

A REMOTE SENSING AND GIS INTEGRATED STUDY ON URBANIZATION WITH ITS IMPACT ON ARABLE LANDS: FUQING CITY, FUJIAN PROVINCE, CHINA

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ABSTRACT

Landsat TM images were employed to characterize land-cover types and land-cover changes in Fuqing City and its adjacent areas in Fujian Province, southeast China. Three TM scenes from 1991, 1994 and 1996 were used to cover the city and the adjacent areas and a five-year time period. Socio-economic data were also integrated with remotely sensed data for the study. Digital image processing with assistance of GIS has produced three classified image maps. The comparison of the three maps reveals that the urban expansion was very rapid, a large number of arable lands have been lost, and deforestation has taken place in the study area during the five study years. The main driving forces to the urbanization appeared to be the rapid economic development and traffic infrastructure. The suggestion on the regional sustainable development for the county is also presented. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS: urbanization; arable land; remote sensing; GIS; Landsat TM; Fuqing; China

INTRODUCTION

The use of digital data, spatial information and computer networks have become the key factors in modern technology, and as the flood of raw data moves into the digital frameworks, it becomes critical to make use of what is now available. This will not only gather the data, but, more importantly, it will also manage, index and interoperate this wealth of information, which is of different scale and time span, for the user community, governmental decision making and environmental management. This study demonstrates the application of remotely sensed satellite data to dynamical monitoring of the process of urbanization and the loss of arable land. Integrated technologies of remote sensing and the geographic information system (GIS) were used to analyse the urbanization process of Fuqing City with its impact on regional environmental changes. Spatial information was acquired from remotely sensed data, while factors responsible for urban expansion were analysed using socio-economic data.

The economy in China has been growing very fast since the early 1980s, especially in the coastal zone areas of east China. County Fuqing is located in east Fujian, southeast China, on the west coast of the Pacific Ocean. The county's economic development has been rapid even by China's standard and is one of the counties showing fastest economic growth. Moreover, various plans for further development of the county are under design and are to be launched, so Fuqing now has to contend with some of the more negative aspects of this. The over-fast development of the economy has already caused many changes in the environment. The urban development of Fuqing City has been very rapid during the last decade, and this has dramatically increased the impact on ecosystems. It is therefore necessary to dynamically monitor this expansion. This would be very helpful for the strategy of regional sustainable development and would contribute substantially to the decision-making process.

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The goal of this study was to assess the expansion of Fuqing City and its environmental impact, to understand the rate of land-cover changes and to ascertain the places where the changes occurred. This is essential to urban planners in making their decisions. The goal was achieved by using geoinformation technology, i.e. remote sensing with the assistance of GIS and socio-economic data. Satellite-based earth observation offers the ability to provide synoptic and repetitive measurements over very large geographic areas, and over long periods of time. Remote sensing techniques can be used to monitor the conversion of land-cover types. The GIS is widely used for capturing, storing, updating, analysing and displaying all forms of geographically referenced information. These advanced technologies are recognized worldwide as valuable technologies in environmental applications and are very useful in monitoring the environmental changes due to human activity (Gao and Skillcorn, 1995; Migul-Ayanz and Biging, 1997; Riaza *et al.*, 1998; Yeh and Li, 1998).

The study was concerned with two aspects: (1) Dynamical monitoring environmental changes in the study area using remotely sensed data. Landsat TM satellite image data were employed for land-cover classification and the analysis of urbanization and land-cover and environmental changes. Satellite data of different time periods were used. The work included ground truth survey and data collection with the help of GPS global positioning technology. (2) Through the study of land-use and land-cover changes and their consequences, conclusive statistical information and visualization data were obtained regarding the processes, causes and impacts of the urbanization. This will enable us to use natural resources scientifically, to assess the regional sustainable development plan and to protect our living environments.

STUDY AREA

County Fuqing administratively falls under Fuzhou Prefecture, Fujian Province. The county lies across the Taiwan Strait from Taiwan. The approximate geographical position of the county is 25°18' to 25°50'N and 119°34' to 119°40'E. Fuqing has a total area of 2430 km², of which about 63 per cent is land and 37 per cent is water-covered areas. Mountains are dominant in northern and western Fuqing, while hilly to flat areas are located mainly in eastern and southeastern regions that are extensively cultivated. Fuqing features an irregular coast, indented by many bays and harbours. The lowlands are crisscrossed with waterways and dotted with lakes. The longest river system in Fuqing is the Rong River, which flows in a generally west to southeast direction to the Pacific Ocean. The county is also known as Rong named after this major river system. Fuqing has a subtropical climate. Temperatures average 18 °C. Typhoons occur mainly between July and September. Rainfall, which is especially abundant in spring, averages 1525 mm annually. The county has a 10-month growing season. Rice, double-cropped in the humid subtropical climate, is grown in small alluvial valleys and flat lowlands, while wheat and sweet potatoes are grown in upland areas. Fishing is also important. Today, Fuqing's population is one of the largest in the counties of the Fujian Province. It has a population of ca. 1.17 million (1997). The average population density was 481.03 persons per square kilometre (1997), while the nation's average was 127 persons per square kilometre (1995). The population growth rate was 0.93 per cent (1997).

The study area is focused on Fuqing City and its adjacent areas, which covers some 220 km² (Figure 1). Fuqing City is located in the north of the county. There are two major towns in the areas to the west and east of the city. These are Honglu in the west and Haikou in the east. These two towns are characterized by industry and have contributed a lot to the county's economy. The Yaohua Industrial Estate is situated in Honglu and the Yuanhong Industrial Estate in Haikou.

METHODS

Materials and General Procedures of Data Processing

Land cover was studied using remote sensing techniques. In order to maintain consistent data for the study period, all image data used in this study were Landsat TM data. The TM data are one of the

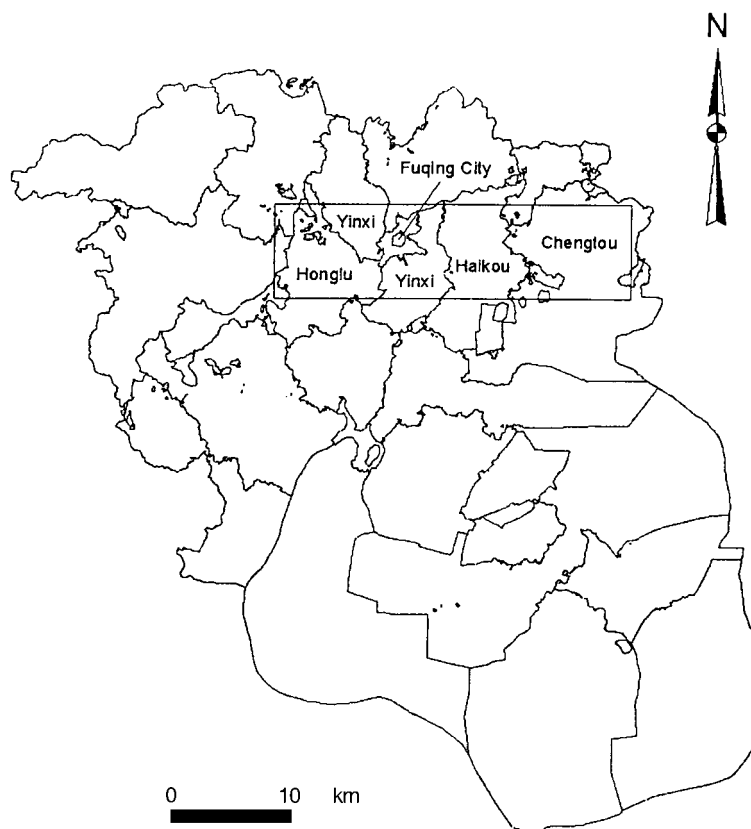


Figure 1. Map of County Fuqing. A rectangle encloses the study area.

most frequently used data for environmental assessment and monitoring. Three images acquired on 11 October 1991, 4 November 1994, and 27 December 1996 were selected from data available for this study. Accordingly, the study period covered about five years. Socio-economic data are strongly related to the biophysical environmental data (Lo and Faber, 1997), therefore, statistical material regarding the county's population and economy (Fuqing Bureau of Statistics, 1991, 1996, 1997) was also integrated with the remotely sensed data. To register the Landsat TM images with the socio-economic data, topographic maps on a scale of 1:50 000 (1988) were used as a source of ground control points. The land-use maps on a scale of 1:10 000 (1991) were also available for the study.

Data processing was performed using ER Mapper 5.2, ARC/INFO NT 7.2.1[®] and ArcView 3.1[®]. The TM imageries were imported into ER Mapper format. The bands selected in generating false colour composite images were 4, 3 and 2. For the study of urbanization, the TM images of 1991, 1994 and 1996 were specially processed to extract city data from the whole Landsat TM scenes into three subscenes of corresponding years to cover the entire city and the adjacent areas. Distinctive ground control points on the images were identified and matched with coordinates from the 1:50 000 topographic map sheets. The Landsat TM data were rectified using polynomial rectification based on the selected ground control points. To avoid the image being twisted too much and increasing inaccuracy and unpredictability away from the points, a linear polynomial rectification with a nearest-neighbour resampling method was employed. This yielded acceptable average RMS errors of generally less than 0.5 pixel, which signifies an error less than 15 m for TM imagery.

Various image enhancements and classifications were performed to help the identification of the land cover types and features of interest in the data. The final results of the classified image data were further processed using ARC/INFO NT 7.2.1[™] and ArcView 3.1[™] to generate GIS databases so that the data could be further analysed taking the advantages of these powerful GIS software.

Classification Schema

This study attempted to account for major land-cover areas presented in the images. The classification schema was therefore arrived at on the basis of the cover types in the study area that were present in large quantities. The classes were urban/built-up land, arable land, orchard, forest, water body and barren. These were the classes which were extracted as thematic classes from the images and for which area statistics were generated.

Image Enhancement and Normalization

Once the image data had been imported into the system and, using a band 432 combination, false colour composite images had been generated, several image-processing techniques were applied to obtain the best visual display for interpretation and analysis. These includes brightness/contrast adjustment, TM NDVI index analysis and principal components analysis, which were particularly important for training site selection for a later supervised classification.

The normalized difference vegetation index (NDVI) was used to measure the vegetation, as NDVI is highly correlated with vegetation parameters such as green-leaf biomass and green-leaf area and is a sensitive measure of vegetation distribution in both fine- and coarse-resolution images (Lo and Faber, 1997). In this study, NDVI is calculated using the following formula (Ray, 1995):

$$NDVI = (TM4 - TM3)/(TM4 + TM3)$$

This can be easily achieved using ER Mapper's formula processing. 'Input1' was assigned to TM band 4 and 'Input2' to TM band 3 while using the processing. The enhanced vegetation index image produced clearly delineated the built-up lands (with very dark tones on the image) from the vegetated areas (with very light tones), because the band combination took advantage of high vegetation reflectance in TM band 4 (near infrared light) and low vegetation reflectance in band 3 (red light).

Image Classification

No assessment of environment is possible without a characterization of each land-cover type by classification of remotely sensed data. Classifications are usually divided into two categories, supervised and unsupervised approaches, that can agglomerate remotely sensed data into meaningful groups. Initially, unsupervised classification was applied. This grouped the multispectral data into a number of classes based on the same intrinsic similarity within each class. Classes were later labelled by visual checking of the classified imagery. Supervised classification got benefit from the result of unsupervised classification. To perform supervised classification, statistics and histograms were first computed; these were useful for the grouping areas with similar spectral plots. Samples of data from each class identified by the statistical process were then used for training the pattern classifier. Spectral signatures for each class were determined from training sites. The training sites were also selected with aid of available reference information including the land-use maps and topographic maps mentioned earlier. Finally, the supervised classifications were carried out using the training regions recognized in the statistical procedures.

Ground truth is commonly used to determine the accuracy of categorized data obtained through classification. All classified land-cover types stated in the early section were examined during the ground truth survey to establish relationships between the ground and sensor data. This was very useful for the later classification of the image data.

After the ground truth survey, further classification consisted of steps such as statistical extraction, training class refinement and actual maximum likelihood calculations. Six regions were trained upon using the earlier-mentioned classification schema. Spectral statistics for each region were used for supervised classification. The maximum likelihood algorithm was used with equal prior probabilities. The supervised classification finally produced three classified images of 1991, 1994 and 1996 for the study area.

Each identified class was labelled and coloured for visual assessment. To decrease noise patterns and smooth out the isolated open pixels in the imagery, the operation of a median filter was applied. To avoid smoothing the datasets too much and losing smaller details, a 3×3 filter processed at dataset resolution was used. The resultant classified images were finally saved as new datasets.

Change Detection

Change detection processing using satellite imagery is an ideal way to determine changes in land-cover types (Kwarteng and Chavez, 1998). The periodic availability of remotely sensed data makes it well suited to change detection applications. Two methods employed for change detection were red green difference and image differencing (Hall, 1995).

Red Green Difference Image

The production of a red/green difference image is a technique widely used for interactive viewing of change areas. To detect land-cover changes in this study, the most current image used the red layer and the older dataset used the green one. The two layers were displayed simultaneously. The resultant combined image mainly showed yellowish colour, but areas which had changed would appear as red, because the changed areas used to increase in pixel brightness.

Image Differencing

The technique of image differencing was also employed in this study. This subtracted the pixel responses in one image from the corresponding pixel responses in the other image using the following formula of ER Mapper:

$$\text{Input1} - \text{Input2}$$

The latest image was assigned to the formula Input1 because of looking for increase in pixel brightness. This means that all increases in pixel brightness would have a positive response in the output image. A neutral grey tone represents zero whereas white tones represent the maximum positive differences. Contrast stretching using histogram equalize was employed to emphasize the differences.

Further Processing of Remotely Sensed Data using GIS

The classified imagery was exported into ARC/INFO (BIL) image and then further processed using ARC/INFO NT 7.2.1[®]. This would make use of the GIS software to create coverages for spatial analysis. The classified images were converted into coverages using ARC/INFO Grid module. Tiny patches composed of 1–3 pixel size of imagery were eliminated in order to reduce the number of pixels along polygon boundaries. To improve the accuracy of land-cover classification, the classified images were visually checked carefully and ARC Edit module was used to correct the falsely classified patches caused by similarities of spectral reflectance among land-cover classes. Finally, the statistics function of ARC Plot was carried out to obtain conclusive area data for each class representing the land-cover type.

Desktop GIS, ArcView 3.1, has been employed to handle the ARC/INFO-produced coverages. The software was powerful for visualizing, exploring, querying and analysing data geographically. The classified land-cover types were treated as themes in the above procedures. The hard copies of final classified image maps are shown in Figure 2.

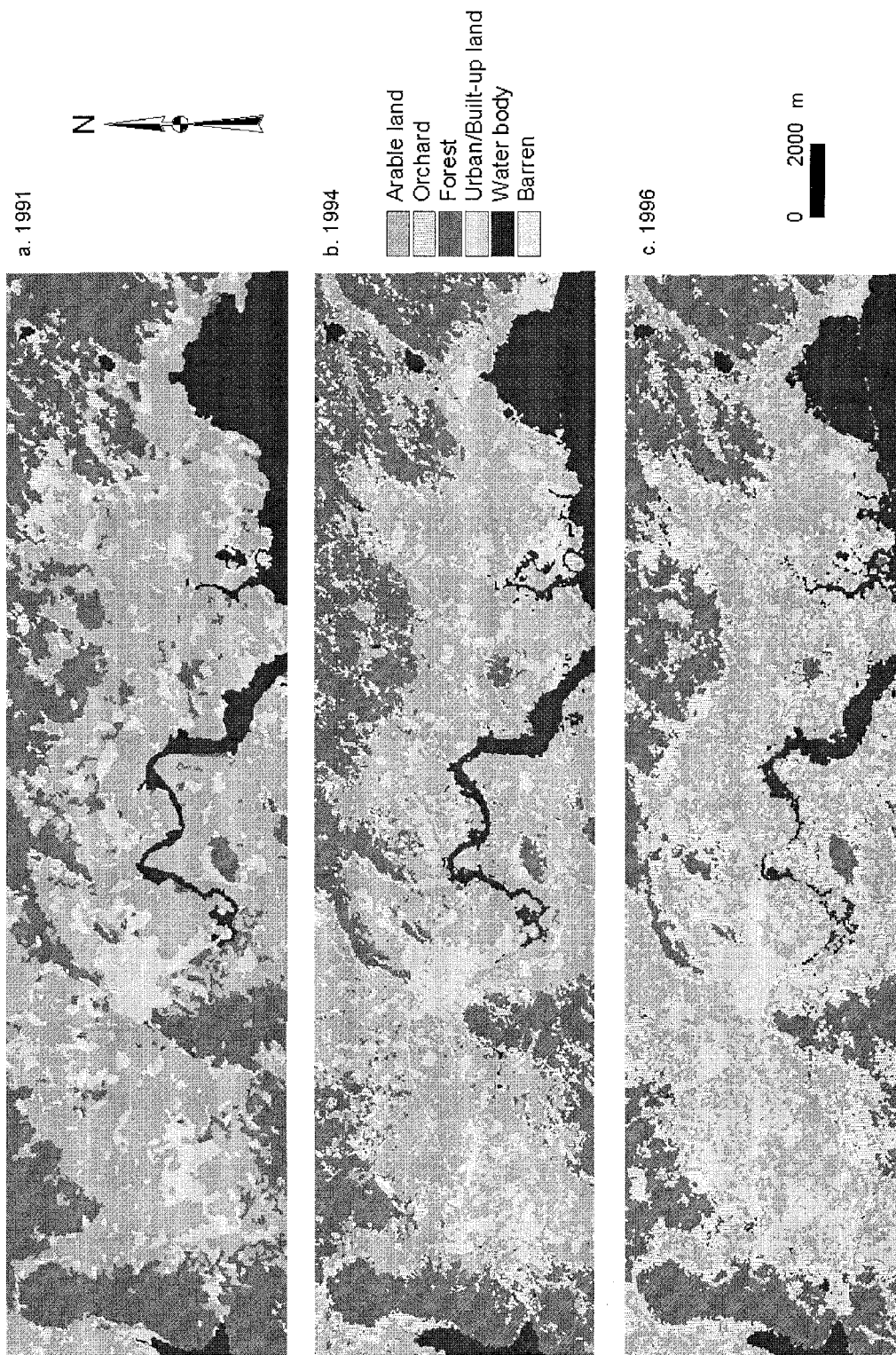


Figure 2. Classified image maps showing land-cover types of the study area in different years.

RESULTS

Using the methods described above, regional characterization of land cover and land-cover changes were estimated for the study area over the five-year period. The area of land-cover types in each of three study images has been obtained using ARC/INFO statistics function (Table I; Figure 3). The remotely sensed data reveal that substantial changes took place during the five-year period from 1991 to 1996. All the studied land-cover types are of two broad groups, those that experienced considerable change and those that experienced little change. The considerably changed land-cover types are the focus of this study and are discussed below.

Urban/Built-Up Land

The urban/built-up land in the study area has increased substantially during the five study years. It occupied 1897.6 ha of land in 1991 and increased to 4100.1 ha five years later (Table I), an increase of 2202.5 ha in only five years. The average increase rate was 16.66 per cent annually. During this study period, Fuqing City has undergone massive expansion. This will be discussed in detail in the following section.

Table I. Area of land-cover types of the study area in County Fuqing in 1991, 1994 and 1996

Types	1991 (ha)	1994 (ha)	1996 (ha)
Arable land	10 097.7	8780.7	6386.0
Orchard	1021.1	1508.9	3569.1
Forest	6280.2	5948.9	5054.1
Urban/build-up land	1897.6	2928.0	4100.1
Water body	1872.1	1992.0	2005.1
Barren	817.8	828.0	872.1
Total	21 986.5	21 986.5	21 986.5

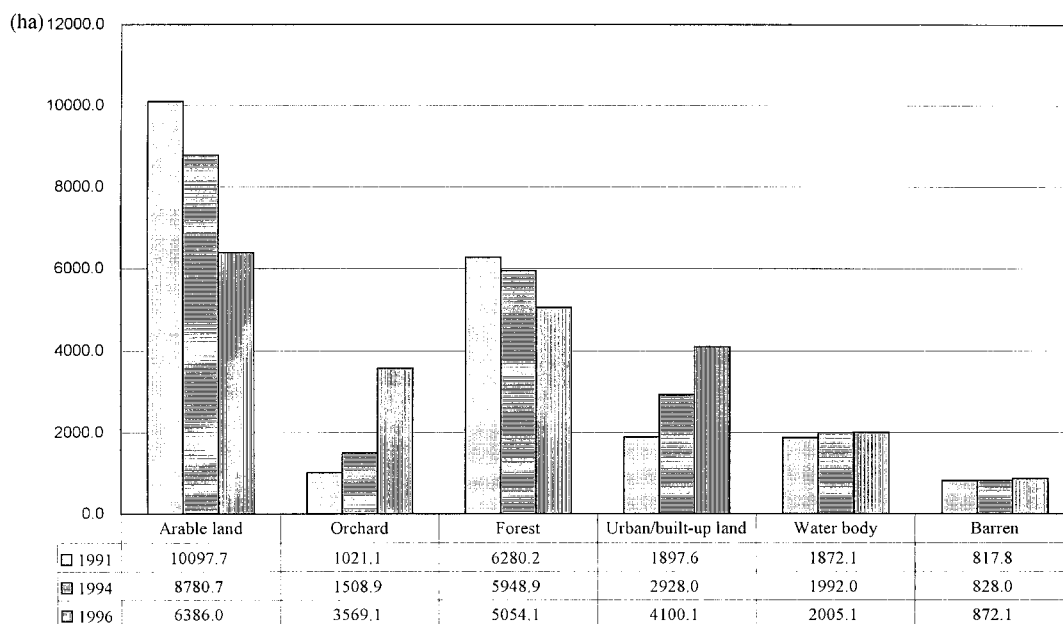


Figure 3. General land-cover types of the study area in 1991, 1994 and 1996.

Both visual comparison and change detection maps generated using the techniques mentioned earlier reveal that numerous formal arable lands in the study area have been occupied by residential complexes, indicating that agricultural soil was lost to the urbanized/residential land-use class. This can be examined especially in the areas east and west of Fuqing City where a number of large patches of arable land have transformed into residential sectors between 1991 and 1996 (Figure 2). Urban or residential development appears to have been taking place on the soil groups well suited to agriculture because poorly rated soils, such as shallow soils or those on steep slopes, are often unsuitable for construction (Imhoff *et al.*, 1997). The situation in Fuqing well demonstrates this trend. Of the lost arable lands, paddy-field loss was much more serious than dry-land loss. In the areas west of Fuqing City, the paddy fields were significantly lost to urban/built-up land use due to the city expansion. Fuqing City is located on/near the river flood plain of the Rong River and this is also the most productive farming area of the county. The loss of these productive fields has led to substantial reduction in agricultural products in the area. Short-term economic factors might have undervalued agricultural use relative to infrastructure development.

Forest

The remotely sensed data reveal that the forests have undergone deforestation during the five-year study period. The forest area decreased from 6280.2 ha in 1991 to 5054.1 ha in 1996, in which some 1226 ha of forests were lost. The deforestation rate can be calculated using the following formula (Veldkamp *et al.*, 1992):

$$\text{Deforestation rate (per cent, } y^{-1}) = \frac{(F_1 - F_2)/F_1}{N} \times 100$$

where F_1 is the forest area at the beginning of reference period, F_2 is the forest area at the end of reference period, N is the number of years in reference period and y is the year.

The calculated annual deforestation rate from 1991 to 1996 was 3.9 per cent. In general, the forest was mainly converted to orchard land use. The remotely sensed data reveal a sharp increase of 2548 ha in orchard area between 1991 and 1996 (Table I), nearly half of which was developed from former forested land.

Arable Land

Arable land has decreased substantially in the area during the five study years. A total of 3711.7 ha of arable land was lost during the period. The annual decrease rate was 4.55 per cent from 1991 to 1994 and 14.72 per cent from 1994 to 1996. The sharp decrease during the last two years may have resulted from the dramatic economic development in 1996. According to the data from the Fuqing Bureau of Statistics, the economic increase rate of 1996 was an astonishing 33 per cent, largely caused by industrial development. The more the factories and industrial estates are built up, the more the valuable arable lands are lost.

Both remotely sensed data and socio-economic data from the Fuqing Bureau of Statistics show that the arable lands were mainly lost to the urban/built-up-land and orchard-land classes (Figure 4). Some 59 per cent of total lost arable land was converted into the urban/built-up land use and 41 per cent to orchard class. The area of orchard land was greatly increased in the five years. The area of orchard was 1021.1 ha in 1991 and increased to 3569.1 ha in 1996. As the price of fruit was much higher than that of crops, more and more farming lands were converted to orchards.

URBAN EXPANSION OF FUQING CITY

As a result of economic reform and industrialization, Fuqing City has become one of the regions with the most rapid economic growth. The spatial expansion and population growth of the city were very rapid during the five study years. Obviously, quantitative and dynamical monitoring and describing the expansion of the city is valuable for the sustainable development of County Fuqing.

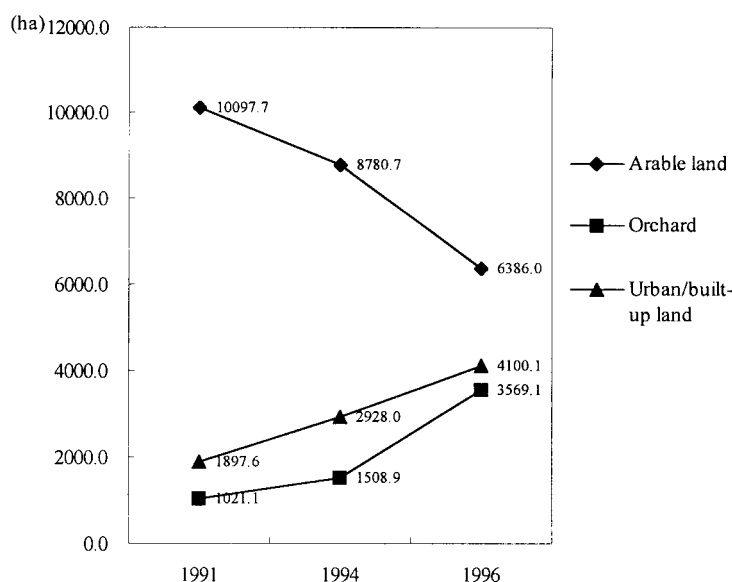


Figure 4. The increase in urban/built-up land and orchard land and the decrease in arable land.

In essence, urban spatial expansion in which non-urban land use changes to urban land use is one aspect of urbanization. As urbanization is a very complex process, it is usually difficult to detect the accurate level of its development. There are two main methods in determining its extent – the main index and compound index methods (Xu *et al.*, 1997). In this study, the main index method was selected to study the degree of urbanization in Fuqing City. The main index method is the one that selects individual indexes having the strongest relationship with urbanization and that is statistically simple. There are two main indexes, population ratio and land use. Of them, the ratio of urban population to total population was most frequently used to determine the degree of urbanization. In the context of Fuqing, the non-agricultural population was taken to be the urban population. The land-use index was used to indicate the urbanization level on the basis of the ratio of non-urban land use to urban land use in a period of time.

Urban Spatial Expansion

Expanded area and expansion rate. The data extracted from the above three images reveal the size of city area (Table II). The area of Fuqing City was 4.495 km² in 1991, 6.216 km² in 1994 and 7.864 km² in 1996. The city area of 1991 obtained using remote sensing technique remarkably coincided with the statistical data from 1:10 000 land-use map of 1991, which indicated 4.516 km². The statistical data extracted from the satellite image show that the city area has increased 3.369 km² in only five years, exceeding half of its size in 1991. This was very fast expansion indeed. Annual increased rates were 11.41 per cent from 1991 to 1994 and 12.48 per cent from 1994 to 1996.

Table II. Area and expansion rate of Fuqing City

	1991	1994	1996
Urban area (km ²)	4.495	6.216	7.864
Expanded area during the interval (km ²)	–	1.721	1.648
Expanded percentage during the interval	–	38.29%	26.51%
Expanded area compared with 1991 (km ²)	–	1.721	3.369
Expanded percentage compared with 1991	–	38.29%	74.95%

Table III. Expansion direction of the city entity

	1991–94		1994–96		1991–96	
	Area (km ²)	Percentage (%)	Area (km ²)	Percentage (%)	Area (km ²)	Percentage (%)
West	1·083	62·93	0·566	34·34	1·649	48·95
East	–	–	0·635	38·53	0·635	18·85
Northeast	–	–	0·297	18·02	0·297	8·82
Southeast	0·529	30·74	0·136	8·25	0·686	20·36
Total expanded area	1·721		1·648		3·369	

Expansion direction. When studying urbanization, researchers usually pay more attention to urban expansion speed and increased area than to expansion direction. In fact, the last is also important, especially in city management and the study of land-use change.

To examine the expansion direction of Fuqing City, the city areas of three above classified maps were overlain one on another using GIS software. This clearly revealed that the city was expanding mainly in the east, west and southeast directions (Table III; Figure 5). From the table, we can see that the area extended 1·649 km² to the west from 1991 to 1996, nearly half of the total increased area in the five years. This indicates that the west was the major expansion direction during the study period. This expansion mainly happened in the years from 1991 to 1994. The increased area was 1·083 km², nearly two-thirds of the entire expansion area to the west. The westward expansion has slowed down and the expansion to the east has become the other main direction since 1994. This was largely because the Yuanhong Industrial Estate, lying to the east of Fuqing City, was under construction at that time. However, the expansion to the west still continued and the increased area to the west was 0·566 km², 34·34 per cent of the total increased area during the years from 1994 to 1996.

Urban Population

The economic development resulted in the population tending to be concentrated on industrial areas – the agricultural population shifts to non-agricultural population and the rural population transforms into urban/town population. This led to an increase in the ratio of non-agricultural and town population to total population. The demographic data of Fuqing City in 1991, 1994 and 1996 are listed in Table IV and the annual increase/decrease rate of population components is shown in Table V.

Table IV. Population of Fuqing City

	1991	1994	1996
Total population	51 033	61 329	66 979
Non-agricultural population	40 128	50 089	55 844
Agricultural population	10 905	11 240	11 135
Non-agricultural population (%)	78·63	81·67	83·38

Table V. Annual increase/decrease rate of population components of Fuqing City

	1991–94 (%)	1994–96 (%)
Annual increase rate of total population	6·32	4·50
Annual increase rate of non-agricultural population	7·67	5·59
Annual increase rate of agricultural population	1·01	–0·47

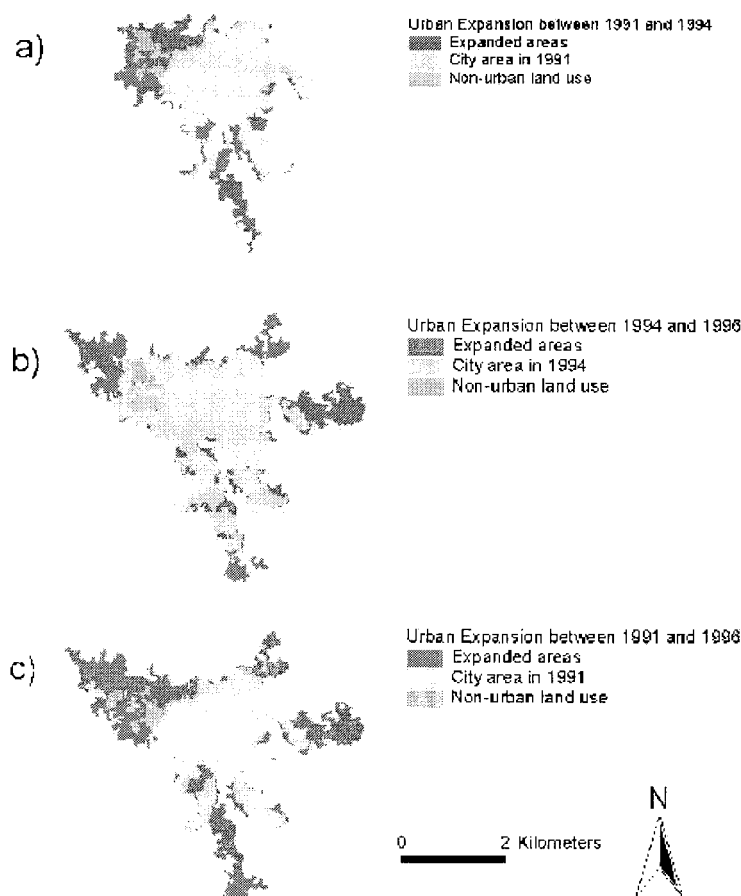


Figure 5. Overlay of the city maps to show the urban expansion directions.

Data in the tables indicate that, in Fuqing City, the non-agricultural population constituted the absolute majority and that the ratio of non-agricultural population increased rapidly. The annual increase rate of the non-agricultural population was 7.67 per cent in the period from 1991 to 1994 and 5.59 per cent in the years from 1994 to 1996. On the other hand, the agricultural population increased very slowly. The annual increase rate was only 1.01 per cent from 1991 to 1994 and even decreased in the years from 1994 to 1996, with a negative annual rate of -0.47 per cent. Because the net increase rate in the population of County Fuqing was below 1 per cent, we can conclude that many from the agricultural population became non-agricultural in the five study years. The negative increase rate also confirms this. The increase in the non-agricultural population suggests that the urbanization process in the city was fast and that the urbanization level was enhanced during the study years.

Driving Forces to Urban Expansion

Urban expansion is the combined result of numerous factors. Urban expansion in different cities or at different time intervals always has different dominant factors. According to the two main indexes of urban expansion rate and population ratio analysed above, the urbanization speed of Fuqing City was rapid and the urbanization level was also largely improved. In this study, we believe that the driving forces to this urban expansion resulted from the following main factors.

Rapid economic development. This is believed to have been a dominant factor. The rate of urban spatial expansion always changes with the fluctuation of economic development. In the 1990s, Fuqing's economy has developed rapidly, the gross national product (GNP) was 2.031 billion yuan in 1990, 7.870 billion yuan in 1994 and 13.532 billion yuan in 1996. Based on the comparable price of 1990, GNP increased two to three times in 1994 and four to five times in 1996. With the rapid development of the economy, the county's industrial structure has changed dramatically. The ratio of the agricultural and industrial products to GNP was 49.36 per cent and 29.17 per cent in 1990, 30.62 per cent and 43.50 per cent in 1994, and 23.29 per cent and 48.76 per cent in 1996. The data reveal that during the five-year period the ratio of agriculture to GNP has significantly decreased, while the ratio of the industry to GNP has increased dramatically (Figure 6). The rapid growth of the ratio of industrial products to GNP indicates a rapid development of industry during the study years. In China, urbanization is closely related to the industrialization and the industrial estates are almost located within or near the city areas. Similarly, the rapid growth of the county's industry resulted in establishment of several industrial estates in the county during the last decade. Of them, the Yaohua and Yuanhong Industrial Estates are the important ones. The Yaohua and Yuanhong Industrial Estates are located in the areas west and east of Fuqing City, respectively. The latter is one of the biggest industrial estates in China for foreign investment. With the construction of these two estates, the city has mainly extended to these two areas. Dai (1966) studied the urbanization of the major cities on the Yangtze River delta and also concluded that the industrial development was a major driving force to the urbanization of the cities.

Fast economic development also brings increases in investment in urban construction, which leads the urban area to expand at an accelerated rate. In County Fuqing, rapid economic development caused real estate to boom in the middle 1990s. For instance, in 1991 the area of completed private buildings/houses in County Fuqing was 38 163 m². In 1996, however, this increased up to 1 516 608 m², nearly 39 times more than that in 1991. Of this figure, 468 608 m² (about 30 per cent) was completed in the city area, which is even larger (11 times more) than the total area of the completed private buildings/houses of the whole county in 1991. The fast development of real estate in the city resulted in the demand on the land and thus the expansion of the city.

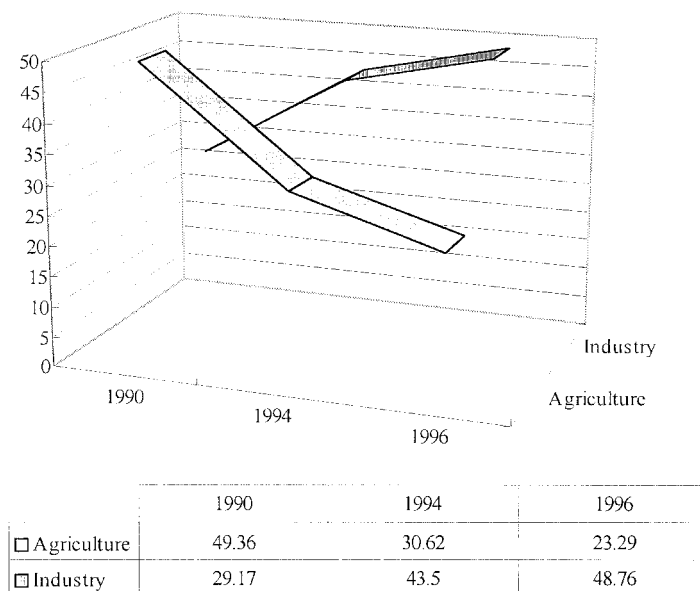


Figure 6. The ratio of agriculture and industry to GNP of County Fuqing in 1990, 1994 and 1996.

Briefly, the development of the county's economy is considered the basic driving force behind the urbanization of Fuqing City. The economic development led to the change of county's industrial structure, the establishment of industrial estates, the boom of real estate and finally to the expansion of the city.

Traffic infrastructure. Another driving force that contributed to the expansion of the city was the traffic infrastructure. Fuqing City is the cultural and economic centre of Fuqing County. The city is connected with other regions of the county mainly by road transportation because of a lack of rail and air transport in the county. There is a Fuxia Highway passing west of Fuqing. The highway connects Fuzhou with Xiamen, two major cities in the province. Moreover, a new Fuxia Express Highway, close and roughly parallel to the old highway, was under construction. This traffic infrastructure had a significant effect on Fuqing City's expansion. As indicated earlier, the city expanded 1·649 km² to the west from 1991 to 1996, nearly half of the total increased city area in the five years, and the west was the major expansion direction of the city during the study period. Obviously, this highway was also one of the factors that had driven Fuqing City to expand westwards.

Topographical factor. In addition to the aforementioned factors, the direction of the urban expansion was also controlled by the topographical factors. The city's westward and eastward expansion was due to two hills, the Yuping and Guoxi Hills, lying in the areas northeast and southwest of Fuqing City, respectively. These two hills substantially limited the expansion of the city to northeast and southwest (Figure 7). Quite obviously, it was much easier for the city to expand into flat areas than into hilly ones, consequently, its expansion was mainly to the flat areas to the east and west.

CONCLUSIONS

Remote sensing is very helpful for dynamical monitoring of the process of urbanization. Land-cover or land-use data can be extracted from the Landsat TM imagery by using a computer-assisted image-processing approach. The remotely sensed data with the aid of a GIS can provide valuable data for both quantitative and qualitative studies on land-cover changes.

Urban/built-up land class has increased in area from 1897·6 ha to 4100·1 ha in the study area during the five-year period from 1991 to 1996. The increase of urban/built-up lands was at the expense of the

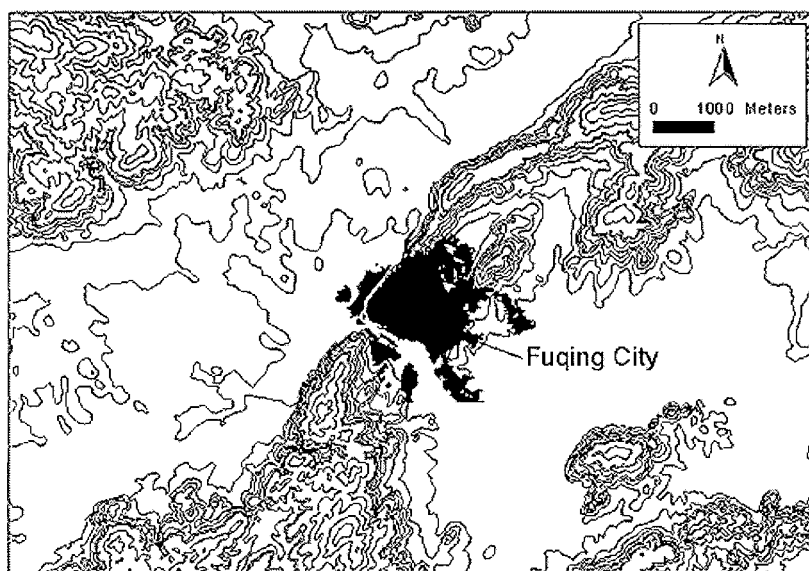


Figure 7. Topographical map of the area surrounding Fuqing City in 1990.

massive reduction of the valuable arable lands. A total of 3711.7 ha of arable lands was lost during those years.

Fuqing City has expanded rapidly in the five study years. The area of the city increased from 4.495 km² in 1991 to 7.864 km² in 1996. The city expanded mainly westwards and eastwards, to the locations where major industrial estates and traffic infrastructure were situated. This led to the massive loss of the most productive paddy fields in the areas west and east of the city. The major driving forces to the urbanization are believed to be the fast economic growth and the traffic infrastructure. The hills lying southwest and north of the city have blocked its expansion in those two directions.

The fast economic development has also brought about the negative aspects to County Fuqing. Arable lands are under great pressure from rapid urban and industrial growth. Severe arable land loss will have a significant impact on the county's further development, so special care should be taken to conserve these lands. This is most important if Fuqing is to support its population, as the county's average population density is already much higher than the national average population density. The decision-makers of County Fuqing should control urban and industrial estate sprawl under rapid urbanization so that regional development can be sustained in the future.

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