable climate accounts for only 7.63%. Meanwhile, the results of disaster assessment show that 23.86% of the study area is high risk area, and most of them are distributed in areas with good water and land resources.

4.2 Current status of urban development in the study area

Affected by natural conditions, geographical location, and other factors, urbanization in the study area is relatively slow. In 2018, the urbanization rate in the study area was about 30%, only half of the national urbanization level (Guan et al., 2018). Based on the regional development gap assessment and relevant literature analysis, the low economic development level, lagging infrastructure construction, and unbalanced regional development are the main factors that restrict the urbanization process in the study area.

Economic development is the main driver of urbanization. Relevant research show that when the per capita

GDP is less than 8000 US dollars, the urbanization rate will increase significantly with an increase in per capita GDP (Deng et al., 2013; Du et al., 2021). The long-term low economic development in the study area makes it difficult to effectively support the healthy development of regional urbanization. Except for Ruoqiang County, the economic development and industrial scale of other counties are in the bottom position in Xinjiang, characterized by weak aggregation, low level, and slow growth (Wang et al., 2020). The imbalance in industrial structure is a prominent problem in the economic development of the study area (Ouyang et al., 2021). In 2020, the proportion of primary industries in the study area reached 25%, which was significantly higher than the level of 14% in Xinjiang. Meanwhile, the development of secondary industry is seriously lagging, and the proportion of secondary industries in the study area is below 15%, except in Ruoqiang County. The results of the employment analysis also show that the economy of the study area is still in the stage of adjustment and optimization, and is mainly driven by the government, while the region itself has not yet formed a stable and coordinated economic development model, and the intrinsic motivation of urbanization development is insufficient.

Second, the relatively lagging transportation infrastructure construction is another limiting factor of urbanization in the study area. As an important infrastructure to promote urban development, the layout of transportation facilities has a significant impact on the spatial distribution of population and economic activities (Yu et al., 2013; Yin et al., 2016). Because of the special physical geography, the urbanization in Xinjiang is particularly affected by transportation conditions (Yang et al., 2017). The location of the study area is relatively independent and far from the neighboring cities, and thus transportation infrastructure construction is relatively lagging behind. The hierarchical structure of the road network is defective, mainly in low-grade and rural roads, and the proportion of high-grade roads is low. Taking Qira and Yutian counties as examples, the proportion of tertiary highways and above was only about 10% in 2017. The shortage of major transportation channels has made the spatial connection between the study area and surrounding cities relatively weak, making it difficult to be radiated by the development of the surrounding cities. In addition, the internal transportation links in the study area also need to be strengthened. Relevant studies show that the urban and rural passenger transportation services in the study area are still at a low level, which not only reduces the city's ability to attract population and economy but also restricts the links between counties and towns in the study area (Li, 2021).

Moreover, the socioeconomic development of these counties in the study area is significantly different, and the level of regional coordinated development is low. The economic development and income level of Ruoqiang and Qiemo counties in the east are better than those of the other three counties, and this advantage has been maintained for a long time. Under the influence of the relatively backward transportation infrastructure, resources continue to concentrate in the relatively advantageous areas (Qiemo and Ruoqiang counties), and finally form a Mathew effect in our study area (Fan and Guo, 2015).

4.3 Policy suggestions on sustainable urbanization

First, based on the urban spatial carrying capacity, the regional urban distribution should be scientifically arranged. The natural conditions in the study area are poor and the ecological environment is fragile. Unreasonable urban construction will lead to the deterioration of the regional ecological environment, thereby threatening the sustainability of the city itself. Therefore, it is necessary to consider the urban carrying capacity evaluated in this study and control the extent of urban development and construction activities.

Second, regional economic development has been steadily promoted based on local characteristics. Due to the coupling of urbanization and economic development, economic development in the study area will be the main driving force of urbanization in the future. In view of the weak economic foundation, insufficient investment, small market scale and other problems, it is necessary to closely combine the local industrial layout with the advantages of natural and social resources and actively develop featured agriculture, folk tourism, cultural industries, *etc*. Meanwhile, the study area should promote industrial transformation and upgrading, and steadily improve the regional economic level.

Third, it will further improve transportation infrastructure construction and optimize the urban development environment. Strengthening the construction of major traffic arteries in the region will effectively improve the connectivity between the region and surrounding areas. And the layout, density, and grade of branch roads should be optimized to strengthen the spatial connections within the study area.

Fourth, strengthen the cooperation between the Xinjiang Production and Construction Corps (XPCC) and local governments and promote the construction of XPCC cities in the study area. Promote the level of joint construction and sharing of infrastructure between the XPCC and local governments; realize the interconnection of railway, highway, aviation, and other transportation forms; and jointly build and use high-quality public services such as education, medical care, and elderly care. Strengthen cooperation in industrial transformation and upgrading, ecological environment protection and other aspects and promote the formation of a spatial economic pattern with complementary advantages between the XPCC and local governments.

5 Conclusions

There is a systematic coupling between resources and environment carrying capacity and regional sustainability, which makes carrying capacity a scientific decision-making tool to solve regional sustainable development problems. As a key area for coordinated development in Xinjiang, the study area has an urgent internal demand to promote rapid urbanization. However, the harsh and fragile ecological environment and relatively weak development foundation in this area make it difficult to realize traditional urbanization procedures. In view of this problem, this study constructs an evaluation framework of urban spatial carrying capacity to systematically analyze the comprehensive supporting capacity of natural conditions in the study area for urban construction. Based on the evaluation results, we investigate the limiting factors and key issues affecting sustainable urbanization in the region. The main conclusions are as follows:

(1) In general, the natural conditions in the study area are very harsh. The mismatch of water and land resources, relatively unsuitable climate conditions, and high level of seismic hazard pose strong constraints on urban construction in the study area. At the same time, limited by the relatively lagging transportation infrastructure construction, the external and internal spatial connections of the study aera are weak, which is not conducive to the flow and aggregation of population, industries, and other resources, and has a certain negative impact on the development of urbanization.

(2) The evaluation results of urban spatial carrying capacity show that 95.78% and 1.81% of the study area belongs to low and relatively low level, and the areas of the medium, relatively high and high level account for 1.39%, 0.04% and 0.98%, respectively. Areas with medium and above levels are mainly distributed in small clusters in the central alluvial fan oasis plains. The distribution pattern of urban spatial carrying capacity has a strong spatial correlation with the restrictive conditions of resources and environment.

(3) The main characteristics of socioeconomic development in the study area were analyzed based on the three dimensions of economic development, income level, and employment status. It is found that the overall level of socioeconomic development in the study area is low, and the spatial divergence is obvious, showing a development pattern of decreasing characteristics from east to west. Further comparison of the distribution pattern of urban spatial carrying capacity and socioeconomic development in the study area reveals a good correspondence between the two.

(4) Based on the comprehensive evaluation and analysis results, we propose policy recommendations for sustainable urbanization in the study area from four aspects, including scientific urban spatial layout, characteristic industrial development, transportation infrastructure improvement, and strengthening cooperation between the XPCC and local governments.

References

Ait-Aoudia M N, Berezowska-Azzag E, 2016. Water resources carrying capacity assessment: the case of Algeria's capital city. *Habitat International*, 58: 51–58. doi: 10.1016/j.habitatint.2016.09.006

Bahtebay J, Zhang F, Ariken M et al., 2021. Evaluation of the coordinated development of urbanization-resources-environment from the incremental perspective of Xinjiang, China. *Journal of Cleaner Production*, 325: 129309. doi: 10.1016/j.jclepro.2021.129309

Beaudoin J, Farzin Y H, Lawell C Y C L, 2015. Public transit investment and sustainable transportation: a review of studies of transit's impact on traffic congestion and air quality. *Research in Transportation Economics*, 52: 15–22. doi: 10.1016/j.retrec.2015.10.004

Bentley H L, 1898. *Cattle Ranges of the Southwest: A History of the Exhaustion of the Pasturage and Suggestions for Its Restor-*

ation. Washington DC: US Government Printing Office.

Cheng Jingyao, Zhou Kan, Chen Dong et al., 2016. Evaluation and analysis of provincial differences in resources and environment carrying capacity in China. *Chinese Geographical Science*, 26(4): 539–549. doi: 10.1007/s11769-015-0794-6

Daneshvar M R M, Khatami F, Zahed F, 2017. Ecological carrying capacity of public green spaces as a sustainability index of urban population: a case study of Mashhad city in Iran. *Modeling Earth Systems and Environment*, 3(3): 1161–1170. doi: 10.1007/s40808-017-0364-2

Davidson K M, Kellett J, Wilson L et al., 2012. Assessing urban sustainability from a social democratic perspective: a thematic approach. *Local Environment*, 17(1): 57–73. doi: 10.1080/13549839.2011.631990

Deng Xiangzheng, Zhong Haiyue, Bai Xuemei et al., 2013. Path of sustainable urbanization in western China. *China Population, Resources and Environment*, 23(10): 24–30. (in Chinese)

Du Hongru, Tang Yuting, Zhang Ziyun, 2021. Regional characteristics and high-quality development path of urbanization in arid region of Xinjiang. *Economic Geography*, 41(10): 200–206. (in Chinese)

Du Zheyuan, 2017. 'The Belt and Road' and new geo-strategic value of Xinjiang. *World Regional Studies*, 26(5): 32–43. (in Chinese)

Fan Jie, Guo Rui, 2015. Discussing some core issues of innovated regional governance system oriented to the thirteenth national five-year plan period. *Economic Geography*, 35(1): 1–6. (in Chinese)

Fan J, Wang Y F, Ouyang Z Y et al., 2017. Risk forewarning of regional development sustainability based on a natural resources and environmental carrying index in China. *Earth's Future*, 5(2): 196–213. doi: 10.1002/2016EF000490

Fan Jie, 2019. Spatial organization pathway for territorial function-structure: discussion on implementation of major function zoning strategy in territorial spatial planning. *Geographical Research*, 38(10): 2373–2387. (in Chinese)

Fan Jie, Zhao Hao, Guo Rui, 2022. The new trend and coping strategies of regional development gap in China. *Economic Geography*, 42(1): 1–11. (in Chinese)

Fan M T, Xu J H, Chen Y N et al., 2020. How to sustainably use water resources—A case study for decision support on the water utilization of Xinjiang, China. *Water*, 12(12): 3564. doi: 10.3390/w12123564

Fedeski M, Gwilliam J, 2007. Urban sustainability in the presence of flood and geological hazards: the development of a GIS-based vulnerability and risk assessment methodology. *Landscape and Urban Planning*, 83(1): 50–61. doi: 10.1016/j.landurbplan.2007.05.012

Ford A C, Barr S L, Dawson R J et al., 2015. Transport accessibility analysis using GIS: assessing sustainable transport in London. *ISPRS International Journal of Geo-Information*, 4(1): 124–149. doi: 10.3390/ijgi4010124

Future Earth, 2013. Future earth initial design. In: *Report of the Transition Team*. International Council for Science. https://council.science/wp-content/uploads/2020/06/Future-Earth-Initial-Design-Report.pdf.

Gao Xiaolu, Wu Danxian, Zhou Kan et al., 2019. The urban space and urban development boundary under the framework of territory spatial planning. *Geographical Research*, 38(10): 2458–2472. (in Chinese)

Giller K E, Drupady I M, Fontana L B et al., 2018. Editorial overview: the SDGs-aspirations or inspirations for global sustainability. *Current Opinion in Environmental Sustainability*, 34: A1–A2. doi: 10.1016/j.cosust.2019.02.002

Guan X L, Wei H K, Lu S S et al., 2018. Assessment on the urbanization strategy in China: achievements, challenges and reflections. *Habitat International*, 71: 97–109. doi: 10.1016/j.habitatint.2017.11.009

Guo Q, Wang J Y, Yin H L et al., 2018. A comprehensive evaluation model of regional atmospheric environment carrying capacity: model development and a case study in China. *Ecological Indicators*, 91: 259–267. doi: 10.1016/j.ecolind.2018.03.059

Hasanah N A I, Maryetnowati D, Edelweis F N et al., 2020. The climate comfort assessment for tourism purposes in Borobudur Temple Indonesia. *Heliyon*, 6(12): e05828. doi: 10.1016/j.heliyon.2020.e05828

Higgins G M, Kassam A H, Naiken L et al., 1982. *Potential population supporting capacities of lands in the developing world*. Food and Agriculture Organization. https://digitallibrary.un.org/record/53564

Huang L, Wu J G, Yan L J, 2015. Defining and measuring urban sustainability: a review of indicators. *Landscape Ecology*, 30(7): 1175–1193. doi: 10.1007/s10980-015-0208-2

Li Jianli, 2021. *Study on the Development Level of the Integration of Urban and Rural Passenger Transport at County Level – A Case Study of Four Prefectures in Southern Xinjiang*. Urumqi: Xinjiang Agricultural University. (in Chinese)

Lin Y M, Zhu F X, Li W J et al., 2022. Assessment of climate suitability for human settlements in Tibet, China. *Journal of Resources and Ecology*, 13(5): 880–887. doi: 10.5814/j.issn.1674-764x.2022.05.012

Liu J J, Dong S C, Mao Q L, 2012. Comprehensive evaluation of the water resource carrying capacity for China. *Geography and Natural Resources*, 33(1): 92–99. doi: 10.1134/S1875372812010155

Mega V, 2000. Cities inventing the civilisation of sustainability: an odyssey in the urban archipelago of the European Union. *Cities*, 17(3): 227–236. doi: 10.1016/S0264-2751(00)00015-9

Mejía-Navarro M, Wohl E E, Oaks S D, 1994. Geological hazards, vulnerability, and risk assessment using GIS: model for Glenwood Springs, Colorado. *Geomorphology*, 10(1–4): 331–354. doi: 10.1016/0169-555X(94)90024-8

Meng C H, Du X Y, Ren Y T et al., 2020. Sustainable urban development: an examination of literature evolution on urban carrying capacity in the Chinese context. *Journal of Cleaner Production*, 277: 122802. doi: 10.1016/j.jclepro.2020.122802

Oh K, Jeong Y, Lee D et al., 2005. Determining development density using the urban carrying capacity assessment system. *Landscape and Urban Planning*, 73(1): 1–15. doi: 10.1016/j.landurbplan.2004.06.002

Ouyang Jinqiong, Zhou Chuanrong, Li Wenyao, 2021. Industrial upgrading, urbanization and population agglomeration in South Xinjiang: based on county statistics and SDEM models. *Northwest Population Journal*, 42(3): 117–126. (in Chinese)

Pan Hao, 2019. Problems and countermeasures of poverty alleviation by employment in four prefectures in Southern Xinjiang. *Tribune of Social Sciences in Xinjiang*, (2): 30–35. (in Chinese)

Park R F, Burgess E W, 1921. *Introduction to the Science of Society*. Chicago: The University of Chicago Press.

Rees W E, 2018. Ecological footprints and appropriated carrying capacity: what urban economics leaves out. In: Cecilia T (eds.). *The Earthscan Reader in Rural –Urban Linkages*, London: Routledge: 285–297.

Salerno F, Viviano G, Manfredi E C et al., 2013. Multiple carrying capacities from a management-oriented perspective to operationalize sustainable tourism in protected areas. *Journal of Environmental Management*, 128: 116–125. doi: 10.1016/j.jenvman.2013.04.043

Smith P, House J I, Bustamante M et al., 2016. Global change pressures on soils from land use and management. *Global Change Biology*, 22(3): 1008–1028. doi: 10.1111/gcb.13068

Song Zhouying, Yu Yang, 2019. Urbanization sustainable development trend of urbanization in the border areas of China. *Economic Geography*, 39(5): 55–64. (in Chinese)

United Nations, 2021. *The Sustainable Development Goals Report 2021*. New York: United Nations. https://digitallibrary.un.org/record/3932350

Voigt S, De Cian E, Schymura M et al., 2014. Energy intensity developments in 40 major economies: structural change or technology improvement? *Energy Economics*, 41: 47–62. doi: 10.1016/j.eneco.2013.10.015

Wang Xiangdong, Wang Kanglong, Shan Na'na et al., 2020. Comprehensive development regionalization of territorial space in Xinjiang Uygur Autonomous Region under the background of territorial spatial planning. *Economic Geography*, 40(11): 176–185. (in Chinese)

Wang Zhuo, Li Menghe, 2022. Effect of rural women's nearby employment in South Xinjiang from the perspective of feasible ability. *Journal of Xinjiang University (Philosophy and Social Sciences)*, 50(5): 79–86. (in Chinese)

Xiao C, Li M, Fan J L et al., 2021. Salt leaching with brackish water during growing season improves cotton growth and productivity, water use efficiency and soil sustainability in southern Xinjiang. *Water*, 13(18): 2602. doi: 10.3390/w13182602

Yang Zhen, Lei Jun, Cheng Longying et al., 2017. Comprehensive measurement and spatial differentiation pattern analysis of the county urbanization in Xinjiang. *Arid Land Geography*, 40(1): 230–237. (in Chinese)

Yin Jiangbin, Huang Xiaoyan, Hong Guozhi et al., 2016. The effect of transport accessibility on urban growth convergence in China: a spatial econometric analysis. *Acta Gepgraphica Sinica*, 71(10): 1767–1783. (in Chinese)

Yu Haozhe, Li Lijuan, Li Jiuyi, 2021. Construction of risk assessment model of water resources carrying capacity in Beijing-Tianjin-Hebei region. *Geographical Research*, 40(9): 2623–2637. (in Chinese)

Yu N N, De Jong M, Storm S et al., 2013. Spatial spillover effects of transport infrastructure: evidence from Chinese regions. *Journal of Transport Geography*, 28: 56–66. doi: 10.1016/j.jtrangeo.2012.10.009

Zhang G Q, Shen D P, Ming B et al., 2019. Using irrigation intervals to optimize water-use efficiency and maize yield in Xinjiang, northwest China. *The Crop Journal*, 7(3): 322–334. doi: 10.1016/j.cj.2018.10.008

Zhao Y N, Chen D, Fan J, 2020. Sustainable development problems and countermeasures: a case study of the Qinghai-Tibet Plateau. *Geography and Sustainability*, 1(4): 275–283. doi: 10.1016/j.geosus.2020.11.002

Zhou Daojing, Xu Yong, Wang Yafei et al., 2020. Methodology and role of 'double evaluation' in optimization of spatial development pattern. *Bulletin of Chinese Academy of Sciences*, 35(7): 814–824. (in Chinese)

Zhou Kan, Li Jiuyi, Wang Qiang, 2021. Evaluation on agricultural production space and layout optimization based on resources and environmental carrying capacity: a case study of Fujian Province. *Scientia Geographica Sinica*, 41(2): 280–289. (in Chinese)

Zhu Xiaodan, Ye Chao, Li Simeng, 2020. Research progress of sustainable cities and its implications for national territory spatial plan. *Journal of Natural Resources*, 35(9): 2120–2133. (in Chinese). doi: 10.31497/zrzyxb.20200907