Recognition and Extraction of Spatial Objects from Satellite Data using GIS and Image Processing Techniques for Urban Monitoring

Case from Delhi Mega-City, India

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Dedicated to

My mother and
the memory of my father

Abstract

Management and planning of urban space requires spatially accurate and timely information on land use and their changing pattern. Monitoring provides the planner and decision-maker with required information about the current state of development and the nature of changes which have occurred. The synergism of remote sensing and GIS techniques can play an important role for monitoring the urban land cover/use.

This study demonstrates the use of GIS and image processing techniques in recognizing and extracting spatial objects from satellite data, particularly recognizing urban boundary and inner city land cover/use objects and automatic extraction of such objects. The purpose of this research was to examine the advantage of IRS-1C PAN data over SPOT PAN data in recognizing land cover/use objects, and to examine the potentials of automatic object extraction from satellite data in order to accelerate the geoinformation production. Spatial resolution is one of the major parameter in recognizing and extracting objects. The effects of spatial resolution was examined through IRS-1C PAN (5.8m resolution) and SPOT PAN (10m resolution) resampled to IRS-1C PAN and their fusion with SPOT multi spectral data taking case from Delhi mega-city, India. There is a big gap between the information availability and information requirements in case of planning and management of the city. Examination of spatial resolution effects shows that IRS-1C PAN image can provide better information than SPOT PAN image because the image is sharp and contains more information. Urban boundaries and inner city land cover/use object edges can be reliably delineated from these data.

Automatic segmentation method embedded in a quadtree based GIS and image processing system are used for generating object-based spatial information. Experiments on panchromatic image segmentation based on pixel radiometry shows that single band image cannot be used to derive any meaningful segments. Also multi spectral image segmentation does not produce meaningful segments. Experiments on texture addition to tonal information provides promising result .Finally, it is suggested that visual and digital interpretation method should be used as complementary approach. For detailed level information visual method should be preferred while for low level information extraction, automatic method should be preferred. Image processing and GIS should be treated as an integrated tool while extracting objects from satellite data to enhance the certainty of geoinformation generated from space.

CONTENTS

List of appendices

Chapter 1

GEO-INFORMATION FOR MONITORING URBAN SPACE:
From Pattern to Process

1.1 Introduction

Management and planning of urban and sub-urban space requires timely and spatially accurate information on existing land use. It also requires a basic understanding of the trends in land use change. The dynamics of land use in urban and peri-urban areas are associated, especially cities in developing countries, with environmental degradation. Sustainable management of urban space requires that researchers, planners, and decision-makers have access to ample supply of various types of resource and environmental information. The United Nations Conference on Environment and Development (UNCED) in its recent report *"Agenda 21- An Action Plan for the 21st Century"* (UNCED, 1992) addresses the fundamental problems in environmental and sustainable development planning caused by inadequate availability, analysis, interpretation, and use of environmental information.

Monitoring land use as well as the development plan, especially in rapidly growing areas, is essential to sound management of urban space. Land use is one of the key data layers in GIS for physical planning and environmental modelling. Urban planners, managers and related professionals are usually dependent on conventional methods for deriving land use and their change information. The commonly used approach to quantify land use and their changes has been the acquisition of aerial photographs and their visual interpretation and comparison with existing photographs and map data (Jensen *et al.*, 1983). This procedure, generally, yields information at wide time gaps and it is static in nature. Moreover, the traditional methods can not keep the track of time in generating information. They are labour-intensive, time-consuming and uneconomic in nature, the result is relatively *infrequent information availability* in making decisions. Advent of satellite technology with high resolution data such as Landsat TM, SPOT HRV, IRS-1C Panchromatic (PAN) and LISS-III, gives a new tool for generating information at very short interval of time. This leads to the notion that we can not only generate pattern information, but also process information i.e. changing pattern of land cover/use. Digital data availability brings more focus on the development of automated or computer assisted techniques for the interpretation and change detection (Wharton, 1987). These high resolution digital data coupled with computer-assisted geographic information system (GIS) technique has become a very powerful tool in cost-effective and quicker generation of information on the distribution of land cover/use, their change, and urban growth in a city environment.

A per-pixel multispectral classification algorithm is, generally, used for mapping urban areas. This method, however, produces a low levels of classification accuracy (Forster, 1980; Toll, 1985). The main reason behind is the size of terrain objects compared to a pixel. The other reason may be the needs periodic monitoring of its state. Conventional methods of monitoring are generally hampered by data poor situations. From satellite data coupled with GIS technique we can periodically monitor the implementation status (extent and rate) and deviations of development plan which is not possible by any other means.

The synergism of remote sensing and GIS techniques may be viewed from two perspectives: (i) *process monitoring*, where remote sensing plays important role, and (ii) *process measuring and displaying* for which GIS provides a powerful tool. This synergism results in the provision of more reliable statistics and illustrations of changes with respect to independent factors. For example, the spatial distribution of different land cover/use types and the percentage of change over time can be compared with the specifications of the development plan. Inherent limitations of satellite data because of its character of providing only cover information are a major impediment for its optimal use in studying urban change.

1.3 The Research Problem

The city of Delhi has been experiencing rapid growth over the last four decades. This growth is characterized by two main features- areal expansion and population increase (Table 1.1). Since 1961, the rate of increase is coming down but still it is one of the highest in the country. In 1911, the city consisted of a little over 43 km^2 of area with a population of nearly 0.21 million, it rose to over 195 km^2 of area and more than 1.4 million population in 1951. By 1991, urban area spreads to over 700 km^2 with nearly 8.5 million population, an absolute increase of over 500 km^2 of area and

Table 1.1 *Urban area and population, Delhi (1911-1991).*

Year	Urban area (km^2)	Percent increase (area)	Urban popolation (millions)	Percent increase (population)
1911	43.25	-	0.21	-
1921	168.09	288.65	0.24	27.94
1931	169.44	0.80	0.30	46.98
1941	174.31	2.87	0.45	55.48
1951	195.54	12.18	1.44	106.58
1961	326.34	66.89	2.36	64.17
1971	446.30	36.76	3.65	54.57
1981	591.90	32.62	5.77	58.16
1991	700.23	18.30	8.47	46.87

Note: Percent increase indicate variation over previous census year.
Source: 1. Statistical Abstract 1974-1993, Directorate of Economics and Statistics, Delhi.
2. Diwakar and Qureshi, 1993.

over 7 million people between 1951-1991. The phenomenal growth of population is also characterized by densification. In 1951, urban Delhi was lived by nearly 7,400 persons per km^2 of area, while in 1991 this figure rose to over 12,000 persons (a densification rate of 1.6 percent per annum). This rapid growth has caused acute shortage of housing and of social and physical infrastructures, which in turn caused deterioration of the environment. According to World Health area by now (as can be seen on the IRS-1C PAN satellite image) (see Appendix III). River beds on the eastern bank of the Yamuna river, which are enmarked for no development, are developing rapidly with slums and squater settlements. These are the few examples of the relation between plan and reality.

The fundamental problem faced in effectively managing our cities is the lack of precise knowledge about urban spatial processes. The land use plan, one of the basic components of the Master Plans of Delhi, deviated from the reality since the formulation stage due to the non-availability of reliable and up-to-date information. Since MPD-1962, the only available detailed map is the 1981-82 land use map, prepared for formulation of MPD-2001, which is published in 1990. Survey of India, which prepared a city guide map for Delhi with 1:25,000 scale in 1984 is only a good base map. On the whole, there is a big gap between the information availability and information requirements. In such a information poor situation, no plan be a comprehensive one. Haphazard development in many parts of Delhi in general and TYA in particular is a noted example.

Satellite images can help to change the information poor situation of planning organizations, to a great extent, although satellite data have their limitations in information extraction. The present study focused on the following issues/questions:

(i) What is the effect of spatial resolution in:
   (a) recognizing urban physical boundary? and
   (b) discriminating urban land cover/use objects?
(ii) What is the effect of data fusion in recognizing and extracting urban land cover/use objects?
(iii) How far automatic segmentation approach be helpful in extracting land cover/use objects from urban satellite images?

1.4 Approaches to Geo-information Genesis: *Review of Relevant Work*

1.4.1 *General relevance*

Sequential aerial photographs are commonly used to detect land use change over a period of time in a region (Avery, 1965; Richter, 1969; de Bruijn, 1976, 1987; Adeniyi, 1980). The time gap of data for change analysis is usually very wide.

Satellite remote sensing is a powerful means of growth detection and monitoring land use at high temporal resolution and lower costs than those associated with the use of traditional methods (Jensen and Toll, 1982; Jensen *et al.*, 1983; Forster, 1985; Pollé, 1988; Martin, 1989; Ehlers *et al.*, 1990; Bhargava and Sokhi, 1995). It is also very useful for monitoring development plan (Sokhi, 1995). The problem in satellite-based information generation, however, is that urban areas represent complex land cover types. Each cover type may have different spectral reflectance characteristics. It is felt that the interfacing of GIS technology with remote sensing is required to provide maximum information content and benefit to land-use planners (Nellis *et al.*, 1990). It has been recognized by various authors (e.g. Welch, 1985; Forster, 1985; Quarmby and Cushnie, 1989; Kam, 1995) that there are many advantages to combining remotely sensed data with existing spatial, image, and statistical data to maximize the information on which to make responsible decisions for land-use interpreter, but only urban/rural differentiation may be made. At low resolution, relative location of features along with tone/colour are available to distinguish major urban land cover/use types, major transportation arteries and commercial strip development, and land clearing for new construction. When using medium resolution data, some degree of texture/pattern permits urban land cover types, particularly at the rural-urban fringe, to be detected and delineated with higher confidence. With high resolution data, shape and shadow of urban features are available; when added to other image parameters mentioed earlier, can produce detailed level of 5 to 9 land cover/use types. Their study was devoted to the data of cities of the United States where, in general, urban land parcels are quite large in size compared to cities of developing countries. So some of their findings have no or little relevance to cities of developing world. For example, at 80m resolution data it is not possible to distinguish what they mentioned. Woodcock and Strahler (1987) using the graph of local variance as a function of image resolution method concluded that spatial resolutions of Landsat TM and SPOT HRV are generally characterized by high local variance in urban and suburban scenes. No distinct group of objects of a specific size dominate the scene within the range of resolutions covered in the graph as the graph of local variance lacks a well-developed peak. Johnson and Howarth (1987) examined four different resolution images- 2.5m aerial photographs and 10m, 20m, and 50m digital images acquired using Multi-detector Electro-optical Imaging Scanner (MEIS) II, in a test site of Toronto city, Canada. Thematic information extraction was carried out by means of unsupervised classification. The study found that as spatial resolution increases, high spatial frequency land cover/ land use classes (e.g. dwelling unit roof) can be extracted in increasing detail while the precision of border locations improves for low spatial frequency land cover/ land use classes (e.g. water, bare field).

(b) *Examination of image fusion effects*

SPOT image data was found most useful when multispectral and panchromatic information merged together to create enhanced multispectral images of 10m resolution (Lillesand, 1987). Recently, Raghavswamy *et al.* (1996) also found merged images of IRS-1C LISS-III and PAN are very useful.

Welch and Ehlers (1987) in their experiment, SPOT HRV 20m and Landsat-5 TM 28.5m resolution multispectral images were merged separately with SPOT PAN 10m resolution images using intensity-hue-saturation (IHS) algorithm. Merged datasets were generated by taking intensity component from PAN data, hue and saturation from XS data, after transforming red-green-blue (RGB) channels of XS into IHS domain. They found the multisensor and multiresolution composite SPOT and SPOT+TM images are of similar spatial resolution to the panchromatic reference image, yet provide excellent spectral discrimination of natural and cultural features in urban environment. Ehlers (1988) after describing different techniques for synergistic merging of SPOT HRV, Landsat TM and SIR-B images, concluded that significant improvements in rectification accuracy, detail of cartographic features and interpretability can be realized using multisensor image fusion techniques. He concluded that merged data products will prove useful to scientists seeking to maximize the amount information that can be extracted from satellite data. Ehlers *et al.* (1990) in their study of an area located in Maine, USA, merged SPOT XS 20 m resolution images with SPOT PAN 10 m structures and classification rules in Nexpert Object (rule-based expert system shell). He first classify the image based on spectral properties followed by determination of size and neighbour relations for segments, and then classify the segments into land use categories through rule-based classification. The study found significant improvements in classification accuracy for built-up land (from 45 percent to 55 percent) by applying four classification rules. Gorte (1996) used an segmentation method embedded in a quadtree-based GIS (with "merge" criterion only) and image processing system for Landsat TM image of Flevopolder in Netherlands. He found that due to the largeness of field size, the method produced nice segments (based on spectral properties), but boundary (mixed) pixels results in a large number of very small segments (e.g. single pixel, two pixel segments). However, he concluded that with high resolution satellite data, this method will strengthen the GIS and remote sensing integration as it can support integration of satellite, map and attribute data. Using Gorte's approach (Gorte, 1995b, 1996) Gueye (1996) in an attempt to resolve the image pixels into 'objects' using Landsat TM image of Flevoland, the Netherlands, found pixel-based classification gives about 4 percent improved result than segment-based classification, which he added as repercussion of mixed pixels along boundaries.

The present study is an attempt to examine the effects of (currently available) two high resolution satellite datasets of the same band i.e. panchromatic band, with different sensors, different resolutions, for recognition and discrimination of land cover/use types. Image fusion technique has been attempted for more rigorous examination of the effect. This study also attempts to apply quadtree GIS-based image segmentation technique for object extraction from panchromatic as well as merged XS+PAN images. The texture features of panchromatic images has been attempted to merge with the fused XS+PAN images in extracting objects. Previous works are taken as source of ideas and inspiration for all these exercises. Examining the prospects of generating reliable information from space sensors for urban monitoring is the ultimate aim of this study. It is an exercise on the developing country's complex urban situation.

1.5 The Research Objectives

The main objective of the study is to examine the spatial resolution effects in urban land cover/use object recognition/discrimination from satellite images as well as to extract cover/use objects from images taking cases from Delhi-megacity, India. Within the frame of this broad objective, the following are the specific objectives of the study:

(i) To examine the effect of spatial resolution in:
   (a) recognizing urban physical boundary, and
   (b) discriminating urban land cover/use objects;

(ii) To examine the effect of image fusion in recognizing and extracting urban land cover/use objects;

(iii) To extract urban land cover/use objects using automatic image segmentation approach.

1.7 Data and Methodology

1.7.1 *Data Base*: The following data sets were used in the present study.

Remotely sensed data

- SPOT HRV PAN digital data of 1986 with 10 m ground resolution acquired in 12 May 1986 (Path/Raw: 207/293)
- SPOT HRV XS digital data of 1989 with 20 m ground resolution acquired in 3 January 1989 (Path/Raw: 206/292)
- IRS-1C PAN digital data of 1996 with 5.8 m ground resolution acquired in 22 November 1996 (Path/Raw: 96/51).

Other data

- Survey of India (SOI) topographical map at 1:50,000 scale of 1980
- Existing land use map of Delhi Development Authority (DDA) of 1981-82 at scale 1:20,000
- Land use plan map of Delhi prepared by Town Planning Organization, Ministry of Health, Government of India for DDA of 1962 at scale 1:72,725
- Land use plan map of Delhi prepared by DDA of 2001 at scale 1:72,725
- Zonal map of Delhi published by DDA at 1:72,725 scale
- Guide map of Delhi of Survey of India of 1985 (Third edition) at 1:25,000 scale
- Tourist map series, Delhi of Survey of India of 1996 at scale 1:50,000
- Eicher city map, Delhi of 1996 published by Eicher Goodearth Limited at scale 1:12,500
- Population data of Census of India for 1981 & 1991
- Other reports/documents.

1.7.2 *Methodology*

The following approaches were employed to achieve the objectives of this study. A vector GIS was used to input GIS data in digital form. The image processing technique was used for processing and analysing image data. PC-based ILWIS GIS and a quadtree-based GIS and image processing system at the Workstation forms the major softwares used.

Method- objective 1:

The effects of spatial resolution in recognition of urban physical boundary and land cover/use objects from satellite images has been examined using two pair of sub-scenes. One pair of sub-scene has been selected from urban expansion areas (5.8 km x 7.0 km or 1000 x 1200 pixels) and the other from the built-up areas (5.8 km x 5.8 km or 1000 x 1000 pixels) of SPOT PAN and IRS-1C PAN images of east Delhi (see Appendix IV & V). A visual comparison approach has been employed in examining the resolution effects.

Prior to analysis the two sets of images were geometrically registered by identifying and using a few well-distributed ground control points. The detailed procedures are shown in Figure 1.2. For this, as built-up areas. The samples areas were selected, in case of built-up areas, such that samples belong to same built-up areas on both images. In case of city growth areas, different sample sets were selected to assess the resolution effects in urban boundary recognition. The first group of samples measure the discriminatory power of spatial resolutions in recognizing land cover/use types while the second group of samples measures the recognition capability of urban boundary or edges.

Method- objective 2:
For more rigorous examination of spatial resolution effects in object recognition and extraction, image fusion technique was applied. The second part of objective 2 (i.e. the effect of image fusion in object extraction) is included in the second experiment of objective 3.

Detail procedures of first part are given in Figure 1.3. Here, satellite images of north-west Delhi has been taken. At the first stage, three individual SPOT XS bands and SPOT PAN data sets are registered to geocorrected IRS-1C PAN 5.8 metres square spatial resolution by selecting 8 well-distributed CTPs with $RMSE_{xy}$ of less than 1 pixel and later resampled using a cubic convolution algorithm. A common test site of 5.2 km x 5.0 km area (900 x 875 pixels) has been selected from these datasets. The next stage consists of two sets data fusion: (i) individual bands of the registered SPOT XS data are merged with the registered SPOT PAN data, and (ii) individual bands of the registered SPOT XS data are merged with the IRS-1C PAN data, using pixel-by-pixel arithmetic operation. Later, sample sets from SPOT XS colour composite, SPOT XS+PAN merged colour composite and SPOT XS+IRS-1C PAN merged colour composite are selected for comparison.

Method- objective 3:
For extracting spatial objects from satellite images two experiments has been carried out. The procedure for first experiment is given in Figure 1.4. In this experiment, first a common test site located in east Delhi has been selected from geocorrected IRS-1C PAN and rectified SPOT PAN images. The site covers 5.8 km x 5.8 km of area (1000 x 1000 pixels). The test site images were segmented using quadtree-based image segmentation approach to extract objects on the basis of spectral similarities. A rasterized land use map (which is vectorized from Eicher city map) was used for taking training samples to classify segments into land cover/use types. Prior to taking training samples, this map was registered to IRS-1C PAN test site image. Classification (limited to IRS-1C segmented image) of the segments results in maps and classification accuracy tables. All these exercises were carried on Workstation of image processing laboratory (IPL).

The second experiment of segmentation and classification was carried out on merged images. Here, satellite images of north-west Delhi has been taken. At first, the segmentation has been attempted on merged SPOT XS and SPOT PAN images. In this experiment, three individual SPOT XS bands are registered and resampled to SPOT PAN 10 metres square spatial resolution using image-to-image transformation function and cubic convolution algorithm, respectively. A test site of 10 km x10 km area (1000 x 1000 pixels) has been selected. Individual bands of the registered SPOT XS data are merged with SPOT PAN data. Using quadtree-based image segmentation technique images were segmented. When compared with colour composite of merged images as well as with existing land use map, segments are found to be very unrealistic. So, no further experiments has been carried out on these datasets.

For the next experiment, the same test datasets [5.2 km x 5.0 km area (900 x 875 pixels)] of objective 2 (Figure 1.3) has been taken. However, as a separate experiment the procedures of this exercise is shown in Figure 1.5. Here, merged datasets of individual bands of the registered SPOT XS data with IRS-1C PAN data are used. Similar to earlier experiment, a quadtree GIS-based image segmentation approach has been used. Texture element of IRS-1C PAN images has been

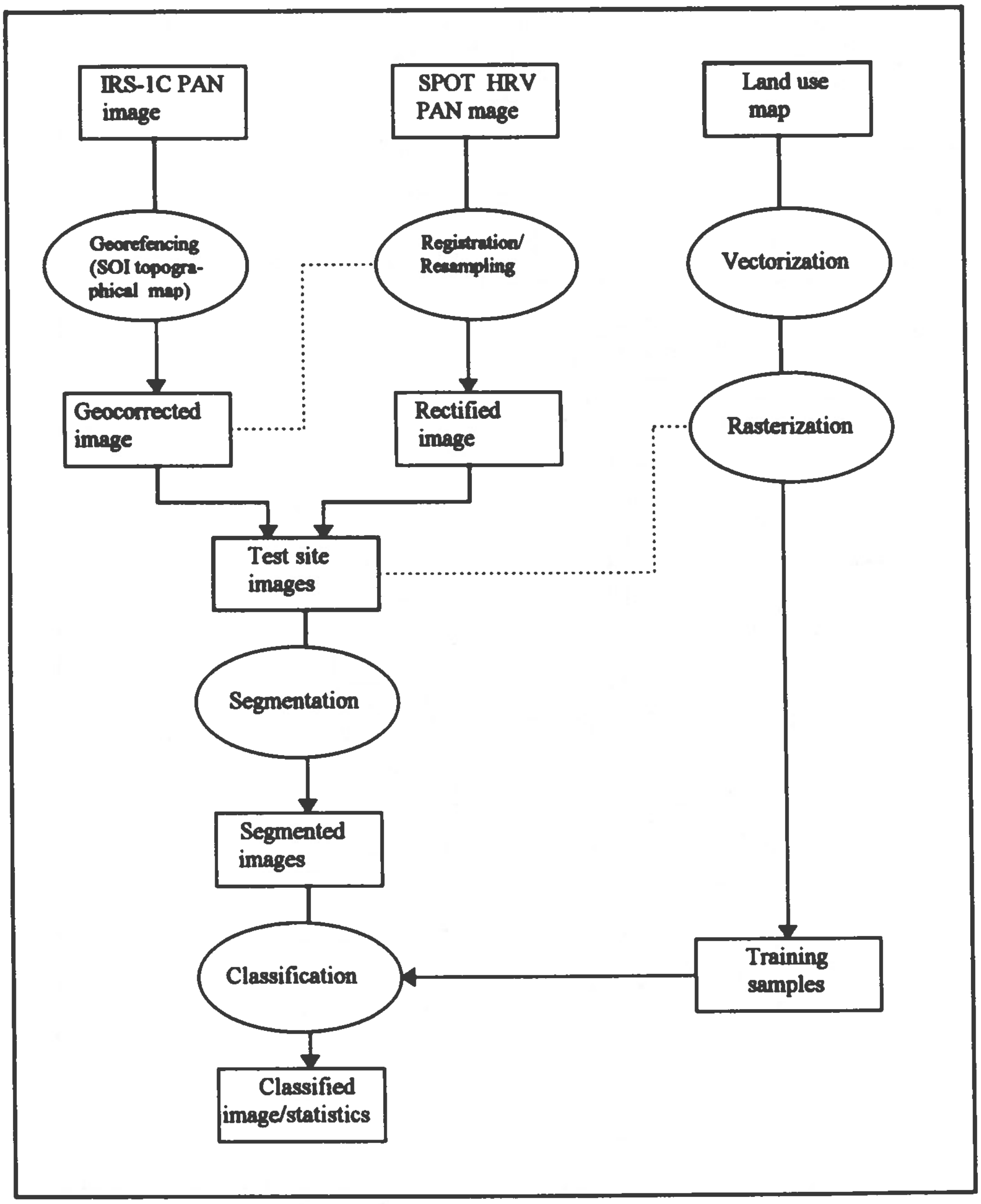


Figure 1.4 *The procedure for segmentation and classification of panchromatic image.*

1.8 Limitations

The present study is limited to three sets of remotely sensed data- two sets of high resolution panchromatic satellite data and one set of multispectral data. Examination of the effects spatial resolution of IRS-1C and SPOT panchromatic images in object recognition were limited to visual comparison of sample sets from test sites. Ancillary geographical data were used as additional layers in image processing and spatial analysis. In classifying segmented panchromatic image, the GIS (land use) data was used for extracting training samples whereas in classifying segmented merged image, they are used for training sample selection. The data used for examining resolution effects are for different time periods. Merging of panchromatic and multispectral data was also carried out on these different time period data. This study is an experimental/evaluative research.

1.9 The Organization of the Thesis

The present experimental/evaluative study deals with the problems of examining spatial resolution effects in recognition and discrimination of land cover/use types in urban and peri-urban areas. Automatic object extraction forms a major challenging part in this research. A discussion on the different methodological aspects like city growth area and pattern detection, examining spatial resolution effects, data fusion effects, object definition, object extraction from satellite data, designing land cover/use classification system, interfacing GIS data with remote sensing, measuring land cover/use patterns, texture element in automatic image segmentation, evaluating the reliability of segmentation approach in deriving spatial information forms the foundation of the kind of experimental/evaluative study carried out here.

For systematic presentation, the remainder of this study is structured into the following chapters. The importance of GIS and space imaging techniques for managing urban development were described in the Second Chapter. The Third Chapter presents detailed methodological descriptions of resolution effects in urban boundary and land cover/use object recognition, data fusion technique and spatial object extraction through automatic segmentation approach. The fourth and fifth chapters forms the main body of the thesis. In Fourth Chapter, the effects of spatial resolution has been examined. Image segmentation and classification results were presented in the Fifth Chapter. The summary of the findings form the main part of concluding chapter i.e. Chapter Six. This chapter also included a few recommendations and concluded by identifying certain areas for further research. The Figure 1.6 shows the relationship among these chapters.

Chapter 2

GEO-INFO SYSTEMS AND SPACE IMAGING TECHNOLOGY:
Tools for Sustainable Urban Management

"remote sensing and GIS are tools not only for scientific research on how the world works, but also for technological applications in meeting human needs."

(Curran, 1987)

The intent of this chapter is to describe how GIS and space technology be helpful as decision-making or problem-solving tool in managing our cities. Before describing the roles these techniques can play, it is imperative to give a brief account of some of the aspects of urban problems and management.

2.1 Urbanization at World Level

The combined force of constant technological, economic, social, and above political changes, with each serving as an impetus to the other, has made the world strikingly distinct from what it was a century ago. The fast rate of urban development is a manifestation of the economic restructuring of the modern society. The percentage of rural population which was around 75 percent a few decades ago has already shrunk to 60 percent and is expected to further decrease to just 30 percent by 2025. The number of million cities (cities with a population of 1 million and above) has grown from 31 in 1950 to 150 as of today and is likely to reach 280 by the year 2000 (Rao *et al.*, 1995).

Urbanization and industrialization are ubiquitous processes. These processes occur both due to *in-growth* and due to *continuous migration* of people from rural areas to urban centres in search of better economic opportunities and social status. Another important feature of urbanization in developing countries is the *migration of people from small towns to the big metropolitan cities* (can be termed as "metropolitanization") as big cities offer more and varied opportunities. As Raghavswamy *et al.* (1996:582) rightly mentioned, it is '...primarily because the level of economic development is linked to growth of particularly the big metropolitan and mega cities.' The ratio between the two sources of population increase in urban areas vary from one country to another.

The effects of growing urbanization are being felt both in developed and developing countries of the world. However, in the developing countries, urbanization has been growing at a much faster rate than in the developed nations. In 1950, the percentage of the total population living in urban areas in developing countries was only 17 percent, in 1970 it reached 25.4 percent, and in 1990 it rose to 33.6 percent. By the year 2025, more than half of the population of developing countries (57 percent) will live in cities (Tolba *et al.*, 1992). The Table 2.1 shows that the projected built-up area increase in developing countries between 1980 and the year 2000 is estimated to be around 118 percent. The doubling of the urban world's physical size as well as the population number implies an increase in demand for residential plots from all income groups, locations for commerce and

(a) All places with a municipality, corporation, cantonment board or notified town area committee, etc.

(b) All other places which satisfy the following criteria:
   (i) a minimum population of 5,000;
   (ii) at least 75 percent of male working population engaged in non-agricultural pursuits; and
   (iii) a density of population of at least 400 persons per km^2.

The legal/administrative urban places, as per first part of definition, may not satisfy the criteria listed in the second part of the definition. On the other hand, a large number of revenue villages (smallest administrative units) satisfied the criteria listed in the second part, but were not legally/administratively recognized as towns (Ramachandran, 1995). Census definition does not consider the concept of physical urban space (or contiguously built-up space). The administrative boundaries of towns do not accurately represent the real world limits of urban space. While the administrative boundary remain rather static, the spatial limits of urban space changes with time corresponding to the expansion of space.

In some other case, the emphasis upon local authorities as the primary collectors and users of land use information gives the exercise an immediate framework of administrative areas (Kivell, 1993). This type of unfitting definition clearly misleads the physical planners in making precise decisions for planning and management of urban space. There are some attempts to refine the definition such as consideration of continuous developed areas covered by buildings and urban structures (DoE, 1978), imposition of a population size threshold (Best, 1981) and generalization of urban/rural boundaries by statistical techniques (Ward, 1983).

Land is a scarce resource. In urban areas the changes of land use is very fast unlike it's rural counterpart. The changes in urban areas are characterized by horizontal expansion and vertical intensification. The horizontal expansion is more decisive issue than vertical intensification as the former encroaches the fertile rural surroundings. Realistically, an urban place should be defined based on the continuity of built-up space while other factors such as population number, occupational activities should also be given due consideration depending on the location and planning needs. However, accomplishing such a task, i.e. determining the edge of an urban area, is almost paradoxical using traditional survey methods as urban physical growth is a constantly occurring phenomenon. In defining physical form of the city, its edge or boundary is the most obvious visual delimiter of its size and shape (Batty and Longley, 1994:164). Remote sensing have the advantage of providing synoptic and repetitive imageries. The images can effectively be used to delineate and up-date the urban place boundary. GIS technology using satellite data can ascertain the rate and extent of urban expansion. Taking advantage of these two complementary tools, in the context of present study, an urban place is defined *as the contiguous built-up areas, with few tracts of vacant or agricultural land inside, villages linked to the urban area by ribbon development and large land estates of developing state which are likely to become part of the urban fabric.*

material to finished product (Davis and Olson, 1985), as shown in the Figure 2.1. An information processing system processes data into information.

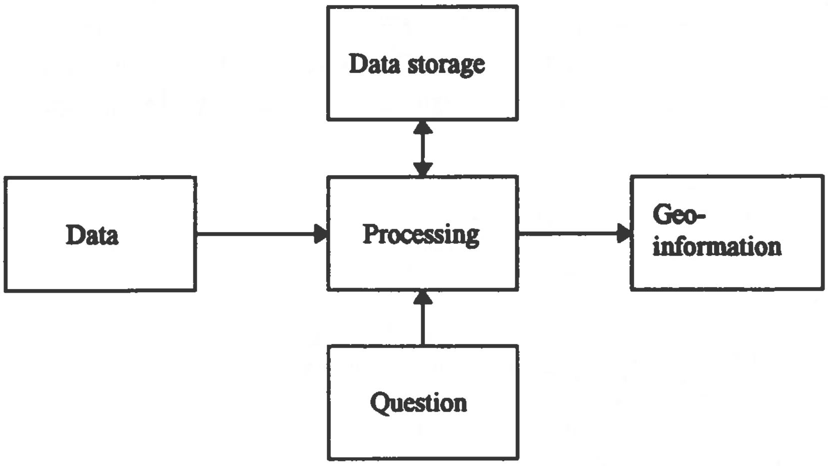


Figure 2.1 *Transformation of data into information in a geographic information system.*

Majority of the information requirements for urban planning and management are spatial or geographic in nature. Geographic information (GI) is "information which can be related to a location (defined in terms of a point, area or volume) on the Earth, particularly information on natural phenomena, cultural and human resources" (GIS Dictionary, 1991). The Department of the Environment's Chorley Committee report *Handling Geographic Information* (DoE, 1987:7) defined the term more elaborately as:

> "'*Geographic Information' is information which can be related to specific locations on the Earth. It covers an enormous range, including the distribution of natural resources, the incidence of pollutants, descriptions of infrastructure such as buildings, utility and transport services, patterns of land use and the health, wealth, employment, housing and voting habits of people.*"

2.3.1 *Geoinformation data types*

There are many different sources of data from which geo-information can be derived. Ehlers (1991) presents a schematic view of the geoinformation data types, their sources and conversion strategies (Figure 2.2). A good amount of spatial information may be derived from remotely sensed images. In case of urban remote sensing, the type of information that we might expect to be able to derive from satellite sensors includes the range and spatial distribution of land cover types and land use categories present, as well as the physical extent of the urban area (including some description of its shape and perimeter) (Barr, 1992).

2.3.2 *The importance of geo-information*

Information is resource, the geographic information is very fundamental resource. The ability to that for management, strict updating of the basic information is necessary while for planning, only periodic updating is necessary (Thornley and McLoughlin,1974). Geo-information has great value in the spatial decision making process in that it changes the probabilities attached to expected outcomes in a decision situation.

2.4 Urban Land Use Information

Geo-information, especially land use information is key to monitoring the environment for conditions requiring a decision. Land, according to McAuslan (1985:13) '- its use, abuse, control and ownership - is the central problem of the city.' The use information of land is a particular set of geo-information, and in fact very essential one. Curtis (1973) in this regard rightly stated that 'of all the factors that determine the quality of our environment, the most fundamental is the use we make of the land' (cited in Estes *et al.*, 1982:100).

The demands for land usually exceeds the supply particularly in case urban areas. The problem becomes more acute in cities where there is no or weak delivery system. Information on existing patterns of the varied uses of land and its periodic changes is a key determinant to organize urban planning. The inventory of urban changes is required to have an up-date picture of the existing land use pattern as well as to monitor the changes that are constantly occurring in different parts and peripherals of the city. As Kivell (1993:3) precisely stated 'Urban land use must ... be seen as a constantly evolving pattern rather than a static entity ....'

2.4.1 *Land- the basis of urban planning system*

A city or a city planning can not be seen in isolation. A system approach is key to the effective urban planning and management. A city can be referred as an urban ecosystem in which different components interact with each other. The very fundamental element of that ecosystem is land. It is the very basis upon which all other components or functions depends. Among all functions most important is the activity function. It is land surface which provides foundation for all forms of human activity. Sir Bernard Binns, in a seminal report to the Food and Agricultural Organization (FAO), observed:

> *"The land is man's most valuable resource. It is indeed much more than this: it is the means of life without which he could never have existed and on which his continued existence and progress depend"* (cited in Dale and McLaughlin, 1988:1).

Indicating the urban importance of land, some scholar view it is the central problem of the city (McAuslan, 1985). To lessen the problems of the use of land and simultaneous planning for better use, it is of utmost necessary for urban and regional planners to have the necessary spatial information at continuous basis.

2.4.2 *Land cover/use classification*

The physical space of a city are characterized by complex land cover/use features. Through classification we can model that complexity in such a way valuable to the user. The term *land cover* information, coupled with data on proximity to existing infrastructure, to identify and prioritize potential distribution system expansions (Ehlers *et al.*, 1990).

2.5 GIS and Urban Management

A great volume of information is needed for managing and planning urban space. Majority of them are spatial in nature. Advanced tools and techniques are needed to generate and manage information. GIS can serve as means to accomplish that task. An information system is a chain of operations from planning the observation and collection of data, to storage and analysis of the data, to the use of the derived information in some decision-making process (Calkins and Tomlinson, 1977, cited in Star and Estes, 1990). A GIS not only permits all information on traditional paper maps to be handled in digital form but, in principle, enable it to be linked to all other kinds of digital data.

2.5.1 *GIS defined*

A GIS is an information system for spatial data that are referenced by geographic coordinates. A large number of definitions of GIS has been put forward by different spatial science scholars and GIS practitioners over the last thirty years. These results in successful implementation of the Canadian Geographic Information System or CGIS under Roger Tomlinson in 1964 (Peuquet, 1977). However, a comprehensive and widely accepted definition of GIS has been given in the glossary of ESRI's workbook *"Understanding GIS- The ARC/INFO Method"* (ESRI, 1993). It described a GIS as:

> *"An organized collection of computer hardware, software, geographic data, and personal designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information*" (p.4-16).

The operation of a GIS involves a string of activities from observation and collection of data through to its analysis and use in the processes of decision-making. In short, a GIS can be referred to as a computer-based spatial decision support system.

2.5.2 *Functional views of GIS*

As the GIS technology is evolving both in case hardware-software and applications, it's not surprising that it will encompass more and more wave bands in the functional spectrum. This can be viewed from the advocacy of different experts. The process "inventory to management" advocated by Crain and MacDonald (1984) implies that a successful GIS must evolve from an inventory tool to an analysis tool, and then ultimately to a management tool. Cowen (1988) termed GIS as decision support system involving the integration of spatially referenced data in a problem solving environment. Aronoff (1995) viewed GIS from four capability points to handle georeferenced data: (i) input, (ii) data management (data storage and retrieval), (iii) manipulation and analysis, and (iv) output. Goodchild (1990) presented four functional views of GIS: (i) GIS as automated mapping, (ii) GIS as map analysis, (iii) GIS as inventory, and (iv) spatial analysis and decision support. A schematic functional view tendered in Star and Estes (1990:3) portrayed a GIS is both database

(Ottens, 1990) of "GIS-coin" planners choose, they recognized the value and potentials of GIS. The Royal Town Planning Institute's GIS panel identified eleven potential areas of GIS under which benefits are likely to accrue (RTPI, 1992) (Appendix VI).

Application of GIS in urban problems visualizes the scenario true to its spatial position on a two or three-dimensional maps. These information are extremely valuable in making spatial decisions. GIS can be used to produce and visualize both pattern and process information. For instance, we can visualize the areas of change between two or more time periods using remote sensing or map data. The importance of map lies in its capability of visualizing spatial or locational configuration of place characteristics, relevant to the objectives of spatial classification. However, it's not only maps, through GIS we can generate spatially accurate statistical information for measuring the rate and extent of change. Wenger (1984) rightly observed that the purpose of GIS not so much to draw maps as to provide information on the spatial location of resources. The statistical information produced by GIS applications can then be used for rigorous statistical analysis for model building.

2.6 Remote Sensing as a Data Source for Urban GIS

Whatever the specific urban problems might be, it is important that the timely and spatially accurate information is available to aid forward planning and sustainable management of urban areas. Remote sensing can furnish some of the information, indeed the most valuable information.

2.6.1 *Remote sensing as data source*

Remote sensing is the technique of collecting information from a distance. The data are so collected termed remotely sensed data. These data may be analyzed to obtain information about the objects and phenomena being investigated. Remote sensing is defined, in narrower sense, as measurement of the electromagnetic properties of a surface or object without being in contact with it (Davis and Simonett, 1994). In an operational sense, *remote sensing* can be defined as the *art, science and technology of obtaining information by detecting, recognizing and identifying, classifying, delineating, measuring, and analyzing objects and phenomena of earth's surface with sensor (mounted onboard either on aircraft or satellite) acquired imageries through manual interpretation and computer-assisted classification techniques*. For a variety of applications, remotely sensed data, while only one source of potential input to a GIS, can be valuable (Star and Estes, 1990). The synoptic and repetitive imageries from satellites, with their versatility, timeliness and change-detection capabilities can replace the traditional methods of urban mapping. One of the main use can be of thematic mapping, which becomes additional layers of data in a GIS. This will also keep the GIS update, infact in most cost effective way (Goodenough, 1988). As data is still the most expensive component of a GIS, the need for inexpensive, accurate and timely GIS data has created a collateral demand for digital imagery (Green, 1992). Table 2.3 gives information about the currently available high resolution satellite data relevant to urban GIS.

Urban planners apathy towards this technology, due to limited spatial resolution could be remove from the observation of noted space scientists:

- *Slow changes of large objects*. These needs a low temporal frequency and low spatial resolution.
- *Slow changes of small objects*. For this a high spatial resolution and low temporal resolution are required.

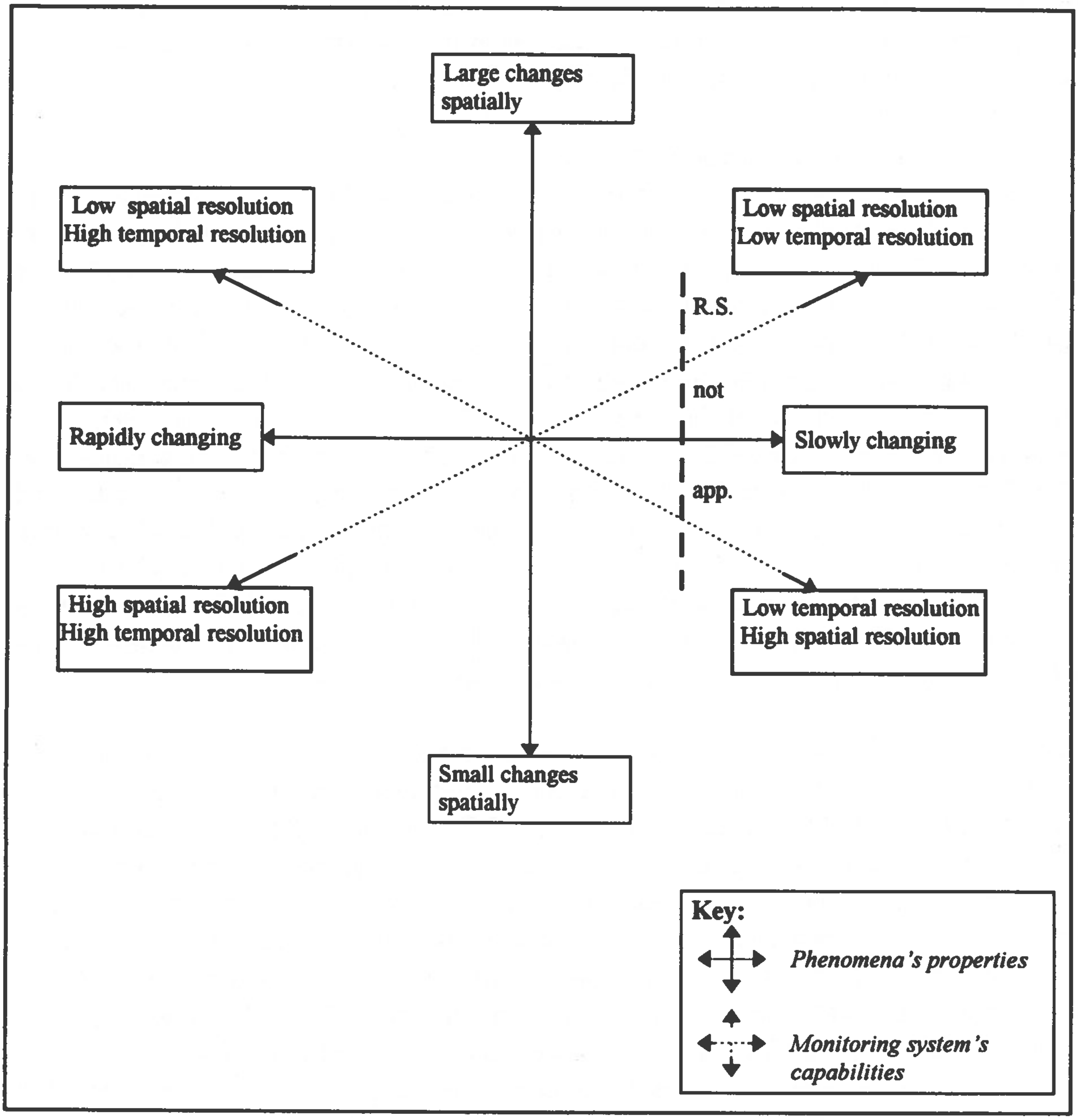


Figure 2.4 *Types of monitoring* (from Townshend, 1977:3)

The temporal frequency of observation provides an estimation of the rate of changes e.g. how fast vacant land changed into urban, whereas the spatial unit of observation allows to detect and measure changes e.g. how much vacant land changed into urban.

2.8 GIS as an Integrating Technology

Integration of data is conceivably the primary realm of GIS. The capability to store, map and analyse data of different types together is what makes a GIS more than just a computer mapping system (Flowerdew and Green, 1991). The real benefits of GIS can only be achieved by linking different data sets together. Gilfoyle (1991:9) correctly asserted that 'by combining different kinds of data we can add value to the information we hold and then use it to assist in the planning and delivery of services.'

Remote sensing requires other GIS data to realize its immense value and the highest levels of spatial accuracy. Simonett *et al.* (1983:25) rightly puts it, 'remotely sensed data alone cannot become scientific information as the information is fundamentally related to algorithm/theory.'

2.8.1 *Integrating GIS with remote sensing*

Recent research emphasised on the issue of integration of GIS and remote sensing. The US National Science Foundation (NSF) consortium on GIS has selected integration of remote sensing and GIS technologies as one of the twelve primary research initiative (NCGIA, 1991). The immense volume of data generated by the satellite sensor needs maximum exploitation and utilization. The quality of spatial databases can be improved through integration by reducing spatial errors resulting due to specification or measurement or due to a combination of both.

Different approaches are being experimenting to improve the reliability of remote sensing derived information. GIS and remote sensing integration is realized, in several studies, by converting data stored in a GIS into raster format in order to be integrated into the image processing system. Hutchinson's (1982) suggested that classification could be improved through the inclusion of ancillary geographical data as another image band. Some studies experimented integration in the vector environment to the extent of updating vector information by using an image as backdrop for vector editing and on-screen digitizing (Lynn Usery and Welch, 1989; Sanchez, 1991). Automatic image segmentation using combined spectral/spatial properties of the image and other digital map data and domain expertise (or knowledge-based system) become an intelligent area of research (Mason *et al.*, 1988; Corr *et al.*, 1989). Gorte (1996) felt that integration can be strengthened through segmentation method embedding in a quadtree based GIS and image processing system which have potential to integrate satellite, map and attribute data.

2.8.4 *Spatial and temporal scaling problems*

The concept of scale is pivotal to both GIS and remote sensing. Scale is one of the primary attributes in portraying spatial data. It also gives a perception of spatial characteristics. The data used in many tasks of urban and environmental resources management and planning comes from different sources. For land resources management, urban planners require the use of not only remotely sensed data but also other information from existing maps and field surveys. Spatial data from these different sources have different accuracy and measurement scales because they are dependent on methods of data collection, manipulation, and presentation. The accuracy of remotely sensed data depend largely on their spatial and radiometric resolutions whereas accuracy of map

Chapter 3

URBAN LAND COVER/USE OBJECT RECOGNITION AND EXTRACTION: *Methods and techniques*

the first law of geography: ***"everything is related to everything else, but near things are more related than distant things"***

(Tobler, 1979)

The chapter describes the methods and techniques used in this study for detection, recognition and extraction of spatial objects from satellite data. The term 'spatial object' is limited to uniform land cover/use in terms of visual image characteristics and spectral properties.

3.1 Introduction

Satellite data can be interpreted either visually through combined use interpretation elements (e.g. tone, texture, size, shape, pattern, association, etc) and terrain knowledge or digitally based on spectral (or combination of spectral and some spatial such as texture, size) properties. In either cases, the intent is to segment an image to derive meaningful land cover/use information by categorizing similar characteristic areas or classifying similar spectral properties. Visual interpretation directly results in areal or polygonal objects through detection, recognition and identification of features (of course we need a land cover/use classification scheme beforehand). It requires image characteristics to be known. So, in this case an object is a homogeneous land unit in terms of cover or use. The digital interpretation of satellite data can generate object-based land cover/use information through the application pattern recognition techniques (Castleman, 1979; Schowengerdt, 1983). This can be realized by isolating the objects (areas of similar spectral or combination of spectral and some spatial properties) using region growing image segmentation technique, followed by assigning each object to a predefined class based on the feature selected by the use of a classifier (e.g. maximum likelihood or k-nearest neighbour classifier). There are several limitations in automatic extraction of objects such as low ground resolution of images, complexity of terrain objects and complexity of the segmentation procedure itself. However, in both visual and digital interpretation, Tobler's law of geography provides a good basis in defining, recognizing and identifying land cover/use objects .

3.2 Land Cover/Use Object in the Study Context

In this study, an object is defined as the homogeneous land cover/use features in terms of image characteristics. Image characteristics are the set of attributes and geometry of the image objects. While attributes refer to non-spatial characteristics of the objects, the geometry refers to the spatial dimensions of the object in horizontal direction. As image analyst, we can only think of deriving land cover object. However, we can infer cover information to use information using professional knowledge and other GIS data.

(Haack *et al.*, 1987; Khorram *et al.*, 1987; Martin *et al.*, 1988; Townshend, 1992). Curran (1987) termed it as falsified theory of saying 'spatial resolution is related positively to classification accuracy'. Recent availability of IRS-1C PAN data with the highest resolution available from commercial/civil satellites brings up the thesis for further investigation.

3.4.1 *Spatial resolution*

Spatial resolution can be defined as size of the smallest object that can be reliably detected against a spectrally contrasting background, referred to as the *effective resolution element* (ERE) (Davis and Simonett, 1994). It is the ability to measure the extent of small but finite targets. Since satellite sensors produce images comprised of cells (pixels), image resolution is the ground area covered by pixels. A pixel has both spatial and spectral properties. The spatial variable defines the apparent size of the resolution cell (the area on the ground represented by the data values), and the spectral variable defines the intensity to the spectral response for that cell in a particular band. Spatial resolution is also described as the instantaneous field of view (IFOV) of the sensor, although the IFOV is not always the same as the area represented by each pixel. The IFOV is a measure of the area viewed by a single detector in a given instant in time (Star and Estes, 1990). In GIS context, the IFOV generally corresponds to the size of a single raster cell. For evaluating the spatial resolution needed for a particular application, three levels of resolution- detection, recognition and identification are useful parameters.

3.4.2 *Detectability and recognizability*

The ability to discriminate objects on an image is directly related to the spatial and radiometric resolution of the remote sensor system. Object on the ground itself displays a spectral contrast with respect to nearest surroundings. As geo-information analysts, our concern is not only in object detection but also in object recognition and identification. The required resolution at each level is different. Roughly, it takes about 3x improvement in spatial resolution to move from detection level to the recognition level, and about 10x improvement to move from the recognition level to the identification level (Simonett *et al.*, 1983:23). For instance, an object can be detected if there is an indication that something different from the surroundings is present (e.g. an object in the mid of the residential area that is not 'residential'). The recognition level resolution can categorize the objects being detected (e.g. the object inside the residential area a different type of building, a play ground or a water feature). The identification level resolution may help to derive the information on the specific land cover/use type (e.g. recognized building is an industrial firm or building).

In short, at the detection level, our objective is to discern separate objects discretely, at the recognition level we attempt to determine what objects are, and at the identification level [what Aronoff (1995) termed *analysis level*] we more specifically identify objects (Lillesand and Kiefer, 1994). The spatial resolution is the basis of detectability of an object. Higher the resolution more the objects can be detected. However, the problem is that based on gray or colour tone differences we may establish the presence of certain shapes and patterns, but these may not necessarily lead to recognition. Professional experience and local knowledge (i.e. knowledge about the terrain) are prerequisites for recognizing terrain objects. On a sharp image, it may be that only a few pixels are be adequate for analysis of some urban areas in the United States. However, the experiments with 5.8m resolution IRS-1C PAN data of Delhi give rise to the point that mapping detailed urban features require far more higher resolution data. Davis and Simonett (1994) identified three major task with which spatial resolution vary: (i) *detection*, determining the presence of an object; (ii) *identification* or labeling of an object; or (iii) *analysis*, where information is obtained about an object beyond its initial detection and identification.

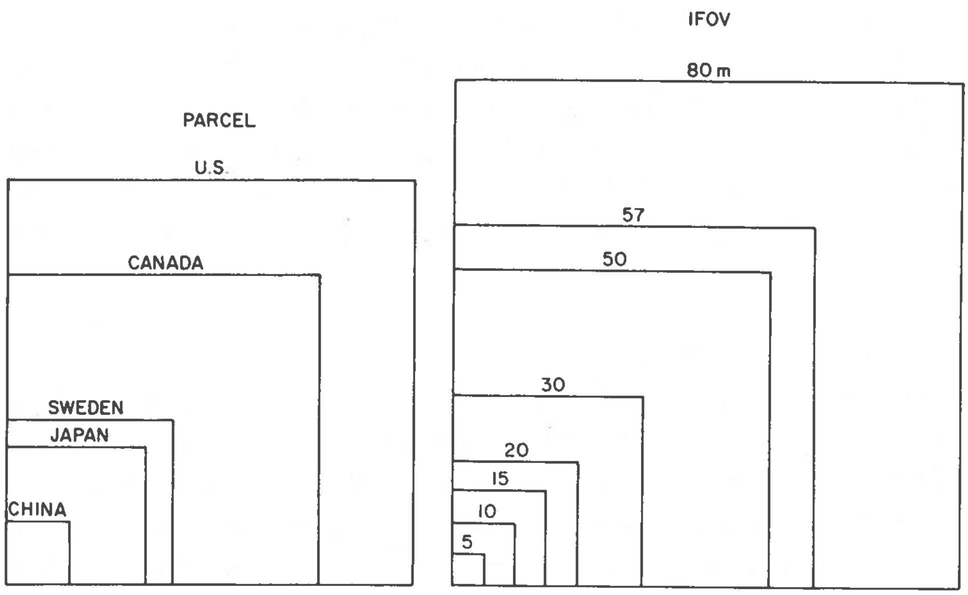


Figure 3.2 *Comparison of representative urban land parcel sizes for different countries with the IFOVs of current or proposed satellite sensor systems* (from Welch, 1982).

In change detection analysis, it is not only spatial resolution but also other resolution parameters needs consideration. Townshend and Justice (1988) observed that the ability to detect changes in a surface imaged over time depends on the spatial (geometrical registration and resolution), spectral (band location and width), radiometric and temporal (imaging frequency) properties of the sensor system.

3.5 Data Integration

There are two important aspects in the integration or linking of the remote sensing and other digital geographical data: geometric and thematic aspects.

3.5.1 *Geometric aspects*

Geometric aspects concerns the topographical problems of converting both satellite and other geographical data to the same map projection, scale and coordinate system. To enable change to be detected from the satellite imagery the data needs to be co-registered and preferably matched to a map projection system. The terms georeferencing, geocoding and co-registration all refer to a type

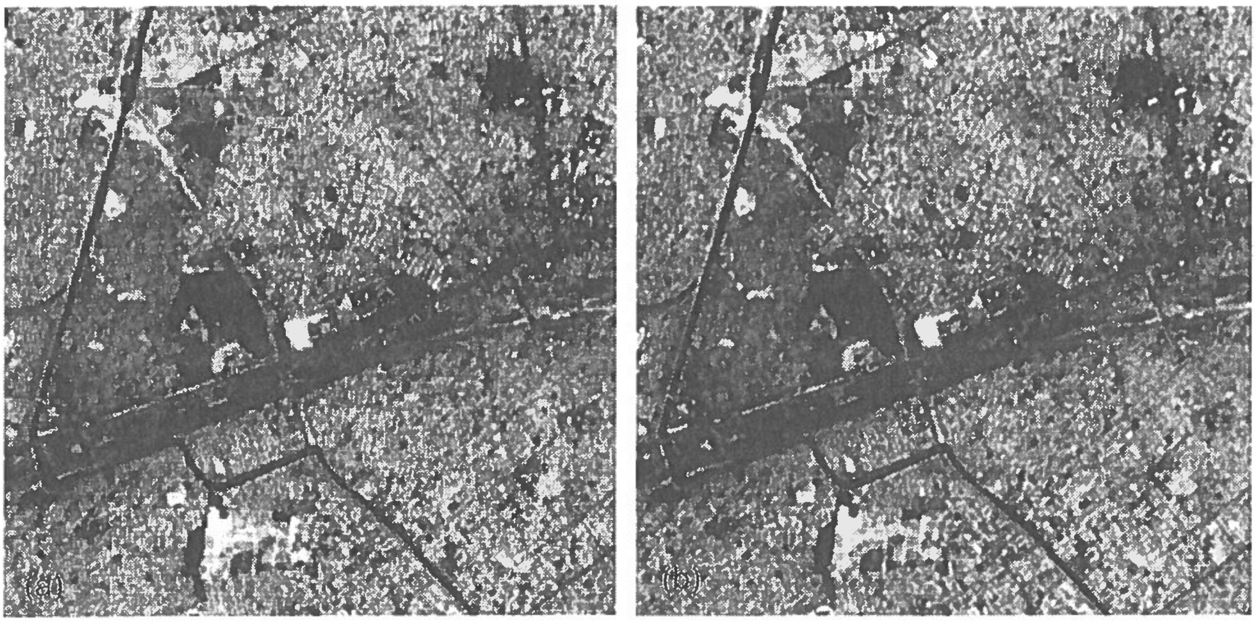


Figure 3.3 *Results of resampling method. (a) Image produce using nearest-neighbour interpolation logic; (b) Image produce using cubic convolution logic.*

land cover/use information. The most commonly used digital enhancement techniques fall into three categories- contrast manipulation, spatial feature manipulation and multi-image manipulation (Lillesand and Kiefer, 1994). This study used three specific techniques namely contrast stretching, spatial filtering (convolution) and intensity-hue-saturation colour space transformations.

3.7.2 *Visual comparison*

The trend of increased spatial resolution for earth-orbiting satellites has the potential to increase information content within remotely sensed images. The effects can be assessed by means visual comparison of geometrically corrected different spatial resolution images over an area. For example, this study used two pair of sub-scenes of two different resolution images. One pair of sub-scene has been selected on the city growth areas to examine how reliably we can detect/recognize urban boundary at the edge of the city between 'built-up' and 'non-builtup' entities. The problem, however, is that there is no standard criteria for defining urban boundary on satellite images. The parameters included in defining an urban place gives only conceptual bases. Pollé (1988) discussed three techniques of visual boundary delineation- *generalization, idealization or agglomeration*. Of these, idealization technique may serve well in identifying city boundary as in reality only a diminishing density of built-up area can be seen on the satellite image (Figure 3.4). The template of minimum curtilage (i.e. smallest area to be delineated) and minimum width provide the standard for the minimum area to be delineated. The other pair of sub-scene has been selected in the built-up areas on two images to examine how reliably we can recognize/discriminate different land cover/use object types. A few sample sets associated with a few land cover/use classes (recognizable using visuall image characteristics) were taken from both pair of sub-scenes for detail examination. Adopting a visual approach in assessing resolution effects is being guided by the notion that the human brain can synergistically apply many clues/parameters while interpreting an image. In terms of usefulness, visual interpretation remains a valuable information extraction technique that often cannot be matched by automated methods (Aronoff, 1995).

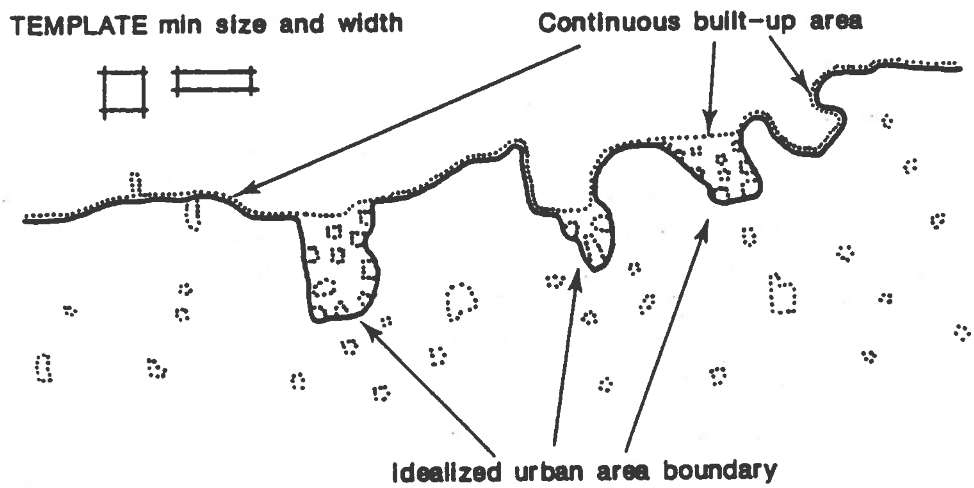


Figure 3.4 *Idealization of the boundary of the urban area* (from Pollé, 1988)

A more rigorous examination of resolution effects has been attempted using image fusion technique. Spectral information of SPOT and spatial information of IRS-1C were combined to exploit the best of both . Different sample sets were taken to examine the quality of information content.

3.8 Multi-sensor Image Fusion

Due to the availability of more and more data from satellite sensors in recent years there is concern about efficient use these data. Integrating and merging digital image data collected by different sensors has become an important component of digital image processing for full utilization of complementary information, what some scholars termed as "vertical" spatial data analysis (Gong, 1994). Multi-sensor integration, according to Luo and Kay (1989:903), refers to the synergistic use of information provided by multiple sensory devices to assist in the accomplishment of a task by a system. By distinguising between multi-sensor integration and multi-sensor fusion, they referred fusion to the actual combination of data from different sensors.

turn require reliable delineation of objects (i.e. land cover feature with similar attributes). In computer-assisted digital image analysis, a crucial step is the image segmentation for object extraction. The problem involved in segmentation can be defined as the splitting up of an image into a set of connected regions or coherent parts, each region or part having more or less uniform property (for example, in terms of tonal value or texture). In simpler form, segmentation means processing an array of numeric values to extract homogeneous spatial objects.

There are a number of techniques of image segmentation. These techniques, generally, fall into two different approaches: (i) region-forming techniques such as region growing, thresholding, spatial clustering, and (ii) edge detection techniques. The first approach is concerned with analyzing properties of areas to split or merge them into regions, while the second approach is concerned with finding the boundaries which delimit the regions (Sijmons, 1986). Here our concern is with the region growing technique. There are two subdivisions within this method: (a) Pyramidal data structure: "split and merge", and (b) aggregation: "merge" (Mulder, 1993).

Selection of algorithms for segmentation depends on the types or classes of objects to be extracted, the resolution of the image, and the types of sensor. The best known segmentation algorithm is the "split and merge" algorithm (Chen and Pavlidas, 1981), which is based on splitting and merging square shaped regions until a homogeneity criterion is met. This technique initially splits an image into a set of square regions depending on some split criterion followed by a merging of adjacent regions based on a merge criterion (Spann and Horne, 1989). Pixel radiometry-based segmentation splits an image on the basis of the global variance of the signal within the block to be split. Merging is based on some measure of inter-region contrast.

This study, however, used "merge" algorithm applying quadtree approach to arrieve at homogeneity decision i.e. small leafs into larger ones, leafs into regions and regions into larger regions (Gorte, 1995b).

3.9.2 *Objects in satellite images*

A group of pixels with similar pixel radiometry is considered as an object in case panchromatic image segmentation. However, a spatial property of image, i.e. texture have been added with tonal value in multispectral segmentation. The resultant objects are discrete objects (i.e. unclassified individual object). Supervised classification of these objects results in object types (land cover/use types).

3.9.2 *Objects in quadtree GIS*

The term *quadtree* describe a class of hierarchical data structures whose common property is based on the principle of *recursive decomposition* of space. The most commonly used structure for holding areal raster data is the *region quadtree* (Samet, 1993), which is based on the successive subdivision of a non-homogeneous square array of pixels into four equal-sized quadrants. The decomposition is applied to each sub-array until there is homogeneity. This data model provides more compact raster representation by using a *variable-sized or resolution* grid cell. Instead of

Texture provide important characteristics for object identification from satellite images. A common characteristic of these images is that ***neighbouring pixels are highly correlated*** and there exists a spatial interaction among them. The quadtree texture segmentation is based on the decomposition of a given image into four sub-images which can be termed as the parent and children nodes in a tree. For each decomposed image, i.e. children nodes, some texture elements are computed. The decomposition process of sub-images is stopped when the corresponding texture parameters satisfy a homogeneity criterion. Once the original image is completely represented by a quadtree, the process of segmentation involves the regrouping adjacent nodes which are characterized by similar texture parameters.

3.9.4.3 *Image texture characterization*

The application of image texture to the digital analysis requires a quantitative characterization of texture. Unlike tonal measurements (i.e. digital measurements of gray levels), quantitative texture information is not directly acquired by remote sensing systems. Several methods have been used to extract quantitative textural information from digital image data in such a way that is usable for digital analysis. Different methods are excellently described in Rosenfeld (1975), Haralick (1979) and Irons and Petersen (1981). The texture measure used here is based on average gray value difference (Weszka, et al., 1976, cited in Cross *et al.*, 1988). This measure is calculated at each pixel by taking the average of the absolute grey level differences between the pixel and each of its nine neighbours.

3.10 Conclusion

The above discussion provides a sound conceptual/methodological foundation for recognizing land cover/use objects visually on satellite image and extract them automatically. The objects are defined based on what can be derived from satellite data either by manual segmentation or automatic segmentation. An understanding of image characteristics are prerequisite for object definition. Resolution of the image forms the basis in determining how small an object can be recognized and extracted for urban monitoring. It is also important to understand how we can increase the information content in an image through mullti-sensor image fusion. Automatic segmentation approach embedding in quadtree GIS and image processing system forms one of the solid foundation of object extraction.

Chapter 4

SPATIAL RESOLUTION AND ITS EFFECT IN OBJECT RECOGNITION: *Comparison of IRS-1C PAN and SPOT PAN Urban Images*

4.1 Introduction

One of the fundamental characteristics of a remotely-sensed image is spatial resolution, or the size of the area on the ground from which the measurements that comprise the image are derived (Townshend, 1980; Woodcock and Strahler, 1987). In other words, it is a measure of the area on the ground represented by each pixel. A spatial resolution of 30 meter is coarser than a spatial resolution of 5.8 meter.

It is a well recognized fact that increased resolution of satellite data clarifies shapes, sharpens boundaries and alters the textural appearance of classes (Irons *et al.*, 1985). The increase in resolution of the data results in more image characteristics (or *recognition elements* according to Avery and Berlin (1992)) for interpretation. On the basis of these facts, this chapter examines the effect of spatial resolution in recognizing land cover/use objects in urban and peri-urban satellite images. The chapter consists of two parts. The first part deals with the examination of resolution effects of IRS-1C and SPOT panchromatic datasets. The second part deals with the examination of resolution effects of panchromatic images by fusing them with the information of SPOT multispectral images. As per convention, assuming recognition of objects on an image leads to identification, the study concentrated on recognition which is always preceded by detection.

The effects of image resolution are assessed by means of visual comparison based on the general assumption that a human image interpreter is better equipped to recognize an object on image through synergistic use of different image parameters (which a computer cannot do). Another important aspect is that single band PAN image can only be classified through visual interpretation, not digitally. Added to these, most existing studies found higher classification accuracy through visual approach than digital classification (e.g. Trolier and Philipson, 1986; Gastellu-Rtchegorry, 1990).

4.2 Some Characteristics of IRS-1C and SPOT Satellite Sensors

Before examining the spatial resolution effects in object recognition from images of these two satellites, it is imperative to give a brief description of the characteristics of satellite sensors. Table 4.1 shows that IRS-1C PAN system records a single visible band with a spatial resolution of 5.8m and a swath width of 70km. This system acquires the highest spatial resolution images being offered by any civilian/commercial remote sensing satellite, presently orbiting the earth. The PAN camera of this system has off-nadir viewing capability with a revisit frequency of 5 days which can provide about 5.8mx5.8m. The pixel values are represented in image form using a range of brightness values. For instance, both IRS-1C PAN and SPOT HRV PAN can record only 64 different levels of brightness, represented by the integer values 0 to 63 inclusive. It means the radiometric sensitivity (or radiometric resolution) in both cases is low. In general, the greater the number of levels the greater the detail in the information (Mather, 1987).

The spectral limitations of the data is also a major problem in information extraction. For example, SPOT HRV sensor possesses no SWIR band near 1.6 *um*, whereas many studies of TM band 5 (1.55-1.75 *um*) have shown the unique contribution of this spectral region (Fuller *et al.*, 1989). IRS-1C LISS III possesses SWIR band in this region of 1.55-1.70 ***um*** with 70.5m spatial resolution (the data is resampled to a 23.5m resolution of other bands). Thus, IRS-1C has better spectral resolution than SPOT HRV.

4.3 Comparison of IRS-1C and SPOT PAN Images for Object Recognition

In general, we need data for the same time period if our purpose is to see how spatial resolution effects in recognizing objects on satellite image. This study, however, uses data for two different time periods as an experiment.

4.3.1 *Test dataset*

For assessing the spatial resolution effects of SPOT PAN and IRS-1C PAN two sub-scenes are used. The first sub-scene (test site A) was taken from resampled SPOT PAN and IRS-1C PAN for recognizing urban boundary. This test dataset consists of 800x1200 and 1350x1200 pixels, respectively for two PAN images. The second sub-scene (test site B) was taken from resampled SPOT PAN and IRS-1C PAN for recognizing land cover/use objects in built-up areas. This test site dataset consists of 1000x1000 pixels. The data preparation procedures are described in the methodology section of chapter one. The same type of stretching (i.e. linear contrast stretch) and convolution kernel are used for enhancing images for comparison of PAN images. Note the high frequency kernel are used only for Figure 4.2 and Figure 4.3, where it produced nice quality images in comparison to linear stretching.

4.3.2 *Comparison of PAN images for urban boundary recognition*

4.3.2.1 *Test site A and characteristics*

From rectified IRS-1C and SPOT PAN images a test site was selected based on fast expanding nature of this part of the city growth area. The site is located in the northern part of east Delhi (Planning Zone "E"). This area experienced rapid urban development from 1986 to 1996. Most of these development are took place in an illegal manner. The predominant land use is residential. The test site images are shown in Figure 4.2. The test site covers an area of approximately 4.6km x 7.0km and 7.8km x 7.0km for SPOT PAN and IRS-1C PAN, respectively.

4.3.2.2 *Boundary recognition and discussion*

East Delhi's urban physical boundary changed to a great extent from 1986 to 1996. In recognizing the boundary on satellite image of two different time, the following aspects are considered:

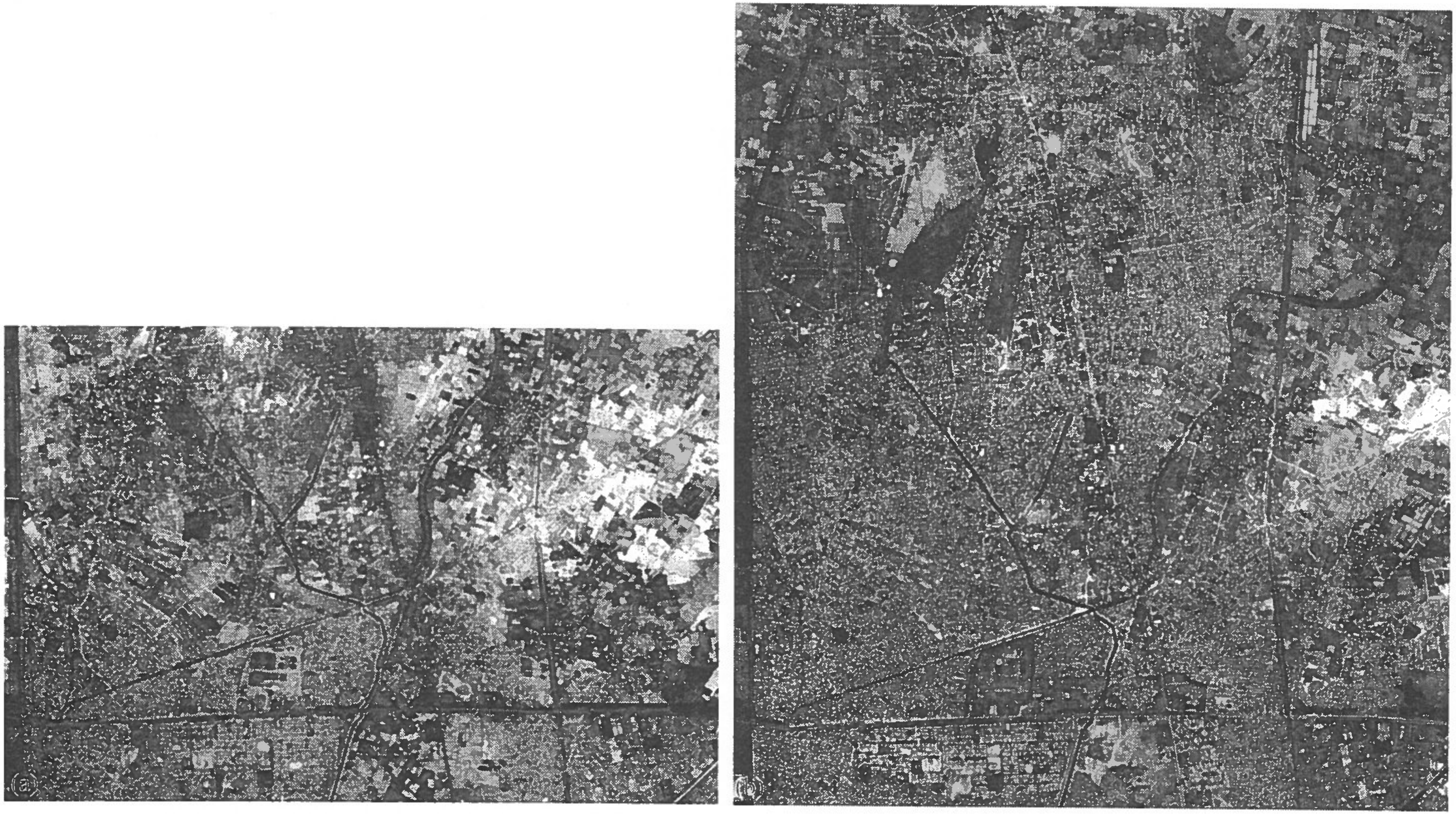


Figure 4.2 *Sub-scenes for urban boundary recognition, Test site A, east Delhi. (a) Resampled SPOT PAN image, 800x1200 pixels;(b) IRS-1C PAN image, 1350x1200 pixels [Scale 1: 58,000]*

Urban boundary on SPOT PAN image (1986) : $P_1 T_1 S_1$
Urban boundary on IRS-1C PAN image (1996): $P_2 T_2 S_1$

where,

S_1 is the subject, i.e. urban boundary
P_1 & P_2 means place, i.e. city growth area, and
T_1 & T_2 stands for time.

The logic used here is that the city growth area (not the place) shifted over time through structural change, but our subject remained the same (i.e. boundary recognition). The Table 4.2 shows the cover characteristics of land based on different image parameters and the broad land cover object classes used to guide the boundary recognition.

Table 4.2 *Land cover/use characteristics and object classes for boundary recognition at the city growth areas.*

Land cover/use characteristics	Object class
1. Land covered by residential, industrial and other building roofs and associated road/railway network	Built-up land
2. Land covered by vegetation, open cultivated field, water features, and other open spaces	Non built-up land
3. Land covered by scattered building roofs, unsurfaced roads, construction materials and other under construction features.	Land in transition

We first consider Figure 4.2. If we look at the images, immediately it gives us an impression that the right side image (i.e. IRS-1C PAN) is sharper and has general contrast than the left side image (SPOT PAN). Using different image parameters, particularly tone, texture, pattern, association and shape synergistically, we can delineate a boundary between the two entities- built-up and non built-up in IRS-1C PAN image at even 1: 58, 000 scale. On the other hand, SPOT PAN image is blurred and the contrast between built-up and non-built-up entities is less. A boundary delineation is not possible.

If we look at the larger scale (1: 30, 000) sample images in Figure 4.3 (taken from Figure 4.2) we still get the same impression. Using the method of idealization, in IRS-1C PAN image (right side images) a dividing line can be drawn between built-up and non-built-up areas. Image texture is finer, tone is clear, patterns in the transition zone is quite clear and the shape of the built-up area is also quite clear. In areas where there is no transition zone, a clear boundary can be delineated. The idealization technique can be used to delineate the boundary at the transition zone. On the other hand, in SPOT PAN image a boundary delineation is not possible even at this larger scale.

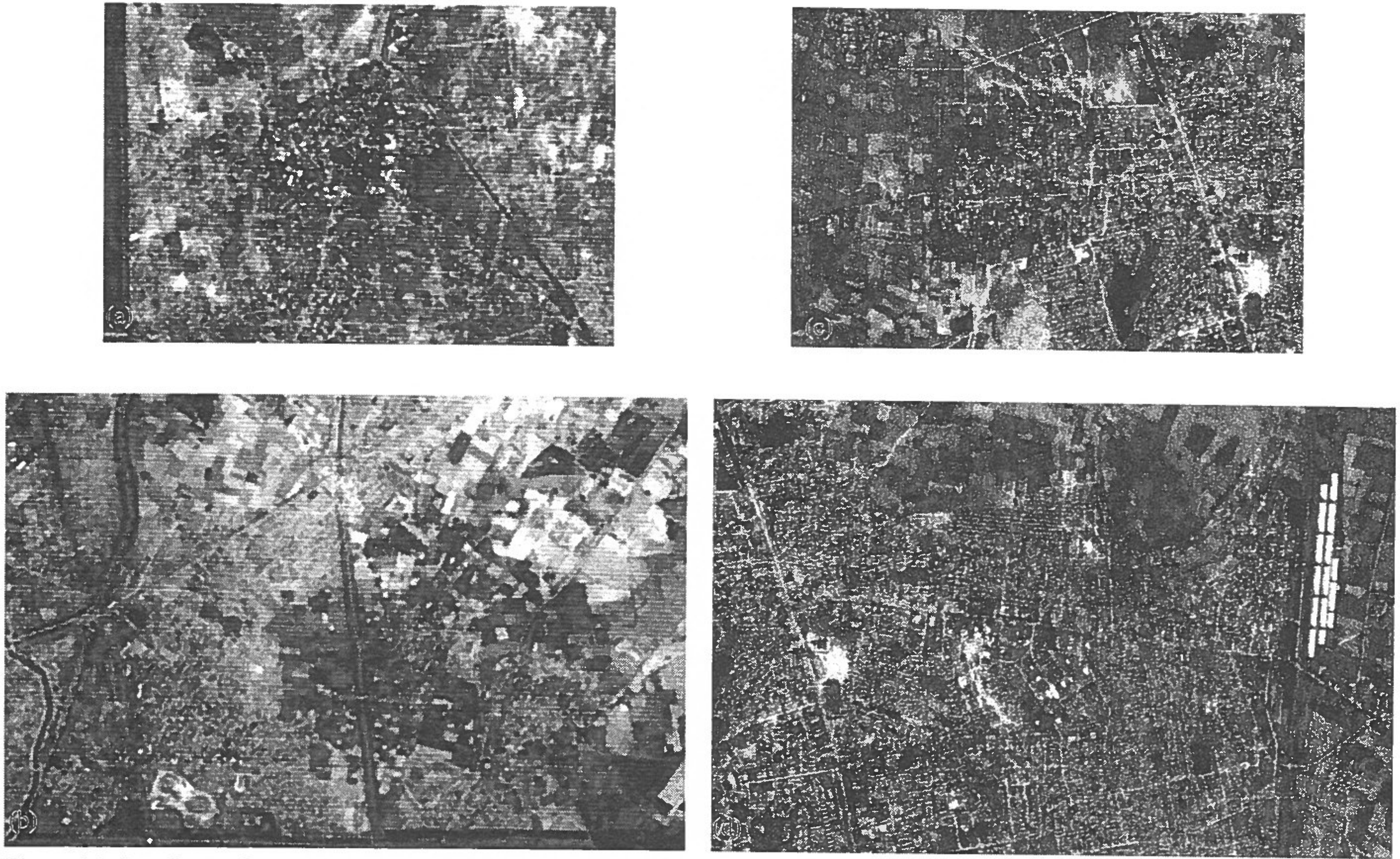


Figure 4.3 *Sample sets for comparing SPOT PAN and IRS-1C PAN images for urban boundary recognition, east Delhi. Left side images: SPOT PAN products; Right side images: IRS-1C PAN products. [(a) & (c) 300x450 pixels, (b) & (d) 400x600 pixels; Scale 1: 30, 000]*

4.3.3 *Comparison of PAN images for inner city land cover/use object recognition*

4.3.3.1 *Test site B and characteristics*

This test site is located at the centre of east Delhi (i.e. Planning zone "E"). It covers an area of 5.8km x 5.8km. This part of the city is characterized by very high density of houses and consequently very high population density. The western half of the site is developed in an unplanned/haphazard manner whereas eastern half is better planned. Unlike the western part, the eastern part still has some open/ vacant space. Industrial land use also occupy some portion of eastern site. The test site images are given in Figure 4.4.

4.3.3.2 *Object recognition and discussion*

The sample areas are selected such that on both images they conform more or less to same characteristics in terms cover features (e.g. densely built-up area), as the images are for two different time periods.

At scale 1: 52, 000 of the IRS-1C PAN image (Figure 4.4a), certain broad land cover classes like high density unplanned residential, planned residential, apartment cluster, industrial site, vacant space can be delineated without much difficulty. Image is quite sharp. On the other hand, SPOT PAN image (Figure 4.4b) is blurred. Discrimination of land cover type is not possible, even with just two classes- built-up and non-built-up.

If we look at the images of Figure 4.5, the first clear distinction is image sharpness. Right side images (IRS-1C PAN) are sharper and gives more information than the left side SPOT PAN images. A specific thrust (i.e. object type) is given while comparing each sample sets. Comparison of image (4.5a) with image (4.5d) shows that in image (4.5d) in the top right side an area with very high density houses can be recognized as this is the very low income people's residential area through its distinct texture feature and linear pattern than the surrounding areas. In image (4.5a), the area shows distinct tone but recognition is not possible. Image (4.5b) and (4.5e) are more similar in their structure as the area is densely built-up on both the images. The difference is that image (4.5e) is sharper and a clear densely built-up area is visible. In image (4.5f), planned residential areas can be delineated with confidence, whereas in image (4.5c) it is not possible. Between two linear features (road and railway line) in image (4.5g & 4.5i) the area is covered by industrial buildings. Although image (4.5i) is sharper than image (4.5g) nothing more can be recognized. In image (4.5j), cluster of apartment buildings can be clearly delineated, industrial sites are too. In image (4.5h), the area was vacant at the time when the image was acquired and no comparison can be made. In IRS-1C PAN image (4.5l), linear feature (e.g. street network) is more clear than SPOT PAN image (4.5k). Street networks can be better delineated in IRS-1C PAN image than SPOT PAN image even from such congested residential areas.

Figure 4.4 *Sub-scenes for land cover/use object recognition in built-up areas, Test site B, east Delhi. (a) Resampled SPOT PAN image; (b) IRS-1C PAN image [1000x1000 pixels, Scale 1: 52,000]*

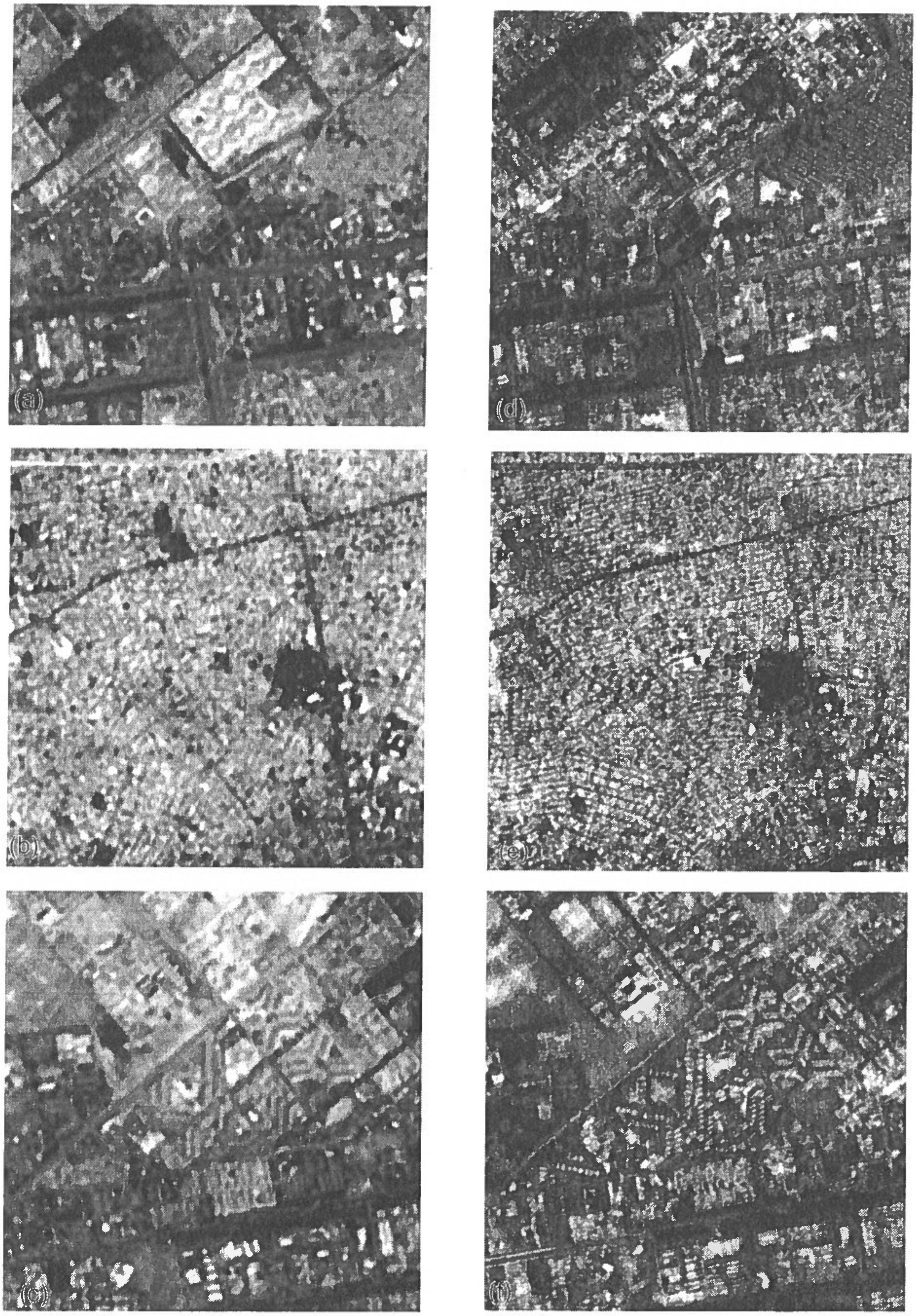


Figure 4.5 *Selected sample sets for comparing SPOT PAN and IRS-1C PAN in recognizing land cover/use objects in built-up areas, east Delhi. Left side images: SPOT PAN; Right side images: IRS-1C PAN [300x300 pixels, Scale 1: 24,000]* Contd...

Figure 4.5 *Selected samples for comparing SPOT PAN and IRS-1C PAN images in recognizing land cover/use objects in built-up areas, east Delhi. Left side images: SPOT PAN; Right side images: IRS-1C PAN [(g), (h), (i) & (j) 300x400 pixels, Scale 1: 28,000; (k) & (l) 200x200 pixels, Scale 1: 18,000]*

4.4 Comparison of IRS-1C and SPOT PAN Images through Multi-sensor Image Fusion

The main purpose of merging multispectral and panchromatic image is to increase the information content on the image and thereby interpretability. A great deal of additional information can be extracted from multispectral imagery even without merging, in an appropriate combination of data from different wavelength regions, compared to the amount that can be extracted from the same area using panchromatic imagery acquired at the same time (Star and Estes, 1990). Fusion of high resolution panchromatic data with multi-spectral data increases the discrimination ability of objects (Ehlers *et al.*, 1990; Raghavswamy *et al.*, 1996).

4.4.1 *Test dataset*

For assessing the spatial resolution effects of SPOT PAN and IRS-1C PAN through image fusion, three sets of data was taken- SPOT XS resampled to IRS-1C PAN, SPOT PAN resampled to IRS-1C PAN and IRS-1C PAN. Dataset consists of 900x875 pixels. The detailed procedures of data preparation are described in the methodology section of chapter one.

For this exercise, SPOT multispectral images were merged separately with IRS-1C PAN and SPOT PAN images assuming little change in land cover/use in the area. The test site selected is nearly built-up for all the three time period images.

4.4.2 *Test site and characteristics*

This test site area is located in north-west Delhi (approximately 5km west of Delhi railway station). The test site covers an area of approximately 5.2km x 5.0km. Residential and industrial land use are predominant in this area. Most part of the residential area is developed in an unplanned manner and hence characterized by high density of houses. Commercial, institutional land use are distributed within residential areas. Some portion of the area is covered by green and vacant space. The test site images are given in Appendix IX.

4.4.3 *Object recognition and discussion*

IRS-1C PAN+SPOT XS fusion produced better quality image than fusing SPOT PAN+XS in terms of its visual interpretability (Figure 4.6). The image (4.6b) shows that the image is sharper, clear information content in recognizing and delineating land cover objects (e.g. low income residential area) than image (4.6a). This can be clearly seen from the Figure 4.7. From left to right, we can see a distinct, clear-cut increase of information content in terms of clarity and sharpness. Land cover objects can be delineated with greater confidence from IRS-1C PAN merged image than SPOT PAN merged image which is blur and edges of objects (e.g. a low income people's residential area) are not sharp. A clearer picture can be seen from the Figure 4.8. The three sample sites clearly depicts the story. In image (4.8d), the object boundary (e.g. a vacant plot inside residential area or the residential area itself) can be more clearly delineated than image (4.8a). A low income people's residential area as in the centre of the image (4.8b & 4.8e) can be recognized in image (4.8e) through its distinct tone than surrounding areas. In case of image (4.8b), it shows no distinction from the surroundings. Linear features (e.g. a drain) can be more clearly delineated in image (4.8f) in comparison to image (4.8c). A narrow bridge over the drain can be recognized

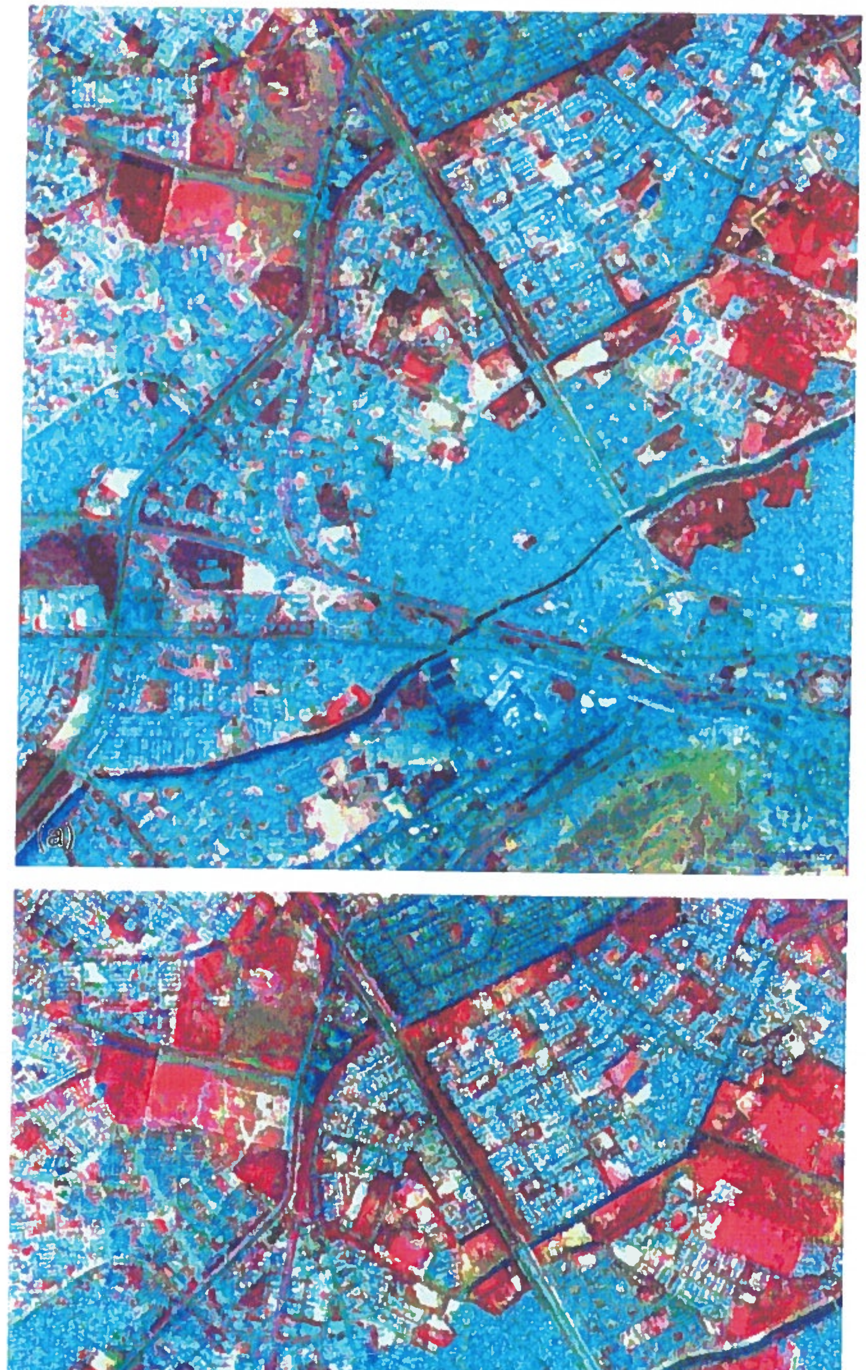


Figure 4.6 *Results of multi-sensor image fusion. (a) Image produced by merging SPOT PAN with SPOT multispectral images; (b) Image produced by merging IRS-1C PAN with SPOT multispectral images [900x875 pixels, Scale 1: 46,000].*

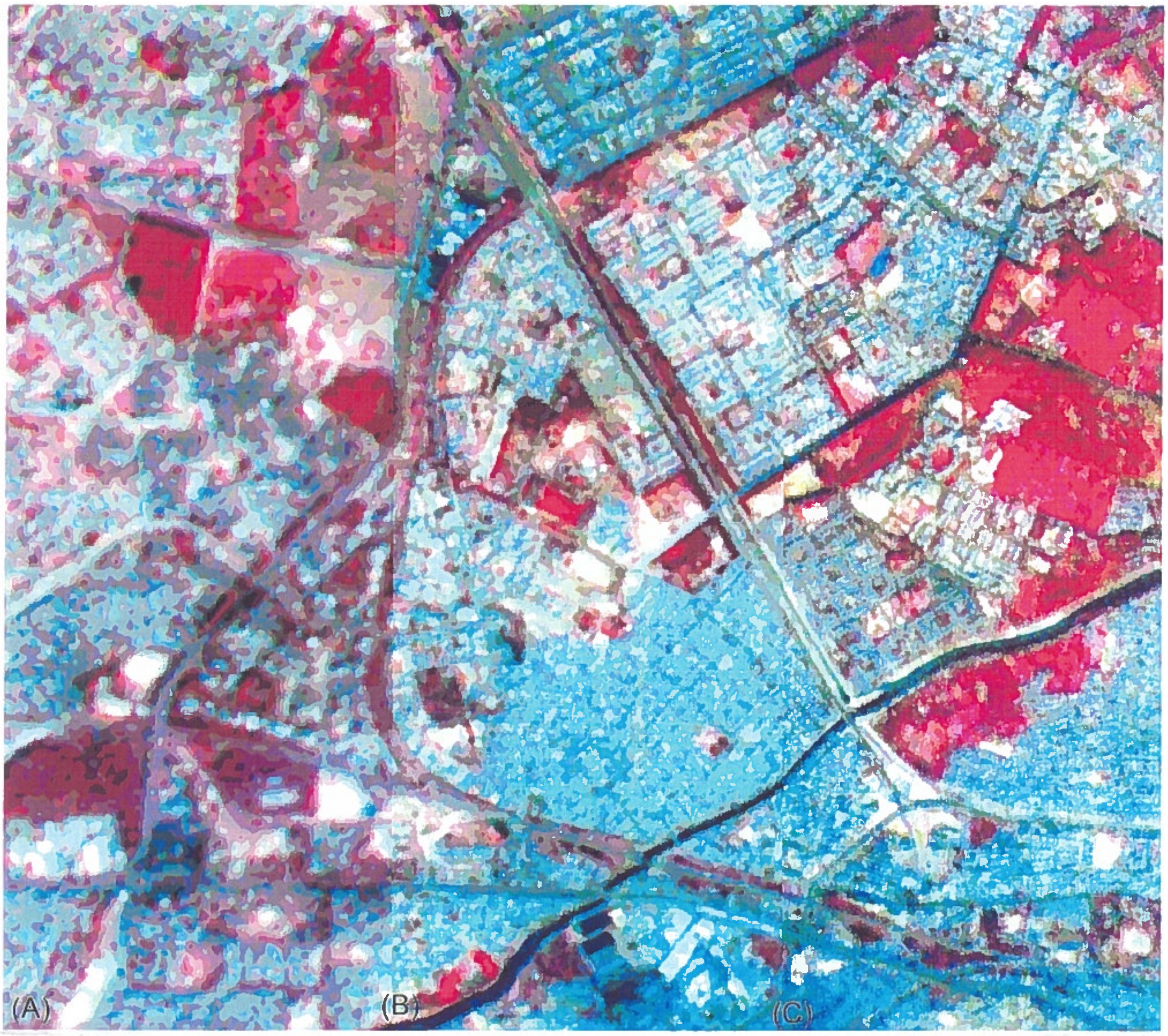


Figure 4.7 *Improving information content (a) SPOT colour composite; (b) SPOT XS + PAN merged imags; (c) SPOT XS + IRS-1C PAN merged image [768x875 pixels, Scale 1: 30, 000]*

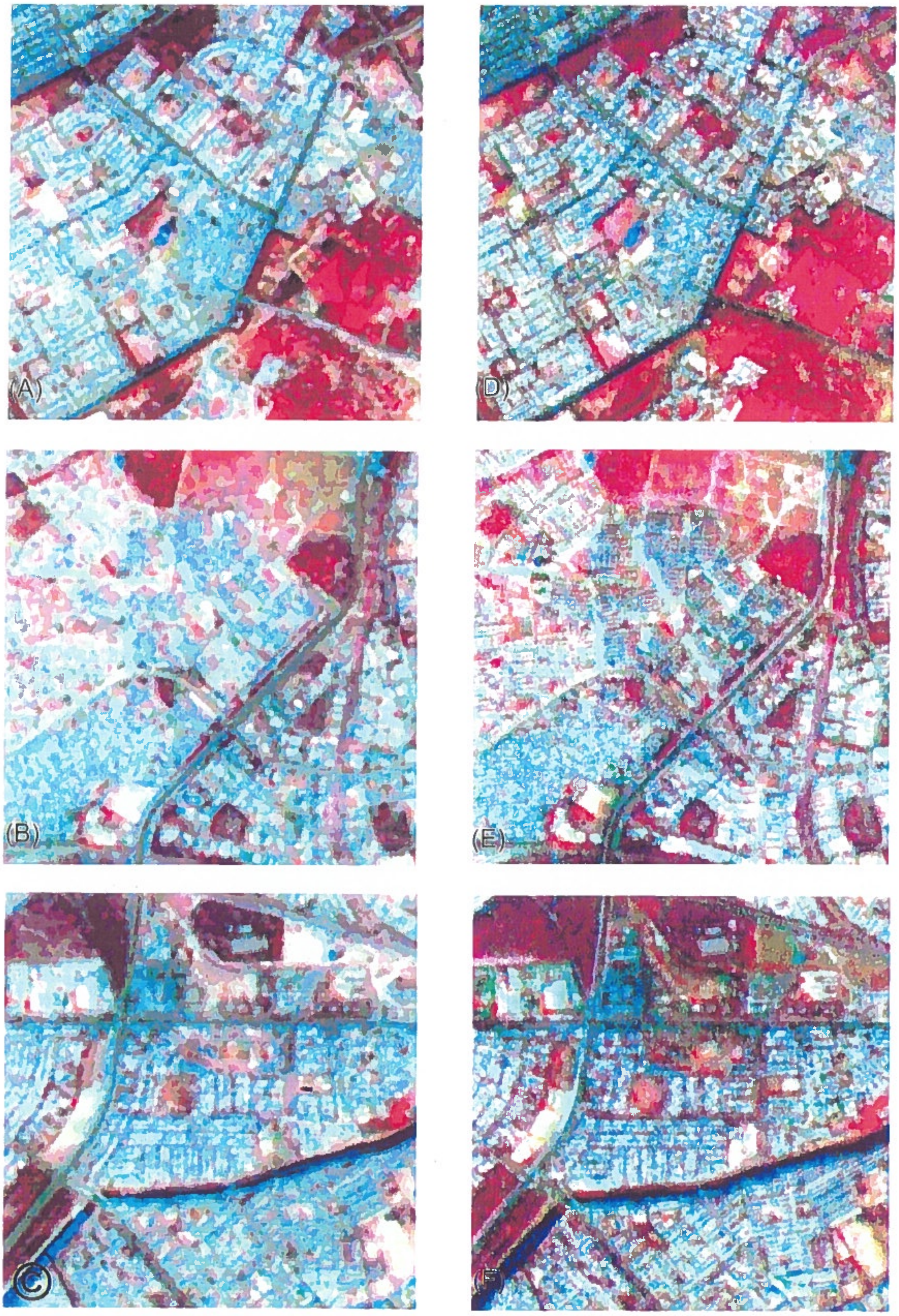


Figure 4.8 *Selected samples for comparing SPOT PAN and IRS-1C PAN images in object recognition through image fusion. Left side images: SPOT XS + PAN merged products; Right side images: SPOT XS + IRS-1C PAN merged products[350x350 pixels, Scale 1: 30, 000]*

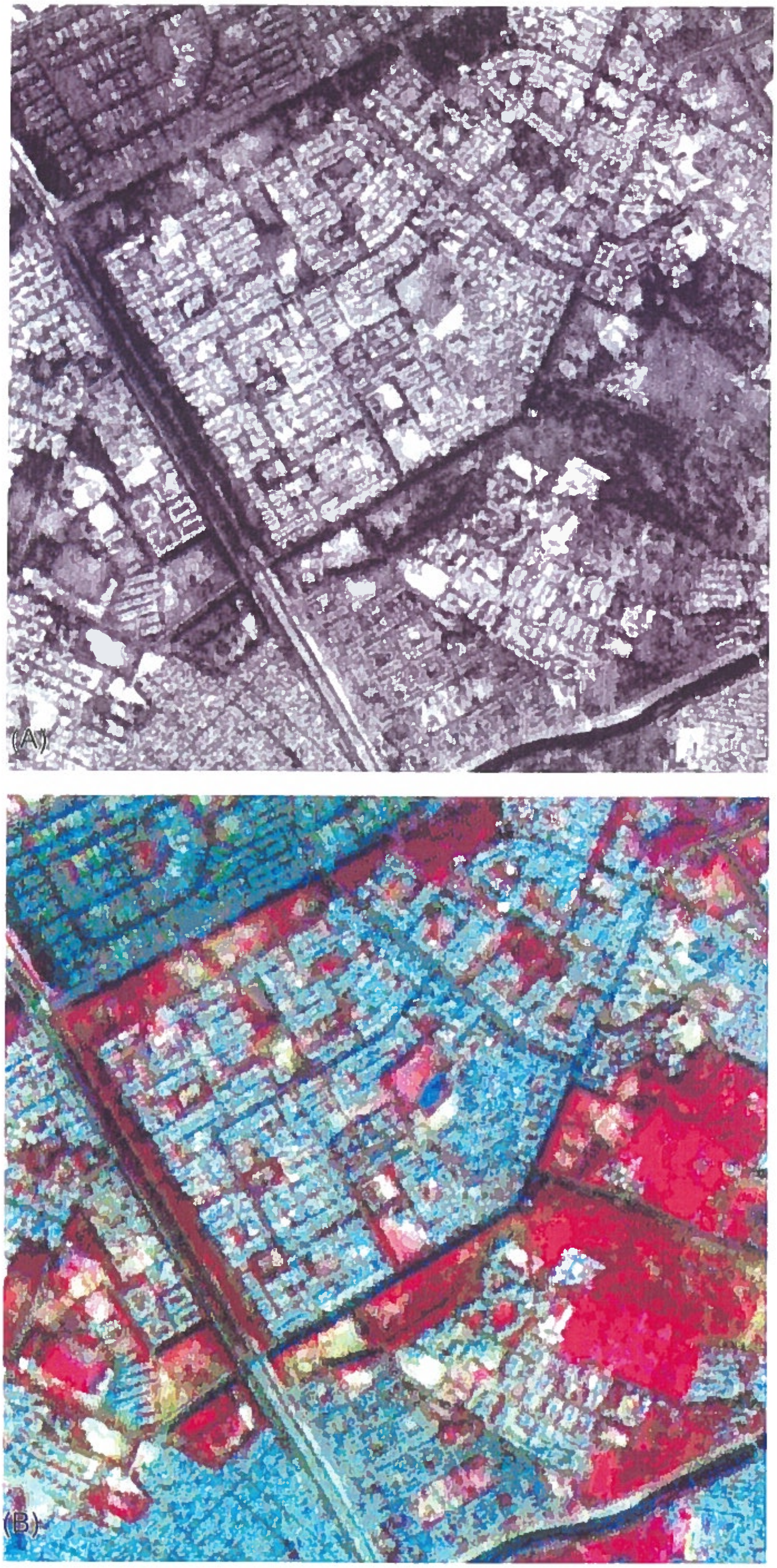


Figure 4.10 *Advantage of image fusion over PAN image in object recognition. (A) IRS-1C PAN image; (b) Merged IRS-1C PAN and SPOT XS image [500x500 pixels. Scale 1: 25. 000]*

in image (4.8f). These are few examples of what can be recognized in an IRS-1C PAN merged image and what cannot be recognized in SPOT PAN merged image. However, there are some objects which can not be recognized in IRS-1C PAN merged image as is the case of SPOT PAN merged image (e.g. institutional area).

The advantage of using fused images over PAN image can be seen from Figure 4.9. The fused image (4.9b) immediately gives us an impression of different cover type objects. The vacant plots inside the built-up area can more reliably be delineated unlike in only PAN image. The boundary of objects (e.g. an unplanned residential area) can be delineated more accurately in merged image. The merged image is like a map.

4.5 Conclusion

Spatial resolution of remote sensing data plays an important role in improving the quality of information extracted from these data. This exercise clearly implies that increased resolution of IRS-1C PAN gives better clarity of edges, shapes in comparison to SPOT PAN image. The fine textural appearance in IRS-1C PAN image clearly shows the built-up areas from non built-up areas and the land that has been cleared for construction or urban expansion. The importance of boundary recognition, and hence, identification (or delineation) is that it provides information for measuring the extent and rate of urban expansion. Also, we can show the direction of city growth. IRS-1C PAN has preference over SPOT PAN image in recognizing land cover/use objects in built-up areas. However, for some cases it shows similarity. Detailed land cover/use mapping from SPOT PAN image is difficult in the case of Delhi because many pixels of the original data are "mixed pixels", i.e. pixels containing more than one cover types. Although IRS-1C PAN is not sufficient enough to discriminate detail cover types, still it has many more advantages over SPOT PAN in terms its sharpness and information content.

A substantial improvement in interpretability can be achieved through image fusion over the original multispectral data or PAN data. Visual evaluation of PAN image through image fusion indicates that IRS-1C PAN merged image provides more and better quality information than SPOT PAN merged image. Merged IRS-1C PAN image produces map-like output and hence improved information quality than a single IRS-1C PAN image.

Chapter 5

SPATIAL OBJECT EXTRACTION AND CLASSIFICATION
A Quadtree-based GIS/Images Processing Approach

5.1 Introduction
The satellite images of the Earth and our reaction to them are qualitative. But from these images we can quantitatively characterise our surface cover and provide the basis for a scientific understanding of the system (NASA, 1988). For example, the understanding of an urban system will enable us to predict the future state of the environment and how it will respond to natural events and human activities. Automatic or computer-supported technique is an appropriate approach (but not substitute to human visual system) for understanding a system through fast generation of spatial information.

Spatial object (here land cover/use object) extraction from satellite data is a complex, interpreter-dependent process involving both objective and subjective criteria. Manual segmentation of image (either analogue image or on-screen image interpretation) involves more subjectivity and less objectivity in information extraction. Although automatic or semi-automatic object extraction is also analyst-dependent, the main difference is the more uniform application of rules for information extraction across an image or series of images (Duggin and Robinove, 1990). Image segmentation method embedding in image processing systems (IPS), quadtree GIS and knowledge-based systems (KBS) is a recent research perspective in object-based (or segment-based) geoinformation generation from space. The object-based information while combined with other spatially referenced data within an integrated GIS will generate further value-added products.

Since the human brain automatically takes into account texture, structure, context, experience, and 'common sense' in the analysis of the reflectance data, the method is always superior in comparison to computer analysis. This study is an endeavour to automatic extraction of spatial objects through image segmentation method incorporating in quadtree GIS and image processing system. The chapter consists of two parts. The first part deals with the extraction of objects from SPOT PAN and IRS-1C PAN images based on spectral properties of image. The second part deals with object extraction from merged (SPOT XS+IRS-1C PAN) images based on combined spectral/spatial (i.e. tone/texture) properties.

5.2 Spatial Object Extraction from PAN Images and Classification
The purpose of this part is to extract spatial objects from satellite images and to examine the coincidence of objects with the terrain feature.

5.2.1 *Test dataset*
For extracting spatial objects from satellite data, two sets of data for the same area were chosen. The first set is from resampled SPOT PAN image and the second set from IRS-1C

Figure 5.1 *IRS-1C PAN image of the test site, east Delhi, used for segmentation. [1000x1000 pixels, Scale 1: 36,000]*

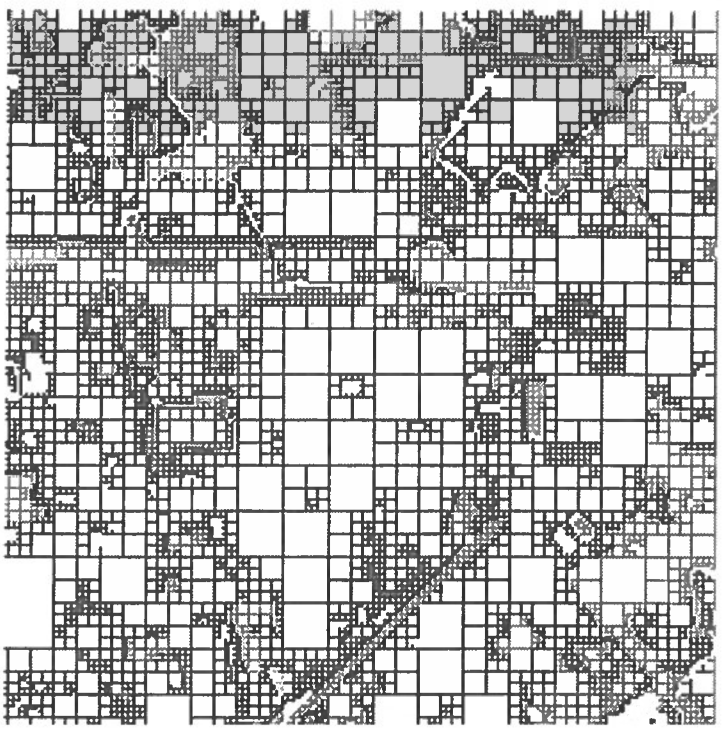


Figure 5.2 *Quadtree structure of part of the IRS-1C PAN image of the test site.*

band image for deriving samples. The Figure 5.4 also shows that only a few image derived segments coincided with the map derived segments. From each land use class 1000 pixels are selected as samples. The sample representation for the area is 2.25 percent. The Figure 5.5 shows the land use distribution over the area from which samples are taken. Ten major land cover/use types can be defined for the area. Table 5.1 lists the original 10 classes defined for classifying segmented image, followed by one level of aggregation with 6 classes. These classes were determined based on the needs of the urban planning agencies and the discriminating

Table 5.1 *Land cover/use object classes used in the classification of segmented panchromatic image.*

Code Land cover/use class [Abbrev.]	Code/Reclass name [Recode]
1. Commercial [Com]	1, 5, 6, 7, 8: Residential [1]
2. Industrial [Ind]	2: Industrial [2]
3. Institutional [Ins]	3: Institutional [3]
4. Green space [Grn]	4: Green space [4]
5. Residential high density [Rhd]	9: Vacant space [5]
6. Residential low density [Rld]	10: Water feature [6]
7. Under construction [Ucn]	
8. Utilities [Utl]	
9. Vacant space [Vac]	
10. Water feature [Wtr]	

capability of the segmented panchromatic image. Existing land use map was used in defining the classes. Classification results of the segmented image at two different levels (10 and 6 classes) are shown in Figure 5.6. The classification accuracies are shown in Table 5.2 and Table 5.3.

5.2.4 *Results and discussion*

The results of the classification of segmented image for the chosen area shows very poor classification accuracies. The overall classification accuracy is less than 30 percent at the 10 land cover/use class level (Table 5.2). A large number of pixels remained as unclassified (over 30 percent). The reliability of the classified 29.58% pixels is nearly 88%. Note that, the classification result of water feature is just 5%, which is unimaginable in case of remote sensing image classification (normally water features produce high classification accuracy because of high reflectance character). On the other hand, land under construction produces classification accuracy of 51%, followed by institutional class with 39%. After aggregating 10 classes into 6, the classification accuracy just increased by approximately 4 percent (Table 5.3). The reliability of the classified 33.81% pixels is also increased by approximately 4% (i.e. 88% to 92%). Now, all built-up areas except industrial/institutional class results in classification accuracy of 37%.

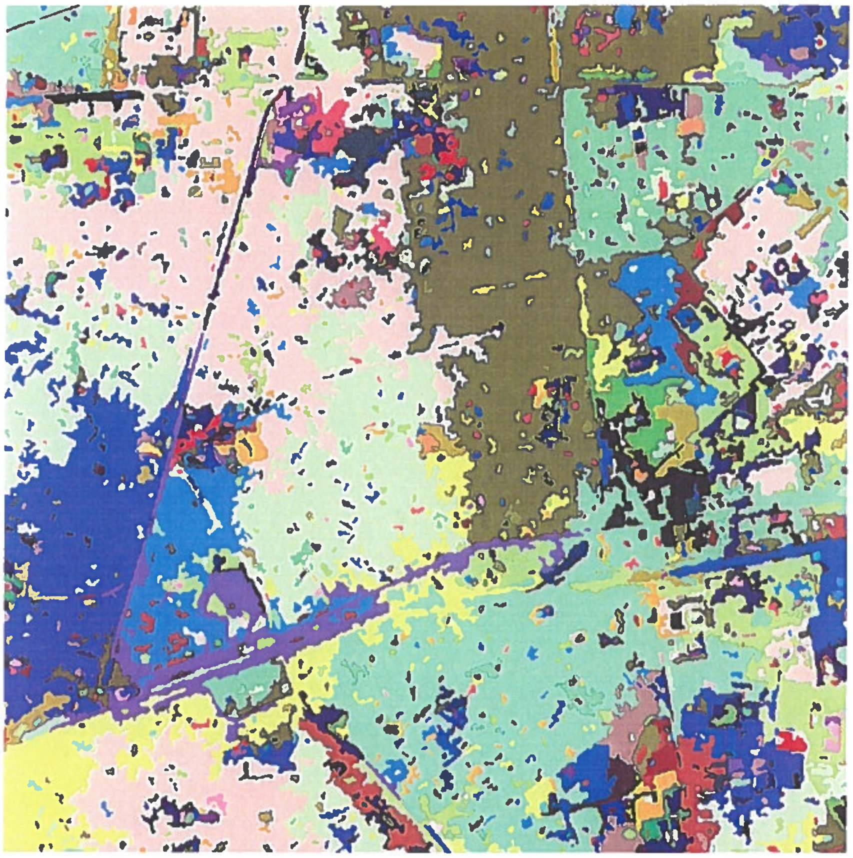


Figure 5.3 *Result of IRS-1C PAN image segmentation, east Delhi [Scale 1: 52, 000]*

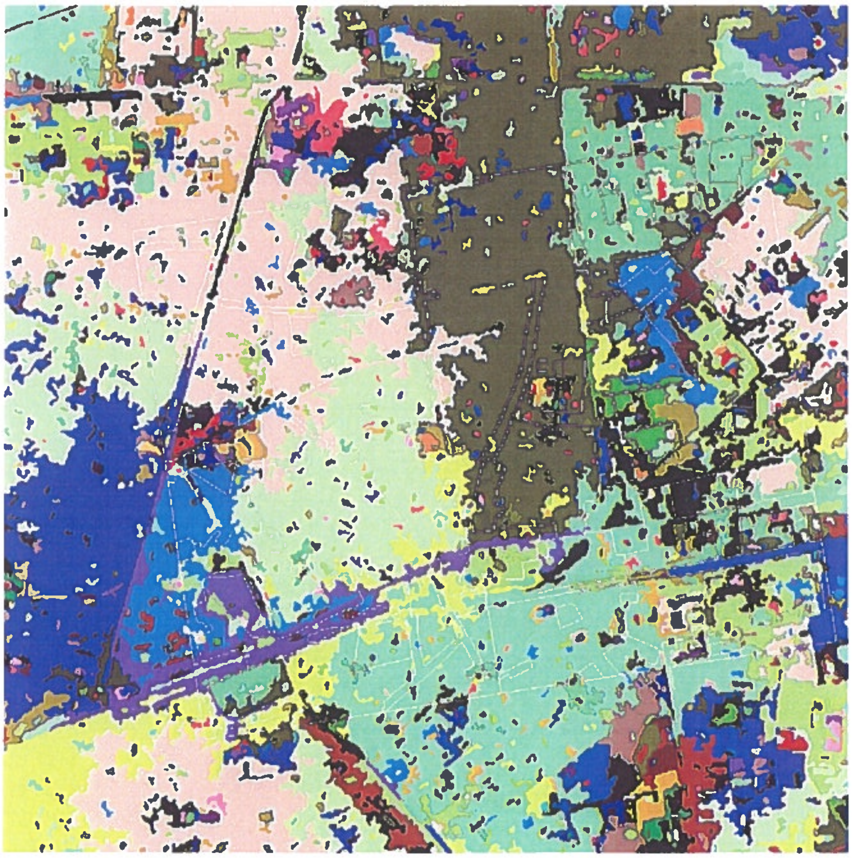


Figure 5.4 *Comparison of spatial coincidence between image derived segments and segments derived from the existing map, east Delhi.*

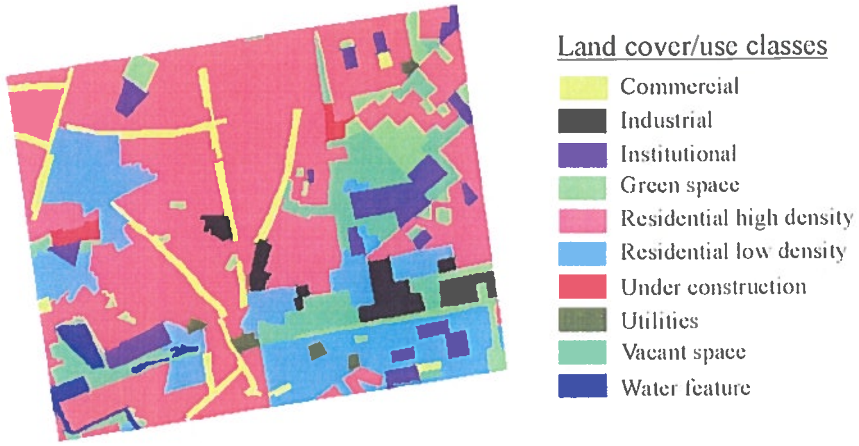


Figure 5.5 *Land use map used for extracting training samples [Scale 1: 72, 500].*

(a) (b)

Figure 5.6 *Results of the classification of segmented IRS-1C PAN image. (a) with 10 classes, (b) with 6 classes.* (Legend as above).

Table 5.2 *Confusion matrix of segment-based classification (10 classes)*

	Classified results											
	Com	Ind	Ins	Grn	Rhd	Rld	Ucn	Utl	Vac	Wtr	Uncl	Acc
Com	1688	0	0	0	3228	77	0	0	1	0	15335	0.08
Ind	0	4961	0	0	518	288	0	0	111	0	8886	0.34
Ins	0	0	10079	10	669	592	48	0	167	0	14059	0.39
Grn	0	26	63	2731	1606	375	0	0	3	0	18481	0.12
Rhd	357	29	1090	82	82404	314	263	28	527	4	153875	0.34
Rld	12	0	662	10	3027	20550	79	29	289	0	52889	0.27
Ucn	0	0	0	0	27	0	1864	0	425	0	1322	0.51
Utl	0	0	0	0	180	37	0	321	0	0	2514	0.11
Vac	0	299	384	7	570	1331	110	8	10469	41	30379	0.24
Wtr	0	0	5	0	224	10	0	0	292	329	6006	0.05
Rel	0.82	0.93	0.82	0.96	0.89	0.87	0.79	0.83	0.85	0.88		

average accuracy = 22.23 %
average reliability = 86.51 %

overall accuracy = 29.58 %
overall reliability = 87.96 %

Table 5.3 *Confusion matrix of segment-based classification (6 classes)*

	Classified results							
	Res	Ind	Ins	Grn	Vac	Wtr	Uncl	Acc
Res	126193	29	1752	92	1242	4	214227	0.37
Ind	833	4961	0	0	111	0	8859	0.34
Ins	1546	0	10079	10	167	0	13822	0.39
Grn	1981	26	63	2731	3	0	18481	0.12
Vac	3755	299	384	7	10469	41	28643	0.24
Wtr	850	0	5	0	292	329	5390	0.05
Rel	0.93	0.93	0.82	0.96	0.85	0.88		

average accuracy = 25.03 %
average reliability = 89.69 %

overall accuracy = 33.81 %
overall reliability = 91.98 %

Rel= Reliability; Uncl= Unclassified; Acc= Accuracy

The HSI transformation separates the spatial information (intensity channel) and the spectral information (hue and saturation channels) from a standard RGB (stretched) image. This ***substitutional*** approach transforms three channels from the ***RGB into the HSI*** colour space. Prior to this, the intensity channel was replaced by IRS-1C PAN data. This step was followed by texture transformation. Based on average grey value difference, at each position *(x,y)* we get the texture measure by averaging them using 9-by-9 window. This transformation separates the texture feature from the intensity channel and created a texture channel or image (Figure 5.7). The corollary is that if the attribute values in this neighbourhood are all similar, the standard deviation is small, then this neighbourhood will have low texture or low variability. On the other hand, where there are many different attributes in a neighbourhood, we will have high texture. An average filter with 9-by-9 window size was used for smoothing the image. This step was followed by RGB transformation. In this step, the intensity channel was first replaced by texture channel, and then hue, saturation and texture channels are transformed back to the RGB colour space.

After RGB transformation, the three-band composite image was segmented with a threshold value of 10 and it results in 5570 segments of varying size (from 787500 pixels). To combine the segment quadtree with the attribute table, map calculation was performed for individual segmented image. Later these individual images are rasterized to be used in the classification stage. The Figure 5.8 shows the composite segmented image.

5.3.3.2 *Object (or segment) classification*

The aim of object-based classification is to derive land cover/use information from fused SPOT XS+IRS-1C PAN data with more certainty than traditional pixel-based classification. Supervised training method was adopted for classification. Selection of training pixels was aided by the use of existing generalised land use map at 1:12,500 scale of 1996 (surveyed around 1992/93). About 100 pixels (contiguous group of pixels) were selected for each class to obtain the training statistics. This was relatively sufficient number, as Congalton (1991) suggests that a good rule of thumb is to collect a minimum of 50 samples for each land-cover class in the error matrix. The Table 5.4 lists the original 7 land cover/use object classes used for this purpose, followed by two levels of aggregation with 5 and 4 classes respectively for aggregation level 1 and 2. These classes were determined based on planning needs and the discriminating capability of the segmented merged multispectral/panchromatic image. Classification of the segmented image using three different levels of classes (7, 5, and 4) results in classified land cover/use maps. They are shown in Figure 5.9, Figure 5.10 and Figure 5.11 respectively.

Figure 5.7 *Grey tone image of IRS-1C PAN image transforms*

Table 5.4 *Land cover/use object classes used in the classification of segmented fused images*

Land cover/use object class (Code)	Code/Reclass name (aggregation level 1)	Code/Reclass name (aggregation level 2)
Residential high density (1)	1, 2, 4: Residential	1,2, 3, 4: Built-up
Residential low density (2)	3: Industrial	5: Vacant space
Industrial (3)	5. Vacant space	6: Green space
Institutional (4)	6: Green space	7: Water feature
Vacant space (5)	7: Water feature	
Green space (6)		
Water feature (7)		

5.3.4 *Results and discussion*

The results using texture as an aid to image segmentation shows that texture does indeed help in producing better land cover/use objects (and consequently better information) in urban areas. Texture alone, however, cannot be used in defining land cover/use object. In this application, texture information is used as secondary to spectral information. The tone-texture based segmentation of multi-sensor, multi-spectral image results in quite nice segments. This was examined by collating segmented image with the existing land use map of 1996 at 1:12,500 scale. Many segments can reliably be represent as per terrain object (e.g. industrial segment, green space segment, etc.). This is, however, possible while we collate with the map. At the first level classification of segmented image, many segments are misclassified. For

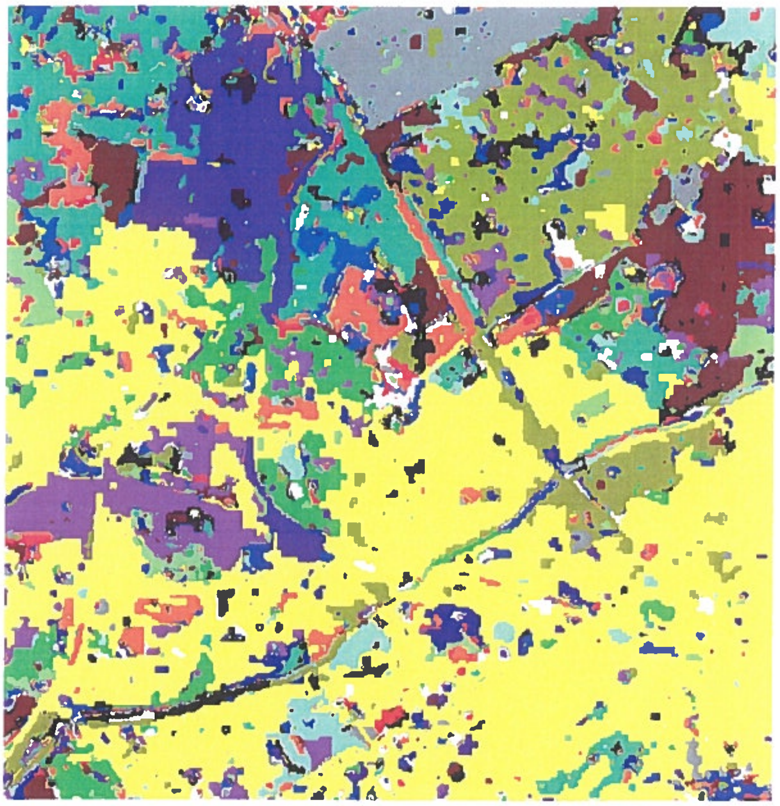


Figure 5.8 *Result of the segmentation of multi-sensor/multi-spectral fused image*

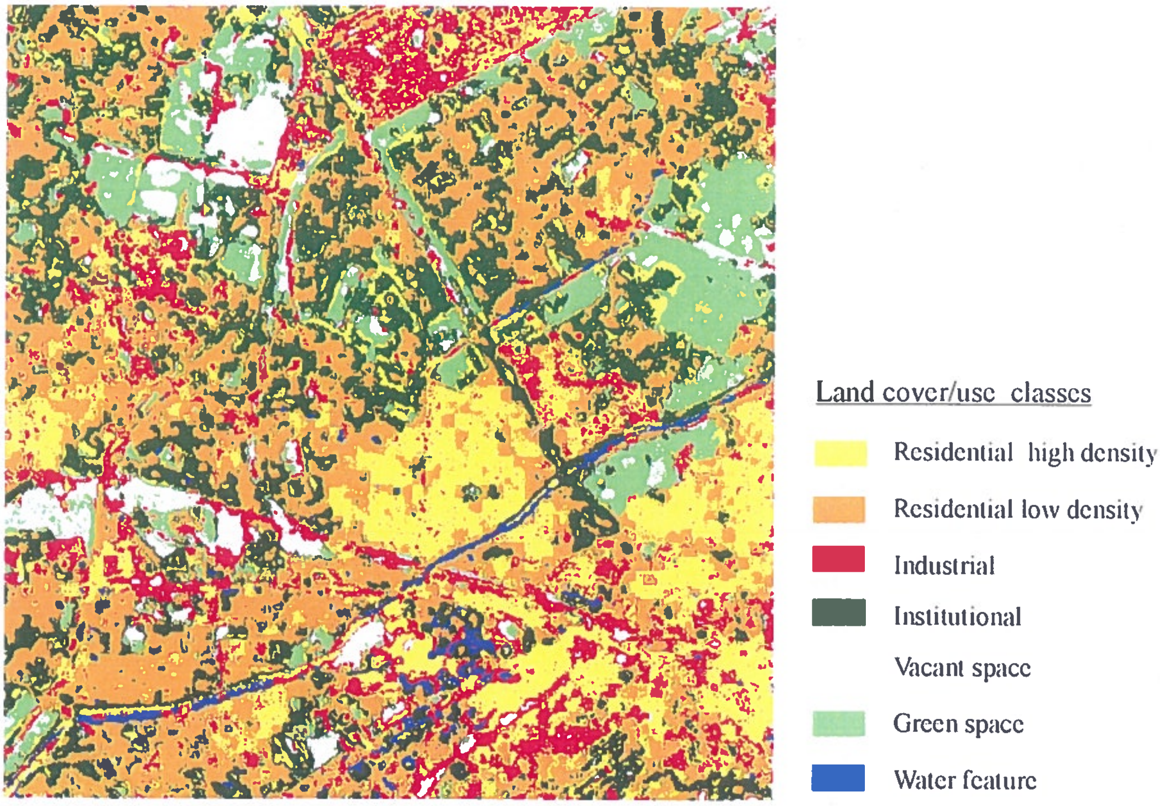


Figure 5.9 *Result of the classification of segmented fused image (7 classes) [Scale 1: 50, 000]*

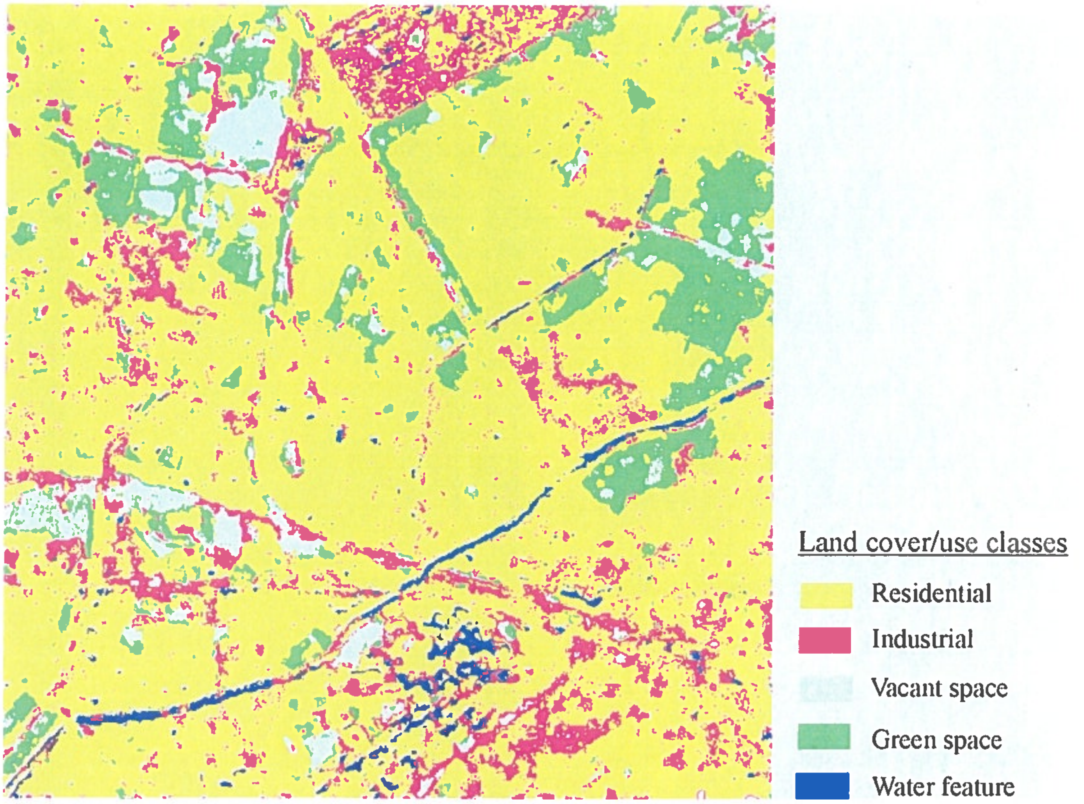


Figure 5.10 *Result of the classification of segmented fused image (5 classes)*

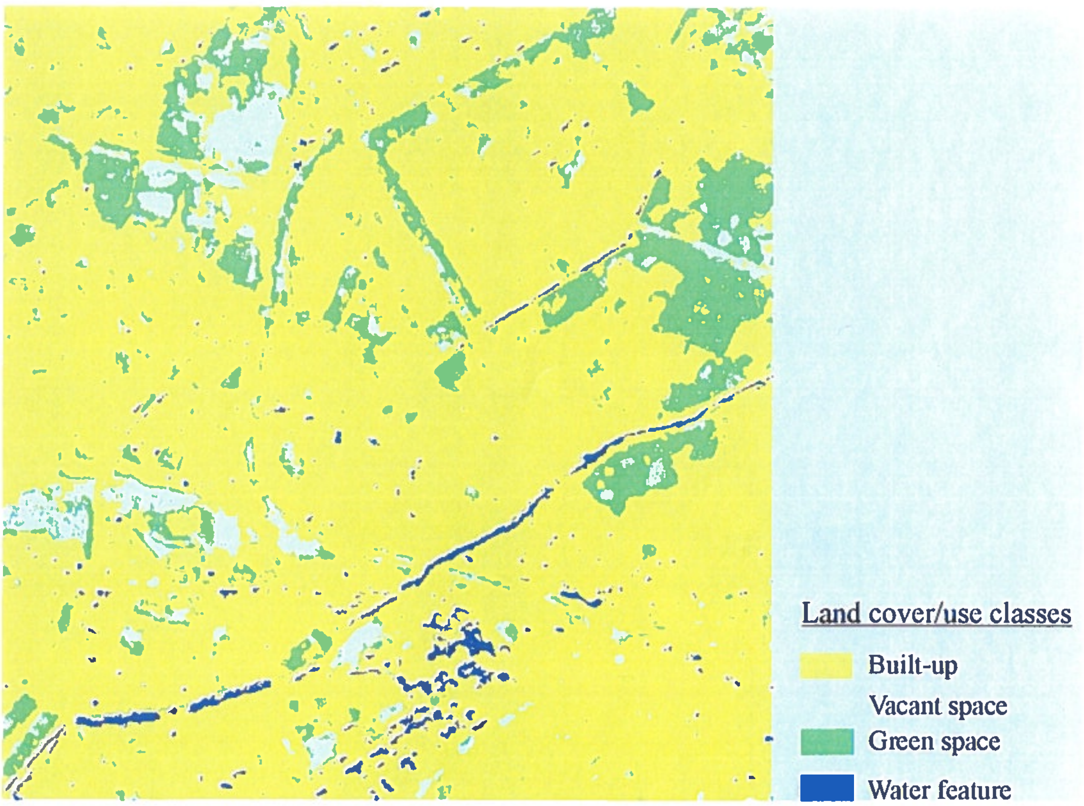


Figure 5.11 *Result of the classification of segmented fused image (4 classes)*

instance, institutional land use class, see Figure 5.9). Through out the image, a large number segments are classified as institutional. This is, however, obvious. From satellite data we cannot distinguish institutional land use from residential/commercial land use. It is also not possible to distinguish between high and low density residential land use classes. After aggregating all built-up classes together into one class other than industrial, the result improved fantastically (Figure 5.10). However, some residential areas are classified as industrial and some industrial areas are classified as residential. While putting all built-up classes including industrial into one class, the result produced could be termed as excellent. Built-up, green space, vacant space and water features can be distinguished with high confidence (Figure 5.11). The sample classification accuracy at all three levels was very high (over 95%).

5.4 Conclusions

The above exercise examines the applicability of automatic image segmentation and segment-based classification. The segmentation process involves a merge algorithm and a quadtree data structure. In PAN image experiment, both the segmenter and the classifier utilises tonal information. However, in case of multi-sensor and multi-spectral image, the segmenter and the classifier utilises tone-texture information.

Experimental results of the segmentation of images of Delhi shows that even a low level (broad land cover/use) segmentation of PAN image could not produce any meaningful segments. A similar result is also from multispectral SPOT image segmentation. Urban classes are still difficult to distinguish. Merging of panchromatic and multispectral image does not help to produce any good result through segmentation. This is because classes get more heterogeneous and (therefore) more overlapping.

The final experiment of multi-sensor/multi-spectral image segmentation based on tone-texture (by deriving texture from the intensity channel) parameters result in something promising.

The object classification of IRS-1C PAN image produces poor result. However, the classification of objects derived from multi-sensor/multi-spectral (tone-texture based) segmentation produces quite promising result.

Chapter 6
SUMMARY AND CONCLUSIONS

This chapter presents a summary of the major findings of the research, followed by a few policy recommendations and the identification of certain aspects for further research.

6.1 Summary of Findings

Urban and regional planning organizations require accurate and timely information on land use and their changing patterns to aid their management and planning decisions. In general, the process of planning and management may be divided into four distinct but overlapping phases: problem recognition and detailed study, data handling, decision making, and actions. The present study, however, is largely devoted to the second phase, i.e. the role of GIS and satellite remote sensing in geoinformation (land cover/use maps and statistics) generation and management.

The city of Delhi is experiencing rapid physical expansion along with its vertical intensification due to population growth. This is resulting in deterioration of the urban environment. There is a big gap between the information available to counteract them and the spatial reality of continuous urban-industrial sprawl and built-up intensification. Proper execution of Urban Land (Ceiling and Regulation) Act 1976, which is meant for controlling speculation and equitable distribution of land and master plans- MPD-1962 and MPD-2001, meant for guiding and controlling city development, requires sufficient spatial information. IRS-1C imagery, in its panchromatic as well as in merged form (i.e. merged with other multispectral images) coupled with GIS technology can provide important information about the development which are taking place in Delhi and thereby can play an important role in planning and managing the city.

The purpose of this study was twofold. First, to examine and demonstrate the advantage of IRS-1C PAN data over SPOT PAN data in recognizing land cover/use objects. Second, to examine the potential of automatic image segmentation for extracting such objects from satellite data in order to accelerate the production and revision of urban land use maps and statistics.

6.1.1 *Spatial resolution effects in object recognition*

The spatial resolution of satellite image plays a crucial role in improving the quality of information extraction from these data. Since the examination was carried out in a qualitative manner, the investigator does not claim that the findings are conclusive. The contribution is offered within the horizon of viewing satellite data as a means for reliable land cover/use information generation. The comparative analysis of spatial resolution effects in object recognition (relative to different urban features) from currently available high resolution satellite data constitutes a useful point of departure. The following points are summarized from this examination:

- Segmentation of one band panchromatic image using 'merge' algorithm of region growing technique, based on spectral properties does not produce meaningful segments and consequently very low classification accuracy.

- Pixel radiometry-based multi-spectral image segmentation for defining urban landscape types does not produce any meaningful segments.

- Automatic segmentation of merged multispectral/panchromatic images also does not produce any meaningful segments. Addition of texture in the segmentation of merged multispectral/panchromatic images produce better and meaningful segments and consequently better classification results. However, in case of urban satellite images only a low level (broad land cover/use types) segmentation is possible from currently available satellite data.

6.2 Recommendations

For efficient management of land use in Delhi, urban planners should recognize and appropriately use the combined technology of GIS and satellite remote sensing. The products from satellite data should be considered as an accurate base map for building-up other GIS data layers. The combined technology will improve the data poor situation.

One of the effective means of reducing uncontrolled sprawl, speculation and the proliferation of slums and squater settlements in Delhi in general and east Delhi in particular is to counter with sound visually impacting information designed to show feasible alternatives that might be employed, within the framework of the rational enabling legislation and land use ordinances.

Visual and digital interpretation should be used as complementary approach in object extraction from currently available satellite images for urban applications. For detailed level information (detailed land cover/use classes) extraction, visual approach should be adopted (particulary on-screen digitization approach), while for low level (broad land cover/use classes) information extraction, automatic method should be preferred.

Image processing system and GIS should be treated as an integrated tool while extracting objects from satellite data to enhance the certainty of geoinformation generated from space. The resultant object-based information of image segmentation method should further be used for other spatial analysis using GIS databases.

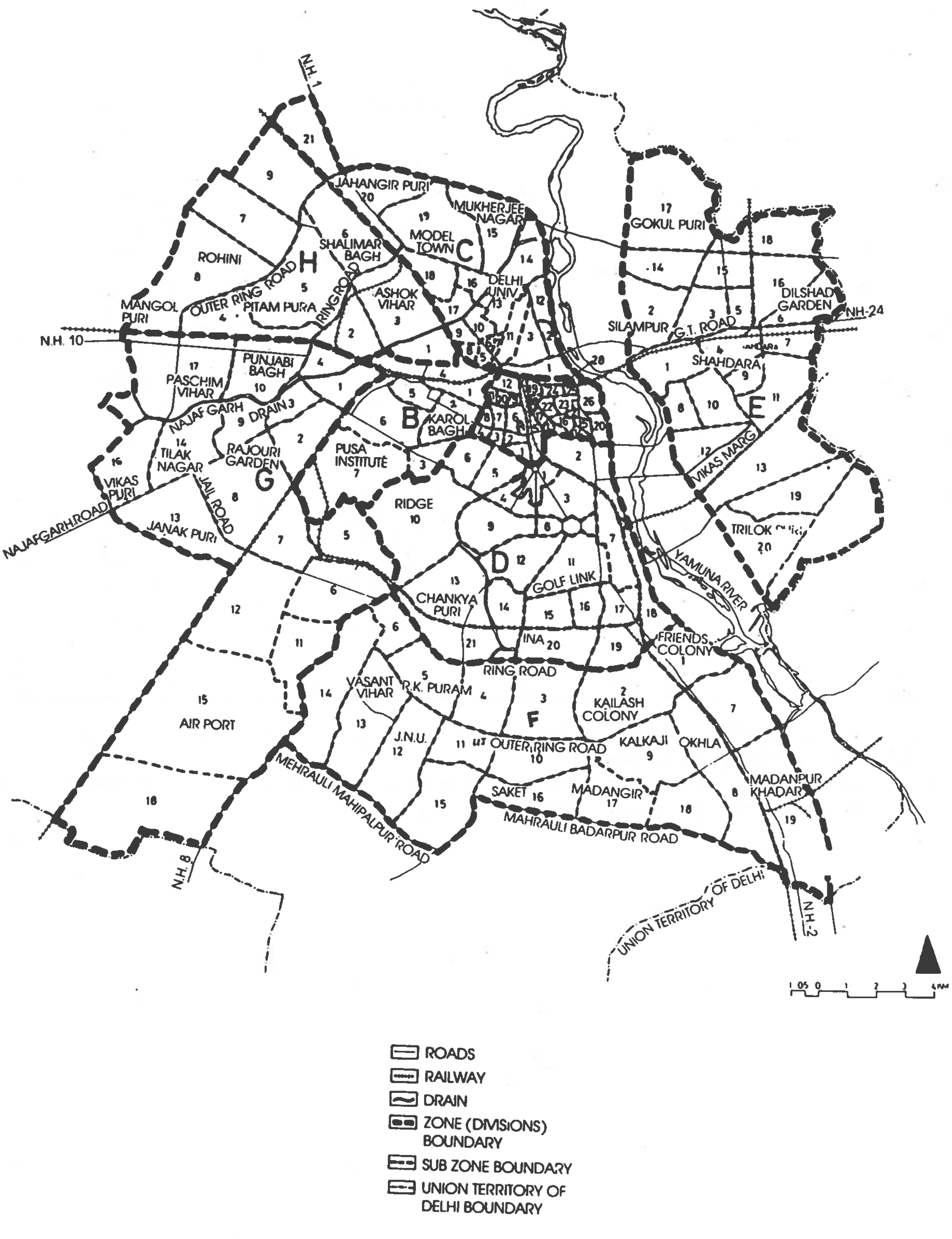
6.3 Further Research Perspectives

This study did not result in something conclusive but it can stimulate further research to achieve a better perspective for geoinformation generation from space. The research issues examined in this study needs further investigation on the following areas:

- The examination of spatial resolution effects of two different resolution PAN images in object recognition needs quantitative investigation by fusing spatial information of these images with

Appendices

Appendix I: *Planning zones (divisions) of urban Delhi (A to H)*



Appendix III: *IRS-1C PAN image of east Delhi and surroundings, 22 November 1996 [4814x3900 pixels, Scale 1: 137, 000]. Zones of Planning zone "E" (i.e. east Delhi) are overlaid.*

Appendix IV: *SPOT PAN image of east Delhi and surroundings, 12 May 1986 [2150x1950 pixels, Scale 1: 115, 000]*

Appendix V: *IRS-1C PAN image of east Delhi and surroundings, 22 November 1996 [4814x3900 pixels, Scale 1: 130, 000]*

Appendix VI: *Potential benefits from a GIS as identified by the RTPI GIS Panel (1992)*

a. Ability to offer an improved map service (covering seamless flexible mapping; improved map currency and consistency; reduced replacement costs; more effective thematic mapping)

b. Opportunity to reduce sets of manual maps held (many of which will be inconsistent and out of date) and associated storage costs

c. Greater efficiency (e.g. in retrieving related information from different sources) resulting in increased staff capacity/savings

d. Faster and more access to geographic information throughout the Department/Authority- enabling greater responsiveness (e.g. information requested during a public inquiry) and ability to explore a wider range of alternatives

e. Improved analysis e.g. of areas, distances, incidents, patterns, site searches

f. Better communication of information to public, members, officers

g. Improved quality of services e.g. speedier access to pertinent information for planning application processing

h. Better targeting of services e.g. match of people to facilities

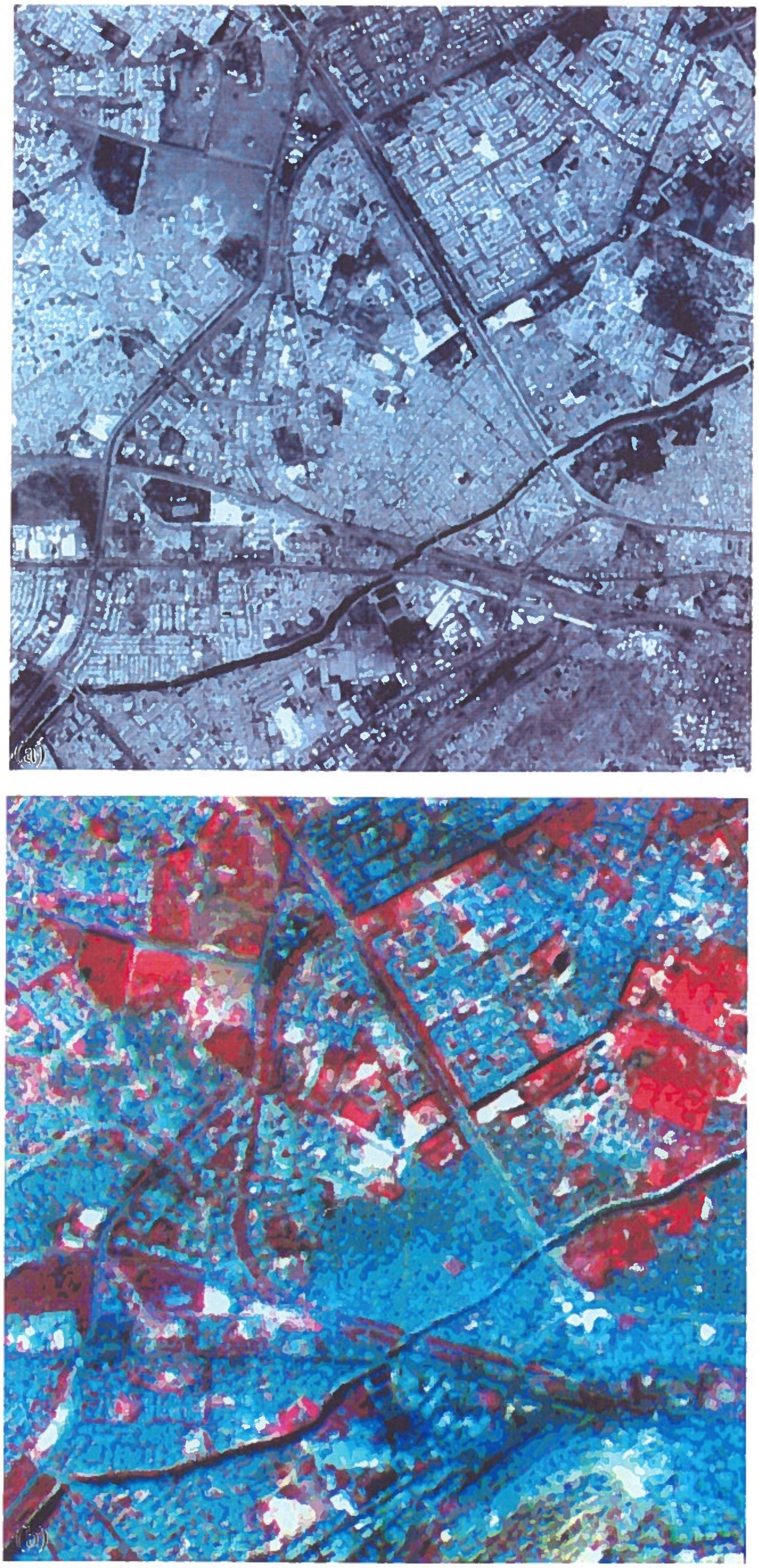
i. Better co-ordination of services within geographical areas e.g. inner cities

j. Increased competitiveness in response to central government and public pressure through the ability to offer a streamlined service, and from improved access to information on assets, liabilities, problems and opportunities

k. Opportunities for external income e.g. sale of retail location maps

Appendix VIII: *IRS-1C vs other major satellite missions*

Capability	Landsat (USA)	SPOT (France)	IRS-1C (India)
Sensors			
Panchromatic	N	Y	Y
Multispectral	Y	Y	Y
Wide-field	N	N	Y
Stereo	N	Y	Y
Resolution (m)			
Panchromatic	-	10	5.8
Multispectral	30	20	23
Wide-field	-	-	188
Swath (km)			
Panchromatic	-	60	71
Multispectral	185	60	141
Wide-field	-	-	810
Coverage	Global	Global	Global



Appendix IX: *Test site images for land cover/use object recognition and extraction, north -west Delhi. (a) Resampled SPOT PAN image; (b) Resampled SPOT multi-spectral image [900x875 pixels, Scale 1: 46, 000]*

Appendix IX: (c) *IRS-1C PAN image of test site, north-west Delhi*

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The following abbreviations are used:

AAAG	Annals of the Association of American Geographers
CJRS	Canadian Journal of Remote Sensing
IEEE TGRS	IEEE Transaction on Geoscience & Remote Sensing
IJGIS	International Journal of Geographic Information Systems
IJRS	International Journal of Remote Sensing
ITPI Journal	Journal of the Institute of Town Planners, India
PE & RS	Photogrammetric Engineering and Remote Sensing
TPR	Town Planning Review

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