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Urban Expansion and Its Influencing Factors in Natural Wetland Distribution Area in Fuzhou City, China

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Abstract: This paper principally focuses on land use dynamics, urban expansion and underlying driving forces in the Natural Wetland Distribution Area (NWDA) of Fuzhou City in the southeastern China. Based on time series Landsat TM/ETM+ imageries and historical data, relationships between urban land expansion and its influencing factors from 1989 to 2009 were analyzed by using an integrated approach of remote sensing (RS) and geographic information system (GIS) techniques. The results showed that built-up land increased from 151.16 km^2 in 1989 to 383.76 km^2 in 2009. Approximately 64.25% of the newly emerging built-up land was converted from cropland (29.47%), forest and shrub (25.78%), water (3.73%), wetland (4.61%), and bare land (0.66%) during 1989 and 2009. With a remarkable decrease in cropland, the proportion of non-agricultural population increased by 23.6%. Moreover, rapid development of infrastructures, facilities, industrial parks, and urban and rural settlements along the Minjiang River resulted in the eastward and southward expansion of built-up land. Additionally, the growth pattern of built-up land in the NWDA is highly correlated with socio-economic factors, including the gross domestic product (GDP), GDP per capita, and structure of industry. As a result, the observed environmental degradation such as loss of cropland and wetland due to heavy pressure of rapid urbanization have greatly impaired the carrying capacity of city. Thus, in addition to scientific and rational policies towards minimizing the adverse effects of urbanization, coordination between the administrative agencies should be urgently strengthened to balance the conflicts between urban development and ecological conservation to make sure the sustainable land use.

Keywords: land use; urban expansion; natural wetland; socio-economic factors; remote sensing (RS); geographic information system (GIS)

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1 Introduction

Globally, rapid urbanization and population growth have been a common phenomenon, especially in the developing countries with an increasing desire for prosperity (Li *et al*., 2009). Nowadays, 70% of the world′s largest cities are found in the developing world (Cohen, 2006). It is estimated that more than 50% of the world population lives in the urban areas, and it is projected that the urban population proportion will reach 69.6% by 2050 (http://esa.un.org/unpd/wup/index.htm). Given the fact that most of the major human settlements were located in low elevation coastal zones (Turner *et al*., 2000; Small and Nicholls, 2003; McGranahan *et al*., 2007), land use/land cover (LULC) change induced by rapid urbanization has impaired ecosystem functions of estuarine regions (Goss-Custard and Yates, 1992; Sato and Azuma, 2002). In these zones, urbanization as a major cause of the loss of natural wetlands exerts significant influences on the structure and functions of natural wet-

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lands, mainly through modifying the hydrological and sedimentation regimes, and the dynamics of nutrients and chemical pollutants, which results in natural wetlands degradation. Thus, compared with small proportion of wetland loss due to sea level rising, it is urgent to take practicable countermeasures to prevent natural wetlands from adverse effects due to intensive human activities (Nicholls, 2004).

China′s reform and open policies have achieved great success in prosperous economic growth since 1978. To date, many large cities in the coastal economic zone, which are the preferred destination for millions of internal migrants and overseas investors, have been the locomotives in propelling China′s economic growth (Chen Manrong *et al*., 2000). Ultimately, the country′s total number of cities increased from 450 in 1989 to 660 in 2009, and its urban population rapidly increased from 3.12×10^8 to 6.22×10^8 (National Bureau of Statistics of China, 2010). However, with rapid development of the economy and urban expansion, the accompanied ecological deterioration and economic loss have been pronounced in these hotspots (Chen S *et al*., 2000; Cao and Wong, 2007; Zhang *et al*., 2011). Given the importance of urban growth, LULC and their long-term adverse effects on ecological functioning, modeling LULC and urban growth has been the focus of many researches (Maktav and Erbek, 2005; Hardin *et al*., 2007; Geymen and Baz, 2008; Bhatta, 2009). However, less attention has been paid to the development of these models to understand the relationships between urban growth and related socio-economic process that underlies land use change and urbanization (Irwin and Geoghegan, 2001). The approach of multi-temporal remote sensing (RS) and geographicinformation systems (GIS) would be important in natural wetlands conservation for their advantages in determining whether these ecosystems have changed over time in terms of size, extent and quality. On the other hand, with the need of sustainable development and scientific decision, the government attempts to come to a comprehensive understanding of implications for urban planning.

This study principally focuses on the natural wetland distribution area (NWDA) in Fuzhou City in the southeastern China. The NWDA is a key area for natural conservation within the domain of the west side economic zone adjacent to the Taiwan Straits. This area provides a useful example for its location advantages, economic power, and supporting function. Accordingly, this study attempts to examine the relationships among spatiotemporal patterns of built-up land, planning policies, and socio-economic factors using time series of information from remotely sensed data and statistical methods. This study will lead to a better understanding of land use dynamics, driving forces for expansion patterns of built-up land, and thus provide useful references for planning researchers, urban planners, and decision makers. Meanwhile, this case study will significantly supply practical implications for the other cities in estuarine areas and similar cities worldwide.

2 Material and Methods

2.1 Study area

Natural wetland distribution area (NWDA) (25°55′–26°13′N, 119°01′–119°42′E) is located at Fuzhou City, the capital of Fujian Province, which consists of five urban districts (Gulou District, Taijiang District, Jin′an District, Cangshan District, and Mawei District), one county and one county-level city (Minhou County and Changle City) (Fig. 1). The NWDA covers an area of approximately 1491 km^2 with a total population of 2.71×10^6. In the end of 2009, local GDP per capita was approximately 36 851 yuan (RMB), approximately 50.1% more than that of nationwide average level (Fuzhou Municipal Bureau of Statistics, 2010). The NWDA has a northern subtropical monsoon climate with an average annual temperature about 20.8°C. During the study period of 1989–2009, the highest temperature was 41°C, happened in summer of 2003, and the lowest was –4°C in winter of 1991. Annual precipitation within the study area varies widely from 796.5 mm to 1913.6 mm, of which approximately 33% is received during the flood seasons from May to June. Topographically, elevation of the area ranges between 1.0 m and 802.4 m. The Minjiang River is the major river throughout the NWDA. This area, which is known as the Fuzhou Basin, is mainly located at an estuarine terrace enclosed by the hills and mountains.

2.2 Data and methods

2.2.1 Data and processing

In this study, all the Landsat TM/ETM+ images with spatial resolution of 30 m were acquired from China Remote Sensing Satellite Ground Station, Chinese

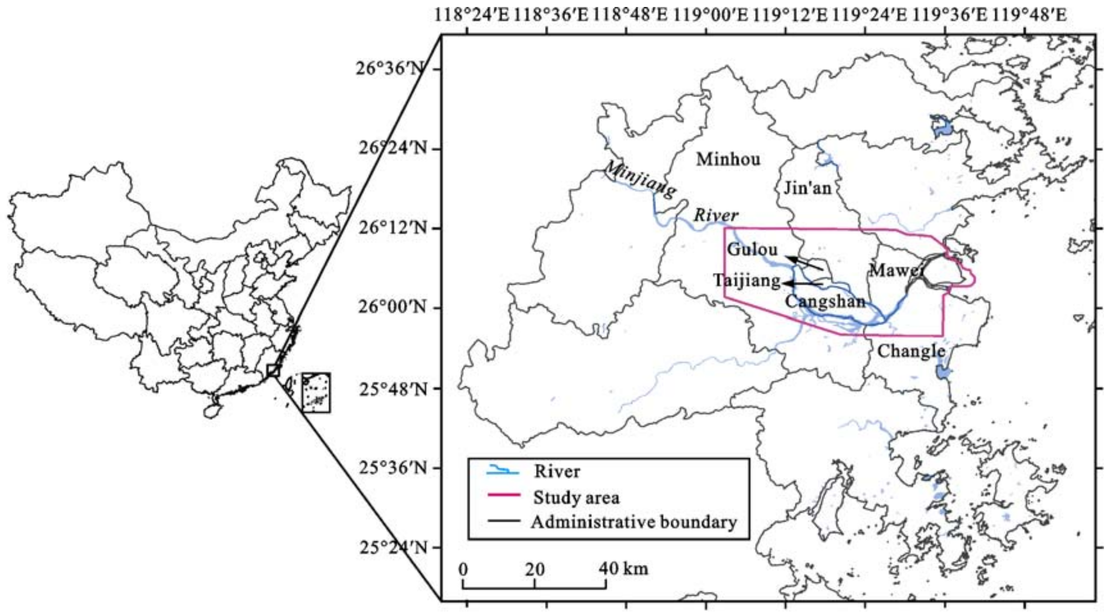

Fig. 1 Location of study area

Academy of Sciences. LULC data were produced by using methods of field survey and supervised classification of multi-temporal Landsat TM/ETM+ images. Besides, local census data , including regional total gross domestic product (GDP), and GDP per capita, the proportion of non-agricultural population, the total population, shares of agricultural, industrial and service sectors in regional total GDP, were extracted from the Fuzhou Statistical Yearbook (Fuzhou Municipal Bureau of Statistics, 1990; 1995; 2001; 2007; 2010; 2011) and China′s Urban Statistical Yearbook (National Bureau of Statistics of China, 2010).

In this paper, a flowchart describing the technical route for change detection of LULC is shown in Fig. 2. Two Landsat TM images (dated on June 15, 1989 and March 11, 1994) and three Landsat ETM+ images (dated on May 18, 2000, August 4, 2006, and June 6, 2009) were used in this study. All the images were rectified and georeferenced to the UTM map projection before interpretation. Subsequently, the images were resampled to 30 m by using the nearest neighbor algorithm to keep the unchanged original brightness values of pixels, and the root mean square error (RMSE) of interpretation index were both within 1 pixel. The image processing and data manipulation were conducted by using ENVI 4.8 image processing software. Furthermore, ESRI ARCGIS 10.0 was used for spatial analyses. Besides, as part of the planned routine, a field survey of land use in Fuzhou City was carried out every three years since 2000. According to image characteristics and predetermined acquaintance on land uses in the study area, six categories of land covers were presented at last. These land covers include forest and shrub, built-up land, cropland, water (mainly including rivers, channels and ponds), wetland, and bare land. Herein, the classification scheme of the study area was modified on the basis of the land use classification system by China National Committee of Agricultural Divisions (1984). Subsequently, the supervised signature extraction with the maximum likelihood algorithm was employed to classify the images.

2.2.2 Accuracy evaluation

For accuracy assessment of imagery classification, ancillary data, including land use survey data derived from historical aerial photos acquired in 2000 and 2007 from Fuzhou Investigation and Surveying Institute, a SPOT image with 2.5 m resolution acquired in 2007, the 1∶10 000 digitized land use maps in 1995, 2000 and 2007 from China Remote Sensing Satellite Ground Station, Chinese Academy of Sciences were used as the reference data. For each image, 289 training sites were randomly chosen to ensure that all spectral classes covering each land use. After classification, for each image 289 samples were randomly selected to check the accuracy of the classified maps. The overall accuracy of the land use and land cover maps in 1989, 1994, 2000, 2006 and 2009 were 78.20%, 77.16%, 79.58%, 77.85% and 81.66%, respectively. Accordingly, the Kappa indices

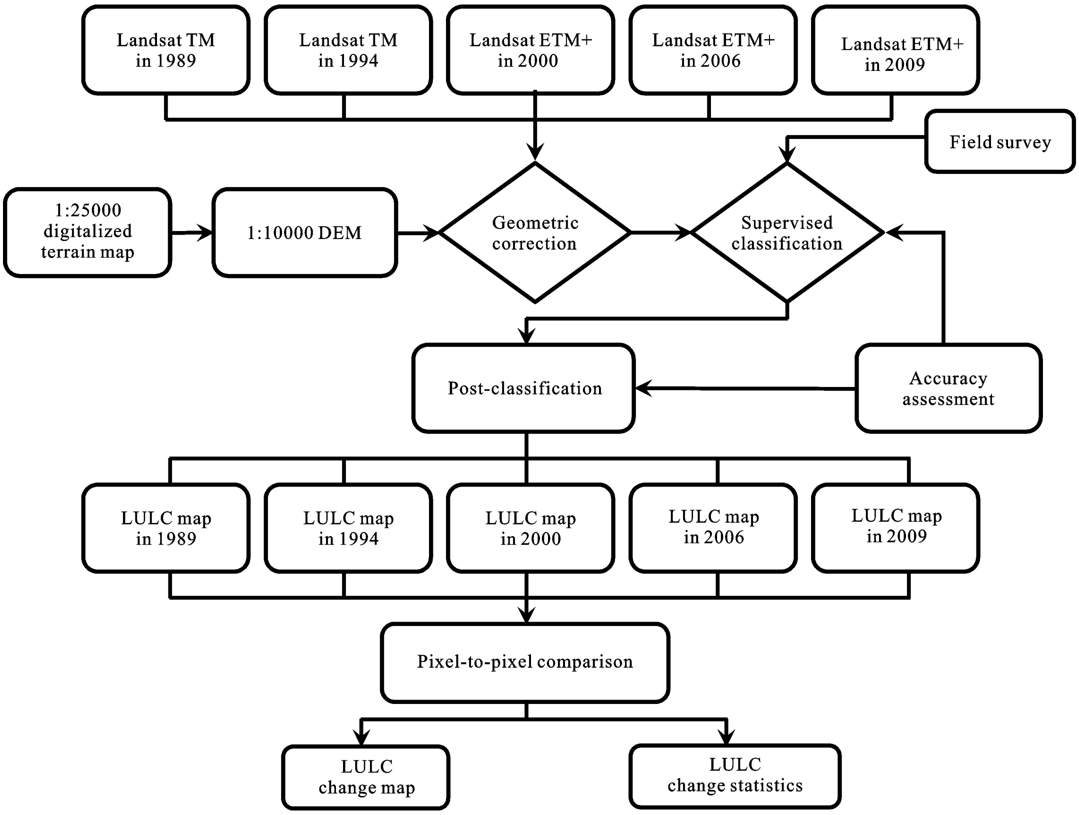

Fig. 2 Flowchart of detection procedure of LULC used in this study

for 1989, 1994, 2000, 2006, and 2009 were 0.74, 0.72, 0.75, 0.73, and 0.78, respectively, with an average of 0.74. These indices meet the recommended value by Jassen *et al*. (1994). Therefore, these data were available for this study.

2.2.3 Land use intensity

To quantify land use intensity, the single land use dynamic degree ($LUDD_{single}$) (Chen *et al*., 1998) was used to determine the changing rate of land use categories over the study period. For a given land use type, the higher the $LUDD_{single}$, the more drastic for change in this land use type. The formulation for computing $LUDD_{single}$ was below:

$$LUDD_{\text{single}} = \frac{U_b - U_a}{U_a \times T} \times 100\% \quad (1)$$

where U_a and U_b are the area of the land use type at time a and b, respectively; T is the interval between a and b.

3 Results and Analyses

3.1 Land use dynamics

Change statistics and the overall pattern of land use in the NWDA from 1989 to 2009 were shown in Table 1, Table 2, and Fig. 3. Table 1 showed that the LULC varied remarkably during study period. There were the increasing trends for built-up land, forest and shrub, and water during the past 20 years (Table 1). Change of the built-up land was most significant, increased by 232.60 km^2 with an average changing rate of 11.63 km^2/yr, followed by forest and shrub, and water with an increasing rate of 0.358 km^2/yr and 0.05 km^2/yr, respectively. In contrast, cropland decreased by 185.49 km^2 during the study period, followed by wetland and bare land, which decreased on average by 2.74 km^2/yr and 0.022 km^2/yr, respectively. In general, forest and shrub, and water changed at a low speed, whereas built-up land, cropland, wetland and bare land changed at a relatively high speed (Table 2). For the built-up land, the changing rates accelerated continuously during almost all periods, reaching the highest rate of 7.29% between 1989 and 1994, with an average changing rate of 7.69% between 1989 and 2009.

Figure 3 showed that the expansion of built-up land in the NWDA was relatively slow between 1989 and 2000. However, this trend was accelerated since 2000. As

Table 1 Land use transformation matrix during 1989–2009 (km^2)

1989	2009						Sum
	Built-up land	Cropland	Forest and shrub	Water	Wetland	Bare land	
Built-up land	137.19	2.87	8.63	0.82	0.22	1.43	151.16
Cropland	113.11	30.80	180.70	8.47	0.03	2.33	335.43
Forest and shrub	98.95	85.24	574.57	3.50	0.00	2.38	764.64
Water	14.31	5.33	1.66	130.15	2.97	1.34	155.77
Wetland	17.68	24.91	4.63	9.76	15.60	1.39	73.96
Bare land	2.53	0.79	1.62	4.08	0.30	0.91	10.22
Sum	383.76	149.94	771.81	156.78	19.12	9.77	1491.18

Table 2 Single land use dynamic degree of study area at different periods (%)

Land use type	1989–1994	1994–2000	2000–2006	2006–2009	1989–2009
Built-up land	7.29	5.19	3.18	6.38	7.69
Cropland	–0.81	–0.77	–4.36	–11.28	–2.76
Forest and shrub	–0.59	–0.15	0.75	0.14	0.05
Water	–0.75	–4.81	5.46	3.56	0.03
Wetland	–5.36	–0.59	–8.73	–7.71	–3.71
Bare land	13.30	2.36	–10.48	11.76	–0.23

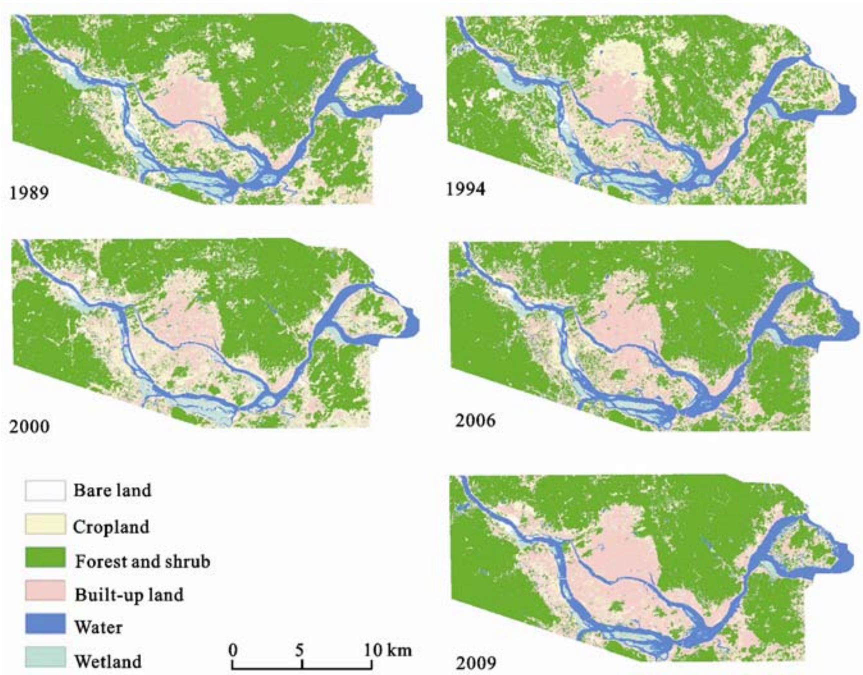

Fig. 3 Land use maps of study area

witnessed, the vast stretches of residences, economic development zones, and supporting traffic facilities were developed along the Minjiang River during the past 20 years. Herein, it is noteworthy that the new town development plan at Cangshan District, which aims at developing the new downtown of Fuzhou City and closely linking the city proper and surrounding counties, has been recently implemented and would further accelerate urban expansion. Meanwhile, as observed, considerable cropland, bare land, and wetland along the Minjiang River were converted to urban built-up land. Therefore, urban encroached into natural and semi-natural ecosystems. The result showed that approximately 64.25% of the newly increased built-up land area was converted from cropland, forest and shrub, water, wetland, and bare land. Thus, recent urban expansion along the Minjiang River represented a huge demand of land resources and resulted in massive land conversion from the other land types to urban built-up land.

3.2 Expansion of built-up land

Based on the description mentioned above, a comprehensive analysis was performed to better illustrate spatio-temporal pattern of LULC in the study area. Therefore, considering natural, political, and socio-economic factors, the span over the study period in the NWDA was divided as follows.

(1) Stage one (1989–1994). This is a rapid development period for the city relatively. Built-up land of the study area increased by 7.29%, from 151.16 km^2 to 206.25 km^2. And the GDP of Fuzhou City increased by 35%, which revealed the development peak in the NWDA. The living standard of people continued to be improved. Thus, most of the newly emerging built-up land was developed in the city proper. Meanwhile, the reclamation of enclosed tidal land sprang up. As a result, the area of wetland greatly decreased by 5.36%, which directly caused the natural wetland degradation in the NWDA. Moreover, free trade zone and high technology park were built in succession.

(2) Stage two (1994–2000). During this period, the development of the study area was slower than stage one. Built-up land in the NWDA increased by 64.18 km^2. Topographically, the Minjiang River limited spatial expansion of the city proper. Besides, urban regeneration slowed down due to urban planning policy constraints until 1999, when the ′Fuzhou Urban Development Planning′ was formally authorized by the State Council of China. Therefore, the overall pattern for development of the NWDA remained nearly unchanged.

(3) Stage three (2000–2006). During this period, the development of the region was greatly affected by the typhoon and tidal effect, resulting in an inundation of the wetland system and the removal of many plant communities. The super typhoon called ′Dragon King′ positively hit the NWDA in 2005. After that, large areas of bare land along river channels were flooded. And many flood control projects appeared. Ultimately, spatial growth of built-up land in the NWDA was relatively lower.

(4) Stage four (2006–2009). During this period, the expansion of the built-up land in the NWDA became faster. The state council issued a series of policies which support the great-leap-forward development of the west-strait economic zone. This resulted in the establishment of intensive industrial parks, settlements, college parks, commercial facilities, and expressway systems linking the city proper, suburban and rural areas. As a result, both urban and satellite towns in suburban area expanded their extents remarkably.

3.3 Driving forces of built-up land expansion

3.3.1 Population growth and its effect

During 1989 and 2009, the total population in the NWDA grew by 173.11% from 1.19×10^6 to 3.25×10^6. However, it should be noted that due to a rigid national policy for population mobility, no one was permitted to leave his birthplace, seek employment, receive education, or settle in the other cities without special official certification before the late 1980s. On the whole, this greatly depressed urban population growth and urban expansion during the period of planned economy. According to a nationwide flexible policy for population migration, both rural and urban residents were permitted to seek employment, receive education, or settle anywhere without any statutory restriction since the 1990s. Therefore, to a large degree, it resulted in unprecedented intra and inter-province migration in the mainland of China. At that time, rural-urban migration from remote rural areas to large cities had been a dominant source for urbanization growth nationwide (Zhang and Song, 2003). In the NWDA, transient population increased from 1.4×10^5 in 1992 to 5.3×10^5 in 2007 in Fuzhou City (Fuzhou Municipal Bureau of Statistics, 2008). In 2009, the immigrants accounted for 37.87% of the total population (Fuzhou Municipal Bureau of Statistics, 2010). Figure 4 showed a significant linear regression relation between the total population and built-up land in the study area, indicating the direct effect of population growth on urban land expansion. With the increase of population, there was a lack of land resources in the NWDA. Before 2010, reclamation of enclosed tidal land was considered as a low cost and practicable way for providing spare land for urban development. Moreover, to accommodate an increasing population, additional settlements in the urban fringe were rapidly developed. This is the main reason why built-up land increase and natural wetland encroachment.

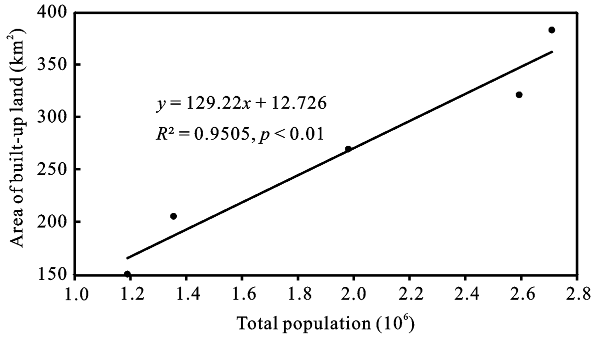

Fig. 4 Relationship between population growth and built-up land in study area

3.3.2 Economic growth and its effect

The achievement in economic development can be evaluated with the total gross domestic product (GDP), and GDP per capita. During the study period, regional total GDP increased 24.6 times, from 9.82×10^9 yuan in 1989 to 2.52×10^{11} yuan in 2009, with an annual average growth rate of 5.67%. The GDP per capita increased 17.4 times, from 1925.5 yuan in 1989 to 35 399.8 yuan in 2009, with an annual average growth rate of 4.83%. Obviously, growth in economic boosted the process of urban construction with a large demand for land resources. Figure 5a shows a significant positive correlation between regional total GDP and built-up land area in the NWDA during the study period, indicating the direct effect of GDP growth on urban land expansion, the same as the linear correlation between GDP per capita and built-up land (Fig. 5b).

All these fitted regression models demonstrated that increasing economic activities and economic output could lead to increasing land for urban expansion. Several factors may help explain the relationship between economic variables and urban growth. With robust economic growth, local governments attempted to expand their public finances for development purposes, including generous investments in industrial parks, key infrastructures, urban regeneration, universities and schools, and so on. On the other hand, local enterprises, especially the booming non-state-owned companies that dominated local economy tended to expand reproduction or invest new commercial facilities. Therefore, economic growth stimulated the demand for more land development, resulting in rapid expansion of built-up land from the city proper to surrounding rural areas.

3.3.3 Industrialization, urbanization process and their effects

Urbanization and industrialization in the NWDA have triggered dramatic land use change from cultivated land to market-oriented land used as built-up land, especially the newly emerging intensive economic development zones at Mawei District in Fuzhou City and residential areas expanded eastward along the Minjiang River. As shown in Table 1, 64.25% of the present built-up land came from other land use types in the study area from 1989 to 2009. Moreover, Fig. 6 shows that the shares of primary industry (mainly farming, forestry, fishery, husbandry and ranching), secondary industry (mainly mining, refining, manufacturing, energy and water supply, construction) and tertiary industry (mainly service and trade) in total GDP were 29.0%, 45.0%, and 26.0%, respectively in 1989; however, they were 9.6%, 47.4%, and 43.0%, respectively in 2009. Simultaneously, in response to significant changes in sector composition among the constituent ratios of total population for major professions, the percentage of the non-agricultural population grew from 24.0% in 1989 to 47.6% in 2009. Furthermore, Fig. 7 shows a positive logarithmic regression relation between the proportion of non-agricultural population and built-up land area in the study area. According to our analysis on LULC detection and local socio-economic development over the study period, this

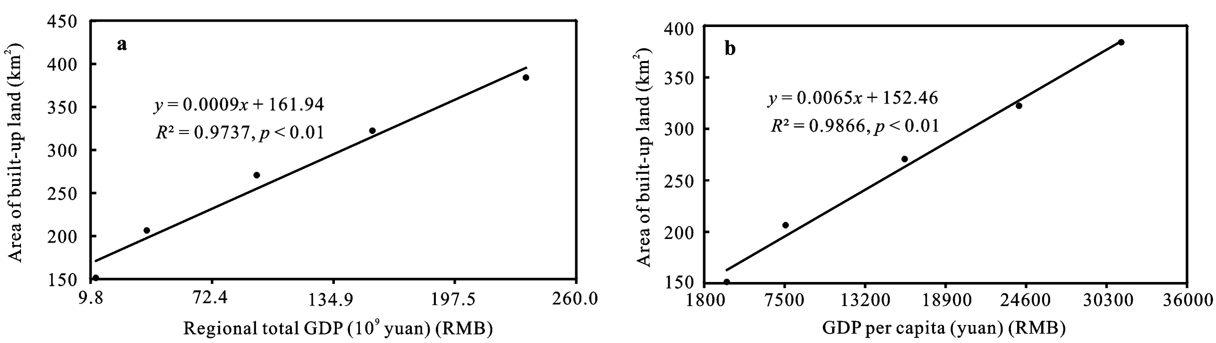

Fig. 5 Relationship between regional total GDP (a), GDP per capita (b) and built-up land during 1989 and 2009

indicated the ongoing trends of agricultural land loss and urban growth, which were witnessed with rapid expansion of industrial parks, infrastructures, and urban and rural settlements. Besides, as addressed in section 3.3.1, the non-local immigrants accounted for 37.87% of the total population, indicating that there was a strong demand for land development due to rural-urban migration and labor mobility during recent industrialization and urbanization, which, in turn, intensified land use in urban area and stimulated expansion of built-up land.

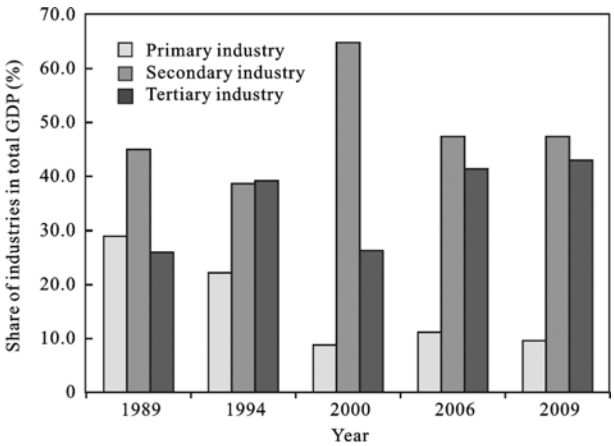

Fig. 6 Change in shares of industries in regional total GDP during 1989–2009

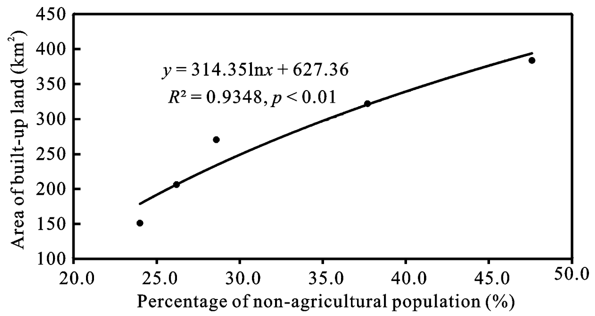

Fig. 7 Relationship between proportion of non-agricultural population and area of built-up land in NWDA during 1989–2009

4 Discussion

Over the past three decades, high speed development of mega cities in China is a problematic dream due to overloading population growth, severe environmental deterioration, and scarcity of land resources (Wu and Zhang, 2012). Similar to the other cities in the mainland of China, the urbanization rate in Fuzhou City between the 1950s and 1970s was much lower. During this period, the planned economy system, rigid state policies, and catastrophic political disorder impeded the development of a market-oriented economy and citizens' freedom of migration nationwide. As a matter of fact, urban development and expansion have also largely been affected by the government planning policy. At macro level, it is widely accepted that the objective of a state political system must serve the economic development during China's recent transition from a planned economy to a market-oriented economy. Since the late 1990s, the State Council of China had released a series of policies to support the development of the west-strait economic zones around the city proper and along the Minjiang River. This stimulated the establishments of intensive industrial parks, settlements, college parks, commercial facilities, and expressway systems along and across the Minjiang River; and therefore encroachment of the wetlands occurred due to pressure of urban development.

At local scale, natural factors such as typhoons and floods usually cause significant environmental disasters and ecological loss in this area. Usually, responses to past flood damage prompted increasing construction of water facilities. This required more investment in flood risk prevention. Therefore, over the recent decades huge amounts of cropland, water bodies, and wetlands along the Minjiang River and its branches have been changed their use to meet the strong demand for the prevention from the typhoons and the floods. However, in pursuing short-term economic gains, local governments failed to effectively managed land development in the flood-prone areas at the loss of considerable key wetlands. As detected by using time series Landsat TM/ETM+ imageries and field survey in this study, the area of estuarine wetland sharply decreased by 74.15%, from 73.96 km^2 to 19.12 km^2 between 1989 and 2009. Over the past decades, in addition to rapid urbanization and related land use conversion, human activities, including river dredging, digging sand, bridge construction, reclamation of enclosed tidal land, and establishment of flood control works have significantly changed the hydrological and sedimentary conditions of wetlands in the NWDA. Inevitably, these caused apparently adverse effect on wetland. For example, the recent digging on river bottom and widening the river channel caused severe degradation of natural wetland with the purpose of tourism development. Besides, invasion of exotic species such as *Spartina alterniflora*, *Eichhornia crassipes*, and *Al-*

ternanthera philoxeroides recently has led to changes in structure of ecological system by changing soil nutrients and physical and chemical features of the wetland, and thus altered the habitats for wetland animals (Liu *et al*., 2005; Ai *et al*., 2009; Zeng *et al*., 2009). In addition, according to a survey on water bird resources in the NWDA performed from 1997 to 2008, a total of 132 water bird species, including 15 species listed in national key protection, l6 species included in the International Union for Conservation of Nature and Natural Resources (IUCN) list of threatened wildlife, and l6 species included in China′s red list of endangered animals, were recorded (Fang, 2008). However, most of these above mentioned water birds are endangered and therefore seldom to be found in the NWDA except local species. Thus, in the long term, much attention should be paid for such key natural wetlands to restore the habitats for endangered water birds.

Institutionally, it is noteworthy that coordination between the administrative agencies should be strengthened to balance the conflicts of land use competition between urban development and ecological conservation. However, it is far from being successful since only the administrative agencies play the key role in preserving the wetland. In fact, the role of public participation is more important. Therefore, we encourage the public to be actively involved in events throughout the decision-making processes and influence the decision-makers.

5 Conclusions

Taking the NWDA in Fuzhou City as an example, this study quantitatively characterize the patterns of urban expansion, and the relationship between built-up land and driving forces from 1989 to 2009 by using an integrated approach combining remote sensing and GIS techniques. The results showed that built-up land increased from 151.16 km^2 in 1989 to 383.76 km^2 in 2009. Approximately 64.25% of the newly emerging built-up land was converted from cropland (29.47%), forest and shrub (25.78%), water (3.73%), wetland (4.61%), and bare land (0.66%) during 1989 and 2009. Moreover, rapid development of infrastructures, facilities, industrial parks, and urban and rural settlements along the Minjiang River resulted in the eastward and southward expansion of built-up land. Additionally, the growth pattern of built-up land in the NWDA is highly correlated with socio-economic factors, including the gross domestic product (GDP), GDP per capita, and structure of industry. Until present, the observed environmental degradation such as loss of cropland and wetland due to heavy pressure of rapid urbanization have greatly impaired the capacity of city to meet the challenges presented by international competition and provide sustainable environment. Therefore, scientific and rational policies for land use and urban planning must be made to minimize the adverse effects of urbanization. Furthermore, coordination among the administrative agencies should be urgently strengthened to balance the conflicts between urban development and ecological conservation to make sure the sustainable land use.

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