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Accelerated Urban Expansion in Lhasa City and the Implications for Sustainable Development in a Plateau City

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Received: 24 July 2017; Accepted: 21 August 2017; Published: 23 August 2017

Abstract: Urbanization challenges regional sustainable development, but a slight expansion mechanism was revealed in a plateau city. We have integrated the urban expansion process and analyzed its determinants in Lhasa (Tibet), and we provide insightful suggestions for urban management and planning for Lhasa. The full continuum of the urban expansion process has been captured using time-series of high-resolution remote sensing data (1990–2015). Four categories of potential determinants involved in economic, demographic, social, and government policy factors were selected, and redundancy analysis was employed to define the contribution rates of these determinants. The results illustrate that considerable urban expansion occurred from 1990 to 2015 in Lhasa, with the area of construction land and transportation land increasing at rates of 117.2% and 564.7%, respectively. The urban expansion in the center of Lhasa can be characterized as temperate sprawl from 1990 through 2008, primarily explained by governmental policies and investment, economic development, tourist growth, and increased governmental investment resulting in faster urban expansion from 2008 to 2015, mainly occurring in the east, south, and west of Lhasa. In contrast with other cities of China, central government investment and “pairing-up support” projects have played an important role in infrastructure construction in Lhasa. The miraculous development of the tourism industry had prominent effects on this economic development and urbanization after 2006, due to the running of the Tibetan Railway. An integrative and proactive policy framework, the “Lhasa development model”, having important theoretical, methodological, and management implications for urban planning and development, has been proposed.

Keywords: Lhasa; urban expansion; determinants; plateau city; policy framework

1. Introduction

Unprecedented urbanization, one of the most irreversible human impacts, has taken place globally in recent decades [1–3]. More than 50% of the global population now lives in cities, and this is expected to exceed 67% by 2050 [4,5]. Urbanization promotes social-economic development, which inevitably converts semi-natural and natural ecosystems into urban environments, which has enormous and inevitable effects on the surrounding area [6–9]. Thus, more attention should be paid to the drastic expansion of urbanization. Many studies have been conducted worldwide [1], including in regions of Africa [10], Europe [11], Latin America [12], North America [13], and Asia [14–16]. Previous studies have also explored the mechanisms of many cities, population and income related to urban

expansion in the USA [17], social infrastructure in the Ulaanbaatar [18], and population, economics, and infrastructure in Freetown [19].

China has been undergoing dramatic urban expansion since the “Reform and Open Policy” in 1978 [20]. Many studies have investigated the spatiotemporal patterns of urban expansion at the national scale [21–31]. Moreover, the spatiotemporal trajectories and patterns of urban expansion have been investigated in “hot” cities in China, such as the megacities in Eastern China [32–39], Northeastern China [40], and Central China [41–44], in addition to a few metropolises in Western China [45–47]. Generally, the primary form of urban expansion in China has been edge-expansion around cities supported by infilling expansion in city centers; leapfrog expansion has been the form in a few metropolises [25].

The speed of urban expansion has fluctuated during different periods [27], and it has been necessary to understand the determinants for urban expansion in different periods [48–50]. Studies have indicated that marketization, globalization, and decentralization accounted for urban expansion in China [51]. However, the mechanisms of urban expansion have differed in different regions and periods [31]. Geographic location, population growth, economic development, and government policies, and the interaction of these factors, have been important drivers for urban expansion in the eastern coastal areas, such as Shenzhen [52,53], Shanghai [54], and Xiamen [55]. As for the resource-based cities, mining activities were considered as one of the most important factors in urban expansion, such as in the cities of Pingshuo and Shuozhou [42,43]. Government policies (“Revitalizing Old Industrial Base of Northeast China”), as well as high-technology, stimulated the re-expansion in Northeast China [40]. Similar situations are found in western cities under the “Development of the West Region” policy [4,56].

Urbanization in mountain cities has become somewhat differentiated from the processes experienced elsewhere. Although there are many studies on urbanization in general, only few studies focus on the urban expansion in mountain cities. In the French Alps, a rapid and continuous urban expansion at the expense of farm land was observed from 1998 to 2009 [57]. In the Peruvian Central Andes, not merely the urban rapidly growth, but also the human land use expanded for the reforestation, as well as range burning for economic development [58]. In the Himalayas, the develop model of urban in Thimphu combined the traditional elements for the site of political, as well as economic, power [59].

To seek the sustainable development (smart cities) in the process of urbanization, for policy-makers, policies should be linked to the reality of local urban expansion [31], encouraging local residents to get actively involved in decision-making processes [60]. Additionally, a compact pattern of urban expansion may be more friendly to ecology and the natural environmental than a dispersed pattern would be [61], and urban redevelopment is also an effective measure [62]. Moreover, stronger measures should be enforced to control inefficient utilization of land on the city fringes [33], promoting reasonable and sustainable transportation [48,54], while also improving citizens’ continuous awareness of sustainable development [44,63]. In general, it is difficult to realize smart cities in mountain regions and creating a database (socio-economic data and GIS data) depends on the consistency of element contents. Modeling the urban expansion boundaries is regarded as an effective approach to guide urban smart growth [64]. More investment should be made for the development and construction of smart low-carbon cities in China [65].

As for the mountain city in China, Lhasa, the average elevation of Lhasa is approximately 3650 m, and solar radiation is strong. With diverse topography, as well as climate, it is rich in biodiversity. However, the natural environment is extremely harsh, with a fragile ecosystem that is extremely susceptible to the impacts of climate change and human activities [66]. In Tibet, Tibetan Buddhism, with its distinctive characteristics, and the politico-religious merged system of government that was established in the 17th century, played an important part in the development of cities and towns before 1951. In 1951, Lhasa was taken as the only urban lay settlement in Tibet; the population of Lhasa was less than thirty thousand, and the urban area was no more than 3 km². Nevertheless, after democratic reform in 1959, especially in the last three decades, Lhasa has been clearly expanding

and transforming in the process of modernization. However, it is important to note that a limited number of studies have analyzed the urban expansion and its determinants in mountain cities in China, especially for Lhasa, which is the most important Tibetan city. This sparse attention has unavoidably created knowledge gaps and left numerous pivotal issues unaddressed and unclear. The mechanism of urban expansion might exhibit different characteristics in the plateau city; revealing the mechanism of urban expansion in the plateau city is essential to understand its environmental impacts and to protect the socio-ecological diversity.

Consequently, against this context, this study aims to reveal the spatial-temporal pattern of urban expansion and its determinants in Lhasa from 1990 to 2015, while simultaneously outlining policy suggestions containing relevant planning and guidelines for local development.

2. Materials and Methods

2.1. Study Area

Lhasa is not only the capital of Tibet, but also the its political, economic, cultural, and religious center (Figure 1). The city contains many archaeological sites that are listed as world cultural heritage sites: these include the Potala Palace, the Jokhang Temple, and Norbulingka. In the present study, the term “Lhasa” refers to the Lhasa urban area, comprised of Downtown Chengguan (DCG), Liuwu New District (LND), Dongcheng New District (DCND), and Dongga New District (DGND).

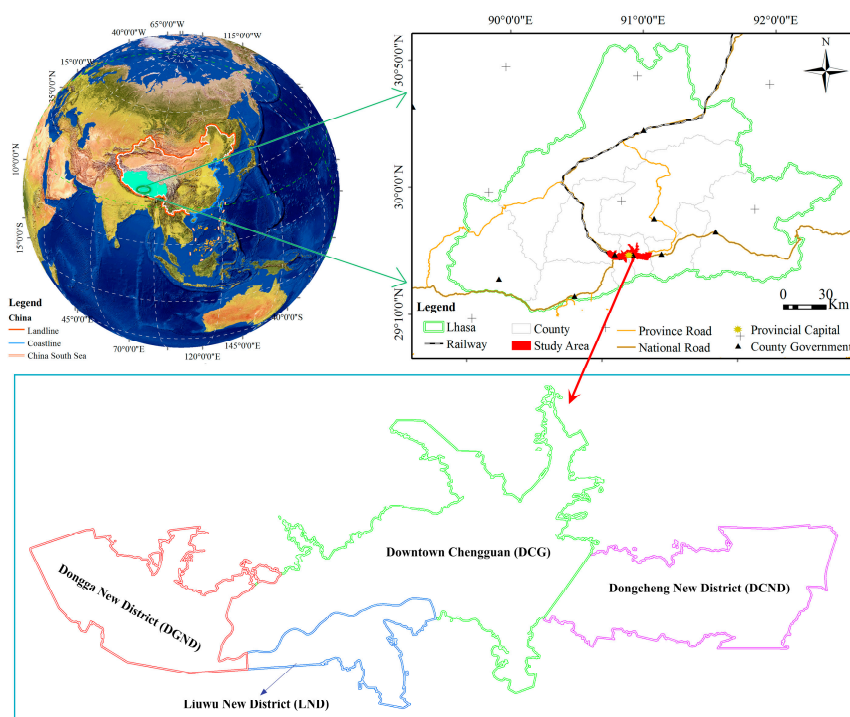


Figure 1. The study area, including the division districts of Lhasa: Downtown Chengguan (DCG), Liuwu New District (LND), Dongcheng New District (DCND), and Dongga New District (DGND).

Lhasa is an old city, with a history going back more than 1300 years. At the beginning of the 7th century, Songtsen Gampo established the first unified regime in the history of Tibet. In AD 633, he moved the capital of Tubo Dynasty from Shannan to today's Lhasa and ordered the construction of Potala Palace and the Jokhang and Ramoche Temples, turning Lhasa into the most populous town in Tibet. From the collapse of the Tubo Dynasty in the 9th century until the Ming Dynasty in the early 14th century, Lhasa lost its previous political status and developed slowly. Potala Palace was destroyed in warfare, but Lhasa remained an important place for Buddhists, because of the Jokhang

Temple. In the early 15th century, the importance of Lhasa as a holy site for Tibetan Buddhism became increasingly significant, following the founding of the “great three” (Ganden Monastery, Salad Monastery, and Drepung Monastery) Gelug university monasteries by Je Tsongkhapa. In the 17th century, with the support of the Qing Dynasty, the fifth Dalai Lama unified Tibet again and established a politico-religious merged system of government named Ganden Podrang. Following the liberation of Tibet in 1951, Lhasa became the capital of the Tibet Autonomous Region in 1965 and entered into a new age. Over the last 50 years, Lhasa has experienced rapid growth and development. Nowadays, Lhasa is still the political and cultural center in Tibet, and has retained its importance as a holy city for the entire realm of Lamaist Buddhism.

2.2. Satellite Images

To delineate the urban area more precisely, high-resolution remotely-sensed data SPOT1/4/5 and Word-View images (Appendix A) were used to acquire the time-series land-use information of Lhasa, covering four time periods (1990, 2001, 2008, and 2015). The preprocessing of the images included atmospheric correction and geometric rectification in ENVI. Then, we adopted the object-oriented method (a method that not only considers the spectral signature in classification but also evaluates the tone, texture, and shape, of image objects at the same time) to obtain the land-use categories, including the classifications of water (W), greenbelt (including natural grassland, GB), forest land (FL), plough land (PL, including arable areas and crops), unutilized land (UL), construction land (CL), transportation land (TL), and wetland (WL). Following classification, manual vectorization was conducted in ArcGIS 10.2 (ESRI, Inc., Redlands, CA, USA) to correct in accurate classifications. Via randomly stratified methods that overlapped the fact-finding points with the land cover maps, the final accuracy of the classification was evaluated. The total accuracy for four land cover maps was 90.1% for 1990, 91.2% for 2001, 92.5% for 2008, and 94.3% for 2015, respectively.

2.3. Determinants and Analysis Methods

Considering data representative and the availability of prior literature [31,42,48,52,67–70], we selected 12 potential determinants for urban expansion in Lhasa that were extracted from the corresponding statistical yearbook: these determinants are total population (TP), urban population (UP), country population (CP), number of foreign travelers (FT), number of domestic tourists (DT), gross domestic product (GDP), GDP in primary industries (GDPPI), GDP in secondary industries (GDPSI), GDP in tertiary industries (GDPTI), tourist income (TI), actual investment (AI), and investment in fixed assets (FA). In addition, the build-up area (BA) was selected to reflect the degree of urban expansion. The redundancy analysis is a linear canonical ordination method, which is advantageous to detect the pattern of dynamics in response variables [71]. The redundancy analysis is closely related to potential explanatory variables, which is effective to evaluate the relationships among multiple interacting variables [72,73]. Thus, the redundancy analysis of R software (Vegan) was employed to explore the relationships of BA with determinants (determinants were partitioned into four explanatory variable groups: TP (UP and CP), GDP (GDPPI, GDPSI and GDPTI), AI, and TI) and to identify the major factors influencing the expansion of Lhasa. The associations between the BA and the determinants with $p < 0.05$ were regarded as statistically significant.

3. Results

3.1. Land Cover Change of Lhasa (1990–2015)

From 1990 to 2015, Lhasa experienced considerable urban expansion. In all, 56.80% of the total land in the study area was urbanized; this urbanization was mainly distributed in the DCND, DGND, and LND (Figure 2D). The areas of CL and TL increased from 45.0 km² and 1.4 km², respectively, in 1990 to 97.7 km² and 9.0 km², respectively, in 2015, with increased rates of 117.2% and 564.7%, respectively. On the contrary, the areas of PL and GB decreased by 38.0 km² and 17.7 km², respectively.

Additionally, the increased TL was mainly found in the center of Lhasa (1990–2001, Figure 2A), the west of Lhasa (2001–2008, Figure 2B), and the east, the south, and the west of Lhasa (2008–2015, Figure 2C), with increased areas of 3.0 km², 2.1 km², and 2.6 km², respectively.

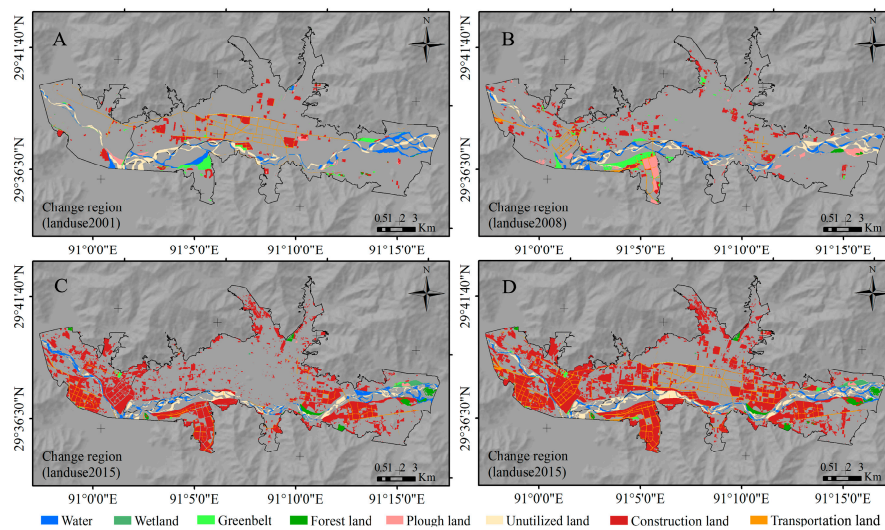


Figure 2. The changed regions of land cover in Lhasa. Graphs (A–D) represent the land-use changed area during 1990–2001, 2001–2008, 2008–2015, and 1990–2015, respectively.

Mutual transfer quantities of land-use were investigated using the overlay analysis and transition matrices in ArcGIS 10.2 (ESRI, Inc., Redlands, CA, USA) (Figure 3). The PL and CL were found to be the main land classes in 1990, while CL was the main land class in 2015. The most extensive and intensive transition occurred between the PL and CL, with approximately 35.1 km² (58.0%) of PL transferred into CL. Approximately 19.0 km² (86.7%) and 1.5 km² (6.5%) of GB and W, respectively, were transferred to CL from 1990 to 2015, and small areas of FL, UL, and TL were transferred to CL. Meanwhile, during the highest urban expansion period of 2008–2015, approximately 24.4 km² PL and 12.3 km² GB changed into CL. Moreover, almost 3.4 km² PL and 2.4 km² CL have been transferred into TL over the past 25 years.

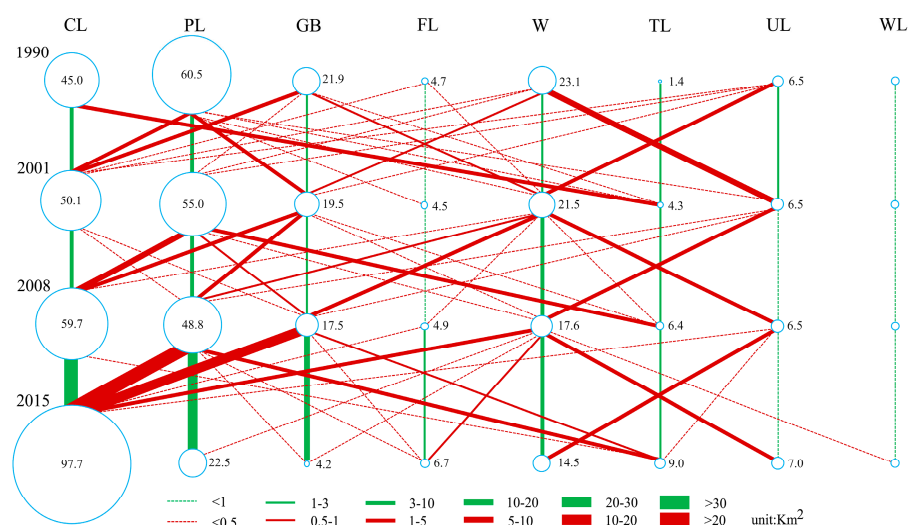


Figure 3. The transition process of classifications in Lhasa from 1990 to 2015. The circles present the area of each land cover in different year, and the blue lines represent the changed area in each land cover between the two periods; the red lines represent the changed area among classes during the two periods.

3.2. The Changes of the Main Socio-Economic Indicators of Lhasa (1990–2015)

3.2.1. Economic Development

During the past 25 years, the GDPSI and GDPTI reflected the economic development traits, and the GDPTI was the dominant economy for the growth of the economy in Lhasa. Figure 4 shows that GDP, GDPSI, and GDPTI grew continuously from 1990 to 2014, while GDPPI increased relatively slowly. As for GDP, a general linear model analysis showed that the year 2006 can be considered as a “tipping point”, with slopes of 5.74×10^2 million/year ($y = 5.74x - 11,423.29$) and 2.90×10^3 million/year ($y = 2.90x - 58,137.54$), respectively, before and after 2006. Similarly, the rate of GDPSI sharply increased from 2007 to 2014 (slope = 12.98), whereas the process was slower from 1990 to 2006 (slope = 1.53), and the GDPSI accounted for 36.77% of the GDP in 2014. Meanwhile, the GDPTI has expanded continuously during the past 25 years; reaching up to 2.07×10^4 million Renminbi (RMB) in 2014, accounted for 59.51% of the GDP in that year. The GDPTI also demonstrated significantly increasing trends after 2005 (before 2005, the slope = 15.17; after 2005, the slope = 3.75).

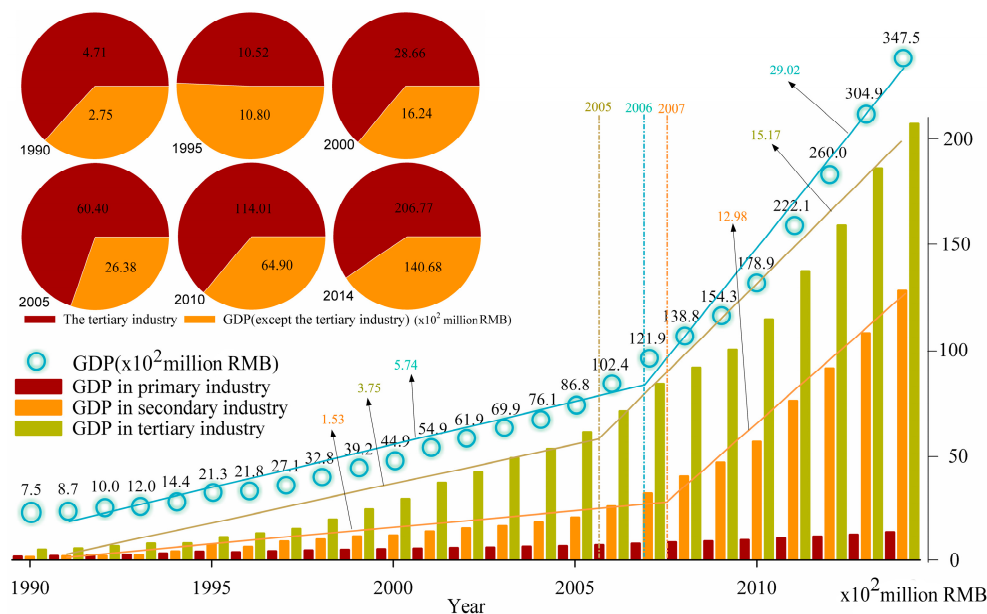


Figure 4. The gross domestic product (GDP), GDP in primary industries (GDPPI), GDP in secondary industries (GDPSI), GDP in tertiary industries (GDPTI), and the variations of GDP from 1990 to 2014.

3.2.2. Urban Population Growth

A growing trend of the total population in Lhasa from 1990 to 2014 was observed (Figure 5). The total population increased from 3.57×10^5 (1990) to 5.27×10^5 (2014), with a rate of increase equal to 47.87%. Incredibly, a sharp expansion of the total population occurred between 2008 and 2009. Moreover, the urban population increased to 2.23×10^5 in 2014, with the proportion increasing from 34.2% in 1990 to 42.3% in 2014. Consequently, the proportion of the rural population decreased by 8.1% during the same period, with the population in 2014 being 3.04×10^5 .

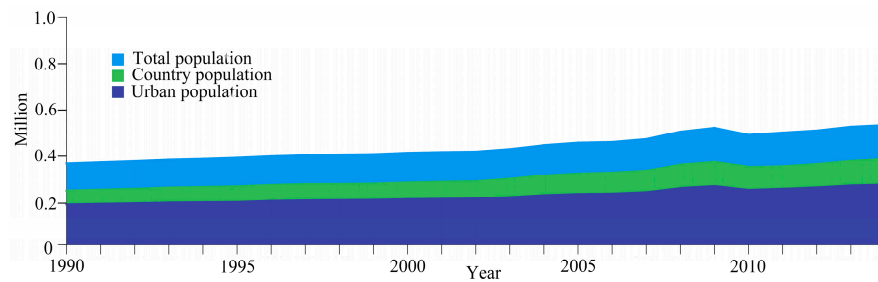


Figure 5. The total population, country population, and urban population from 1990 to 2010.

3.2.3. Government Investment

Along with the time series data, Figure 6 shows that both the budget in public and actual investment and new fixed assets showed increasing trends from 1990 to 2014. Through the budget spending of the public finance merely 1.69×10^4 million RMB in 2014, the actual investment reached 4.55×10^4 million RMB, exceeding 73.20% of the investment from government converted to new fixed assets in 2014. Thus, investment by government was preferred to infrastructure construction and public service. Moreover, the government increased investment after 2008, with slopes of 4.41×10^2 million/year ($y = 4.41x - 8778.4$) and 58.1×10^2 million/year ($y = 58.1x - 116,518.2$), respectively, before and after 2008. Meanwhile, high increasing speeds of direct budget subsidies from the central government and fundraising by the local government were observed between 1990 and 2014 (Figure 6). Moreover, the proportion of state budget appropriation in actual investment accounted for 41.52%, with a value of 89.42 billion RMB from 1990 to 2014. Furthermore, Figure 6 also shows a series of policies and campaigns, including the “Lhasa City Master Plan 1980–2000” in 1983, the “Lhasa City Master Plan 1995–2015” in 1999, the “Development of the Western Region” in 2000, the Tibetan Railway, running in 2006, and the “Lhasa City Master Plan 2009–2020”. The plough land protection policies of “Regulations on the Protection of Basic Farmland” and “The Arable Land Protection Redline of 12 million ha” are also presented.

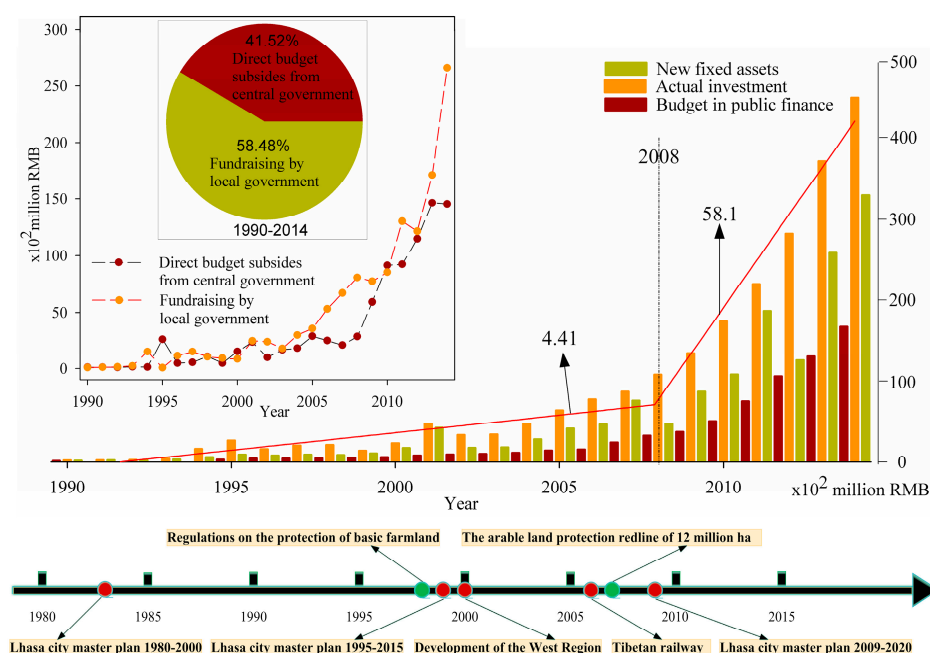


Figure 6. The actual investment of government, new fixed assets, and budget spending of public finance from 1990 to 2014, and the main policies on construction land and transportation land from the 1980s to the 2010s.

3.2.4. Tourism Development

The population of domestic tourists was the presentation of the economic development trait, and the tourist industry gradually became the dominant economy for tertiary industry in Lhasa (Figure 7). From 1990 to 2006, the population of foreign travelers and domestic tourists (slope = 3.5) did not show significant variation; hence, tourist income remained stable (slope = 0.4). Conversely, from 2006 to 2014, with a sharp increase of domestic tourists (slope = 97.4), the tourist income increased by 93.67×10^2 million RMB (slope = 11.0). Moreover, the proportion of tourist income in the tertiary industry economy has been growing continuously, increasing from 1.06% in 1990 to 54.01% in 2014.

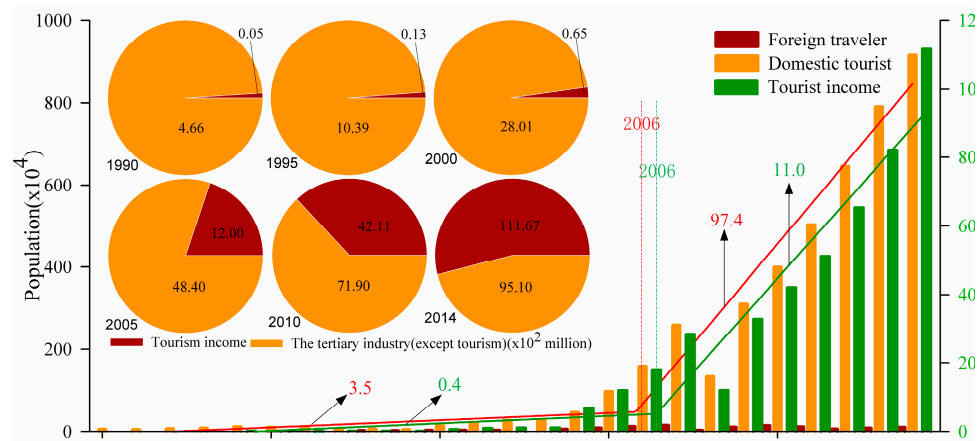


Figure 7. The population of foreign travelers and domestic tourists, as well as the tourist income and its dynamics in tertiary industries from 1990–2014.

3.3. Determinants of Urban Expansion in Lhasa

The relationships among the BA, greenbelt area (GBA) and determinants were examined at 0.05 level (Figure 8). All the selected determinants were observed significantly positively correlated with the BA, the whole of the correlation coefficients were greater than 0.85, except a relatively weak relationship between FT and BA. Moreover, remarkable relationships among the TP, GDP, TI, and AI were observed. However, fickle and lower values of correlation coefficients between the GBA and determinants were presented. Thus, to quantify the determinants for the urban expansion, we conduct a relative importance analysis between BA and TP, GDP, TI, and AI in the next section.

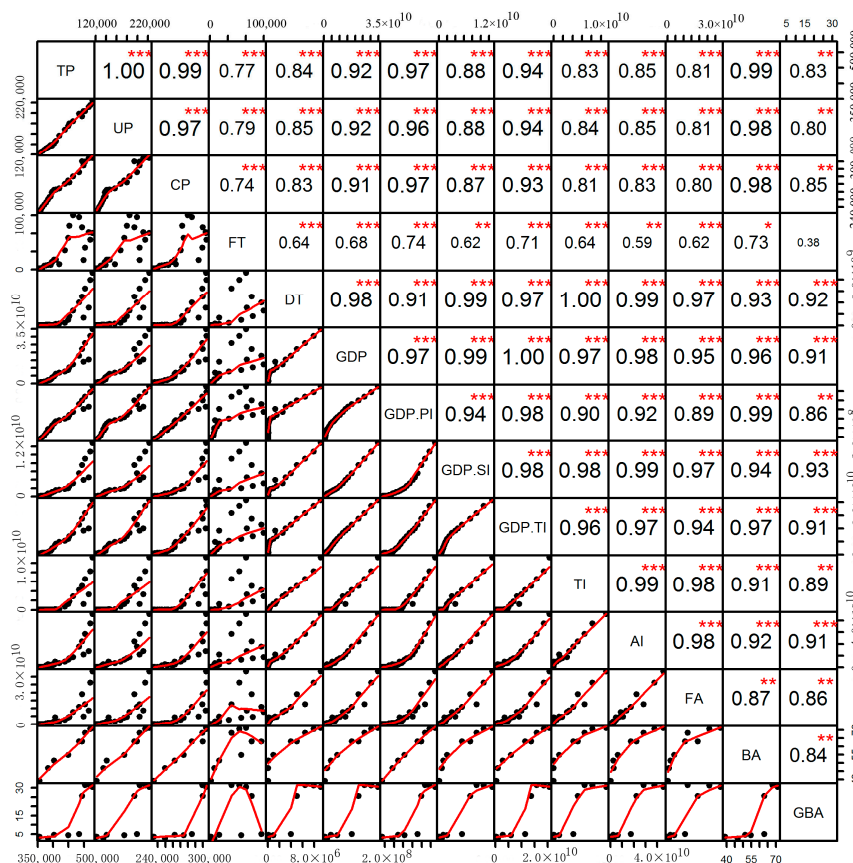


Figure 8. The relationships between the BA, GBA, and the determinants.

3.4. Relative Importance of the Identified Determinants

Based on the redundancy analysis, the relative importance of the main determinants for Lhasa's expansion was investigated (Figure 9). The results showed that the interactions of determinants (TP, GDP, AI, and TI) was the main driver of urban expansion in Lhasa, explaining 81.24% of the urban expansion. More specifically, the determinant TP had a relatively larger influence, explaining 99.38% of the urban expansion, followed by the GDP determinant, which explained 96.04% of the expansion, and AI and TI explained 86.96% and 84.97% of the expansion, respectively.

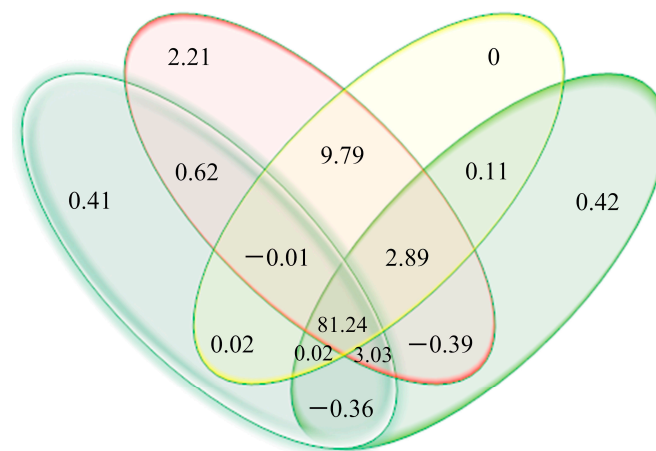


Figure 9. The contributions (%) of different categories' determinants to BA via redundancy analysis is presented in Venn diagrams.

4. Discussion

4.1. Determinants for Lhasa Expansion

The urban expansion of Lhasa is primarily explained by governmental policies and investment in the early stage (1990–2008); economic development, tourist growth, and increased government investment resulted in faster urban expansion from 2008 to 2015. The government's policies controlled and guided the macroscopic development of cities [69]; the development of cities is especially sensitive to administrative policies in China [74]. For historical reasons, urban planning in Lhasa has exhibited relative hysteresis. Until 1983, the local government promulgated and implemented the “Lhasa City Master Plan 1980–2000”, which determined the basic pattern of Lhasa. Of note, most public infrastructures developed around the center of Lhasa during the 30th anniversary of the founding of the Tibet Autonomous Region (1985) and on the 40th anniversary of the peaceful liberation of the Tibet Autonomous Region (1991). Stimulated by the government investment, resulting in insufficient usable land for the development in the center of Lhasa. Specifically, urban expansion of Lhasa can be characterized as temperate sprawl between 1990 and 2001, with an annual average expansion area of 0.47 km^2 , mainly around the “old center of Lhasa” (Downtown Chengguan, Figure 2A). Under these circumstances, the local government implemented the “Lhasa City Master Plan 1995–2015” in 1999, which not only confirmed the spatial layout of Lhasa as seven districts, but also determined the development of the south bank of Lhasa and selected LND, DCND, and DGND as the stand-by spare areas for future development of Lhasa. Moreover, in the national strategy “Development of the West Region”, implemented in 2000, very large amounts of national capital continuously promoted urban and industrial expansion in the western provinces [4,21]. Against this backdrop, the area of construction land expanded by annual average of 1.36 km^2 from 2001 to 2008. With faster urban expansion outward, Lhasa's urban area started to grow past the fringe of the DCG. Thus, the LND in the southwest, the DCND in the east, and the DGND in the west of the DCG were formed gradually (Figure 2B), which was consistent with the connotations of the government policies.

Economic development is fundamental to urban expansion, because city expansion principally depends on the city's financial strength [69]. To further promote economic development, the government may attempt to enlarge investments in industrial parks and key infrastructures [48,60]. As more land is converted into construction land for industrial parks and scenic spots, this, in turn, promotes the growth of GDP [52]. Between 2007 and 2014, the GDP increased by 5.2 times, and the annual GDP was 4.52×10^3 million (1990–2007), which was much lower than the annual value level of 2.29×10^4 million from 2008 to 2014. Additionally, the GDP per capita increased from 1.96×10^4 RMB (2007) to 5.66×10^4 RMB (2014). The effect of rising GDP per capita and better services is to attract more rural people to migrate to the city, bringing more tourists and workers to Lhasa [29,31]. To simultaneously meet the economic development, population concentration, and old-city protection demands, the local government further implemented the “Lhasa City Master Plan 2009–2020” in 2009. This policy proposed the future expansion layouts of Lhasa: “East extension, westward and south pass, one city with two sides and three districts”. Thus, a “tipping point” of government investment is observed after 2008, with governments expanding their public finances from 1.09×10^4 million RMB in 2008 to 4.55×10^4 million RMB in 2014, and 73.20% of the public finances were transformed into new fixed assets in 2014 (Figure 6). Meanwhile, Tibet has the highest proportion of state budget appropriation in fixed assets among western provinces (Appendix B). Consequently, Lhasa has been witnessing unimaginable growth of population and urban expansion: tourism increased by 7.91 million from 2008 to 2014, accompanied by urban expansion rates of $0.82 \text{ km}^2/\text{year}$ and $5.43 \text{ km}^2/\text{year}$, respectively, before and after 2008, mainly occurring in LND, DGND and DCND (Figure 2C).

In particular, the “Pairing-up support” project also played an important role in the infrastructure expansion process, with assistance funds in Tibet being 14.1 billion RMB from 2011 to 2015 (Appendix C). Additionally, the running of the Tibetan Railway in 2006 accelerated the economic

growth because of the “tipping point” found in GDP (Figure 5) and tourism income (Figure 8) was 2006. Overall, Lhasa transformed from a decentralized “old center of Lhasa” (DCG) to a new urban area with different functional zones in the south, west, and east during the study period.

However, with the growth of population and economy, the urban expansion in Lhasa is exactly a dilemma for the limited agriculture land and fragile ecosystem. Meanwhile, the inconvenient and unintelligent transportation hinders the economic development in Lhasa. In addition, education in Lhasa is faced with the challenges, such as the limitation of research teams and a shortage of education resources. It is difficult to evaluate the complete situation in Lhasa for the limited share database. In the future, the government should promote the progress of sustainable mobility payments and increase financial support [75], putting forth efforts to integrate the social-economic, democratic, technological, and sustainable aspects for the sustainable development in the mountain city of Lhasa [76].

4.2. Determinants of Urban Expansion in Different Regions in China

The interactions of GDP growth, population immigration from rural to urban areas, industrial development, and national regional strategies have been significantly positive factors for urban expansion in China [4,5,24,51,63,65]. However, the determinants of urban expansion have varied in different regions (Appendix D). For Eastern China, more international trade has been available for population growth, road construction, and service exports, resulting in economic growth [21,31,55,61]. This is particularly true for the cities in the pearl river delta and the Yangtze river delta, where favorable geographical conditions, accompanied by more government investment, have led to the development of many services, high-tech companies, and commercial centers [3,52,69,77]. Industrial direct investment by foreigners has been a positive determinant for urban expansion in Central China, where the large number of people working in coal enterprises has promoted the industrial output value [21,31,42,78,79]. Economic growth stimulated by industrialization has been considered as the main factor for urban expansion in Western China [24]. In general, the industrialization with population growth (mostly immigrants and workers) has played a critical role in urban expansion throughout China [49,52,80,81].

In contrast with other cities of China, the relatively weaker importance of secondary industries and immigration, and the development of tertiary industries, have contributed positively and significantly to urban expansion in Lhasa. Lhasa has served as the most dynamic potential core area for tourist aggregation in Tibet, which is famous for its unique plateau customs and religious culture and attracted more than 9.26 million tourists in 2014; this is about 17.56 times the TP in Lhasa in 2014. Thus, Lhasa experienced a drastic transformation of its economic structure because of the rapid development of tourism. Simultaneously, in terms of GDP, the proportion of the tourism revenues in Lhasa increased from 0.65% in 1990 to 32.14% in 2014, accounting for 54.01% of the GDP in tertiary industry. Obviously, the demands for residence, traffic, and tourism facilities resulted in rapid urban expansion from the urban areas to surrounding rural areas in Lhasa. With the accelerated social-economic growth, tertiary industries will further influence the urbanization process in Lhasa.

4.3. Suggestions and Implications

China became the world's second-largest economy in 2011. Simultaneously, the “National New-Style Urbanization Plan” and “China's 13th Five-Year Plan” were promulgated and implemented recently. So, how can eco-sustainable urban development be applied in Lhasa? To explore a “smart development model” suitable for Lhasa, it is essential to establish links between financial assistance and economic development to improve the self-sufficiency rate in Lhasa. For the central government, policies should be innovated and unified within the framework of the “Lhasa sustainable development model” for Lhasa's ecological economy. For local government, promoting scientific urban planning and increasing investment in human capital are decisive factors. Local government should implement preferential policies to attract medium and top talents to improve Lhasa's self-development capability. Simultaneously, investment in environmentally-friendly and sustainable economics

of tertiary industries, especially tourism, should be increased. With financial assistance, further transforming and upgrading the industrial structure into a public service-type, developing ecological tourism and more specialized services, and improving access to international markets the rely on Lhasa's unique plateau custom and cultural advantages. Furthermore, full use should be made of the unique plateau's green resources, and technical innovations to avoid insufficient utilization of various resources, such as solar and water resources, should be applied. Lastly, the "Urban-Rural and Regional Integration Strategy" should be implemented to equalize urban-rural development. In practical terms, strategies should include promoting regional traffic and transport, extending specialized industries in villages, and elevating the self-supporting capability of natives through basic education and vocational training. We expect that the policy framework (Figure 10) can provide a few fresh insightful suggestions to policy-makers to establish a smart Lhasa development model for long-term stability and prosperity.

To realize the smart city in China, the coordination and communication between the administrative agencies are particularly important. Thus, contradictions exist between the administrative agencies: local government receives extra budgetary revenue by a land granting strategy [82], while the central government enacts regulations to re-control urban expansion [83]. However, the local government plays a proactive role [84]. In addition, intra-urban planning also touches off the chance to reexamine the distribution of infrastructure for intelligent transportation [85]. Attempts should be made to coordinate the increase of the population and built-up areas for a smart city. It was noticeable that the development of the economy would stimulate the growth of the population and the expansion of the city. The social-economic, population, and policies are spatially correlated and interaction has an effect radius. This implies it is essential to balance the demand for building in urban planning among these variational factors. Thus, a smart city can be realized.



Figure 10. The policy framework of the "Lhasa development model".

5. Conclusions

This study systematically revealed the mechanisms of urban expansion in the plateau city (Lhasa) during the past 25 years. Lhasa has experienced great expansion intensity, with the area of CL increasing by 52.7 km² between 1990 and 2015, and the areas of PL and GB transforming by 35.1 km² and 19.0 km², respectively, to CL at the same time. The faster urban expansion speed that was observed from 2008 to 2015 (5.4 km²/year) mainly occurred in the east (DCND), south (LND), and west (DGND) of Lhasa.

In general, urban expansion in Lhasa is influenced by governmental investment, tourist population growth, and economic development. From 1990 to 2008, a series of governmental policies promoted the infrastructure construction process in the center of Lhasa. From 2008 to 2015, with a more rapid rate of increase of GDP increase, faster growth of the tourist population, and continuous government investment, there was an obvious high rate of urban expansion. In particular, the tourism industry apparently promoted economic development and urban expansion in recent years, and the running of Tibetan Railway accelerated the urbanization process in Lhasa.

In this paper, the spatial-temporal pattern of urban expansion and its determinants are performed for quantitative research to reveal the urban expansion mechanism in Lhasa, from which the integrative and proactive policy framework are put forward for smart city development in Lhasa. However, in this paper, the geographical factors (slope, temperature, precipitation, and so on) were neglected. Modeling the urban expansion under many factors (the socio-economic, policy, and geographical factors) will be a supplemental research agenda. To achieve a win-win situation in the dilemma of urban expansion and socio-economic development, and improve the self-sufficiency rate of Lhasa, the government policy must be innovated and unified, enhancing coordination and efficiency between administrative agencies and establishing links between financial assistance and economic development within the framework of the “Lhasa development model”. In the future, to be a smart city, Lhasa should invest more money in transforming and upgrading industrial structures, especially in the environmentally-friendly and sustainable economic development of tertiary industries.

Acknowledgments: This research was supported by the National Natural Science Foundation of China (Grant No. 41201167, 41571166), Foundation of Youth Innovation Promotion Association, CAS (Grant No. Y4R2190190), and the West Light Foundation of the Chinese Academy of Science.

Author Contributions: J.S. contributed to the study design, W.T., T.C.Z., J.S., Y.L. and W.L. were involved in drafting the manuscript, approving the final draft, and agree to be accountable for the work. All authors read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Source of remote sensing data of Lhasa metropolitan area 1990–2015.

Data	Column/Row	Year	Spatial Resolution (m)
Spot1	5924/6000	March 1990	10
Spot4	5110/1768	November 2001	10
Spot5	18307/6258	December 2008	2.5
Word View	94420/31076	May 2015	0.5

Appendix B

Table A2. Sources of funds for investment in fixed assets in western provinces of China in 2014 (billion RMB).

	Qinghai	Gansu	Sichuan	Xinjiang	Ningxia	Chongqing	Guizhou	Inner Mongolia	Tibet
State budget appropriation	55.994	84.449	152.782	132.678	23.734	106.499	64.44	68.499	84.931
Self-raised funds	136.351	485.644	1688.449	610.044	162.486	835.35	570.403	941.733	38.12
Domestic loans	59.622	94.856	249.009	137.062	74.621	265.193	118.318	152.99	0.58
Foreign investment	0.422	3.448	9.507	0.325	0.285	28.269	2.776	1.02	0.14
Bonds	1.646	2.04	7.421	2.774	0	0.512	0	0	0
Others	28.532	77.054	442.192	96.514	37.764	315.732	239.596	68.637	6.36
Total investment in fixed assets	282.567	747.491	2549.36	979.397	298.89	1551.555	995.533	1232.879	130.131
The proportion of state budget appropriation in investment in fixed assets	19.82%	11.3%	5.99%	13.55%	7.94%	6.86%	6.47%	5.56%	65.27%

Appendix C

Table A3. The financial assistance budgets in “The Twelfth Five-year Plan” from 2011 to 2015.

Districts	Number of Projects	Total (Billion RMB)	2011 (Billion RMB)	2012 (Billion RMB)	2013 (Billion RMB)	2014 (Billion RMB)	2015 (Billion RMB)	Proportion
Lhasa	165	3.08	0.52	0.56	0.63	0.68	0.68	21.82%
Lhoka Prefecture	176	1.30	0.38	0.29	0.13	0.28	0.22	9.17%
Shigatse Prefecture	575	3.26	0.57	0.64	0.60	0.72	0.74	23.10%
Nyingchi Prefecture	361	2.66	0.51	0.52	0.44	0.57	0.62	18.80%
Chamdo Prefecture	132	0.75	0.14	0.15	0.15	0.18	0.14	5.28%
Nagqu prefecture	128	2.11	0.38	0.41	0.40	0.43	0.49	14.89%
Ngari Prefecture	73	0.98	0.17	0.19	0.20	0.21	0.22	6.94%
Total	1610	14.14	2.67	2.75	2.54	3.07	3.10	100%

Appendix D

Table A4. The determinants of urban expansion in different regions.

	Period	Regions	Determinants	Literatures
China	2005–2008	China	Marketization, Globalization, Government	[49]
	1990–2010	China	Immigration rural-urban, Fixed-asset investments, GDP growth, National regional strategies	[4]
	1993–2012	China	Economic growth, Industrial development, Economic structural transformation	[5]
China	-	China	Institutional, cultural conditions, Economy and industry conditions	[65]
China	-	China	Globalization, Government	[63]
Eastern China	2000–2010	Eastern China	Service exports, International trade	[21]
Central China		Central China	Service exports, International trade, Foreign direct investment	
Northeastern		Northeastern	Service exports, International trade	

Table A4. Cont.

	Period	Regions	Determinants	Literatures
Eastern China	1990–2010	Eastern China	Population growth, Road construction	[31]
Middle China		Middle China	Secondary industry, Economic development	
Western China		Western China	Economic growth	
Provincial level	1992–2009	Provincial level	Economic factors	[24]
Prefectural level		Prefectural level	Economic, Demographic, and traffic factors	
County level		County level	Demographic factors	
Beijing	1972–2010	Beijing	Physical, Socioeconomic, Neighborhood factors	[61]
Xiamen Island	1908–2007	Xiamen Island	Natural and socio-economic factors	[55]
The pearl river delta	1979–2002	Guangzhou	GDP, Total population, Urban resident income, Urban traffic	[69]
	1990–2008	Shenzhen	Technology, Government policy, Geographical factor, GDP	[52]
The Yangtze river delta	1985–2013	Nanjing	Non-agricultural population, Foreign direct investment, Tertiary sector	[3]
	1995–2013	Nanjing	Infrastructure, Commercial, Industrial sub-centers, Government policies	[77]
	1985–2006	Shanghai	Industrial structure improvement, Government policy	[70]
Central China	1986–2013	Shouzhou City	Non-agricultural population, Coalindustry	[42]
	1980–2010	Wuhan	Industrialization, Urban population growth, Government policies	[78]
	1949–2004	Changsha	Population, Economic, Transportation infrastructure, Strategic instruction	[67]

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