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# Urban sprawl and its evolution trend of fuzhou city, China

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## ABSTRACT

Urban sprawl is the main characteristic of rapid urbanization in China. Based on six satellite images of Fuzhou City in 1989, 1994, 1999, 2003, 2006 and 2009 respectively, this paper uses the gray system theory to study the urban sprawl process and the evolution trend of Fuzhou City with the aid of GIS technology. Particularly, the compactness index, urbanization speed index, urbanization intensity index, urban land and population growth elasticity coefficient - are employed to analyze the characteristics of urban sprawl. Additionally, the effect of urban sprawl on land use change was investigated. The results show that the increase of population and economic growth are the main driving forces to urban sprawl in Fuzhou City and the urban sprawl process destroyed lots of land ecosystems. Based on our prediction using the GM (1,1) model, the built-up area of Fuzhou in 2015 and 2020 would be 264.03 $km^2$ and 339.02 $km^2$ respectively. These above findings are of great importance to policy makers for a sustainable urban planning and land resources management system in Fuzhou City.

## KEYWORDS

Urban sprawl; Urban expansion; Driving force; Gray system theory; GM (1, 1); Fuzhou city.

## INTRODUCTION

With the rapid development of economy and society, urbanization in the People's Republic of China has been significantly increased following the initiation of the reform and opening policy. As a result, the urbanization rate raised from 17.4% in 1978 to 49.7% in 2010, and the urban built-up area increased from 7438 km$^2$ in 1978 to 38727 km$^2$ in 2010[1]. Moreover, in view of the theory about "S" curve of urbanization[2], China has entered the acceleration development period of urbanization, and the urbanization will be one of the most significant features of China in the near future. The fast urbanization means that there will be an even greater demand for urban construction land, and more agricultural land will be occupied. However, the area of the cultivated land is quite limited in China. The per capita cultivated land area is 933.338 m$^2$ in 2005[3], which equals to approximately 40% of the world average level. Thus, China will face the dilemma of a fast urban sprawl and a decreasing cultivated land. As a result, the monitoring of the urban sprawl in China is greatly needed.

There has been a great amount of research on urban sprawl for a long time. Urban sprawl describes the expansion of human populations away from central urban areas into previously remote and rural areas, particularly resulting in low-density communities reliant upon heavy automobile usage[4]. In other words, it is the space propulsion of the city under the driving forces. The urban space has the characteristics of succession, comprehensiveness, dynamism, cohesiveness, expandability, etc.[5]. Urban sprawl has eight dimensions including density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity[6]. Numerous research have been going on since the Remote Sensing (RS) techniques became available. However, research on urban sprawl in China started relatively late, given the dramatic acceleration of urbanization in China only started after the reform and opening up in 1980s. The previous research about urban sprawl in China mainly covers the five aspects:

(1) extraction on urban built-up areas, which mainly focus on methodology such as RS techniques[7-8];
(2) spatio-temporal characteristics of urban sprawl[1,9-11];
(3) the three types of urban growth mode: infilling mode, edge mode, and leapfrog growth mode[12-15];
(4) driving forces of urban sprawl[16-17];
(5) the effects of urban sprawl[17-20].

Ewing et al.[21] introduced four sprawl factors including residential density; neighborhood mix of homes, jobs and services; strength of activity centers and downtowns; and accessibility of the street network. Dai et al.[22] drew the urban boundaries of Beijing Municipality over time and overlaid these boundaries to study the spatio-temporal sprawl. Liu et al.[23] analyzed the spatio-temporal processes of urban land expansion in Beijing Municipality using spatial clustering and historic morphology analysis and reported different regulations of urban land expansion in Beijing. Xu et al.[24] investigated the urbanization of Fuzhou City in nearly 30 years and discussed the driving forces of urbanization and the relationship between urbanization and the environment of the city. Sebastin et al.[25] integrated satellite imagery with population census data for studying the human environment and in the Caribbean. Habibi et al.[26] analyzed the positive and negative effects of the urban sprawl.

In this paper, we aim to analyze the urban sprawl effects of the Fuzhou City as well as its driving forces and make our anticipation of urban built-up areas using the Grey System Theory[27-29]. The Fuzhou City is the capital of the Fujian Province. The urbanization and space sprawl of the city has been incessantly expedited in recent years. With the establishment of the Economic Zone on the West Coast of the Taiwan Strait, Fuzhou′s urbanization process was accelerated. Fuzhou is surrounded with mountains on its three sides. The special geographical position and basin terrain make Fuzhou City has the typical characteristics of urban morphology and development. Consequently, we take Fuzhou City as the study area for its special natural conditions, economic development policies, urbanization process, etc.

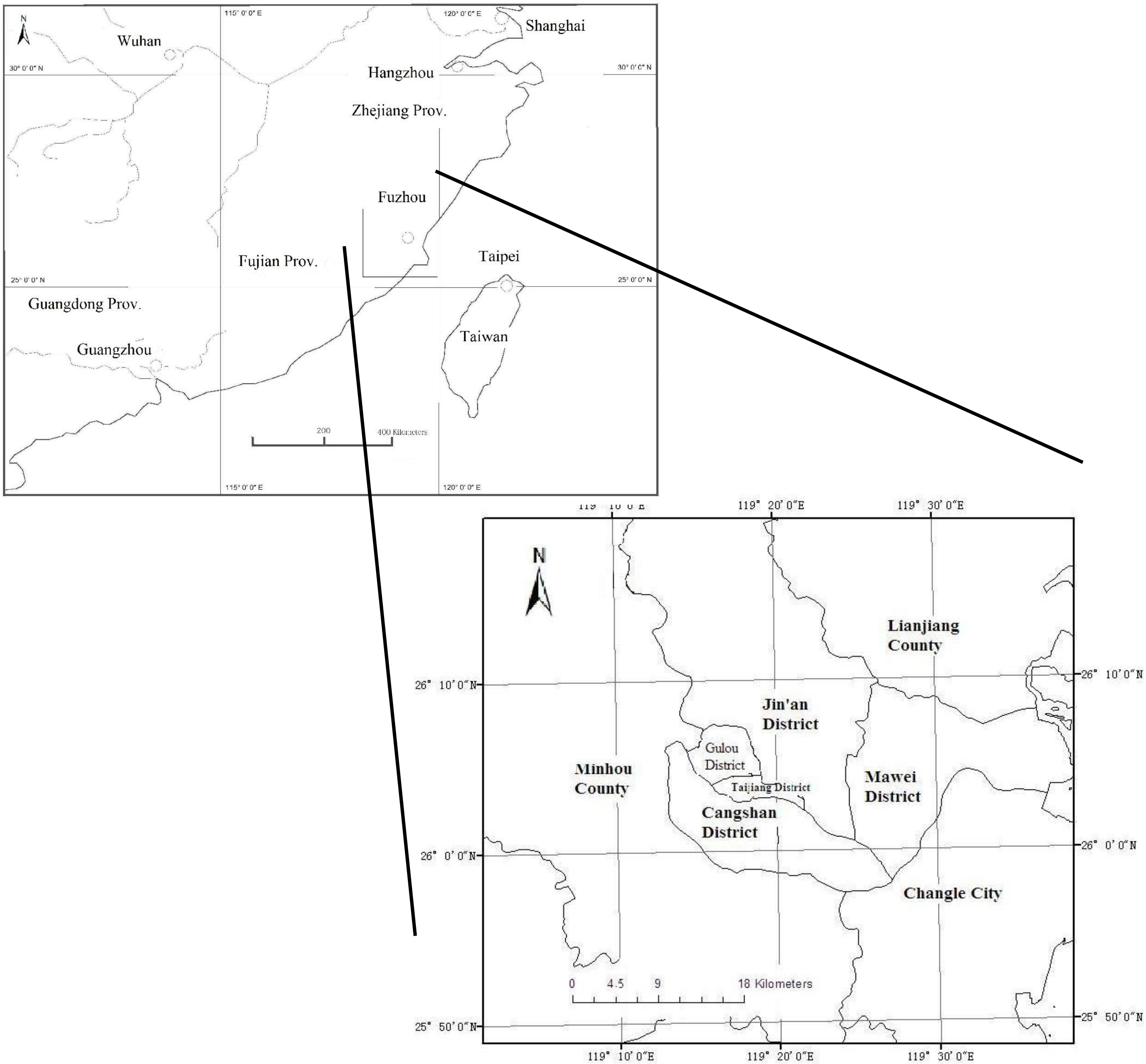
## STUDY AREA AND METHODS

### Study area and data sources

Fuzhou is a coastal city, separated from Taiwan by the East China Sea, lying in the eastern Fujian with Minjiang River flows through the city. Fuzhou City is located around 25°15′—26°39′ N, 118°08′—120°31′ E. Sanming City and Nanping City is located in the west, Ningde City is located in the north, and Putian City is located in the south. Meanwhile, Fuzhou City is an important port city, with a great influence on the development of the Midwest China. Administratively, the Fuzhou metropolis consists of 5 districts, including Gulou District and Jin'an District in the north, Taijiang District in the middle, Cangshan District in the south and west, Mawei District in the east. Minhou County, Liangjiang County and Changle City located around the 5 districts (Figure 1). Fuzhou is chosen for our study because it is one of the fast growing cities in China with special strategic position.

The data used in this study include time-series Landsat TM and ETM+ images and *China City Statistical Yearbook (1990-2010)*. Specifically, Landsat TM images captured on 1989-06-15, 1994-05-12, 2006-09-18, and 2009-06-06 and Landsat ETM+ images captured on 1999-09-26 and 2003-03-26 are selected. They have been preprocessed[31-33].

**Figure 1 : Location map of fuzhou city in fujian province, China**




**Calculate indices**

Research on urban sprawl generally concerns aspects such as urban sprawl mode, speed, intensity, driving forces, effects, etc. The Compactness Index (*C*), Urbanization Speed Index (*USI*), Urbanization Intensive Index (*UII*), Elastic Coefficient between Urban Land and Population Growth (*K*) are used to analyze sprawl characteristics. These indices are defined as:

Compactness Index is calculated as follows:

$$C = 2\sqrt{\pi A}\Big/P \quad (1)$$

Where $C$ is Compactness Index of the city; $A$ means the area of urban built-up area; $P$ is the perimeter of the urban fringe. If the compactness index is closer to 1, it means the city is more compact.

Urbanization Speed Index is calculated as follows:

$$USI = \frac{UA_{n+i} - UA_i}{n} \qquad (2)$$

Where $USI$ is the Urbanization Speed Index, $UA_{n+i}$ and $UA_i$ are the area of urban built-up area in year $n+i$ and year $i$ respectively, $n$ is counted in years.

Urbanization Intensive Index is calculated as follows:

$$UII = \frac{UA_{n+i} - UA_i}{nUA_i} \times 100\% \qquad (3)$$

Where $UII$ is the Urbanization Intensive Index, $UA_{n+i}$ and $UA_i$ are the area of urban built-up area in years $n+i$ and $i$, respectively, $n$ is counted in years.

Elastic Coefficient between Urban Land and Population Growth is calculated as follows:

$$K = (dA(t)/A(t))/(dP(t)/P(t)) \qquad (4)$$

Where $K$ is the Elastic coefficient between urban land and population growth, $A$ is area of the urban built-up area, $P$ is population of the city. According to the analysis of urbanization of China in the recent years made by China Urban Planning Institution, when $K$ >1.12, the increase of urban land is over-speed; when $K$ <1.12, the increase of urban land cannot satisfy the urban development and growth; only when $K$ =1.12, the increase of urban land is sustainable.

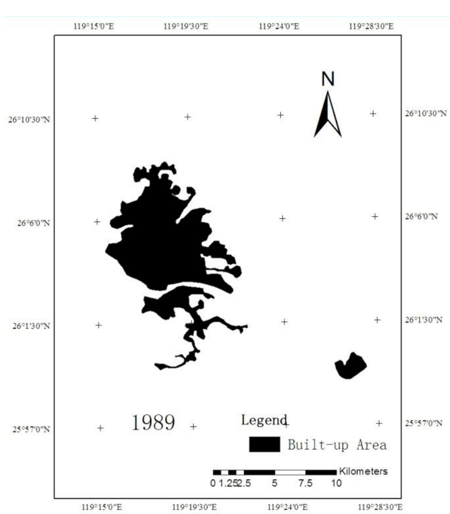
## ANALYSIS OF SPATIO-TEMPORAL CHARACTERISTICS OF URBAN SPRAWL OF FUZHOU

We use the screen digitalization method to extract boundary of urban built-up area, and draw the boundary of urban built-up area of Fuzhou City in 1989, 1994, 1999, 2003, 2006 and 2009, and overlaid them. The results are shown in Figure 2. The area of urban built-up area of each year is listed in TABLE 1.

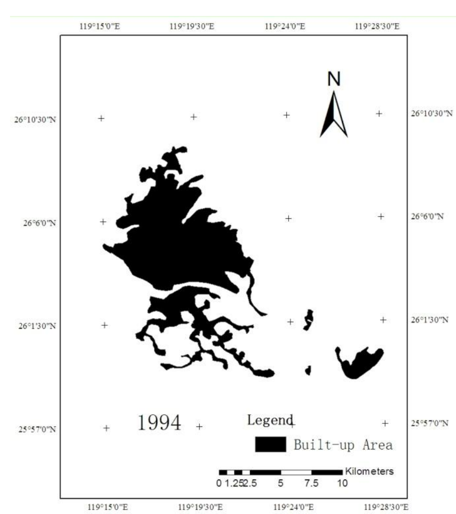
**TABLE 1 : Built-up area from 1989 to 2009 in Fuzhou City (km$^2$)**

| Year | 1989 | 1994 | 1999 | 2003 | 2006 | 2009 |
|---|---|---|---|---|---|---|
| Built-up area | 75.61 | 90.49 | 111.12 | 137.06 | 157.8 | 183.21 |

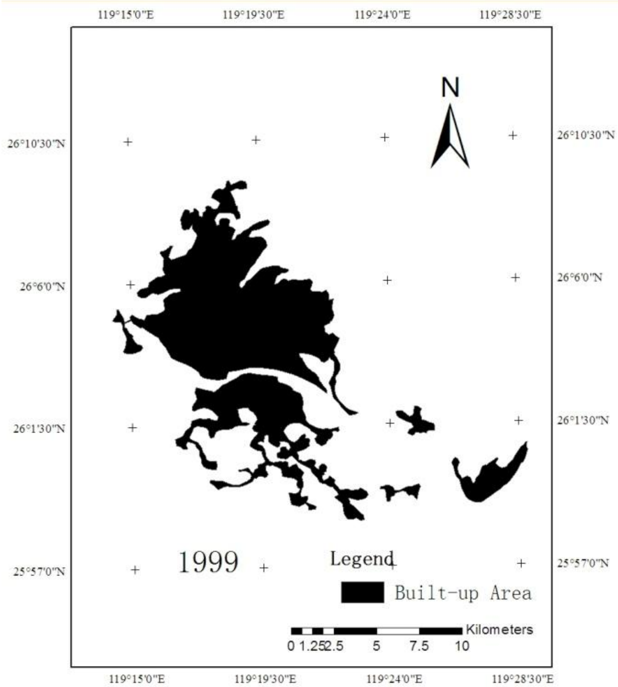
**Figure 2 : The change map of built-up area in Fuzhou City: (a) built-up area in 1989, (b) built-up area in 1994, (c) built-up area in 1999, (d) built-up area in 2003, (e) built-up area in 2006 and (f) built-up area in1989**



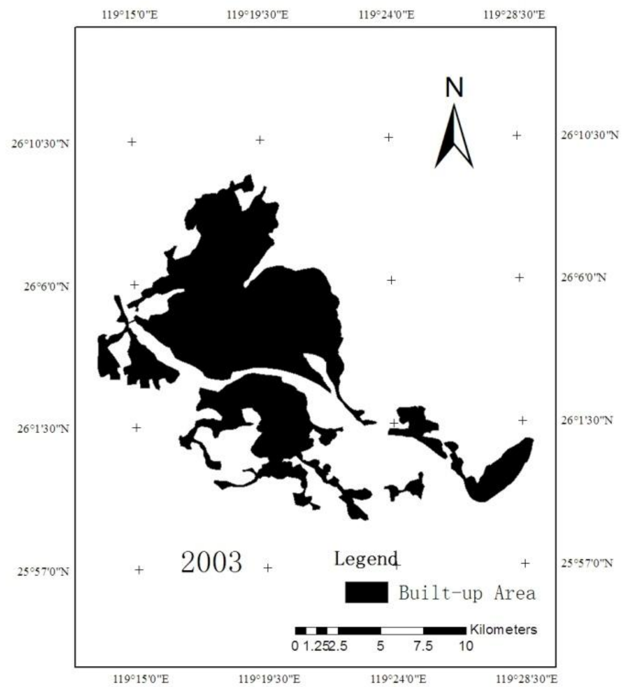

**(a)**



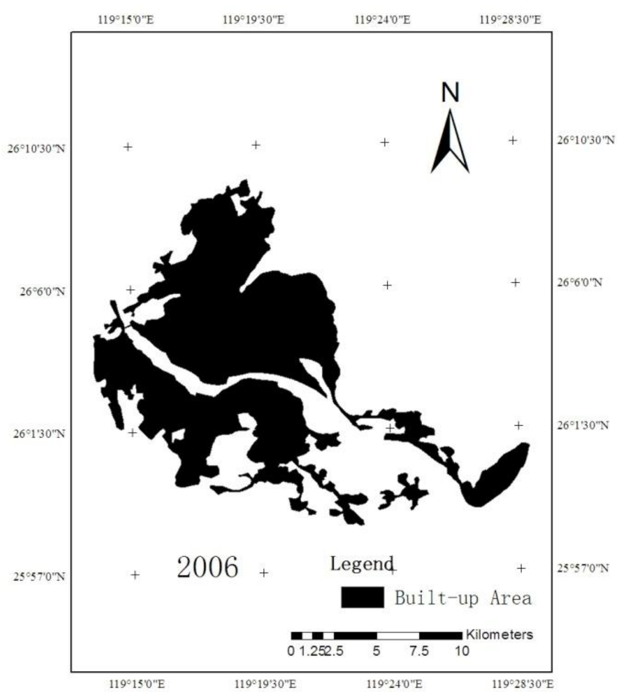

**(b)**



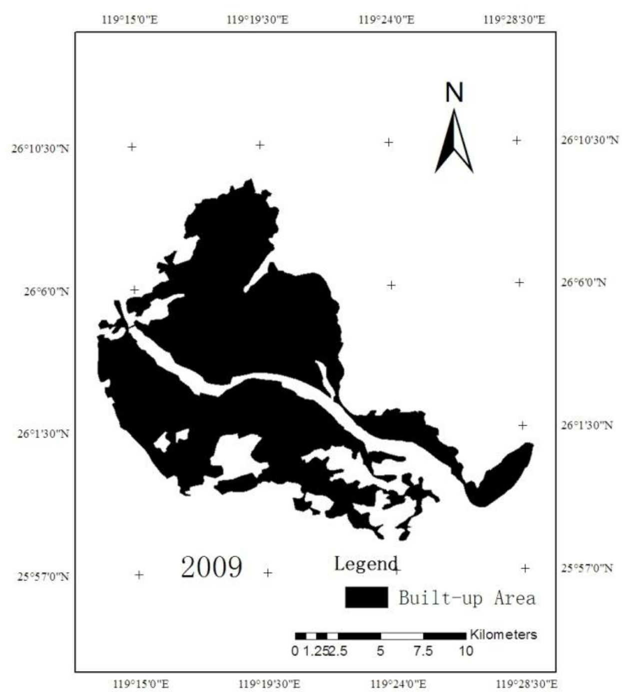

**(c)**




**(d)**




**(e)**




**(f)**

As shown in Figure 2 and TABLE 1, the extent of built-up area of Fuzhou City expanded from 75.61 $km^2$ (1989) to 183.21 $km^2$ (2009), with an increase rate reaching 1.42. During 1989-1994, the extent of built-up area increased by 14.88 $km^2$, and the main expansion directions were the east, the south and the north. During the period of 1994-1999, 1999-2003, and 2003-2006, the extent increased by 20.63 $km^2$, 25.94 $km^2$ and 20.02 $km^2$, respectively, with the main extension direction towards the east and the south. From 2006 to 2009, it increased by 26.13 $km^2$, the main extension direction is the south. The sprawl direction of Fuzhou City in the latest 20 years matches with the *Mater Planning of Fuzhou City (2009-2020).*

In the research, we calculate the *C*, *USI*, *UII and K* of Fuzhou City during 1989-2009, and the results are shown in TABLE 2 and TABLE 3.

**TABLE 2 : Compactness index (*C*) from 1989 to 2009 in Fuzhou city**

| | 1989 | 1994 | 1999 | 2003 | 2006 | 2009 |
|---|---|---|---|---|---|---|
| C | 0.237 | 0.181 | 0.177 | 0.180 | 0.182 | 0.199 |

**TABLE 3 : The urbanization speed index (*USI*), urbanization intensive index (*UII*), elastic coefficient between urban land and population growth (*K*) from 1989 to 2009 in Fuzhou city**

| | 1989-1994 | 1994-1999 | 1999-2003 | 2003-2006 | 2006-2009 |
|---|---|---|---|---|---|
| USI ($km^2$/year) | 2.976 | 4.126 | 6.485 | 6.913 | 8.470 |
| UII | 3.94% | 4.56% | 5.84% | 5.04% | 5.37% |
| K | 4.08 | 3.11 | 1.63 | 1.63 | 5.22 |

The change of *C* is the results of urban sprawl, and different *C*-values indicate different economic and environmental benefits. The increase of *C*-values implies that the city is more compact and service is more concentrated. On the contrary, the decreases of C-values indicate that as the sprawl proceeds, the city is more fragmentized and its shape is more discrete. TABLE 2 shows that the *C*-values of Fuzhou City. The *C* is a fall from 0.237 (1989) to 0.177 (1999) at the first stage, and the city extension was less compact and less ordered. During the second stage, the C-values of Fuzhou City rose from 0.177 (1999) to 0.199 (2009), showing a well-organized expansion process.

The *USI* in TABLE 3 shows that the urban extension of Fuzhou City was speeding up during 1989-2009. The period of 1989-1994 is the smoothest period, and the annual increase was 2.976 $km^2$; during 1994-1999, the annual increase is 4.126 $km^2$, which was much greater than the previous years; during 1999-2003 the annual increase was 6.485$km^2$, which is followed by the annual increase of 6.913 $km^2$ during 2003-2006, and 8.470 $km^2$ during 2006-2009. As the urban sprawl speeding up, the real estate business was booming and a huge amount of foreign investments flood into Fuzhou. Lots of economic and technological development zones were set up and the urban sprawl speed became even higher. The increase of urban sprawl speed has reached a pretty high level since the $21^{st}$ century. The Urbanization Intensive Index (*UII*) offers comparability for the sprawl of urban land in different periods. As shown in TABLE 3, the change of *UII* of Fuzhou City over time is very complex. Generally, since 1989, the *UII* experienced an up-down-up process. During 1989-2003, the *UII* rose from 3.94% to 5.84%, which is a dramatic increase. However, during 2003-2006 the *UII* fell to 5.04%, and after 2006-2009 it reached 5.37% again. The *K*-values in TABLE 3 show that the growth of urban land is not in the same pace with the population growth. The growth of urban land is always faster than that of population. In fact, such phenomenon has appeared in the history of other countries such as America and India. Therefore, although the *K*-value is greater than 1.12, it is not a single case and, instead, it is quite common. As the urbanization speeds up, the technology advances, the fiscal revenue increases and with more social fixed asset investments, more technology and money will be put into urban land development. Added with administrative intervention, the urban sprawl will become even faster. Correspondingly, due to the stricter household registration system, even the population growth is relatively fast, still, it is not compatible with the speed of urban land sprawl.

## ANALYSIS OF DRIVING FORCES AND EFFECTS OF URBAN SPRAWL OF FUZHOU CITY

### Research of driving forces of urban sprawl

The spatial expansion of a city is closely related to its economic development, from which we may explore the driving forces of urban sprawl and factors that affect it. We set the built-up area of Fuzhou during 1989-2009 as dependent variable *Y*, the urban population (*X*1), the urbanization level (*X*2), the GDP (*X*3), the percentages of primary, secondary and tertiary industry in the GDP (*X*4, *X*5 and *X*6), the fiscal revenue (*X*7), the social fixed-asset investments (*X*8) and the average worker wages (*X*9) as the independent variables. Using these variables and data listed in TABLE 4, a stepwise regression model is built:

**TABLE 4 : Socio-economic statistical data of Fuzhou city from 1989 to 2009**

| Variables | 1989 | 1994 | 1999 | 2003 | 2006 | 2009 |
|---|---|---|---|---|---|---|
| Built-up area, *Y* ($km^2$) | 75.61 | 90.49 | 111.12 | 137.06 | 157.8 | 183.21 |
| Urban population, *X*1 (ten thousand) | 129.24 | 135.48 | 145.4 | 166.24 | 181.72 | 187.33 |
| Urbanization level, *X*2 (%) | 68.02 | 70.29 | 74.62 | 80.45 | 82.08 | 85.35 |
| GDP, *X*3 (hundred million Yuan) | 47.97 | 194.94 | 447.48 | 625.49 | 804.42 | 1327.98 |
| Primary industry proportion, *X*4 (%) | 28.72 | 20.87 | 16.3 | 12.37 | 10.44 | 9.29 |
| Secondary industry proportion, *X*5 (%) | 40.25 | 37.65 | 42.07 | 47.24 | 42.74 | 42.56 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Tertiary industry proportion, *X*6 (%) | 31.03 | 41.47 | 41.64 | 40.39 | 46.82 | 48.15 |
| Fiscal revenue, *X*7 (hundred million CNY) | 7.79 | 14.86 | 28.37 | 46.40 | 82.27 | 126.48 |
| Social fixed-asset investments, *X*8 (hundred million CNY) | 17.71 | 84.35 | 137.90 | 276.12 | 444.50 | 944.15 |
| Average worker wages, *X*9 (CNY) | 2245 | 5015 | 10277 | 16122 | 22705 | 26284 |

$$Y = 0.21X2 + 0.288X3 + 0.51X9 \qquad (R^2 = 0.993, P < 0.05) \tag{5}$$

The urbanization level (*X*2), GDP (*X*3), and the average worker wages (*X*9) are maintained in the stepwise selection, indicating that the main driving forces of urban sprawl of Fuzhou are population and economy. Particularly, the main driving factors include:

(1) Population growth. The growth of population is the direct driving force of sprawl. As shown in TABLE 4, the urban population of Fuzhou increased from 1.2924 million in 1989 to 1.8733 million in 2009, with the urbanization level rising from 68.02% in 1989 to 85.35% in 2009. The increase of population requires more land for living and industry, which includes land for housing and supporting facilities, land for transportation and public facilities, land for the industry, etc. As the residents' lives well improved, they would focus on pursuing a higher quality of life. They require more space, which may be used for leisure and entertainment activities. All these factors result in an increase of the urban built-up area. As discussed above, during 1989-2009, Cangshan District made the most significant contribution to sprawl of Fuzhou, and most of its newly developed land was used for new housing estates.

(2) Economic development. Development of economy is vital to the urban sprawl. In the macro level, it determines the size and development speed of a city; while in the micro level, it affects the living standard of citizens given its influence on the urban land use. As can be seen in TABLE 4, the GDP of urban area of Fuzhou ballooned from 4.8 billion CNY (Chinese Yuan) in 1989 to 132.8 billion CNY in 2009. Meanwhile, the percentage of primary industry dropped from 28.72% to 9.28% and the percentage of tertiary industry rose from 31.03% to 48.15%. Because of the dramatic development of GDP and the fall of primary industry proportion and the rising of tertiary industry, there has been a greater demand for urban land. In addition, the economic development also causes a gather of population to urban area and stimulates the population to grow, which will also add to the urban land use. Besides, with the increase of average worker wages, people desire more manufacturing industry land and service industry land. To sum up, economic development is a crucial factor of urban sprawl and will still be a major driving force of sprawl in quite a long time.

(3) Government policy. Government policy plays a crucial role in Fuzhou's sprawl. In 1984, Fuzhou City was approved to be one of the 14 costal opening cities. The establishment of the Fuzhou Mawei Economic-technological Development Area in 1985 made the bulit-up urban area of Mawei District expand three times during 1989-2009. In May 1995, as the *Mater Planning of Fuzhou City (1995~2010)* was approved by the State Council, the Kuai'an District was set up and developed very fast. Thus, we can see that government policy is a very important factor that influences the expansion.

(4) Natural factor. Natural factor directly affects the speed and potential of sprawl; while natural factor may become the threshold of urban development. It generally has both positive and negative effects on urban sprawl. As for Fuzhou City, it is a costal city with abundant fresh water and marine resources, therefore it is capable of forming costal trade markets to enhance the urban sprawl speed. Fuzhou City is also located in a basin, with Mt Gushan in the east, Mt Qishan in the west, Mt Wuhushan in the south and Lotos Peak in the north. Minjiang River flows from the west to the east across city center of Fuzhou City and there are Wu Mountain, Ping Mountain and Yu Mountain within the urban central area of Fuzhou City (Figure 1). The restricted topography is a block for sprawl of Fuzhou City. From the above research, we may conclude that the sprawl of Fuzhou City experienced the direction of north, south and east. Now due to the topographical restriction and other natural factor's restriction, there is little potential for Fuzhou City to expand in these directions, which means the possible direction to expand is the west and the south. With the restriction of sprawl of Fuzhou City, we can see that natural factor is a very significant basis of it.

## Effects of urban sprawl on land cover change

Mostly, urban sprawl can cause the changes of other types of rural land, such as clutivated land, wood land, grassland, and lakes, converting into urban land use. Culitvated land supplies the foods and other necessities of life. Besides, woodland, greassland, water, and ect. are all of great importance to the whole ecosystem. The reduction of ecological land may lead to climate changes, urban heat island effect, ecological deterioration and many other environmental problems. Here we focus on investigating the effects of urban sprawl on the urban land cover change using land use types and quantitative statistics data of Fuzhou during 1989-2009. The RS data used for land use/cover maps are dated on 15th June, 1989 and 18th Sep., 2009. Based on the boundary of built-up area of 2009, we clipped the RS images of 1989 and 2009. Then, we sorted the clipped images to get the land-use change matrix.

**TABLE 5 : The land-use change matrix from1989 to 2009 in Fuzhou city (km$^2$)**

| | Grassland | Cultivated land | Construction land | Woodland | Bare land | Water | Total |
|---|---|---|---|---|---|---|---|
| Grassland | 0.05 | 0.00 | 0.20 | 0.05 | 0.00 | 0.00 | 0.30 |
| Cultivated land | 0.34 | 0.00 | 75.13 | 2.58 | 0.00 | 0.22 | 78.28 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Construction land | 0.17 | 0.00 | 70.01 | 0.08 | 0.00 | 0.11 | 70.37 |
| Woodland | 0.09 | 0.00 | 21.38 | 2.30 | 0.00 | 0.12 | 23.89 |
| Bare land | 0.01 | 0.00 | 1.85 | 0.12 | 0.00 | 0.00 | 1.98 |
| Water | 0.02 | 0.00 | 8.33 | 0.75 | 0.00 | 1.16 | 10.27 |
| Total | 0.69 | 0.00 | 176.90 | 5.88 | 0.00 | 1.62 | 185.09 |

As shown in TABLE 5, the construction land of Fuzhou was enlarged from 70.37 $km^2$ in 1989 to 176.90 $km^2$ in 2009. The increase of construction land comes from cultivated land being 75.13 $km^2$, woodland being 21.23 $km^2$, water being 8.33 $km^2$, bare land being 1.85 $km^2$ and grassland being 0.20$km^2$. Cultivated land, woodland and water are the main sources for urban construction land increase. Cultivated land, woodland and water all belong to ecological land, which may help water and soil conservation, clean the air, beautify the environment, and boom the tourism as well as the leisure and entertainment industry. Sprawl of Fuzhou mainly occupied ecological land, which may lead the fragile ecological system to an even more dangerous situation. Xu et al.[24] studied the urban heat island effect caused by urban sprawl in Fuzhou City. With the urban sprawl taking lots of ecological land, there have been fundamental changes of land cover and the properties of its underlying surface, causing a severe urban heat island effect[20].

## PREDICTION OF URBAN BUILT-UP AREA OF FUZHOU CITY

GM (1, 1) model[27-30], with full name “Grey Model First Order One Variable”, is the most widely used prediction model in the literature. This model is a time series forecasting model. The differential equations of the GM (1,1) model have time-varying coefficients. In other words, the model is renewed as the new data become available to the prediction model. GM (1,1) means a first order grey model of one variable; it is capable of smoothing the randomness of the series, exploring the evolution rules of the system. Its basic model is expressed as Equation (6):

$$x^{(0)}(k) + az^{(1)}(k) = b \tag{6}$$

Where *a* is called the developing coefficient and it represents the developing state of the prediction value, *b* is called the grey input and it represents change contained in the data, $x^{(0)}$ is the raw series, $z^{(1)}$ is the MEAN series (averaging the adjacent data in Accumulated Generating Operation (AGO) series)·

The main steps of GM (1,1) are:

Step 1: Let $x^{(0)}$ be raw series:

$$x^{(0)} = \{x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(n)\} \tag{7}$$

Where $x^{(0)}(i)$ is the time series data at time *i*, *n* must be equal to or larger than 4.

Step 2: On the basis of the raw series $x^{(0)}$, a new series $x^{(1)}$ is set up through the AGO, i.e.

$$x^{(1)} = \{(x^{(1)}(1), x^{(1)}(2), ..., x^{(1)}(n))\} \tag{8}$$

Where

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i) \qquad k = 1,2,\dots, n \tag{9}$$

Step 3: The generated MEAN series $z^{(1)}$ of $x^{(1)}$ is defined as:

$$z^{(1)} = \{z^{(1)}(1), z^{(1)}(2), ..., z^{(1)}(n)\} \tag{10}$$

Where $z^{(1)}(k)$ is the mean value of adjacent data, i.e.

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1) \qquad k = 1,2,\dots,n \tag{11}$$

The least square estimate series of the grey difference equation of GM (1,1) is defined in Equation (6). The whitening equation is therefore, as follows:

$$\frac{dx^{(1)}(t)}{dt} + ax^{(1)}(t) = b \qquad \textbf{(12)}$$

Moreover, from Equation (11), we get:

$$\begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix} = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \times \begin{bmatrix} a \\ b \end{bmatrix} \qquad \textbf{(13)}$$

Let

$$Y_n = \left[x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n)\right]^T \qquad \textbf{(14)}$$

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \qquad \textbf{(15)}$$

Both take Equation (11) and (16):

$$A = [a, b]^T \qquad \textbf{(16)}$$

Where $Y_n$ and $B$ are the constant vector and the accumulated matrix respectively, $z^{(1)}(k)$ is the $k^{th}$ background value. Applying ordinary least-square method to Equation (13) on the basis of Equation (11) and (14) - (16), coefficient *A* becomes：

$$A = \left(B^T B\right)^{-1} B^T Y_n \qquad \textbf{(17)}$$

Step 4：Substituting *A* in Equation (6) with Equation (17), the approximate equation becomes the following

$$\hat{x}^{(1)}(k) = \left( x^{(0)}(1) - \frac{b}{a} \right) \times e^{-a(k-1)} + \frac{b}{a} \qquad \textbf{(18)}$$

Where $\hat{x}^{(1)}(k)$ is the predicted value of $x^{(1)}(k)$ at time *k*. After the completion of the AGO on Equation (18), $\hat{x}^{(0)}(k)$, the predicted value of $x^{(0)}(k)$ at time *k* becomes available and if $c = x^{(0)}(1) - \frac{b}{a}$, therefore,

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) = ce^{-a(k-1)} + \frac{b}{a} - (ce^{-a(k-2)} + \frac{b}{a}) = ce^{-a(k-1)}(1 - e^{a}) \qquad \textbf{(19)}$$

However, as for different time gap, we can get the grey model[28] as follows:

$$\hat{x}^{(0)}(t_i) = \hat{c} e^{-\hat{a} t_i} (1 - e^{\hat{a}}) \qquad \textbf{(20)}$$

Step 5： Error test. We calculate the Average Relative Error (*Δ*), Difference Ratio (*C*) and Little Probability of Error (*P*) for checking grey model.

First, we calculate the Variance and Standard Deviation of the raw series:

$$S_1^2 = \frac{1}{n}\sum_{i=1}^{n}[x^{(0)}(t) - \overline{x^{(0)}}]^2 \quad \textbf{(21)}$$

Then we calculate the Variance and Standard Deviation of the Residual Error:

$$S_2^2 = \frac{1}{n}\sum_{i=1}^{n}[\varepsilon^{(0)}(t) - \overline{\varepsilon^{(0)}}]^2 \quad \textbf{(22)}$$

Thus, the Average Relative Error is:

$$\Delta = \frac{1}{n-1}\sum_{k=2}^{n}\Delta_k \quad \textbf{(23)}$$

Where $\Delta_k = \frac{|\varepsilon(k)|}{x^{(0)}(k)}$.

The Difference Ratio $C$ and the Little Probability of Error $P$ are

$$C = \frac{S_2}{S_1} \quad (20)$$

$$P = \left\{ \left| \varepsilon^{(0)}(t) - \overline{\varepsilon^{(0)}} \right| < 0.6745 S_1 \right\} \quad \textbf{(24)}$$

If there are $r$ amount of $\varepsilon^{(0)}(t)$ satisfies the relation that $\left|\varepsilon^{(0)}(t) - \overline{\varepsilon^{(0)}}\right| < 0.6745 S_1$, then $P = \frac{r}{n}$.

TABLE 6 is the evaluation criterion of grey forecasting precision.

**TABLE 6 : Evaluation criterion of grey forecasting precision**

| Evaluation Criterion | Difference Ratio (*C*) | Probability of Error (*P*) |
|---|---|---|
| Good | $<$0.35 | $>$0.95 |
| Qualified | $<$0.50 | $>$0.80 |
| Merely qualified | $<$0.65 | $>$0.70 |
| Fail | $\geq$0.65 | $\leq$0.70 |

Built-up areas of 1989, 1994, 1999, 2003, 2006, 2009 and 2013 are 75.61km$^2$, 90.49km$^2$, 111.12km$^2$, 137.06km$^2$, 157.8km$^2$, 183.21km$^2$ and 239.2 km$^2$ respectively. Analyzing the data above, we can see the values are always positive and distributed in a valley form. Therefore, we may use the GM (l, l) to build up our model; from the GM (l, l) steps above, we get our Grey Model:

$$\hat{x}^{(0)}(t_i) = 1334.982e^{0.05t_i}(1 - e^{-0.05}) \quad \textbf{(21)}$$

TABLE 7 is the Gray Model Error Test.

**TABLE 7 : Error test of gray model**

| Year | 1994 | 1999 | 2003 | 2006 | 2009 | 2013 |
|---|---|---|---|---|---|---|
| Anticipation of our model ($km^2$) | 87.89 | 112.85 | 137.83 | 160.14 | 186.06 | 238.9 |
| Real value ($km^2$) | 90.54 | 111.12 | 137.06 | 157.8 | 183.21 | 239.2 |
| Residual Error | 2.65 | -1.73 | -0.77 | -2.34 | -2.85 | 0.3 |
| Relative Error | 2.93% | 1.56% | 0.56% | 1.48% | 1.56% | 0.13% |
| Average Relative Error | | | 1.37% | | | |
| Difference Ratio ($C$) | | | 0.151 | | | |
| Probability of Error ($P$) | | | 1 | | | |

As can be seen from TABLE 7, the Grey Model we built up has an Average Relative Error of 1.37%, a Difference Ratio 0.151, and a Little Probability of Error P=1. Our model is very accurate that it can be used for urban area prediction. We use this model to simulate the built-up area of Fuzhou City in 2015 and 2020, thus:

$$\hat{x}^{(0)}(28) = 1334.982 \times e^{0.05\times 28}(1 - e^{-0.05}) = 264.03$$

$$\hat{x}^{(0)}(33) = 1334.982 \times e^{0.05\times 33}(1 - e^{-0.05}) = 339.02$$

The simulated results show that the built-up area of Fuzhou City in 2015 and 2020 would be 264.03$km^2$ and 339.02$km^2$. For the predicted built-up area in the future, the results suggest that urban land would occupy more rural area.

According to TABLE 4 above, Fuzhou experienced the rapid economic development and population growth over the past 15 years; hence the urban built-up area of the city increased a lot. And, the *K*-values in TABLE 3 show that it is the extensive growth mode in China. However, the government would make more effort to implement a series of measures to control land use for urban expansion and encourage intensive urban land use in future development; moreover, the economic slowdown is likely to be continued in the next 10 to 15 years. For these reasons above, the real built-up area would be lower than predicted built-up area of Fuzhou City in 2015 and 2020.

## CONCLUSIONS

During 1989-2009, the built-up area of Fuzhou City is increased from 75.61$km^2$ to 183.21 $km^2$. Our analysis suggests that the population growth and economic increase are the two main driving forces of urban sprawl in Fuzhou City. Moreover, the government policy and natural factors are also the driving forces of sprawl. As a result, the loss of the ecological land (such as cultivated land, woodland and water) caused by urban sprawl is getting more serious. The Grey-Model-based prediction shows that the urban built-up area may be reach 264.03$km^2$ in 2015 and 339.02$km^2$ in 2020 if the current developing mode was maintained, which means the urban growth of Fuzhou will keep occupying ecological land in the future. On the other hand, the sprawl of Fuzhou City is restricted by its surrounding environments such as topographical restriction. Extensive growth mode of Fuzhou City is contrary to "*Smart Growth Mode*". The expansion of urban land in the future will lead to further agricultural land loss which will affect the grain production and lead to more negative effects such as heat island effect and inefficient land use.

To prevent excessive growth of urban land in Fuzhou City, we suggest that:

(1) The local government should make rational planning of urban land, strictly following the urban planning and land use planning to approve any land use change;

(2) It is necessary to increase urban land use intensity by carrying out old city reconstruction plan and increase the efficiency of land use;

(3) We must set up the urbanization mode to prevent the city from expanding out of control, and to enhance the sustainable development of the city.

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## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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