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AN ASSESSMENT OF LAND USE CHANGES IN FUQING COUNTY OF CHINA USING REMOTE SENSING TECHNOLOGY

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ABSTRACT: Fuqing County of southeast China has witnessed significant land use changes during the last decade. Re mote sensing technology using multitemporal Landsat TM images was used to characterize land use types and to monitor land use changes in the county. Two TM scenes from 1991 and 1996 were used to cover the county and a five – year time period. Digital image processing was carried out for the remotely sensed data to produce classified images. The images were further processed using GIS software to generate GIS databases so that the data could be further spatially analyzed taking the advantages of the software. Land use change areas were determined by using the change detection technique. The comparison of the two classified TM images using the above technologies reveals that during the five study years, a large area of arable lands in the county has been lost and deforestation has taken place largely because of the dramatic in crease in built – up land and orchard. The conclusive statistical information is useful to understand the processes, causes and impacts of the land use changes in the county. The major driving force to the land use changes in the county ap peared to be the rapid economic development. The decision makers of the county have to pay more attention to the land use changes for the county's sustainable development.

KEY WORDS: land use change, remote sensing, GIS, driving force

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1 INTRODUCTION

Human-induced land cover changes, specially their effect on land use, have created heightened awareness and concern in the recent years as these changes have produced an important impact on environments and regional sustainable development. This concern has led to numerous studies on the land cover/land use changes carried out in different parts of the world (MILLER *et al.*, 1998; CALSON and SANCHEZ-AZOFEIFA, 1999; LI *et al.*, 1999; MASEK *et al.*, 2000; ZHU *et al.*, 2001). This type of changes can be detected or monitored with the assistance of the satellite. Satellite remote sensing offers globally consistent, repetitive measurements of the earth surface.

Therefore, it is helpful to use this information technology to gather the spatial information of land cover/land use changes in different scale and time span for the user community and governmental decision making.

The rapid economic growth of Fuaing County of Fujian Province, China, has made it a region of inten – sive interest. Being in the coastal zonal areas with rapid economic development, Fuqing is one of the counties showing the fastest economic growth in China. During the study years from 1991 to 1996, the county's economy developed with an annual growth rate of 37. 2% in GNP. The remarkable economic growth, however, has resulted in significant land use changes during the last decade. Many green areas have been lost during the period, especially in arable lands and forested areas. The urbanization of the country developed very fast during the last decade. Water shortages throughout the county, especially in southeastern areas, may become an even more serious issue as future growth in water usage threat to outpace supplies. These changes have the potential to affect the county's sustainable development. Therefore, there is a strong need to monitor Fuqing's land use changes and to obtain more accurate information for orientating future land use and planning.

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The goal of this study was to assess regional land use change with its impact on the development of Fuqing County. The study will contribute substantially to the decision makers of the county for the strategy of regional sustainable development. The goal was achieved by using remote sensing technology with the assistance of the geographical information system (GIS). These advanced technologies are recognized worldwide as valuable technologies in environmental applications and are very useful in monitoring the land use changes due to humanistic activities (GAO and SKILLCORN, 1995; LO and FABER, 1997; CARLSON and ARTHUR, 2000).

2 STUDY AREA

Fuqing County is located in east Fujian, southeast China, on the west coast of the Pacific Ocean. 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 2430km^2. The county administratively falls under Fuzhou Prefecture, Fujian Province. The county comprises 20 towns and 453 villages. Fuqing's population is one of the largest in the counties of Fujian Province, with a population of c. 1.17 million (1997). The average population density was 481.03 persons per square kilometer(1997), while the nation's average was 127 persons per square kilometer (1995).

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 (Fig. 1). Fuqing features an irregular coast, indented by many bays and harbors. The lowlands are crisscrossed with waterways and dotted with lakes/ponds. The longest river system in Fuqing is the Rong River, which flows in a generally west to southeast direction to the Pacific Ocean. Dongzhang Lake in western Fuqing is the largest one in the county. It serves as a very important reservoir for excess water and supplies water for irrigation and drinking water for Fuqing. Therefore, it is commonly called the Dongzhang Reservoir rather than the Dongzhang Lake.

Fuqing has a subtropical climate. Temperatures average 18℃. Rainfall, especially abundant in spring, averages 1525mm annually. The county has a 10-month growing season. Rice, double-cropped in the humid subtropical climate, is grown in small alluvial valleys, river flood plains and flat lowlands, whereas wheat and sweet potatoes are grown on dry land in upland areas. Fishing is also important.

Fig. 1 A 3-demension view of Fuqing County

3 METHODS

3.1 Spatial Data and Image Rectification

Landsat 5 TM data were selected to generate time-series of land use changes in Fuqing County. The spatial resolution and regular revisit times of the Landsat mission are well suited to studies of regional, national, and global land use changes. Therefore, the TM data are one of the most frequently used remotely sensed data. In order to maintain a consistent data set for the study period, all image data used in this study were Landsat 5 TM data. Two images selected for this study were collected on 11 October 1991 and 27 December 1996, respectively. Accordingly, the study period covered about five years. The TM data of the county were extracted from the whole TM scenes into subscenes covering the county. Topographic maps on a scale of 1:50 000 (1988) and two sets of the land use map on scales of 1:10 000 (1991) and 1:50 000 (1996), respectively, were also used.

Data processing was performed by using ER Mapper 6.1. The TM imageries were imported into ER Mapper format. The bands selected in generating false color composite (FCC) images for visual interpretation were generally 4, 3 and 2 for RGB in order to highlight the vegetation that makes up 57% of the study area. Distinctive ground control points (GCPs) on the raw images were identified and matched with coordinates from the 1:50 000 topographic map sheets. The Landsat TM data were rectified 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 using nearest neighbour resampling was employed with acceptable average RMS errors generally less than 0. 5 pixel, which signifies an error less than 15m for TM imagery.

3. 2 Classification Schema

This study attempted to account for major land use areas presented in the images. For this study, the classification schema was arrived at on the basis of the land use types in the study area that were presented in large quantity (Table 1).

Table 1 Classification schema of land use types in Fuqing County

Level 1	Level 2
Arable land	Paddy field
	New cultivated land
	Dry land
Orchard	Town/Village
Forest	New cleared area
Built-up land	
Water area	Small water body
	Ocean
	Tidal flat
	Saltpan
Barren	Bare soil/rock
	Grass

Note: New cultivated land refers to the new arable lands recently developed in former forested lands and tidal areas. New cleared area refers to the recently cleared areas for construction. Small water body includes rivers, lakes and ponds.

3. 3 Digital Image Enhancement and Classification

Once the image data had been imported into the system and false color composite image using a band 432 combination had been generated, several image-processing techniques were applied to obtain the best visual display for interpretation and analysis. These included brightness/contrast adjustment, TM NDVI index analysis, and principal components analysis (PCA).

No assessment of land use changes is possible without a characterization of each land use type by classification of remotely sensed data. All the original TM bands were used in this study, except for band 6 because it has coarser resolution and provides little useful information for type determination (MIGUEL-AYANZ and BIGING, 1997). Several new bands like NDVI and PCA images were derived from the TM images to assist classification. Classifications are usually divided in two categories, supervised and unsupervised approaches, which can agglomerate remotely sensed data into meaningful groups.

Initially, unsupervised classification was performed using ISODATA clustering. Usually, a 95% convergence threshold was specified for the unsupervised classification. This grouped the multispectral data into a number of classes based on the same intrinsic similarity within each class. This was useful for the selection of spectrally homogeneous areas as training regions for later supervised classifications. By visual checking of the classified imagery with all the information available from the study area, classes were later labeled based on the classification schema used in this study. The training regions were gained from the obtained classes using the method similar to that of RAEY *et al.* (1998), which is based on the statistics of the each class. The core of each class was represented by a cluster image distribution, which was defined by using the mean plus and minor one standard deviation (mean ± 1std dev) of the class under consideration. The distribution of the class was then taken as training region by transforming the raster data into vector data.

Supervised classification got benefit from the result of unsupervised classification. To perform supervised classification, the obtained training regions were checked and modified with the assistance of available reference information including land use maps and topographical maps mentioned earlier. Statistics were computed for each training region and each band and printed in the form of histograms, which were then used for the grouping areas with similar spectral plots. Statistics derived from the training sites characterized each type and were later used by a classifier to perform the classification. Finally, based on the training sites recognized in the above statistical procedures, the supervised classifications were carried out using a maximum likelihood algorithm, which evaluated the variance and covariance of the category spectral response pattern (CHISHOLM and RUMBACKS, 1995).

The preliminary classification revealed the main land use types in the study area. Following the procedure, it was necessary to evaluate the classification. Ground truth is commonly used to determine the accuracy of categorized data obtained through classification and therefore was carried out. All classified land use types used in this study 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.

The further classification after the ground truth consisted of steps such as statistics extraction, training class refinement and maximum likelihood calculations. Regions were trained upon using the ground truth data and spectral statistics for each region were used for supervised classification. Spectral signatures for the land use classes were determined from training sites (Fig. 2). This was useful for the selection of different spectral band combinations to optimize the classification (MIGUEL-AYANZ and BIGING, 1997; MILLER *et al.*, 1998). Two dimensional scatter diagrams were helpful in revealing the relationship between image data values in two bands. For example, the supervised classification of the vegetation group in the study area using the combination of bands 2 and 3 of 1991 image yielded an unreliable result due to the strong correlation between the two bands. However, this was significantly improved when the combination of bands 1 and 4 was applied, which was the best combination for the image to distinguish the vegetation group (Fig. 3). The Bayesian maximum likelihood classifier was used for the classification with the best band combination and prior probabilities. A prior knowledge about the proportion of the land use types in the study area was derived from the county's land use maps of 1991 and 1996, which allowed weighting of the classification algorithm. The supervised classification approaches finally produced two classified images of 1991 and 1996, respectively, for the study area.

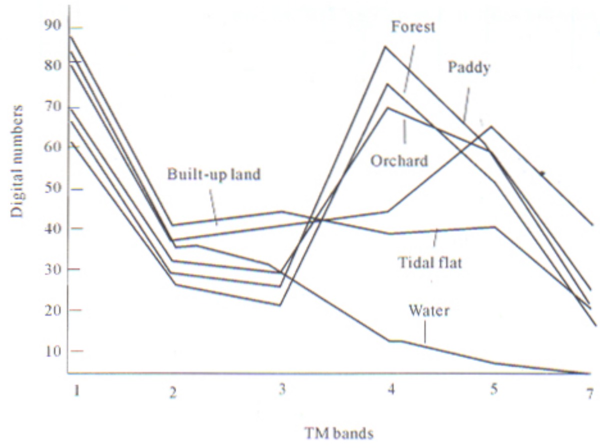

Fig. 2 Accumulated averages of data values in signature format of the main land use types in Fuqing, using 1991 image as an example

Subsequently, the classified images were assessed for the accuracy. Accuracy assessment was performed using the available land use maps and the ground truth information mentioned earlier. The numerous pre-classification efforts mentioned above led the classification approaches to overall accuracy of 90.1% for 1991 image and 87.39% for 1996 image, determined by a stratified random sampling strategy. In 1991 image, the accuracy of paddy class was 84.72%, which was

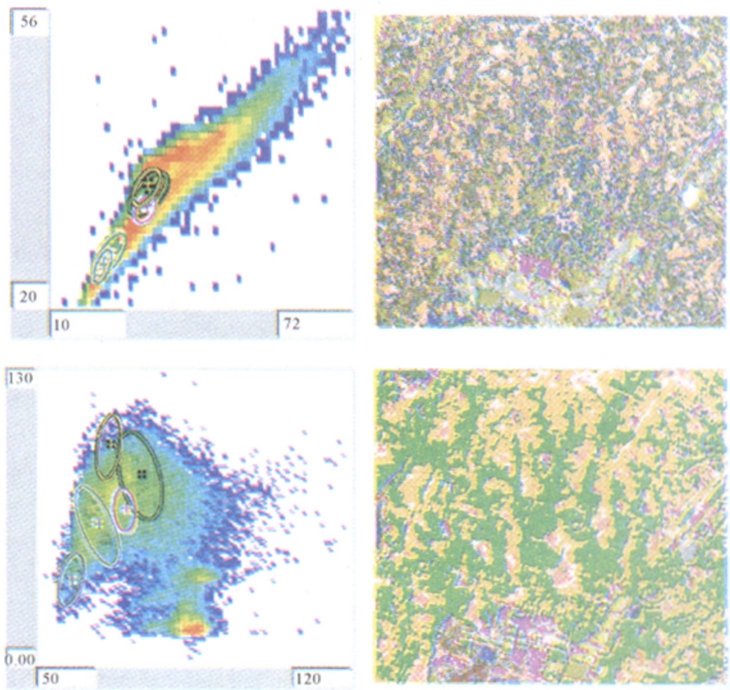

Fig. 3 Scatter diagrams of vegetation classes with their corresponding classification images
Upper: combination of TM2 (X-axis) and TM3 (Y-axis) with the corresponding classification image (poor quality)
Lower: combination of TM1 (X-axis) and TM4 (Y-axis) with the corresponding classification image (improved quality)

somewhat intermixed with forest due to similatrities of spectral reflectance. In 1996 image, misclassifications were prevalent between "salt pan" and "new cultivated land" classes. The former has an accuracy of 75.78% and latter 70.37%. The new cultivated lands were the county's recently developed farming lands for planting rice. Many of the lands have been developed in the reclaimed tidal flat areas and therefore have high content of soil moisture. Similarly, the salt pans are also developed in the tidal flat areas and accordingly have high content of soil moisture. The two classes both show very dark-blue tone on the false color composite image generated using bands 4, 3 and 2 (RGB). The spectral confusion between the two classes largely resulted from their high contents of soil moisture. Moreover, the 1996 image was acquired on 27 December, 1996, a season after rice harvests. Therefore, the fallowed new cultivated land with high soil moisture made it easier to be confused with salt pan in spectral signature. To improve the classification accuracy, the misclassified pixels were later corrected manually through a GIS system discussed in detail in the following section.

3.4 Production of the Classified Image Maps

Upon the completion of the classifications, each class was labeled and colored 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 loosing smaller details, a 3 by 3 filter processed at dataset resolution was used. The resultant classified images were finally saved as new datasets for a later GIS process.

3.5 Further Process of Remotely Sensed Data Using GIS

The classified imagery was exported into ARC/INFO™ system and then further processed using ARC/INFO™ NT 7.2.1. This would make use of the powerful spatial analysis function of the software. The classified images were first converted into the ARC/INFO™ coverages. To improve the accuracy of the land use classification, the coverages were visually checked carefully with the county's land use maps of 1991 and 1996. ARC Edit function was used to correct the falsely classified patches during image classification due to similarity of spectral reflectance among land use classes. All the misclassified pixels determined from a comparison with the land use maps were reassigned to the correct classes. This largely improved the accuracy of the classification. To do statistics for the area of land use types of the county, the images were clipped using a digitized master cover of Fuqing County's boundary. However, 1991 image can not cover the whole Fuqing County, which lacks southeast corner of the county, and thus is only 2239.36km^2 in area. To ensure the comparison of statistics results between images of 1991 and 1996 within an identical image size, the area of 1991 image was used for a standard image size and the extra area in 1996 image was masked out. Finally, two GIS databases and classified image maps of Fuqing's land use types in 1991 and 1996 were obtained (Fig. 4) and the area of land use types in each of two study images has been obtained (Table 2).

3.6 Change Detection

Change detection processing using satellite imagery is an ideal way to determine changes in land use types. The periodic availability of remotely sensed data makes it well suited to change detection applications. The change detection techniques are generally classified as two approaches: 1) determining change based on radiometry and 2) determining changes in independently produced classifications. The second approach is probably the most common change detection technique. The advantage of the approach is that the semantic meaning of the change is immediately obvious. In spite of this, major errors can occur when the classification accuracy is low. Therefore, two approaches were both used in this study. The first one was used for detecting change areas and the second for determining the conversion of the land use types.

Two methods employed for the first approach were Selective Principal Components Analysis (KWARTENG and CHAVEZ, 1998) and Red Green Difference (HALL, 1995). To perform the change detection between two images, the histogram adjustment technique was carried out on both images for haze correction. This normalized the brightness levels of two images into a common range so that the effects of atmospheric scattering could be minimized and the two images could be accurately compared.

Principal components analysis (PCA) is a statistical technique employed in image processing to reduce the correlation between bands of data and to enhance features which are unique to each bands (HALL, 1995). This compresses a multispectral dataset by calculating a new coordinate system and rotates the axes of a multidimensional image space in the direction of maximum variance (SABINS, 1987; KWARTENG and CHAVEZ,

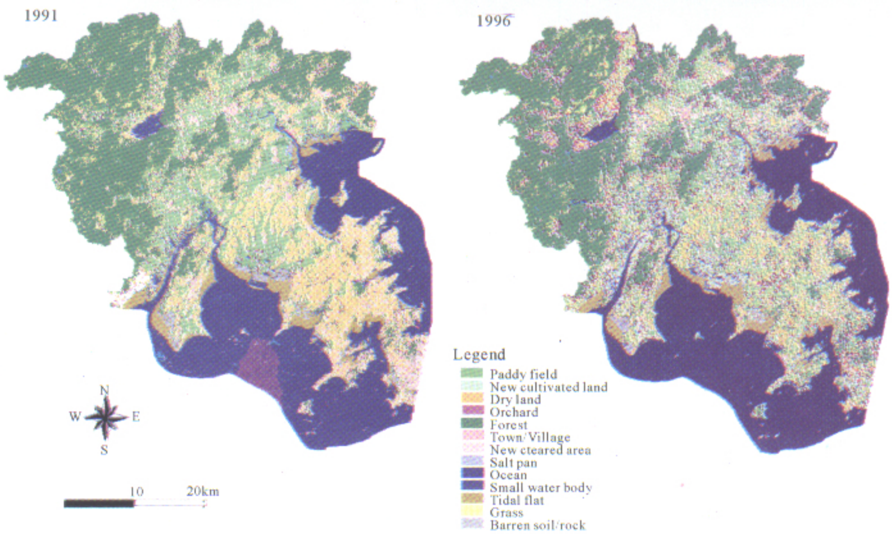

Fig. 4 Land use classification maps of Fuqing County

Table 2 Area of land use types of Fuqing County in 1991 and 1996

Level 1	Level 2	1991 (km²/%)	1996(km²/%)
Arable land		626.750/27.99	550.970/24.60
	Paddy field	310.652/13.87	266.808/11.91
	New cultivated land	23.840/1.06	61.070/2.73
	Dry land	292.258/13.05	223.092/2.73
Orchard		59.574/2.66	140.947/6.29
Forest		595.098/26.57	536.885/23.97
Built-up land		140.304/6.27	195.176/8.72
	Town/Village	115.648/5.16	136.967/6.12
	New cleared area	24.656/1.10	58.209/2.60
Water area		743.003/33.18	733.521/32.76
	Small water body	71.375/3.19	62.095/2.77
	Ocean	546.001/24.38	560.515/25.03
	Tidal flat	98.863/4.41	95.177/4.25
	Salt pan	26.764/1.20	15.734/0.70
Barren		74.634/3.33	81.864/3.66
	Bare soil/rock	55.014/2.46	55.853/2.49
	Grass	19.620/0.88	26.011/1.16
Total		2239.363/100.00	2239.363/100.00

1998). Most of the variance in a multispectral dataset can be compressed into one or two images. If two images covering the same ground area but taken at different times are subject to PCA, then information which is common to each image is mapped to the first component (PC1), whereas information which is unique to each image is mapped to the second component (PC2). In other words, PC1 will contain all of the information that has no changed between the two dates, while PC2 will contain all the change information. Accordingly, PC2 maps temporal contrast when the same bands from two different images are used. The areas of greatest changes are found in the tails of the image histogram. In this study, selective PCA was applied to detect land use changes occurred in Fuqing County between 1991 and 1996. TM bands 2, 3 and 4 from each of the two images were individually used as input to the change detection procedure. Consequently, three separate change images of PC2 were produced with each spectral band pair and a color composite image was generated using the three images (RGB: 432). The composite change image well illustrated the patches indicating the areas of land use changes (Fig. 5a).

The production of a red green difference image is a technique widely used for interactive viewing of change areas. To detect land use changes in this study, the most current image (1996 image) used the red layer and the older dataset(1991 image) used the green one. The two layers were displayed simultaneously. The resultant combined image mainly showed yellowish color, but areas, which had changed, would appear as red, because the changed areas used to increase in pixel brightness (Fig. 5b).

The second approach of change detection was performed by a pixel-by-pixel comparison of the two classified image datasets of 1991 and 1996. A pixel was assigned to a changed land class and re-coded if the pixel in one image was different from the corresponding

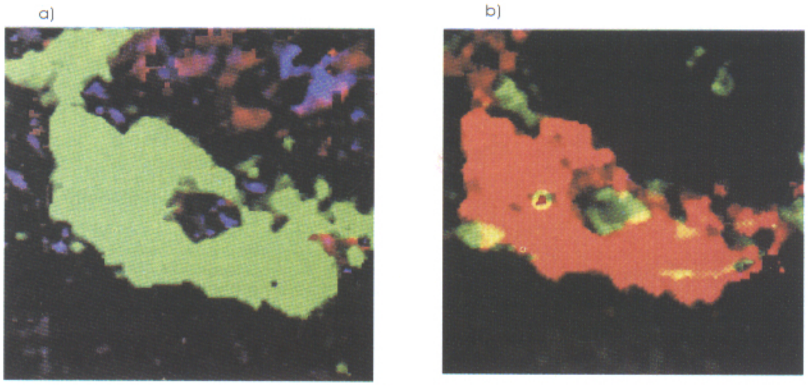

Fig. 5 Change image (1996) of eastern Chengtou Town
a) using PC2, showing a big change area in green color
b) a red green difference image showing the same change area in red color

pixel in the other image. The re-coded pixels were subsequently extracted to form a subdataset. To avoid the errors due to misclassification, the subdataset was then overlaid with the change image produced using the first approach. Only the pixels that were completely within the detected change areas of the change images were regarded as changed pixels. As a result, a final conversion matrix was produced, which indicated the conversion of the land use types during the study period. Table 3 shows the matrix only with the major land use types that will be discussed in detail in the following section.

Table 3 Conversion matrix of the main land use types (km^2)

From	To Built-up land	Orchard	New cultivated land	Grass	Others	Total
Arable land	53.312	52.030			7.668	113.010
Forest	0.351	29.113	21.512	6.300	0.937	58.213
Salt pan			10.170		0.860	11.030
Tidal flat			3.020		0.666	3.686
Others	1.209	0.230	2.528			3.967
Total	54.872	81.373	37.232	6.300	10.131	189.906

4 ANALYSIS OF LAND USE CHANGES

Using the methods described above, the area of land use types in each of two study images has been obtained (Table 2) and regional characterization of land use and land use changes was understood for Fuqing County over the five-year period from 1991 to 1996 (Fig. 6). The data reveal that substantial changes took place during the five study years. All the studied land use types are of two broad groups, those that experienced considerable change and those that experienced little change. The considerably changed land use types are the focus of this study and are discussed below in detail. The ocean area has increased in 1996 but is not discussed in the following section because the change was a result of a higher sea water level and was not caused by humanistic activities.

4.1 Built-up Land

The built-up land in Fuqing has increased substantially during the five study years. It occupied 140.304km^2 of land in 1991 and increased to 195.176km^2 five years later, an increase of 54.872km^2 in only five years. The increase rate was 6.8 % annually. The built land class includes two subclasses,

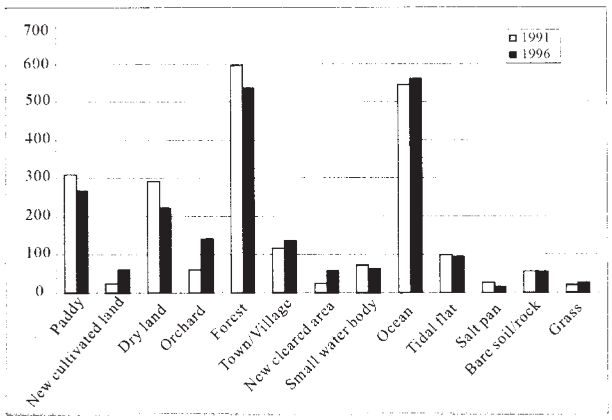

Fig. 6 Comparison of the land use changes in Fuqing between 1991 and 1996

town/village and new cleared area for construction. The high-speed increase in new cleared area indicates that the areas under construction in 1996 were much more than those in 1991. A special study on the urbanization of the county revealed that during this study period, urban/town land use underwent massive expansion. The area of urban/town land use in 1996 was twice as much as that in 1991. The annual increase rate was about 16.8% (XU *et al.*, 2000).

Both visual comparison and change detection maps generated using the techniques mentioned earlier reveal that numerous formal arable lands have been occupied by residential complexes, indicating that agricultural soil was lost to the built-up land use class. The arable land class was lost 113.01km^2 in the five years, of which some 47.2% was lost to the built-up land use (Table 3). The loss of paddy field to urban land use can be examined especially in the areas east and west to Fuqing City where a number of large patches of paddy fields have transformed into residential sectors between 1991 and 1996. Urban or residential development appears to have been taking place on the soil groups well suited to agriculture as poorly rated soils, such as shallow soils or those on deep slopes are often unsuitable for construction (IMHOFF *et al.*, 1997). The case in Fuqing well demonstrates this trend. 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 potential in the area. Short-term economic force might have undervalued agriculture use relative to infrastructure development.

The driving force to the rapid increase in built-up land use usually results from numerous factors. In this Fuqing case, we believe that the major driving force was rapid economic development of the county. The rate of urban/town 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 and greatly increased up to 13.532 billion yuan (RMB) in 1996. With the rapid development of the economy, the county's industry structure has changed significantly. During this period, the ratio of agriculture to GNP has substantially decreased, while the ratio of industry to GNP has dramatically increased. The rapid growth of the ratio of industry product to GNP indicates a rapid development of industry during the study years. This would demand more lands for the expanding industry. Consequently, several industrial estates have been established in the county during the last decade. With the construction of the industrial estates, the built-up land use substantially increased.

Fast economy development also brings up increases in investment in housing construction, which leads the urban/town space to expand at an accelerated rate. In Fuqing County, rapid economic development caused real estate to boomed in the middle 1990s. For instance, in 1991 the area of completed private buildings/houses in the county was 38 163m^2. In 1996, however, this increased up to 1 516 608m^2. Of the figure, about 30% was completed in the city area. The fast development of real estate resulted in the demand on the land and thus the expansion of the built-up land use.

Briefly, the county's economic development, especially the rapid industrial development, led to the establishment of industrial estates, the boom of real estate and finally the increase in built-up land use.

4.2 Forest and Grass

The forests and grasses are mainly located in the hilly and mountainous areas in northern and western Fuqing. The remotely sensed data reveal that the forests have undergone significant deforestation in the five-year study years in which 58.213km^2 of forest were lost. The annual deforestation rate from 1991 to 1996, calculated using the formula of VELDKAMP *et al.* (1992), was 2.0 percent.

In general, half of lost forest was mainly converted to orchard (Table 3), especially in the base areas of mountains/hills. This can be confirmed by the output classified images (Fig. 4), which shows a sharply increase in orchard land area. Forest was also transformed to the new cultivated land, which accounted for 37% of the total lost forest land. Some of the lost forest, about

11 %, have been converted to grass that has also in – creased in the five study years. The increased grass distributed mainly on the upper mountains where the deforestation took place.

The significant economic activities also triggered the deforestation. As mentioned in the above section, urban expansion and building construction all demanded a large amount of wood. Generally, the conversion of the forest started from the most accessible area with convenient transportation conditions. This can be examined from the areas along the Fu – Xia (Fuzhou – Xiamen) Highway, which is a main road in a north-south trend across Fujian Province. Due to short distance from the highway, the forested areas there were seriously reduced, causing the deforested areas to have become barren or been covered only by grass.

Planting orchard would make benefits to farmers more efficiently and faster than planting wood. This would cause farmers to plant orchard rather than forest and thus the conversion from forested land to orchard land. On the other hand, the conversion of forested land to new cultivated land indicates that the crop shortage in some areas of the county may have caused the deforestation.

4.3 Arable Land and Orchard

Arable land has decreased sharply in the county during the five study years. A total of 113.01km^2 of arable land was lost, and only 37.232km^2 of the class increased, a net decrease of 75.78km^2 in the period.

Both remotely sensed data and data from the Fuqing Bureau of Statistics show that the arable lands were mainly lost to the built-up land and orchard land classes. As mentioned in an earlier section, some 47% of total lost arable land was converted into the built-up land use. In the areas west to Fuqing City, the paddy fields were significantly lost to built-up land use due to the city expansion. However, the new developed cultivated land had increased in the five years, which was only 23.8km^2 in 1991 but increased to 61.1km^2 in 1996. This indicates that the governors of Fuqing County have paid attention to making compensation for the serious arable-land loss to built-up land use. The new cultivated lands were developed at the expense of losing forested land, salt pan and tidal flat. They make up 57.8%, 27.3% and 8.1%, respectively, of the new cultivated land. This resulted in the reduction in the area of these three classes in 1996.

The area of orchard land was greatly increased in the five years. A total of 81.373 km^2 of orchard has in – creased. About 63.9 % of the total increased orchard land was developed on arable land, apart from 35.8% on the forested land and 0.3 % from the other classes. As the price of fruit was much higher than that of crop, more and more farming lands were converted to orchard lands. This conversion of arable land into orchard land led to the significant change of the farming structure.

As mentioned earlier, the dramatically decrease in arable land is also attributed to the substantial economic increase of the county. The economy increase largely relies on the industrial development. The more the manufactories and industrial estates are built up, the more the valuable arable lands are lost.

5 CONCLUSIONS

The regular availability of satellite image data allows monitoring of dynamic changes of land use over a large area. The image processing approach with the aid of a geographic information system can provide valuable spatial data for both quantitative and qualitative studies on the land use changes.

The study reveals that the land use of Fuqing County has changed remarkably in the five study years from 1991 to 1996. The arable land and forest have seriously reduced, while the built-up land and orchard have significantly increased. The most serious problem is the substantial loss of arable lands because the county has already had the crop shortage. The lost arable lands were mainly converted into built-up and orchard lands. The paddy fields in the areas east and west to Fuqing City were seriously reduced due largely to urbanization. The deforestation was accompanied by the increase in orchard land, new cultivated land and grass, indicating the conversion of forested land into these three classes.

The driving forces to the above major land use changes in the county is believed to be over-fast economic growth. With the remarkable record of economic growth, however, the development has also brought about the negative aspects to the county. Arable lands are under great pressure of rapid urban and industrial growth. The economic growth was at the expense of the massive reduction of the valuable arable land. Severe arable land loss will have a significant impact on the county's sustainable development. Therefore, the decision makers of the county should avoid short-term economic consideration and well deal with the conflict between the environment and economic development. Special cares should be taken for arable lands. The conservation of arable land is the most important for Fuqing to support its population, as the county's aver –

age population density is already much higher than the national average population density. The government of Fuqing County should issue related laws to protect arable land and to control urban and industrial estate sprawl under rapid urbanization so that regional development can be sustained in the future. The forested land should also be effectively protected. In order to avoid the further deforestation and turnover in the future, the decision makers should make sure the success in Protection Forest and reforestation. The greenness is globally perceived to be a highly desirable quality of the morphological environment.

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