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Characteristics of Changes in Urban Land Use and Efficiency Evaluation in the Qinghai–Tibet Plateau from 1990 to 2020

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Abstract: The Qinghai–Tibet Plateau has seen decades of changes in land use/cover as a result of urbanization and regional planning policy. Research on the efficiency of social development aids in the pursuit of social and environmental sustainability. Based on CLUD and socioeconomic statistical data, this study systematically analyses the spatiotemporal evolution characteristics of urban land use in the Qinghai–Tibet Plateau and evaluates its social development efficiency from three perspectives—the holistic, the municipal, and urban hierarchy—by using indicators such as the Moran index, land use efficiency, and urban expansion speed and proportion. Results show that the urbanization rate climbed from 21.26% to 54.95%, and the area of urban lands increased from 201.93 km^2 to 796.59 km^2 from 1990 to 2020, with urban lands expanding from the Lanzhou–Xining City Area to the central and south of the Qinghai–Tibet Plateau. The holistic urban land use efficiency grew from 1.14 to 1.53, while the UPD decreased slightly from 1.44 to 1.31, and the UED increased steadily from 1.40 to 12.97 per decade. Moreover, we should pay attention to the rational allocation of land in human, social and ecosystem terms to comprehensively improve the quality of urbanization across the plateau.

Keywords: Qinghai–Tibet Plateau; urbanization; land use; spatiotemporal evolution; efficiency

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1. Introduction

Globalization and rapid socioeconomic development have led to an epoch of rapid urban development in China. According to statistics, the urban population is growing at a rate of 1% per year across China, implying that by 2050, the country will have attained an urbanization level of approximate 80–90% if this pace continues [1]. Accelerated urbanization impacts cities with various population sizes and socioeconomic development levels. Uneven and unbalanced urbanization is widespread among large, medium and small cities, as well as the eastern, central and western regions [2], particularly in the western.

Located in the first step of China, the Qinghai–Tibet Plateau is well-known for its complex and diverse landform types. Influenced by natural resources and economic development level, the urbanization process and land demand differ significantly among cities, prefectures and regions in the Qinghai–Tibet Plateau. Since the implementation of The Great Western Development Program, there has been a migration of people from eastern coastal areas to central or western regions and an influx of people from western rural areas to cities, resulting in a series of changes in the spatial structure of urban land and the economic activities of residents in the Qinghai–Tibet Plateau [3]. In particular, the construction of highway infrastructure such as the Qinghai–Tibet Railway in 2006 and the Lanzhou–Wulumuqi High-Speed Railway in 2014 has not only accelerated the transfer of land use types along the route [4], but also had a huge boosting effect on the economic development and industrial upgrading in cities along Qinghai, Tibet and Xinjiang

provinces [5,6]. As "the counterpart support", the herdsmen settlement project, targeted measures in poverty alleviation, and the "Belt and Road", etc., have been implemented one by one, cities of different hierarchies in the Qinghai–Tibet Plateau have focused on developing new energy, green food and other ecological industries, bolstering green growth of the industrial economy and promoting the coupling and coordinating development of urbanization and the ecological environment [7,8]. Hence, to investigate the spatiotemporal evolution of urban land in the Qinghai–Tibet Plateau is of great significance to advance holistic land consolidation, optimize the plateau urban pattern, and contribute to social development in a harmonious and robust manner.

As an essential indicator to measure the degree of urbanization, urban land use is often manifested as a transfer from natural land including vegetation and soil cover types to artificial land such as buildings, squares and highways to accommodate the growing population, with the expansion of built-up area, the increase of output in tertiary industry and the decline of ecosystem service functions [9]. Existing research on urban land in the Qinghai–Tibet Plateau focuses on the spatial and temporal characteristics of land use/cover changes [10], driving forces [11] and impacts on the eco-environment [12]. Related research also tends to concentrate on key areas, such as the Yellow River basin [13], Tibet Autonomous Region [14], the Huangshui River valley [15], etc., or on monitoring the elemental content changes in the region [16,17]. Less attention has been paid to the land, population, economy and evaluation of urbanization efficiency in urban lands of the Qinghai–Tibet Plateau as a whole. Whereas the Qinghai–Tibet Plateau is fragile, vulnerable and highly sensitive to external interference [18], there is an urgent need to clarify the spatiotemporal changes in land use, population density and economic level caused by urbanization to reduce uncertainty about future changes in the ecological environment of the Qinghai–Tibet Plateau [19].

Cities are hubs of population agglomeration and economic development. Urban population, as a criterion for classifying urban hierarchy and as a main index for anticipating urban development [20], is commonly used to evaluate production force and efficiency of cities [21]. The level of urban economic development is also often applied as an evaluation factor for changes in the size and structure of cities [22]. Generally speaking, as the urban population grows, so does the demand for urban land and the burden of social construction [23], and more urban land space is needed to accommodate the growing social and economic activities of urban residents. As a result, urban development continues to deepen in tandem with the expansion of urban land and the optimization of urban structures. Meanwhile, urbanization actually raises the living standards of people. For instance, there have been numerous infrastructure projects built, including water conservation and electric power projects, as well as airport reconstruction projects. One after the other, financial subsidy policies with high pertinence, broad coverage and a large number of beneficiaries have been introduced. In comparison to 1990, the regional GDP has increased by more than CNY 4 trillion, a 35-fold increase. All in all, the positive impact of urbanization cannot be ignored.

In light of the foregoing, this study utilizes the Moran index, land use efficiency, urban expansion speed and proportion to investigate the spatiotemporal evolution characteristics of urban land use in the Qinghai–Tibet Plateau from 1990 based on China Land Use/Cover Dataset (CLUD). The benefits of urbanization are then evaluated using indexes such as urban population density, urban economic density and their change amounts, according to the socioeconomic statistical data and the status of urbanization activities in the Qinghai–Tibet Plateau. This study provides a scientific foundation for land management and renovation, the formulation of ecological protection plans and the sustainable development of human–land relationship in the Qinghai–Tibet Plateau.

2. Materials and Methods

2.1. Study Area

The Qinghai–Tibet Plateau is an important ecological shield to maintain climate stability in China and around the world. According to existing studies [24], the Qinghai–Tibet Plateau in China is taken as the study area (Figure 1), with an area of about 2,581,300 km^2 and an average altitude of about 4400 m, accounting for 83.7% of the total area of the plateau. Located in an alpine climate zone, the climate there is mild and humid in summer, cold and dry in winter, with large temperature differences and intense solar radiation. Because of the extremely fragile and sensitive ecosystem, the Qinghai–Tibet Plateau is suffering from myriad environmental issues such as freeze–thaw erosion, hydraulic erosion, wind erosion and soil salinization.

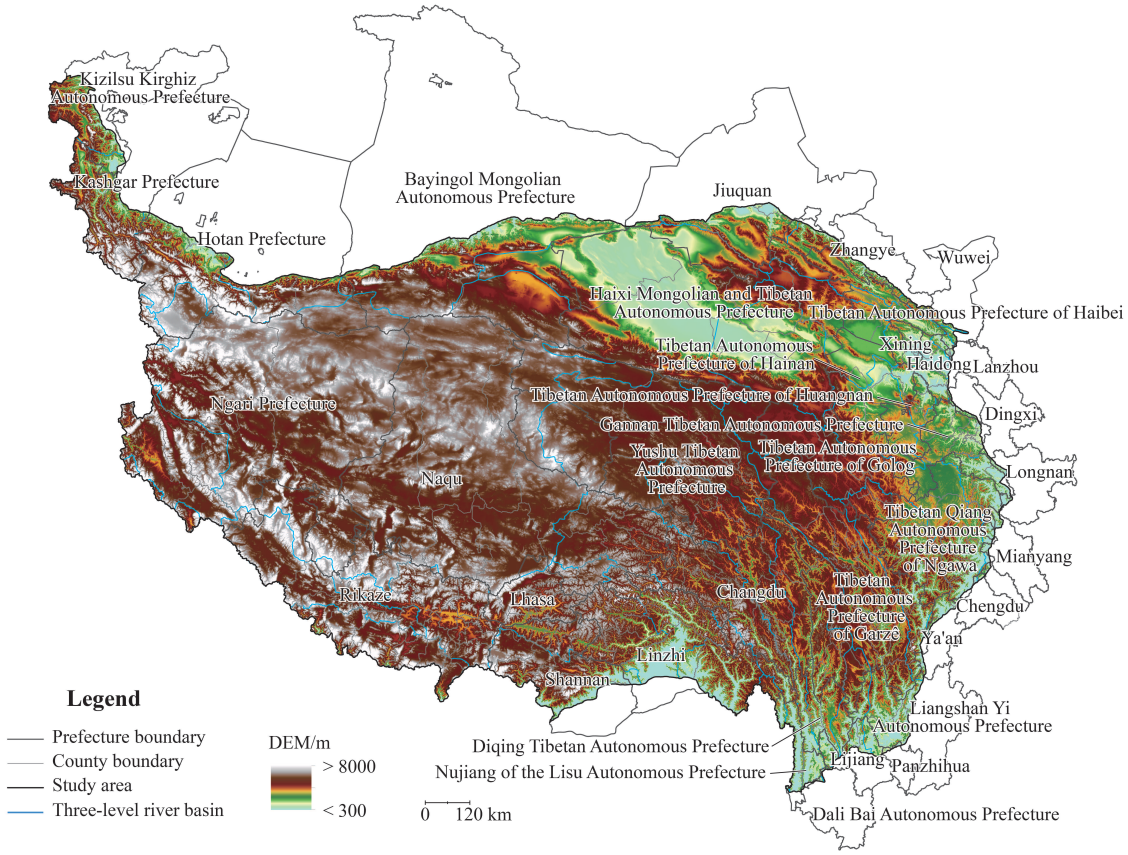

Figure 1. Study area.

The study area spans six provinces of Tibet, Qinghai, Gansu, Sichuan, Yunnan and Xinjiang, and the land use/cover types are mainly grassland and bare soil and rock, with obvious spatial heterogeneity. The area of urban lands in the Qinghai–Tibet Plateau are 796.59 km^2, accounting for 0.03% of the total lands in 2020. They are concentrated in the 'YLN' Region of Tibet and the grassland and woodland areas in the east. Population distribution in the Qinghai–Tibet Plateau differs greatly by region. Northeastern regions experience a higher population density than northwesterly ones, and population density varies from sparse in many areas to dense in some regions of the plateau [25]. According to the seventh National Census, permanent residents of municipal administrations located wholly or partially in the study area amount to 7878.24 $\times$ 10^4, accounting for 5.46% of the total population in China (1.44 billion), with the urban population of 4329.20 $\times$ 10^4 and an urbanization rate of 54.95%. Moreover, the background, development plans and level of economic development vary greatly from city to city. In 2020, the regional GDP of the Qinghai–Tibet Plateau was CNY 436.73 billion, and the proportion of three industries was 1:3:6. Additionally, the National Ecological Environment Construction Plan and

Outline for National Ecological Environmental Protection Program formulated by the State Council in 1998 and 2000, together with the Ecological Environment Construction Plan of Tibet Autonomous Region formulated by the People's Government of Tibet in 2000, have played a positive role in the comprehensive planning and deployment of eco-environment construction in the region, further promoting a healthy development of urbanization in the Qinghai–Tibet Plateau.

2.2. Data Collection

The data of this study include CLUD and socioeconomic data at 5-year intervals from 1990 to 2020. CLUD is from the Regional Environmental and Ecological Information Research Room, Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, CAS (http://www.igsnrr.ac.cn/, accessed on 15 January 2022), which is a 30 m spatial resolution dataset obtained from Google Earth high-resolution images and Landsat MSS/TM/ETM+/OLI series images through a human–computer interactive interpretation method and expert knowledge. The overall accuracy of subclasses is above 90% [26,27]. The boundaries of the built-up area of urban lands in each period were extracted from the subclass of urban land in CLUD. Data on the population within urban administrative units were obtained from the fourth National Census, the fifth National Census, the sixth National Census and the seventh National Census in China. In particular, the fourth census of Tibet Autonomous Region shows that there is a zero population of cities and towns in Ngari Prefecture. Data on GDP within urban administrative units were obtained from statistical yearbooks and national economic and social development bulletins. The water system data were derived from the National 1:250,000 three-level River Basin data set posted by the National Cryosphere Desert Data Center (www.ncdc.ac.cn, accessed on 13 January 2022).

2.3. Methods

2.3.1. Spatiotemporal Evolution Method of Urban Lands

In this study, we used land use efficiency [28] and urban expansion speed and proportion [29] to analyze the spatiotemporal evolution of urban lands in the Qinghai–Tibet Plateau.

Land use efficiency (LCRPGR) was evaluated using the UN Sustainable Development Goals (SDGs) 11.3.1–Land Consumption Rate (LCR) to Population Growth Rate (PGR). The urban expansion speed is the annual urban expansion area in a period, and the urban expansion proportion is the ratio of urban expansion to urban land area in the initial year during a period.

$$LCRPGR = \frac{LCR}{PGR} = \frac{\frac{UL_{t2}-UL_{t1}}{UL_{t1}} \times \frac{1}{t2-t1}}{\frac{\ln\left(\frac{P_{t2}}{P_{t1}}\right)}{t2-t1}}, \quad (1)$$

where UL_{t2} and UL_{t1} are the urban areas (km^2) at $t2$ and $t1$, respectively. P_{t2} and P_{t1} are urban population (10,000 people) at $t2$ and $t1$, respectively.

In addition, considering the special topography of the Qinghai–Tibet Plateau and the spatial autocorrelation between urban lands, natural factors such as water, elevation, land use/cover type and slope were selected to be superimposed with the urban land patch factor (urban land patches were assigned a value of 1 and the rest were assigned a value of 5) to obtain a composite variable. The natural condition of the Qinghai–Tibet Plateau was classified into 5 levels (1 to 5) using natural breaks (Jenks). A region with a lower score is more suitable for urban land construction. Areas with water within 1000 m were judged to be more conducive to urban development and were assigned a value of 1, while the rest were assigned a value of 3. Among the land use/cover types, construction land, grassland, forest land, arable land, unused land and water were assigned a value of 1 to 6, respectively. The elevation and slope were classified into 6 levels (1 to 6) using natural breaks (Jenks). Then, we conducted a spatial correlation analysis of Moran's I on this composite variable to further explore the distribution characteristics of urban land [30].

2.3.2. Evaluation Method of Urbanization Efficiency

On the basis of CLUD and socioeconomic data, urban population density (UPD) and urban economic density (UED) indexes [31,32] were used to evaluate urbanization efficiency. Large cities are defined as those with urban populations between 1 million and 5 million, medium cities as those with urban populations between 0.5 million and 1 million, and small cities as those with urban population less than 0.5 million.

$$UPD = \frac{URP}{UA}, \tag{2}$$

$$UED = \frac{TGDP}{UA}, \tag{3}$$

where URP is the urban population (10,000 people), $TGDP$ is the regional GDP in the administrative unit (CNY 0.1 billion), and UA is the area of urban lands (km^2).

3. Results

3.1. Spatiotemporal Evolution Characteristics of Urban Land

3.1.1. Holistic Spatial Pattern

In 2020, the urban land area of the Qinghai–Tibet Plateau was 796.59 km^2, mainly concentrated in Lanzhou–Xining City Area, Lhasa Metropolitan Area and the 'YLN' Region. In view of urban land areas at the prefecture level, approximately 41.67% of urban lands in prefectures of the Qinghai–Tibet Plateau were between 10 and 30 km^2, mainly located in the central-eastern part of the plateau, such as Wuwei, Haixi Mongolian and Tibetan Autonomous Prefecture and Linzhi. Second, 29.17% of urban lands at the prefecture level smaller than 10 km^2 lie in the east of the Qinghai–Tibet Plateau. A total of 12.50% of urban lands in municipal administrations larger than 80 km^2 were widely distributed in Xining, Lhasa and Kashgar Prefecture. Urban lands with an area between 30 and 50 km^2 made up 12.50% of all urban surfaces at the prefecture level, which are in the 'YLN' Region of Tibet and southeastern margin of the plateau. Only 4.17% of urban lands in prefectures larger than 50 km^2 and smaller than 80 km^2 were located in Haidong.

Based on Moran's I, the composite variable has a negative spatial correlation and a discrete trend, with -116.34 less than -2.58 on the Z score and the p value less than 0.01. The local autocorrelation results are shown in Figure 2. Quantitatively, low–high and high–low outliers dominate to a certain extent, suggesting that the holistic distribution of urban lands on the plateau is not always determined by natural conditions, and the distribution is scattered and discontinuous. In detail, low–low clusters, mainly located in the southwestern plateau, are more than the high–high clusters, i.e., those with low composite scores are more likely to cluster spatially, indicating that the construction of urban land in the coastal areas of the Yarlung Tsangpo River has balanced the constraints of natural conditions and is relatively more in line with the principle of sustainable development.

From 1990 to 2020, the spatiotemporal evolution characteristics of urban lands in the Qinghai–Tibet Plateau are obvious (Figure 3). The area and number of urban lands are on the rise, though the area of urban expansion is relatively small (Table 1). The holistic development pattern of urban expansion was transformed from dual-center to multi-center extension, with urban lands gradually expanding from Lanzhou–Xining City Area and Lhasa Metropolitan Area to the central and south of the Qinghai–Tibet Plateau. Crisscrossed by water systems such as Qinghai Lake, the Yellow River, the Jinsha River, the Lantsang River, the Nujiang River, and the Yarlung Tsangpo River and Namtso Lake, the central and southern parts of the plateau have driven the growth and expansion of surrounding towns and cities. In the past three decades, the area of urban land patches in the Qinghai–Tibet Plateau is generally small, with the number of patches smaller than 2 km^2 accounting for more than 70%, and the number of patches larger than 10 km^2 accounting for less than 4%. It illustrates that the distribution of urban lands in the Qinghai–Tibet

Plateau is discontinuous, and the urban aggregation degree and overall urbanization level remain low.

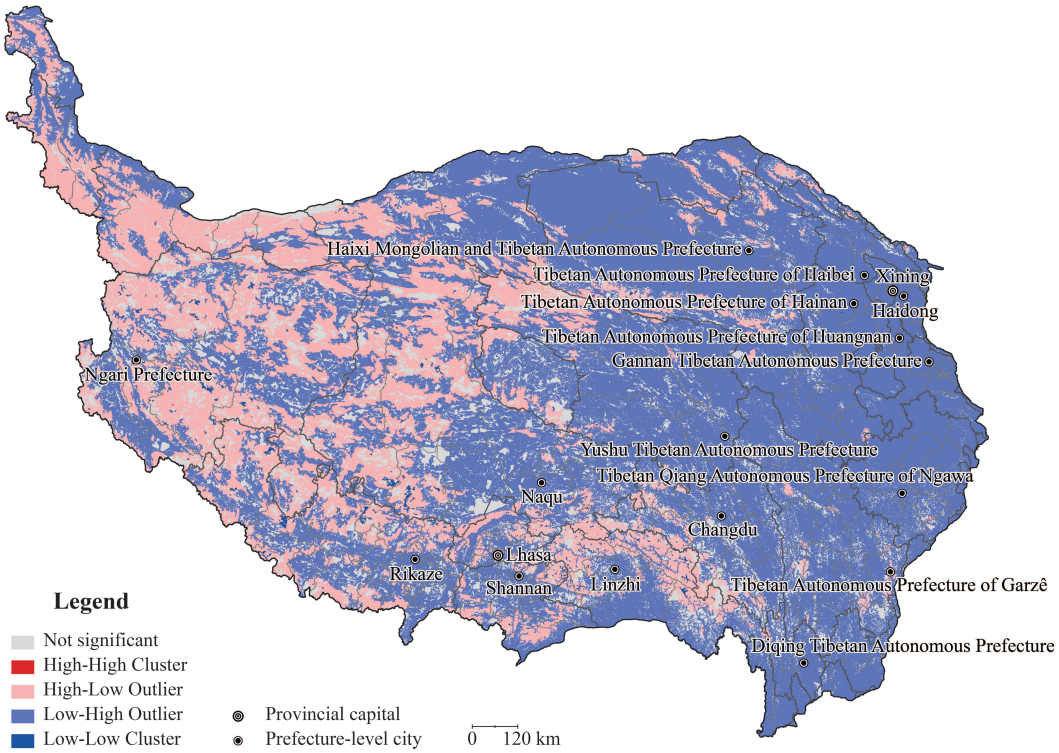

Figure 2. LISA cluster map of the composite variable (p-value < 0.01).

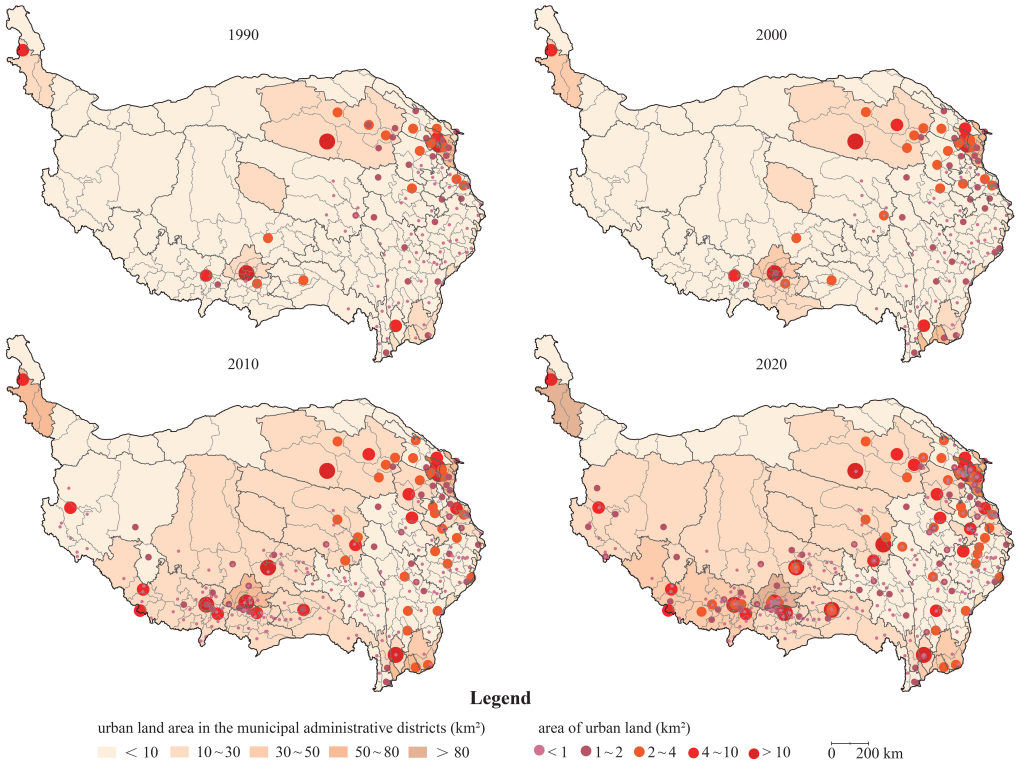

Figure 3. Changes of urban land use in the Qinghai–Tibet Plateau during 1990–2020.

Table 1. Areas of urban land use at the prefecture level in the Qinghai–Tibet Plateau during 1990–2020 (km^2).

Prefecture-Level City	1990	2000	2010	2020
Xining	43.60	49.61	94.53	172.14
Lhasa	26.52	30.90	66.37	107.90
Kashgar Prefecture	24.28	48.53	68.07	106.63
Haidong	12.06	13.05	25.02	56.51
Liangshan Yi Autonomous Prefecture	12.39	27.14	39.02	45.23
Lijiang	6.82	13.33	26.36	40.46
Rikaze	5.98	9.37	17.13	35.82
Wuwei	9.10	12.83	17.98	29.95
Haixi Mongolian and Tibetan Autonomous Prefecture	10.23	12.13	19.35	25.41
Linzhi	1.56	5.45	14.67	23.35
Diqing Tibetan Autonomous Prefecture	4.69	7.69	15.31	22.09
Naqu	4.07	5.53	10.79	19.46
Shannan	7.55	10.05	12.16	18.38
Gannan Tibetan Autonomous Prefecture	6.11	7.17	10.19	13.88
Yushu Tibetan Autonomous Prefecture	5.95	7.13	11.01	13.72
Tibetan Autonomous Prefecture of Hainan	5.89	6.79	11.15	12.10
Ngari Prefecture	0.00	3.91	6.38	12.07
Tibetan Autonomous Prefecture of Golog	3.38	4.46	6.44	9.12
Changdu	0.62	2.21	4.14	6.44
Tibetan Autonomous Prefecture of Haibei	1.49	1.80	2.89	5.78
Tibetan Autonomous Prefecture of Huangnan	2.97	3.07	4.68	5.48
Tibetan Autonomous Prefecture of Garzê	2.54	2.84	4.23	5.32
Nujiang of the Lisu Autonomous Prefecture	2.07	2.41	4.58	5.11
Tibetan Qiang Autonomous Prefecture of Ngawa	2.06	2.09	2.71	4.24

3.1.2. Regional Spatial Pattern

Since the 1990s, the Qinghai–Tibet Plateau region has been in a phase of accelerated urban expansion, with the scale and number of cities and towns continuously increasing. Figure 4 presents statistical results on urban expansion speed and proportion in selected cities, prefectures and regions for each decade from 1990 to 2020. From 1990 to 2000, Kashgar Prefecture had the largest expansion speed, reaching 2.43 km^2/a, followed by Liangshan Yi Autonomous Prefecture, with an expansion speed of 1.48 km^2/a. Changdu has the largest expansion proportion followed by Linzhi and Liangshan Yi Autonomous Prefecture, with corresponding expansion proportions of 259.29%, 249.36% and 119.05%, respectively. From 2000 to 2010, the expansion speed of Xining increased significantly to 4.49 km^2/a, with an expansion proportion of 90.55%, while Lhasa and Kashgar Prefecture also expanded relatively fast at 3.55 km^2/a and 1.95 km^2/a, respectively. In addition, Linzhi expanded more than double. From 2010 to 2020, the expansion speeds of Xining, Lhasa and Kashgar Prefecture kept high, and the expansion proportions of Haidong, Rikaze and Tibetan Autonomous Prefecture of Haibei were at 125.86%, 109.11% and 100.00%, respectively.

Figure 4. Urban expansion speed and proportion in a municipal manner.

According to the classification criterion of urban hierarchy, Xining, Rikaze and Shannan were selected as typical large, medium and small cities. In the Qinghai–Tibet Plateau, there are mostly small cities and fewer large cities. The holistic urban land area of large, medium and small cities shows a steady upward tendency (Figure 5). The speed and proportion of urban land expansion in large cities, medium cities and small cities decrease in order, with an annual expansion of 11.52 km^2, 4.85 km^2 and 3.46 km^2, respectively. The change trends of urban land area in the three typical cities of Xining, Rikaze and Shannan are similar to the holistic situation. From the expansion curve, urban land area in large cities has been rising steadily in a linear pattern with a slightly increased proportion of expansion from 2010–2020 relative to the previous two decades, whilst urban land area of small and medium cities have expanded in an "S"-shaped trend with the largest expansion proportion from 2005 to 2010 and a gradual slowdown after 2015.

As the number and scale of cities are increasing rapidly, urban space is expanding in an "in-fill, out-spread" pattern. Urban spatial form has thus become one of the essential forms to characterize spatiotemporal evolution of urban lands [33]. The spatial distribution of urban expansion in Xining, Rikaze, and Shannan presents that Xining expands outwards in a star shape, but Rikaze and Shannan expand irregularly. This demonstrates that the basic structure of urban land use has been largely formed in large cities, while small and medium cities are still exploring the best land use planning scheme. It is worth pointing out that the relatively rapid speed and large proportion increase of urban expansion may lead to unhealthy urban development.

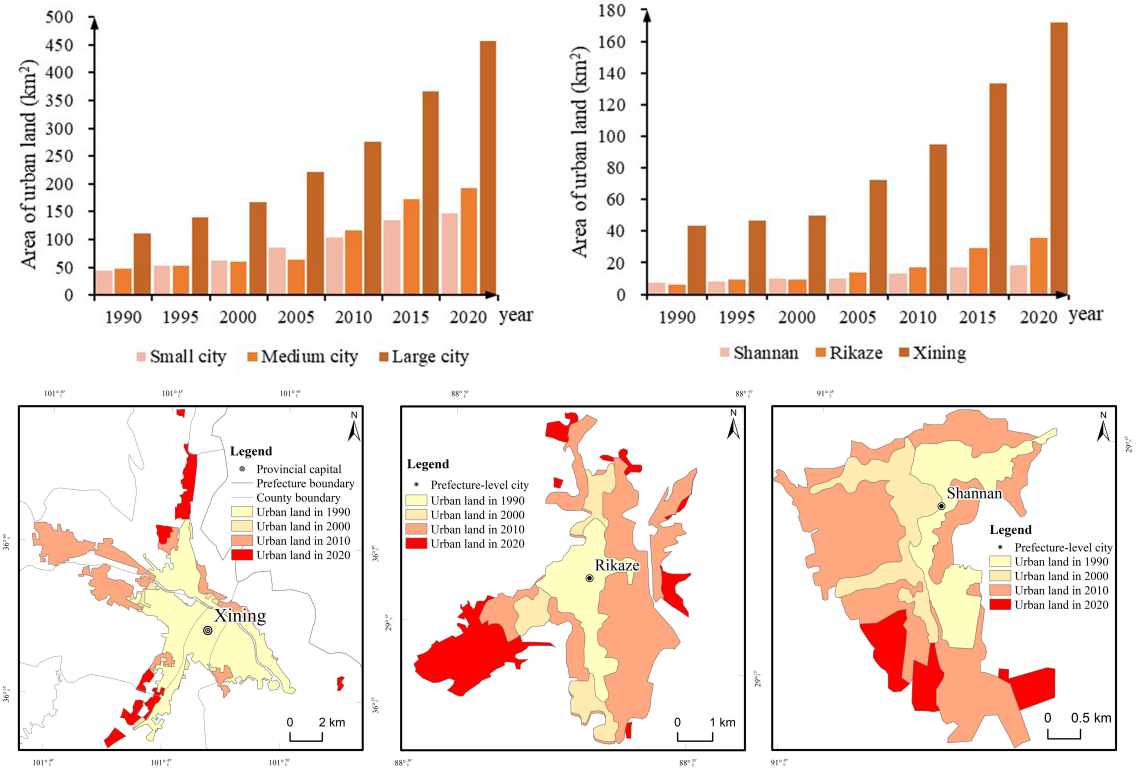

Figure 5. Spatial distribution of urban expansion in urban hierarchies.

3.2. Urban Land Use Efficiency

The land use efficiency values of cities, prefectures and regions in the Qinghai–Tibet Plateau were calculated by year, as shown in Table 2. The mean of urban land use efficiency on the plateau per decade from 1990 to 2020 is 1.37, greater than 1, reaching a relatively effective construction intensity. However, the urban land use efficiency shows a trend of slower growth. An analysis of 10-year intervals shows that the urban land use efficiency in the Qinghai–Tibet Plateau was 1.14 during 1990–2000, increasing to 1.44 during 2000–2010, and again increasing during 2010–2020 to 1.53, whose increase is 20.36% lower than that of the previous decade. The efficiency of urban land use is erratic. Judging from administrative divisions, 33.33% of the 24 cities, prefectures and regions have an overall average urban land use efficiency below 1 which drops a hint that there is still a lot of room for improvement. Among them, Tibetan Autonomous Prefecture of Golog has the lowest urban land use efficiency. Consequently, under the macro planning of urbanization in the Qinghai–Tibet Plateau, it is urgent to reasonably plan the scale and distribution of urban lands and properly address the current situation of incongruity between land urbanization and population urbanization to ameliorate the quality of the ecological environment, enhance the integrated carrying capacity of cities and towns, and give impetus to the steady growth in the efficiency of urban land use.

Small cities such as Haixi Mongolian and Tibetan Autonomous Prefecture and Linzhi have higher land use efficiency compared to other regions, which may benefit from the influence of the radiation of provincial capital cities Xining and Lhasa. The economic development and living standards of residents in large cities such as Xining and Kashgar Prefecture, and medium cities such as Changdu, Rikaze and Lhasa, are relatively high, which results in a correspondingly high level of urban land use efficiency there. Comparatively speaking, the land use efficiency values of large cities are in the middle of the column, which may be due to the fact that large cities have formed a relatively stable urban spatial structure. That is, the urban lands are no longer expanding on a large scale. Moreover, some of the original urban population has been absorbed and accommodated by

the fast-growing small or medium cities around them. Nonetheless, the result of high urban land use efficiency in some medium and small cities suggests that small and medium cities in the Qinghai–Tibet Plateau are committed to urbanization and have attracted a certain amount of urban population on the basis of urban expansion. It curbs the low-density sprawl of urban space in an effective manner and seizes on the coordinated and orderly development of land and population. From the perspective of spatial scale, the regions with high urban land use efficiency are mainly located in the 'YLN' Region of Tibet and the northeastern and southern part of the Qinghai–Tibet Plateau, while the urban land use efficiency in the east and midwest is low.

Table 2. Land use efficiency of urban areas in the Qinghai–Tibet Plateau.

Urban Hierarchy	Prefecture-Level City	1990–2000	2000–2010	2010–2020	Mean
Small city	Haixi Mongolian and Tibetan Autonomous Prefecture	2.94	1.06	6.95	3.65
Small city	Linzhi	3.89	3.80	1.28	2.99
Medium city	Changdu	3.33	1.84	1.25	2.14
Medium city	Rikaze	0.98	2.27	2.74	2.00
Medium city	Lhasa	0.41	4.89	0.68	1.99
Large city	Xining	0.29	2.86	2.55	1.90
Small city	Diqing Tibetan Autonomous Prefecture	1.29	1.74	2.34	1.79
Large city	Kashgar Prefecture	1.93	1.08	2.04	1.68
Large city	Lijiang	1.49	1.49	1.03	1.34
Large city	Wuwei	0.55	1.34	2.07	1.32
Large city	Liangshan Yi Autonomous Prefecture	2.84	0.60	0.44	1.29
Small city	Ngari Prefecture	—	1.58	0.99	1.29
Small city	Tibetan Autonomous Prefecture of Haibei	−0.72	1.24	3.16	1.23
Small city	Yushu Tibetan Autonomous Prefecture	2.58	0.35	0.43	1.12
Medium city	Naqu	0.55	0.88	1.86	1.10
Medium city	Tibetan Qiang Autonomous Prefecture of Ngawa	0.16	0.52	2.43	1.04
Large city	Tibetan Autonomous Prefecture of Garzê	0.97	1.09	0.52	0.86
Small city	Tibetan Autonomous Prefecture of Huangnan	1.50	0.69	0.31	0.83
Medium city	Nujiang of the Lisu Autonomous Prefecture	0.30	1.65	0.14	0.70
Large city	Haidong	−2.91	1.57	2.32	0.32
Small city	Shannan	0.20	−0.66	1.13	0.23
Small city	Tibetan Autonomous Prefecture of Hainan	−0.18	0.53	0.23	0.19
Medium city	Gannan Tibetan Autonomous Prefecture	−0.77	0.48	0.64	0.12
Small city	Tibetan Autonomous Prefecture of Golog	−0.83	0.36	0.80	0.11
	the Qinghai–Tibet Plateau	1.14	1.44	1.53	1.37

3.3. Efficiency Evaluation of Urban Construction

To gain a comprehensive understanding of the current situation of urban construction in the Qinghai–Tibet Plateau, this study selects two aspects to evaluate the outcome and benefits of urbanization development, namely, urban population and urban economy.

As the socioeconomic development and urbanization level of the Qinghai–Tibet Plateau continue to rise, the UPD and the UED have changed accordingly, as shown in Figures 6 and 7. In general, 37.5% of cities and towns show a decreasing trend in the UPD, and 71% of cities and towns have seen a change in the UPD of one or less over the

past 30 years. In terms of administrative divisions, the UPD increased the most in Nujiang of the Lisu Autonomous Prefecture, by 3.63, and decreased more in Tibetan Autonomous Prefecture of Haibei by 2.8. In 2020, Tibetan Qiang Autonomous Prefecture of Ngawa in Sichuan Province had the highest value in UPD, followed by Tibetan Autonomous Prefecture of Garzê and Nujiang of the Lisu Autonomous Prefecture with UPDs of 8.05, 6.46 and 5.66, respectively, while Linzhi, Ngari Prefecture and Rikaze in the Tibet Autonomous Region had lower values in UPD of 0.42, 0.45 and 0.51, respectively.

On a time scale, the UPD of the Qinghai–Tibet Plateau varies from decade to decade, with the value increasing from 1.44 in 1990 to 1.47 in 2000 and then decreasing to 1.31 in 2020. The UPD increased by 0.03 between 1990 and 2000, when the development of the Qinghai–Tibet region was still dominated by agriculture. Previous human activities such as deforestation and overgrazing have led to serious damage to the natural ecological environment. However, thanks to the implementation of the Reforestation Project and the Counterpart Support Programme, there has been a slight increase in UPD. The UPD decreased by 0.06 between 2000 and 2010, when the development and use of unused land –gradually intensified, and the industrial development, transport construction, tourism boom and the policy support of the government drew a lot of mobile population to the urban areas. In the last decade, the UPD in the Qinghai–Tibet Plateau decreased by 0.10. The construction of the Sichuan–Tibet Railway and the Lanzhou–Wulumuqi High-Speed Railway during this period spurred the growth of the urban population along the routes. Moreover, under the construction of beautiful cities and towns on the plateau, cities and towns have been strengthening their infrastructure, developing special industries and upgrading public services, which significantly improved the urban living environment and better retained the urban population. In summary, from 2000 to 2020, land urbanization was faster than population urbanization, resulting in lower UPDs. Furthermore, a trend of increasing incompatibility between land urbanization and population urbanization emerged.

The industrial development of the Qinghai–Tibet Plateau has also undergone change, from an extensive form of primary industries, such as animal husbandry and special agricultural planting, to industrial upgrading. Subsequently, the diversification of secondary industries such as mining, agricultural and livestock product processing, as well as tertiary industries such as grassland ecological industries and cultural and tourism integration industries gradually took place. Moreover, an organic and ecological breeding industry system for traditional animal husbandry was formed. Since 1990, the central government has focused on the social-economic development of the Qinghai–Tibet region, promulgating and refining various policies and institutions to bolster its internal economic vitality. The "three packs" in 1985, "the counterpart support" for Tibet in 1994, the Herdsmen Settlement Project in 2006, as well as a series of financial assistance systems and medical systems for farmers and herdsmen have contributed to a better standard of living for Tibetan residents.

The UED in the Qinghai–Tibet Plateau has been on a steady upward trend. The largest increase in the UED was in Tibetan Qiang Autonomous Prefecture of Ngawa, which increased by 92.05 from 5.07 to 97.11, followed by Tibetan Autonomous Prefecture of Garzê whose UED increased by 73.90 from 3.28 to 77.18. The rest of the cities and towns also have an increase in the UED of more than four. In terms of administrative districts, there were regional differences in the UED on the Qinghai–Tibet Plateau in 2020. The UEDs of Tibetan Qiang Autonomous Prefecture of Ngawa, Tibetan Autonomous Prefecture of Garzê and Nujiang of the Lisu Autonomous Prefecture are high. In contrast to UPD, UEDs of Yushu Tibetan Autonomous Prefecture, Tibetan Autonomous Prefecture of Golog and Ngari Prefecture are lower, at 4.64, 5.36 and 5.86, respectively. From the point of time scale, UED varied from decade to decade during 1990–2020. From 1990 to 2000, the overall UED increased by 0.90 owing to the extensive and simple industrial structure. Between 2000 and 2010, the UED rose to 7.81, probably due to the rise of special industries in mineral resources exploration, unused land utilization and ethnic cultural tourism development, which brought quite a few economic benefits. Over the last decade, the UED grew to a value of 12.97. As the increasing number of railways open to traffic, the improved rail

accessibility has contributed to the continued growth in economic output [34]. The urban economic level of the Qinghai–Tibet Plateau is on the path of steady development.

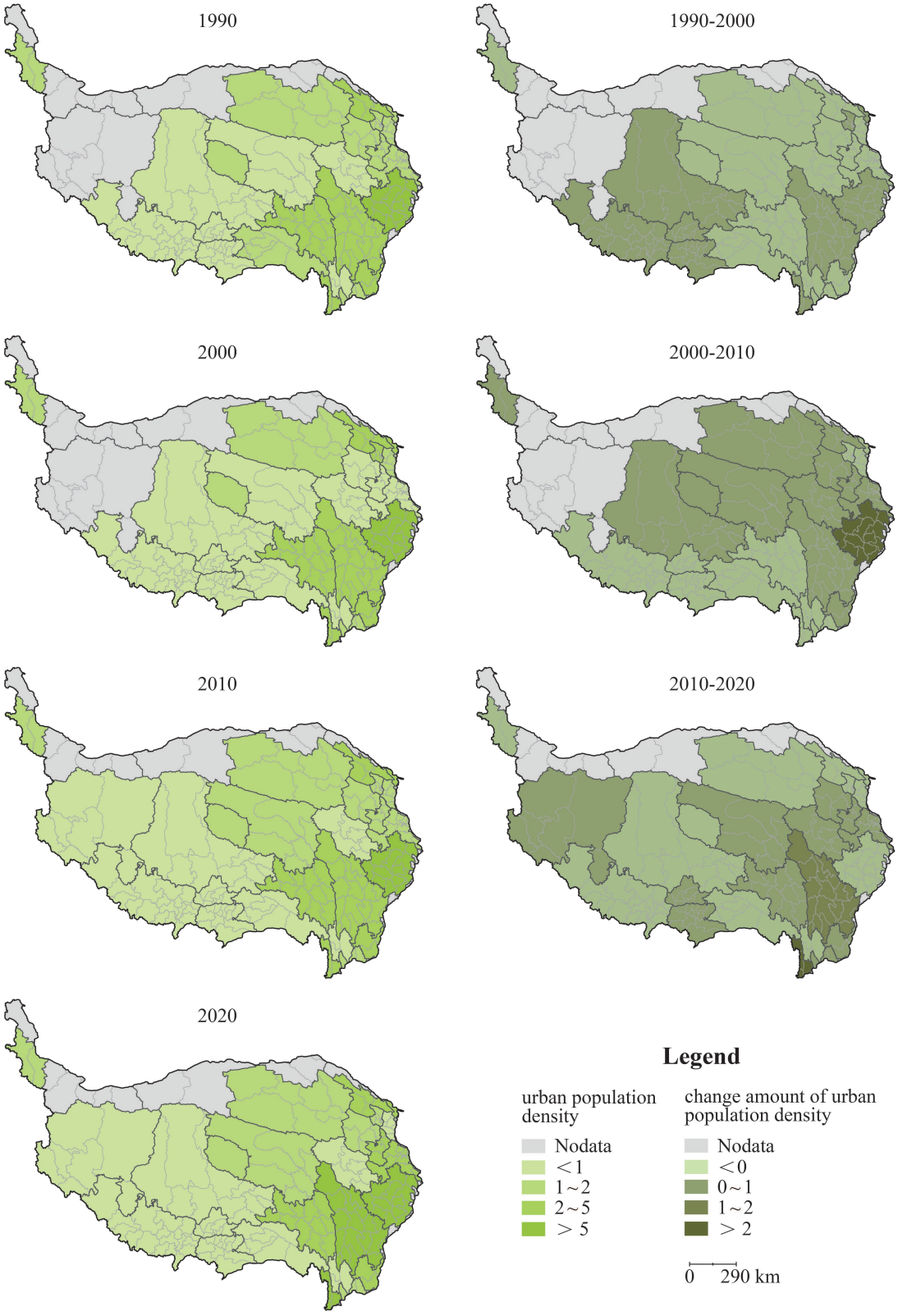

Figure 6. UPD in the Qinghai–Tibet Plateau.

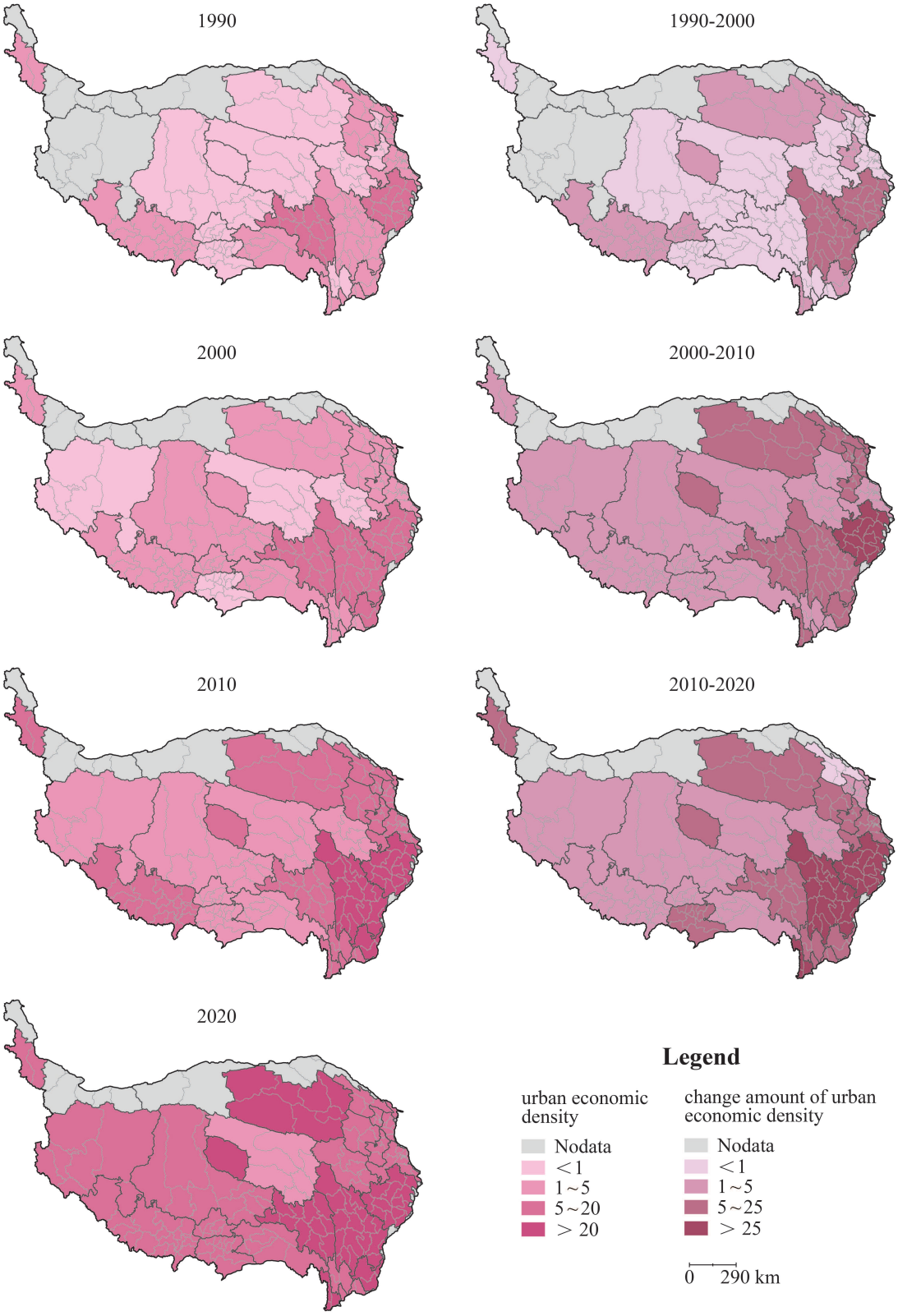

Figure 7. UED in the Qinghai–Tibet Plateau.

4. Discussion

China has experienced rapid urbanization and economic development, and the rate of economic development has been much faster than the rate of urban expansion. In addition, there are differences in the change patterns between UPD and UED in China, with UPD

mostly growing more slowly than UED [31]. This is consistent with the findings of our study in the Qinghai–Tibet Plateau, and we suspect that it may be related to the lower population capacity in the alpine environment.

As an important ecological shield and strategic resource reserve base in China, the urbanization and economic development of the Qinghai–Tibet Plateau have a remarkable impact on the social environment and ecological environment. Studies have shown that the development of the urbanization in population, economy and land on the Qinghai–Tibet Plateau is not synchronous, which in turn leads to regional eco-environmental problems [35,36]. Fortunately, the implementation of policies such as land use planning and cropland reconversion programs have strengthened the induced effect of land use in the Qinghai–Tibet Alpine Mountain Areas [8]. The "Belt and Road" cooperation initiative has propelled the advancement of a green low-carbon economy in parts of the Tibetan Plateau, including cultural tourism and commercial and logistics industries. The deployment of several ecological conservation projects and the introduction of planning systems such as the the Qinghai–Tibet Plateau Regional Ecological Construction and Environmental Protection Plan (2011–2030) have effectively preserved and ameliorated the vital ecological assets and human settlement environment of the Qinghai–Tibet Plateau, which serves to attract more people to settle in the Tibetan Plateau region. Given that land use utilization on the plateau is limited by the alpine environment, it is worth further study on how to achieve sustainable development in the Qinghai–Tibet Plateau under the joint pressure of the new-type urbanization promotion and ecological environmental protection.

Since the whole Qinghai–Tibet Plateau region started urbanization late, this study only focuses on the spatiotemporal evolution of urban lands and the benefits brought about by urbanization in the Qinghai–Tibet Plateau during 1990–2020. According to our findings, the spatiotemporal evolution characteristics and urbanization efficiency of the Qinghai–Tibet Plateau are obvious. Nevertheless, the UPD is showing a downward trend, and 33.33% of the administrative districts have an average urban land use efficiency below one, which mean that there is still a lot of room for improvement. Furthermore, scattered and discontinuous urban lands manifest the urgency of rational land allocation on the plateau. Currently, special industries in the Qinghai–Tibet Plateau are developing at an accelerated pace, ecological conservation is effective and new-type urbanization is being steadily promoted. Hence, it is necessary to keep a focus on the urban development in the Qinghai–Tibet Plateau of China and to investigate the transfer of various land use types on the plateau.

5. Conclusions

This study investigates the spatiotemporal evolution characteristics of urban land use in the Qinghai–Tibet Plateau from 1990 based on CLUD and socioeconomic statistical data. We evaluated the society efficiency using indexes such as UPD and UED. The main conclusions are as follows: (1) The holistic development pattern of urban expansion has transformed from dual-center to multi-center extension, with urban lands gradually expanding from Lanzhou–Xining City Area to the central and south of the Qinghai–Tibet Plateau. (2) Urban land areas in large cities have been rising steadily in a linear pattern with the largest proportion of expansion in 2010–2020, while small and medium cities expand in an "S"-shaped trend with the largest expansion proportion from 2000 to 2010. (3) The mean of urban land use efficiency on the plateau per decade from 1990 to 2020 is 1.37, reaching a relatively effective construction intensity. Tibetan Autonomous Prefecture of Golog has the lowest urban land use efficiency. (4)The UPD of the Qinghai–Tibet Plateau increased from 1.44 in 1990 to 1.47 in 2000 and then decreased to 1.31 in 2020. The trend of increasing incompatibility between land urbanization and population urbanization has emerged. The UED in the Qinghai–Tibet Plateau has been on a steady upward trend. The UEDs of Tibetan Qiang Autonomous Prefecture of Ngawa, the Tibetan Autonomous Prefecture of Garzê and Nujiang of the Lisu Autonomous Prefecture are high.

This study highlights the population and economic impacts of urbanization, but social development is multifaceted and more quantitative indexes of social development efficiency should be taken into account [37]. It is expected that further research will be conducted to quantify ecological effects and other indexes spatially at a county scale. The spatiotemporal characteristics of land, population, economy and ecology of urban lands in the Qinghai–Tibet Plateau from the inner city would be discovered and the causes of the incompatibility between land urbanisation and population urbanisation should be uncovered. In addition, each region in the Qinghai–Tibet Plateau should formulate reasonable plans that are in line with the realities of the plateau and strengthen the division of labor between cities and towns to achieve complementary advantages to improve the overall quality of urbanization in the Qinghai–Tibet Plateau, especially large cities and city groups.

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