MULTITEMPORAL ANALYSIS OF LANDSAT MSS DATA FOR LAND COVER CHANGES IN CENTRAL WEST JAVA PROVINCE 1976 - 1985

BY

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<u>Declaration for the Degree of M.Sc.</u>

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ABSTRACT

High population growth on Java Island has produced pressure on natural resources. Deforestation for fuelwood and cultivation and the decrease of prime agricultural land for urban usage are the most recent problems in West Java. Lack of information to monitor these changes gives problems for planners and resource managers concerned with conservation issues. Analysis of Landsat MSS data is seen as a fast, inexpensive method of obtaining these data over a wide area. This is the aim of this thesis.

Two different Landsat images from 1976 and 1985 were used to detect land cover changes in three sample areas: Saguling, Malabar, and Bandung in West Java. A box classification of the imagery using GEMS image processor produced land cover maps from which change might be detected. Owing to differences in Landsat image scales and the lack of geometrical rectification, a post classification method using a zoom transfer scope was applied to the cover maps to detect change.

Eight land cover types were determined (forest, rice fields, dry fields, estates, bush and shrubs, mixed crops, urban, and reservoir) using ground information. The superimposition of classified imagery detected cover change. In Saguling four changes were recognized: dry fields to forest, forest to rice field and dry fields, and rice fields to reservoir. In Malabar six changes were detected: estates to rice fields, dry fields and mixed crops, and a replacement of forest by rice and dry fields. Some dry fields had been reforested. In Bandung urban extension to the south and west had reduced the area under rice.

Problems of change detection are discussed and alternative strategies are suggested whereby the difficulties encountered in this study might be overcome, notably the use of geometrically corrected satellite data with a higher spatial resolution (Landsat TM or SPOT data) and alternative pre-processing and classification procedures.

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1. Background

Indonesia is the fifth most populous country in the world, in 1986 the total population was estimated at over 150 million. Most of the Indonesian population was spread unequally over the various islands; 63% of the total population live in Java island (Garuda, 1986). In recent years, the population growth rate has dropped from 2.5% to 2.3% per annum due to the Planned Parenthood Program, but it still creates tremendous problems for the provision of food, housing and job opportunities, especially in Java island (Asmoro, 1978).

Increasing population pressure influences many environmental aspects. The exploitation of natural resources and the changes in land use to improve social and economic status may be inappropriate to the sustainable utilization of natural resources. The most common problems of land use change as a result of population pressure such as that seen in Indonesia are (a) deforestation caused by shifting cultivation, timber production, extension of plantation areas, and transmigration areas, and (b) the decrease of prime agricultural land caused by urbanization, industrialization, and commercial activities. Furthermore, these problems will stress the quality and quantity of the natural resources. Haphazard and uncontrolled urban growth, advancing land desertification, soil erosion, watershed destruction, and floods are a sample of these unmanageable land use changes (Wagner and Bartolucci, 1980). However, these situations require a continuous monitoring of the earth's surface. Therefore, it is necessary for planners and resource managers to collect past and present land use / land cover data and process this to make accurate and appropriate plans for further land use development and conservation. The survival of the human race and the conservation measures necessary for balancing the environmental ecosystem depend on careful and systematic development planning and optimal utilization of natural resources (Nanayakkara, 1980).

To keep pace with fast population growth and exploitation of natural resources such as land, water, and forest, rapid, up to date, repetitive, accurate and reliable information of land use / land cover is needed for better policy making and management of natural resources. Remote sensing is a very useful data acquisition technique applicable to many resource inventory problems. Aerial photographs, the conventional remote sensing imagery source for compilation of many maps, is a useful basis for monitoring land use / land cover changes localized at a small site. However, in extensive areas where land use / land cover changes occurred, this technique is not efficient, being more expensive and time consuming in preparation and analysis. To overcome these problems, satellite remote sensing data may offer an available alternative. Landsat satellite data, a major input for many natural resources information systems, also provide a repetitive coverage for monitoring seasonal changes. Since July 1972, when Landsat 1 was succesfully launched, Landsat images have increasingly been applied to monitor land use / land cover changes due to several advantages, (1) high speed processing, (2) continuity in obtaining new data, (3) unbiased and uniformly repetitive classification, (4) production of print-out maps at relatively low cost (Gordon, 1980). Even though Landsat imagery has many advantages, however, there are also some problems with this new technology. One of the major problems is that Landsat MSS data cannnot provide information for detailed planning purposes due to the spatial resolution of the early scanning systems a Landsat series 1, 2, and 3.

Indonesia applied the Landsat data for land cover mapping at an early date. Land cover maps based on manual interpretation of Landsat photographic prints have been produced for test areas in southern Sumatra, central and south Sulawesi, and Lombok island. These maps provide updated information and were accepted by resource managers and planners (Asmoro et al., 1978). The first land cover map produced from Landsat digital data was Lombok island, using the digital image processing software package system ARIES of the Canadian Forest Service (Kalensky et al., 1978). More recently, since a digital image processing system has been installed, the National Coordination

Agency for Surveys and Mapping (BAKOSURTANAL) have produced land cover maps of Central and East Java using digital Landsat data (BAKOSURTANAL, 1985b).

In West Java Province, as in many other tropical regions, it is often difficult to obtain reliable and up-to-date information on land use / land cover data. The latest aerial photographs of West Java were taken in 1982, therefore, it is a problem for planners and policymakers to monitor land use / land cover development, in order to make further land utilization plans. Even in West Java Province, less populous than Central and East Java Provinces (Fryer and Jackson, 1977), there are still many problems in land utilization. Previous studies of land cover mapping using digital Landsat data suggest, it should be possible to make land cover maps of West Java, and to make comparisons between two different dates of Landsat data to detect land use / land cover changes.

1.2. The Aim of Study

The main purpose of this study is to detect land cover changes using Landsat MSS digital data of two different dates, from 1976 and 1985.

This is to be achieved by :

(1) Selecting a study area and study extract from two different dates of Landsat digital data.

(2) Producing a land cover classification of the images 1976 and 1986 using supervised classification method.

(3) Detecting land cover changes by superimposing the classified images on the zoom transfer scope.

(4) Presenting a land cover alteration map as a result of the comparison of image classification of two different dates.

1.3. Study Area

The specific study area selected for detailed analysis is located between north latitude 6°18′ and 7° 41′, and east longitude 107°10′ and 107° 43′. It covers central West Java Province and comprises an area of approximately 7,906 square kilometers, including parts of Cianjur, Purwakarta, Subang, Garut Regencies, and Bandung as the capital of West Java Province (Figure 1).

Central West Java Province is comprised mostly of hilly and mountainous terrain and slightly dissected alluvial plains in the north and extensive plateaux in the central area. The Province varies in elevation from approximately 26 meters to 2,434 meters above mean sea level. Whilst much of Indonesia has dry and rainy seasons in a year, West Java has almost no dry season. The average annual rainfall is about 1000 - 2500 mm in the north area and about 1500 - 3000 mm in the central and south areas. The average monthly rainfall in the Bandung area is about 92 - 200 mm during the dry season (May - October) and about 114 - 404 mm during the rainy season; the heaviest rainfall usually occurs in December and

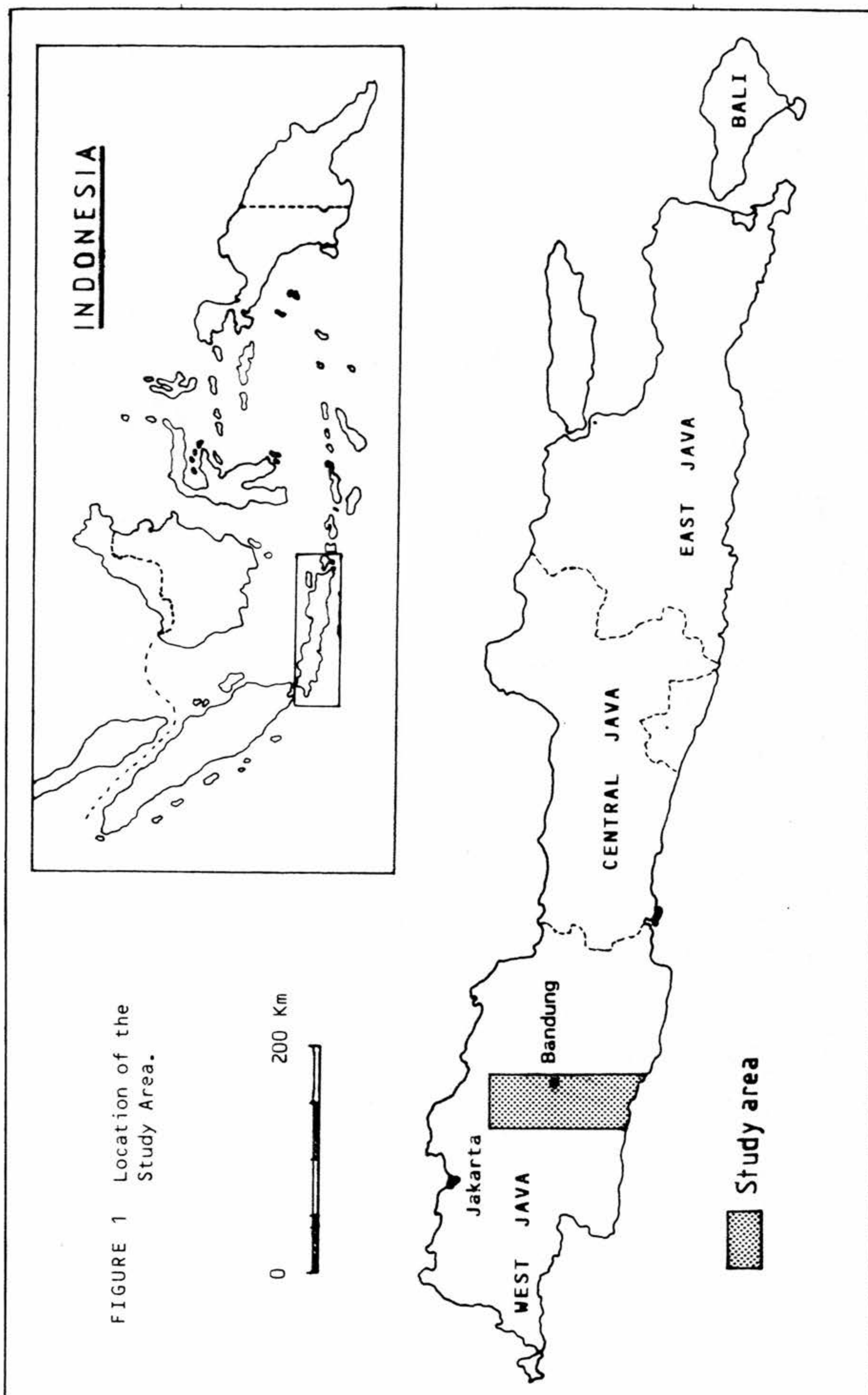

FIGURE 1 Location of the Study Area.

August is the driest month. The average annual air temperature in the Bandung area is about 22.5°C and there are no extreme annual changes. The average highest air temperature is in February and lowest in July. The air temperature shows changes in the highland with differences about 0.5°C lower for every 100 m increase in elevation. The average annual air humidity in west Java is about 80% - 90% and about 75% - 85% in the Bandung area.

The geology of study area can be divided into three regions (FAO-Unesco, 1979), namely (1) the southern belt which composed of miocene limestone, marl, sandstone and conglomerate, (2) the central belt, a volcanic zone which is composed of a succession of volcanoes. Lapilli and volcanic ash coveres a major part of this area, (3) the northern belt which comprises of alluvial plain in the north of study area.

There are five main soil types in the study area, namely, Alluvial, Gleys, Regosols, Andosols, Grumusols, and Red-yellow Mediterranean. Alluvial soil is found in the south of the Bandung area, while Regosol occurs on the foothills, volcanic cones, and also in the rolling macrorelief. Andosols occur at elevations ranging from lowland to over 1500 meters, commonly on long smooth slopes of volcanic mountain complexes. Grumusols are commonly found near the footslope of old alluvial areas with macrorelief varying from nearly level to gently undulating. Most of this soil is found in the west of the Bandung area. The Red-yellow Mediterranean are found in the southeast of the Bandung area.

The study area has fertile soils which give possibilities for many types of land uses. Forest, pine forest, mixed forest, scrub and bush are generally found on steep and very steep slopes, whereas teak forest is found mostly on the moderatly steep slopes. Irrigated rice fields and rainfed rice fields are common and widespread from level/gentle to moderate slopes, nevertheless, they can be found on moderately steep and steep slopes. Dry fields and plantations are found in areas varying from level/gentle slope to the very steep slopes, whilst urban / settlement areas are found mostly in the level/gentle slope areas, but can be found also in the moderate and steep slope areas. Slope classes are defined in the following terms : level/gentle : 0% - 8%; moderate : 8% - 15%; moderately steep : 15% - 25%; steep : 25% - 45%; very steep : >45%.

1.4. Organization of the Thesis

The result of the research are presented in six chapters. Chapter 1 (Introduction) discusses the background, and aim of the study, and describes the study area. The previous study and research relating to the use of Landsat for land cover mapping in the humid tropics, the use of Landsat to monitor land cover changes, and the use of Landsat in Java are presented in Chapter 2 : the Literature Review.

In chapter 3, Landsat and image processing system, presents some aspects which relate to the Landsat system, namely, electromagnetic energy reflectance, the Landsat sensor of the multispectral scanner and the Landsat orbit. Another part of this chapter introduces Gemstone, the image processing system used in this reseach. The land cover of central West Java is presented in Chapter 4. The imagery of the study area, the ground information sources and the land cover classification scheme of West Java are presented in the first part of this chapter, followed by a description of image classification techniques including density slicing, box, maximum likelihood, and unsupervised classification. The remainder of this chapter describes the land cover 1976 and 1985 including selecting images of the study area and the choice of study extracts, the box classification results of images for 1976 and 1985, and description of land cover for the study area from the result of image classification.

In Chapter 5 : Land cover change 1976 - 1985, is presented the change detection techniques including manual comparison and digital comparison. Following this first part are the results of detection of land cover changes involving image comparison using post classification techniques and detected land cover change. The last part of this chapter considers the accuracy of the analysis. The main topics are the accuracy of image classification and the accuracy of the change detection techniques. The last chapter, Chapter 6, presents the problem and potential of remote sensing techniques for land cover change in the humid tropics and recommendations for further work.

CHAPTER 2

LITERATURE REVIEW

Landsat MSS imagery has been applied to many earth resource surveys such as geology, hydrology, oceanography etc. This second chapter will describe briefly the use of Landsat for land use and land cover mapping in the humid tropics, the use of Landsat to monitor land cover changes in the humid tropics, and the use of Landsat in Java.

2.1. Use of Landsat for Land Cover Mapping in the Humid Tropics

Prapinmongkolkarn et al. (1980) chose the Northern region of Thailand as a study area. The study site is located between 18°45′ and 19°00′ north latitude and 98°30′ and 98°45′ east longitude, in Amphoe Samong and part of Ampoe San Pa Tang and Amphoe Mae Cham of Chiangmai Province, with an approximate area of 730 square kilometers. The major part of this study area is mountainous in which topographic elevation varies from approximately 600 meters to 1700 meters above mean sea level and more than 60% of this area is covered by forest land.

This study area was based on Landsat MSS imagery collected on 26 February 1976, from the scene ID E - 2400 - 03074. This image was geometrically corrected , using a topographic map at 1:50,000 scale with the UTM projection as reference. Principal components analysis was applied in the preprocessing and gave a much clearer relationship of topographic aspects such as ridges and slopes.

A maximum likelihood classification was applied to classify the land cover types, resulting in six land cover types, namely : dense forest , open forest, rice field, orchard / plantation field, opium poppy plantation and shadow. The delineating of the training area boundaries was based on topographic maps, aerial photographs, and ground truth data.

The result of this research showed that land cover classification by maximum likelihood classification gives much better contrast in dense forest, open forest, rice field, orchard, and shadow rather than Mahalanobis distance classification which was also applied in this research. The texture and contrast of land cover classification using Mahalanobis distance classified images are not as good as maximum likelihood classification. The opium poppy was not clearly identified even though a specific approach to recognize opium poppy plantations was used. This remained as a problem to be solved.

It is often difficult to obtain reliable and up-to-date information on land use and agriculture, as in tropical areas. Adeniyi (1986) has undertaken research in Nigeria to developed a multilevel land use classification scheme for Nigeria and to test the effectiveness of different remote sensing techniques for agricultural land use mapping.

The test site for this study was selected in west central Nigeria, centred on $8^{\circ}45'$ north latitude and $6^{\circ}15'$ east longitude. aThe rea of this study site was approximately 1,600 square kilometers, corresponding to a Landsat subscene of 500 x 500 pixels. This Landsat image was taken on 25 December 1973, with geometric and radiometric correction, and image restoration procedures were also applied for image enhancement. The soil type of this study area is alluvial, and the crop types are rice, yam, sorghum, ground nut, and cow pea.

Landsat images of this study site have very low contrast. The linear contrast stretching and high pass filtering (3 x 3 pixel size) were used to produce a better colour composite image. Contrast stretching and band ratioing techniques generally improved the interpretability of land use, however, identification and delineation of crop land remained difficult due to the small size of fields and their dispersion. The unsupervised classification was applied in this study, resulting in 10 land use classes, namely, riparian forest and dense riparian forest; cropland (yam and rice) and wooded scrub; wooded scrub, grass and cropland (rice, sorghum); aquatic grassland; mosaic farmland and wet grassland; dry upland grassland; bare or cleared ground; burnt area; built up area; and bare sand.

Comparing the Nigerian Radar Project (NIRAD) vegetation and land use map of the study area, the image classification result was found to contain more detail than the NIRAD's map. Particularly, a total of 48 classes was identified, however, it was realized that many factors affected the reflectance of objects such as soil type or colour, moisture content, local relief, differences in tillage, and it separated the class in otherwise homogeneous vegetation or land use type. In this study, only ten classes are identified to compare with the general land use and vegetation categories used in the NIRAD mapping project which has recently been used for resources mapping in Nigeria. Supervised digital classification would have been even more effective, however, this technique requires the aquisition of field data in order to provide a training set for establishing the classification, and the lack of such training data is one of the major problems.

Omakupt and Vunpiyarat (1980) have completed research in identifying and mapping of the Uttaradit area using digital analysis of Landsat MSS data. The area of the study site was approximately 1,890 square kilometers, located in northern Thailand, centred in approximately 17° 37′ north latitude and 100°06 east longitude. This study area has a mean annual temperature of about 27.7°C and a mean annual rainfall of 145.5 cm.

Landsat MSS data of 31 January and 15 November in 1977 were used for land use analysis. The black and white Landsat imagery of MSS band 5 and band 7 for January and November were printed at a scale of 1:250,00 and 1:500,000, the land use map of 1977, and topographic map also prepared at scales of 1:250,000 and 1:50,000. All of these data were used in the classification stage to make a better training set.

A supervised maximum likelihood classification technique was utilized to classify the Uttaradit test site using the RECOGX computer classification program. 32 training classess of 10 land uses were used in this research, 2 for perennial crop sites, 9 for field crop sites, 7 for rice paddy fields, 1 fallow land, 6 forest sites, 1 urban area, 2 soil types, 2 water sites, and 2 for miscellaneous sites representative of vegetation types, urban features, soils, surface water, and miscellaneous land. The field crop class was divided into 2 subclasses, namely, sugarcane and mixed field crop. This mixed field crop class represents several individual field crop types including soy bean, kidney bean, sesame, peanut and cotton.

The analysis of Landsat MSS data of January and November, showed that supervised classification technique can be used to separate agricultural land, forest, urban, soil, water, and miscellaneous classes, which were identified and mapped with approximately 88.2% of accuracy. The mixed field crop was quite heterogeneous and had a lower response than sugarcane in both visible and near infrared bands caused by plant geometry, growing season, and agricultural pattern. The accuracy of mixed field crop was 90.7% and 94.4% for sugarcane. Perennial crop or orchard was identified on accuracy of 90% and fallow land was identified at 100% accuracy.

Topographic complexity, soil moisture and types of forest have an influence on the spectral characteristics, however, the forest class could be then identified and mapped with 97% accuracy. Spectral distribution of urban and soil classes have some spectral overlap in the classification, particularly on MSS band 5, and it was also equally reflected on MSS band 7. These may be caused by part of the urban area which was characterized by a variety of lawns in residential areas and recreation areas laid out alongside other man made features. On band 5, dry soils have higher reflectance than urban areas. A miscellaneous class which consisted of areas having extremely low reflectance in all wave bands was classified at an accuracy of 94,4%. Rice / paddy was classified with an accuracy of 80%, this result is not only because of some rice fields being mixed with aquatic shrubs or some rice fields were in upland or slopes, but also because of other factors including differences in elevation and slope, flooding, drainage pattern, and growing season. Furthermore, reflectance of the rice fields was also mixed with field crop, forest, miscellaneous, soil, and urban classes.

From the result of this study, it could be concluded that classification of major crop types can be accomplished using computer analysis techniques for a large geographical area and it can be used as a guideline for other remote sensing projects.

By using principal component transform as a data compression technique for Landsat MSS processing, Hadisumarno and Arymurthi (1978) have attempted to produce a better Landsat MSS image for land use interpretation.

The study area of this research was situated in the middle of the Lombok Island, in Indonesia, an area approximately 40 X 80 kilometers, elongated from north to south. This area comprises a part of Mount Rinjani crater lake, the volcanic cone slope, the volcanic foot slope, the volcanic foot plain and a small part of the plain deposits.

Selected Landsat MSS data of 12 October 1972 were used for this study. However, because there is no ground truth data available for this study, nine land cover classes have been decided without reference data. These land cover are water, rice fields, dry fields, grassland, pine forest, villages and undetermined.

In this study, the principal component analysis was used to produce an optimum image features for visual interpretation. Four principal components have been achieved for MSS band 4, 5, and 7. The variance-covariance matrix, eigen values and eigen vector were calculated giving the result that the variance of MSS 5 was high and the variance of MSS 7 was low. These findings affected the result of the pictures where image MSS 5 looks clean and not so much contrast in MSS 7. The eigen values of PC1 and PC2 were higher than PC3 and PC4 and gives the result that the pictures of PC1 and PC2 are sufficient to be used for interpretation purposes.

To achieved the purpose of this study, three different colour images have been produced. The first image was the combining of PC1 with lower range of radiance level in one colour (cyan), the upper range of PC1 in another colour (magenta), and PC2 in the third colour (grey). The second image combined PC1 (cyan), PC2 (magenta) after a rotation of the axes for 45° in order to obtain a better comparison between PC1 - PC2 transform image and the original bands. From the interpretation result of these three different images which can be used to detect water bodies, rice fields, dry fields, grassland, forest, plantation, villages, burnt forest, drainage pattern, crater lake and dissected land, it could be summarized that the second and the third images are most suitable for visual land use interpretation. The best interpretation was found in the second image particularly for plantation and also in the third image for drainage pattern.

2.2. Use of Landsat to Monitor Land Cover Change in the Humid Tropics

Gautham and Chenniah (1985) studied land use and land cover mapping and change detection using Landsat data. The selected study area was Tripura, between $22^{o}56'$ to 24^{o} $32'$ north latitude and $90^{o}8'$ to $92^{o}20'$ east longitude, situated in eastern India, having an area approximately of 10,480 square kilometers.

The study was based on Landsat MSS data collected on 15 April 1975 and 7 April 1978, with topographic maps at 1:250,000 and 1:50,000 scale also being used for land use and land cover classification. Generalisation on the land use and land cover classification occurred owing to the small scale of Landsat data, and it resulted in five main land use classes in the Tripura study area being recognized : built up land, agriculture, forest, water bodies, and others. These five main land use classes have been divided into 12 subclasses.

The Landsat MSS images of band 4, 5, 6, and 7, and false colour composite combination of band 4, 5, and 7 on 1:1,000,000 and 1:250,000 scale were used for preliminary interpretation, and Landsat bands 4, 5, 6, and 7 were also used for interpretation and analysis on MDAS computer image analysis. Land use and land cover changes are detected by comparing Landsat interpretation results at the scale of 1:250,000.

The result of these comparisons showed that shifting cultivation activities which in 1975 covered 2.60% had changed to 10.76% in 1978. In 1975, 60% of the study area was covered by forest, by 1978 this forest land had been reduced to 47.40% caused by heavy destruction in 1977 and 1978 for shifting cultivation. Ninety percent accuracy was achieved in this study.

Suwahyuono (1983) has studied detection of forest land cover alteration, using two different dates of Landsat MSS image. The study site was selected in Makornrajasima Province, in northern Thailand, located between $14^{\circ}26'47''$ and $14^{\circ}33'50''$ north latitude and 101° $49'42''$ and 101° $58'03''$ east longitude, an approximate area of 151 square kilometers.

Two different Landsat MSS images of path 138 and row 50 scanned on 13 November 1979 and 4 January 1982 were selected from three other images. The available reference data which supported this study were topographic maps at a scale of 1:50,000, land use maps at 1:60,000 and classification based on visual interpretation of false colour infrared aerial photographs at a scale of 1:50,000. All of these reference data were very helpful during the selection of training sets to represent each land cover type.

Preprocessing operations which were very important to make the Landsat data easier to interpret by human eye or machine analysis, were done before the classification stage. Image normalization due to line banding in the image of 1982 was processed using the image normalization facility in DIMAPSAR image processing system. The choice of the study area from the whole image was applied based on selected ground control point and referenced to the topographic map at scale of 1:50,000.

A supervised classification technique was applied in this study. Seven training sets were selected: four for dry evergreen forest, two for dry dipterocarp forest, and one for swidden areas, resulting in four main land cover classes, namely, dry evergreen forest, dry dipterocarp forest, swidden area, and unclassified. Unfortunately, because of similarity in the reflectance characteristics, some part of dry evergreen forest were also classified as a dry dipterocarp forest. Reference data were very useful for separating dry evergreen forest from a dry dipterocarp forest class. Cover type of the swidden area represented grass, cultivated areas, or a mixture of them. An unclassified group was represented mostly by a slight shadow area with brush land cover type.

Detection of land cover alteration using post classification methods was done by comparing two classification images of different dates using a zoom transfer scope, and image band 7 was also used as a guide for determining various geographical positions in the image. Some difficulties were found at and around the cloud cover area in the 1982 image. Furthermore, four kind of alterations were found in this study being recognized : dry evergreen forest to swidden area, dry dipterocarp forest to swidden area, swidden area to dry evergreen forest, and swidden area to dry dipterocarp forest.

2.3. Use of Landsat Imagery in Java

The National Coordination Agency for Surveys and Mapping of Indonesia (BAKOSURTANAL) established a research programme in land cover mapping using Landsat MSS data in 1985, located in Central Java and East Java Provinces. The topography of the study area is varied, with alluvial plains in the north, and hilly and mountainous land in the south. This study area was covered by various types of land cover such as forest, plantation, orchard, rice field, and dry field.

There are three Landsat images covering the study area: path 128 / row 065 recorded in September 1972 and 1982, path 128 / row 066 recorded in September 1972 and 1982, and path 127 / row 065 recorded in October 1972 and 1982. All of these images are of good quality without cloud cover and have been processed using a DIPIX Aries II system. Based on the study of histograms of bands 4, 5, 6, and 7, it was decided that data from band 5 and 7 are very good for interpretation of land cover and water bodies, and this statistical study was also useful to decide the training area boundaries. Delineation of training areas was also based on aerial phothographs, topographic maps, and ground survey.

A maximum likelihood classification was applied in this study, resulting in 10 land cover types, namely, forest, bush and scrub, plantation, rice field, dry field, salt pond, fish pond, sand dunes, rural setlement, and urban areas. Topographic, soil moisture, and climatic conditions influenced the reflectance of the earth surface objects and may cause two different objects have the same reflectance e.g. scrub and rural settlement, rice fields and urban area, rice fields and fish pond. To achieve the best result, manual interpretation was also applied in some part of this study area using a masking program to classify the exact known object which cannot be distinguished from another object. The large extent of the study area also caused some problems in classification because the same object in different places occasionally has a different reflectance caused by different climate, soil, and topographical conditions.

Meijerink and Donker (1978) have studied digital processing of Landsat data applied to land use mapping in the Lesser Himalayas and Central Java. This study has been developed at International Institute for Aerial Survey and Earth Science (ITC), Enschede, Netherlands, based on the ideas that: (a) multiband and multi temporal images are difficult to handle in one operation; (b) effective data compression techniques should be used; (c) most scene and themes are so complicated that experience on the interpretation is needed to do the mapping; (d) the operation should be performed on a relatively simple hardware.

Principal component transform and Euclidean distance methods were used in the preprocessing stage to seperate the effects of illumination due to varying slope exposure and azimuth from the effects of land use. This processing was applied in both of Himalayas and Central Java images.

In the image of Himalayas processed by Euclidean distance method, the drainage network could be traced accurately when compared with a topographic map at a scale of 1:63,360. Land use classification in the November image was done using nine grey tones, resulting in : oak and coniferous forest, deciduous mixed with Himalayan forest, dense scrub, in the dark tone; open scrub with grass or outcrops, bare soil, cultivated areas with scattered trees or patches of scrub, in the grey tone; and light tone can be related to the grassy areas. In the May image, the deciduous forest and dense scrub areas can be easily separated from the evergreen cover type.

In the Central Java test area, the Landsat image used in this study was taken in November. The study site of Central Java was located around Wonosobo including the Sundoro volcano. The aim of the study was to test the principal components transform for land use mapping in a complex situation, typically for Java island. By using the Euclidean distance method, the pattern of drainage and the local relief appeared clearly in the image.

Image classification of Central Java has been done based on ground truth data such as aerial photographs taken in July and August 1972, topographic maps, and land use maps based on the World Land Use Classification at a scale of 1:150,000. Thirteen classes of land use have been attempted, but the result of this classification is not satisfactory. There are many spectral characteristics overlapping within each class, it is not possible to separate the various classes except water, dense forest, and upland farming without trees. The other classes all show large margins of overlap, particularly for irrigated rice which have different characteristics at the different stages of growth. Another factor wich caused difficulties in the classification is the small size of rice fields in relation to the spatial resolution of Landsat, varying from 0.02 - 1 hectares in the irrigated rice area and 0.03 - 1.5 hectares in the dry cultivated area. In the forest area, many classes of forest types may be distinghuised due to the effect of altitude, wood cutting and forest management. However, the best imagery for interpretation was generated by principal component transform based on sample sets. The conclusion is that the image, if properly produced, is a very convenient base map for land use mapping.

CHAPTER 3

LANDSAT AND IMAGE PROCESSING SYSTEM

Landsat is the first generation of earth resources satellites and was designed for observation of earth resources with high resolution imagery. The imagery used in this research has been collected by the Landsat multispectral scanner sensor. It is important to discuss briefly some aspects which are related to the Landsat system such as electromagnetic energy reflectance, the multispectral scanner and Landsat's orbit. In the remainder of this chapter the GEMS image processing system used in this reseach for manipulating and interpretation will be described.

3.1. Electromagnetic Energy Reflectance

There are four components of a passive remote sensing system: a source, earth surface interaction, atmosphere interaction and sensor (Curran, 1985). The link between these components is called electromagnetic energy. The electromagnetic energy which is reflected from the earth's surface will be recorded by a sensor either from aircaft or from satellite (Figure 2). Electromagnetic energy occurs as a continuum of wavelengths and frequencies from short wavelength to long wavelength or from gamma rays to radio waves. Not all of these wavelengths are useful in the remote sensing system. The visible light and near

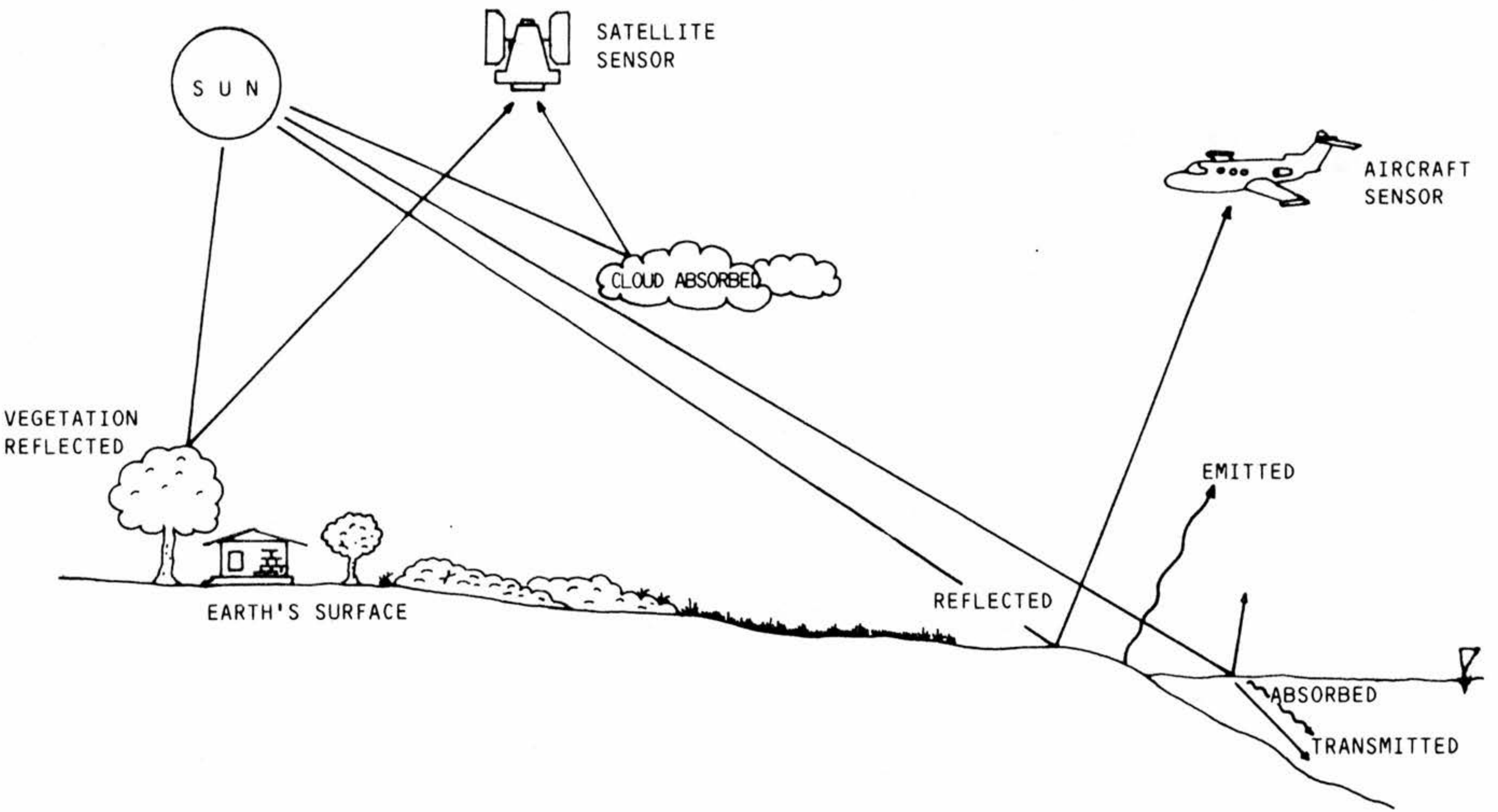

Figure 2 A Remote Sensing System and Interaction of Solar Energy
(Modified from Lindgren, 1985)

infrared radiation in the waveband 0.5 - 3 µm, infrared radiation in waveband 3 - 14 µm and microwave radiation are the most important wavelength in remote sensing (Figure 3). The Landsat multispectral scanner sensor records only electromagnetic energy of the earth surface in visible light and near infrared waveband (0.5 - 1.1 µm). Electromagnetic radiation from the sun which is reflected by the earth's surface and detected by aircraft or satellite sensor must pass through the atmosphere twice, first, on its journey from the sun to the earth and second, after being reflected from the earth's surface (Mather, 1987). During its passing through the atmosphere, the electromagnetic radiation interacts with particles suspended in the atmosphere or with large molecules of atmospheric gases which will scatter or absorb radiation. A number of interactions are possible when electromagnetic energy encounters earth surface matter, radiation might be transmitted, absorbed, emitted, and reflected so that different earth surface materials such as soil, water and vegetation will have different reflectance values within different wavebands (Figure 4).

There are many interrelated factors which influence the reflectance value of the earth surface, however, it is possible the same object of the earth surface in the same wave band will have different reflectance values or different objects will have same reflectance values. Some of the factors affecting soil reflectance are moisture content, soil texture (proportion of sand, silt, and

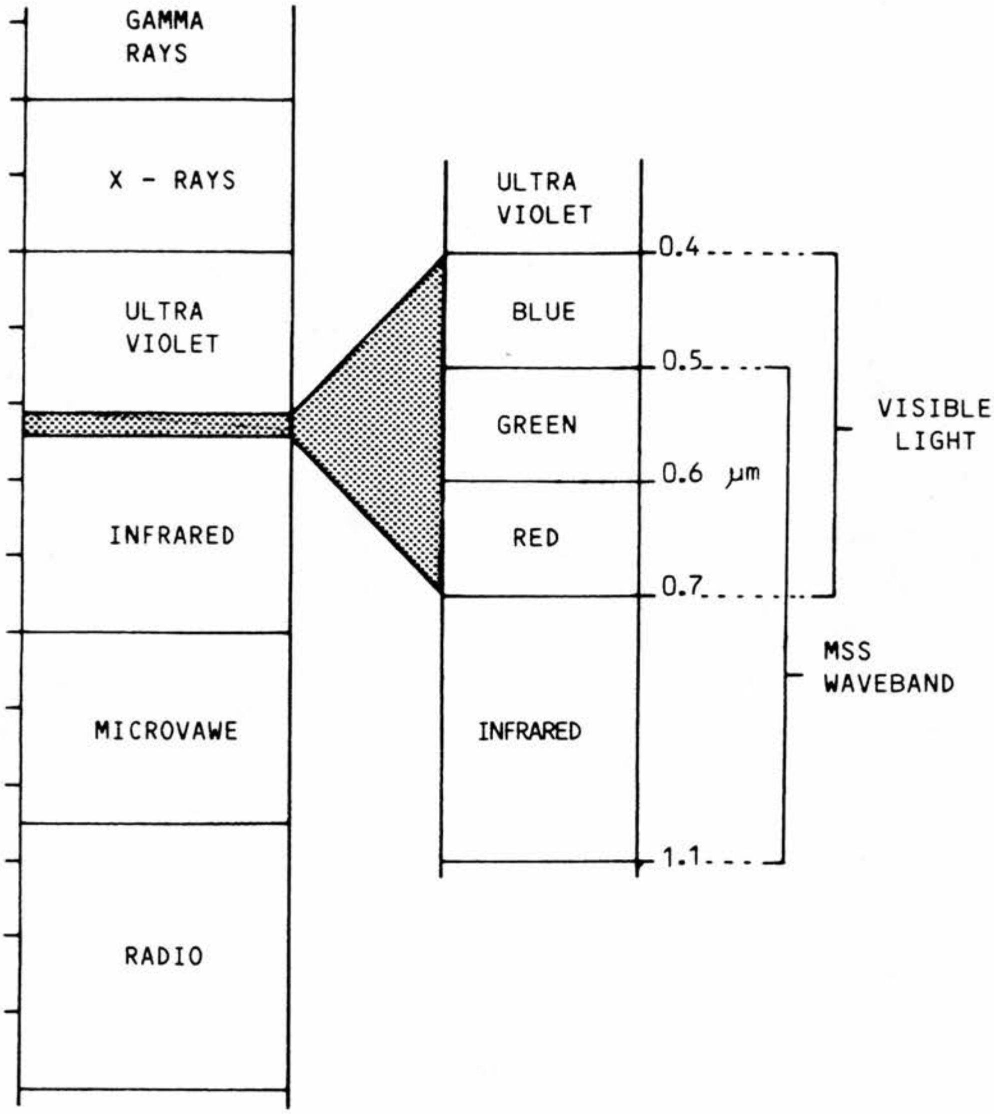

Figure 3 The Electromagnetic Spectrum and MSS Waveband (Modified from King, 1985)

clay), surface roughness, percentage of iron oxide, and organic matter content (Lillesand and Kiefer, 1987). The spectral reflectance curve of bare soil rises in reflectivity as wavelength increase. Low moisture content produces a relatively high reflectance and poorly drained soil will generally have lower reflectance. Higher values of surface roughness , the content of organic matter, and percentage of iron oxide in a soil will also significantly decrease energy reflectance.

The reflectance of a water body also depends on interrelated factors such as material suspended in the water, the depth of the water and the surface roughness of the water. Water containing large quantities of suspended sediment has much higher reflectance than clear water. In shallow water some of the radiation is reflected not only by the water itself but also from the bottom of the water bodies, therefore, reflectance of shallow water will be higher than deep water. Deep water at 20 meters depth is only represented by visible light (mainly blue) as the near infrared has been totally absorbed. The spectral reflectance curve of water shows a reduction as wavelengths increases.

The spectral reflectance of vegetation canopies have more variety and depend on the wavelength. Pigmentation, physiological structure and water content in a green leaf all have an effect on the reflectance. The effect of the soil background and the effect of canopy geometry also have relationships in the spectral radiation value of vegetation. There is no ideal spectral reflectance curve for any particular vegetation types and the recorded radiance from the earth's surface will depend upon the viewing and illumination angles, as well as other variables. The spectral reflectance curve of vigorous vegetation shows relatively low in the blue, the green, and the red region of visible band, but rises sharply in the near infrared region (Figure 4).

3.2. Landsat Multispectral Scanner

The most widely used imaging instrument in satellite sensing is the multispectral scanning system (MSS), which has been carried by the Landsat satellite series (Landsat 1, 2, 3, 4, and 5). The multispectral scanner is a line scanning device which uses an oscillating mirror to continuously scan in a direction perpendicular to the space craft's path (Thomas et al., 1987). The MSS in the Landsat satellite is an electro optical system which is sensitive to electromagnetic radiation in 4 waveband regions (Table 1).

There are 6 detectors on each band (a total of 24 detectors) used for the MSS. The MSS system scans from west to east with six line of data being scanned at one time for a distance of 185 km long on the ground (Figure 5). During each scan, the electromagnetic radiation coming from the earth's surface is reflected by the mirror through a reflecting telescope optics system to the

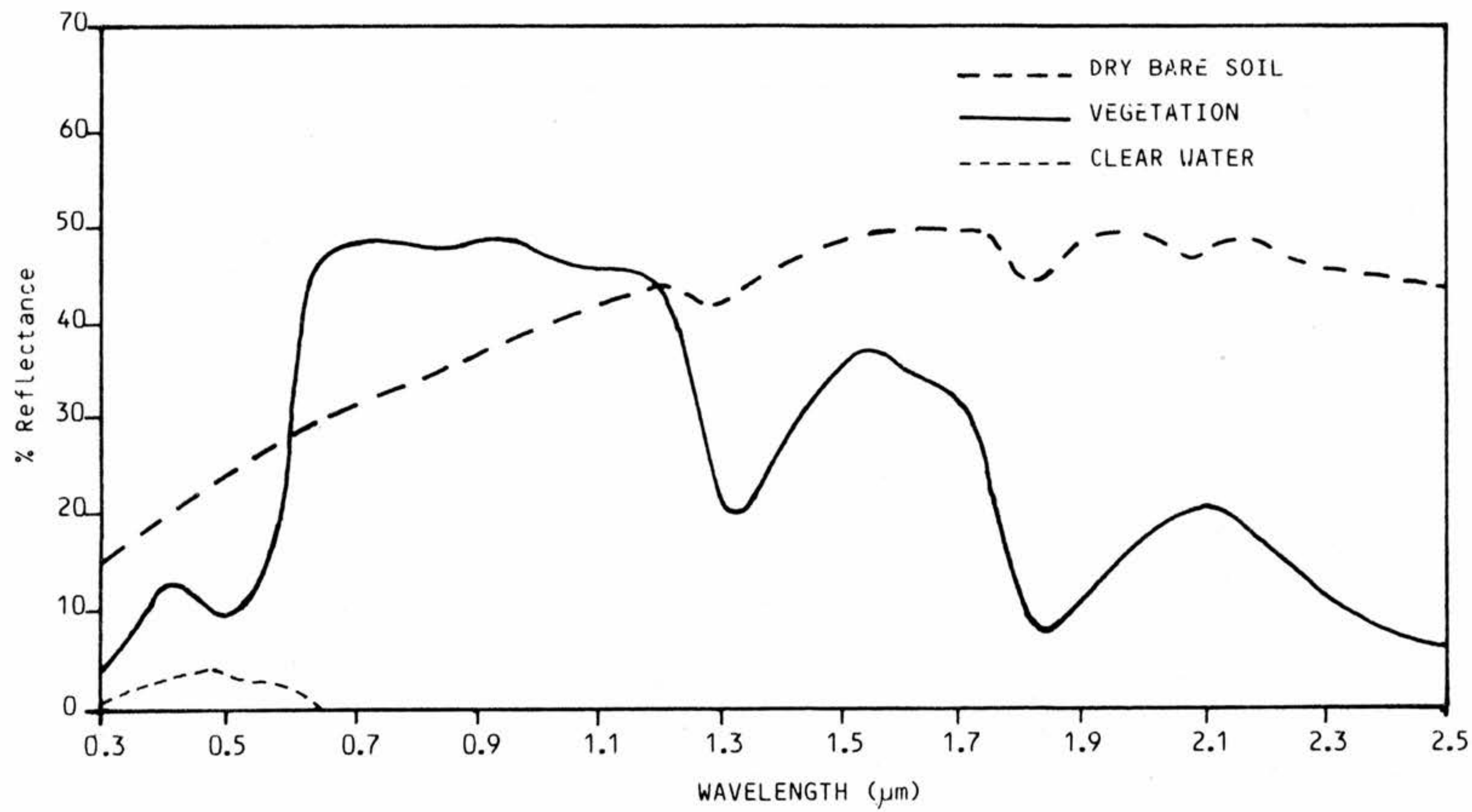

Figure 4 Idealized Spectral Reflectance of Bare Soil, Vegetation and Clear Water (Adapted from Lillesand and Kiefer, 1987)

detector. Each detector produces a voltage according to the intensity of radiation recieved, and this voltage is converted by multiplexer to a digital value between 0 - 63 which can be further scaled to a wider range during ground processing such as 0 - 127 for bands 4, 5 and 6 (Lo, 1986). Band 7 which is not compressed will be left on the original 0 - 63 scale. The original CCT format of the EROS Data Center used a 0 - 127 scale for band 4, 5, 6, and left the band 7 on the original scale, whereas the European Space Agency and all ground receiving stations that used Canadian CCT format used a 0 - 255 (8 bit) scale for all of four bands (Mather, 1987).

The data comunication system of Landsat 1, 2, and 3 was quite different from those of Landsat 4 and 5. In Landsat 1, 2, and 3, direct transmission from satellite to the ground station was possible when the satellite had direct line of sight view to the ground station. The imagery of areas outside receiving range of ground stations was recorded in the two tape recorders on board of Landsat and was transmitted to the receiving stations as the satellite moved within range of the ground station. In Landsat 4 and 5, image data acquired from Landsat satellite were relayed to the tracking and data relay satellites (TDRS) and transmitted to the central ground receiving station near White Sand, New Mexico. The TDRS satellite are also in geosynchronous orbits, therefore, it's allowed for direct transmission to the central ground receiving station without being recorded before

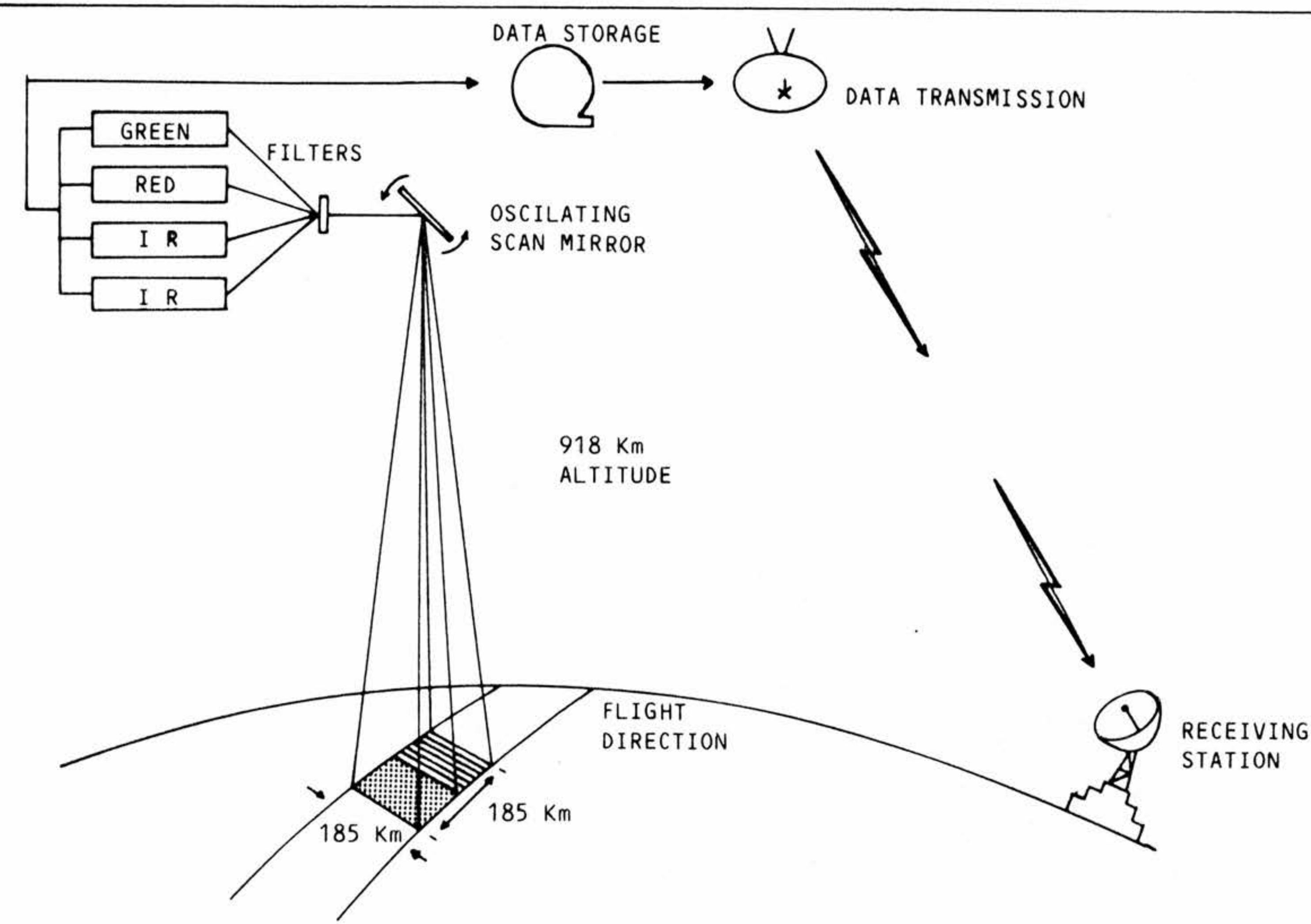

Figure 5 Multispectral Scanner System and Data Flow of Landsat 1, 2 and 3
(Adapted from Barret and Curtis, 1982)

transmission (Campbell, 1987).

Landsat MSS band number		Band width (μm)	Waveband name
Landsat 1, 2, 3	Landsat 4 , 5		
4	1	0.5 - 0.6	Green
5	2	0.6 - 0.7	Red
6	3	0.7 - 0.8	Near infrared
7	4	0.8 - 1.1	Near infrared

Table 1 The four wavebands recorded by the multispectral scanning system (MSS) on board the Landsat series of satellites (after Curran, 1985).

3.3. Landsat Orbit and Ground Coverage

To date five Landsat satellites have been launched and the last two of them are still operational (Table 2). Landsat 1 through Landsat 5 were launched into the same operational, repetitive, circular, sun-synchronous and near polar orbit. Landsat 1, 2, and 3 had similar orbits but show a slight difference from Landsat 4 and 5.

Landsat Satellite	Launch	Ended Operation	Orbit
1	23-7-1972	6-1-1978	18 days / 900 Km.
2	22-1-1975	25-2-1982	18 days / 900 Km.
3	5-3-1978	31-3-1983	18 days / 900 Km.
4	16-7-1982	-	16 days / 705 Km.
5	1-3-1984	-	16 days / 705 Km.

Table 2. Characteristics of Landsat Series (adapted from Lillesand and Kiefer, 1987).

Landsat 1, 2 and 3 were launched into circular orbit at an altitude approximately 900 km (variated between 880 - 940 km) and circled the earth once every 103.3 minutes, to achieve 14 orbits per day. Every successive day the satellite orbit progressed slightly westward, the resulting capabilities covering the earth once every 18 days to completed 251 orbits and yielded an image overlap with that of the previous day. The overlap is about 85 percent at 81 degree north and south latitude and 14 percent at the equator. These Landsat orbits are referred to as sun-synchronous and the satellite crosses the equator at about 9.42 a.m. local time on each pass. Each Landsat MSS frame covered 185 by 185 km earth surface area with 10 percent endlap, and consists of 2340 scanlines with 3240 pixels per line or about 7,518,600 pixels per frame, in which each pixel (picture element) represents 56 by 79 meters of ground cover (Lillesand and Kiefer, 1987).

Landsat 4 and 5 were launched in similar manner to their predecessors but their orbits were lowered from 900 to 705 km and crossed the equator at 9.45 a.m. local time. Each orbit takes approximately 99 minutes resulting in 14.5 orbits per day and repeated once each 16 days to achieve 233 orbits. The pixel size of Landsat 4 and 5 is 82 by 82 meters of ground cover and each Landsat frame covered 185 by 185 km area. The side lap in Landsat 4 and 5 is 7.3% between adjacent orbits at the equator and increasing to a maximum of 84% at 80 north and south latitude.

Because of orbital altitude differences between Landsat 1, 2, 3 and Landsat 4 and 5 which causes difference in orbit coverage, the Worldwide Reference System (WRS) used to index Landsat scenes by location were also different (Figures 6 and 7). The WRS for Landsat 1, 2, and 3 has 251 paths (corresponding to the number of orbits from east to west) and 248 rows, while Landsat 4 and 5 has 233 paths and 248 rows. The path and row of Landsat series started at the same position, row 1 of each path starts at $80^\circ 47'$ north latitude, whereas row 60 positioned at the equator and path 001 crossing the equator at $64^\circ 36'$ west longitude (Lillesand and Kiefer, 1987).

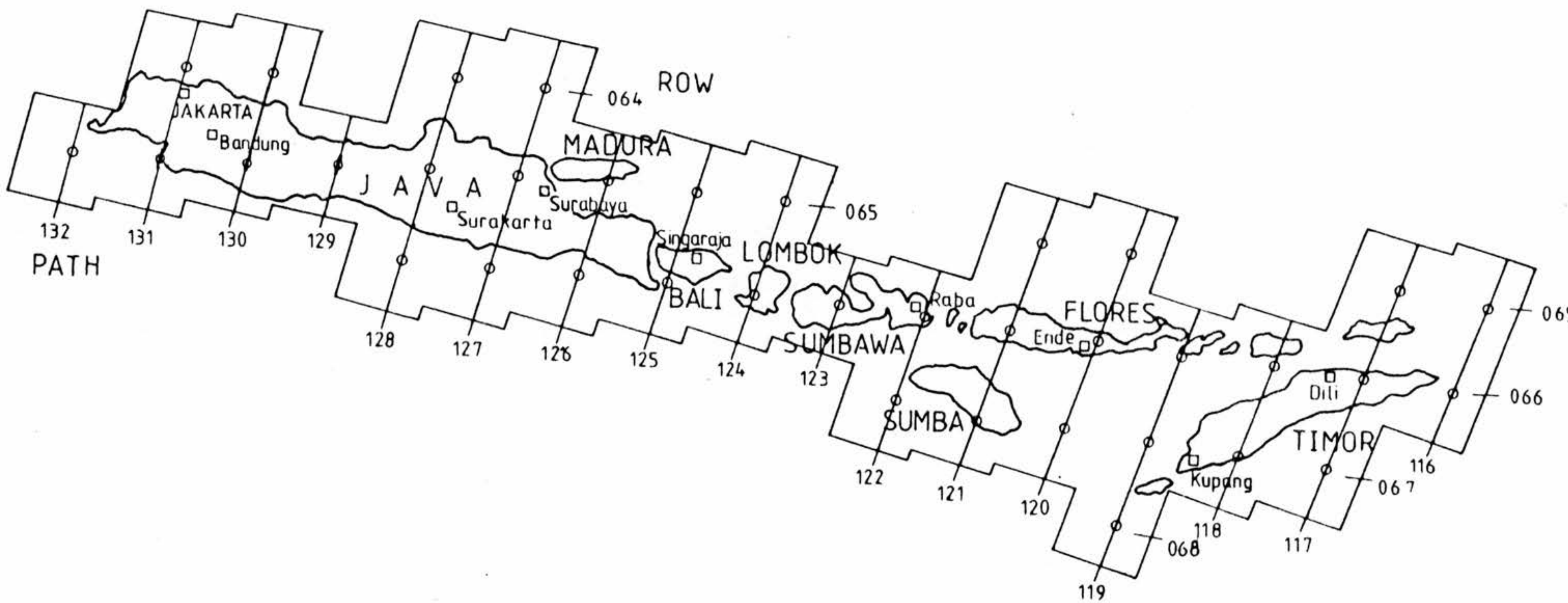

Figure 6 The Landsat 1, 2, and 3 Map Index of Java and the Lesser Sunda Island
(After NRSC, 1985)

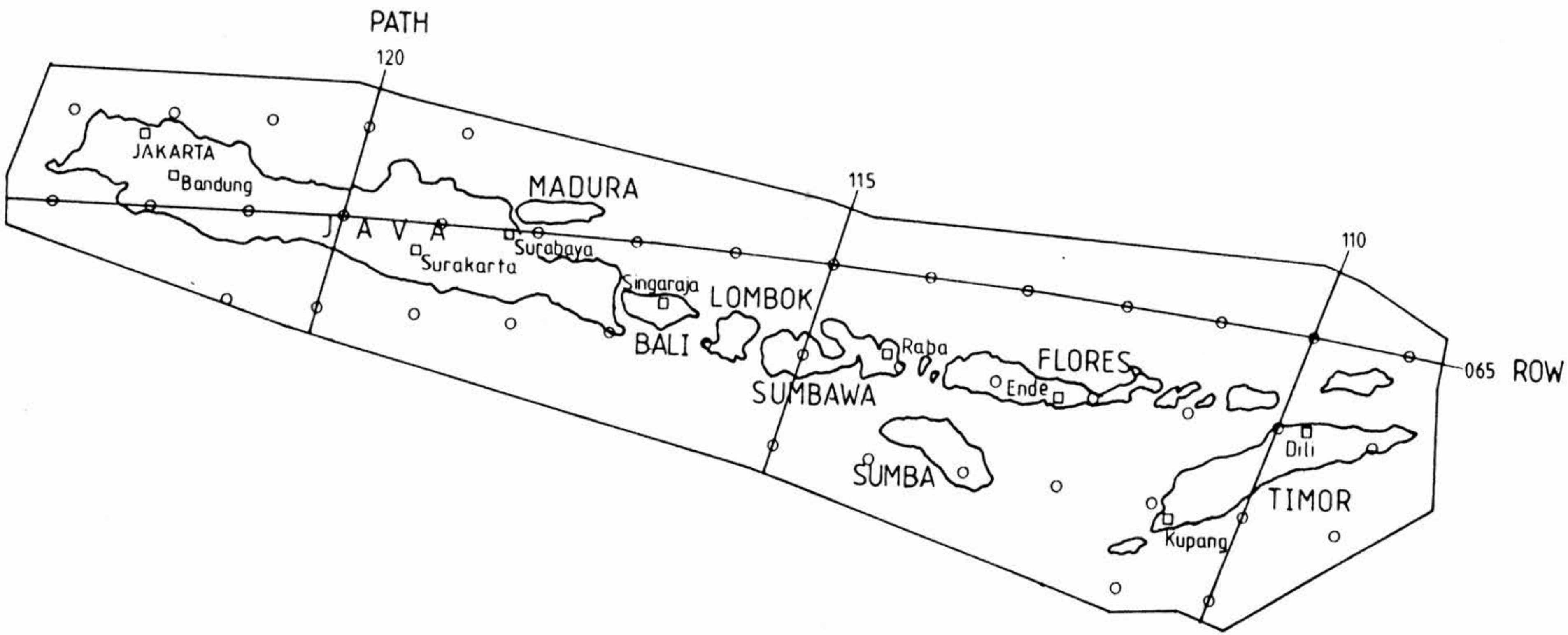

Figure 7 The Landsat 4 and 5 WRS Map Index of Java and the Lesser Sunda Islands
(After NRSC, 1985)

3.4. GEMS Digital Image Processor

A wide variety of image processing systems have been developed which can improve the quality, quantity and speed of acquisition of information from remotely sensed data. Appropriate digital methods in particular will improve the accuracy of classification and can produce processed images with far more detail.

Digital systems for processing Landsat, SPOT and other images have been developed by a number of universities, government facilities and commercial organization. One of these is GEMS, made by Computer Aided Design Centre, United Kingdom (Curran, 1985), which was used at the University of St. Andrews for this research. GEMS is an image processing instrument and GEMSTONE is the software system that controls Gems (Bagot, 1986). The system consist of a dedicated memory unit interfaced to the Vax main frame and accessed from the black and white monitor and the Gems operator console via a system of interactive software packages. This system operates using a default system to guide the user through a series of interactive menus. Contrast stretching, density slicing and mathematics operations are part of the master menu in this software and each minor menu has primary and secondary commands.

Landsat images are generally studied as false colour composites with bands 4, 5 and 7 in the whole image or extracts being displayed on 512 by 512 pixels. Automatic programs can be used for contrast stretching of the image, however, it was generally found that manual linear stretching gave the best result. Landsat MSS may produces data containing striping or banding, Gemstone provide three methods of removing the stripes on an image.

Image enhancement is useful to improve the visual interpretability of an image by increasing the apparent distinction between the features in the scene (Lillesand and Kiefer, 1987). A number of image enhancement techniques are available in the GEMS including smoothing, edge enhancement, and principal component analysis.

Image classification in Gemstone allows the user to carefully examine the image and locate areas of spectral homogeneity as training areas. The methods for classification are supervised box classification (parallelepiped), supervised maximum likelihood and unsupervised classification. An image masking technique can be used to exclude certain image areas from classification.

The result of classification will be displayed in the colour monitor and allows 35 mm colour slides or negative film to be taken from the static camera.

CHAPTER 4

LAND COVER OF CENTRAL WEST JAVA

In this chapter the Landsat imagery of the study area, the land cover scheme of West Java, ground information sources, image classification and the result of Landsat images classification of 1976 and 1985 will be discussed.

4.1. Landsat Imagery of the Study Area

The Landsat group of earth's resource satellites have been operational since 23 July 1972, and almost all of the world has been scanned to date. Although Landsat has repetitive scanning within 18 days, it does not mean that every frame of Landsat ground track in every orbit will be useful due to cloud cover and image quality problems. Furthermore, it is quite often difficult to obtain a good image as required, particularly in tropical countries where cloud cover is the most frequent and significant problem. In West Java, only 11 images which have cloud cover less than 30% have been acquired during the period 1971 - 1983, and no more than six were of good quality (Malingreau, 1986).

Landsat data of Indonesia, can be ordered from the Earth Resources Observation System (EROS) Data Center, South Dakota, USA. Since 1984 Indonesia has operated a new ground receiving station, which is capable of receiving Landsat MSS data. This station was essential for the Indonesian government to support development planning, especially the mapping programs. It will be easy to obtain the Indonesian imagery for many research purposes which need Landsat imagery as a data source.

Multitemporal imagery was required for land cover monitoring, even though not necessarily on aniversary dates. It is essential to get an image in the same season, and it is also necessary to use imagery which was taken in the dry season to reduce cloud cover and spectral problems. Two available scenes of Landsat on computer compatible tape (CCT) were already selected for this study. The Landsat image which covered central West Java Province was taken on 20 June 1976 and 6 July 1985 (Figure 8). The choice of images was based on three important factors in image selection. First, these images are of good quality, there is no line banding. Second, these images are free from cloud cover. Third, these two images were taken in the same season of the year, in the dry season, and this was helpful in the interpretation process.

The Landsat image of 1976 was selected from the available data in the National Remote Sensing Centre (NRSC), Farnborough, United Kingdom, archives. There are three Landsat images of Java available at the NRSC, but only one of them was of good quality, the image of path 130 / row 065, taken on 20 June 1976 (NRSC, 1985). The Landsat image of 1985 was obtained from Indonesian

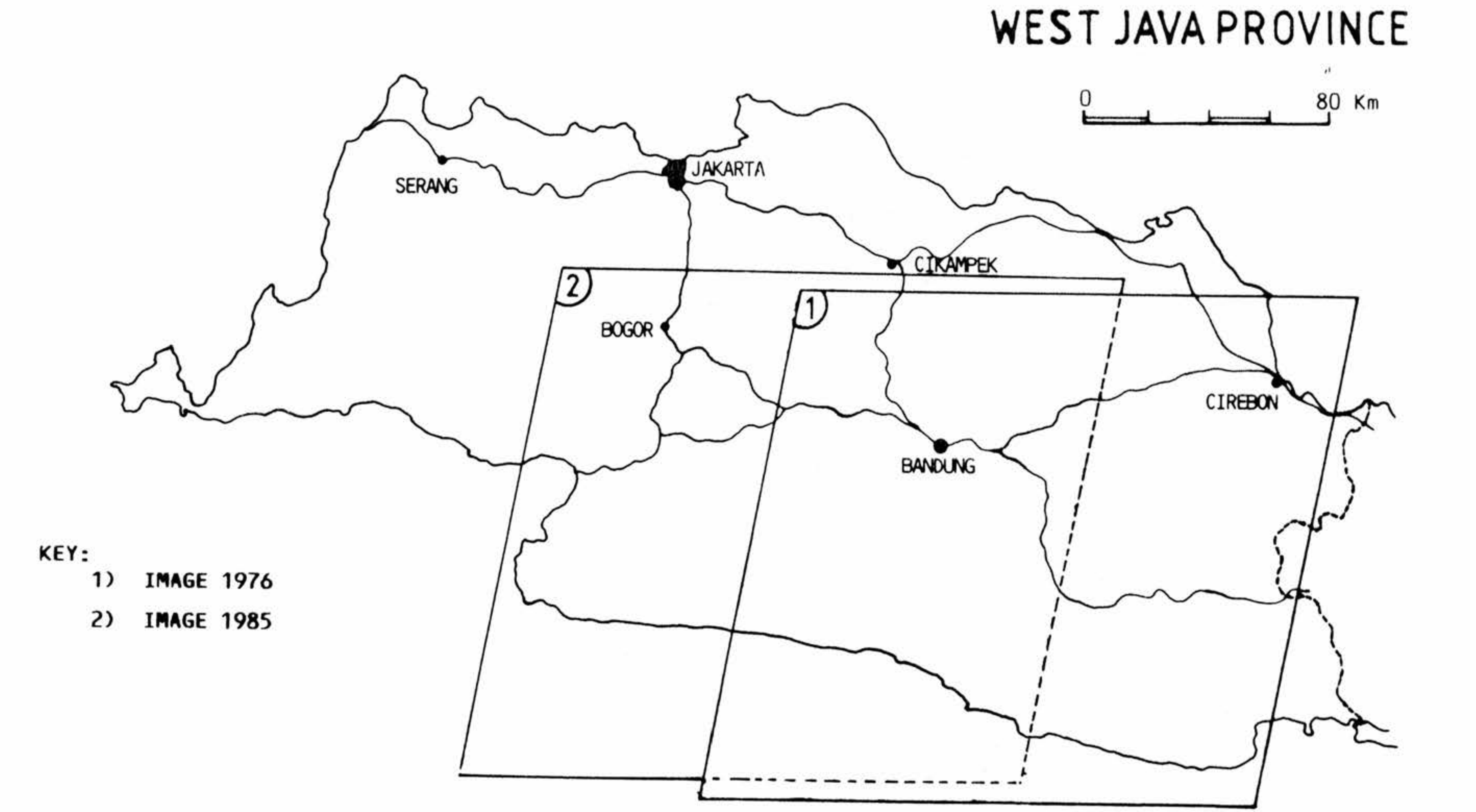

FIGURE 8 Landsat Scene Location Diagram.

Institute of Space and Aeronautics (LAPAN), this image is of good quality and has no cloud cover. There are two images available in LAPAN, but only the image of path 122 / row 065 was of use for this study. Landsat images of 1976 and 1985 were generally good, with no cloud cover and no line banding problems. Unfortunately, because of limitations on computer facilities, these images were not geometrically rectified.

The overlap area between the image of 1976 and the image of 1985 was approximately 65% due to the differences of Landsat orbit between Landsat 2 and Landsat 4. Therefore, this study will only use a part scene of these two images.

4.2. Ground Information Sources

Ground ancillary data was also needed in this study to support Landsat imagery interpretation, particularly in the training area stage. However, the result of digital image interpretation is dependent on the results of the training area stage, because better training classes will give better interpretation results. To achieved homogeneous and exact training classes, ground information data such as topographical maps, aerial photographs, land use / land cover maps, and other ground truth data are needed as a guide to the delineation training area boundaries.

In this study, two kinds of ground truth data have been obtained: topographical maps and land use / land cover maps. The best available ground information data was the land cover map at a scale of 1:50,000, compiled from the false colour infrared photographs at a scale of 1:30,000 taken in 1983. This map was published by BAKOSURTANAL in 1986 to support the land critical mapping program of Indonesia. This land cover map was very useful in indicating details of land cover types in the study area, and also helpful for guidance in the location of training area boundaries. The land cover categories of this map are shown in Table 3.

The new aerial photographs of the study area were taken in 1983 at a scale of 1:30,000 in false colour infrared, and at a scale of 1:60,000 in black and white panchromatic. All of these photographs were obtained by BAKOSURTANAL. Unfortunately, these photographs were not available from Indonesia for this study.

The other map is a land cover map of 1972 at a scale of 1:250,000, compiled by Direktorat Agraria based on land use maps of 1969, 1970 and 1971 at a scale of 1:50,000. Another land cover map is the land cover map of 1985, published by BAKOSURTANAL at a scale of 1:250,000. This map was based on several data such as manual interpretation of Landsat photographic colour composites of 1980, at a scale of 1:250.000, estate commodity maps of 1983 at a scale of 1:250,000, and land cover maps of 1972 at a scale of 1:250,000. The land cover map of 1985 was

INDONESIAN TERM	ENGLISH TERM
- Sawah irigasi	= Irrigated rice fields
- Sawah tadah hujan	= Rainfed rice fields
- Ladang	= Dry fields
- Tanaman campuran	= Mixed crop
- Kebun campuran	= Mixed garden
- Kina	= Quinine platation
- Teh	= Tea plantation
- Hutan	= Dry land forest
- Hutan campuran	= Dry land mixed forest
- Hutan pinus	= Pine forest
- Hutan bambu	= Bamboo forest
- Belukar	= Bush
- Semak	= Scrub
- Padang rumput	= Grassland
- Lahan terbuka	= Open land
- Pemukiman	= Settlement
- Bangunan Industri	= Industrial building
- Danau	= Lakes
- Tambak ikan	= Fish ponds
- Pelabuhan udara	= Airport

Table 3 Land cover categories used for land critical mapping in West Java Province at a scale of 1:50,000.

much more detailed than the land cover map of 1972, but was more complicated due to the land cover classes and map scale.

There are also two topographic maps available, the Joint Operation Graphic Ground's map at a scale of 1:250,000, published in 1966 by the Ministry of Defence, United Kingdom, and a topographic map at a scale of 1:50,000, compiled in 1966 by the Indonesian Army Mapping Division.

4.3. Land Cover Classification Scheme of West Java

Land use and land cover data are very important for many planning and management activities related to the earth's surface. These data are usually presented in map form accompanied by area statistics for every land use and land cover type.

Land use is any kind of permanent or cyclic human intervention to satisfy human needs, either material or spiritual or both, from the complex natural and artificial resources which together are called land (Vink, 1975), and land cover is vegetational, soil and artificial construction covering the land surface (Lo, 1986). It was known that land cover including natural or artificial cover was directly visible from the remotely sensed imagery, but some land uses were not usually directly visible from the imagery such as hunting and recreational activities which quite often occur on the land that would be classified as forest or range. Although the concept of land use and land cover activities are closely related and sometimes have been used interchangeably, however, it is important to define both of those for land planning and land management activities.

There is no ideal classification of land use / land cover which will satisfy the needs of all surveyors within different agencies. The USGS has devised a land use and land cover classification system for use with remote sensor data (Table 4), however, not all of this classification was useful for land use and land cover mapping in Indonesia due to the various type of land cover characteristics in many parts of this country. Furthermore, resource inventories and evaluation carried out in various part of the Indonesian archipelago are usually prepared and mapped using a wide diversity of land use / land cover classifications within different agencies or by different surveyors (Malingreau, 1977). To fulfil the need of a standardization in national land use / land cover classification, in 1985, BAKOSURTANAL has formulated a land cover classification for Indonesia (Table 5).

The important factor in determining success of land use and land cover mapping depend on the choice of an appropriate classification scheme. For this study, the land cover / land use classification scheme was adapted from the BAKOSURTANAL land cover classification. This classification was chosen according to the following criteria which was stated by Anderson et al., (1976):

LEVEL I	LEVEL II
1. Urban or built-up land	11 Residential
	12 Commercial and service
	13 Industrial
	14 Transportation, communication, and utilities
	15 Industrial and commercial complexes
	16 Mixed urban or built-up land
	17 Other urban or built-up land
2 Agricultural land	21 Cropland and pasture
	22 Orchards, groves, vineyards, nurseries, and ornamental hoticultural areas
	23 Confined feeding operations
	24 Other agricultural land
3 Rangeland	31 herbaceous rangeland
	32 Shrub and brush rangeland
	33 Mixed rangeland
4 Forest land	41 Deciduous forest land
	42 Evergreen forest land
	43 Mixed forest land
5 Water	51 Streams and canals
	52 Lakes
	53 Reservoirs
	54 Bays and estuaries
6 Wetland	61 Forest wetland
	62 Nonforest wetland
7 Barren land	71 Dry salt flats
	72 Beaches
	73 Sandy areas other than beaches
	74 Bare exposed rock
	75 Strip mines, quarries, and gravel pits
	76 Transitional areas
	77 Mixed baren land
8 Tundra	81 Shrub and brush tundra
	82 Herbaceous tundra
	83 Bare ground tundra
	84 Wet tundra
	85 Mixed tundra
9 Perennial snow or ice	91 Perennial snowfields
	92 Glaciers

Table 4 USGS Land Use and Land Cover Classification System for use with Remote Sensor Data (after Anderson et al., 1976).

a) SCALE 1:1,000,000	b) SCALE 1:250,000
1. Vegetated Area	1. Vegetated Area
1.1. Cultivated area	1.1. Cultivated area
1.1.1. Rice fields	1.1.1. Rice fields
1.1.2. Dry fields	1.1.2. Tidal rice fields
1.1.3. Plantation	1.1.3. Dry fields
	1.1.4. Plantation
	1.1.5. Mixed plantation
	1.1.6. Mixed crops
1.2. Non Cultivated Area	1.2. Non Cultivated Area
1.2.1. Dry land forest	1.2.1. Dry land forest
1.2.2. Wet land forest	1.2.2. Wet land forest
1.2.3. Bush and scrub	1.2.3. Bush and scrub
1.2.4. Grassland	1.2.4. Grassland
1.2.5. Swamp grass	1.2.5. Swamp grass
2. Non Vegetated Area	2. Non Vegetated Area
2.1. Open land	2.1. Open land
	2.2. Lahar and Lava
	2.3. Beach ridges
	2.4. Sand dunes
3. Settlement and Associated Non Agricultural Land	3. Settlement and Associated Non Agricultural Land
3.1. Settlement	3.1. Settlement
	3.2. Industrial building
3.2. Roads	3.3. Roads
3.2.1. Artery	3.3.1. Artery
3.2.2. Collector	3.3.2. Collector
	3.3.3. Local
3.3. Railroads	3.4. Railroads
3.4. Airport	3.5. Airport
3.5. Seaport / Harbour	3.6. Seaport / Harbour
4. Water Bodies	4. Water Bodies
4.1. Lakes or Reservoirs	4.1. Lakes or Reservoirs
4.2. Swamps	4.2. Ponds
4.3. Rivers	4.3. Swamps
4.4. Canals	4.4. Rivers
4.5. Coral reef	4.5. Canals
	4.6. Coral reef
	4.7. Offshore bars

Note: a) This classification was based on Landsat photographic colour composites at a scale of 1:250,000.
b) This classification was based on Landsat photographic colour composites at a scale of 1:250,000 and aerial photograph at a scale of 1:100,000.

Table 5 Land cover classification for Indonesia (BAKOSURTANAL, 1985 b).

1. The land cover / land use maps must be approximately 85% accurate.
2. The classification system should be suitable for use with remote sensor data obtained at different times of the year.
3. Comparison with future land use data should be possible.
4. The classification system should be applicable over extensive areas.

Land cover generalization will also occur as a result of the image classification used, the spatial resolution and the scale of Landsat imagery, the degree of homogeneity of the land cover types, and the final scale of the resultant map. For example, only extensive urban area can be classified, small urban areas will be included in some other class.

Eight land cover types were selected for this study, based on the land cover condition of West Java Province, namely, rice fields, dry fields, estates, mixed crops, dry land forest, bush and scrub, urban area and reservoirs. The definition of these land cover type will be described following, and adapted from, Malingreau and Christiani, (1981):

Rice fields are defined as cultivated areas with level and bounded fields supporting at least one crop of transplanted rice in the rotation. The fields are flooded from transplanting until a few weeks before harvest. Included in this classification are irrigation rice fields and rainfed rice fields.

Dry fields are the areas where crops are planted on the original slope, on benches, or on terraces and are supplied by rain water only. Fallows are rare and only prevail for a short time, and the seasonality is controlled by rainfall patterns. The major crops of this group are cassava, corn, sweet potatoes, soya beans, and ground nuts. Intercropping between these crops is also common.

Estates are defined as an area with tree, bush and crops managed for commercial or industrial production. The units are usually monocultural although intercropping can be found. Tea estates are the most extensive commercial estate area in West Java, and the other common estates were quinine and rubber.

The mixed crop class consists of fields occupied by field crops, mixed with trees and bush crops (often fruits). Bamboo and fruit trees (coconut, bread fruit, banana, papaya) are usually predominant in the upper storey of mixed crops.

Forest is defined as land covered with trees that form a natural biological living community with its environment and which is declared as such by government. Dry land forest is a forest area which is found in the drier part of a well drained site, such as on the mountains or foothills.

The bush and shrub class is defined as a shrubby formation composed of low woody plants, often interpersed with trees and grass. Often this indicates that human activities have taken place within the original tree formation.

Urban areas are defined as settlement or built-up areas which are areas of intensive use with much of the land covered by building structures. Included in this category are cities, towns, and villages.

Reservoirs are defined as impounded bodies of water or controlled lakes in which water is collected and stored for irrigation, flood control, hydroelectric power, recreation etc.

4.4. Image Classification

A Landsat MSS image consists of 7.5 million pixels per channel or about 30 million pixels per scene of 4 bands. In each pixel, the spectral reflectance is recorded in four different wavelength bands, therefore, every pixel will be characterized by its spectral signature within different wavelength bands.

The intensity value of a pixel which is recorded by a digital number (DN) depends on the level of electromagnetic energy received by the sensor from the earth's surface and the number of intensity levels that have been used to describe the intensity range of the image. Many remotely sensed image are given an 8 bit intensity range which stretched from 0 for low radiance to 255 for high radiance, or from black to white in the grey scale.

Hybrid two methods of Landsat image interpretation include (1) manual interpretation based on the photographic Landsat image and (2) automatic interpretation by using a digital image processing system. Image classification is one of the steps in digital image processing. The objective of the image classification operation is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand and Kiefer, 1987). The result of this categorisation may then be used to produced thematic maps of the present land cover of an image. In the image classification process, the visual analysis of the image data will be replaced with quantitative techniques for automating identification of feature in the image. In particular, the analysis of multispectral image data and also statistical analysis will be used as a basis for decision making to determine the land cover identity of each pixel in an image.

The two general methods of image classification are supervised classification including the box classifier, maximum likelihood classifier and density slicing, and unsupervised classification (Curran, 1985).

Supervised classification is a computer-implemented process through which each image pixel is assigned to a class according to a specific decision rule (Curran, 1985). In this case, the decision rule means the criterion used to establish a discriminant function during the training stage of a supervised classification. Supervised classification uses independent information such as spectral reflectance or terrain features to define training data that are used to establish classification categories. Therefore, this method will need training areas to be established. The aim at this stage is to obtain sets of spectral data that can be used to determine specific criteria for the classification of each pixel in the whole image. Thus, a training area set which is known to consist of a specific ground cover type is required, and the training data of each land cover type must be representative of all data for that class. The choice of training area should consider that (a) the location of the training area pixels should be chosen using some form of random sampling, and (b) the sample data should ideally have multivariate normal distribution (Harris,1987). To achieve this purpose, ground information and ancillary data are needed as a reference framework in deciding training area boundaries. Homogeneous training areas will result in accurate classification. However, errors in the decision making process may be unavoidable in a few cases, because in a great number of samples some pixels may be included from other classes. The result of image classification accuracy is also dependent upon the numbers of land cover classes that are initially chosen. The percentage accuracy will be high among a small number of selected land cover classes, and it will be lower if land cover classes are more numerous, but much depends upon landscape complexity.

Unsupervised classification produces a grouping from a similarity of pattern in digital numbers, either decided automatically or interactively. The group of digital numbers will be chosen through the statistical histogram of the scene with an assumption that the same land cover type will have similar digital numbers and different groups will have different digital numbers. After some groups of digital numbers have been chosen, the pixels of the whole image which have similarity in each group will be automatically classified. This method is very useful if there is no available ground data or when the intepreter is unfamiliar with imagery of a new geographical area. Therefore, in unsupervised classification ground information data relating to the image pattern will, in theory, be less useful.

From the description above, it could be summarized that the main differences between supervised and unsupervised techniques are : (a) the supervised technique starts with training area classes which are used to define useful informational categories from the feature already known, and then examine their spectral separability, and (b) the unsupervised technique starts with determining spectrally separable classes of similar digital number and then the result is checked in the field afterwards.

A discussion of the supervised classification of the box classifier and maximum likelihood, and the unsupervised classification (including density slicing) now follows :

4.4.1. Box Classifier

Box classification or parallelepiped classification is currently the most popular supervised classifier for remote sensing applications as it is faster and more efficient than other classification techniques (Curran, 1985). As discussed previously, supervised classification need a training sets of land cover types, therefore, these training areas should be representative of the intended classes.

Before using a box classification technique, all training areas which have been decided will be plotted on the scatter diagram of two different bands. One band digital number (DN) will be plotted on the X axis and another band digital number on the Y axis. For example, training area of water bodies in band 5 DN was plotted on the X axis and band 4 DN on the Y axis (Figure 9a). These two digital number will locate each pixel value in the two dimensional measurement space of the graph. Furthermore, if a pixel in band 5 has a value of 45 DN, and the same pixel in band 4 has a value of 47 DN, the measurement

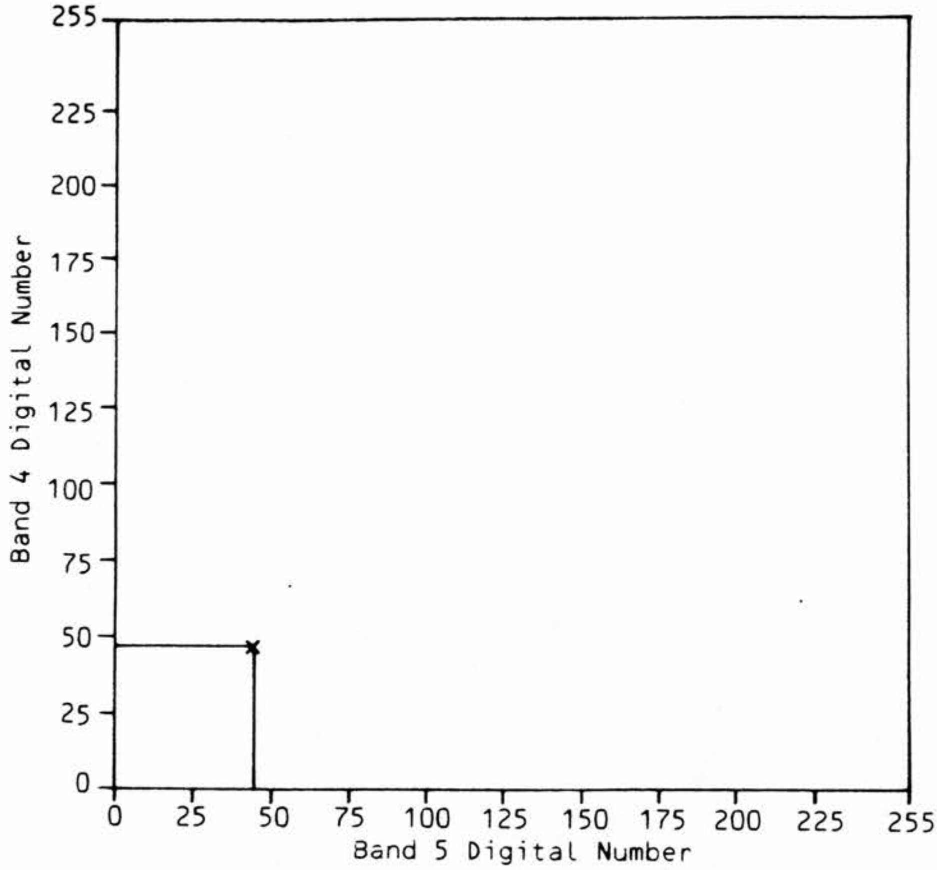

Figure 9a Two dimensional Scatter Diagram Band 4(47DN) and Band 5(45DN)

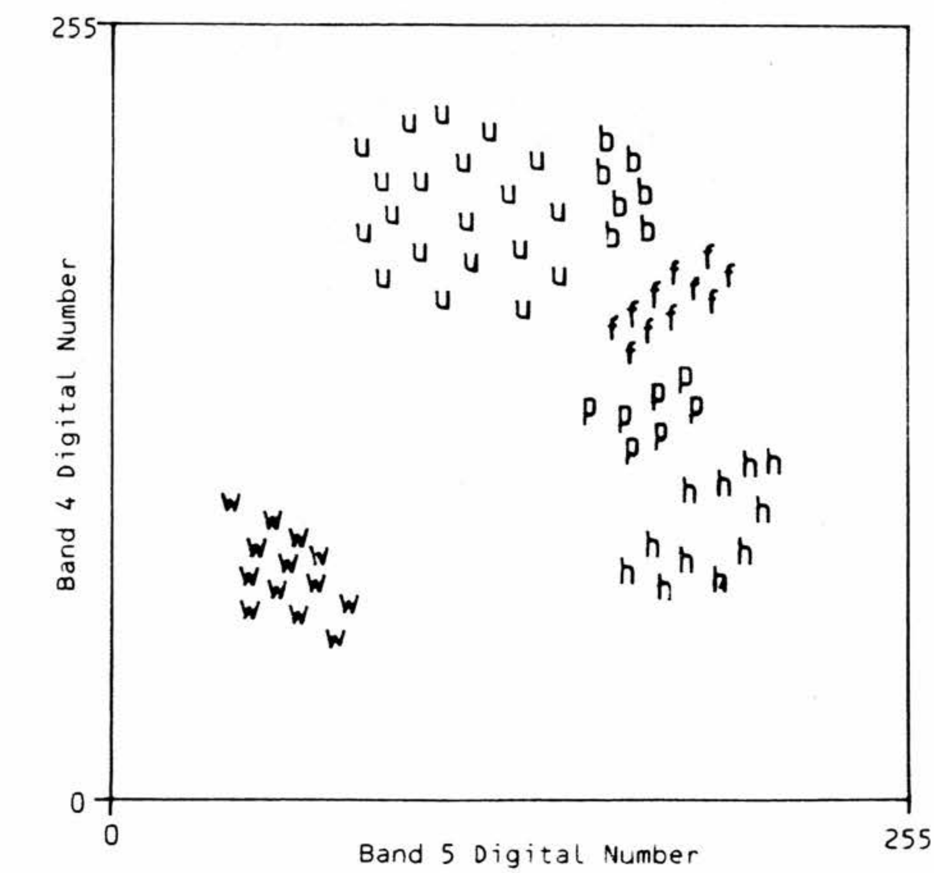

Figure 9b Pixel Observation Plotted on Scatter Diagram
(Adapted from Jewell and Taylor, 1986)

vector for this pixel is represented by a point plotted at co-ordinate (47,45). This process will continue for all of the known pixels in the training area classes (Figure 9b), however, the scattering of a cluster of pixel value is characterized by the natural variation in spectral response within each cover type.

Box classification will be used to establish qualitatively that a pixel belongs to a specific cluster, because quite often some pixels will be plotted far from these groupings. This classifier will establish the decision boundaries which separate groups and differentiate these from each other by defining upper and lower bounds of digital number value in each band of training data. This classification region will appear as rectangular boxes around each cluster of training area points in the scatter diagram (Figure 10). If an unknown pixel lies in the decision area, it will be classified according to the class limits, however, if this pixel lies outside of the decision areas, it will be grouped as unclassified. Difficulties will arise when decision areas overlap. These overlaps will occur when spectrally similar classes have been chosen for training areas or when there is a high degree of correlation between spectra of objects in different bands. This problem can be avoided by modifying from rectangles of decision area to a series of stepped rectangle boundaries.

4.4.2. Maximum Likelihood Classifier

The maximum likelihood classification is usually the most accurate classifier. As in box classification, this technique also needs training area sets. The principle of maximum likelihood classifier operates by calculating the mean vector, variance and correlation for each land cover class in the training data (Curran, 1985). This method assumes that the training data of each class are represented by a multivariate normal (Gaussian) probability distribution. Under this assumption, the spread of pixels around each mean vector can be described using a probability function. The pixel will be classified to the specific class based on the highest probability value. The probability of a pixel belonging to a class will decrease with distance from the mean vector, higher probability will be close to the main vector.

The maximum likelihood classifier's decision boundaries can be represented as a series of equiprobability contours (Figure 11). The GEMS image processing system allows the operator to choose a cut-off probability level to define the limit of contour boundaries. A high probability level restricts the class, while a low probability level allows the class to expand on the screen (Jewell and Taylor, 1986). An unknown pixel will be allocated to the class for which it has the highest level of probability using a specified cut-off limit to define the bounds of a class. If pixels cannot

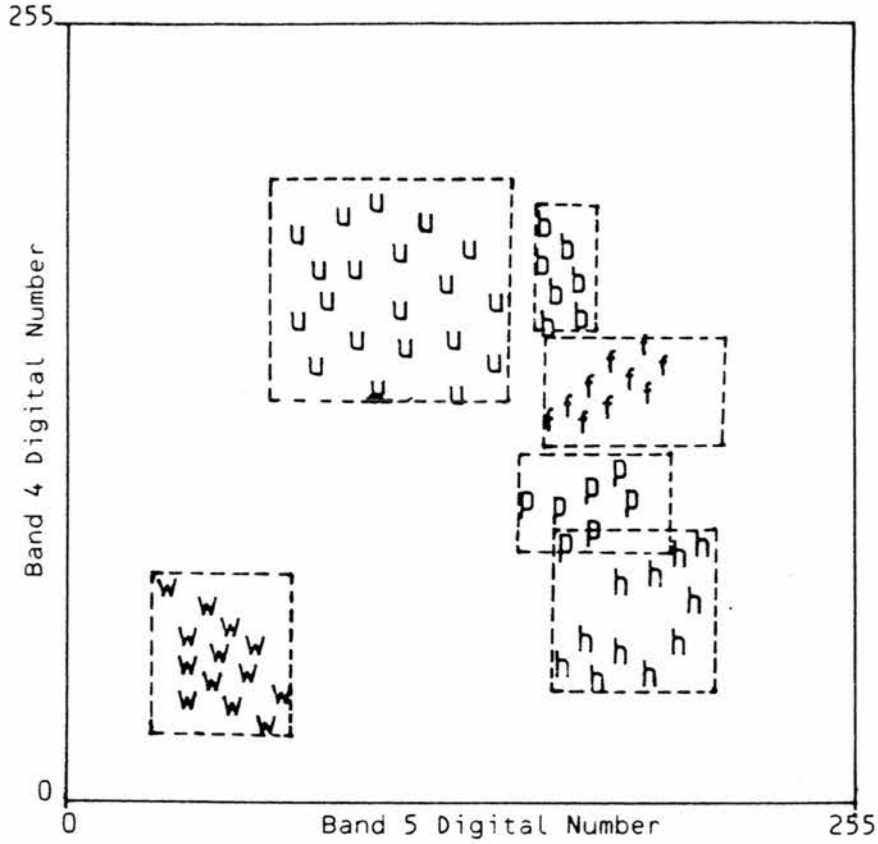

Figure 10 Box Classification Strategy
(Adapted from Curran,1985)

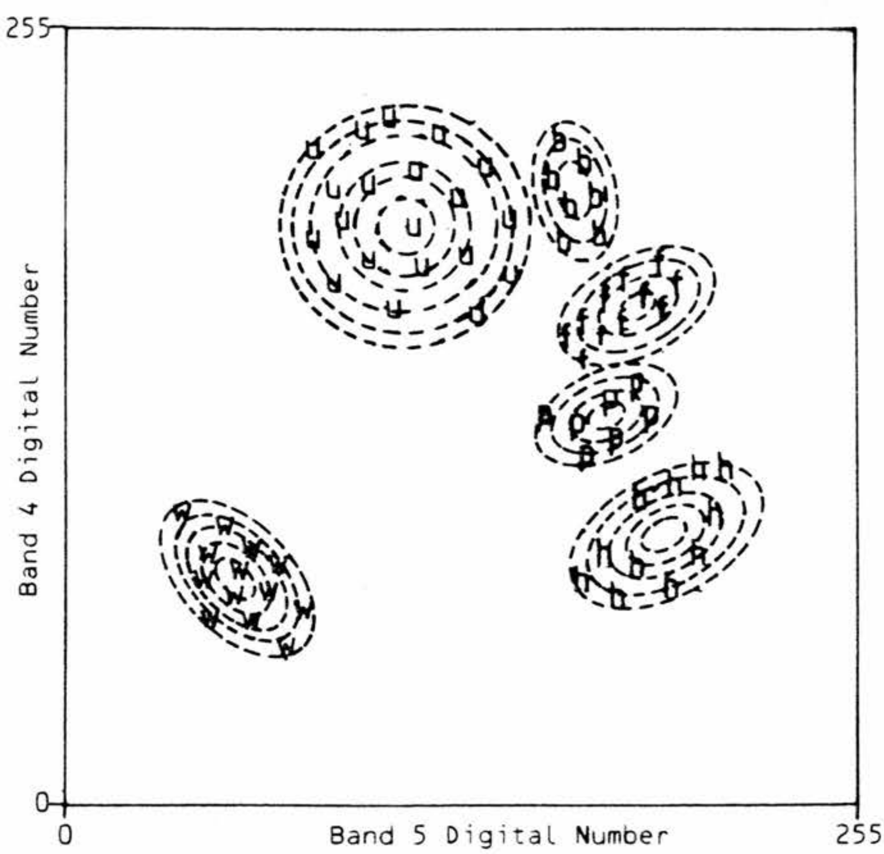

Figure 11 Maximum Likelihood Classification Strategy
(Adapted from Curran,1985)

be included in any of the class areas, they could be defined as unclassified.

4.4.3. Density Slicing

Density slicing is an interactive technique to group the contrast range of an image into a number of discrete intervals through either a histogram or the continuous grey tone of the image. In this process, the continuous grey tone (digital number) from 0 - 255 will be divided into a series of density intervals or slices interactively specified by the operator. Each pixel which corresponds to a specific range of digital numbers will be classified automatically. The range and number of slices which are defined will vary depending on the band of an image and user requirements. Different bands of an image will have different characteristics and may produce different results on slicing.

On the GEMS image processing system, the operator can see the effects of increasing or decreasing the range of brightness values within each interval through the indicator line of grey tone scale, and the result of this process can be seen directly in the video colour monitor. The digital range of each slice is decided by rolling the track ball, and while the track ball is rolled, pixels related to the slice will appear in the chosen colour. It enables the user to see the spatial distribution of the pixel values and to relate a slice to a specific type of ground feature. However, it should be agreed that every digital range is related to a particular type of ground cover. A maximum of sixteen density slices can be specified on one image and the pixel numbers in each slice can be calculated automatically. This technique is useful to recognize the characteristics of spatial distribution of pixel values before using a supervised classification or before deciding training area boundaries.

4.4.4. Unsupervised Classifier

As previously discussed, unsupervised classifications do not utilize training area data as the basis for classification, even though this technique is also based on clustering. Without an exact knowledge of the feature to be encountered, the pixels of the remotely sensed data are grouped into a number of classes (Hartl, 1976). Grouping of patterns within the feature space use some measure of nearness to define clusters, the positions of which are then used to define class limits.

The classes that result from unsupervised classification are spectral classes because they are based on the natural grouping of the image's pixel values, and in this the identity of the classes will not be known previously. The identification of the classes will be obtained by ground check after the classification has already been completed.

In GEMSTONE, unsupervised classification is carried out by effectively searching an n-dimensional histogram for the between cluster minima with suitable adjustments being made for noise and noncontinuous data (Jewell and Taylor, 1986). The principles of GEMSTONE unsupervised classification process is discussed briefly as follows :

At first, the n-dimensional feature space histogram (Figure 12) is created by dividing the intensities of each band into groups the size of which is set by the intensity resolution. This procedure is necessary because of the spurious features which might be produced due to noise or noncontinuous data, and also because of the limited storage space of a histogram. The histogram is then searched for the feature space bin which contains the highest number of pixels and this bin is assigned to the first class.

The search process is then repeated for the next bin which has the highest number of pixels. When the bin is found, its location in feature space is then compared with the location of the first class. If the distance between two points of these highest pixel numbers is less than the capture range, then this bin is assigned to the first class. If, however, the distance is greater than the capture range in any dimension, the bin is assigned to the next class (second class). This process will continued with the pixel numbers of each bin being compared to those previously classified pixels and will be assigned to the nearest class in feature space if they fall in the capture

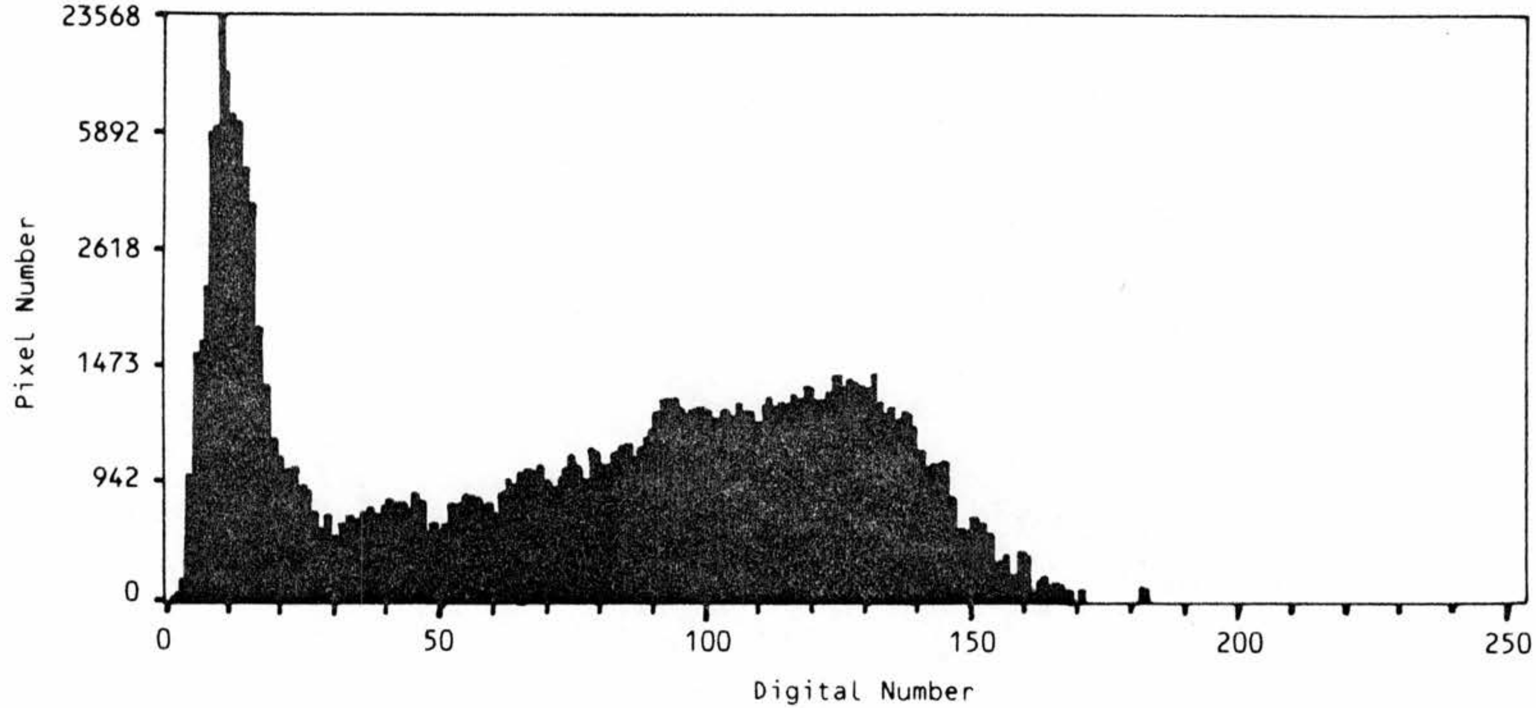

Figure 12 One Dimensional Histogram of Landsat Data before binning (After Jewell and Taylor, 1986)

range or it will be used to create a new class if out of the capture range. This process will continue until all remaining bins are classified, and up to 255 possibly classes can be formed in this manner. The result of this binning for a one dimensional histogram can be seen in figure 13.

When the clustering process has terminated, the process could be continued with editing, because some resulting clusters may have a zero width in one or more dimension, thus producing a low probability of any data being classified. Furthermore, classes can either be deleted or merged with other nearby classes to form a new class.

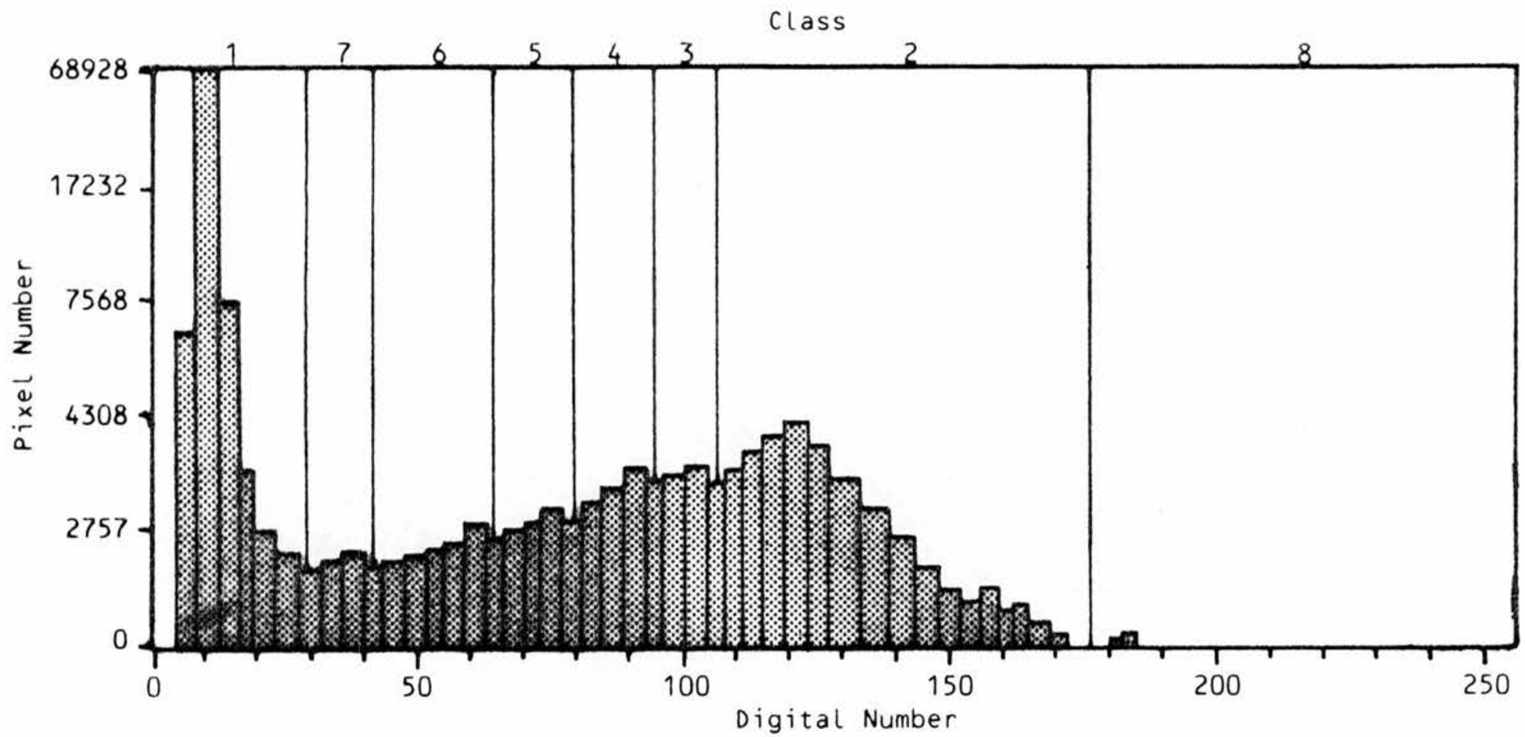

Figure 13 One Dimensional Histogram of Landsat Band Data after binning
(After Jewell and Taylor, 1986)

4.5. Land Cover 1976 - 1985

In this section, choice of study extract, box classification of images 1976 and 1985, and main land cover types of the study area will be discribed briefly.

4.5.1. Choice of Study Extract

It is an advantage for land use / land cover map makers that each Landsat image as a mapping data source has an areal coverage of approximately 185 X 185 kilometers. However, in an extensive area which has a variety of landform and complex land cover, some problems will arise during image classification processing particularly in spectral pattern recognition. In West Java province, different altitudes will have different weather condition, and different land forms have different land use / land cover, all of which could affect the spectral response.

To reduce misclassification risk during image processing due to the uncertainties of spectral resolution and to enlarge the image scales, it was necessary to define study extracts whithin the images of the study area. As the study area cannot be processed at full resolution, these study extracts were selected in order to (a) cover an area in which as many land cover types occur which represent the whole study area, (b) cover areas where suspected land use / land cover changes have occurred within a complex land use / land cover pattern.

To achieve the purpose of this study (comparing two different images acquired at different dates), and to facilitate superimposing those two different images, it was essential to match one to another due to differences in space craft position, altitude, and attitude (Sabins, 1978). Furthermore, ground control points (GCPs) must be decided upon before defining study extracts. GCPs needed to be detectable, well-defined, and recognizable features that can be located accurately on maps and on the corresponding image (Mather,1987). Ideally GCPs could be as small as a single pixel and easy to identified against its back ground, such as an intersection of a major highway, distinctive water bodies, stream junction, edges of land cover parcels and similar features (Campbell, 1987).

In this study, GCPs were chosen to define the starting point of line and pixel on the upper left corner of the study extract's boundaries, therefore, the image matching could be done more accurately. As these GCPs were only for deciding the boundaries of the study extracts, these two images were not geometrically changed.

Using the GEMS image processing system, the study extract boundaries can be decided automatically using the "define extract" routine. In particular the size of extracts must be 512 X 512 pixels, but because of technical problems in the GEMSTONE software, the extract size of image 1976 was only 496 X 468 pixels while the extract size of image 1985 was only 472 X 457 pixels.

Nevertheless, this problem did not influence the superimposing activity because the upper left corner of study extracts from image 1976 was matched to the image 1985.

Three different GCPs have been selected to define three different study extracts. Part of the Citarum river was determined as the first GCP for the Saguling study area. This GCP was chosen because it is easy to detect on both dates of Landsat image and there are no reflectance changes between 1976 and 1985. The Saguling study extract was chosen to consider some obvious land cover changes such as a new reservoir which replaced extensive areas of some land cover types, and forest areas which changed to another cover type. The second GCP was decided for the Malabar study extract using Cileunca reservoir as a reference, while the crater lake of Mount Tangkuban Perahu was decided as the third GCP to define the Bandung study area. In order to minimize misclassification which might occur between the Bandung urban area and rice fields nearby, and also to see the changes in the urban areas between 1976 and 1985, the Bandung study extract has been reduced from about 232,000 pixels into about 59,000 pixels. Most of this study area is covered by Bandung and Cimahi cities. The Malabar study area was chosen on the assumption that there would be deforestation due to the population pressure within this area or there should be reforestation in some areas due to the government policy which aims to protect and increase the forest area.

In order to find more precise locations of the extract areas, the study of image 1976 will be decided at first. Using the pixel value routine on the GEMS, the GCPs pixel value, X and Y screen co-ordinate and image co-ordinate could be identified. This GCP screen co-ordinate will then be used as reference to determine the starting pixel (X,Y) co-ordinate of the study extract's boundaries of image 1985. To define the first X co-ordinate of study area 1985, the X image co-ordinate 1985 will be substituted with X GCP screen co-ordinate of study extracts 1976, and the first Y co-ordinate of study area 1985 will be decided by substituting the Y image co-ordinate 1985 for the Y GCP screen co-ordinate of study extract 1976. The result of this process could be seen in Table 6.

Study Extract	GCPs Screen Co-ordinate Image 1976		GCPs Image Co-ordinate Image 1985		Upper Left Study Extract Co-ordinate	
	X	Y	X1	X2	X1-X	Y1-Y
SAGULING	130	93	2363	1050	2233	957
MALABAR	214	205	2867	1680	2653	1475
BANDUNG	136	6	2795	1078	2659	1072

Table 6 GCPs Co-ordinate of Study Extracts.

4.5.2. Box Classification of Image 1976 and 1985

Digital image classification is the process of analysis of the spectral signature and then automatically assigning pixels to land cover classes or themes. By using comparison from the known identity pixel to others, it is possible to define similar pixels into one required class or more.

The supervised classification, such as the box classifier which is used in this study requires estimates of certain statistical characteristics of the classes to which the unknown pixels are to be allocated (Mather, 1987). These estimates are derived from training areas or training samples. Therefore, the selection of training area will be an important step in the supervised classification. The more accurate and homogeneous the training areas selected, the more accurate the classification achieved, or in other words, the quality of the training areas will determine the success of the classification result.

Training areas based upon the spectral signature recognition of known earth surface objects will be used as samples for classification purposes. The appropriate location of training areas will be decided based on the external knowledge of the area shown on the image. Therefore, some input derived from field work, or aerial photograph analysis, or thematic maps is required. As these stages are important in the supervised classification process, Campbell (1987) suggested that there are seven categories which can affect the result of training area selection : a) the number of the pixels selected for each training area class should be at least 100, b) the size of individual training area should not be too big, to minimize involving undesirable pixels. The recommended size of each training areas is about 10 to 40 pixels, particularly for Landsat MSS data, c) the shapes of the training areas should be square or rectangular as it is easy to define and to minimize the number of vertices that must be specified, d) each category should be represented by several training areas positioned throughout the image and should be easy to detect from aerial photographs or thematic maps, e) each information category should be represented by a minimum number of about 5 to 10 training areas, to make certain that differences in spectral values of each class are represented. It usually better to define many small training area than to use only a few large areas, f) training areas should be placed to avoid pixels located along the edges between land cover types, g) data within each training area should be uniform and show unimodal frequency distribution in each band to be used.

In this study, training areas of three different study extracts will be defined based on those criteria with an assumption that using those categories the better training area could be achieved. Beside the requirement as mentioned above, it was necessary to recognize the pseudocolour of image colour composites for each land cover type in order to located the training area in the correct place. The description of every land cover type will also be considered in the following discussion.

Eight training classes from the Saguling study extract have been selected for image 1976 (Plate 1) and 1985 (Plate 2), and represent seven land cover types, namely, rice fields, forest, bush and shrubs, dry fields, mixed crops, reservoir, and shadow. Two of the training classes were assigned to rice fields, but more than two different rice field spectral classes can be recognized due to the different growing stages. However, because of limitations on computer facilities for the box classification method only 8 classes are available and in order to retain space for other cover types, rice fields will be generalized only into 2 classes. Rice fields class one incorporates fallow, field preparation, and the growing crop stage, while class two was assigned to full cover and maturing stages. This generalization was also based on the visual analysis of both colour composites images of 1976 and 1985 in which only three major different colour can be identified. These colour differences represent three different growing stages (Table 7).

From colour composite imagery, identification of rice fields showed that rice fields 1 was represented by light green to dark green and light blue to dark blue colours, and that rice fields 2 was represented by reddish to red

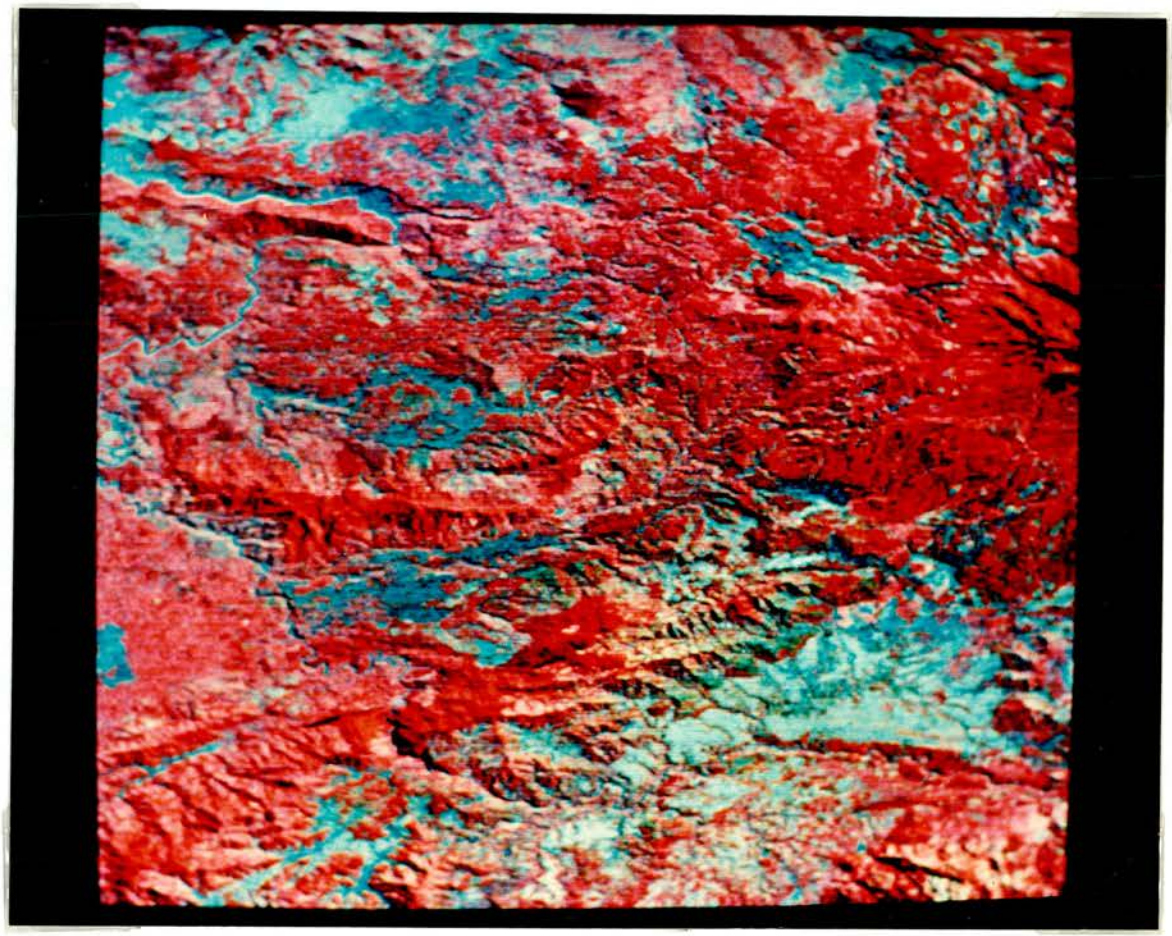

PLATE 1 Landsat Colour Composites Band 4, 5, and 7 of Image 1976, Saguling Study Area (after stretching).

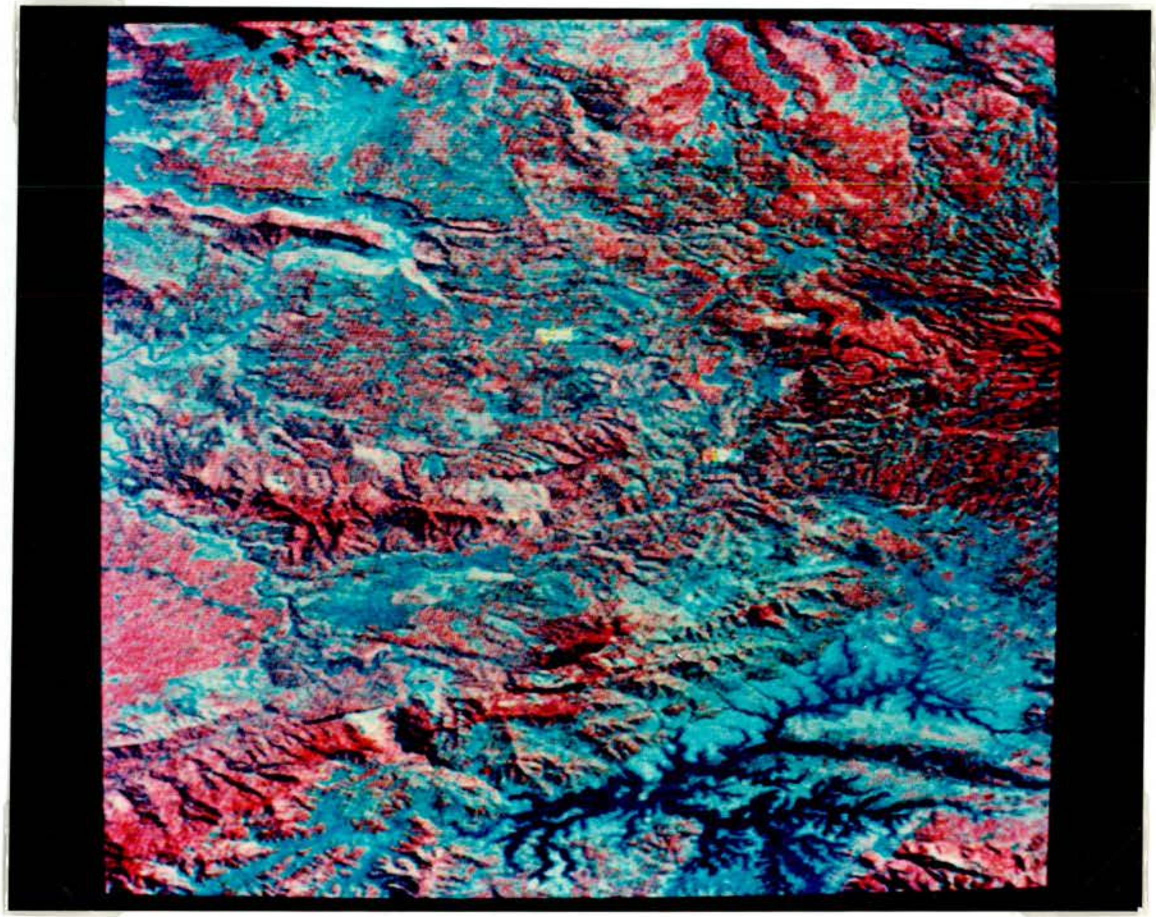

PLATE 2 Landsat Colour Composites Band 4, 5, and 7 of Image 1985, Saguling Study Area (after stretching).

Crop stage	Enhanced colour composite image (bands 4, 5, and 7)	Single-band MSS images 4	5	6	7
1. Fallow	light grey, light yellow; brown and green patches	white-light grey	white-light grey	white-light grey	white-light grey
2. Field preparation	dark blue, blue, dark to light green	medium grey	medium grey	dark grey	dark grey-black
3. Transplanting	dark blue, blue, dark to light green	medium grey	medium grey	dark grey	dark grey-black
4. Growing crop (tillering)	pink, blue	medium grey	dark grey	light grey	light grey
5. Full cover; end of vegetative period	red (bluish tint)	dark grey	dark grey-black	light grey	light grey-white
6. Maturing	reddish-orange	medium grey	medium grey	light grey	light grey
7. Maturing	orange, yellow, some pink	medium grey	medium grey	light grey	light grey
8. Stubble/fallow mix	yellow, pink, blue, green	mix of different tones			

Table 7 Photophenological Calendar for Rice Fields of Java Island (after Malingreau, 1986)

colour. It could also be recognized that most rice field areas were located on flat terrain. Forest areas, represented by red to dark red colour, covered hilly areas, therefore, this cover type will have a varied spectral reflectance. Shadowed forest, located in the steeply sloping areas, will have a different spectral response, so these areas will be classified as shadow. Bush and shrubs were slightly difficult to recognize as these areas are mostly located on the edge of the forest area and are represented by a reddish colour. Mixed crops are quite difficult to classify in a single category due to the various spectral reflectances which are similar to other land cover classes such as rice fields, tea estates, and dry fields. In particular, this land cover class represents mixed garden and mixed crops, and is located in various topographic conditions, therefore, it will have varied spectral reflectance and various colours corresponding to various vegetation types included in this land cover class. Dry fields are more readily recognizable as this cover type is mostly located on hilly slopes and are represented by bright terrain colours of light yellow, light brown and light red.

In the Malabar study area of image 1976 (Plate 3) and 1985 (Plate 4), seven land cover types have been decided upon representing forest, rice fields, estates, dry fields, mixed crops, reservoir and shadow. Two different training classes were decided for rice fields while the other six training classes was determined for six other

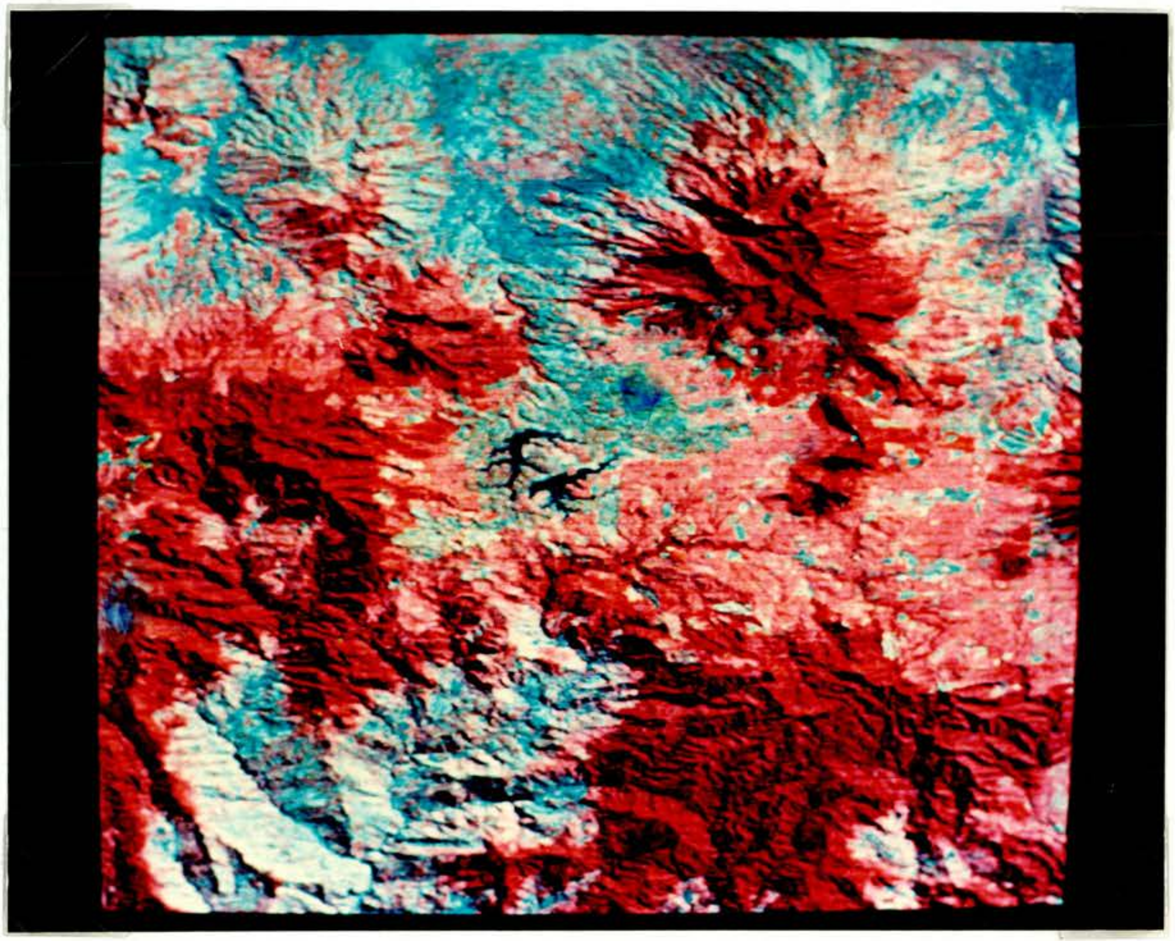

PLATE 3 Landsat Colour Composites Band 4, 5, and 7 of Image 1976, Malabar Study Extract (after stretching).

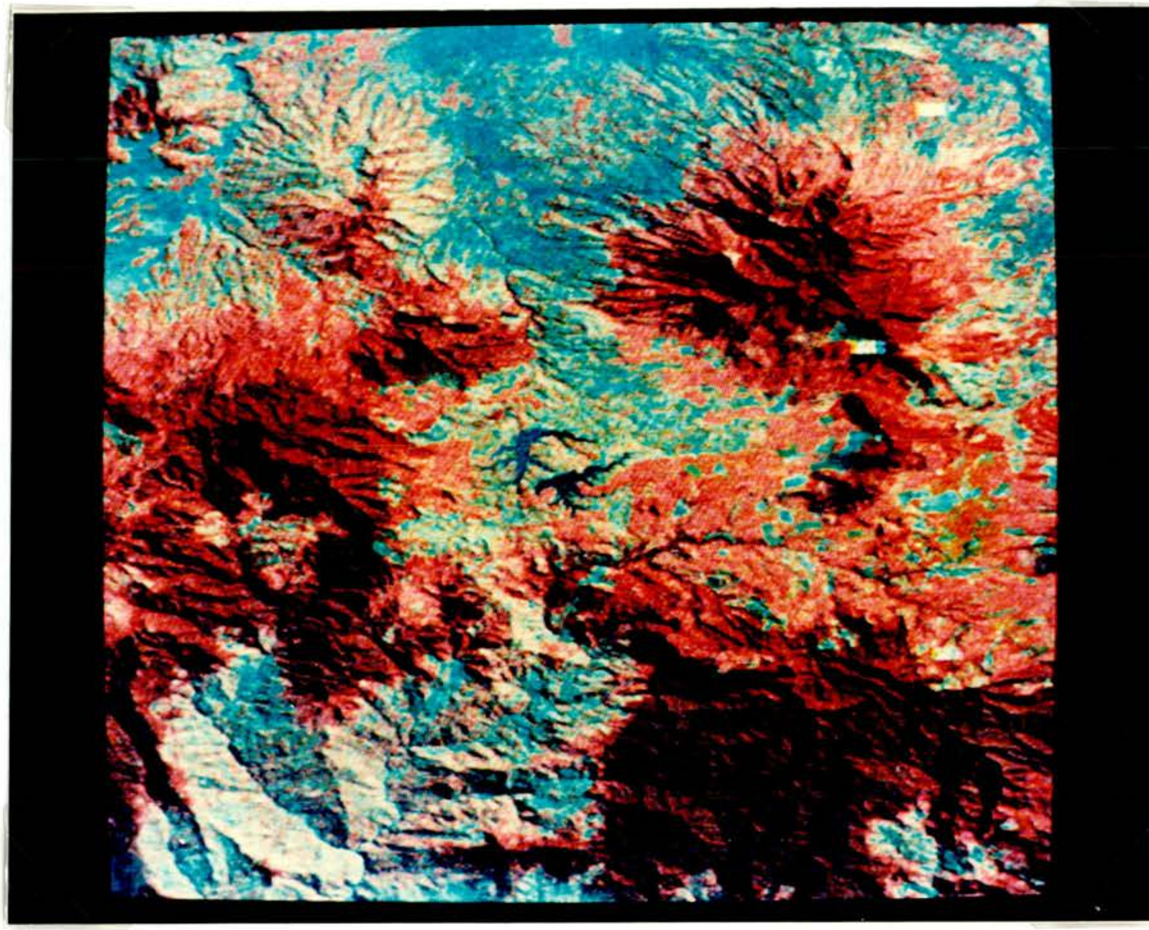

PLATE 4 Landsat Colour Composites Band 4, 5, and 7 of Image 1985, Malabar Study Extract (after stretching).

land cover types. Even though the image of this study area uses the same Landsat frame as the other two study areas, there are small differences in the colour composition of each land cover type. However, the estates cover type (which is represented by tea estates) can be detected more easily than in the Saguling study area even though this cover type also has a red colour. Most of the estates cover type is located in the undulating areas which will affect the spectral reflectance. Similar spectral reflectance to that of forest can be found in some parts of the estates areas. The forest cover class was easy to recognize as this cover type appears on the mountain or hilly terrain. Most of the rice fields are located on the flat terrain, whilst dry fields areas are wide spread and occur mostly in the foot hill zone.

For the Bandung study area, eight training class have been decided upon representing seven land cover types, namely, urban, rice fields, dry fields, forest, mixed crops, bush and shrubs, and open land. The full image of the Bandung study extract can be seen in plate 5 and after reduction using the mask routine in plate 6. As the reduced Bandung extract is limited in size, many of the land cover types occur in small parcels except for the urban area. Furthermore, it is difficult to distinguish between urban and rice fields 1 as these two land covers display similar reflectances. To locate training areas for urban areas and rice fields, the land cover map of 1985 was very helpful as this map is constructed at a large scale (1:50,000). Forest areas located to the north of Bandung city, appear only in small patches and have red colours. This class was easy to detect in the 1976 image (Plate 5) but more difficult to recognize in the 1985 image (Plate 6) as the mixed crops areas also appear in similar red colours. However, the forest training areas have been located in the same place as in the image 1976. Open land cover type, which represented new urban areas, appears in a light blue colour and is easy to identify. This cover type can be found mostly on the 1985 image and is located in the former rice fields areas of 1976.

After training classes have been defined, the box classifier is used to classify the unknown pixels based on the statistical data obtained from training areas. Therefore, the result of the classification will depend upon the training area statistics data. As was discussed in a previous chapter, the box classifier is used in this study because of its fast and efficient use of computer time. Furthermore, the training area statistics of the study areas such as mean, standard deviation, upper and lower limits of spectral reflectance range can be obtained using supervised box classifier routine (Tables 8 - 13).

To analyse land cover class separability, the upper and lower limits of the training classes reflectance can be plotted in the individual band diagrams (Figures 15 -20) and the result of the class separability analysis are presented in the matrix of training class separability (Tables 14 -16). One land cover class can definitely be

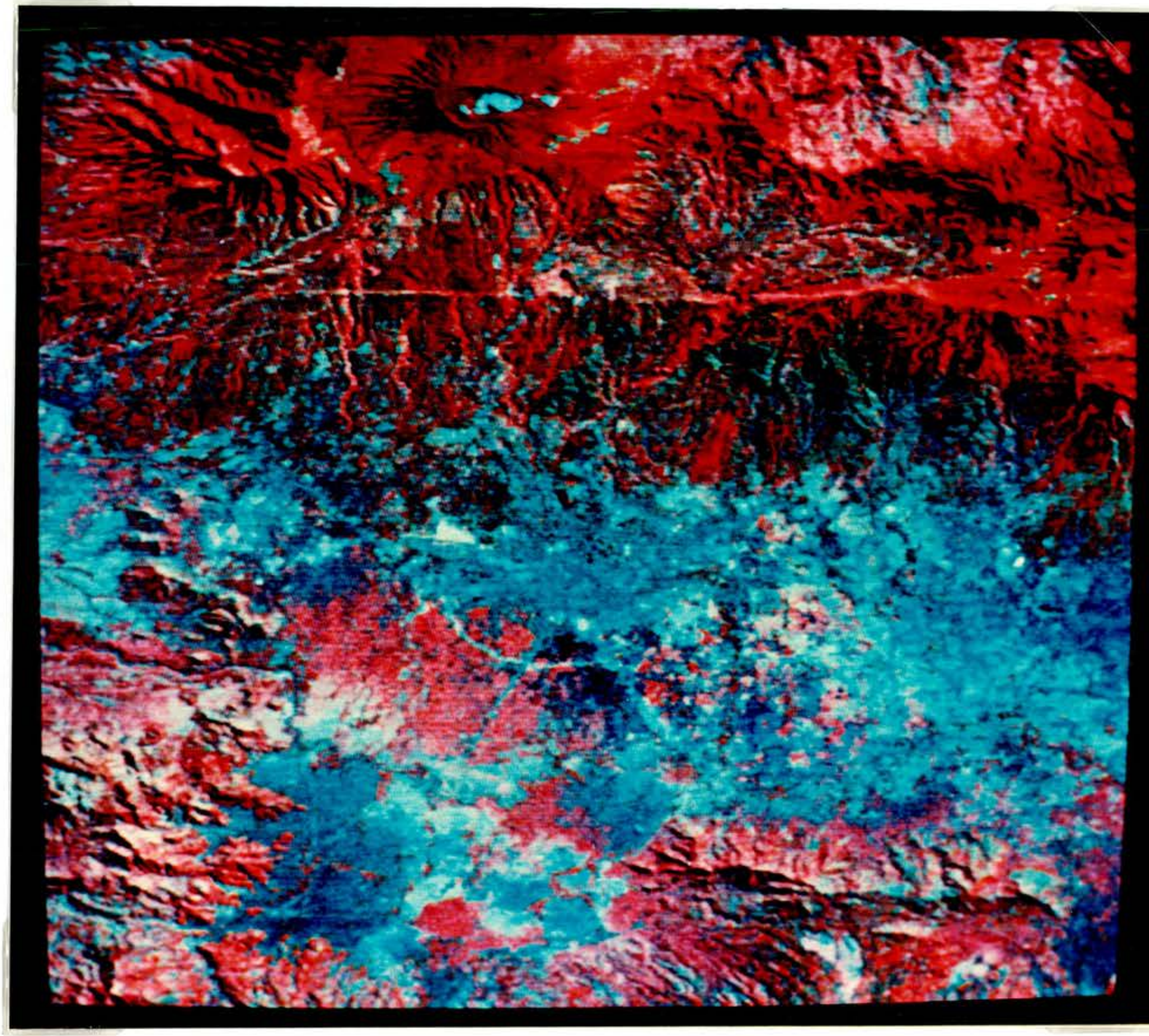

PLATE 5 Landsat Colour Composites Band 4, 5, and 7 of Image 1976, Bandung Study Extract at full coverage (after stretching).

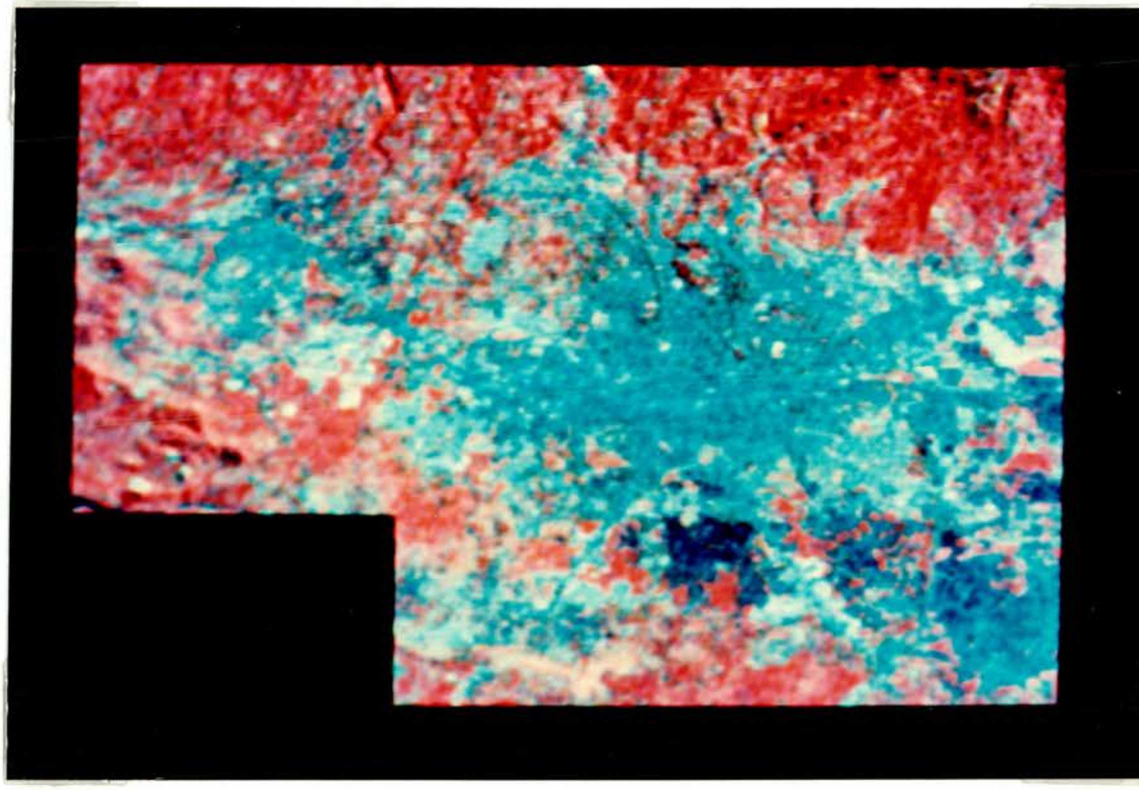

PLATE 6 Landsat Colour Composites Band 4, 5, and 7 of Image 1985, Bandung Study Area after Masking (Stretched image).

No. T.C.	TRAINING CLASS	No.T.A. (Pix.)	Band 4				Band 5				Band 7			
			Low (DN)	High (DN)	Stand. Dev.	Mean	Low (DN)	High (DN)	Stand Dev.	Mean	Low (DN)	High (DN)	Stand. Dev.	Mean
1.	FOREST	342	10	15	0.96	12.0	9	15	1.2	11.3	25	35	2.4	29.5
2.	RICE FIELDS 1	334	13	27	2.60	18.2	14	36	4.6	23.0	5	19	3.9	12.8
3.	RESERVOIR	552	17	28	2.90	23.1	19	29	2.9	24.0	1	12	2.7	2.8
4.	DRY FIELDS	177	14	38	3.95	17.2	14	60	7.0	20.9	18	29	2.8	23.5
5.	BUSH & SHRUBS	106	12	18	1.3	15.5	10	17	1.4	14.0	23	33	2.1	27.9
6.	MIXED CROPS	98	10	15	1.0	12.4	8	16	1.5	12.6	8	18	2.0	14.1
7.	SHADOW	560	5	12	1.7	8.3	3	10	2.0	6.0	1	14	3.9	6.4
8.	RICE FIELDS 2	96	12	16	0.9	13.7	10	13	0.8	11.8	19	22	1.0	20.7

Table 8 Training Area Statistics of Saguling Study Area 1976

No. T.C.	TRAINING CLASS	No.T.A. (Pix.)	Band 4				Band 5				Band 7			
			Low (DN)	High (DN)	Stand. Dev.	Mean	Low (DN)	High (DN)	Stand Dev.	Mean	Low (DN)	High (DN)	Stand. Dev.	Mean
1.	FOREST	86	22	32	1.98	27.9	17	28	1.8	22.8	102	144	8.5	126.8
2.	RICE FIELDS 1	201	28	48	4.5	37.6	26	56	7.3	40.1	39	83	10.7	63.0
3.	RESERVOIR	1764	23	49	7.3	33.2	17	48	8.3	27.4	7	49	6.9	15.7
4.	DRY FIELDS	152	33	75	6.8	41.8	29	77	11.3	41.6	69	131	19.7	96.6
5.	BUSH & SHRUBS	113	28	37	2.3	33.1	20	29	1.9	25.0	104	137	8.6	118.1
6.	MIXED CROPS	202	22	34	2.7	26.9	14	29	3.0	22.8	16	88	13.6	67.9
7.	SHADOW	481	16	29	2.8	23.3	11	23	2.9	18.0	24	74	11.0	51.8
8.	RICE FIELDS 2	109	27	34	1.7	30.1	20	27	1.5	23.5	89	107	4.6	97.9

Table 9 Training Area Statistics of Saguling Study Area 1985

No. T.C.	TRAINING CLASS	No.T.A. (Pix.)	Band 4				Band 5				Band 7			
			Low (DN)	High (DN)	Stand. Dev.	Mean	Low (DN)	High (DN)	Stand Dev.	Mean	Low (DN)	High (DN)	Stand. Dev.	Mean
1.	FOREST	310	7	10	0.8	8.7	6	10	0.98	7.7	10	22	2.77	15.9
2.	RICE FIELDS 1	334	10	20	2.5	14.7	13	27	4.6	18.9	4	19	3.9	10.9
3.	RESERVOIR	460	7	12	0.96	9.4	4	12	1.97	7.2	1	11	3.2	2.4
4.	DRY FIELDS	99	11	17	1.4	13.7	12	20	1.87	15.5	17	32	3.1	25.5
5.	MIXED CROPS	162	10	14	0.97	11.5	9	16	1.4	13.0	9	23	2.98	16.4
6.	SHADOW	654	4	8	0.9	6.2	2	7	0.98	4.0	1	9	2.5	3.7
7.	ESTATES	453	10	14	0.8	11.4	9	13	1.0	10.8	19	31	2.3	26.2
8.	RICE FIELDS 2	171	10	18	1.1	13.8	9	19	1.49	13.9	19	27	1.63	22.7

Table 10 Training Area Statistics of Malabar Study Area 1976

No. T.C.	TRAINING CLASS	No.T.A. (Pix.)	Band 4				Band 5				Band 7			
			Low (DN)	High (DN)	Stand. Dev.	Mean	Low (DN)	High (DN)	Stand Dev.	Mean	Low (DN)	High (DN)	Stand. Dev.	Mean
1.	FOREST	352	16	26	2.0	21.3	12	23	2.4	17.3	41	91	13.9	63.3
2.	RICE FIELDS 1	296	26	49	4.4	34.5	24	52	6.1	37.3	35	81	10.8	52.7
3.	RESERVOIR	413	21	32	2.8	25.9	15	25	2.4	20.2	7	36	6.5	14.8
4.	DRY FIELDS	109	28	41	3.4	33.3	26	40	3.3	32.1	69	137	13.0	108.9
5.	MIXED CROPS	174	21	33	2.6	26.7	16	32	3.4	24.5	47	106	11.2	76.6
6.	SHADOW	734	12	23	2.3	17.6	8	19	2.4	13.1	12	53	10.0	26.6
7.	ESTATES	290	22	31	1.9	26.5	17	27	2.0	21.3	95	139	9.7	116.3
8.	RICE FIELDS 2	110	25	33	1.5	28.4	19	26	1.4	22.4	89	118	5.5	101.3

Table 11 Training Area Statistics of Malabar Study Area 1985

No. T.C.	TRAINING CLASS	No.T.A. (Pix.)	Band 4				Band 5				Band 7			
			Low (DN)	High (DN)	Stand. Dev.	Mean	Low (DN)	High (DN)	Stand Dev.	Mean	Low (DN)	High (DN)	Stand. Dev.	Mean
1.	URBAN	134	13	18	1.29	15.6	16	23	1.26	19.3	6	11	0.96	8.8
2.	FOREST,	72	9	12	0.73	10.4	6	11	0.8	8.8	14	21	1.7	16.8
3.	MIXED CROPS	87	10	14	0.88	12.1	12	20	2.2	16.8	7	14	1.4	10.8
4.	DRY FIELDS	73	13	18	1.0	15.8	15	22	1.3	18.8	17	27	2.0	22.0
5.	OPEN LAND	109	19	59	7.9	28.6	25	69	9.96	34.2	9	26	4.3	14.8
6.	RICE FIELDS 2	209	11	15	1.06	12.9	10	14	1.0	11.6	15	27	2.85	23.1
7.	RICE FILEDS 1	117	10	19	2.1	14.6	9	23	3.4	14.9	2	17	3.98	6.8
8.	BUSH & SHRUBS	126	8	12	1.0	9.7	5	13	1.8	8.7	4	22	4.1	11.4

Table 12 Training Area Statistics of Bandung Study Area 1976

No. T.C.	TRAINING CLASS	No.T.A. (Pix.)	Band 4				Band 5				Band 7			
			Low (DN)	High (DN)	Stand. Dev.	Mean	Low (DN)	High (DN)	Stand Dev.	Mean	Low (DN)	High (DN)	Stand. Dev.	Mean
1.	URBAN	174	28	47	3.2	35.9	27	49	3.6	37.6	30	65	6.3	42.9
2.	FOREST	78	23	31	1.98	26.8	18	27	1.7	21.8	60	86	6.2	75.9
3.	MIXED CROPS	122	24	37	2.9	29.9	22	39	3.1	29.0	46	93	9.3	65.5
4.	DRY FIELDS	44	32	41	2.1	35.6	30	36	1.7	33.2	90	127	7.2	101.3
5.	OPEN LAND	179	48	110	12.99	64.7	47	136	17.2	70.4	55	128	13.1	79.7
6.	RICE FIELDS 2	190	25	37	2.2	29.6	19	30	2.1	23.7	78	114	7.2	95.9
7.	RICE FIELDS 1	268	25	47	5.4	35.2	21	59	7.7	32.6	18	66	11.1	30.9
8.	BUSH & SHRUBS	150	18	30	2.4	23.8	12	23	2.6	18.6	21	125	23.5	58.8

Table 13 Training Area Statistics of Bandung Study Area 1985

separated from another class if its spectral distribution does not overlap in one or more bands. Furthermore, a land cover class will be shown as partially separable if the data are overlapping by less than their respective means and will be inseparable if the data are overlapping by more than the respective means. Misclassification will occur when the training data are partially overlapping with, or inseparable from the other class in two or more MSS bands. The amount of misclassification will depend upon the spectral inseparability, and most problems arise when spectral data are inseparable in all of the MSS bands.

For the Saguling study area, the statistical analysis of image 1976 shows that forest and bush, rice field 1 and reservoir cannot be spectrally distinguished. The problem of inseparability in two bands and partially separable in another band occurred with rice field 1 and mixed crops, as well as dry fields and bush. In image 1985, the inseparable spectral reflectance occurred between mixed crops and reservoir. Inseparable in two bands and partially separable in another band occurred between forest with rice field 2 and bush, rice field 1 with dry fields and reservoir, rice fields 2 with bush, and mixed crops with shadow.

In the Malabar study area, the statistical analysis of image 1976 shows that there is no inseparable spectral signature within land cover classes. Most problems occur through two bands being inseparable but the difficulty is

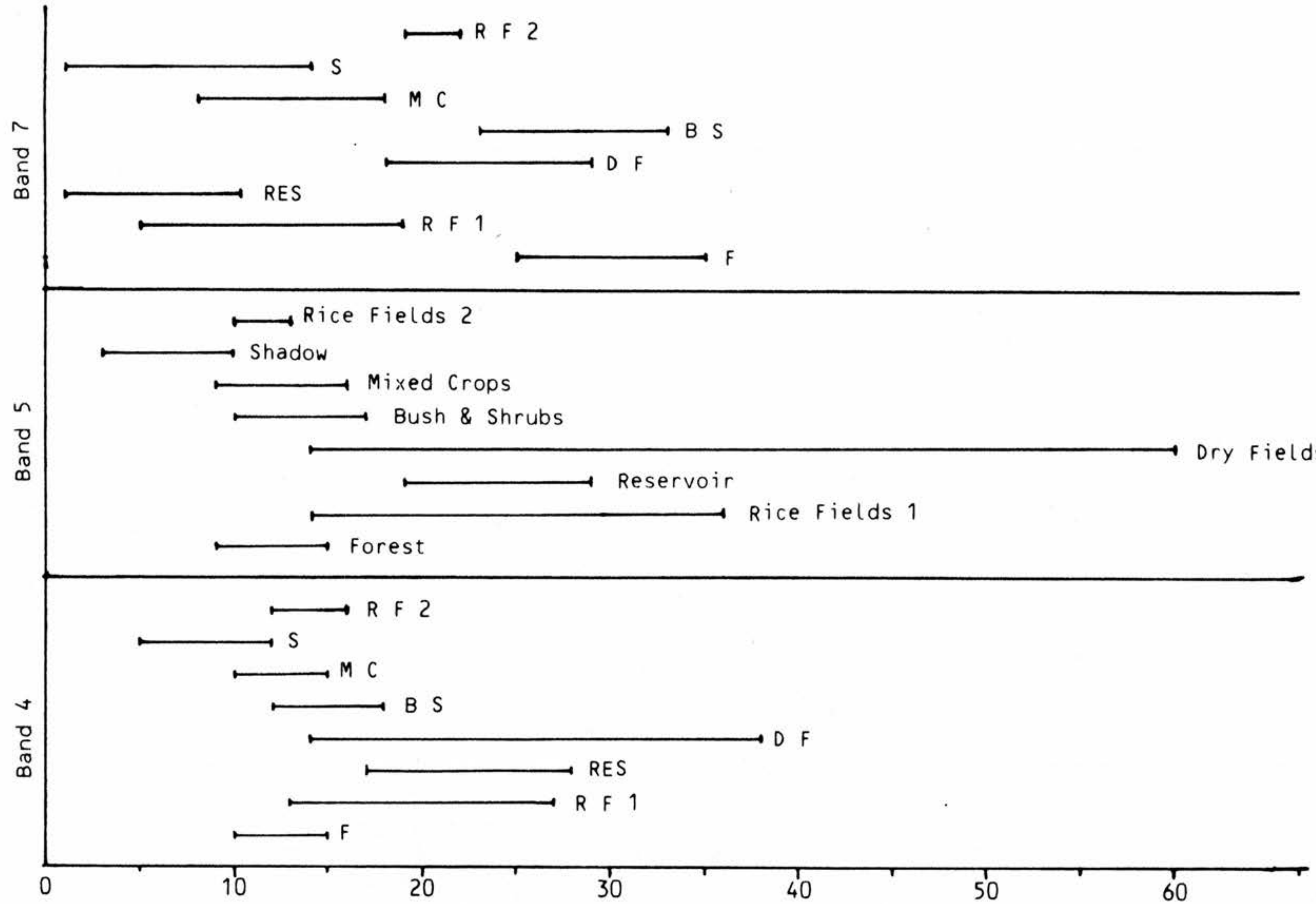

Figure 15 Training Classes Spectral Data Plot of Saguling Study Area 1976

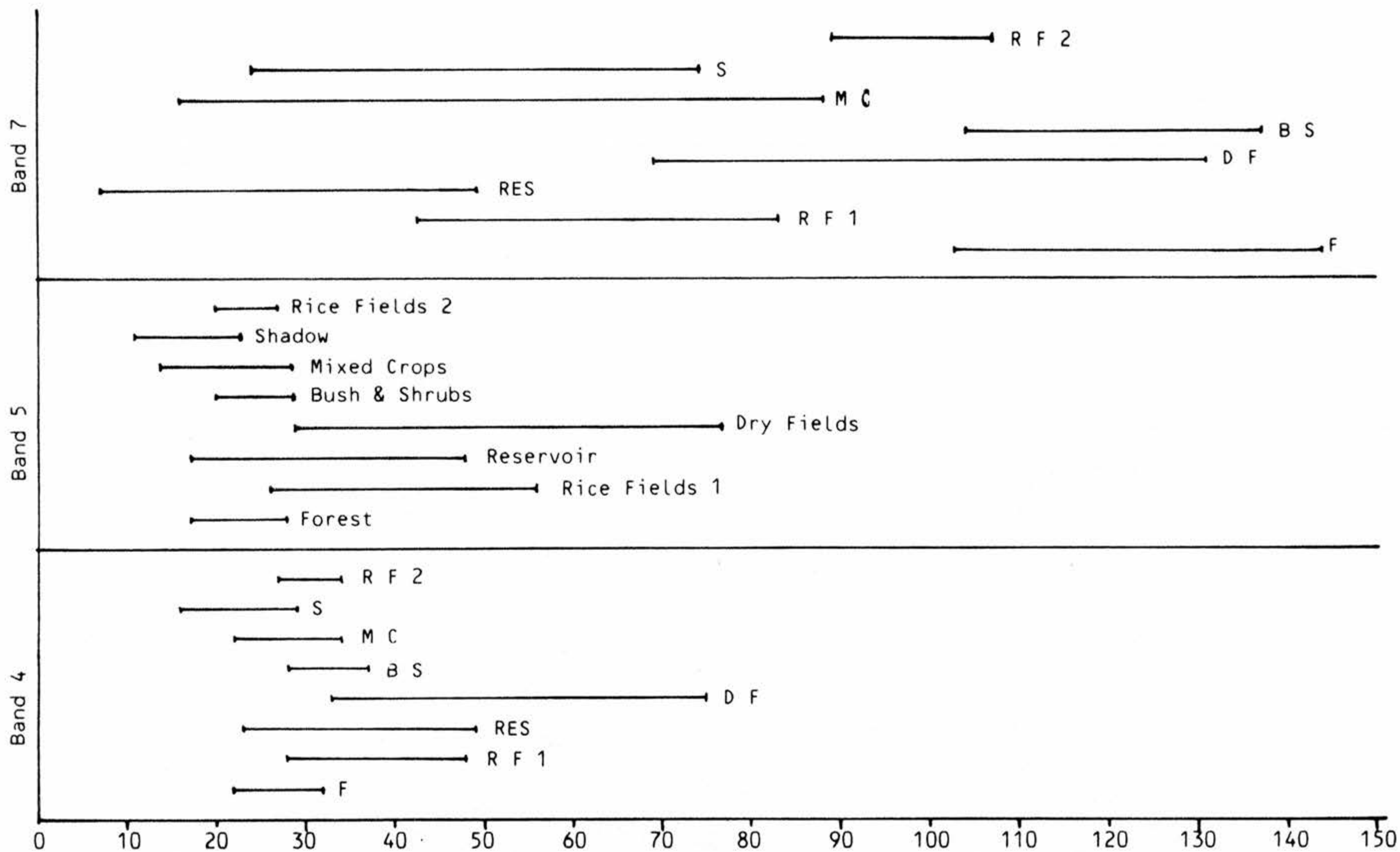

Figure 16 Training Classes Spectral Data Plot of Saguling Study Area 1985

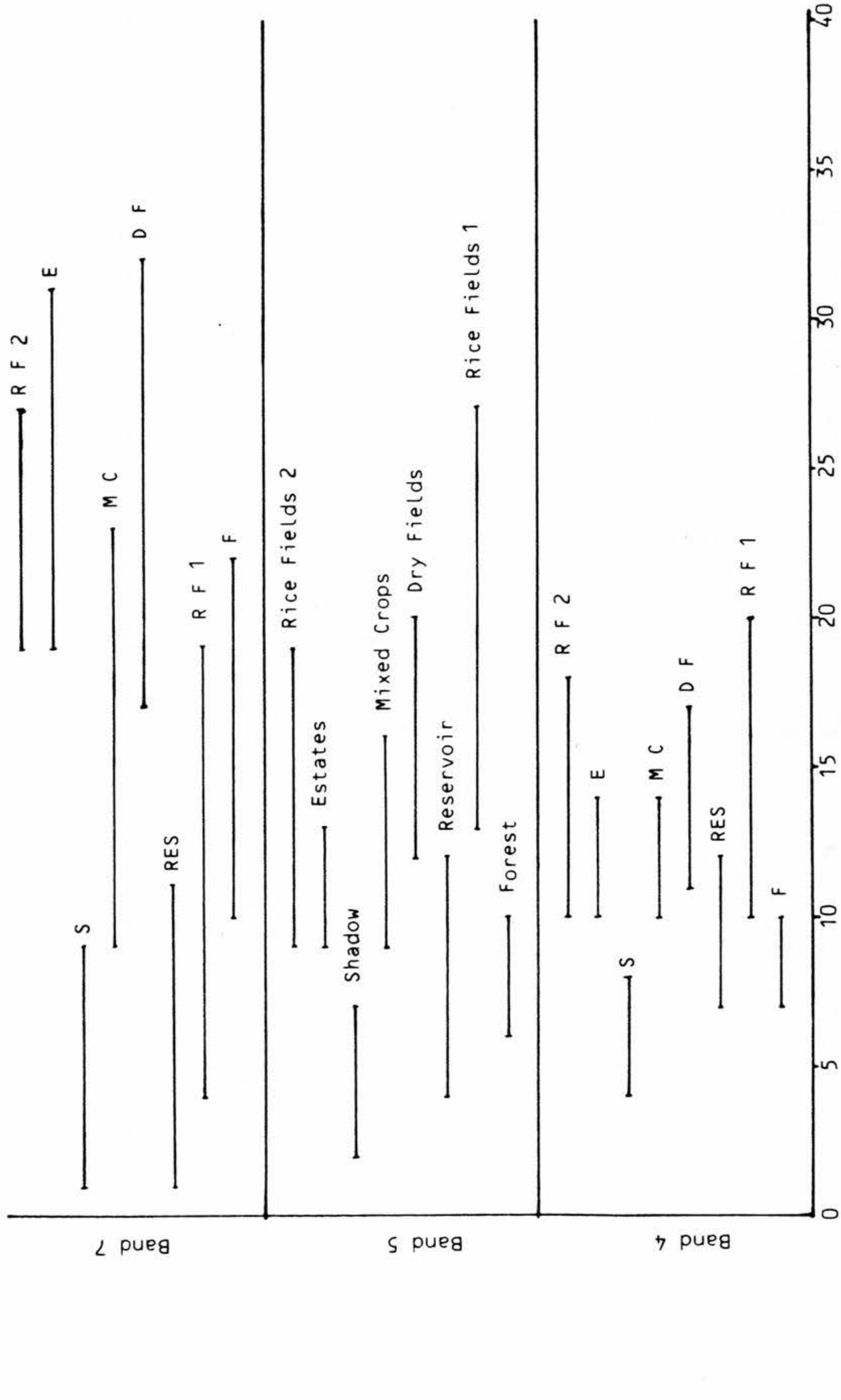

Figure 17 Training Classes Spectral Data Plot of Malabar Study Area 1976

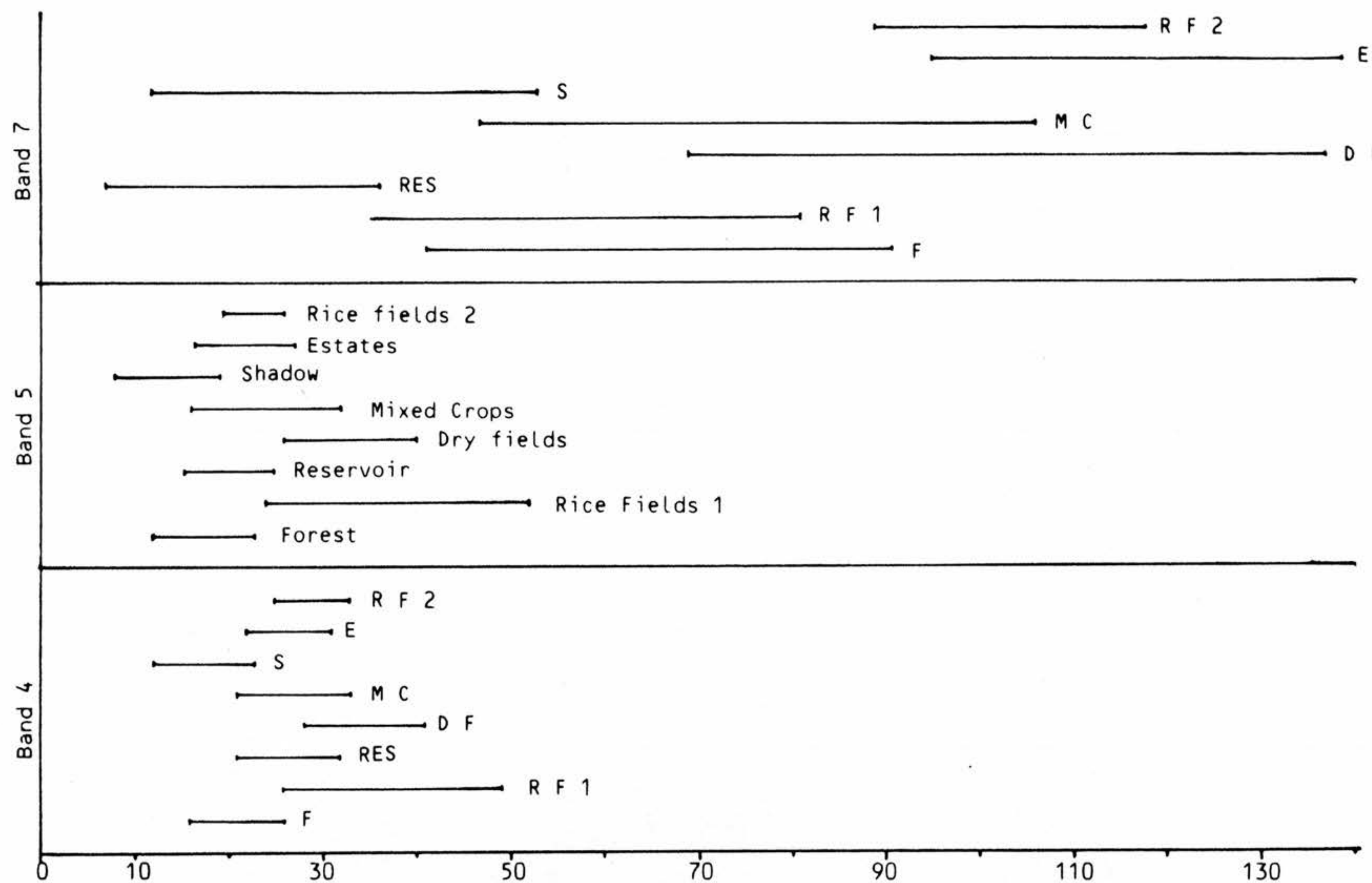

Figure 18 Training Classes Spectral Data Plot of Malabar Study Area 1985

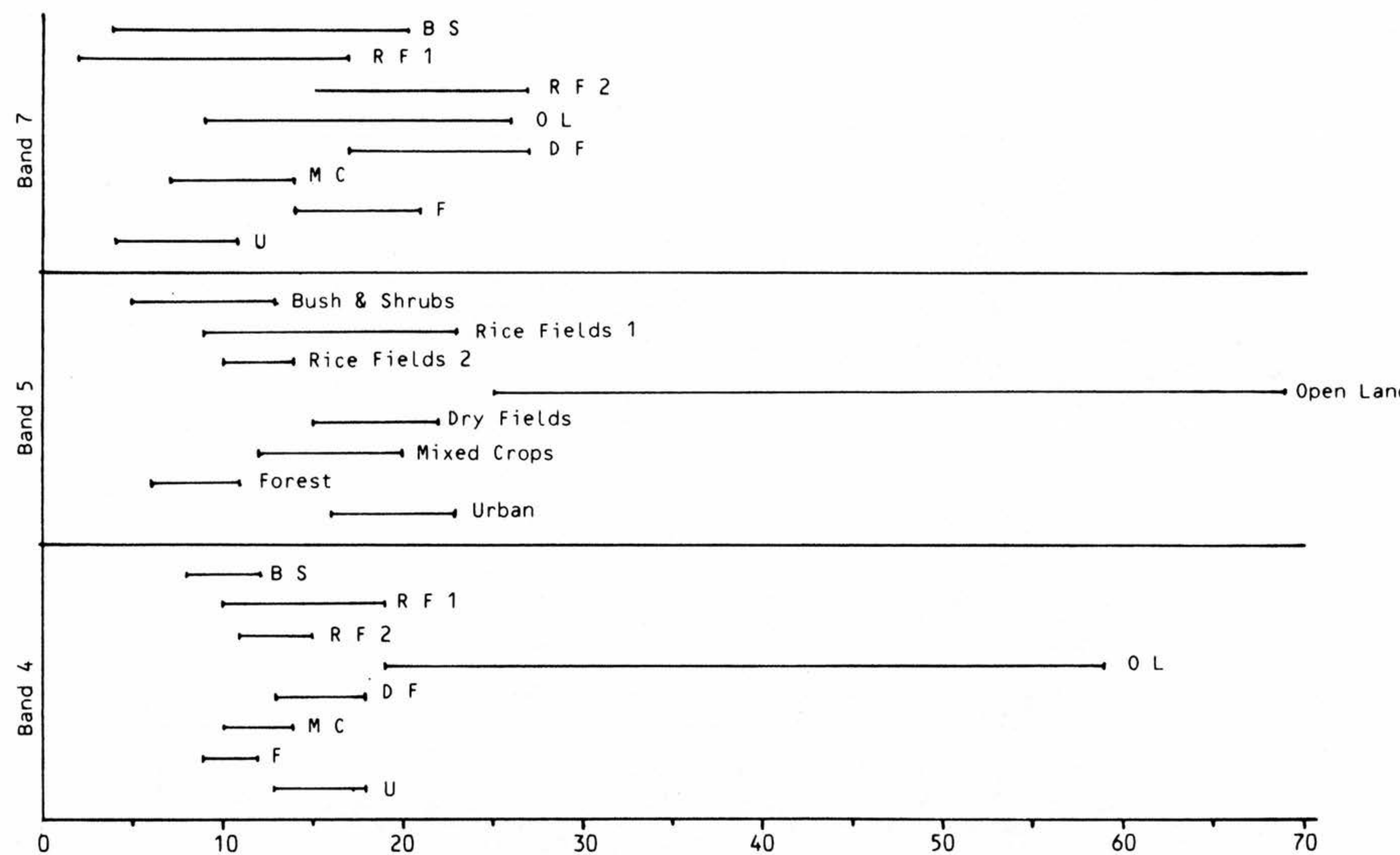

Figure 19 Training Classes Spectral Data Plot of Bandung Study Area 1976

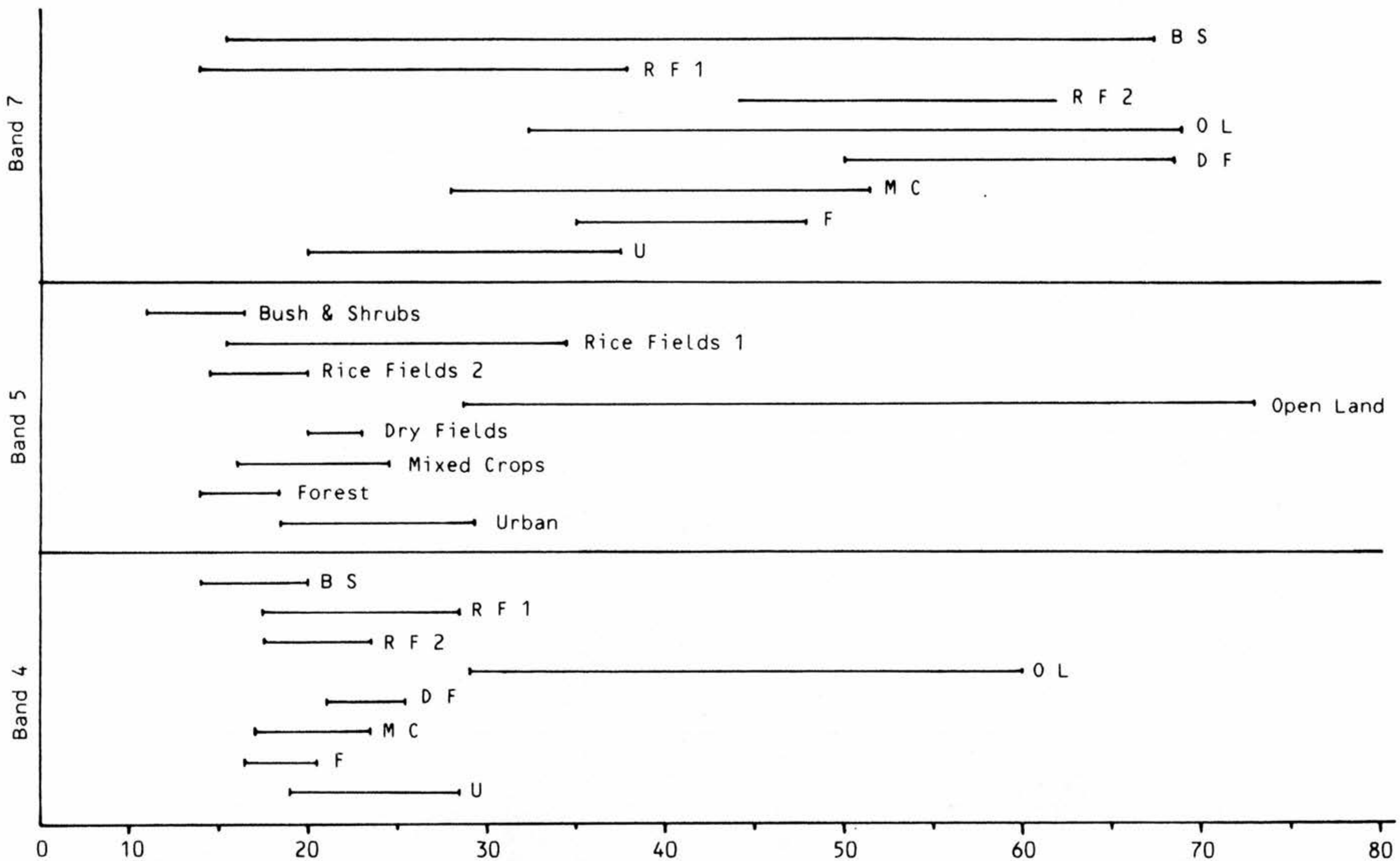

Figure 20 Training Classes Spectral Data Plot of Bandung Study Area 1985

a) Landsat image 1976

Land Cover Class	Forest	Rice Fields 1	Rice Fields 2	Dry Fields	Mixed Crops	Shadow	Bush & Shrubs	Reserv.
Forest		Part Part Yes	No No Yes	Part Part Part	No No Yes	Part Part Yes	No No No	Yes Yes Yes
Rice Fields 1			No Yes Yes	No No Part	Part Part No	Yes Yes No	No Yes Yes	No No No
Rice Fields 2				Part Yes No	No No Yes	Yes Yes Yes	No No Yes	Yes Yes Yes
Dry Fields					Part Part Yes	Yes Yes Yes	No Part No	No No Yes
Mixed Crops						Part Part Part	No No Yes	Yes Yes Part
Shadow							Yes Yes Yes	Yes Yes Yes
Bush & Shrubs								Part Yes Yes
Reserv.								

b) Landsat image 1985

Land Cover Class	Forest	Rice Fields 1	Rice Fields 2	Dry Fields	Mixed Crops	Shadow	Bush & Shrubs	Reserv.
Forest		Part Part Yes	No No Part	Yes Yes No	No No Yes	No Part Yes	Part No No	No No Yes
Rice Fields 1			No Part Yes	No No Part	Part Part No	Part Yes No	No Part Yes	No No Part
Rice Fields 2				Part Yes No	No No Yes	Part Part Yes	No No Part	No No Yes
Dry Fields					Part Yes Part	Yes Yes Part	Part Yes Part	No No Yes
Mixed Crops						Part No No	No No Yes	No No No
Shadow							Part Part Yes	Part Part No
Bush & Shrubs								No No Yes
Reserv.								

KEY :
- Yes - Spectral Separability in Band 4
- Part - Spectral Separability in Band 5
- No - Spectral Separability in Band 7

Table 14 Spectral Separability Matrix of Training Classes Saguling Study Area

a) Landast image 1976

Land Cover Class	Forest	Rice Fields 1	Rice Fields 2	Reserv.	Dry Fields	Mixed Crops	Shadow	Estates
Forest		Yes Yes No	Part Part Part	Part No Yes	Yes Yes Part	Part No No	No No Part	Part No Yes
Rice Fields 1			No Part Yes	Part Part Part	No No Part	Part No No	Yes Yes Part	Part Part Yes
Rice Fields 2				No Part Yes	No Yes No	No No Part	Yes Yes Yes	No Part No
Reserv.					Part Yes Yes	No No Yes	Part Part No	No No Yes
Dry Fields						Part Part No	Yes Yes Yes	Part Part No
Mixed Crops							Part Part Part	No No Part
Shadow								Part Part Yes
Estates								

b) Landsat image 1985

Land Cover Class	Forest	Rice Fields 1	Rice Fields 2	Reserv.	Dry Fields	Mixed Crops	Shadow	Estates
Forest		Yes Yes No	Yes Part Part	No No Part	Yes Yes Part	Yes Part No	Yes Yes No	Yes Yes Part
Rice Fields 1			No No Yes	Part Yes No	No No Part	No Part No	Yes Yes No	No Yes Yes
Rice Fields 2				Part Part Yes	No No No	No No Part	Yes Yes Yes	No No No
Reserv.					No Yes Yes	Part Part Part	Part No No	Part No Yes
Dry Fields						No No Part	Yes Yes Yes	No Part No
Mixed Crops							Yes Yes Yes	No No Part
Shadow								Yes Yes Yes
Estates								

KEY : Yes - Spectral Separability in Band 4
Part - Spectral Separability in Band 5
No - Spectral Separability in Band 7

Table 15 Spectral Separability Matrix of Training Classes Malabar Study Area

a) Landsat image 1976

Land Cover Class	Urban	Rice Fields 1	Rice Fields 2	Mixed Crops	Dry Fields	Forest	Open Land	Bush & Shrubs
Urban		No No No	Part Yes Yes	Part Part Part	No No Yes	Yes Yes Yes	Yes Yes Part	Yes Yes No
Rice Fields 1			No No Part	No Part No	No No Yes	No Part Part	Yes Yes Part	Part Part No
Rice Fields 2				No No Yes	Part Yes No	Part Part No	Yes Yes No	Part No Part
Mixed Crops					Part No Yes	No Yes Yes	Yes Yes No	Part No No
Dry Fields						Yes Yes No	Yes Yes No	Yes Yes Part
Forest							Yes Yes No	No No No
Open Land								Yes Yes No
Bush & Shrubs								

b) Landsat image 1985

Land Cover Class	Urban	Rice Fields 1	Rice Fields 2	Mixed Crops	Dry Fields	Forest	Open Land	Bush & Shrubs
Urban		No No No	No Part Yes	No No Part	No No Yes	Part Yes Part	Yes Part Part	Part Yes No
Rice Fields 1			No No Yes	No No Part	No No Yes	No No Part	Yes Part Yes	Part Part No
Rice fields 2				No No Part	Part Yes No	No No Part	Yes Yes No	Part Part No
Mixed Crops					Part No Part	No No No	Yes Yes No	Part Part No
Dry Fields						Yes Yes Yes	Yes Yes No	Yes Yes No
Forest							Yes Yes No	No Part NO
Open Land								Yes Yes No
Bush & Shrubs								

KEY : Yes - Spectral Separability in Band 4
Part - Spectral Separability in Band 5
No - Spectral Separability in Band 7

Table 16 Spectral Separability Matrix of Training Classes Bandung Study Area reduced by covers being partially separable in another band. These problem can be detected among forest with mixed crops and shadow, rice fields 1 with mixed crops and dry fields, rice fields 2 with mixed crops and estates, and also mixed crops with estates. Partially inseparable covers occurs between forest and rice fields 2, rice fields 1 and reservoir, dry field and mixed crops, and mixed crops with shadow. In image 1985, inseparable spectral reflectance occurred among rice fields 2 with dry fields and estates. However, more separation problems of similarity in two bands and partially separability in another band occurred within rice fields 1 with dry fileds and mixed crops, rice fields 2 and mixed crops, reservoir and shadow, dry fields with mixed crops and estates, and mixed crops with estates.

For the Bandung study area, problems of insepararability of data of image 1976 occurred within urban and rice fields 1, and also for forest and bush. The problem of similarity in two bands but separable in another band occurred among rice fields 1 with rice fields 2 and mixed crops. In image 1985, inseparable data occurred among urban class with rice fields 1, and also between forest and mixed crops. Therefore, most of the mixed crops area have been classified as forest area. There was a problem of inseparability in two bands and partially separable in another band, particularly with urban and rice fields 2, rice fields 1 and rice fields 2 with mixed crops and forest, and also forest with bush.

Comparing the image classification result, it could be deteted that misclassification occurs when the training data are spectrally inseparable in two MSS bands even though separable in another band, for example, in the Saguling study area of image 1976, some forest pixels appear in the rice fields area.

From the statistical training data analysis above, it could be concluded that most of the problems occurred in the image for 1985, caused by Landsat image quality.

4.5.3. Main Land Cover Types of the Study Area

The land cover of the study area will be described in this section based upon the classification results of the three study extracts: Saguling, Malabar, and Bandung. The description of the statistical results will be based on the classification even though there are differences in study extract areas between image 1976 and 1985.

4.5.3.1. Saguling Study Area

It was stated in the previous chapter that the Saguling study area had been classified into 7 land cover types, namely, forest, rice fields, dry fields, mixed crops, bush and shrubs, reservoir, and shadow. The image classification result can be seen in the plate 7 for image 1976 and plate 8 for image 1985.

The forest cover which exists in the mountains and hilly terrain is mainly of the dry land forest type. There are two different types of forest in this study area, namely primary forest and secondary forest. The primary forest is characterized by a closed canopy and a strongly mixed nature, the upper storey is more than 20 meters high, the middle storey consists of medium size trees and the lower storey is covered by shrubs and trees. This forest is found on the foot of Burangrang mountain. The secondary forest can be found in the mountainous areas of Takungtung and Kasur and in the hilly areas of Pasirsusuru and near Jatiluhur reservoir. Most of these areas has been disturbed by people living nearby who have cut the forest for fire wood or for charcoal. Therefore these areas have an open canopy and are mostly covered by bush, shrubs, and medium trees (Plates 13 and 14). However, in some parts the forest area was not classified as forest due to its similar spectral reflectance to another land cover, namely mixed crops. In image 1976, only 2.4% of the area was classified as forest while in image 1985 3.03% of the study area fell in to this group

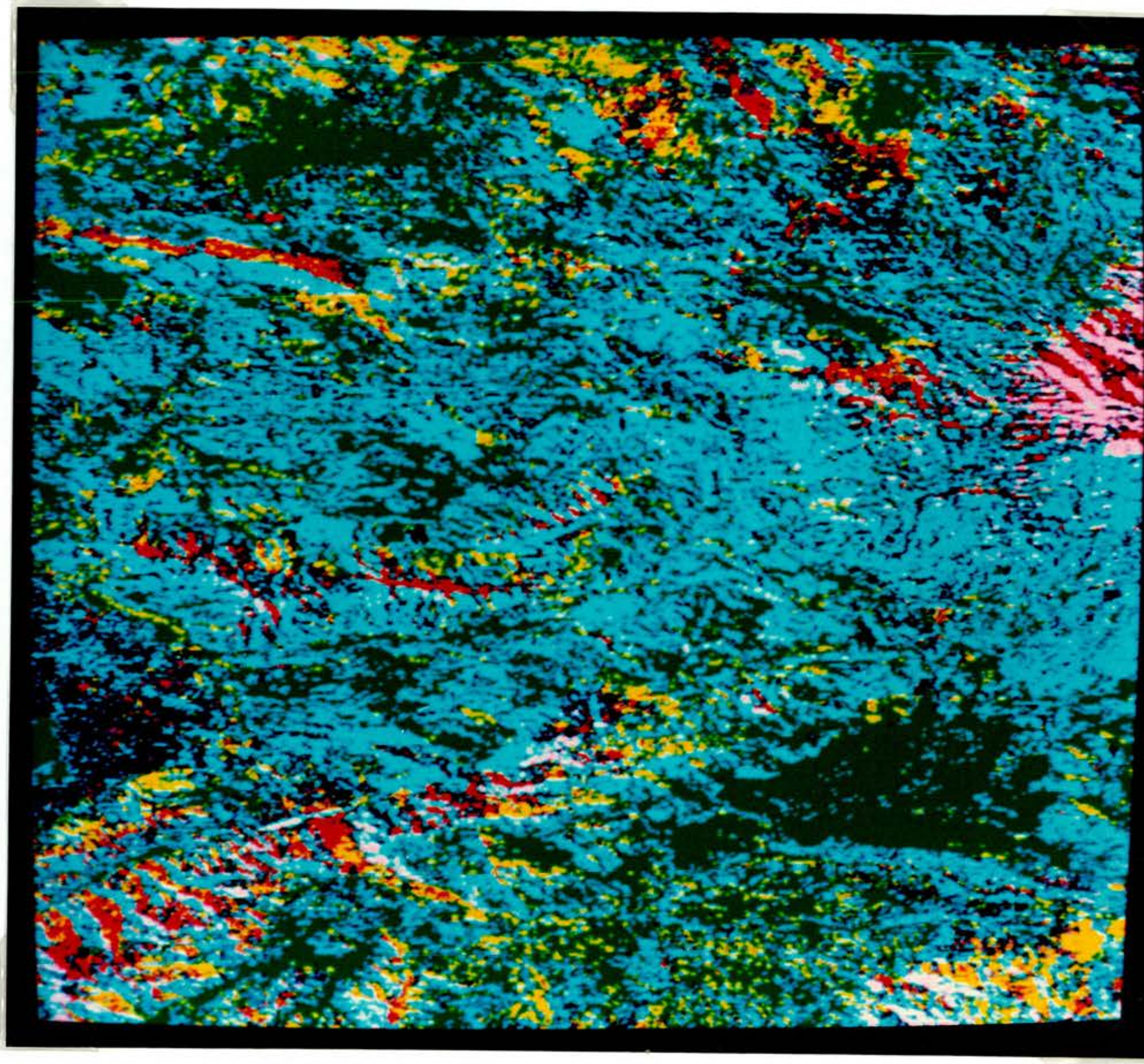

PLATE 7 Classified Image of Saguling Study Area 1976.

KEY TO CLASSIFICATION COLOUR :

Red	: Forest	Dark Green	: Rice Fields 2
Magenta	: Shadow	Yellow	: Dry Fields
Blue	: Reservoir	Cyan	: Mixed Crops
Green	: Rice Fields 1	Purple	: Bush & Shrubs

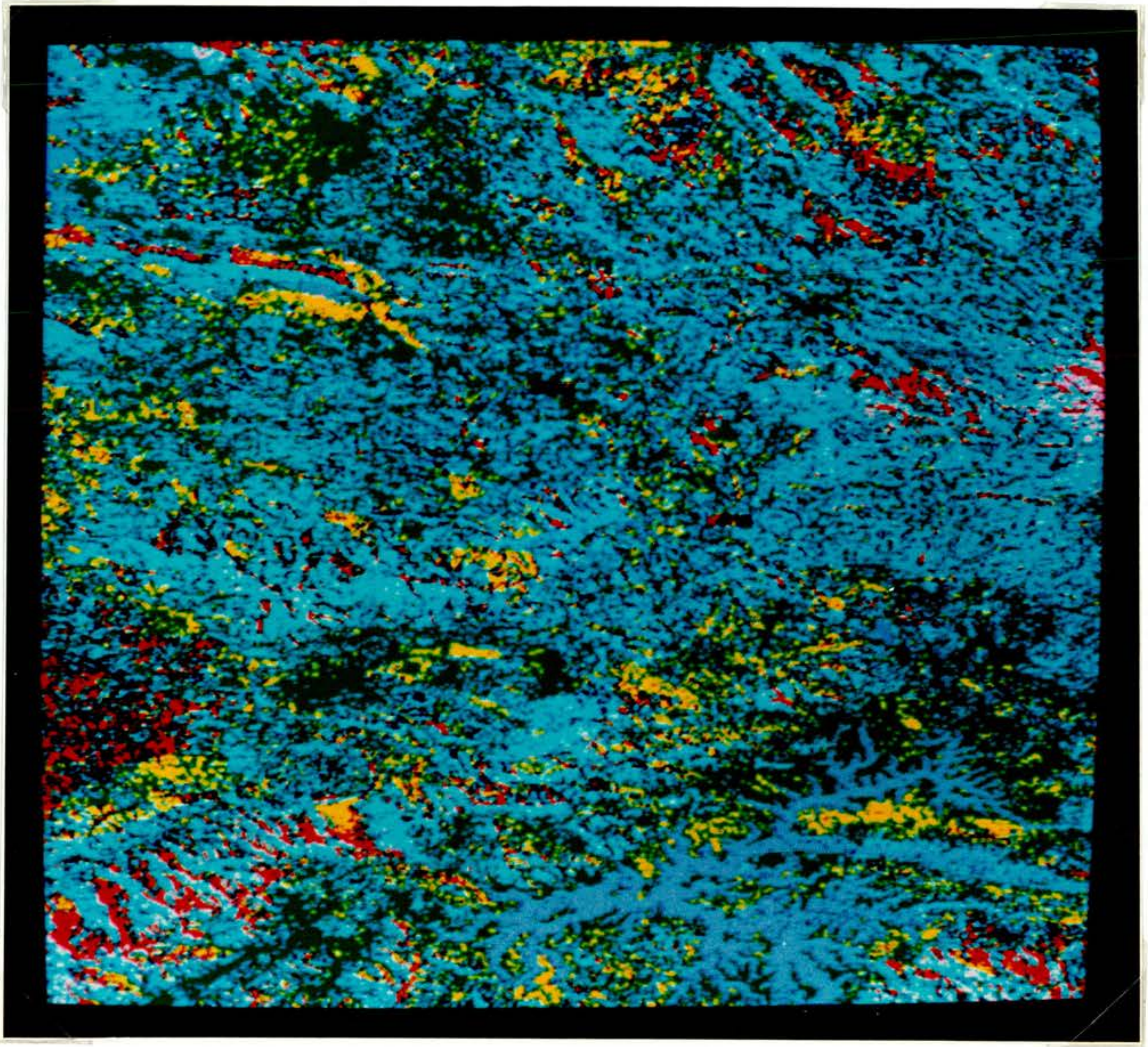

PLATE 8 Classified Image of Saguling Study Area 1985.

KEY TO CLASSIFICATION COLOUR :

Red	: Forest	Dark Green	: Rice Fields 2
Magenta	: Shadow	Yellow	: Dry Fields
Blue	: Reservoir	Cyan	: Mixed Crops
Green	: Rice Fields 1	Purple	: Bush & Shrubs

(Table 17). Shadow areas, which are located on the steep slope terrain, are mainly covered by forest. A few pixels of shadow areas in the hilly terrain were occupied by dry fields. In image 1976, 1.28% of the study area was classified as shadow compared with 0.31% on image 1985.

CLASS	1976		1985	
	Total Pixels	%	Total Pixels	%
1. Forest	5,618	2.42	6,536	3.03
2. Rice Fields 1	76,022	32.75	75,215	34.87
3. Reservoir	627	0.27	11,626	5.39
4. Dry Fields	13,579	5.85	12,640	5.86
5. Bush & Shrubs	6,755	2.91	1,704	0.79
6. Mixed Crops	84,193	36.27	72.261	33.50
7. Shadow	2,971	1.28	669	0.31
8. Rice Fields 2	30,896	13.31	22,369	10.37
Unclassified	11,467	4.95	12,684	5.88
Total	232,128	100.00	215,704	100.00

Table 17 Classified pixels of Saguling Study Area

Rice fields dominate the land cover of the Saguling study area. Most of rice fields are located on the flat area, however, they could also be found in the hilly terrain. As it can be seen from Plate 15, some areas in the hilly terrain are used for rice fields if there is a possibility of irrigation. Some dry land will be used as rainfed rice fields if there are no irrigation facilities.

Plates 16 and 17 show that rice fields areas are located on different land forms. For image 1976, 32.75% of the study area was classified as rice fields 1 and 13.31% for rice fields 2, while in image 1985, 34.87% was classified as rice field 1 and 10.37% for rice field 2 (see above chapter 4.5.2. for definitions of rice fields classes 1 and 2).

Besides rice fields, mixed crops were also classified in extensive areas. In image 1976 this land cover occupied 36.27% of the sudy area and 34.87% in image 1985. This cover type was distributed between the various land forms. As stated by Malingreau and Christiani (1981) that mixed crops are present in Indonesia in an extraordinary variety of forms which are difficult to categorize. This cover type is a transition between dry fields and forest garden where trees and bushes are mixed with dry fields and planted at random. From plates 16, 18, 19 and 20, it can be seen that mixed crops are located in various geographical situations. Most of the dense mixed crops were also associated with rural settlements and were spread out mostly among the rice fields. However, it should be noted that these conditions will influence classification results.

Hilly slopes which have no irrigation facilities are mainly covered by dry fields. In some areas, people also plant rice, particularly during the rainy season. However, it is possible that dry field will be classified as rice fields. Approaching the end of rainy season in the end of June or at the begining of July, this cover type will have a similar spectral reflectance to rice field 2 or at the maturing stage. In image 1976, the dry fields class occupies 5.85% of the study area and 5.86% in image 1985 (See Table 17).

Bush and shrubs which mostly covered the foot hill or at the edge of forest area (Plate 21) was classified as 2.91% of image 1976 and 0.79% of image 1985. Nevertheless, this class is not obvious in plates 7 and 8 due to the photographic processing.

There are two reservoirs in the Saguling study area, Jatiluhur reservoir located in the top left corner of the extract and the new reservoir which can be seen in image 1985 (Plate 2). In image 1976, only 0.27% was classified as reservoir, while in image 1985, 5.39% of the study area fell into this class as the Citarum river was starting to flood a part of Saguling reservoir areas.

4.5.3.2. Malabar Study Area

Seven land cover types have been classified in the Malabar study area, forest, estates, dry fields, mixed crops, reservoir, rice fields and shadow. The result of image classification can be seen in plate 9 for image 1976 and plate 10 for image 1985.

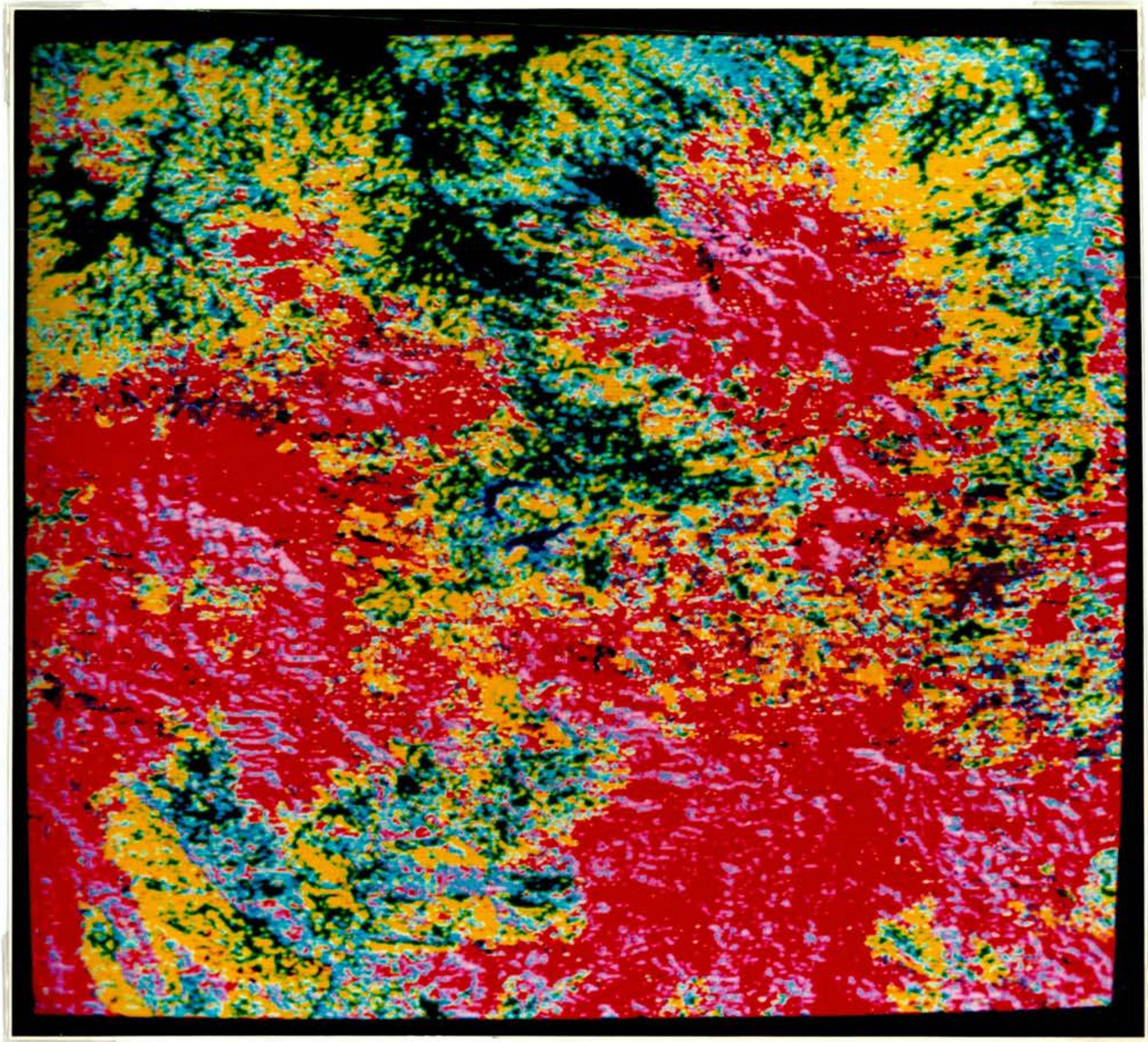

PLATE 9 Classified Image of Malabar Study Area 1976.

KEY TO CLASSIFICATION COLOUR :

Red	: Forest	Dark Green	: Rice Fields 2
Magenta	: Shadow	Yellow	: Dry Fields
Blue	: Reservoir	Cyan	: Mixed Crops
Green	: Rice Fields 1	Purple	: Estates

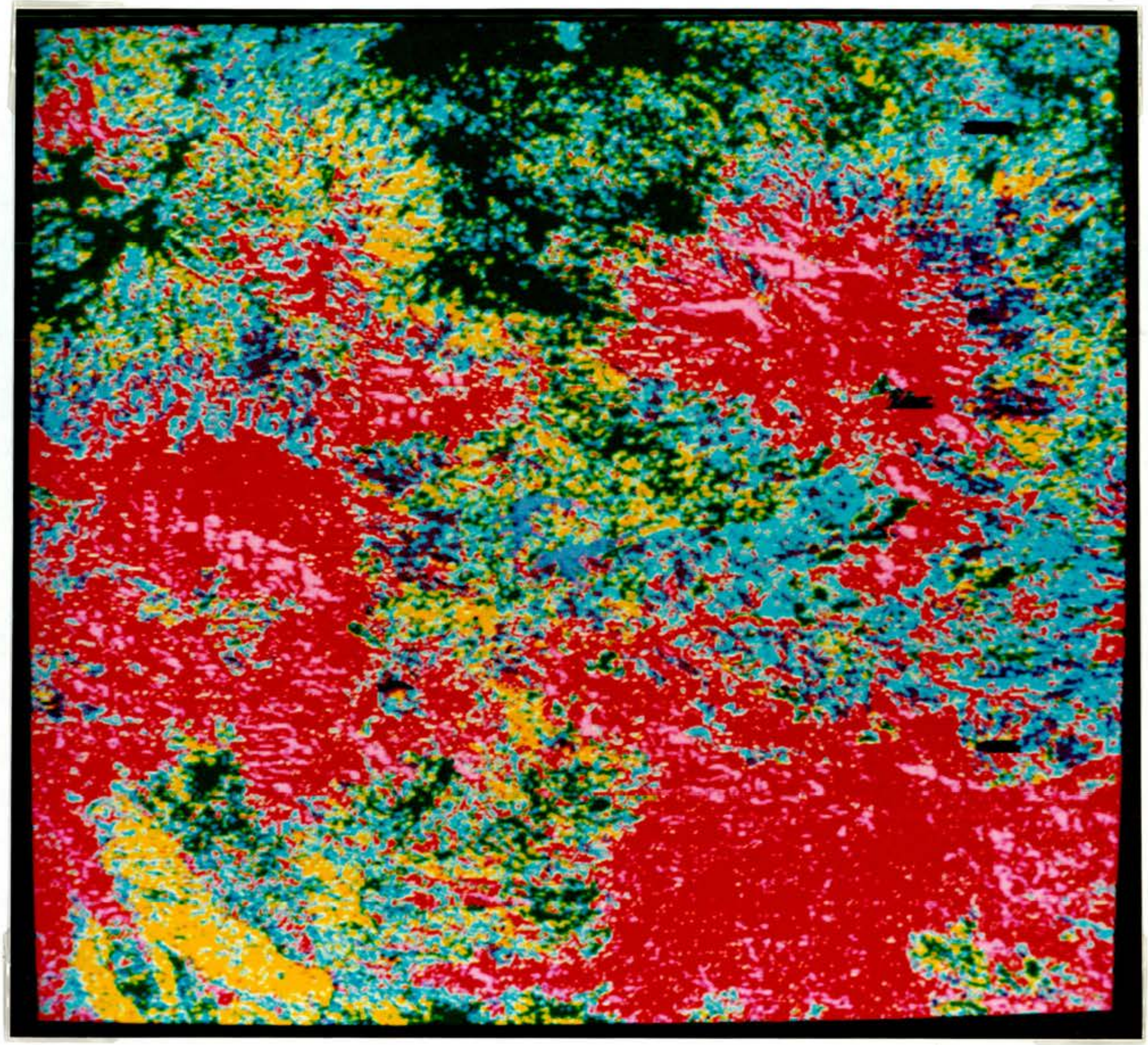

PLATE 10 Classified Image of Malabar Study Area 1985.

KEY TO CLASSIFICATION COLOUR :

Red	: Forest	Dark Green	: Rice Fields 2
Magenta	: Shadow	Yellow	: Dry Fields
Blue	: Reservoir	Cyan	: Mixed Crops
Green	: Rice Fields 1	Purple	: Estates

Most of this study area was covered by forest, located in the mountainous areas of Malabar, Kencana, Puncakwalang and Tilu. Due to the quite rugged topographic condition, some part of the forest area is presented as shadow. In image 1976, the forest area covered 34.11% of the study area compared with 36.76% for image 1985. Shadow areas located in the forest area was covered 1.11% of image 1976 and 3.18% of image 1985 (Table 18).

CLASS	1976		1985	
	Total Pixels	%	Total Pixels	%
1. Forest	79,179	34.11	79,293	36.76
2. Rice Fields 1	45,404	19.56	40,466	18.76
3. Reservoir	15,785	6.80	1,230	0.57
4. Dry Fields	43,338	18.67	22,433	10.40
5. Mixed Crops	27,438	11.82	49,094	22.76
6. Shadow	2,576	1.11	6,859	3.18
7. Estates	14,253	6.14	12,912	5.99
8. Rice Fields 2	929	0.40	216	0.10
Unclassified	3,226	1.39	3,192	1.48
Total	232,128	100.00	215,704	100.00

Table 18 Classified Pixels of Malabar Study Area

The estates cover type represents tea and quinine estates, and occupy 6.14% of the the study area 1976 and 5.99% of the study area 1985. However, because of spectral similarities with other cover types, this land cover class was not recognized in some areas where it is known to occur. This is particularly the case for quinine estates which are mostly included in the forest area, and it can be seen from plate 22 that quinine estates have many of the same characteristics as forest. Most estates areas are located between Mount Malabar and Kencana.

Dry fields, mostly located in the foot hills covered 18.67% of the study area 1976 and 10.40% of study area 1985. As it can be seen in plate 23, dry fields can usually be found in the foot hill near the forest area margins and some areas can be found as rainfed rice fields.

Rice fields in the Malabar study area are mostly located in the flat terrain, however, they also can be found in the hilly areas which have irrigation facilities (Plate 24). In image 1976, rice fields 1 covered 19.56% of the study area and 0.40% for rice fields 2 while in image 1985, 18.76% was classified as rice fields 1 and only 0.19% as rice fields 2.

Cileunca reservoir was classified on 6.80% of the study area 1976 and only 0.57% in study area 1985. However, there is a misclassification in image 1976 where some reservoir pixels occupied the shadow area. The classification is now assessed as being much more accurate on image 1985.

4.5.3.3. Bandung Study Area

The Bandung study extract (reduced from about 200,000 pixels to about 60,000 pixels) was classified in 7 land cover classes namely, urban, forest, mixed crops, dry fiėlds, bush and shrubs, rice fields, and open land. The image classification result of the Bandung study area can be seen in plate 11 for image 1976 and plate 12 for image 1985.

The Bandung study extract was reduced in size in order to avoid misclassification which quite often occurred between urban areas and rice fields in the preparation stage. However, difficulties arise when deciding where to locate the boundaries of the study area as Bandung city is surrounded by rice fields, therefore, some wrongly classified land cover type still appears in this study area. Misclassification within urban and rice fields 1 cannot be avoided easily even when a smaller sample area is taken.

In image 1976, 14.45% of the study area was classified as urban areas and 45.90% of image 1985 was classified as urban (Table 19). However, the possibilities of misclassification was high in image 1985 than image 1976 due to the poorer image quality of the 1985 date.

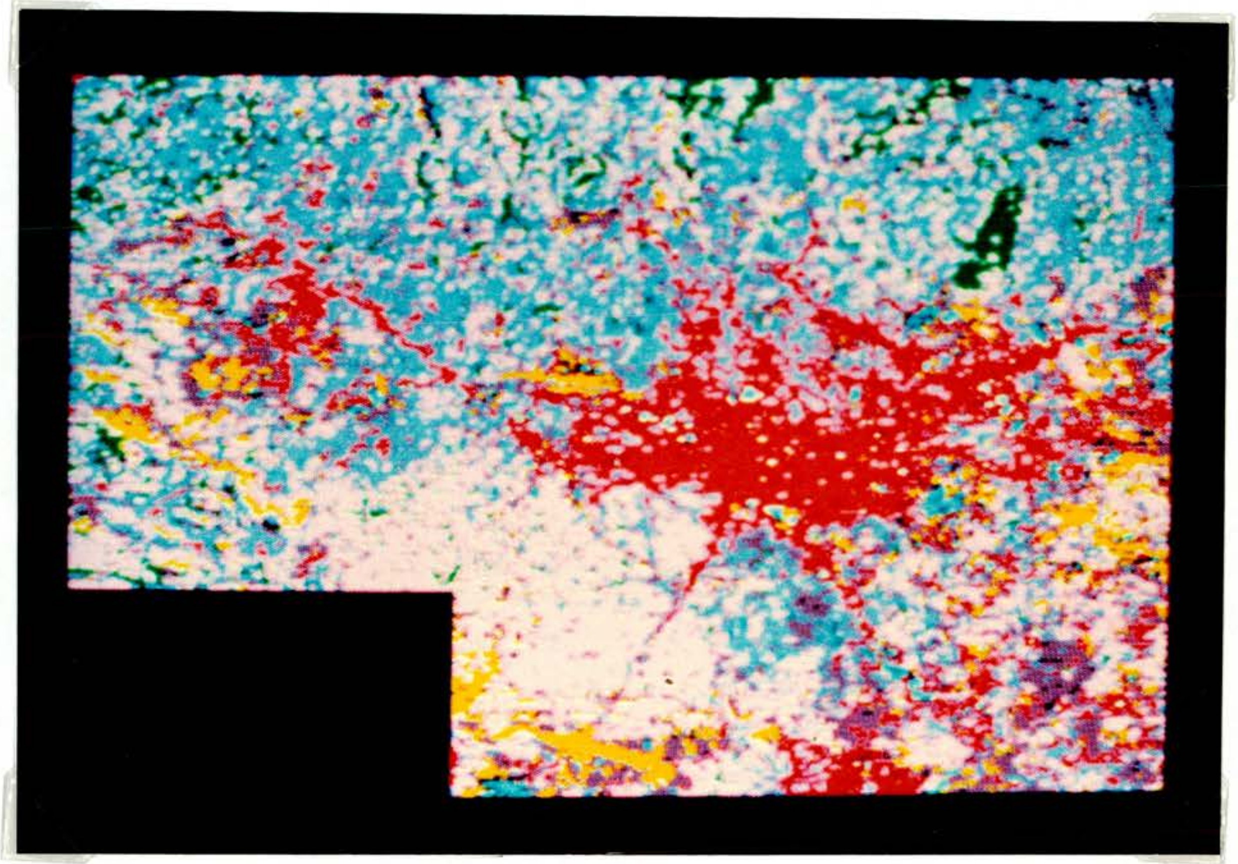

PLATE 11 Classified Image of Bandung Study Area 1976.

KEY TO CLASSIFICATION COLOUR :

Red	: Urban	Dark Green	: Bush & Shrubs
Magenta	: Rice Fields 2	Yellow	: Dry Fields
Blue	: Rice Fields 1	Cyan	: Open Land
Green	: Forest	Purple	: Mixed Crops

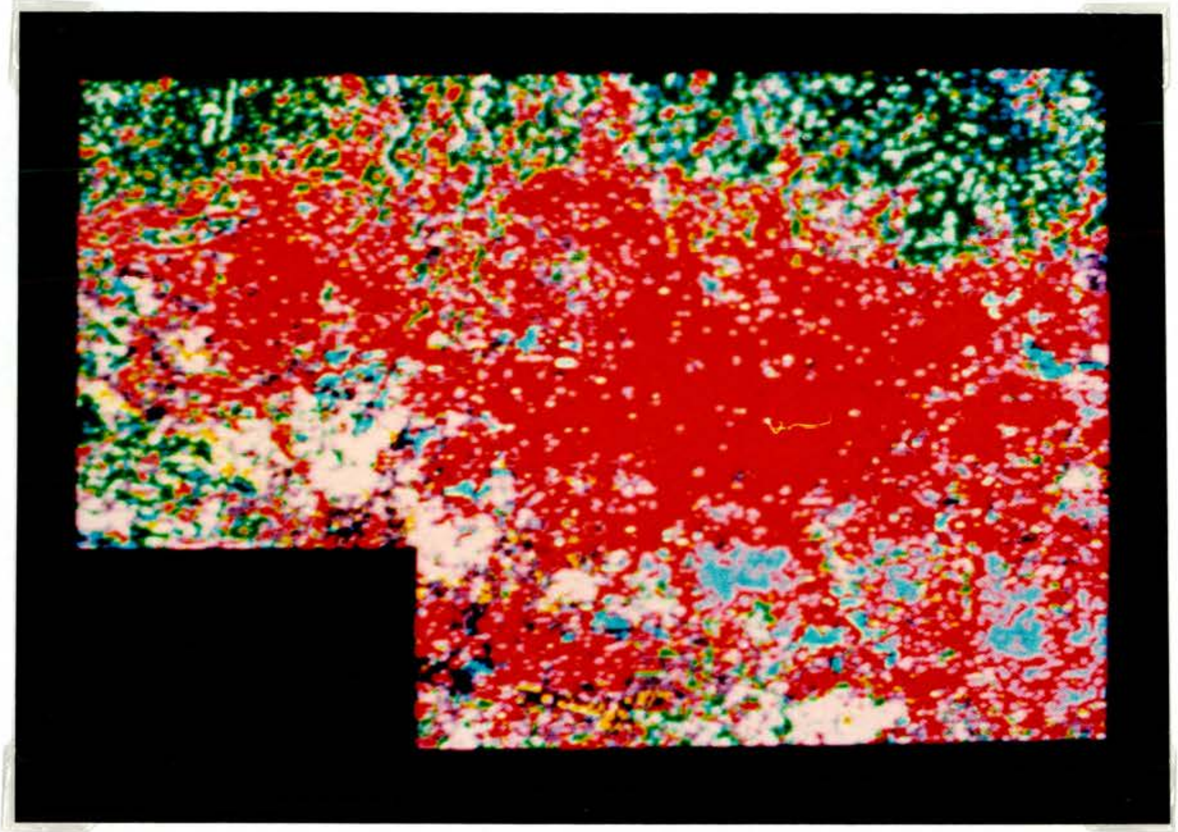

PLATE 12 Classified Image of Bandung Study Area 1985.

KEY TO CLASSIFICATION COLOUR :

Red	: Urban	Dark Green	: Bush & Shrubs
Magenta	: Rice Fields 2	Yellow	: Dry Fields
Blue	: Rice Fields 1	Cyan	: Open Land
Green	: Forest	Purple	: Mixed Crops

Rice fields in image 1976 which mostly covered the east, the south and the west of the Bandung town margins were classified as 26.20% for rice fields 1 and 23.36% for rice fields 2 whereas in image 1985, 7.26% were classified as rice fields 1 and 9.91% as rice fields 2.

Mixed crops, mostly located to the north of Bandung town, covered 19.34% of the study area 1976 and 15.17% of study area 1985.

Open land was defined in the Bandung classification to represent the build up areas of the new urban settlement. Therefore, this area appeared among the rice fields and is mostly located to the west of Bandung and also along the road to the southeast. In image 1976, 1.04% of the study area was classified as open land and in image 1985 it covered 1.36%. However, this cover type is not obvious in the image classification result for 1976 due to the photographic processing of plate 11.

CLASS	1976		1985	
	Total Pixels	%	Total Pixels	%
1. Urban	8,737	14.45	25,093	45.90
2. Forest	3,920	6.49	9,421	17.23
3. Mixed Crops	11,689	19.34	8,240	15.07
4. Dry Fields	4,070	6.73	673	1.23
5. Open Land	629	1.04	742	1.36
6. Rice Fields 2	14,119	23.36	5,416	9.91
7. Rice Fields 1	15,838	26.20	3,981	7.28
8. Bush & Shrubs	317	0.52	555	1.02
Unclassified	1,128	1.87	551	1.00
Total	60,447	100.00	54,672	100.00

Table 19 Classified Pixels of Bandung Study Area

PLATE 13 Ground Features of Secondary Forest in Saguling Study Area. Mixed with dry fields in the centre and mixed crops.

PLATE 14 Secondary Forest in Saguling Study Area. Located in the hill slope.

PLATE 15 Terrestrial Features of Irrigated Rice Fields in Saguling Study Area. Located in the gentle slope, surrounding by dry fields and mixed crops in the background.

PLATE 16 Irrigated Rice Fields in Saguling Study Area. Surrounded by mixed crops in the left and right side and forest area in the background.

PLATE 17
Dry Fields in Saguling Study Area. Rice fields in the foreground and mixed crops inthe right and in the background.

PLATE 18 Rainfed Rice Fields and Dry Fields. Surrounded by mixed crops (in the background).

PLATE 19 Dry Fields Area in Saguling Study Area. Surrounded by mixed crops and located in the hill slope, near rural settlement (in the background).

PLATE 20 Mixed Crops in Saguling Study Area. Located between rice fields (in the foreground) and dry fields (in the background). There are clove, coconut palm and fruit trees in the mixed crops area.

PLATE 21 Bush and Shrubs in Saguling Study Area. Located near secondary forest (in the background) and rural settlement in the foreground.

PLATE 22 Quinine Estates in the Mount Malabar Area. Located in the hill slope and besides the forest area (in the background).

PLATE 23

Dry Fields Area in Malabar Study Area. Located in the foot hills next to the forest area.

PLATE 24

Rice Fields in the Malabar Study Area. Located in the foot hills and surrounded by mixed crops and bush and shrubs.

CHAPTER 5

LAND COVER CHANGE 1976 - 1985

Land cover and land use patterns change over time as a result of economic, social, and environmental forces. The difficulties of monitoring and recording environmental changes can readily be appreciated, particularly for planners concerned with changes occurring over large administrative areas. However, detecting land cover changes through comparison of Landsat data acquired at two different dates should help to overcome this problem.

Change detection techniques, the detection of land cover changes, and the accuracy of analysis will be discussed briefly as follows:

5.1. Change Detection Techniques

In recent years, a considerable amount of effort has gone into developing change detection techniques using Landsat MSS imagery. Many procedures have been proposed and used to detect land use and land cover changes; the

5.1.1. Manual Comparison Technique

The most common technique in identifying land cover change is manual comparison using different land cover maps or different Landsat photographic images of different dates. Even though digital image processing systems have many advantages in change detection, they also have the disadvantages of being relatively expensive and requiring more operational skills. Before digital image processing became common for detecting land cover changes, many researchers chose visual maps comparison or photographic comparison techniques, as these techniques were simpler and cheaper.

5.1.1.1. Visual Maps Comparison

The principal of this technique is the superimposition of two different maps, then recording on a third map the changes observed. These can be tabulated by area and categories to reveal the extent and placement of land cover changes (Campbell, 1987). Usually these maps are compiled from visual interpretation of either aerial photographs or photographic Landsat images obtained for two different dates. Although in theory preparation of land cover maps for this purpose is easy and simple, many problems quite often occur in practice. Therefore, several requirements are needed to achieve better results (1) All maps must use the same base map to achieve a fixed register to each other, (2) All maps must be prepared on the same scale and at a consistent level of detail, as a result, the change map will present the true changes rather than miss delineation during the interpretation process, (3) All maps must use the same classification scheme. Thus, comparison with any future land cover map will be possible.

Using this technique, the interpreter must work carefully even though the two maps have same base map. Different placements in delineating land cover boundaries of the same areas during the interpretation process can create different results, although there is no evidence of land cover changes. The interpreter also needs to examine the imagery as a source of land cover maps, for example, the appropriate imagery must be chosen from varying scales, spatial resolution, cloud coverage and image qualities, in relation to the base map scale and classification detail. It is necessary to choose compatible imagery according to the level of detail and accuracy suitable for change detection mapping.

5.1.1.2. Photographic Comparison

Three different types of photographic comparison for land cover change detection have been performed by Crapper and Hynson (1983): (a) A side by side comparison of two aerial photographs or Landsat photographic images, annotating the areas in which change has occurred. In practice, this procedure is wearisome and it is easy to make an error, especially if the photographs have different scales, (b) Transparancies of two images can be superimposed, registered and viewed over a light table. These two images must have the same scale, however, a detailed examination is still required to determine areas of changes, (c) One negative and one positive transparency can be superimposed. Areas in which no change has occurred will appeared as a uniform neutral (medium density) tone and areas in which changes have occurred will appear as either a darker or lighter tone of grey scale.

Two Landsat images have been selected by Crapper and Hynson (1983) for a study of land cover change detection using Landsat photograpic imagery. Landsat images acquired on 26 August 1972 and June 1975 covered the Penrith- Katomba-Waragomba Dam area in central eastern New South Wales.

In this study, the negative transparencies bands 4, 5 and 7 of image 1977 were superimposed and registered on positive transparencies of bands 4, 5 and 7 of image 1975, at a scale of 1:1,000,000. Using a multispectral viewer, these superimposed images were projected onto the screen using a red filter for bands 4, a blue filter for bands 5, and a green filter for bands 7. The result of these superimpositions was then photographed using colour or black and white film. In the black and white photographs, the areas of change could be detected as light and dark areas against a neutral background. From the colour photographs, the areas of change could be recoqnized from individual bands, particularly in bands 4 and 5, the colour will be darker or brighter.

Areas of change have been identified in this New South Wales study, e.g. discoloration of the river upstream from Warragamba Dam, changes in the reflectance of water impounded by Warragamba Dam, changes in vegetation caused by fires in the Springwood area, and forest clearing operations. However, if the change does not affect the image reflectance then it obviously will not be detected.

Another study of photographic comparison technique to detect land cover changes has been presented by Eyton (1983). This method combined film images of several Landsat scenes of different dates, acquired in the same spectral reflectance band, into a single composite image. Three different dates at the same area and on the same band are printed in three different colour positive transparencies to form a single false colour composite. Each image will be printed in different colour, e.g. cyan, magenta and yellow. For example, a multitemporal composite could be established using MSS band 7 images of three different dates in three different colours, or using MSS band 5 of three different dates in three different colours.

From these color composites areas can be detected in which change has occurred. These will appear in subtractive or additive primary colour. If no change has occurred, the final colour composite will show a neutral colour black or white, depending upon the reflectance of the feature. The only features that consistenly appeared as a neutral grey are urban areas, and other features which show a little changes are often displayed as a slightly coloured neutral tone.

Landsat images of three different dates have been used successfully to detect changes in agriculture areas of Endova, Kansas and Landsat images (band 7) of three different dates have also been used successfully to identify the extent of flooding on the Mississipppi River in 1973. The principal problem of this method are (a) inability to register the entire overlapping portion of the images, and (b) the generally poor quality of the images. These problems can be solved through a photographic copying process or using digital image processing to produce better image quality.

5.1.2. Digital Comparison Technique

Change detection using digital Landsat data is essentially a process of comparing data from two different dates on a pixel by pixel basis, after these data have been digitally overlaid (Todd, 1977). To date, a number of change detection techniques using Landsat digital data are being developed and tested in an effort to test and improve detection accuracy. Since digital image processing was initially developed, various methods of change detection using Landsat MSS data have been achieved. The most common techniques in digital comparison are band ratioing, image differencing, post classification, and principal component analysis. In this technique, the comparison will be done using a digital image processing system and the result will be displayed in the video colour monitor (CRT) or via screen dumps onto a colour printer.

5.1.2.1. Band Ratioing

Band ratioing is one of the simplest and quickest methods of digital change detection. The principle of this method is superimposing the two Landsat images in the same band of two different dates. Furthermore, the intensities of energy reflectance recorded in one band of the pixels of one Landsat scene are divided by intensities in the same band of the other Landsat scene (Howarth and Wickware, 1981). Thus, these data are compared on a pixel by pixel basis, where the intensity of reflected energy is nearly same in each scene, the result of the division is approximately 1.0. Where change has occurred, the result may be either less than or greater than 1.0, depending on the reflectance changes between two dates. If no significant change is recorded from the first observation to the later observation, the ratio is 1.0, then it is assumed that there is no land cover change.

Howarth and Wickware (1981) have studied land cover change detection using the band ratioing method. The Peace-Athabasca Delta (Canada) was selected as a study area in approximately 30 Km by 40 Km, equivalent to part of a Landsat scene displayed at the full resolution of 512 X 512 pixels on a colour minitor.

Two available Landsat data were selected , the first was scene 200557-17522 recorded on 1 August 1976 and second image was scene 10399-18104 recorded on 26 August 1973. These Landsat images were analysed on the Image Analysis System (CIAS) at the Canada Centre for Remote Sensing (CCRS) in Ottawa.

In the ratios band 5 and of band 7, when displayed on the CIAS monitor, areas of no change appeared as grey colour, and the colour tones increased to either darker (in black) or brighter (in white) on a grey scale where the area of changes have occurred. In band 5 ratios changes in water level due to flooding were displayed in the brightest tones. In band 7 ratios, the brightest tone was assigned as areas where vegetation changes were dominant.

Based on the expectation that bands 5 and 7 are best suited for monitoring vegetation and have better differences in water reflectance, the ratio of bands 5 and ratio of bands 7 of the two different dates were displayed together on the CIAS monitor. A colour composite was produced for these combined data. The red gun was assigned to the band 5 ratios and the green gun was applied to the band 7 ratios. The result of this comparison gave area colouration to the areas where changes in water level dominated, especially around the border of Mamawi Lake. In the areas where vegetation had changed blue colours appeared. Furthermore, the areas of relatively little change were displayed in brown, grey and white.

There were six habitat areas were changes between 1973 and 1976, namely, turbid open water, less turbid open water, Scoloclhoa / Scolochloa-Carex, wet carex fen, Carex-Calamagrotis fen, and Picea-Populus. Three habitat areas showed no change and approximately 16% of areas were unclassified.

Todd (1977) studied land cover changes in Atlanta using the band ratioing technique. The selected study area was located 22 Km northeast of downtown Atlanta in approximately 22.5 square kilometers. Available Landsat MSS data for this study was acquired on 15 October 1972 and 5 October 1974, and comparison of these two images was made using a General Electric 100 system.

Detection of land cover alteration using the band ratioing technique indicates that: (a) all areas of the same land cover type will display approximately same reflectance value for each scene, the division result of these two images is nearly 1,0 and these areas will appear as grey colour; (b) in areas where land use and land cover had changed, the quotient of these images is significantly different from 1,0, and these areas will appeared either in dark or light tone. In the Atlanta study, it could be detected that a forest area which was cleared for construction of an industrial plant had low reflectance (dark tone) in image 1972 and high reflectance (light tone) in image 1974.

Six land use and land cover classes have been categorized using Landsat image band 5 of 1974, namely, single-family residential, commercial-industrial-multi family, cleared land, forested, open space, and water. Using two aerial photographs of October 1972 and February 1975 as ancillary data, the changes area have been detected successfully. Extensive warehousing and wholesaling establishments were constructed in the northwestern part of the study area. Two large forest areas, one in the southwestern and another in the northeast were cleared for industrial or commercial expansion. Forested sites were cleared for the construction of multi family residential development in the south-central sector.

Howarth and Boasson (1983) have completed research into Landsat digital image for change detection in the urban environment. The Hamilton - Wentworth Region, located at the westen end of lake Ontario was selected for this study. This study area was recorded by two Landsat MSS images of different dates obtained on 6 July 1974 and 12 July 1978. Change detection on these two images was

carried out using band ratioing method on the CIAS system of CCRS, Ottawa.

In this research, a comparison of two different images was performed using band 5 and band 7. On the band 5 (1978) to band 5 (1974) ratio cultural features appeared in colour contrast. Areas of change in the quarry and at construction sites on the urban fringe are seen as light tones. Changes in the agricultural areas are also emphasized. On band 7 (1978) to band 7 (1974) ratio, it was very difficult to detect any cultural change. Even the quarry cannot be detected on this ratiod image. Both vegetated and bare surface have a high reflectance, and as a result, even though the changes in the areas have occurred, it is difficult to detect.

The colour composite from the two ratios was also displayed on the monitor with red gun for bands 5 ratio and blue and green gun for bands 7 ratio. Because of lack of contrast in the band 7 ratio, the ratioed color composite only emphasize areas of major changes. In this process, the changes are not as clear as on the band 5 ratio overlay.

5.1.2.2. Image Differencing

The principle of image differencing method is based on subtracting the corresponding multispectral image of one date from another to create a new difference image (Nualchawee, 1981). In this method, it is necessary to obtain geometrically registered images of different times. After registration, the two images of the same band are subtracted pixel by pixel to generate the third image which is composed of numerical differences between the pairs of pixels. The resultant values of each pixel shows negative or positive changes or no shift in values near zero. Where the subtraction result in a negative value, the addition of positive constant (e.g. 127) is used to create positive numbers (see Singh, 1986, p 247). Single multitemporal bands or combinations of different band (often MSS band 5 or band 7) can be employed in this technique.

Change detection in the tropical forest environment of northeastern India was successfully studied by Singh (1986) using image differencing methods. The selected study area was located in the northern district of Manipur State, an approximate area of 280 square kilometers. Landsat images of the study area selected for analysis were images path 145 / row 042, obtained on 26 January 1974 and 6 December 1981. Destriping correction, haze correction, and image normalization were carried out to produce better image quality. Three land cover classes were constructed, namely, forest, shifting cultivation, and regenerating forest.

The image differencing method which is used in this study was given by the following equation and presented schematically in figure 14:

$$DX_{ij}^{k} = \frac{X_{ij}^{k}(t2) - X_{ij}^{k}(t1)}{2} + 127$$

where: DX_{j}^{k} = the change pixel value

i = line

j = column

t1 = first date

t2 = second date

127 = a constant used in order to generate out put values between 0 and 254.

After the processing of this comparison, it can be summarized that land cover changes caused by shifting cultivation in the tropical forest environment can be detected on Landsat MSS data using the image differencing method, and approximately 74% change detection accuracy can be achieved.

There are some problems which can affect the accuracy of this process, such as differences in illumination, differences in atmospheric condition, variation in surface moisture, and the possibility of misregistration of images. Furthermore, land cover changes that do not significantly influence the spectral response will be undetected and it will reduce the accuracy of change detection.

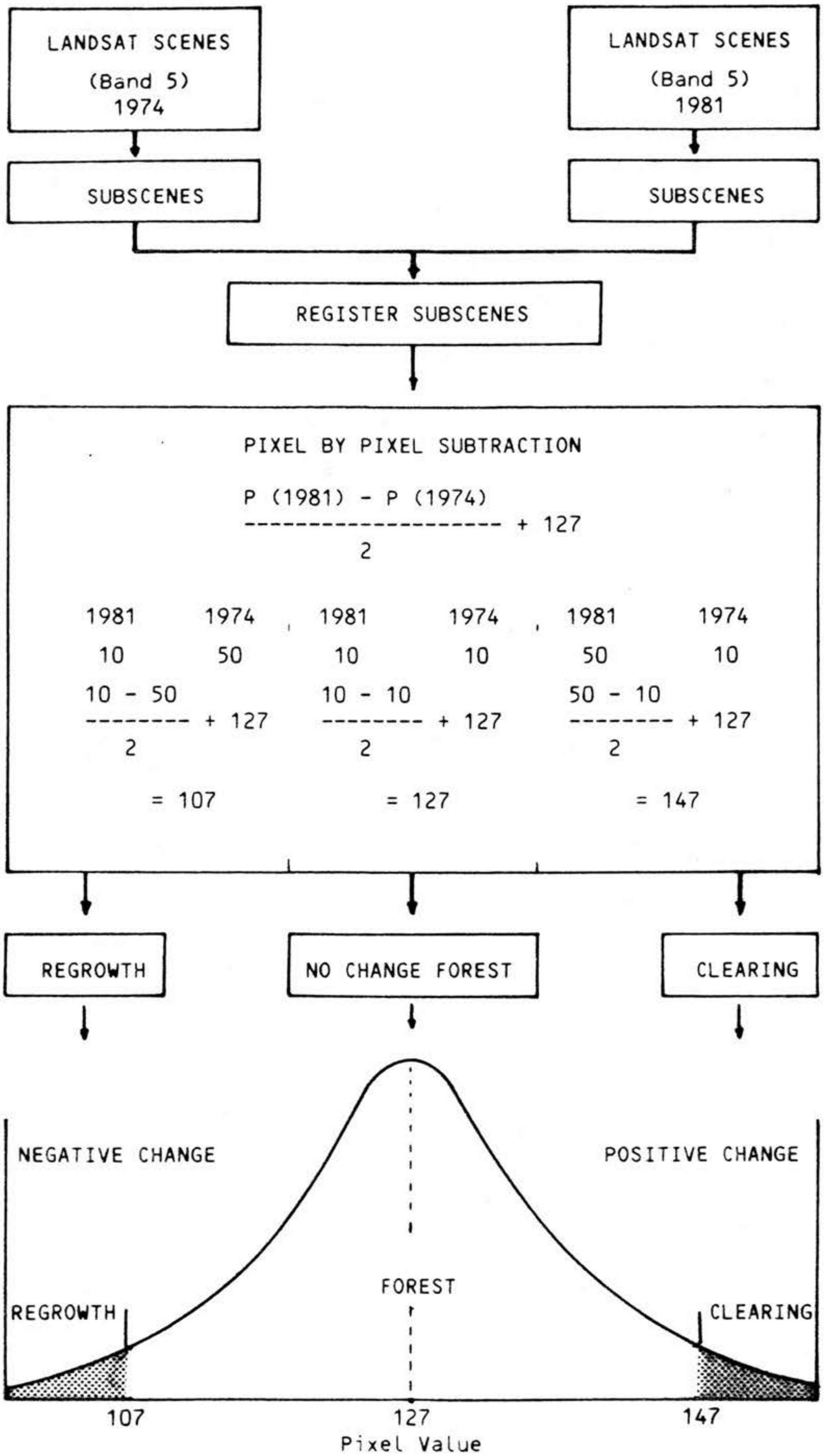

Figure 14 Image Differencing Method
(Singh, 1987)

Jensen and Toll (1982) selected the Fitzsimmons Quadrangle near Denver, Colorado, USA as a study area for detecting residential land use development at the urban fringe using the image differencing method. Landsat images collected on 1 October 1976 and 30 September 1978 were used for this research.

Landsat band 5 of those images were selected for detection analysis based on the result of previous study because: (1) Landsat MSS band 5 data enhance the contrast between vegetated and nonvegetated surface because of the chlorophyll absorption of red radiant flux by green vegetation; (2) In the semi-arid environments of the western United States, band 5 was established as slightly superior to all other bands for binary Landsat change detection at the urban fringe; (3) Landsat image band 5 proved far superior for change detection in more heavily vegetated areas such as Virginia. The image differencing method was selected for change detection and the operation of this method was slightly different from the method used by Singh (1986). It was expressed mathematically as :

$$DX_{ijk} = X(1)_{ijk} - X(2)_{ijk} + C$$

where: DX = the change pixel value

$X(1)$ = value at time 1

$X(2)$ = value at time 2

C = constant, e.g., 255.

i = number of line

j = number of column

k = a single band, e.g., band 5

This procedure resulted in the distribution of subtraction (pixel by pixel of two bands 5) where pixels of minor changes are distributed around the mean while pixels of significant change are distributed in the tails of the distribution.

A comparison process has been done using ten land cover categories. The digital method accurately identified land use changes from natural vegetation to partially or fully landscaped residential development. However, there was a substantial omission error when change from natural vegetation to uncomplete development areas occurred. The error also occurred where some natural vegetation was improperly classified as under going change. It might be caused through Denver receiving slightly less precipitation in September 1978 than in September 1976 and there may have been biomass changes between these dates which may cause changes in spectral response of such land, although it remains the same with the respect to land cover. The accuracy of this process was 77% with the majority of the error being omission.

5.1.2.3. Post Classification

The most obvious method of change detection is comparative analysis of spectral classification of two different times produced independently (Singh, 1986). The principle of this method is comparing two different images of different dates, pixel by pixel, to produce a new image that shows different pixels placed in different classes on the two scenes (Campbell, 1987), Better results could be achieved by improving the classification accuracy of both images, therefore the differences between the two images represent true different land cover rather than differences in classification accuracy. In the post classification change detection method, the accuracy of the result depends upon the accuracy of the initial classifications and geometric correction of two images (Howarth and Wickware, 1981). To gained higher accuracy level, it is necessary to chose an appropriate image classification. However, in urban and suburban landscapes the high percentage of mixed pixels have tended to decrease classification accuracy, particularly at Landsat MSS data (Campbell, 1987). Using this method, the comparison of those two images could be undertaken by visual comparison or digital comparison.

Wickware and Howarth (1981) have studied land cover change detection using Landsat digital data. The Peace-Athabasca Delta was selected as a study area which covered by Landsat MSS images of scene 20557 - 17522 recorded on 6 August 1973 and scene 10399 - 18104 acquired on 1 August 1976.

Landsat image classification of two different dates was carried out using both supervised and unsupervised classification methods. However, the supervised method was established as being more successful, and was used for this analysis. To achieve better accuracy, both Landsat images were registered using 25 matching ground control points that did not change between the dates of the images. Colour-infrared photographs at a scale of 1:7,000 acquired on July 1976 were used for guidance in chosing training area sites, and resulted eight habitat classes and one unclassified group.

Using data of different dates, the post classification change detection was undertaken through visual and digital comparisons. There were three habitat classes of no change, namely shrub fen / fen / Salix-Alnus-Populus, shrub fen, and Salix-Alnus-Populus, while changes occurred in turbid open water, less turbid open water, Scolochloa / Scholochloa-Carex, wet carex fen, and Picea-Populus. Approximately 16% of black pixels were unclassified during the analysis.

Weismiller, et.al. (1977) have selected a part of the Matagorda Bay estuarine system, situated on the Texas Coast, for land cover change detection study using the post classification method. This study was based on Landsat MSS data collected on 27 November 1972 and 25 February 1975, which were geometrically corrected and registered to ground control point selected from USGS topographic maps. The analysis of Landsat images used a Larsys image processing system, supported by reference data such as colour and colour-infrared aerial photographs of 1970, 1971, and 1975, a spectral environmental classification overlay result, and geologic atlases.

Post classification comparison of these images produced six ecological categories, namely, urban, woody / herbaceous vegetation, submerged vegetation and tidal flats, spoil areas, and open water classes.

By utilizing post classification comparison techniques, eleven land cover information classes were detected in which six land cover areas have changed, namely any non burn to burned, any non spoil to spoil, any non woody to woody, any non water to water, any non submerged to submerged, and any non urban to urban. Areas of major change were readibly identified by this technique, and it shows that the analysis procedures required are routine and quite well understood.

5.1.2.4. Principal Component Analysis

It has been known that all the spectral data in the four bands (channels) of Landsat mutispectral scanner image are highly correlated (Byrne et al., 1980). When two four-band images of the same area are obtained at different dates and compared to monitor temporal or seasonal change, there will be high correlation between these two images. Before comparison of these two images, uniformity of inter-channel and / or interpixel effects for atmospheric and radiation factors should be attempted (Byrne and Crapper, 1980). Principal component analysis has provided an effective way of identifying areas in which change has occurred between two four-channel multispectral scanner images (Byrne et al., 1980). One of the most popular technique to remove or reduce such redundancy in multispectral scanner data is principal component transformation.

The purpose of principal component transformation procedure is to compress all of the data information contained in an original n-channel data set into fewer than n-new channels or components (Lillesand and Kiefer, 1987). The first principal component accounts for the largest proportion of the total scene variance in the original dataset. The succeeding component (PC2, PC3,...,PCn) each contain a decreasing percentage of the scene variance. The first principal component normally shows albedo or brightness for visible and near infrared data, and the second principal component often shows an indication of green-ness (Harris, 1987).

Byrne et al. (1980) have monitored land cover change using principal component analysis. The selected study area was centred on the township of Batemans Bay, New South Wales. The study area was approximately 24,200 Ha and comprised 31% water.

Two Landsat images of different dates were selected for this study, scanned on 6 November 1972 and 13 October 1975. These images were overlaid and registered by eye using the nature of the coastline as ground control. Two sets of four-channels data were combined before principal component analysis was applied.

Principal component analysis was performed on the variance-covariance matrix, and five components were achieved. The first component had very high correlation with brightness in the infrared channels 3, 4, 7, 8, and is responsible for 91% of the variance. This image provided a good impression of topography and gave an excellent impression of ruggedness. The second component appears to be a measure of brightness in the two visible bands. Both of these two components appear smooth varying over the study area. The third and fourth components, as was obvious from the eigenvectors result, show the differences between these two images, component 3 being a measure of difference between the two images and component 4 having differences in the infrared channels reversed. The result of component five is not a clear image and is difficult to interpreted, only association with regrowth of vegetation and forest clearing could be detected.

Land cover changes could be detected from the component 3 image by identified black and white areas. Eleven land cover changes were successfully detected, namely, (a) acacia regrowth, (b) clearing associated with the new Catalina housing estate, (c) tidal changes on mudflats, (d) forest clearing activity, (e) regeneration following forest fire early in 1972, (f) intensive logging of native forest, (g) tidal changes in oyster farm areas, (h) urban development, (i) clearing and windrowing, (j) gravel extraction activity, (k) intensively managed forest.

5.2. Detection of Land Cover Changes

There are many methods of multitemporal comparison, using either manual or digital techniques as discussed in the previous section. In this study, the post classification comparison method was applied because of unrectified imagery and the comparison between two different image classification results will be done manually.

The comparison activity using post classification and the result of land cover change detection will be discussed in the following chapter.

5.2.1. Image Comparison Using Post Classification

As was discussed in the previous chapter, the main aim of post classification methodology is to compare the independently produced image classifications for the two dates. Because the classification activity has already been discussed in chapter 4.5., the comparison of two different image classification results will be discussed in this section.

Even though the differences of each land cover classification result can be seen in the tables 15 - 17, it cannot be used to determine the land cover changes because of differences in the areas of the study extracts and differences of image scale as this imagery was not rectified. Land cover changes could be detected using the image classification results by superimposing these two images using a zoom transfer scope.

Because of some difficulties in finding control features on the classified imagery result which could be matched to each image, the comparison of these classified images could not be done directly. However, this problem can be sorted out by using the original band 7 from each image as features control. Band 7 has been chosen as a guide for superimposing the image classification because there are many recognizable land features which can be used as feature control such as water bodies, road, and shadow.

For the Saguling study area, Jatiluhur reservoir, Citarum river and the shadow areas in the hilly terrain will be used as control features. In the Malabar study areas, the Cileunca reservoir and shadow areas of hilly terrain will be used as control features whereas in the Bandung study area the roads, and the airport are used.

After control features of each study extract have been decided, the comparison can be done by first matching band 7 and then the classified images were overlaid on band 7 at the same position so that matching could take place. However, because of distortion resulting from the unrectified images and also because of computer screen distortion which can occur when the image classification results are obtained using a static camera, only partial comparison of these images will be undertaken. To facilitate detecting activities, the image of the study area can be divided into five regions, upper left, bottom left, upper right, bottom right and the centre of the image. Furthermore, the comparison of two different image will be done based on these regions. When the classified imagery has already been overlaid on the zoom transfer scope, the land cover changes can be recognized from the colour differences. Due to the differences in study extract area between image 1976 and 1985, the image of 1985 will be used as a standard area base.

Because of misclassification posibilities which could have occurred in each land cover type, the detection of land cover changes will also be done using ground information resources as a guide so that land cover changes can be detected accurately. Therefore, it means that not every place which has different colour will be detected as land cover changes. For example, rice fields on image 1976 were classified as rice field 1 and on image 1985 they were classified as dry fields. This does not mean that there is a land cover change from rice fields to dry fields. It is possible because of plant rotation where some rice fields areas will be planted, as in dry fields areas.

5.2.2. Detected Land Cover Change

The comparison of the classified images to detect land cover changes will be done for all of the land cover classes. Furthermore, to achieve a better result and to make change detection easier, rice fields 1 and rice fields 2 will be regrouped to a single class of rice fields. Shadow areas which represented forest area will be regrouped as forest. After regrouping has been done, there are six land cover types for the Saguling and Malabar study areas and seven land cover types for the Bandung study area.

Land use / land cover of Java Island is very complex because this island has fertile soils and about 63% of the Indonesian people live in this island. Therefore, to reduce the misdetection which could occur, the observation of land cover changes will focus on the more obvious components. In particular, change detection will be determined only for changes from agriculture land to non agriculture land or vice versa. It is very important to investigate the addition or reduction of agriculture land and also the reduction of forest land cover. In this study, the comparison will also using land use / land cover maps of 1986 as a reference in order to minimize errors.

In the Saguling study area, there is an extensive area which has changed mostly from rice fields and small area of dry fields to the reservoir area (Figure 21). The

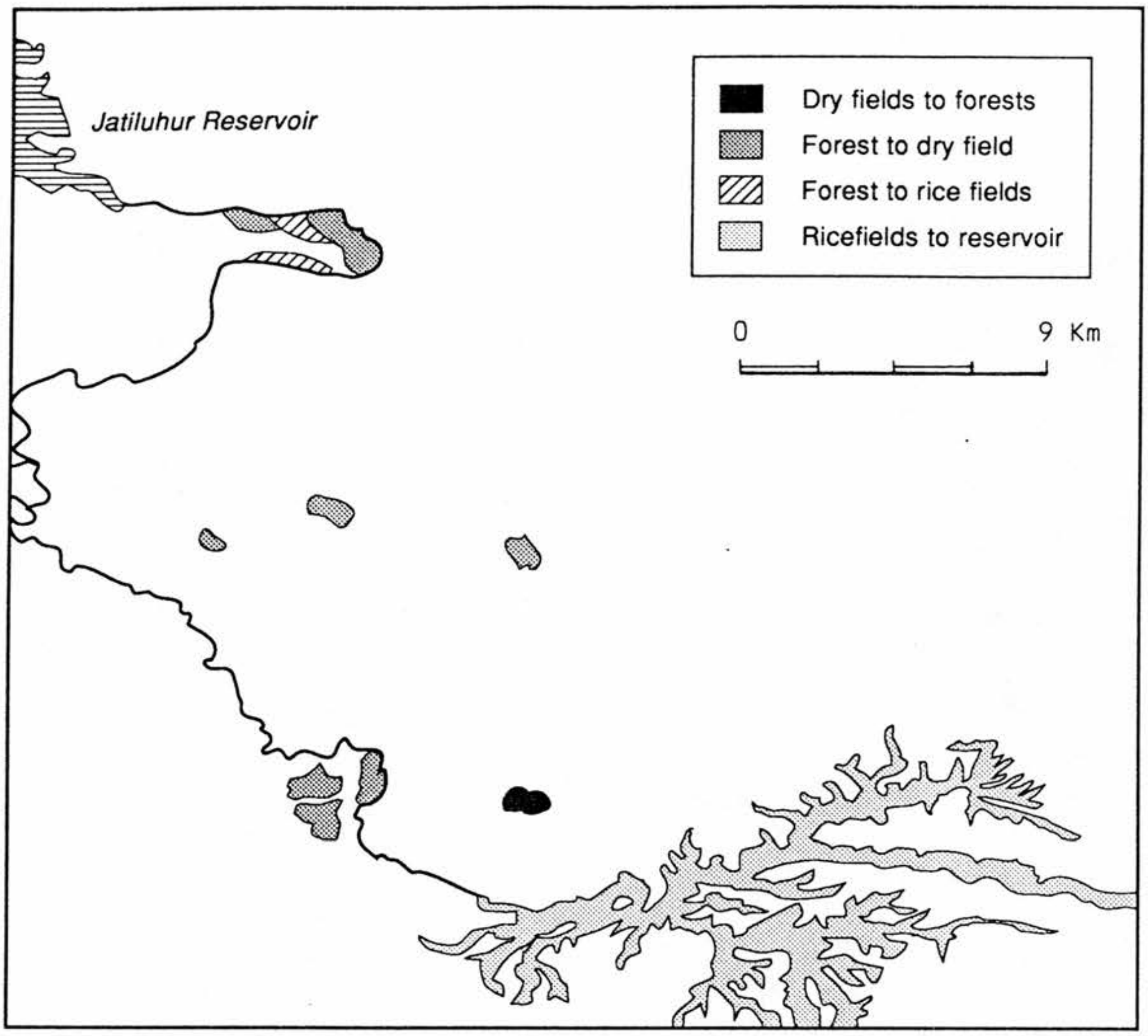

Figure 21: Land cover change detection map of Saguling study area

Saguling reservoir which was built in 1984 has started to flood part of its projected area. Even though it will **reduce** an extensive agricultural areas, many advantages can be achieved such as the extension of irrigated rice fields, reducing the risk of flood, and producing electricity. Nevertheless, many people who live in settlement areas have been evacuated as this areas will eventually be flooded.

Deforestation has occurred in the Takungtung hilly terrain near Saguling dam, in the Pasirsusuru hilly terrain and also in the hilly area near Jatiluhur reservoir. Most of the forest areas in these locations have been replaced by dry fields while in areas near Jatiluhur reservoir change to rice fields has taken place. Actually, there is reforestation in some forest areas, but it cannot be detected as a forest class because this area was misclassified as mixed crops. This problem also occurs in other secondary forest areas which are characterized by open canopy, therefore, it will have a similar spectral reflectance to that of mixed crops. Only small areas which are located in the Mount Kasur area can be seen to have changed from dry fields to forest. It is a result of a reforestation program particularly for the critical land area which is located in the steeply sloping terrain.

In the Malabar study area, there are various types of land cover change mostly from forest area to rice fields and also from forest to dry fields (Figure 22). The land cover changes from forest to dry fields can be detected in the Puncakwalang areas which is located in the bottom left corner of the study area. Deforestation has occurred in the Puncakwalang areas, and land use has changed to rice fields. Because there is no urban class in this study area (due to the small settled areas which are difficult to detect), most of the rural settlement will be included in the rice fields class. Another detected land cover change is in reducing estates areas which are mostly replaced by rice fields. In some areas estates are being replaced by dry fields or mixed crops. This has been detected even though the land cover changes was from one agriculture land use to another agriculture land use due to the assumption that some rice fields areas actually represented the rural settlement and it was quite easy to detect this. Small areal changes from estates land cover to dry fields have occurred in the Malabar areas and also in Puncakwalang. Most of the changes from estates to rice fields has occurred in the Kencana areas and also in some areas in the Puncakwalang foot hills near Cileunca reservoir.

Another land cover change which can be detected in the Malabar study area is dry fields in the Mount Bubut, located in the top left corner of the study area, which has changed to forest. This is a result of reforestation

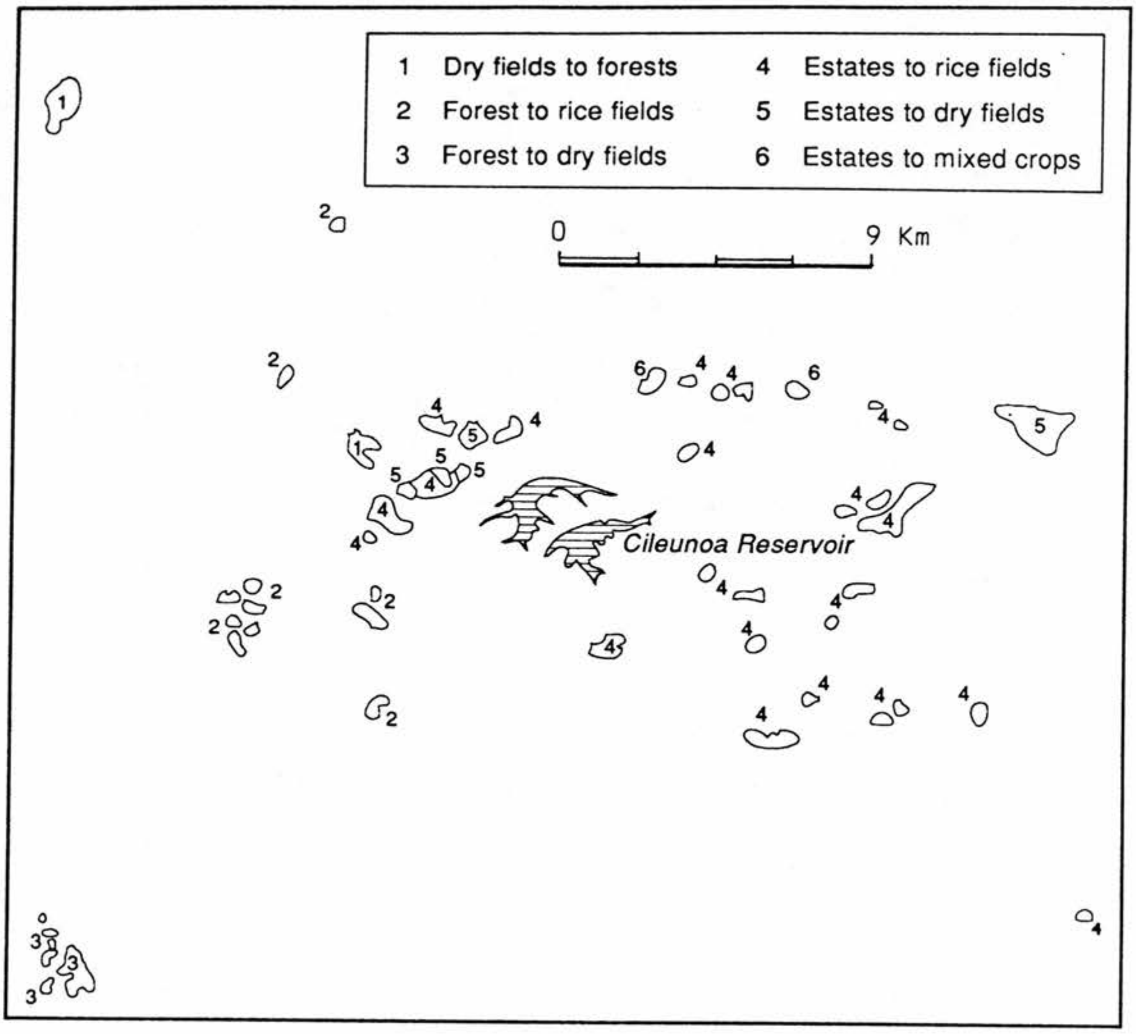

Figure 22: Land cover change detection map of Malabar study area

in a critical land use area.

In the Bandung study area, the detected land cover changes focus on the urban land cover changes. As can be seen in the figure 23, most land cover changes has occurred in the south and west part of Bandung study area. The extension of the urban area in western Bandung stretches along the main road between Bandung and Cimahi town. In the south of Bandung, the urban areas was developed along the Sukarno - Hatta by-pass. Therefore, a lot of rice fields areas changed to urban uses. In the north of Bandung area, the land cover changes were not obviously detected due to the possibilities of misclassification. However, the land form condition of northern Bandung will reduce a chance of urban development as this area is in the moderate to steep slope valley and mainly covered by mixed crops. The land cover changes in eastern Bandung are also associated with the road.

The open land which actually represents new urban built-up areas mainly appear in western Bandung and have changed from rice fields areas. In southern Bandung, this land cover change has occurred along the road mainly on the east side.

Because of the misclassification, which cannot be avoided between rice fields 1 and urban areas, the detection of urban land cover changes was done only in the area that urban development was obviously occurred, therefore, the land cover map of 1985 was quite helpful.

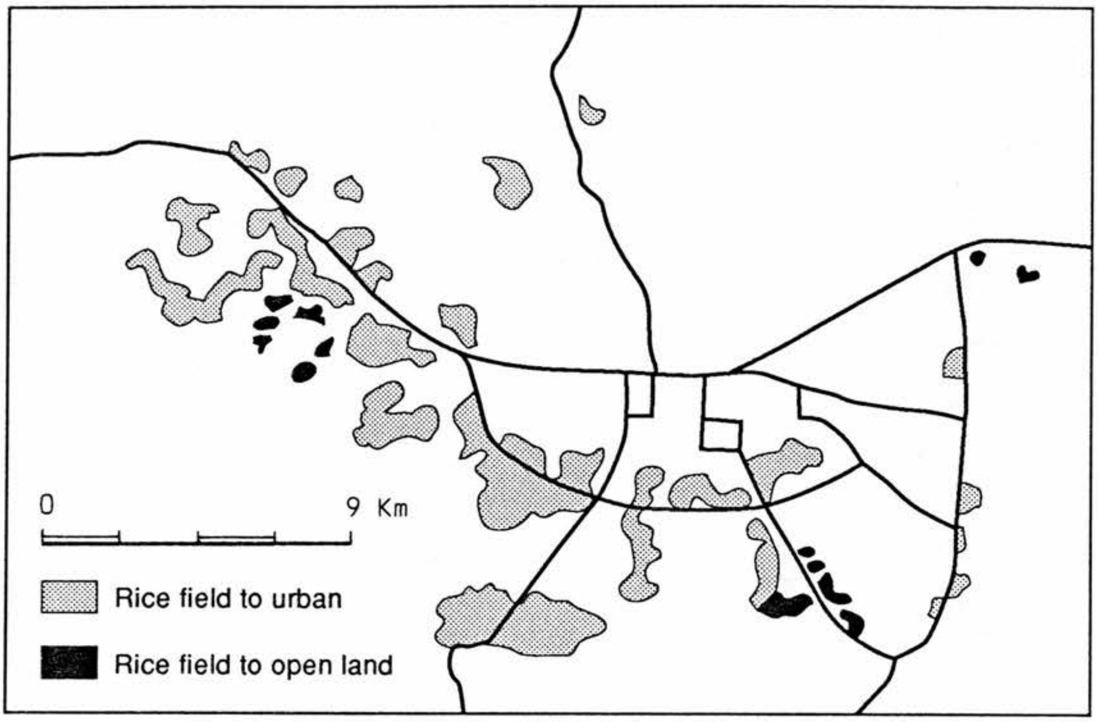

Figure 23: Land cover change detection map of Badung study area

5.3. Assessment Accuracy

It was mentioned in the previous chapter that the success of the land cover change detection using a post classification method was dependent upon the result of individual image classification result. Therefore, it was necessary to analyse the result of the image classification and the change detection result. This will be discussed in the following section.

5.3.1. Image Classification Accuracy

There are many methods of image classification and every method has advantages and disadvantages. As was discussed in section 4.4.2., the box classifier used in this study has some advantages and disadvantages. It is fast, simple, and effective; these are the major advantages of the box classifier. Supported by a better selection of training areas, it will result in better image classification. Some problems will arise when training areas are selected and used at inappropriate location. This causes misclassification, particularly when some pixels are located within the intersects of box spectral regions. Another problem occurs when this classification method is used to classify images with a complex land cover on complex and varied landforms, because the same land cover type will have different spectral reflectance when located on different land forms giving a variety of spectral patterns.

In this research, some assessment accuracy of the box classification result was obtained by comparing some test sites of the image classification result with available ground information sources - the land cover maps. In particular, it was suggested that about 30 samples of each land cover type should be selected as it was stated by van Genderen and Lock (1977) that sample points for each land cover class should be at least 20 - 30 to achieved 85 - 90 percent interpretation accuracy. Difficulties arise, however, when different land covers only occur in small patches. Furthermore, there are additional problems in the quantitative analysis of classification accuracy such as : a) it is difficult to accurately locate the sample site of the land cover on the image classification in relation to the ground information sources because the Landsat imagery was not geometrically rectified, b) the availability of the ground information source, which was produced at different date from the Landsat imagery, will produce more likelihood of a mistake when the sample site in the ground information source is compared due to the possibilities of land cover changes, c) there are no reasonable ground information sources for the Saguling study area for comparison with the image classification result of 1985.

Because of the problems outlined above, accuracy analyses of image classification were not obtained in quantitative terms but investigated for the relative accuracy of qualitative depiction of the box

classification result. The investigation attempts to **indicate the nature** of misclassification.

Due to the differences in scales between the image classification and the land use / land cover maps and in order to reduced mislocation, the comparison of sample site was done using a zoom transfer scope. Random sampling should have been applied to locate sample sites, but rigorous random sampling was not used because the sample site must be related and spatially recognized on both image classification and land cover map. Therefore, sample sites had to be easily located on both data sources.

The result of the Saguling study area of image 1976 shows that forest land cover has been classified, not in its real location but to some other class. This is particularly true for secondary forest area which was classified as rice field 2 or mixed crops. These could be caused by high correlation of those land cover types in band 4 and band 5 even though they are separated in band 7. Misclassification also occurred with the bush and shrubs class where some bush and shrub was classified as forest. In particular, some areas of tea estates and rubber estates were included in the bush and shrubs class, because of high correlation in bands 4, 5, and 7.

Rice fields 1 was classified much more accurately. Misclassification only occurred in small areas, mostly being confused with the Citarum river. There is a high correlation between shallow areas of water bodies with rice fields 1 in the flooding / fields preparation stage, therefore shallow water bodies will be classified as rice fields 1. The misclassification problem of rice fields 2 occurred with other classes such as bush and shrubs, and secondary forest with an open canopy, but these small areas were not extensive. High correlation occurred in the band 4 and 5 even though spectrally separable in band 7.

Because the mixed crops cover type dominated the Saguling study area, most of the sample sites were located in the correct place. Misclassification occured with rice fields 1 even when it was not obviously detected. Further problems of misclassification also occurred between open canopy forest (secondary forest) and mixed crops in the hilly terrain of the Mount Takungtung, and Mount Kasur areas. This problem is difficult to avoid as the characteristics of these cover types were not so very different, but it does reduce the classification accuracy. There is also misclassification which can be detected in the hilly areas near Jatiluhur reservoir, caused by the small intesity of shadow covering in this area even though it cannot be classified as shadow area because of different spectral reflectance.

For the Saguling study area of image 1985, most of the misclassification problems were similar to those of image 1976. However, misclassification of forest was greater than image 1976; particular confusion occured with rice fields 2. In some areas of the Saguling reservoir, rice fields 1 was classified as dry land. It was probably caused by peole who abandoned this area because this area will be eventually flooded by the reservoir, therefore, the reflectance of this area was changed and out of the rice fields reflectance region.

Results from the box classifier in the Malabar study area for image 1976 were more succesful than the Saguling study area, even though some problems of misclassification did occur. The forest area was classified successfully and only a small number of pixels were misclassified in the estates area. However, the bigest problem was found in the estates area where some areas of estates were classified as mixed crops, dry fields, rice fields 2 and also forest. These problem probably arise from various spectral reflectances being inseparable one from another as a result of undulating land forms being occupied by estates areas. The accuracy was also reduced by misclassification of reservoir, in which most of the shadow areas was classified as reservoir particularly in the low reflectance scales. Cileunca reservoir was only classified as a small area. This occurred because on the 1976 image, the expected spectral reflectance value of zero for a water body was enhanced to a higher value, giving a confused classification.

In image 1985, the problem of misclassification occurred mostly for mixed crops as this cover type appeared in the estates areas. As in the image 1976, some areas of dry fields were classified as mixed crops, but most of this cover type was classified correctly as was the reservoir area.

The Bandung study area of image 1976 classification produced better results, even though misclassification with rice field 1 cannot be avoided. However, these misclassifications did not occur in large areas. Another detectable misclassification was dry field which appeared to occupy the airport zone. However, this problem could be ignored as the airport was not including in the land cover class, and should be classified as part of the urban group.

For the Bandung study area of image 1985, the application of the box classifier was less successful than for image 1976. Most of the mixed crops in northern Bandung was classified as forest while some areas of rice fields 1 was classified as urban area (as in image 1976). The dry fields area was not correctly located whilst bush and shrubs was difficult to detect due to misclassification and also a result of photographic processing problems. However, open land was successfully classified and detectable because there is no confusion problem with another classes.

From these analyses, it could be concluded that the misclassification problem which occurred in all the images results from the high correlation within each land cover type in two or more of the MSS bands. The correlated data distribution cannot be separated using the box classifier, particularly for the spectral reflectances located within the intersects of box spectral regions. The box classifier will determined the land cover classes using box boundaries based on the upper and lower limit of training class spectral reflectance. Various land cover types on the various land forms, soil moisture, and variable vegetation canopy are the most common aspects which produce misclassification difficulties. However, using a maximum likelihood classifier, these problem could be reduced and classification accuracy will be increased.

CHAPTER 6

CONCLUSION

The purpose of this study is to detect land use / land cover changes using two different Landsat MSS image of different dates, the data of path 130 / row 065 taken on 20 June 1976 and path 122 / row 065 taken on 7 July 1985. Supervised box classification was used to produce digital image classification. The result of these classifications were superimposed on the zoom transfer scope to investigate the land use / land cover changes.

Due to the limitation of overlapped imagery between image 1976 and image 1985 as a result of differences in orbital altitude of the different Landsat satellite series it was not possible to achieve the classification result at full image resolution. It was necessary to define study extracts within the major study area of West Java province. Three different study extract have been chosen, namely, Saguling, Malabar, and the Bandung study areas.

Thus the investigation of land cover changes was not easy, but as suggested earlier, the detection of land cover changes was generally succesfully done. In the Saguling and Malabar study areas, it appears that major changes have occurred in the forest area. Deforestation has taken place, and land use has changed to dry fields and rice fields. On the other hand, it also can be seen that dry fields land cover located near the forest area has changed to forest. This results from the reforestation program which was directed towards those areas regarded as the critical land areas or at the restricted and conserved forest region which was disturbed. There is an extensive reduction in rice fields in the Saguling study area. The Citarum river as an intake for the Saguling reservoir has started to flood a part of the reservoir region. In the Malabar study area, estates were also reduced, and mainly replaced by dry fields, rice fields and mixed crops.

The Bandung study area was masked off and is therefore smaller than the other study areas, in order to detect the urban development of Bandung town and to reduce the risk of misclassification between rice fields 1 and Bandung urban area. Therefore, it can be detected that most of rice fields to the west of Bandung was reduced as a result of urban development. Most of the urban growth stretched to the west because this area was relatively flat, located near Cimahi town, and located along the main road which links Bandung to Jakarta, the Indonesian capital city.

This study has shown that it is possible to use Landsat MSS data to detect the land use / land cover changes in West Java Province. The problems and potential of using remote sensing to detect land use / land cover change and the possibilities of improving for further work will be discussed in the following section.

6.1. Problems and Potential of Remote Sensing Technique for Land Use / Land Cover Change Detection in the Humid Tropics

Landsat satellite data which can be obtained at intervals of approximately every 16 days is a very useful data source for detecting land use / land cover change. To date, it has not been a problem for Indonesia to obtain Landsat MSS data particularly for the west and central part of the country as LAPAN already operates the ground receiving station. Nevertheless, the problem of cloud coverage, the bigest problem in humid tropical countries, will reduced the image quality. The low spatial resolution of MSS imagery also causes difficulties in obtaining better image classification results, in addition to other factors which affected the spectral reflectance such as topographic conditions, vegetation canopy, soil condition, etc.

The supervised box classifier, a fast and effective method for image classification was very useful, particularly in the matter of land use / land cover change detection. Under conditions such as those on Java island where approximately 63% of Indonesia people live, the possibilities of rapid land use / land cover changes are very high. Therefore, a fast and effective method for land use / land classification processsing to investigate the land cover alteration is needed.

The box classification method is based upon the range of values within training area data to define land cover classes. Some problems will arise when it is applied to imagery of complex land use / land cover. If the training data do not represent the complete range of spectral values of the each training class, large areas remain which are unclassified or misrepresented. On the other hand, if the spectral data range of the training data was more than was estimated, it will causes overlap with another class. Therefore, misclassification will occur. It was difficult to obtain better training area data in the complex land cover patterns located on various landforms. Every land cover class was located on different topographic conditions, and the addition of other factors which influence the spectral reflectance, e.g. various vegetation canopy, different spectral patterns are produced. This results in heterogeneity of spectral reflectance; therefore, misclassification cannot be avoided. The high spectral data correlation in the three bands of MSS data for some land covers also gives possibilities of misclassification. Although rigorous accuracy testing cannot be achieved due to the non-availability of ground information sources, the accuracy of the box classification result was generally high, given the image resolution problems of MSS.

Because the Landsat imagery used in this study was not geometrically corrected, the post classification method to detect the land use / land cover changes was quite useful. However, the image classification result will influence the result of the change detection process. As the study areas are located in hilly regions, the feature control which was needed during the superimposition process could be defined easily. However, it would be difficult if the study areas were located on flat terrain. The result of detection activity can be also affected by the result of hard copy processing. The less the distortion of the hard copy, the better the result which can be obtained.

6.2. Recommendations for Further Work

Although simple in concept, a comparison of Landsat classification images of the same area from two different dates, however, is in practice, one of difficulty considering the problem of producing classified imagery of the complex environment.

With the low spatial resolution of Landsat MSS data in which each pixel has a size of 56 X 79 meters, there is a greater chance of mixed pixels occuring, and as a result it will be difficult to define homogeneous classes. As stated by Campbell (1987) the number of mixed pixels will increase as spectral and spatial resolution decreases. Besides the other factors which can affect the spectral reflectance such as soil moisture, soil texture, surface roughness and canopy geometry, spatial resolution remains the most important factor in achieving better

classification.

To obtained a better image classification result due to the complex land cover, it is recommended that imagery with a higher resolution than that of MSS be used, such as Landsat TM which has a pixel size of 30 X 30 meters or SPOT imagery, the finest spatial resolution of satellite imagery at present, which has a pixel size of 20 X 20 meters for multispectral data and 10 X 10 meters for panchromatic data.

There are many methods of image preprocessing which can be used to improve the image quality before classification is carried out. Geometric rectification, image smoothing, principal component analysis etc. are the most common preprocessing operations. The acquisition of aerial photographs and other ground ancillary data will improve the classification result as this data will be useful to locate the training area data in the most appropriate place.

As the box classifier produces difficulties in the classification of a complex land cover, it is recommended that an alternative classifier such as maximum likelihood classifier be used, even if it will take more computer processing time. The result will be better than the box classifier. It is also recommended that the box classifier be used to recognize the spectral distribution of each class before the maximum likelihood classification is applied. Even more computer time will be required but a better result will be achieved. Alternatively, to reduce misclassification because of a complex land cover and a variety of land forms with the same land cover type which produces a different spectral reflectance, it is necessary to minimize land cover types into more specific land cover classes e.g. three categories of rice field (fallow, flooded and pre-harvest mature) can be recognized. In this instance, the land cover classification is not only based upon spectral reflectance pattern recognition, but it also takes into account, and combines with, spatial pattern recognition.

In order to minimize misdetection during land use / land cover change detection, it is recommended that the imagery is geometrically rectified so that the two images can be superimposed accurately. If the imagery was rectified, the comparison with ground information sources to analyse the classification and the detection of change process could be done much more accurately.

REFERENCES

Adeniyi, P.O. (1986). Agricultural land use inventory and mapping in Nigeria: the application of remote sensing. In Eden, M.J.E. and Parry, J.T. (editors) Remote sensing and tropical land management. John Wiley and sons, Chichester, pp 175 - 187.

Anderson, J.R. (1976). A Land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Prof. Paper 964.

Asmoro, P. (1978). The application of remote sensing in support of the national program for the inventory and evaluation of the country's natural resources. Country Report No. 07/1978. National Coordination Agency for Surveys and Mapping (BAKOSURTANAL), Jakarta, Indonesia.

Asmoro, P. et al. (1978). Integrated resource mapping by multistage and multisensor remote sensing in Indonesia. Internal Report No. 19/1978. National Coordination Agency for Surveys and Mapping, Jakarta, Indonesia.

Bagot, K.H. (1986). Hand book of GEMS image processing system. Technical Report 86062. Procurement Executive, Ministry of Defence, Farnborough, United Kingdom.

BAKOSURTANAL. (1985a). Klasifikasi liputan lahan untuk Indonesia. Dokumen No. 3/1985. Badan Koordinasi Survey dan Pemetaan Nasional, Jakarta, Indonesia.

BAKOSURTANAL. (1985b). Penelitian pemrosesan citra penginderaan jauh secara digital untuk pemetaan liputan lahan di daerah Jateng dan Jatim. Laporan No. 3/LP/INEV/85. Proyek Inventarisasi dan Evaluasi Sumber Daya Matra Darat. Badan Koordinasi Survey dan Pemetaan Nasional, Jakarta, Indonesia.

Barrett and Curtis L.F. (1982). Introduction to Environmental Remote Sensing. Chapman and Hall, London.

Byrne, G.F. et al. (1980). Monitoring land cover change by principal component analysis of multitemporal Landsat. Remote Sensing of Environment. 10 (1), pp 175 - 184.

Byrne, G.F. and Crapper, P.F. (1980). Land cover change detection by principal component analysis of multitemporal MSS data: the presence of cloud. Proc. 14th International Symposium on Remote Sensing of Enviroment, Ann Arbor, Michigan, pp 1375 - 1382.

Campbell, J.B. (1986). Introduction to remote sensing. Guilford Press, New York.

Crapper, P.F. and Hynson, K.C. (1983). Change detection using Landsat photographic imagery. Remote Sensing of Environment. 13 (3), 291 - 300.

Curran, P.J. (1985). Principles of remote sensing. Longman, London.

Eyton, J.R. (1983). Landsat multitemporal colour composites. Photogrammetric Engineering and Remote Sensing. 49 (3), pp 231 - 235.

FAO-UNESCO. (1979). Soil map of the World. 1:5,000,000. South East Asia, vol IX. UNESCO, Paris.

Fryer, D.W. and Jackson, J.C. (1977). Indonesia. Ernest Benn Ltd. and West View, London.

Garuda. (1986). Introducing Indonesia. Garuda Magazine. 6 (3), pp 7 - 9.

Gautam, N.C. and Chennaiah, G.C. (1985). Land use / land cover mapping and change detection in Tripura using satellite Landsat data. International Journal of Remote Sensing. 6 (3 and 4), pp 517 - 528.

Genderen, J.L.van and Lock, B.F. (1977) Testing land use map accuracy. Photogrammetric Engineering and Remote Sensing. 43, pp 1135 -1137.

Gordon, S.I. (1980). Utilizing Landsat imagery to monitor land use change: a case study in Ohio. Remote Sensing of Environment. 9, pp 189 - 196.

Hadisumarno S. and Arimurthy A.M. (1978) Digital Processing and Tentative Land Use Interpretation in Relation to Landform of Landsat-1 Recording of Lombok Island Indonesia. The Indonesian Journal of Geography. Faculty of Geography, Gadjah Mada University, Yogyakarta. pp 15 - 31.

Harris, R. (1987). Satellite remote sensing: an introduction. Routledge and Kegan Paul, London.

Hartl, Ph. (1976). Digital picture processing. In Schanda, E. (editor) Remote sensing for environmental science. Springer - Verlag, Berlin, pp 304 - 348.

Howarth, P.J. and Boasson, E. (1983). Landsat digital enhancement for change detection in urban environment. Remote Sensing of Environment. 13 (1), pp 149 - 160.

Howarth, P.J. and Wickware, G.M. (1981). Procedure for change detection using Landsat digital data. International Journal of Remote Sensing. 2 (3), pp 277 - 291.

Jensen, J.R. and Toll, D.L. (1982). Detecting residential land use development at the urban-fringe. Photogrammetric Engineering and Remote Sensing. 48 (4), pp 629 - 643.

Jewel, N. and Taylor, J. (1986). GEMSTONE Manual. GEMS of Cambridge Ltd., Cambridge.

Kalensky, Z.D., Kardono Darmoyuwono and Kaser, J. (1980). Resource mapping by Landsat in developing countries. Proc. 14th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp 1285 - 1296.

King R.B. (1984). Remote Sensing Manual of Tanzania. Land Resources Development Centre, UK Overseas Development Administration, Surrey.

Lillesand, T.M. and Kiefer, R.W. (1987). Remote sensing and image interpretation. 2nd ed. John Wiley and Sons, New York.

Lindgren, D.T. (1985). Land use planning and remote sensing. Martinus Nijhoff Publisher, The Netherland.

Lo, C.P. (1986). Applied remote sensing. Longman, New York.

Malingreau, J.P. (1977). A proposal land cover / land use classification and its use with remote sensing data in Indonesia. The Indonesian Journal of Geography. 7 (33), pp 5 -27.

Malingreau, J.P. (1986). Monitoring tropical wetland rice production system: a test for orbital remote sensing. In Eden, M.J and Parry, J.T. (editors) Remote sensing and tropical land management. John Wiley and Sons, Chichester, pp 279 - 305.

Malingreau, J.P. and Christiani, R. (1981). A land cover / land use classification for Indonesia. The Indonesian Journal of Geography. 11 (41), pp 13 - 50.

Mather, P.M. (1987). Computer Processing of Remotely Sensed Images : An Introduction. John Wiley and Sons, England.

Meijerink, A.H.J. and Donker, N.H.W. (1978). The ITC approach to digital processing applied to land use mapping in the Himalayas and Central Java. In Collin, W.G. and Genderen, J.L. van (editors) Remote sensing apllication in developing countries. Remote Sensing Society, London, pp 75 - 78.

Nanayakkara, C. (1980). Mapping for multiple resources development and management. Proc. 14th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp 315 - 323.

Nualchawee, K. et al. (1981). Monitoring forest land cover alteration in Thailand with the analysis of ancilary and digital data. Proc. 15th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp 1167 - 1173.

Omakupt, M. and Vunpiyarat, V. (1980). Remote sensing on land use inventory. Proc. 14th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp 897 - 904.

Prapinmongkolkarn, P. et al. (1980). Remote sensing application to land cover classification in Northern Thailand. Proc.14th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp 1273 - 1284.

Sabins, F.F.Jr (1978). Remote Sensing : Principle and Interpretation. Freeman, San Fransisco.

Singh, A. (1986). Change detection in tropical forest environment of Northeastern India using Landsat. In Eden, M.J. and Parry, J.T. (editors) Remote sensing and tropical land management. John Wiley and Sons, Chichester, pp 237 - 254.

Suwahyuono. (1983). Detection of forest land cover alteration in Northeastern Thailand based on the Landsat and ancillary data. Unpublished M.Sc. thesis, Asian Institute of Technology, Bangkok, Thailand.

Thomas, I.L. et al. (1987). Classification of remotely sensed images. Adam Hilger, Bristol.

Todd, W.J. (1977). Urban and regional land use change detection by using Landsat data. Journal of Reseach, U.S. Geological Survey, 5 (5), pp 529 - 554.

Wagner, T.W. and Bartolucci, L.A. (1980). Remote sensing application in Latin America and the Caribean. Proc. 14th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp 27 - 33.

Weismiller, R.A. et al. (1977). Change detection in coastal zone environment. Photogrammetric Engineering and Remote Sensing. 43 (12), pp 1533 - 1539.

Wickware, G.M. and Howarth, P.J. (1981). Change detection in the Peace Athabasca Delta using digital Landsat data. Remote Sensing of Environment. 11 (1), pp 9 - 25.