Journal of Zhejiang University SCIENCE
ISSN 1009-3095
http://www.zju.edu.cn/jzus
E-mail: jzus@zju.edu.cn

Satellite remote sensing for urban growth assessment in Shaoxing City, Zhejiang Province*

RAMADAN Elnazir†, FENG Xue-zhi (冯学智), CHENG Zheng (程 征)

(*GIS & RS Laboratory, Department of Urban and Resources Sciences, Nanjing University, Nanjing 210093, China*)

†E-mail: elnazeerramadan@yahoo.com

Received Nov. 11, 2003; revision accepted Feb. 5, 2004

Abstract: Urban growth represents specific response to economic, demographic and environmental conditions. Rapid urbanization and industrializations have resulted in sharp land cover changes. The present investigation was carried out from Shaoxing City to quantify satellite-derived estimates of urban growth using a three-epoch time series Landsat TM data for the years 1984, 1997 and ETM 2000. The methodology used was based on post classification comparison. The use of GIS allowed spatial analysis of the data derived from remotely sensed images. Results showed that the built-up area surrounding Shaoxing City has expanded at an annual average of 7 km^2. Analysis of the classified map showed that the physical growth of urban area is upsetting the other land cover classes such as farming, water resources, etc. The study conclusion mainly emphasized the need for sustainable urban capacity.

Key words: Change detection, Post classification, Urban growth, Shaoxing
doi:10.1631/jzus.2004.1095 **Document code:** A **CLC number:** TP79

INTRODUCTION

The land cover change could be regarded as change in biotic diversity, actual and potential productivity, soil quality, run-off and sedimentation rates (Steffen *et al.*, 1992) and, it is affected greatly by land use change. Therefore land use and land cover changes play an important role on local and regional environmental conditions of that particular territory and they are linked to global environmental change. Urbanization is one of many ways in which humans are altering the land cover of the globe. Most of these landscape transformations occur within a regional context, but specific year-to-year changes occur at local scales, often distributed in a seemingly random pattern. These changes are estimated to have significantly altered more than 80% of the earth's land area over the last several centuries (Vitosek *et al.*, 1997). Rapid urbanization and industrialization are the key factors for both social and economic developments of regions, and are also responsible for further environmental changes. The technology that offers considerable promise for monitoring land cover change is satellite remote sensing and geographical information systems. This technology provides globally consistent, repetitive measurements of earth surface conditions relevant to climatology, hydrology, oceanography and land cover monitoring. One mission in particular field was the Landsat series started in 1972, and operating with objective of tracking changes in land cover monitoring. The

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†Lecturer at Department of Geography, University of Juba, Sudan

* Project (No. 20001500012021) supported by Ministry of Land Resources and Zhejiang Bureau of Land Resources, China

spatial resolution and the frequent revisit times of the Landsat mission are well suited for studies of regional, national and global urbanization aspects.

STUDY AREA AND DATA

Study area

Shaoxing is a famous historical and cultural city of China; is among the key developing areas open to the outside world in China's coastal economic zone; and is situated in the central northern part of Zheijiang Province, on the south side of the Qiantangjiang River. The city is situated at 29°13′–30°16′N and 119°53′–121°13′E (Fig.1).

Fig.1 Study area

Shaoxing has monsoon climate with hot summer and cool winter and precipitation with marked seasonal variations. Based on available meteorological data, the annual mean temperature of Shaoxing was estimated to be 16.5 °C, and annual precipitation was estimated to be 1397 millimeters. The snow-free period lasts for 237 days and the relative humidity is about 81 percent.

During recent years, Shaoxing City has strengthened its traditional industries such as cloth making, printing and dyeing, wine making, machine building, electronics, chemicals, building materials, etc. and is becoming a growing industrial center.

Data acquisition and processing

The data used in this study were comprised of a time-series Landsat TM images for the years 1984, 1997 and ETM 2000. IRS 1C LISS 111 panchromatic image acquired for 1996 and also the topographic map for the year 1974 (scale 1:50000) were also used for the analysis. The spatial resolution for 1984 and 1997 satellite digital data was 30 meters, but 33 meters in the case of 2000 (ETM) and, 6 meters for PAN data. The high resolution PAN data was used as reference for classification. In the pilot fieldwork the most useful conventional parameters such as detailed geographic status, physical environment and socio-economic data were collected. Due to spatial, spectral and temporal radiometric resolution constraints, the complexity of physical environment cannot be accurately recorded by normal remote sensing sensors. As a result, it is necessary to preprocess the remotely sensed data before the analysis was made. Image restoration involved the correction of distortion and noise that occurred during the imaging processing. Radiometric and geometric errors are the most common types of errors in remote sensing data. The data provider should correct radiometric and systematic geometric errors of Landsat TM data and correct the unsystematic geometric errors using Ground Control Points (GCPs).

Previous and on-going efforts of investigators showed that 30-meter pixel land cover data derived from Landsat Thematic Mapper (TM) imagery can be used for educational and planning applications at the local level. However, more accurate land-cover information is needed if we move beyond the first generation impacts of educational programs to provide local end-users with the information and products that can be easily and directly incorporated into land-use plan and policies (Civco *et al.*, 2002).

Urban expansions around Shaoxing City and the considerable change in different land-use categories over a period of 17 years were the main concern for the present study. Supervised classification was carried out for all the TM images of 1984, 1997 and 2000 with the help of ERDAS imagine 8.4.

METHODOLOGY

Remote sensing has become an inevitable tool for resource inventory and environmental monitoring at local, regional and global scales during the last thirty years. It has become an integral part of information technology and provides solutions to facilitate sustainable development of natural resources and conservation of environment. The applications oriented research in many countries has led to operational and commercial use of this technology in many fields. In the present investigation, this technology was used to investigate both qualitative and quantitative estimates of urban growth of Shaoxing City.

A number of researches were carried out using various methodologies and algorithms to derive land cover and change information from different sets of remotely sensed data (Tateishi and Kajiwara, 1991; Lichtenegger, 1992; Muchoney and Haack, 1994; Lambin, 1996; Sailer *et al.*, 1997). However, the complexity and variations of the geographic regions make it difficult to develop a general method for all applications in different regions. Additional consideration in this study was to link appropriate scientific research methodology with regional social and economic development objectives in order to promote regional sustainable development.

Various algorithms were developed for change detections such as multi-date composite image change detection (Fung and LeDrew, 1987; Eastman and Fulk, 1993), image algebra change detection (Green *et al.*, 1994) using univariate image differencing, image regression, image rationing (Howarth and Wickware, 1981), vegetation index differencing (Nelson, 1983), manual on screen digitization of change (Lacy, 1992; Light, 1993), post classification comparison change detection (Rutchey and Velcheck, 1994), etc.

The selection of an appropriate change detection algorithm should primarily be based on cultural and biophysical characteristics of the study area and secondly the precision with which the multiple-date imagery are registered and finally, the utility, flexibility, and availability of change detection algorithms (Jensen, 1996).

Strategies for urban change detection

Nowadays, many techniques are available for land cover change detection with the help of satellite images. Broadly, these can be separated into two approaches like (1) Detection of changes in independently produced classification images and, (2) Determination of changes directly from radiometry (Malila, 1980). The advantage with the first approach is that the semantic meaning of the land cover change is immediate, and that the confusion between different kinds of land cover changes is avoided. While this is probably the most common change detection technique where major errors could be noticed if the amount of change is very small in comparison with that of the total area under investigation. In these cases, the spatial pattern of change may be masked by random independent errors from the image classifications and necessitating unreasonably high classification accuracy (Gordon, 1980). This represents a severe problem for automated detection of urban growth where land cover classifications often contain classes with accuracy as low as 70%–80% (Toll, 1985; Haack *et al.*, 1987; Martin *et al.*, 1988; Harris and Ventura, 1995) and the real growth is only 1%–2% per year when considered over the entire urban area. Some authors also reported obvious success in using this method (Roger and Charbonneau, 1988).

Estimates of urban growth in this study area were obtained by using multiple-date classification maps of Shaoxing City extracted from TM images of 1984, 1997 and 2000. In order to analyze the nature, rate and location of urban change, a total number of five land cover classes such as fallow land, farming, forest, settlements and water were inventoried on each date (Fig.2).

Each image was enhanced using histogram equalization to increase the volume of visible information. This procedure is important in helping to identify ground control points in the image rectification. All images were rectified to a common UTM (Universal Transverse Mercator) coordinate system based on 1:50000 topographic map. Each image was then radiometrically corrected using relative radiometric correction method. A supervised classification with a maximum likelihood algorithm was conducted to classify the TM images. The accuracy of the classification was verified by field checking and by comparing with existing land use maps. The confusion matrix for the most recent year 2000 is provided in Table 1 showing an overall classification accuracy of 92%. Subsequently, the same assessment was carried out for 1984 and 1997 land use classifications with accuracies of 81% and 87% respectively.

In order to analyze the nature, rate and location of the urban land use changes, an image of urban built-up land was extracted from each of the original land cover images. The extracted images were then overlaid and recoded to obtain an urban expansion image (Fig.3).

The urban expansion image was further overlaid with county/city boundary image, major roads, and major urban centers. These layers were constructed in a vector GIS environment later converted into raster format. The county/city boundary image was utilized to find urban land change information as urban development normally following the major roads accesses.

It is noteworthy that most studies relied on only a pair of images separated in time for urban growth map. This limitation reflects the substantial cost of high-resolution satellite imagery as well as the technical hurdles associated with processing multiple scenes. In fact the application of remote sensing to real problems in urban growth requires a time-series approach for enhancing the current knowledge on urban areas.

RESULTS AND DISCUSSION

One of the goals of remote sensing data analysis was to produce a land-use map of Shaoxing City and its surroundings. This was done in a two-step process. First, a maximum likelihood supervised classification was carried out using training areas chosen according to extensive field

Table1 Confusion matrix and Kappa statistics of maximum likelihood classification and the ground truth for 2000

		Maximum likelihood classification					Total	Accuracy (%)
		Fallow land	Farming	Forest	Settlement	Water		
Ground truth	Fallow land	30	–	4	–	–	34	88
	Farming	1	15	–	–	1	17	88
	Forest	–	–	13	–	–	13	100
	Settlement	–	1	–	24	1	26	92
	Water	–	–	–	–	10	10	100
	Total	31	16	17	24	12	100	
	Accuracy (%)	97	94	76	100	83		
	Overall accuracy: 92%; Kappa statistics: 0.896							

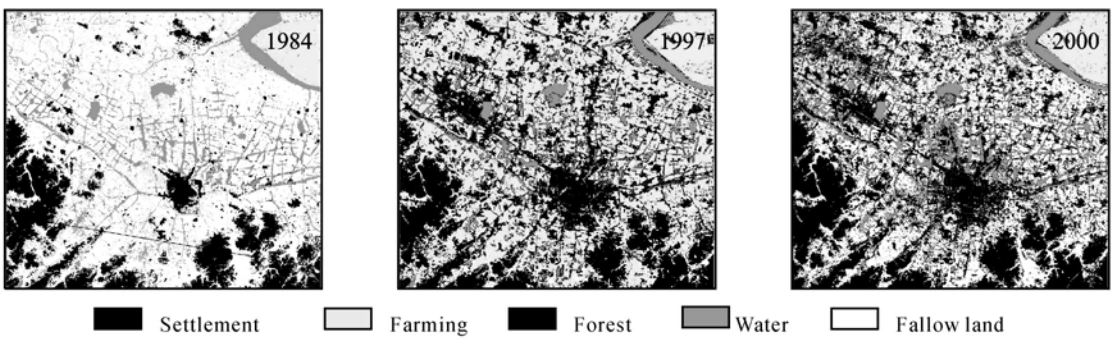

Fig.2 Multi-date classification maps

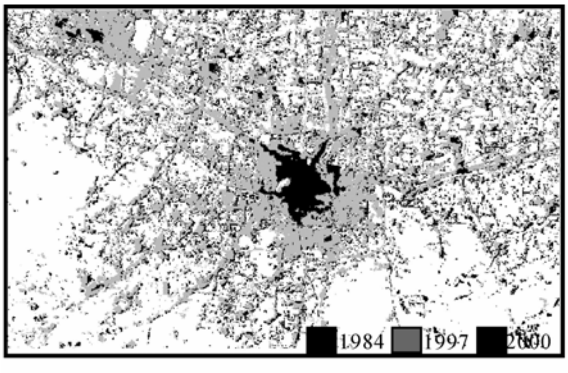

Fig.3 Composite image of Shaoxing City reflecting its urban growth

knowledge. Afterwards, the raw results of the supervised classification maps were checked during visual interpretation of the satellite image and field visits. Small obviously wrong polygons were recoded for comparison with the field knowledge.

Area statistics analysis (Fig.4 and Fig.5) indicated that Shaoxing City has grown by 167.8 km^2 during the last 17 years (average of 7 km^2 increase per year). However, the drastic changes that occurred between 1984 and 1997 when compared with those in 2000 comprised sufficient time gap. Overlaying classified images from 1984, 1997 and 2000 on the growth scale gave an indication of different land cover conversions associated with this rapid development. The continuous increase in urban area has strongly favored the replacement of fallow land during the first 13 years. The results showed that the growth was about 98% from 1984 to 1997 but was only 2% from 1997 to 2000. It is noteworthy that the residential area development was mainly at the expense of agricultural land. The period from 1984 to 2000 also witnessed an increase of agricultural land (258 km^2) through the conversion of existing fallow land. This could be due to the efforts made to promote the agricultural development at the same time.

However, a serious decrease (115.14 km^2) in the agricultural land was noted because of local settlements (3.2 km^2) and abandonment of farming (111.9 km^2) from 1997 to 2000. This abandonment also resulted in the increase of fallow land (119.8 km^2) from 1997 to 2000. In the case of forest, the green vegetation cover was found to be decreased by about 24.5 km^2 from 1997 to 2000 owing to the denudation of existing forest. Regarding the development of the built up area in Shaoxing City and the spatial pattern of regional economic developments, there was an apparently rough expansion of development toward outlying areas through time as expounded in traditional theories of land use evolution. With the improved transportation systems some growth centers are also emerging from small towns near Shaoxing. Based on this time scale series the urban growth has varied substantially over the whole period. Its acceleration during the first period (1984 to 1997) could be attributed to various policies to promote Shaoxing as an industrial center. The development may also reflect the expansion of credit and better economic conditions for the population allowing speculative development of residential and commercial areas.

Of great importance is linking these observed changes in land cover to socio-economic or environmental factors. The geography of urban growth

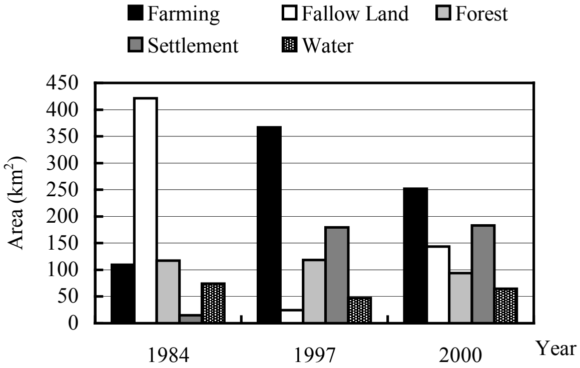

Fig.4 Area Statistics

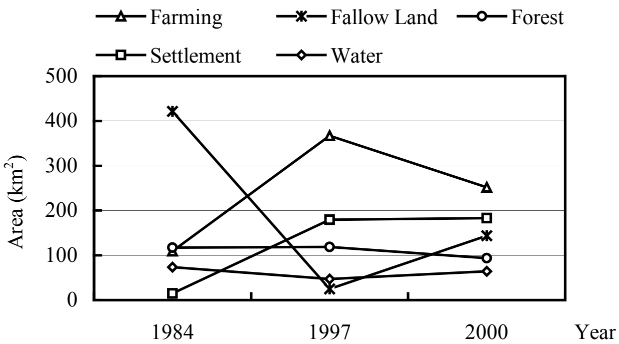

Fig.5 Changing trends of land-use/land-cover patterns

offers a graphic depiction of interplay between economics, political system and the environment. While the growth of cities may appear inexorable and monolithic, it reflects multiple conscious choices made by individuals and institutions reconciling these competing factors for their own interests. The end result of these choices appears as suburbs and industrial centers which could have great effect on the sustainability of Shaoxing environment. Unfortunately, very few conventional data sources are available for the study area. Forests are most important ecosystems because of their economic and environmental values. In Shaoxing the vegetation land that includes both forest and farming areas witnessed a dramatic decrease from 1997 to 2000. The statistics of classification results showed that the area occupied by both classes decreased approximately by 50%. It is therefore necessary to take some measures to protect forests and agricultural lands. Agricultural land is the most important land resource, and its degradation is one of the most serious problems facing Shaoxing area.

Another factor is the quantity and quality of water resources. Rapid urban growth and industrialization are putting severe strains on water resources and the capabilities of environmental protection. Unfortunately, study results showed that the depletion of water resources in Shaoxing, particularly during 1984 and 1997, could be due to expansion of agriculture and the growing textile industry that consumes large amount of water.

CONCLUSION

In the present study, an integrated approach of remote sensing and GIS was used for evaluation of urban growth and its impacts on regional sustainable development in Shaoxing City of Zhejiang Province. Results revealed a notable increase in urban land use/land cover between 1984 and 2000. Urban land development due to industrialization was intensified around the outskirts of the city along the major highway between Shaoxing and Keqiao. Integration of remote sensing and GIS provides an efficient way to detect urban expansion and to evaluate spatial patterns. Digital image classification coupled with GIS has demonstrated ability to provide comprehensive information on the nature, rate and location of urban land expansion. The study showed that Landsat TM alone is inappropriate for many practical planning applications, but is well suited for synoptic views of urban development. The 30 m spatial resolution of Landsat TM is sufficient for capturing the characteristic scales of human development. The spectral range of the instrument can be taken advantage of to distinguish urbanization from other types of land cover changes. Additional data such as maps of elevation, slope, geology, soils, and hydrology should be incorporated into the classification process to improve the accuracy and quality of remote sensing derived information. Despite of all the data above, delineating the boundaries between the land use classes such as fallow land and farming areas is difficult due to the fact that the season plays an important role particularly in regard to spectral characteristics. This type of errors can however be reduced or eliminated using multi-date classification of images taken at different seasons covering the same study area. The present study led to the conclusion that land cover in the study area is undergoing significant change due to urbanization and industrialization resulting in serious depletion of natural resources like arable land and water, which threatens the sustainability of that environment.

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