

Article

Urban Expansion and Its Impact on the Land Use Pattern in Xishuangbanna since the Reform and Opening up of China

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Abstract: Since the Chinese government carried out the reform and opening up policy, Xishuangbanna Dai Autonomous Prefecture has experienced rapid urbanization and dramatic land use change. This research aims at analyzing urban expansion in Xishuangbanna and its impact on the land use pattern using combined methods, including radar graph, the gradient-direction method and landscape metrics. Seven land use maps from 1976 to 2015 were generated and analyzed, respectively. The results showed that urban and rubber expanded rapidly, while forest decreased during the last 40 years. The city proper, the county town of Menghai and the county town of Mengla showed the most significant and fastest urban expansion rates. In response to rapid urban expansion, land use types outside urban areas changed dramatically. In Jinghong and Mengla, urban areas were usually surrounded by paddy, shrub, rubber and forest in 1976, while most areas were dominated by rubber by 2015. With the development of Xishuangbanna, landscape diversity increased along urban-rural gradients, but decreased in some key urban areas. Urban expansion slightly reduced the connectivity of forest and increased agglomeration of rubber at the same time. Based on the analyses above, we moved forward to discuss the consequences of urban expansion, rubber plantations and land fragmentation.

Keywords: urban expansion; radar graph; landscape metrics; urban-rural gradients; the reform and opening up

1. Introduction

Over the past few decades, our world is urbanizing at an unprecedented speed, as the population residing in urban areas has increased from 30 percent in 1950 to 54 percent in 2014 [1]. Today, only Africa and Asia remain mostly rural, with 40 and 48 percent of their respective populations living in

urban areas. However, they are urbanizing faster than the other regions and are projected to become 56 and 64 percent urban, by 2050 [2].

With the unique pattern of urban development, urbanization in China has supported higher growth and rapid transformation of the economy, allowing 260 million migrants to move from agriculture to more productive activities [3]. Although it has avoided some of the common problems, China's urbanization has relied excessively on land use conversion and land financing, which are causing inadequate urban sprawl, urban-rural inequalities and many environmental and ecological problems [4,5]. Land is the basic resource for the survival and development of cities and towns [6]. Urbanization will affect land use change especially along the urban-rural gradients [7] and lead to land use-related problems, such as land changed into discrete land uses, conversion from native to designed land cover or development into a non-contiguous or "leap frog" pattern [8]. These consequences could then affect the ecosystem and environment properties, including ecosystem services, biodiversity, biogeochemical cycles, climate conditions, etc. [9,10]. For example, the rapid urbanization will contribute to the direct loss of agricultural land and increased agricultural land use intensity [11] and, finally, affect food production [12]. Besides, the development of the road network in the process of urbanization has already threatened biodiversity by dividing the landscape into fragmented areas and reducing the ecological connectivity [13,14]. Plenty of case studies also indicate that urbanization could lead to ecosystem degradation and loss of ecosystem services [15], especially provisioning service [16]. Urbanization, especially urban land expansion, also has a significant effect on land surface temperature [17] and accounts for 0.09 °C/10a to 0.12 °C/10a of total warming in China [18,19]. Thus, understanding the process of urban expansion, which reflects urbanization in a spatial-temporal form and its impact on the pattern of land use, could help us cope with the emerging problems with respect to urban development and ensure both environmental and socio-economic sustainability for the ever-growing urban population [20].

With the development of remote sensing technology, land use maps derived from satellite images have become the basis of land use change analysis, while the Geographic Information System (GIS) makes it possible to detect and analyze the spatial-temporal dynamics of land use patterns with these maps [21–24]. Numerous studies have reported on urban expansion and land use change [25–29]. Some fundamental approaches, like a land use change matrix or the growth rate, could give us an overview of the land use change; however, it is necessary to further develop the specific spatial-temporal variation of the land use pattern. In the study of urban expansion, a radar graph is commonly used as an effective way to reflect the orientation characteristics of urban expansion [30,31] by summarizing urban expansion indexes (like area or distance to urban center) in different directions. Since the spatial compositions and configurations of land use patches may also have significant impacts on urban eco-environmental properties, a large number of landscape metrics has been developed to quantify the complexity of the urban landscape pattern and reveal some eco-environmental properties that are not directly observable [32,33]. Basically, these metrics can be categorized into different groups [34], such as area metrics, shape metrics, contrast metrics, aggregation metrics, diversity metrics, etc. Landscape metrics can be applied over an entire area to reflect the overall situation of the urban landscape pattern; however, this approach could sometimes lead to incorrect interpretations because of missing internal spatial variation analysis of the urban landscape. Gradient analysis combined with landscape metrics has been effectively used to provide information of specific landscape pattern change [35]. Generally, gradient analysis can be implemented by a series of equal width concentric rings around the urban center or an urban-rural gradient/transect passing through the urban center. Compared to concentric rings, the urban-rural gradient seems to be more effective in characterizing the landscape pattern due to the unchanged sampling size [36].

With further cooperation between China and the Mekong region countries through the Greater Mekong Subregion (GMS) mechanism and Lancang-Mekong Cooperation, stakeholders, including urban planners and policy makers, have paid great attention to the communications and experience sharing of urban management and planning in order to achieve sustainable development [37,38].

Therefore, there is an urgent need to analyze the consequences of urban expansion and land use pattern changes in some typical cities in these areas. These analyses could then help urban planners and policy makers avoid the ills or negative impacts associated with urban expansion and land use pattern change. Xishuangbanna Dai Autonomous Prefecture in Yunnan Province, in the southwest of China, is a key corridor located along the Lancang-Mekong River, connecting China and the Lower Mekong countries. In recent decades, especially since the reform and opening up policy, Xishuangbanna has also experienced fast urban expansion and dramatic land use change. Previous studies in Xishuangbanna mainly focused on specific issues, like rubber plantations [39–41], road network impact [42–44] or biodiversity [45], and few of them have paid attention to a comprehensive understanding of land use pattern change in response to urban expansion. This paper aims to figure out the characteristics of urban expansion and land use pattern change in Xishuangbanna by addressing the following questions: (1) how did the urban area expand in Xishuangbanna in the spatial-temporal perspective ever since 1976; (2) how did urban expansion affect land use pattern change in Xishuangbanna; (3) what are the consequences of land use pattern change in response to urban expansion. To answer these questions, radar graphs, landscape metrics and a gradient-direction method were adopted to analyze the urban expansion and land use pattern change in Xishuangbanna. Consequently, some key issues are summarized and discussed based on the analyses of urban expansion and land use pattern change.

2. Materials and Methods

2.1. Study Area

Xishuangbanna Dai Autonomous Prefecture lies at the latitudes between $21^{\circ}10'$ and $22^{\circ}40'N$ (Figure 1), the longitudes between $99^{\circ}55'$ and $101^{\circ}50'E$, includes one city (Jinghong) and two counties (Menghai, Mengla) and borders Lao People's Democratic Republic (PDR) to the south and Myanmar to the southwest [46]. The total area of Xishuangbanna is approximately $19,120 \text{ km}^2$. The altitude varies from 475 m to 2430 m above sea level. Annual mean temperature ranges from 18°C to 22°C and the annual precipitation from 1200 mm to 1900 mm. The climate of this region is influenced by warm-wet air masses from the Indian Ocean in summer, including monsoons, and continental air masses of subtropical origin in winter, resulting in a rainy season from May to October and a dry season from November to April. Primary vegetation can be organized into four main types: tropical rain forest, tropical seasonal moist forest, tropical mountain evergreen broad-leaved forest and tropical monsoon forest [44]. With rapid urbanization, the urban population and GDP per capita have grown from about 50 thousand and 347 RMB in 1978 to 483 thousand and 26,507 RMB in 2014.

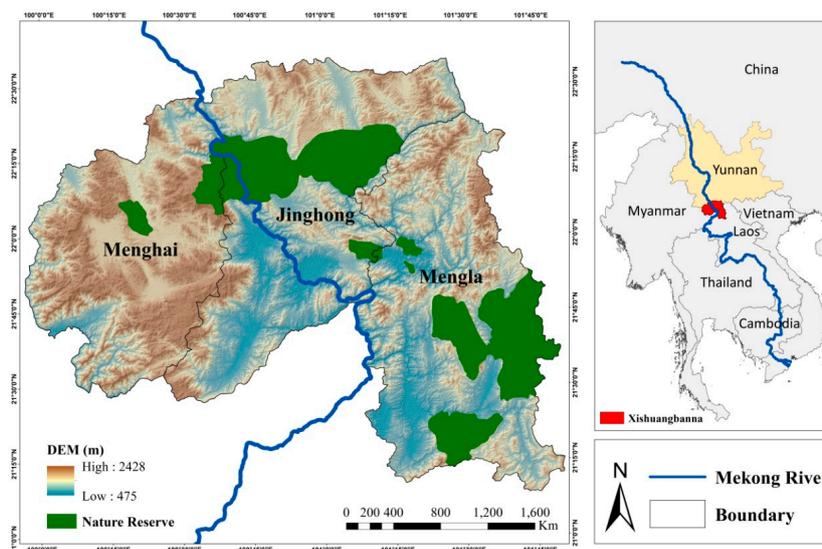


Figure 1. Location of Xishuangbanna.

2.2. Data Processing

In this research, time series of land use datasets were produced based on Landsat TM/ETM+/OLI imagery (<http://glovis.usgs.gov>) [47] from 1976, 1990, 1995, 2000, 2005, 2010 and 2015 (Table 1). All of the downloaded images were the L1T product (systematically, radiometrically, geometrically and topographically corrected; highest quality). Most of these raw images met the requirements of classification, and the exceptions are ortho-rectified using Digital Elevation Model (DEM) data. The Xishuangbanna image of each period was then acquired with the processes of band composition, image mosaicking and clipping. Image interpretation was carried out using a decision tree process supplied by eCognition Developer 8.7. In this study, 13 land use types were classified as built up (including city proper and towns), river, water (including lake, reservoir and ponds), pending construction land, rural, road, flood land, rubber, forest, shrub (natural vegetation and economic plants including tea, coffee, banana, etc.), paddy, upland field and others (grassland, bare land, vacant land, etc.). Visual modification was employed to improve the accuracy of classification. For each classification map, 520 stratified random samples were created to check the accuracy. With the validation of Google Earth and GPS points from the field survey, the overall classification accuracy of each land use map was 87.5%, 92.12%, 92.5%, 93.85%, 94.42%, 91.73% and 94.23%, with Kappa statistics of 0.7599, 0.8681, 0.8816, 0.9026, 0.9158, 0.8781 and 0.9161, in 1976, 1990, 1995, 2000, 2005, 2010 and 2015, respectively.

Table 1. List of Landsat remote sensing images.

Year	Path/Row	Date	Sensor	Resolution (m)	Year	Path/Row	Date	Sensor	Resolution (m)
1976	139/44	24 February 1976	MSS	60	2005	129/45	23 February 2004	TM	30
	139/45	24 February 1976	MSS	60		130/44	1 March 2004	TM	30
	140/44	24 February 1976	MSS	60		130/45	1 March 2004	TM	30
	140/45	24 February 1976	MSS	60		131/45	21 February 2004	TM	30
1990	129/45	20 January 1989	TM	30	2010	129/45	7 February 2010	TM	30
	130/44	27 January 1989	TM	30		130/44	February 2010	TM	30
	130/45	27 January 1989	TM	30		130/45	14 February 2010	TM	30
	131/45	11 February 1989	TM	30		131/45	5 February 2010	TM	30
1995	129/45	16 March 1995	TM	30	2015	129/45	9 March 2015	OLI	30
	130/44	25 March 1995	TM	30		130/44	16 March 2015	OLI	30
	130/45	25 March 1995	TM	30		130/45	16 March 2015	OLI	30
	131/45	19 April 1995	TM	30		131/45	7 March 2015	OLI	30
2000	129/45	6 February 2001	ETM+	30					
	130/44	21 February 2001	ETM+	30					
	130/45	21 February 2001	ETM+	30					
	131/45	4 February 2001	ETM+	30					

Notes: Considering the accessibility of Landsat images and the phenological laws of some main land use types, the time phases of the selected images above are mainly from February and March, with a few from January and April.

2.3. Methodology

There are two forms of urbanization occurring in China: the development of cities and the growth of smaller towns [48]. In Xishuangbanna, the largest urban area is the city proper, which includes the center of Jinghong and part of Gasa town. The other small towns are scattered over Xishuangbanna, due to its large area and complex terrain. Although Xishuangbanna has experienced fast urbanization in the past 40 years, many small towns are still too small to be detected or analyzed individually. Thus, this study mainly focuses on some key urban areas. When analyzing urban-related issues based on land use maps, urban is always defined as impervious surface area [49,50]. In Xishuangbanna, there are two types of impervious land use: urban and rural. We define that the built up area, namely urban area, includes impervious land use patches, which are geographically clustered and are contiguous with each other; the rural area consists of individual impervious land use patches that are separated with urban clusters and usually smaller than 0.3 km².

The radar graph is effective in characterizing the spatial directions of urban expansion. In this research, the city proper, the county town of Menghai and the county town of Mengla, which account for nearly 40% of the total built up area in Xishuangbanna, were selected and analyzed using radar graph analysis. Firstly, we defined the government of Xishuangbanna Dai Autonomous Prefecture as the center of the city proper, the centroid of the built up polygon of Menghai in 1976 as the center of Menghai and the centroid of the built up polygon of Mengla in 1976 as the center of Mengla, and 16 fans were drawn by extending the rays from each center with an interval of 22.5° . Radar graph analysis could then be implemented by summarizing the urban area in each fan.

To further analyze land use pattern change in response to urban expansion in these three key urban areas, we developed a gradient-direction map (Figure 2, CR1 to CR3). This method firstly draws several concentric rings over the three key urban areas with an interval of 1 km. For each urban area, the scope of the largest concentric ring should cover almost the whole urban area, reach to land use types with less of a human activity effect (usually forest), while not colliding with the scope of other urban areas at the same time. These concentric rings would then intersect with the 16 fans and generate a series of segment zones. Finally, each segment zone was represented by the land use type with the largest proportion. This method is actually an upscaling process for summarizing the trend of the spatial-temporal variation of the land use pattern.

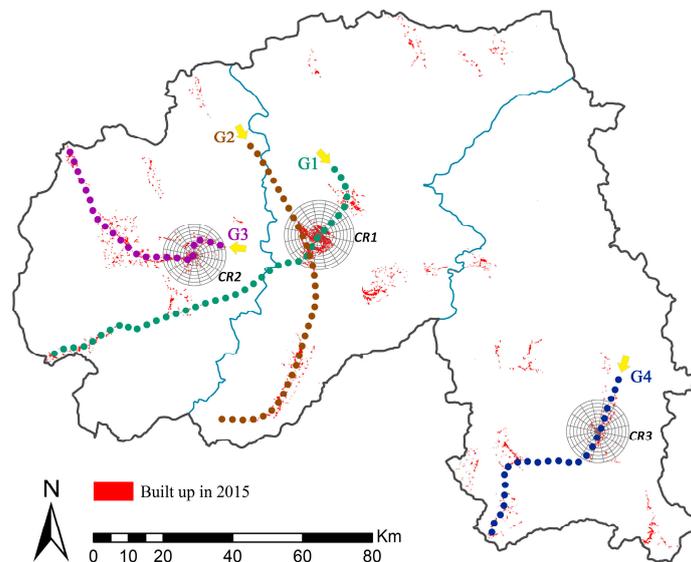


Figure 2. Gradient-direction maps and urban-rural gradients for the analysis (some points of urban-rural gradients are not shown due to the plotting scale). Gradient-direction maps: CR1 for the city proper; CR2 for the county town of Menghai; CR3 for the county town of Mengla. Urban-rural gradients: G1 and G2 went through the city proper and smaller towns; G3 went through the county town of Menghai and Mengzhe town; G4 went through the county town of Mengla and Mengpeng town.

Landscape metrics analysis has been widely used to describe the landscape pattern that could sometimes not be observed visually [8]. The spatial-temporal changes of the land use pattern can be detected and characterized using landscape metrics based on the shape, size, number and other parameters of land use patches derived from remote sensing data [51,52]. To investigate the spatial-temporal changes of the land use pattern and their relationships with urban expansion, two groups of landscape metrics were selected in this study (Table 2). The first group includes the Landscape Division Index (DIVISION), the Patch Cohesion Index (COHESION), the Aggregation Index (AI) and the Contagion Index (CONTAG), to measure landscape composition and configuration. DIVISION and COHESION quantify the connectivity of the landscape habitat; AI provides a measure of class-specific aggregation; while CONTAG measures both patch interspersion and dispersion at the

landscape level. The other group consists of Patch Density (PD), Shannon’s Evenness Index (SHEI) and Shannon’s Diversity Index (SHDI), which could depict landscape fragmentation and diversity. These indexes mainly reflect landscape diversity in two components: richness and evenness. Richness refers to the number of patch types; evenness refers to the distribution of the area among different types. All of these quantitative analyses were implemented using the landscape pattern analysis software FRAGSTATS (Version 4.2) [34]. To further reflect land use pattern change affected by urban expansion, we developed 4 urban-rural gradients. Considering the resolution of land use maps and the scale of built up areas, we set the square sampling blocks with a side length of 900 m for the urban-rural gradients. For each gradient, we firstly drew a polyline consisting of a line segment with 900 m and passing through important built up areas along the transportation, hydrology or topography corridors. Sampling blocks were then generated through buffering each line segment with 450 m towards both sides. Finally, these sampling blocks composed a specific urban-rural gradient. Figure 2 showed the urban-rural gradients represented by central points of the sampling blocks.

Table 2. Landscape metrics used in this study [34].

Landscape Metrics	Definition	Description
Landscape Division Index (DIVISION)	$DIVISION = \left[1 - \sum_{j=1}^n \left(\frac{a_{ij}}{A} \right)^2 \right]$	a_{ij} = area (m) of patch ij. A = total landscape area (m ²).
Patch Cohesion Index (COHESION)	$COHESION = \left[1 - \frac{\sum_{j=1}^n P_{ij}^*}{\sum_{j=1}^n P_{ij}^* \sqrt{a_{ij}^*}} \right] \cdot \left[1 - \frac{1}{\sqrt{Z}} \right] (100)$	P_{ij}^* = perimeter of patch ij in terms of number of cell surfaces. a_{ij}^* = area of patch ij in terms of number of cells. Z = total number of cells in the landscape.
Aggregation Index (AI)	$AI = \left[\frac{g_{ii}}{\max_{i \rightarrow j} g_{ij}} \right] (100)$	g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the single-count method. $\max_{i \rightarrow j} g_{ij}$ = maximum number of like adjacencies (joins) between pixels of patch type (class) i based on the single-count method.
Contagion Index (CONTAG)	$CONTAG = \left[1 + \frac{\sum_{i=1}^m \sum_{k=1}^m \left[P_i \frac{g_{ik}}{\sum_{k=1}^m g_{ik}} \right] \left[\ln \left(P_i \frac{g_{ik}}{\sum_{k=1}^m g_{ik}} \right) \right] \right]}{2 \ln(m)} \right] (100)$	P_i = proportion of the landscape occupied by patch type (class) i. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the double-count method. m = number of patch types (classes) present in the landscape, including the landscape border if present.
Patch Density (PD)	$PD = \frac{n_i}{A} (10,000)(100)$	n_i = number of patches in the landscape of patch type (class) i. A = total landscape area (m ²).
Shannon’s Diversity Index (SHDI)	$SHDI = - \sum_{i=1}^m (P_i \ln P_i)$	P_i = proportion of the landscape occupied by patch type (class) i. m = number of patch types (classes) present in the landscape, excluding the landscape border if present.
Shannon’s Evenness Index (SHEI)	$SHEI = \frac{- \sum_{i=1}^m P_i \ln P_i}{\ln m}$	P_i = proportion of the landscape occupied by patch type (class) i. m = number of patch types (classes) present in the landscape, excluding the landscape border if present.

Note: Here we keep all parameters as original form in the referred literature. p_{ij}^* is to distinguish p_{ij} which means length (m) of perimeter of patch ij. Same with a_{ij}^* and a_{ij} .

Using these methods above, we implemented the study as follows.

Firstly, land use maps and the land use change matrix were produced to reflect quantitative changes of the overall land use pattern from 1976 to 2015. Secondly, we created three radar graphs to show the spatial-temporal expansion of three key urban areas in Xishuangbanna, including the city proper located in Jinghong, the county town of Menghai and the county town of Mengla (Figure 2). Lastly, the land use pattern changes due to urban expansion were analyzed in three aspects: (1) changes of the land use pattern outside three key urban areas; (2) landscape fragmentation and diversity along four urban-rural gradients; (3) the impact of urban expansion on landscape configuration and composition (DIVISION, COHESION, CONTAG and AI) at the scale of the whole of Xishuangbanna.

3. Results

3.1. Dynamics of Land Use Change in Xishuangbanna from 1976 to 2015

Figure 3 shows the overall changes of the land use pattern of Xishuangbanna in the last few decades. As observed, forest and rubber are the two main land use types, which cover more than half of all of Xishuangbanna. Rubber was mainly planted outside paddy fields in the central and southwest of Jinghong in 1976 and appeared in the south of Mengla in 1990. Since then, rubber plantations started to expand, dramatically centered on these places.

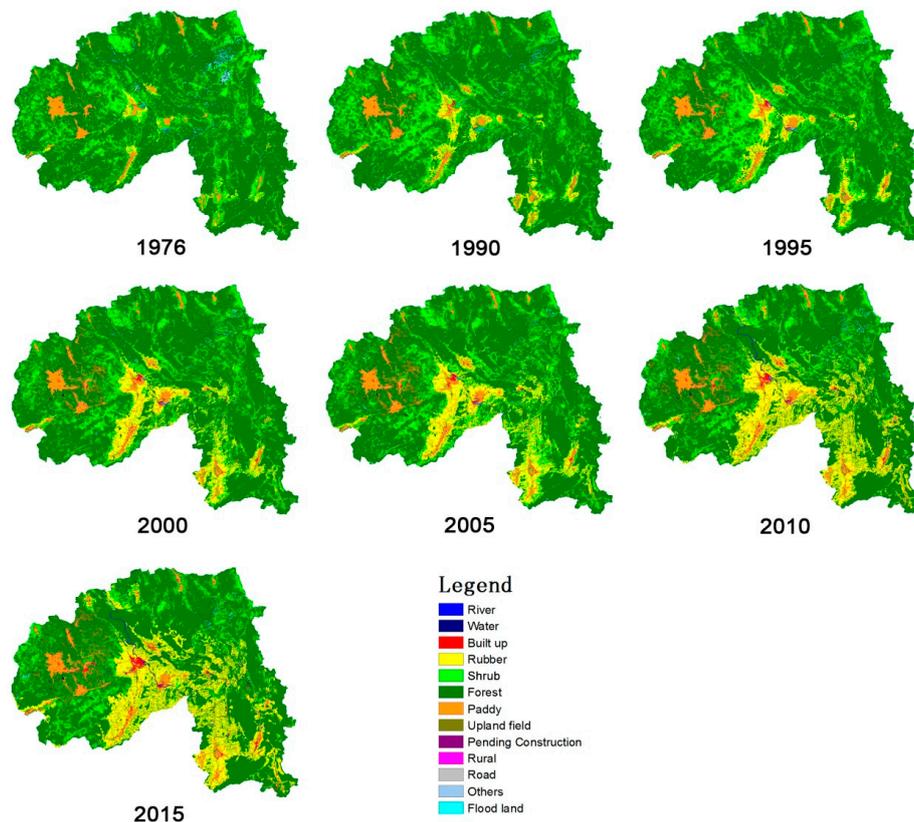


Figure 3. Land use maps from 1976 to 2015.

From Table 3, the area of rubber increased by more than 12-times from 1976 to 2015. The fastest expansion occurred between 2005 and 2010 by 254.49 km² per year, and the second was between 1995 and 2000 by 193.15 km² per year. Forest kept decreasing in the last few decades, except a slight increasing during the period from 1995 to 2000. Paddy stayed stable relatively, ranging from 730 km² to 840 km². Upland field, which was mainly distributed in central Menghai, increased from 187.76 km² in 1976 to 777.19 km² in 2015. Shrub fluctuated during the last few decades. It was 3713.31 km² in 1976, decreased slightly during 1995 to 2000 and 2005 to 2010 and increased during the other times. Both built up area and rural area experienced rapid expansion in the past. The areas of built up and rural increased from 15.10 km² and 6.24 km² in 1976 to 193.61 km² and 114.95 km² in 2015, respectively. The inter-annual expansion of built up was relatively slow before 1990, but accelerated between 1990 and 2005 and then became even faster since 2005. The area of pending construction was merely 0.03 km² in 1976, while it went up to 33.47 km² in 2015. The significant growth of built up and pending construction area especially between 2010 and 2015 also indicated that built up area would still expand rapidly in the near future.

Table 3. Area and inter-annual change of land use from 1976 to 2015.

Class	Area (km ²)							Inter-Annual Change (km ²)					
	1976	1990	1995	2000	2005	2010	2015	1976–1990	1990–1995	1995–2000	2000–2005	2005–2010	2010–2015
Built up	15.10	40.74	60.12	80.53	97.98	129.03	193.61	1.83	3.88	4.08	3.49	6.21	12.92
Rubber	303.88	801.82	1036.88	2002.65	2456.00	3728.47	4077.05	35.57	47.01	193.15	90.67	254.49	69.71
Shrub	3713.31	3968.51	4323.63	2945.92	2993.34	1736.86	1781.44	18.23	71.02	−275.54	9.48	−251.30	8.92
Forest	13,758.25	12,901.05	12,241.98	12,326.49	11,740.89	11,478.11	11,039.05	−61.23	−131.81	16.90	−117.12	−52.56	−87.81
Paddy	733.67	772.58	816.77	838.94	791.35	818.70	788.54	2.78	8.84	4.43	−9.52	5.47	−6.03
Upland field	187.76	266.64	290.44	577.69	688.19	785.36	777.19	5.63	4.76	57.45	22.10	19.43	−1.64
Pending construction	0.03	0.97	3.30	0.75	5.86	12.45	33.47	0.07	0.47	−0.51	1.02	1.32	4.20
Rural	6.24	10.12	21.85	25.65	38.90	85.98	114.95	0.28	2.35	0.76	2.65	9.42	5.80
Road	0.35	4.30	4.26	9.14	13.59	21.01	20.96	0.28	−0.01	0.98	0.89	1.48	−0.01
Others	229.09	130.77	87.56	82.52	66.03	85.38	50.20	−7.02	−8.64	−1.01	−3.30	3.87	−7.04
Flood land	6.27	9.20	4.73	5.54	6.10	4.03	0.25	0.21	−0.89	0.16	0.11	−0.41	−0.76
River	95.25	122.18	124.39	117.54	114.75	118.32	122.46	1.92	0.44	−1.37	−0.56	0.71	0.83
Water	6.27	28.71	39.27	41.40	43.68	52.24	56.01	1.60	2.11	0.43	0.45	1.71	0.75

Notes: Inter-annual change = [Area(T2) − Area(T1)]/(T2 − T1). For example, the inter-annual change of 1976 to 1990 equals (40.74−15.10)/(1990−1976).

3.2. Process of Urban Expansion

As shown in Table 4 and Figure 4, shrub and paddy contributed most to urban expansion, and there were specific orientations of urban expansion. The city proper mainly expanded in the directions of west of northwest and southwest by 2015. The county town of Menghai expanded towards west and northeast, and the expansion directions of the county town of Mengla were northeast and south, generally. The detailed expansions of the city proper, the county town of Menghai and the county town of Mengla during different periods are described as follows.

Table 4. Contribution rate matrix of urban expansion from 1976 to 2015.

Class	1976–1990 (%)	1990–1995 (%)	1995–2000 (%)	2000–2005 (%)	2005–2010 (%)	2010–2015 (%)
River	0.45	0.16	0.44	0.41	1.46	0.56
Water	0.44	1.14	0.71	1.52	1.60	3.16
Rubber	1.63	0.76	8.24	1.33	5.97	31.46
Shrub	52.27	71.16	47.01	35.45	34.06	16.88
Forest	3.05	0.35	0.75	-	0.73	1.54
Paddy	41.88	23.36	35.92	53.88	44.16	33.40
Upland field	0.21	1.33	0.40	2.25	7.16	3.38
Pending construction	-	1.48	6.22	0.26	1.27	6.03
Rural	-	-	-	4.43	0.51	0.95
Road	0.06	0.25	0.06	0.25	1.97	1.82
Others	-	-	-	0.05	-	-
Flood land	0.02	-	0.23	0.18	1.11	0.83

Notes: “contribution rate” means during a certain period, the proportion of other land use types that were transformed into built up area.

Period 1 (1976 to 1990): The overall built up area increased from 15.1 km² to 40.74 km², with an annual growth rate of 1.83 km² (Table 3). Shrub and paddy contributed most (above 90%) to the expansion of built up area (Table 4) during this period. The city proper, the county town of Menghai and the county town of Mengla increased by 6.13 km², 2.48 km² and 0.70 km², from 3.07 km² to 9.2 km², 0.89 km² to 3.37 km² and 1.15 km² to 1.85 km², respectively. The city proper mainly expanded towards southwest with the construction of the Jinghong Theater, the buildings of the Xishuangbanna Bureau of Housing and Urban-Rural Construction, Peacock Lake Park and Xishuangbanna International Airport, which impacted the development of Xishuangbanna significantly. Menghai expanded more along the directions of southwest and north. The outpatient building of Menghai Hospital, Menghai Cinema and the building of the Workers’ Club were constructed during those years. Urban area in Mengla did not increase too much before 1990. Only a few buildings, such as the Department Store and Mengla Stadium were built.

Period 2 (1990 to 1995): Shrub and paddy were still the major contributors to the expansion of built up area. However, shrub contributed more (71.16%), while paddy contributed less (23.36%) during this period. City proper kept expanding towards the southwest with the annual growth of 0.53 km². The mansion of Xishuangbanna and National Stadium were built within these years. The directional growth of Menghai was not obvious, while Mengla expanded greatly towards the northeast.

Period 3 (1995 to 2000): There was a slightly decreasing trend for the contribution of shrub and paddy, and rubber accounted for 8.24% of the increased built up area. The city proper, the county town of Menghai and the county town of Mengla increased by 5.87 km², 0.79 km² and 1.22 km², respectively. The city proper still expanded towards southwest with the construction of Xishuangbanna Library, Broadcasting and TV Center and the first high-grade road (Airport First-class Highway) in Xishuangbanna. Northwest was also explored with the construction of Jinghong Business and Travel Pedestrian Street, which was the largest investment business at that time. The northern part of Xishuangbanna started to develop since the completion of Xishuangbanna Bridge crossing over Lancang River. Menghai and Mengla expanded along southwest and south, respectively.

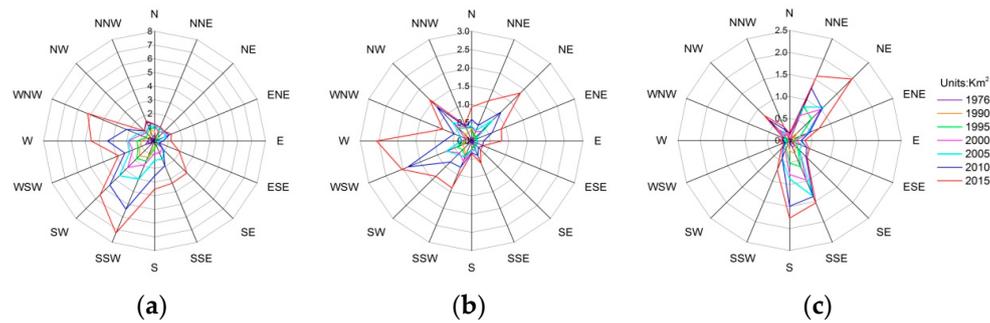


Figure 4. Spatial orientation of urban expansion, 1976 to 2015. (a) The city proper; (b) the county town of Menghai; (c) the county town of Mengla.

Period 4 (2000 to 2005): The contribution of paddy exceeded 50%, while the added built up area transferred from shrub decreased to 35.45%. The city proper, the county town of Menghai and the county town of Mengla increased by 4.28 km², 0.73 km² and 1.12 km², respectively. The most significant urban expansion occurred in the direction of the south, with the construction of Jinghong South Passenger Station and Xishuangbanna Procuratorate. Besides, Jinghong Port was built at the northern shore of Lancang River in 2004. The Menghai Grain Wholesale Market and Menghai Passenger Station were built around the center of the county town, and Menghai Industrial Park started construction in the northeast during this period. Nanla City Square of Mengla was completed in the southeast and close to the center of the county town in 2004.

Period 5 (2005 to 2010): Besides paddy and shrub, rubber and upland field accounted for 5.97% and 7.16% of the increased built up area. The urbanization of the whole Xishuangbanna stepped into a new stage during this period. The city proper, the county town of Menghai and the county town of Mengla increased from 22.06 km², 6.17 km² and 6.95 km² to 33.17 km², 10.87 km² and 8.97 km², respectively. Jinghong Industrial Park, which was located in the northwest of the city proper and played the most significant role in inviting investment, was starting to be constructed at the end of 2006. Another important project was the extension of Xishuangbanna International Airport started in 2008. Menghai expanded towards northwest, northeast and west of southwest during this period, while Mengla mainly expanded in the direction of northwest, northeast and south, with the construction of Tenglong Square and Sewage Treatment Plant.

Period 6 (2010 to 2015): Xishuangbanna experienced an unprecedented urbanization during this period. Paddy, rubber and shrub took the top three contributions to urban expansion. The city proper, the county town of Menghai and the county town of Mengla increased by 14.75 km², 6.71 km² and 2.76 km², respectively. The city proper kept expanding towards west of northwest and southwest with the construction of Xishuangbanna International Resort and Xishuangbanna Social Welfare Home, etc. The northern shore of Xishuangbanna was further developed with the major project of the Gaozhuang-Xishuangjing Tourism Resort. Menghai also expanded rapidly in the directions of west, northwest and southwest, with continuous development of Menghai Industrial Park and the construction of Menghai People's Court. Mengla, at the same time, kept expanding mainly towards south and northeast. More importantly, national road G203 passing through the county town of Mengla started to be constructed during this period.

3.3. Urban Expansion Impact on Land Use Pattern

3.3.1. Dynamics of Land Use Types due to Urban Expansion

In this section, how land use pattern outside built up areas changed in response to urban expansion was analyzed using the gradient-direction method. In the gradient-direction maps, the land use type with the largest area in each segment was selected and displayed. The three most important built up areas, including the city proper, the county town of Menghai and the county town of Mengla, were

analyzed to help with visualizing and understanding their impact on the spatial-temporal dynamics of land use pattern.

In 1976 (Figure 5a), the land use types outside the city proper were mainly paddy, rubber, shrub and forest, accounting for about 11%, 21%, 26% and 36%, respectively. The city proper was mainly surrounded by shrub, and rubber was distributed in the left side of Lancang River surrounding paddy. Since then, rubber has been expanding dramatically, while shrub and forest kept decreasing. By 2010, shrub almost disappeared, while paddy remained nearly unchanged. However, with accelerating urban expansion in recent years, a large area of paddy was transformed into urban land. By 2015, the area outside the city proper was dominated by rubber, with barely any shrub, 5% of paddy and 12% of forest.

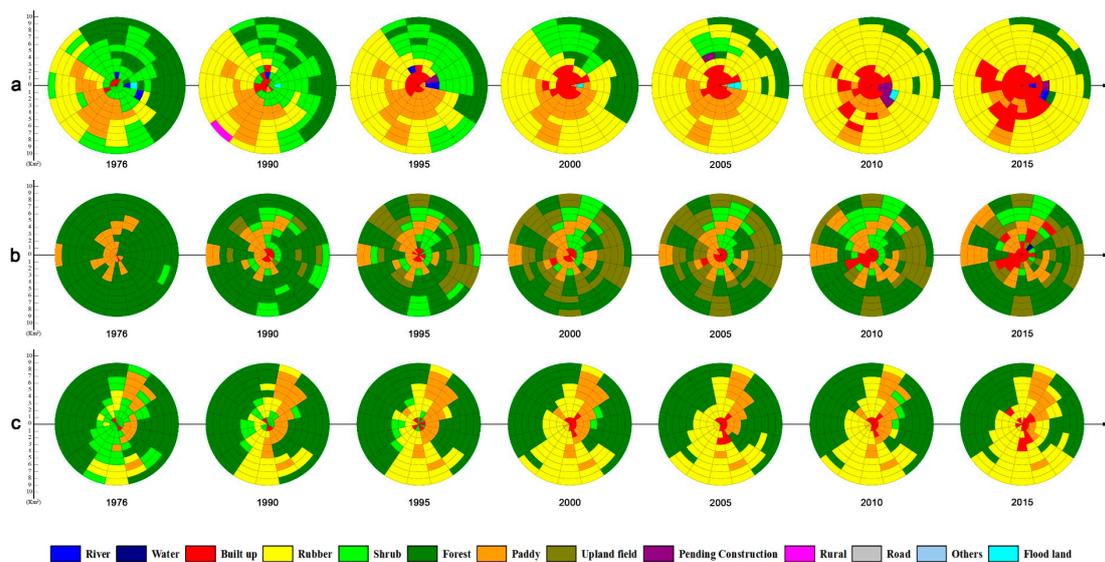


Figure 5. Dynamics of the land use pattern outside of built up areas. (a) Dynamics of the land use pattern outside the city proper within an area with a 10-km radius; (b) dynamics of the land use pattern outside the county town of Menghai within an area of a 9-km radius; (c) dynamics of the land use pattern outside the county town of Mengla within an area of a 9-km radius.

Confined by altitude and climate conditions, there was no massive rubber plantation in Menghai (Figure 5b). The land use pattern was simple in Menghai before the reform and opening up. The county town of Menghai was surrounded by paddy, which accounting for 12% of the total area, and forest (58%) dominated the rest of the area. After that, forest was exploited and turned into upland field and economic shrub. More than half of the forest outside the county of Menghai disappeared in the last 40 years. A slight growth of paddy from 12% in 1976 to 14% in 2015 could be seen as the compensation mechanism to defend the red line of 1.8 billion mu of farmland.

The county town of Mengla, which was distributed within the radius of 1 km from the center, was surrounded mainly by shrub in 1976. Rubber plantation was also a typical trend outside the county town of Mengla (Figure 5c). Since Mengla National Nature Reserve was located in the northwestern and eastern part, the added rubber mainly came from shrub outside the county town of Mengla and forest in the southern part outside protected area. However, by 2015, there was still a small area of forest at the edge of Mengla National Nature Reserve transformed into rubber.

Generally, the expansion of rubber plantation and deforestation were the common trends in response to urban expansion, especially in Jinghong, Mengla and the southern part of Menghai. The rest of the area of Menghai was mainly characterized by the development of upland field and economic shrub. Although forbidden by laws and regulations, there was still a small area of rubber planted at the margin of national nature reserves by the local community.

3.3.2. Landscape Diversity along Urban-Rural Gradients

From Figure 6, patch density increased along urban-rural gradients from 1976 to 2015 in general. Figure 6a showed the variation of patch density along the first urban-rural gradient (G1). The first peak appeared at the ninth sampling block in Mengyang town, the second at around the 33rd sampling block in the fringe between the city proper and rural area and the last at 117th block in Daluo town. In the second gradient (Figure 6b, G2), several peaks appeared at both sides of the urban-rural fringe around the city proper, and the rest of the peaks were located in Gasa town and Menglong town. The city proper showed relatively lower values of patch density in both G1 and G2. G3 (Figure 6c) extended along the national road G214, and patch density increased in most sampling blocks. Peaks also appeared in the fringe between the county town of Menghai and the rural area. The values of the patch density kept small and varied slightly between the 42nd and 55th sampling blocks, because these blocks were located within Mengzhe town where the land use pattern was dominated by paddy field and had no obvious change since 1976. G4 (Figure 6d) showed a similar trend with G3, except that there was one peak appearing at the end of the gradient in Mengman town.

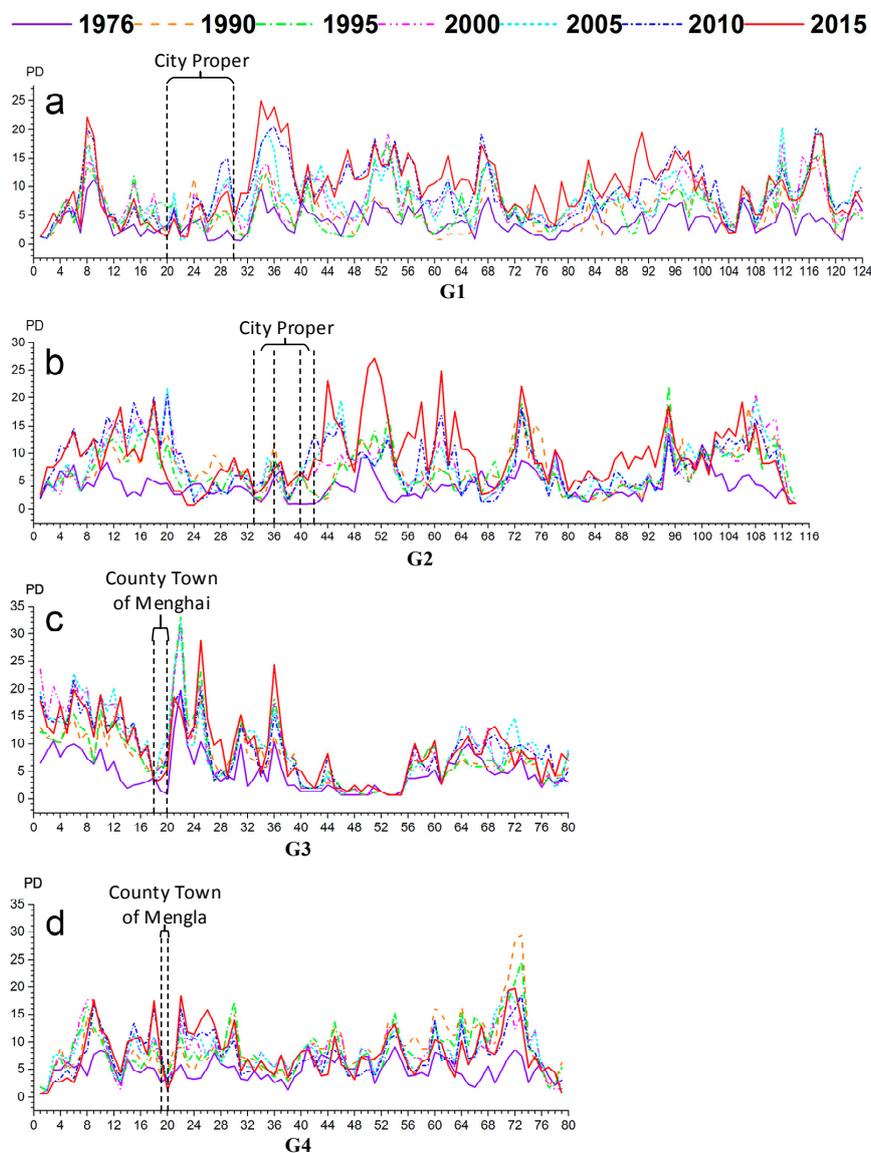


Figure 6. (a–d) Patch Density (PD) along four urban-rural gradients. X-axes represent the number of sampling blocks from the starting directions.

Generally, Shannon's Diversity Index (SHDI) also displayed an increasing trend from 1976 to 2015 as shown in Figure 7, indicating that the land use pattern became more diversified in the process of urban expansion and development. This trend was particularly obvious at the urban fringe, road and small towns along the four gradients. Landscape diversity was relatively low in the city proper, the county town of Menghai and the county town of Mengla, because most of these areas were covered with built up area.

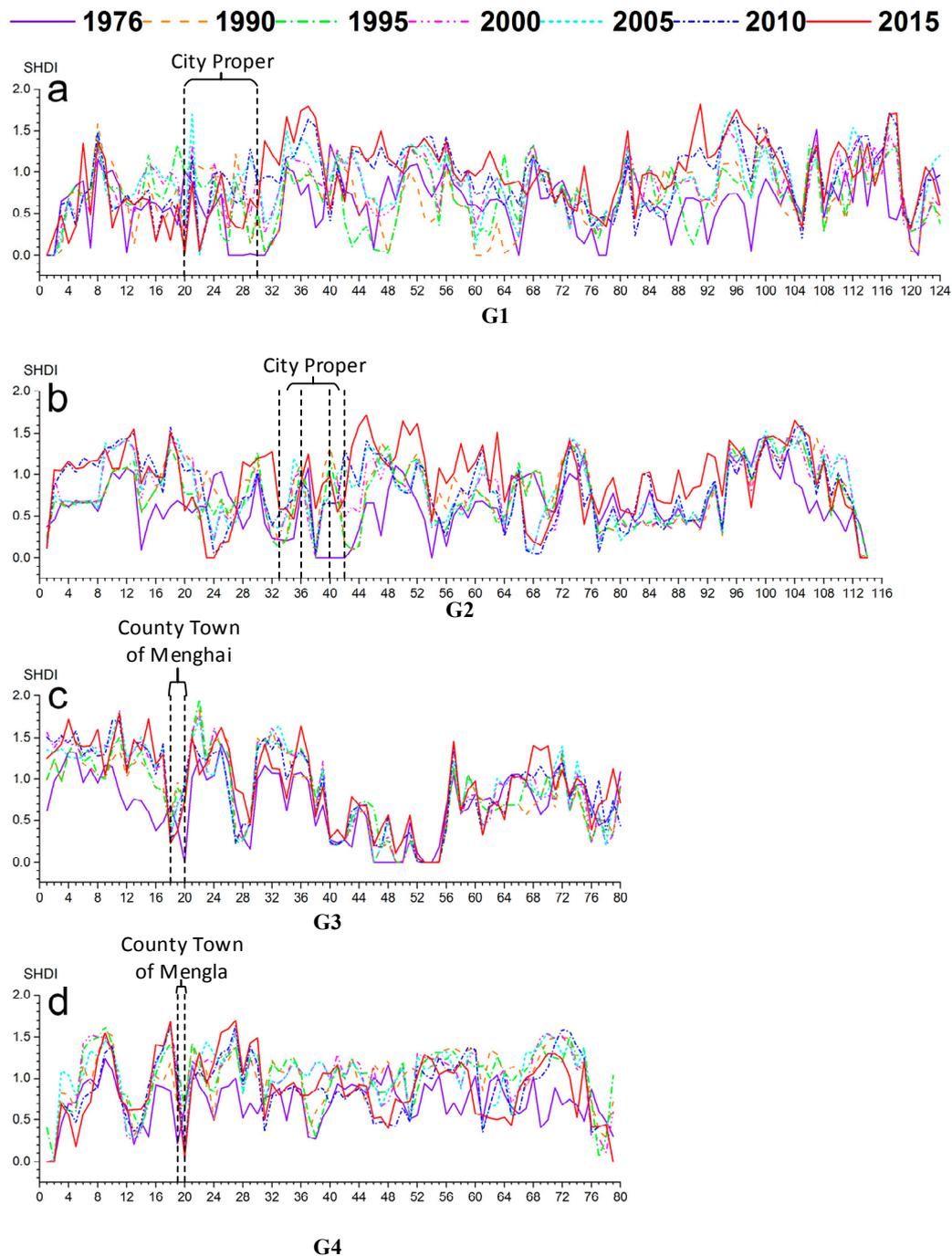


Figure 7. (a–d) Shannon's Diversity Index (SHDI) along four urban-rural gradients. X-axes represent the number of sampling blocks from the starting directions.

Figure 8 shows us the variation of Shannon's Evenness Index (SHEI). The higher the value of SHEI is, the more even the distribution of patch types will be. There were no obvious changes at most

sampling blocks, except some unique blocks. Generally, there are two types of exceptions. One is that SHEI was relatively high before, but decreased afterwards. For example, some places might be covered by multi-land use types, such as forest, paddy or shrub in 1976, but eventually turned to rubber in 2015. The other has the opposite trend. This situation happened where some places might be dominated by forest or shrub in 1976, but developed into low density developed areas, which were covered by several land use types. The value of SHEI was also lower in the city proper, the county town of Menghai and the county town of Mengla, since these areas were dominated by built up area.

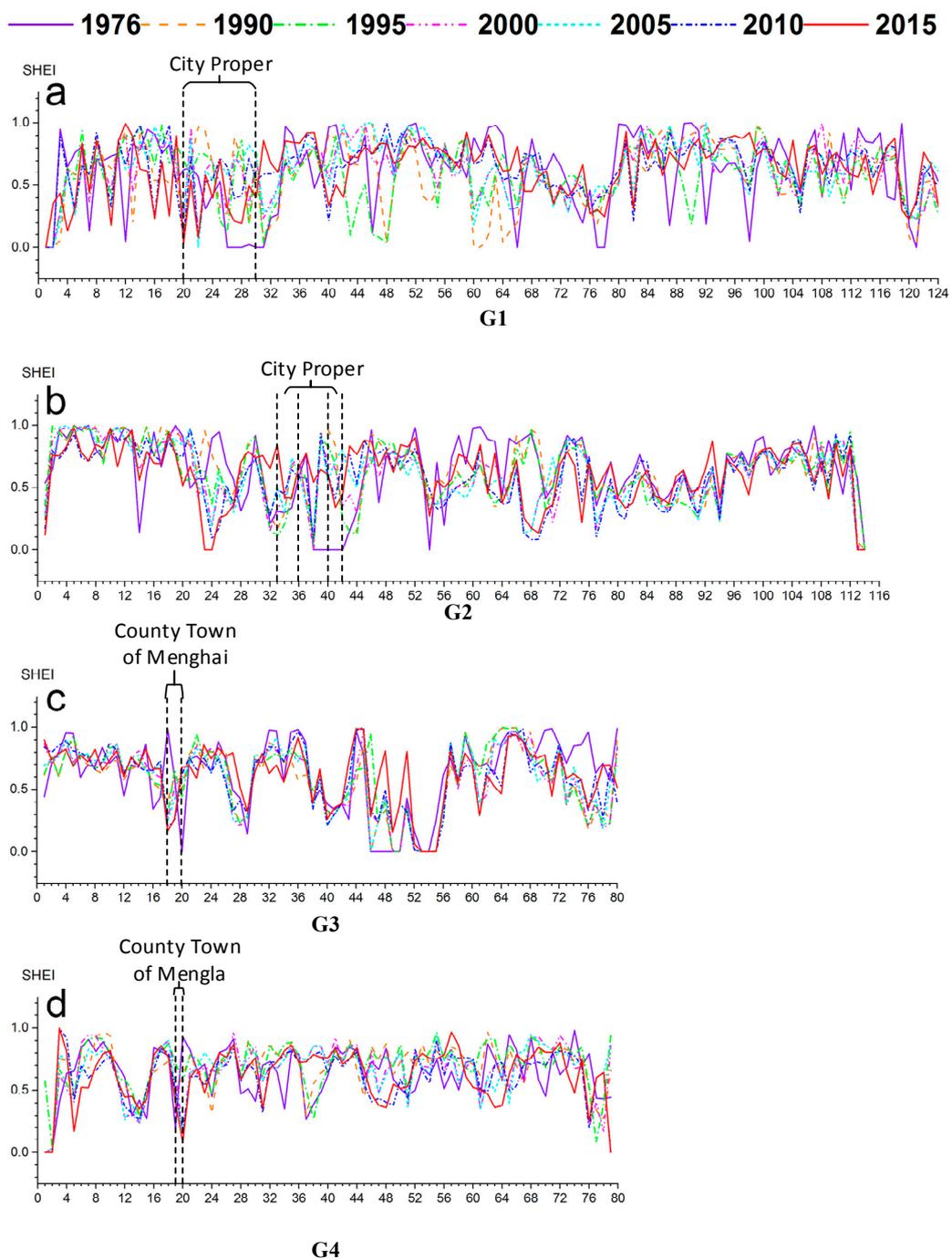


Figure 8. (a–d) Shannon’s Evenness Index (SHEI) along four urban-rural gradients. X-axes represent the number of sampling blocks from the starting directions.

Among the four urban-rural gradients, most of the sampling blocks, except the city proper and small towns, were located along corridors, such as rivers and roads. Generally, both PD and SHDI showed an increasing trend at these blocks and indicated that corridors increased land fragmentation and landscape diversity in the last few decades.

3.3.3. Landscape Configuration and Composition at the Scale of the Whole of Xishuangbanna

Although the area variation of built up was quite small compared to the scale of the whole of Xishuangbanna, the changes of the configuration and composition of the land use pattern caused by urban expansion should not be ignored. In this section, CONTAG, COHESION, DIVISION and AI were selected to reflect fragmentation, connectivity and agglomeration of land use types in Xishuangbanna at both the landscape level and class level.

At the landscape level, CONTAG (Table 5) decreased from 79.4108 in 1976 to 69.0123 in 2015, which indicated that land use types became more disaggregated and the degree of land fragmentation increased in the past 40 years.

Table 5. Variation of landscape configuration and composition.

Level	Landscape Metrics	Class	1976	1990	1995	2000	2005	2010	2015
Landscape Level	CONTAG		79.4108	75.4637	74.0361	72.1619	70.7705	69.7569	69.0123
	COHESION	Forest	99.9926	99.9621	99.9557	99.9552	99.9492	99.9402	99.927
Rubber		98.7481	98.9433	99.342	99.5554	99.581	99.7762	99.7871	
Class Level	DIVISION	Forest	0.836	0.936	0.9446	0.9465	0.9525	0.9542	0.9608
		Rubber	1	1	0.9999	0.9997	0.9996	0.9984	0.9983
	AI	Forest	97.9951	96.9081	96.7486	96.7862	96.6815	96.1578	96.0264
		Rubber	94.3915	93.5737	94.1102	93.3902	93.647	93.7818	94.5192

Forest and rubber were analyzed at the class level, because these two types accounted for the largest area in Xishuangbanna and were closely associated with the condition of the environment and ecosystems. Due to the scale of Xishuangbanna, the variation of COHESION, DIVISION and AI was gradual. For forest, COHESION kept decreasing from 1976, while DIVISION increased from 0.836 in 1976 to 0.9608 in 2015. These two parameters together indicated that forest became less physically connected. The decreasing tendency of AI illustrated that forest turned to being disaggregated and subdivided. On the contrary, rubber showed an increasing tendency on connectivity and kept aggregating after 2000. Since rubber tapping is a labor-consuming work, the aggregation and good connectivity of rubber plantations could make rubber management easier.

4. Discussion

4.1. Urban Expansion in Xishuangbanna

Since the reform and opening up of China, Xishuangbanna experienced fast urban growth, especially after 2005. Urban land expanded from about 15 km² in 1976, to 97 km² in 2005 and reached more than 190 km² in 2015. The explosive increasing trend of fixed assets investment (Figure 9) manifested the accelerating urban expansion since 2005. Although growing fast, the urban area only covered about 1% of the total land use in 2015, which means Xishuangbanna has potential still in urban development. Besides, the Xishuangbanna New Urbanization Plan (2014–2020) promulgated in 2014 highlighted the strategy to accelerate the urbanization process and promote the urbanization layout, quality and culture. Pending construction land also kept increasing in recent years (Table 3). All of these signals indicate that urban area will keep expanding rapidly in the near future.

Based on the process of urban expansion, the city proper can be divided into four zones. The downtown area lies along south bank of Lancang River, and most municipal departments are located in this zone. In the first 20 years of the reform and opening up, almost all of the urban expansion in the city proper happened here. The second zone is located at the south of the downtown

area and developed along several main roads, like the Airport Highway and Mengle Ave. This area started to develop in the late 1990s when the roads were constructed. The third zone is located at the north bank of Lancang River. The construction of Xishuangbanna Bridge enhanced the connection of the downtown area and this zone, and a series of tourist resorts were built in the south of this zone, consequently. Although Jinghong Industrial Park, which lies in the northwest of the city proper, is still under construction, this zone has already made a significant contribution toward the economic development of Xishuangbanna. The county town of Menghai includes two zones: the central area and Menghai Industrial Park. Menghai Industrial Park, which was constructed in the early 2000s and is separated from the central area, lies in the northeast. The county town of Mengla is mainly developed along several main roads. In Xishuangbanna, these urban areas are largely confined by terrain (Figure 1). The extent of the city proper has already reached the edge of the mountainous region. There are two options for further development of the city proper (Figure 5a). One is to convert the rest of the land use types in the center of Jinghong. Currently, paddy and rubber are the two main land use types around the center of Jinghong. Paddy was well protected before 2005; however, more than half of the paddy was transformed into built up area since then. Considering that, the conversion from paddy to built up areas is not recommended. Rubber, which lies between the downtown area and Jinghong Industrial Park, may contribute to urban expansion in the city proper. The other option is to develop the Gasa town in the southwest of the city proper and close to Xishuangbanna International Airport. The Xishuangbanna New Urbanization Plan (2014 to 2020) also comes up with ideas to incorporate Gasa town into the center of Jinghong at an appropriate occasion. In the county town of Menghai, the area between the central area and Menghai Industrial Park has great potential for urban expansion. As for the county town of Mengla, the construction of the G203 national road might lead to a new round of urban expansion.

For urban planners or policy makers, the rubber plantation around most urban areas should be taken seriously. Before the reform and opening up, Xishuangbanna was at quite a low level of urban development, like many other cities in China, and agriculture accounted for more than 70% of the GDP. Thus, urban planners could not foresee the dramatic urban development. Since rubber is the pillar industry in Xishuangbanna, rubber plantations around built up areas were not controlled at that time. However, with fast urban expansion, rubber in these areas has already collided with urban development. On the one hand, the compensation mechanism is more complicated since the conversion from rubber to built up area is not cost effective. This will affect investors' interests to some extent. On the other hand, rubber has a negative impact on urban eco-environmental conditions. Besides, the urban green space in the newly-built urban areas could also be affected because of water and soil degradation [39,40]. Therefore, this situation must be addressed in urban planning and development.

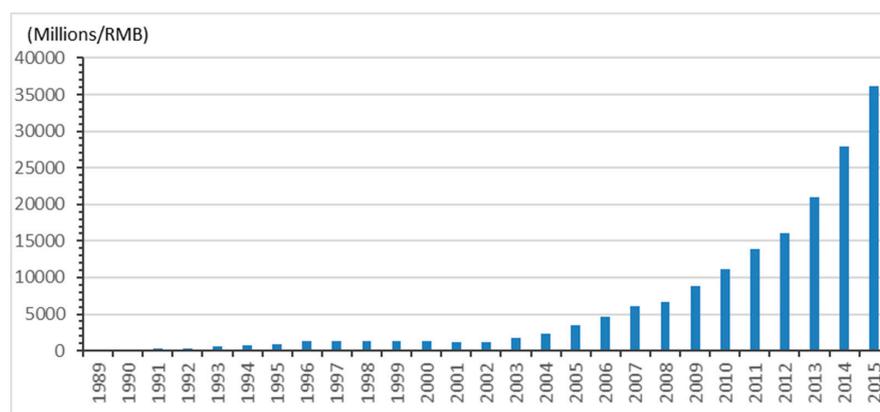


Figure 9. Fixed asset investment in Xishuangbanna from 1989 to 2015 (data from Yunnan Statistical Yearbooks).

4.2. Threats of Rubber Plantations

Due to the state's interest in achieving self-efficiency in rubber production, rubber was introduced into Xishuangbanna in the 1950s. However, rubber was mostly planted on state farms at that time. Since the land tenure reform in the 1980s, with the government incentive policy and the rising prices of natural rubber, rubber plantations not only by state farms, but also by smallholders had been flourishing [53]. Consequently, the livelihood of those smallholders became vulnerable, since the rubber trees, especially seedlings and immature rubber trees, are quite sensitive to frost or other chill injuries [45,54]. The area of rubber expanded by over 12-times in the past few decades and covered more than 25% of the whole of Xishuangbanna by 2015. Considering the convenience of management and transportation [55], rubber was mainly planted around urban areas, rural settlements, roads and rivers. Thus, the expansion of urban areas and the development of the road network enhanced the connectivity and aggregation of rubber (Table 5), while also leading to negative impacts on biodiversity, especially insects, such as beetles, spiders and wild bees [56,57]. In 1991, the Regulations on Lancang River Basin Protection in Xishuangbanna was passed for the purpose of the protection and rational exploitation of Lancang River Basin. The regulations stipulated that economic plantations, especially rubber plantations, should not expand within the shelterbelt in the basin, because rubber has a negative impact on runoff generation [58]. However, after 20 years of exploitation, the Lancang River banks, especially the lower reaches, were largely covered by rubber (Figure 3). The rapid rubber plantation expansion also brought huge pressure on the forest. A large area of forest was transferred to rubber since the reform and opening up. To protect forest from deforestation and degradation, the Regulations on the Protection of Forest Resources in Xishuangbanna and the National Natural Forest Protection Program were promulgated in 1992 and 1998, respectively. These actions led to a slight increase of forest by 2000 (Table 3). As a result of these laws, the rate of forest loss declined, and instead, more shrub land was converted to rubber after 2000. Compared to rubber, natural forest functions better in controlling splash erosion [59] and soil erosion (e.g., pH and soil nitrogen) [60]. Soil erosion in monoculture rubber plantations is 40-times more than that in natural rainforest [55]. Soil erosion and hydrological problems could then lead to a potential threat of landslide because large areas of rubber were converted from natural forest and planted in the slopes.

Although rubber expanded dramatically in the past few years, there was a great depression of rubber prices by the end of 2008 [61]. Consequently, the increasing trend of rubber plantations was slowed down after 2008, and rubber only expanded about 350 km² from 2010 to 2015 (Table 3). This is a good occasion to effectively control rubber plantation and restore natural forest for sustainable development. Local government and policy makers need to find market-based solutions and eco-compensation mechanisms for forest restoration, rather than direct governmental subsidies [41,62]. Recently, the rethinking of ecological governance based on indigenous land use experiences and knowledge is addressed to promote the local sustainability of rubber plantations [55,63].

4.3. Land Fragmentation and Its Effect

The decreasing of the CONTAG index at the landscape level indicates the trend of land fragmentation. Besides, the number of land use patches increased by more than two-times from 1976 to 2015. Considering topographic fluctuation, land fragmentation will increase the difficulty of land management in Xishuangbanna. Specifically, for agriculture, the fragmented farmlands would lead to low efficiency in crop production and the profit of economic plantations [64]. For forest, more than 2500 km² natural forest, which can effectively purify the air and conserve underground water, were converted to rubber and other land use types since 1976. Besides, forest became dispersed and less connected geographically in the last few decades. Consequently, the loss and fragmentation of natural forest leads to the reduction of wildlife habitat [65,66].

The analyses of patch density, Shannon's diversity index and Shannon's evenness index reveal the trend of land fragmentation along urban-rural gradients. Firstly, due to the agglomeration effect of built up and residential areas, the city proper, the county town of Menghai and the county town

of Mengla have lower degrees of landscape fragmentation and diversity. Secondly, lower density developed areas along roads, rivers and small towns are usually of the greatest landscape diversity and fragmentation [42–44]. Different from urban life, people are still partially living on land in low density developed areas. Therefore, the intensive land use activities along roads, rivers and small towns will form a barrier-network and affect the migration and communication of wild animals and plants. For example, there are two separate areas of Mengla National Nature Reserve located at each side of the county town of Mengla. These areas are connected by the shrub and forest corridor; while this corridor was almost destroyed in the process of rubber expansion and agricultural activities around the county town of Mengla. Since the habitat and corridors of wildlife are endangered, there is an increasing trend of conflicts between humans and wild animals in recent years [67,68]. This situation sounds an alarm that local government should consider the balance between urban expansion and biodiversity conservation.

5. Conclusions

In this paper, we employed radar graphs, the gradient-direction method and landscape metrics for the analysis of urban expansion and its impact on the land use pattern in Xishuangbanna. Land use dynamics were firstly identified. Rubber expansion, deforestation and urban expansion were the most significant characteristics of land use changes in Xishuangbanna. Rubber increased more than 3500 km², while forest decreased more than 2500 km² since 1976. Built up area increased by almost 12-times from 1976 to 2015, and most added built up area was converted from shrub and paddy.

Land use pattern was dramatically changed in the process of urban expansion. The city proper and most towns in Jinghong, Mengla and the southern part of Menghai were surrounded by rubber by 2015; while upland field and economic shrub expanded outside the rest of the towns in Menghai. Through the analysis of patch density, Shannon's diversity index and Shannon's evenness index, the greatest landscape diversity and fragmentation existed in low density developed areas, such as the urban-rural fringe and small towns. Landscape diversity decreased in the real urbanized areas, such as the city proper. In the scale of the whole of Xishuangbanna, land use patches turned to being more fragmented with the agglomeration of rubber and the dispersion of forest.

Generally, the urban area will keep expanding in the near future. The city proper could further expand through either developing Gasa town southwest of the city proper or converting rubber between Jinghong Industrial Park and the downtown area into urban land. The county town of Menghai may further develop the area between the central area and Menghai Industrial Park, while the county town of Mengla could expand along G203. For the urban development of Xishuangbanna, no more rubber should be planted around urban areas. Rubber plantations also threaten natural forest and biodiversity and lead to soil and water degradation. Therefore, there is an urgent need for sustainable measures on rubber management and reforestation, such as eco-compensation mechanisms and ecological governance, combining science and indigenous knowledge. Land fragmentation is another problem that will make land management more difficult and increase conflicts between humans and wildlife. Urban planners and policy makers should find solutions to balance urban development and biodiversity conservation.

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