Spatial-Temporal Monitoring of Urban Growth: A Case in Kunming, Southwest China

Min Liu[1,2], Zhiming Zhang[1], Hongli Zhang[1], Mingyu Yang[1], Ding Song[3], and Xiaokun Ou[1(✉)]

[1] Institute of Ecology and Geobotany, Yunnan University, 2 Northern Green-Lake Road, Kunming 650091, China
{minliu14, xkou}@ynu.edu.cn

[2] Yunnan Key Laboratory of International Rivers and Transboundary Eco-Security, Yunnan University, 2 Northern Green-Lake Road, Kunming 650091, China

[3] Kunming University of Science and Technology, No. 727 South Jingming Road, Chenggong 650500, China

Abstract. With the rapid growth of urban population and economic development, the urban growth has also accelerated dramatically. The paper monitored the urban growth of Kunming by detecting the land use change after supervised classification and analyzing urban expansion rate and intensity index in 1974–2013. The result shows the urban has experienced rapid expansion. Moreover, since 1992 the spatial extension has speed up. The main source of land expansion were farmland, woodland and grassland. And the urban expansion is expanding rapidly to the southeast, northwest and northeast with the old city as the core in Kunming. The urban growth is mainly affected by the natural terrain, economy, population and administrative factors. The study summarized the regularity of expansion and the driving force factors of the city growth, and provide a basis theory for future urban healthy development and provide experience for relevant government and scholars.

Keywords: Urban expansion · Land use change · Remote sensing · Dynamic monitoring · Kunming city

1 Introduction

LUCC (Land Use/Cover Change) research has become hot topics of global change, in where the urban growth (sprawl) is the main content [1–6]. The contemporary urbanization differs markedly from historical patterns of urban growth in terms of scale (large-scale), rate (high speed), location (Europe and America transferred to Asia and Africa) and form (expansion of concentric circles to complex forms), especially concentrated in developing countries [7, 8]. China as the world's fastest growing economy since reform and opening up in 1970s, experienced a rapid urbanization process with a urbanization rate of 17.16 % in 1974 to 53.7 % in 2013 [9]. Urbanization process not only is the concentration of population and economy, especially a geographical space change process, and the urban expansion is a significant characteristics [10, 11].

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With the urban growth, there are great changes in urban land use structure with sharp increase of urban land and a large reduction of non urban land resources such as farmland, which cause more serious problems of the conflict between people and the environment. In recent years, the research on urban land use is getting more and more attention, mainly concentrated in the urban growth pattern change and driving force analysis [12–17]; urban expansion morphology and growth pattern [20–22]; the environment and global change effects of urban growth [23–25]; and urban development simulation research [26–31]. The combination of RS and GIS is a effective way to dynamic monitoring and simulating urban growth, because it can grasp the dynamic land space with specific, rapid and quantitative [14, 18, 19, 32]. However, the current domestic urban expansion research case is mainly concentrated in the eastern developed cities, few in middle-west underdeveloped cities [10].

Kunming as the economic, political and cultural center of Yunnan province in southwest China. Its urbanization process is very significant [33]. In recent years, with the upsurge of LUCC research, some researchers have carried out a series of related research work on urban growth feature and driving force of Kunming [35]. The landuse change in the process of urbanization have rarely been studied, which are either lack of large spatial-temporal scale or direct analysis of land use change in urban area [35–37]. In this context, in order to understand the urbanization characteristics and development mechanism in underdeveloped cities in Western China, Kunming city was selected as a typical sample. The paper used supervised classification to extract the land use of the city based on images of 1974, 1992, 2002, 2013 year, to explore the urban growth of Kunming during 40 years, and also attempt to analyze the specific features and driving factors of urban expansion for the plateau city. The study can effectively guide and control the urban growth of Kunming city and will have positive practical significance in reasonably guiding the regional planning and controlling the scale of urban land. It will provide scientific support for scientific and reasonable land use and other related urban development.

2 Study Area

Kunming city (102°10′–103°40′E, 24°23′–26°33′N; 1890 a.s.l.) is the capital and the only one mega-city of Yunnan province in southwestern China, located in the central of Yunnan province. Situated in a lake basin, surrounded by mountains on three sides, the city enjoys a mild, temperate climate and is known as the "City of Eternal Spring", which has experienced rapid urban construction and expansion since 1992. The city began to receive more attention after 1999 when it held the International Horticulture Exposition and was recognized as an international radiation center for South and Southeast Asia. The master plan 2008–2020 of Kunming city identified the main direction of the city development, it is more obvious that the trend of the city development toward the south of Kunming. In this paper, the study area focused on the main city of Kunming (Wuhua district, Panlong district, Guandu district, Xishan district), Chenggong district and Jinning county (Fig. 1).

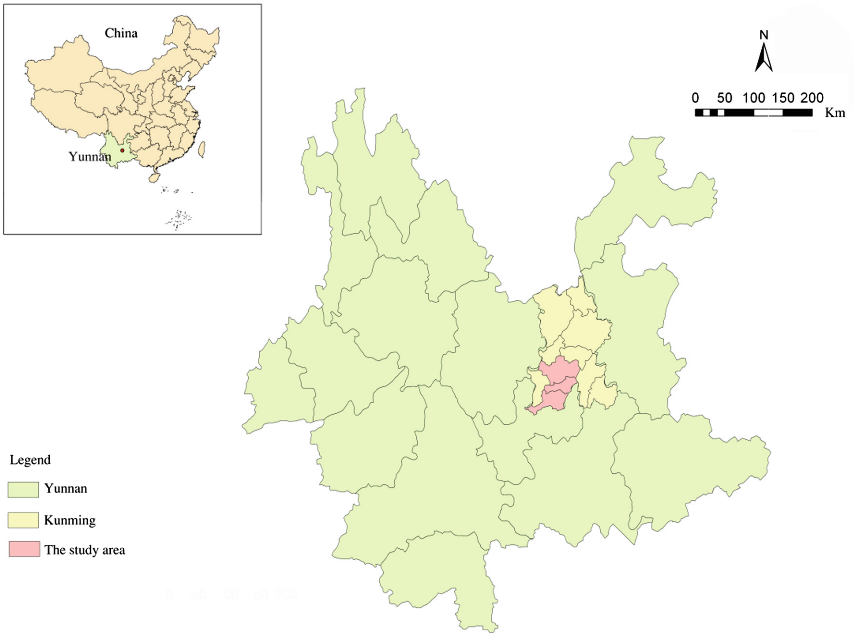


Fig. 1. The location of study area.

3 Materials and Methods

3.1 Data Source

The remote sensing image data of this study were derived from The Geospatial Data Cloud platform (http://www.gscloud.cn/). Four Landsat imageries of MSS, TM, OLI-TIRS, ETM+ in 1974, 1992, 2002 and 2013 were adopted. Table 1 shows the specific information of data source.

Table 1. The information of remote sensing image data.

Satellite type	Imaging date	Data type	Bands	Spatial resolution	Cloud amount
Landsat1-3	1974.01.20	MSS	4	79 m	0
Landsat4-5	1992.08.16	TM	7	30 m	0
Landsat7	2002.10.07	ETM+	7	30 m	0
Landsat8	2013.04.20	OLI-TIRS	11	30 m	0.01

3.2 Image Data Processing

This research adopted the Landsat images from many periods and multiple sensors, firstly, the four remote sensing images were geo-referenced to the Universal Transverse Mercator (UTM) coordinate system using ERDAS IMAGINE software package, secondly, geometric correction and image fusion and other preprocessing were made. Finally, in order to match the spatial resolution, the images were resampled to 79 m as the Landsat 1–3 images.

3.3 Land Use Classification

Considering the spatial resolution of the acquired satellite images and the focus of the study on land use change and urban expansion, According to current land use classification (GB/21010-2007) and prior researcher's land classification standard, and combining remote sensing image features and land use status of the study area, land use in this study was subdivided into urban, forest land, agriculture land, grass land, water and other land [33]. The current Google Earth image resolution of the study area is up to 0.27 m enough to replace the field sampling to examine the accuracy, so we used Google Earth image data as a reference for obtaining the ground data of training samples and testing samples. The maximum likelihood classifier of supervised classification in IDRISI was used for land use classification, fifty sampling plots for each land use class were randomly selected to divide into training data and testing data for classification and assessing the classification accuracy. After classification, the corresponding merger and other post processing were carried out, and the precision of Kappa coefficient method was used.

The standard false color composite images are used in the process of classification. The phenomenon of different object with the same spectra characteristics and same object with different spectrum often appears in the process of image recognition, which will affect the classification. So we make the original 6 kinds of landuse for detailed classification to set up the corresponding interpretation signs, according to the texture, color and other information of images. For example, urban was divided into white and blue built up area, water can be divided into blue water, black water, etc. Table 2 shows the main features of the interpretation in the study area and 1992 TM fusion image as an example.

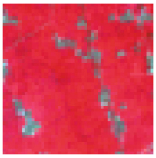
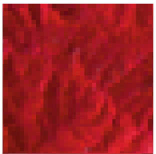
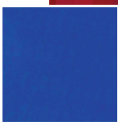
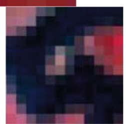
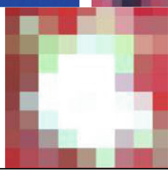
3.4 Urban Growth Monitoring

Urban growth mainly contains area and space change of built-up land. Analysis of land use change is a good way to understand the overall trend of urban sprawl [35, 36]. In this study, the urban expansion rate and the urban expansion intensity are used to reflect the dynamic of urban growth, and the urban spatial expansion rate reflects the average expansion rate, which was calculated by comparing the urban area change of four period in the study area. Its calculation formula is:

$$V = (B - A)/T \tag{1}$$

V is the urban expansion rate; A is the urban area at the beginning of the study; B is the urban area in the end of the study; T is the time interval.

Table 2. Various types of land use interpretation symbol of TM remote sensing image in study area.

Land use	Description	Interpretation instructions(RGB-432)	Image feature
Urban	Including urban and rural residents, transportation facilities and other construction sites (such as industrial area, airport, etc.).	Mainly located in the inner cities, residential areas are light blue, hard court is bright white.	 
Agriculture	Including cultivated land, paddy field, vegetable field, etc.	Mainly has two kinds: slope cropland and paddy field. The former general distributed in the slope on the mountain; the latter distributed in the flat area of the water margin or the edge of the city.	
Forest	Namely, woodland, parks and protective green space, etc.	Mainly distributed in a certain elevation of the mountain, and present a dark red or red.	
Grass	Shrub forest, grass and sparse trees	Generally mixed in forest land, a small amount distributed in the river and the plain area.	
Water	Rivers, lakes, reservoirs, pits and tidal flats.	Mainly has main rivers, lakes and reservoirs and shows blue or bluish black	 
Other land	Bare soil, bare rock, gravel and other construction built land	Including the construction land, bare land, gravel, etc. Mainly distributed in the mountains and nearby rivers , few distributed in nearby the built up area.	

Urban expansion intensity index is an important indicator to reflect the change of urban space, which can be quantitatively shows the urban expansion rate and degree [34]. Its calculation formula is:

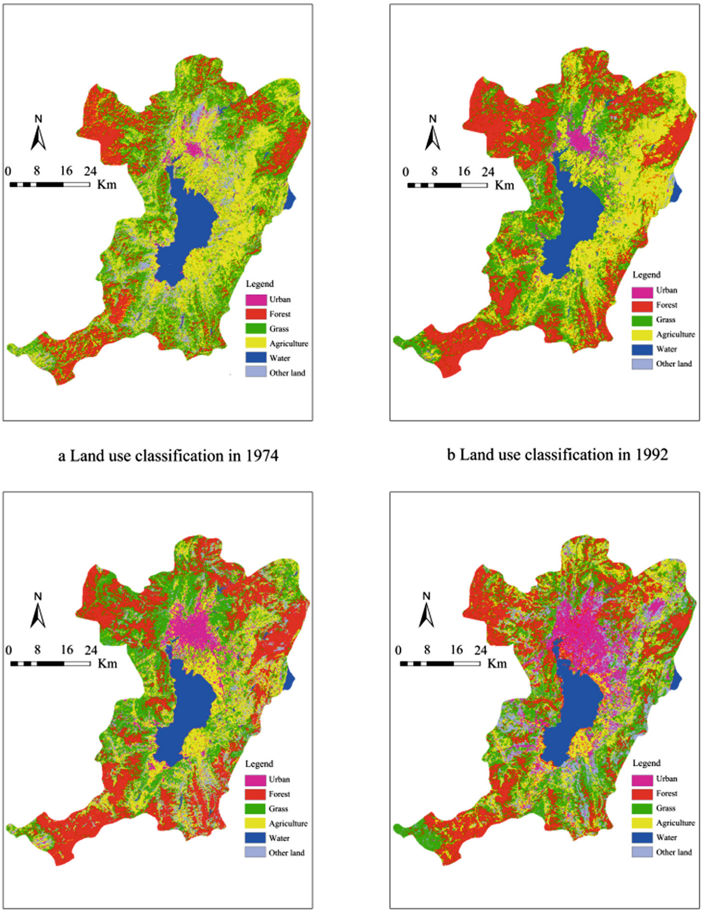
$$R = (B - A)/A \times (1/T) \times 100\%. \tag{2}$$

R is the urban expansion intensity index; A is the urban area at the beginning of the study; B is the urban area in the end of the study; T is the time interval.

4 Results

4.1 The Land Use Change in the Process of Urbanization

The land use classification of the four periods is shown in Fig. 2. The overall accuracy is respectively: 80.58 % (1974), 84.30 % (1992), 86.48 % (2002), 89.82 % (2013), which all meet classification interpretation standards.



a Land use classification in 1974

b Land use classification in 1992

c Land use classification in 2002

d Land use classification in 2013

Fig. 2. Land use of the study area in 1974, 1992, 2002 and 2013.

Four image interpretation results shows there are significant urban expansion and intense land use/cover change in the study area, which reflects in four landuse of urban, agriculture, forest and grass land. During 1974–2013, the urban had substantial increase and the proportion of increased by 7.38 %. In particular, the growth of the last two periods was outstanding with an increase of 3.23 % in 1992–2002 and an increase of 3.25 % in 2002–2013. However, farmland is experiencing sustained and rapid reduction. It was reduced by 15.31 % in recent 40 years from 1974 to 2013. The proportion reduced largest with a decrease of 9.31 % in 1992-2002, followed by 2002–2013 years with a decrease of 3.15 %. The decrease rate of grassland was relatively slow with a decrease of 4.26 % during the last 40 years, and the largest decline in 1974–1992, followed by 1992–2002. Forest had increased during 1974–1992, and decreased by 3.3 % in 1992–2013. Other land use decreased significantly in 1974–1992, while continued to rise in 1992–2013. And the water remained basically unchanged in the entire study period (Table 3).

Table 3. The comparison of land use types of study area in 1974, 1992, 2002 and 2013.

Land use class		Urban	Forest	Grass	Agriculture	Water	Other land
1974	area/hm^2	8546.95	66945.99	139329.45	135510.45	32277.14	32045.7
	percentage/%	2.06 %	16.14 %	33.60 %	32.68 %	7.78 %	7.73 %
1992	area/hm^2	12272.19	112393.7	124468.78	123684.64	33713.35	8123.02
	percentage/%	2.96 %	27.11 %	30.02 %	29.83 %	8.13 %	1.96 %
2002	area/hm^2	25668.25	109821.72	122807.06	85067.36	31500.93	39790.35
	percentage/%	6.19 %	26.48 %	29.62 %	20.52 %	7.60 %	9.60 %
2013	area/hm^2	39142.24	98981.78	121665.03	72007.07	30304.74	52554.81
	percentage/%	9.44 %	23.87 %	29.34 %	17.37 %	7.31 %	12.67 %

The area changes of the 4 periods show the same trend. The urban has been in rapid expansion with a increase of 30595.29 hm^2 in the study area in 1974–2013. Similarly, agriculture land decreased rapidly with a lose of 63503.37 hm^2 in the same period. The grassland also showed a decreasing trend with a lose of 17664.42 hm^2. Forest land decreased 13411.91 hm^2 in 1992–2013.

4.2 The Urban Expansion Form of Kunming

The urban of Kunming has been experiencing rapid outward expansion around the center of old town from 1974 to 2013. The shape of the urban in the city was mainly based on the old urban area and scattered in the periphery (Fig. 3a). The urban development centered on the old city and expanded to the north and southeast in 1992 (Fig. 3b). It has been developed both in the north and in the south, and also expanded to west (Fig. 3c). It is more obvious that the urban continue expanding expand to the southeast in 2013, the northeast expansion also was led by the new airport construction (Fig. 3d). To the area of urban expansion, the city area of Kunming was 8546.95 hm^2 in 1974, and 39142.24 hm^2 in 2013, which was 4.5 times of 1974.

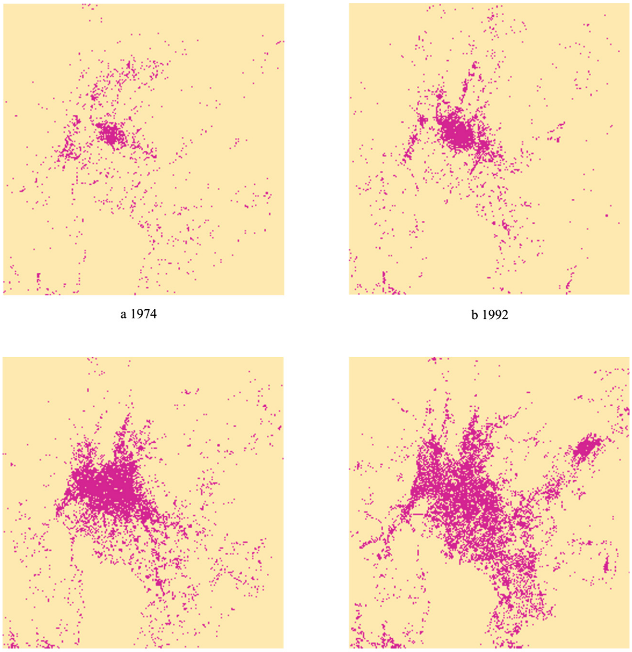


Fig. 3. Spatial distribution of urban (built up area) in 1974, 1992, 2002 and 2013.

4.3 Urban Expansion Rate and Intensity

Table 4 shows the urban spatial expansion rate from 1974–2013. Overall, the average expansion rate was 784.49 hm^2/ year during 1974–2013. And fastest extension at 1339.61 hm^2/year was happened in the period of 1992–2002, followed by the period of 2002–2013 at 1224.91 hm^2/year.

Table 4. The rate of urban expansion.

Rate / Time	A/hm²	B/hm²	v/hm²
1974-1992	8546.95	12272.19	206.96
1992-2002	12272.19	25668.25	1339.61
2002-2013	25668.25	39142.24	1224.91
1974-2013	8546.95	39142.24	784.49

At the same time, expansion intensity of 4 periods showed a consistent trend with the extension rate. The urban expansion intensity index in study area was 9.18 % in the whole study period and maximum of 10.92 % during 1992–2002. Followed by 2002–2013 with a rate of 4.77 % (Table 5).

Table 5. Urban expansion intensity index of Kunming in different periods.

Rate / Time	A(hm²)	B(hm²)	R(%)
1974-1992	8546.95	12272.19	2.42%
1992-2002	12272.19	25668.25	10.92%
2002-2013	25668.25	39142.24	4.77%
1974-2013	8546.95	39142.24	9.18%

4.4 The Driving Force of Urbanization

Refer to the relevant literature and data, the urban expansion force of Kunming mainly include natural factors, economic factors, demographic factors and administrative factors. Economic and demographic factors mainly affect the expansion rate, natural and policy factors mainly affect the spatial form.

Kunming is located in the central Yunnan Plateau basin, where is high in the north and east, low in south and west, Its northwest has a group of low mountains, hills, with a ribbon snake mountain in the back and the largest lake (Dianchi lake) in south. Restricted by the above terrain conditions, the urban construction of the city only can take the old city as the core to expand in northeast, southwest, Southeast with “Star” pattern. Economic development is the main driving force of urban expansion. There is ample funds to support urban construction, to promote the city’s accelerated expansion with high-speed economic development. During the period of 1992–2002, the conduct of “99 World Expo of Kunming” led the economic development of the city and promoted the urban development by leaps and bounds. Population growth will increase the demand of urban land, which will directly result the increase of residential land with rising demand for the traffic and public services and have a impact on the size and shape of the city development. In 1974, the population of Kunming was 1.09 million [37], and the resident population was 6.43 million in 2010 (the sixth national census of Yunnan province). So that, the population expansion of 1974–2013 in Kunming directly lead to the expansion of urban area. On the other hand, the expansion of the city is largely dependent on the government policy, which not only guide the development of the city, but has a certain extent for the blind expansion of the city and make the urban development more scientific and reasonable. The master plan (1996–2010) was proposed to form the space structure with the second ring area as core to develop four vice center in each direction. Subsequently, the master plan (2008–2020) puts forward the idea of the construction of modern new Kunming, which will implement “4 zones with 1 lake and 4th ring road with 1 lake” around the Dianchi Lake to expand the scope of the original city (Wuhua, Panlong, Guandu, Xishan) to develop in the Chenggong, Jinning, Songming. These administrative policies are consistent with the direction of urban space expansion, and play a key role in the expansion form of the city in a large extent.

5 Conclusion

Supervised classification was used to extract and analyze the land use of Kunming in 1974–2013, and analyze the urban expansion rate and strength to monitoring dynamic the urban growth feature in relatively long time scale (nearly 40 years). The results shows that the city is experiencing rapid and dramatical urban space expansion. The expansion of the urban area in 2013 was 4.5 times in 1974, it was the most rapid during the period of 1992–2002 years, followed by the period 2002–2013. Land use change and urban expansion rate and intensity also reflect the above results. The urban expansion makes the corresponding landuse pattern changes. It is mainly reflected in other land use transform into a new urban land. Through the analysis of the land use classification map in 4 periods, the urban expansion is relatively slow and the land mainly from farmland and grassland in 1972–1992 due to the economic and demographic factors. In 1992–2002, urban sprawl was relatively quickly, mainly due to "99 World Expo of Kunming" driving the development of regional economy, population growth and urban planning policy factors, the land mainly from farmland which has disappeared largely, and some from the forest land and grassland. During 2002–2013, the urban sprawl was also relatively fast by the economic development and population growth. It develop a new district of Chenggong affected by the terrain and the government's macro planning policies. The main source of expansion is still farmland, forest and grassland. There has consistent results with the previous researches, the urban expansion led to a sharp loss of farmland and woodland, and ecological landscape fragmentation serious [33, 36]. And the urban spatial form development shows that it is mainly influenced by the terrain and government policy.

The paper has monitored the urban growth dynamic characteristics of Kunming in large spatial-temporal scale, to investigate the historical evolution of urban growth, and explore its mechanism. The study will provide the scientific theory and guidance for city planning, at the same time, it can be used for the construction of ecological and livable city construction for government, planners and ecological experts. However, China will still be in the stage of rapid urbanization, especially in the western cities, where locate the early stage of rapid urbanization.

Further study of urban growth drivers is urgent need, our next work will simulate the future development trend of the city and optimize the structure of urban space to provide important support for the urban development.

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