COMPUTER TECHNIQUE UTILIZATION
FOR
SPECTRAL SIGNATURE IDENTIFICATION

A THESIS

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Dedicated in memory of my teacher
Late Dr.Mahfuzur Rahman Khan, Professor,
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CONTENTS

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SUMMARY

An introduction to the development of remote sensing technology has been outlined in chapter one. The gradual development stages of remote sensing and the stages of development of sensors and satellites with their individual capabilities have been described. A present day state-of-art of the technology has also been explained. The objectives of the research and the methodology of image classification and comparison of different data sets from different sensor types have also been added in this chapter. Description has also been given of the data base used in the study.

In chapter two general digital image handling stages such as construction, reconstruction and display of digital images, sampling and quantization, histogram manipulations, Landsat tape formats, image enhancement techniques, image classifiers and the two image classifying approaches are explained.

The image analysis of MSS & TM data for the present study have been described in chapter three. Preparation of Landuse map of the study area, collection of ground-truth data, enhancement and the classification techniques utilized for the study have also been described in this chapter.

The results of the study are mentioned in chapter five and the photographic and statistical outputs are given in different tables and figures. Discussions about the results, difficulties, suitability of classification techniques and the process of comparison of data sets developed for the study have been included in this chapter. A brief remark has been made in chapter five about the further scope and importance of the study.

GLOSSARY OF TERMS

BLP - Bangladesh Landsat Programme
CCT - Computer Compatible Tape
DN - Digital Number
ELAS - Earth Resources Laboratory Application Software
FFT - Fast Fourier Transform
GIS - Geographic Information System
HDDT - High Density Digital Tape
I^2S - International Imaging System
LI - Line Increment
MSS - Multispectral Scanner
NL - Number of Lines
NS - Number of Samples
SARC - Space and Atmospheric Research Centre
SI - Sample Increment
SL - Starting Line
SPARRSO - Space Research and Remote Sensing Organization
SS - Starting Sample
TLM - Trackball Linear Mapping
TM - Thematic Mapper
VDU - Video Display Unit

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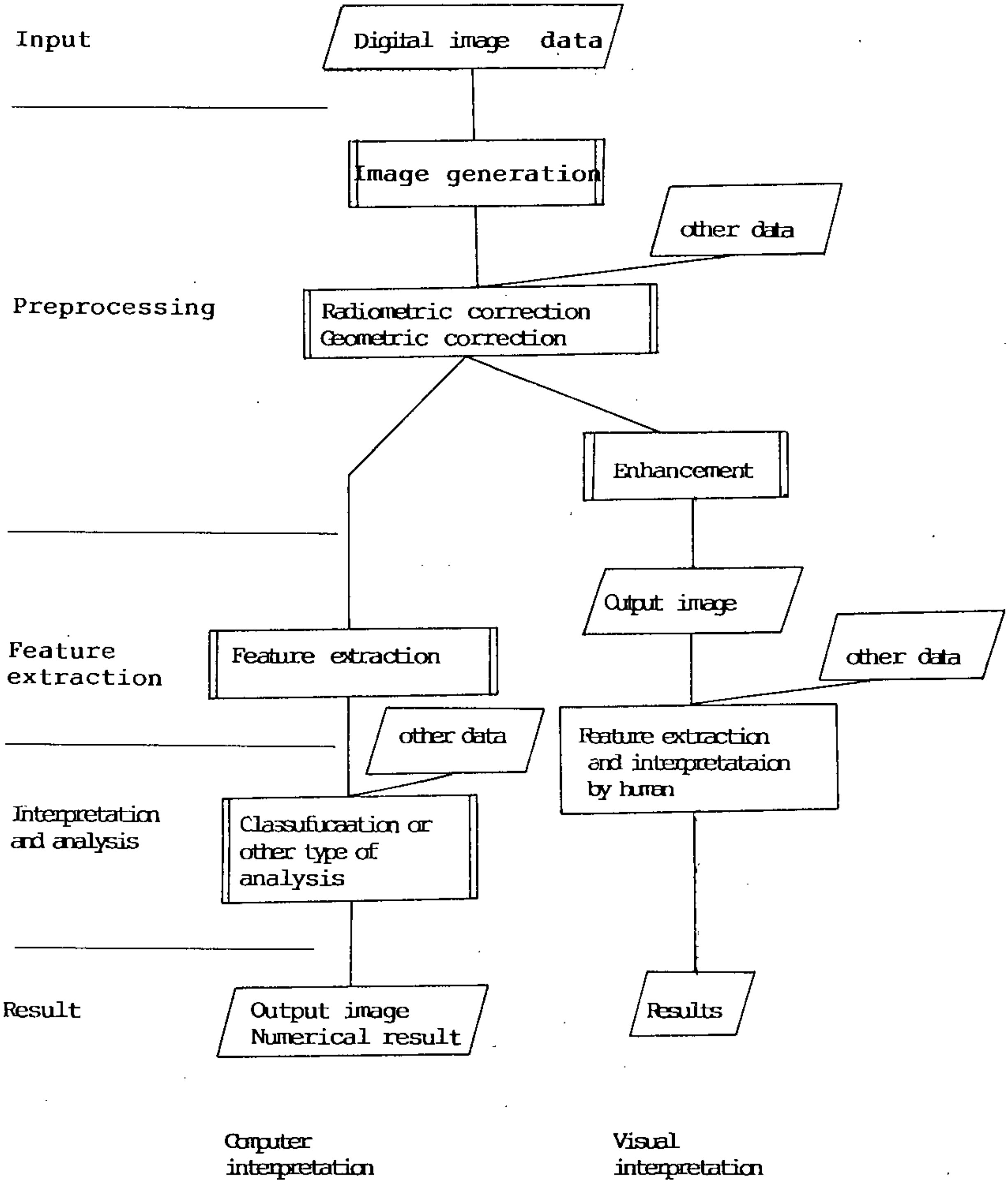
CHAPTER ONE
INTRODUCTION

1. INTRODUCTION:

Digital image processing has been gaining momentum during the 70's with the increased utilization of imagery in manifold applications coupled with improvements in the size, speed and cost-effectiveness of digital computers and related signal processing techniques. This modern technology has been effectively used in the fields of scientific, industrial, biomedical, space, and governmental applications. Digital transmission of spacecraft imagery, the resolution improvement of electronic microscope images and compensation of transmission errors of pictures from deep-space probes, automatic classification of terrain and identification of resources from resource survey satellite data, automatic map making from aerial photographs and various bio-medical detections are a few important fields of digital image processing. The next boost will hopefully be in the extensive use of digital image processing in bio-medical fields.

Digital image processing is a subject in employing which besides computer technology, many other subjects such as physics, statistics, electronics and electrical engineering, and mathematics are involved. The digital image processing technique in which the resource surveyors are interested, is the digital processing of aerial photographs and satellite imagery. The large-scale area coverage of satellite imagery and aerial photograph is the most important aspect for them. This is because visual interpretation of aerial photographs and satellite imagery is quite difficult especially when one tries to quantify the patterns he is interested in. If we choose to analyse and interpret an aerial photograph with computer assisted systems we have to take recourse to the digital processing. The ordinary black/white or colour photograph is constituted of a continuous spectrum of gray value or colour. In these types of photographs delineation of features by manual or machine cartographic methods is time consuming, arduous and susceptible to easy errors. This digital techniques provide a quick, more effective and more accurate result on most of the image analysis problems.

For analysing any image with the help of a computer assisted system one has to have sufficient software functions, necessary peripherals and provision of dialogue between the user and the computer. A flow diagram of digital image processing is given in page 3.



Flow diagram of digital image processing.

1.1. Development of Remote Sensing Technology:

The ever increasing human race live on the finite planet "Earth" whose resources are limited. To support the teeming millions living on its surface the available resources must be managed prudently and wisely by estimating them accurately and spending them judiciously. Augmentation of this process of estimation and monitoring has been made possible by the technique of 'Remote Sensing' which is the art of acquiring information on an object without coming into physical contact with it. This technique provides a means to produce data for an area, analyze them and incorporate them in decision-making level. The simplest but most available remote sensor is the eye which performs all the above three tasks. The eye sees an impending danger, sends the information/data to the brain/computer and decision is arrived at how to face/tackle the situation.

1.1.1 Photography & Balloons

The next phase of development of remote sensing owes much to Aristotle for his experiment with a "Camera Obscura" [1]. Then came the advancement in Chemistry which allowed successful permanent recording of images in films. By the end of the 19th century the basis of modern photography was established and photographs were being taken from the ground. In their quest of expanding the sphere of photography the photographers took to balloons. The first ever balloon photograph was taken by a French named Gaspard Felix Tournachon in 1859. He took the aerial view of a village near Paris. Due to military requirement aerial photography gained momentum and were used during American Civil

War (from balloons) and World War I and II. The civilian use of photography in the fields of geology, forestry, agriculture and cartography led to the tremendous development of camera, films and photo-interpretation equipment. The successes made during the 2nd World War provided impetus to improve reconnaissance devices like thermal infrared, and active microwave air-borne systems (radars). The colour-infrared photography was found to be of great use in plant sciences and as a result in 1956, Colwell performed some tests on the classification and recognition of vegetation types and the detection of diseased and damaged vegetation. Parallel to this, was developed the technology of Side Looking Air-borne Radar and Synthetic Aperture Radar [2].

1.1.2 Space Age : Satellites & Sensors

In 1960s, in the pursuit of landing men on the surface of the moon and to device systems to observe their landing, NASA selected some terrestrial sites analogous to that of the moon for observation. The value of these data on geology accelerated expansion of the programme to observe the earth's surface for gathering information on agriculture, forestry, geography, geology and so on. A remote sensing aircraft programme of NASA supported the instrument-development programme and test-site studies. In this process, not only high and intermediate altitude photography were taken but also taken were thermal infrared and radar imagery of a very large area of the US [2].

A Television Infrared Observation Satellite (TIROS-1) was launched by NASA in 1960 to obtain systematic earth orbital observations. Since then NASA has launched about half a century of meteorological and other satellites with gradually improved sensors. The National Oceanic and Atmospheric Administration (NOAA), USA consolidated these activities and continued launching of the NOAA series of satellites which added the new sensors: Advanced Very High Resolution Radiometer (AVHRR), TIROS Operational Vertical Sounder (TOVS), Data Collection and Platform Location Systems (DCS) & Space Environment Monitor (SEM) to observe the environmental aspects around the globe.

Explorer 6 transmitted the first photograph taken from space in August 1959. The first orbital photography became available in 1990 (Unmanned Spacecraft MA-4 took 70 mm colour photographs). The successes thus achieved inspired the U.S. Geological Survey (USGS) to establish Earth Resources Observation Satellite Programme and contributed to the launching of ERTS-1 satellite (known as Landsat 1) by NASA. The first three of these Earth Resources Technology Satellite series were designed to acquire information on the earth's surface and the resources. These were put into near-polar circular orbits varying from 897 to 918 km above the earth's surface. The ERTS was renamed in 1975 as Landsat series.

1.1.3 Channels & Resolution

The Landsat 1 carried a four-channel Multispectral Scanner (MSS) a three-camera Return Beam Vidicon (RBV), a data collection system and two video tape recorders. The MSS had 5 channels including a thermal infra-red channel ranging from 10.4 - 12.6 micro-meter. The MSS and RBV data were transmitted directly to the ground receiving stations within range otherwise those would be recorded in the magnetic tapes on board for subsequent transmission to the relevant ground receiving stations when they fall within range. There has been Landsat 4 and Landsat 5 which are operational in orbit. During the period of operation these satellites scan the earth in a polar-orbital motion 14 times a day (103 minutes per orbit). The orbital sequence of Landsat repeats itself every 18 days to provide global multispectral coverage (Figure 1). The swath of each orbit on the ground is 185 km wide while the entire strip of each pass is divided into scenes of 185 km length making each image of the size of 185 km x 185 km on the ground and the standard image scale in 7.3 inch format is 1:1,000,000 (Figure 2). The effective ground resolution is 80 m for MSS of Landsat 4 and 30 m for Thematic Mapper (TM) of Landsat 5 [3].

The latest among the resource survey satellites is a French one named SPOT. This satellite has a repetitive coverage of 26 days with a special oblique viewing arrangement of ± 5 days. Each SPOT scene covers an area of 60 km x 60 km. The ground resolution for SPOT Panchromatic data is 10mx10m while that of multispectral data is 20mx20m. The characteristics of different satellite data are given in table 1 [1]. A schematic diagram of satellite sensing of the resources is shown in Figure 3 [2].

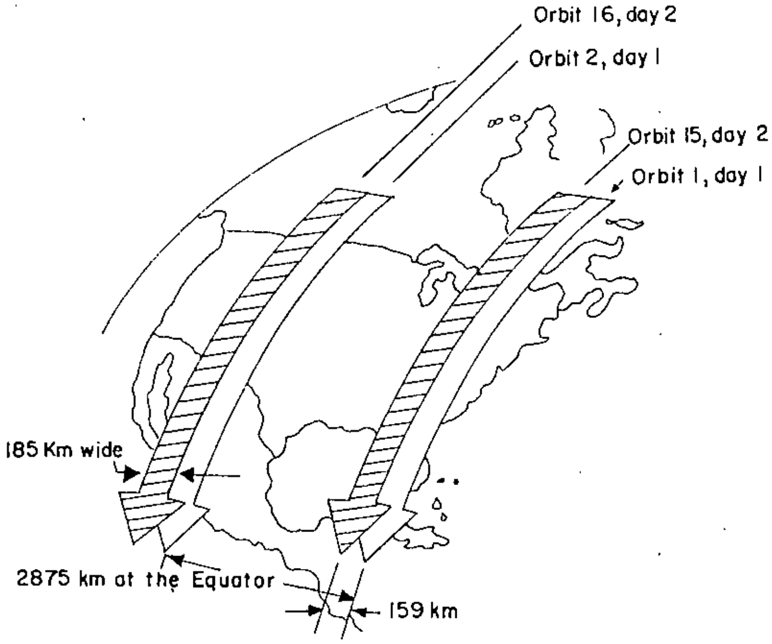


Figure 1 : Landsat Orbital Coverage.

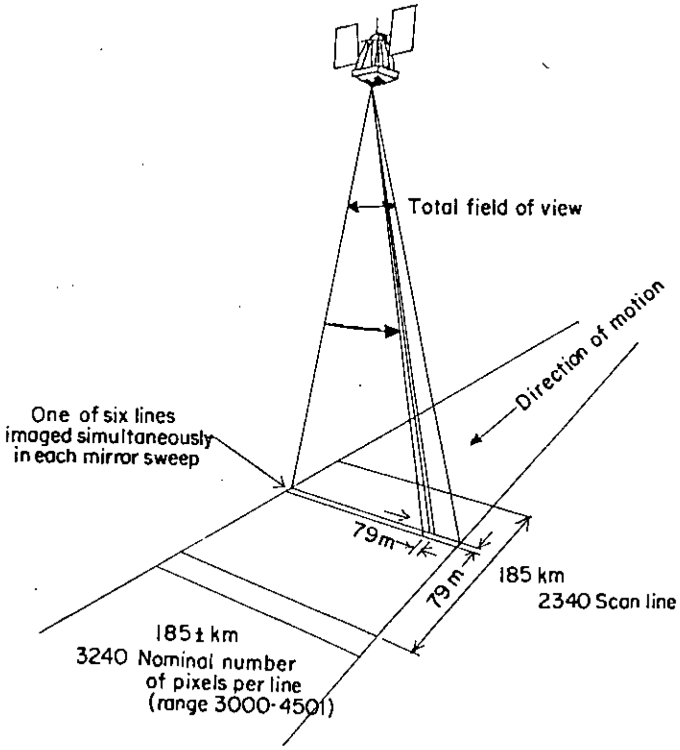


Figure 2 : Landsat Scanning Parameters

Table 1: Sensor characteristics of satellites

Band characteristics of Landsat MSS, Landsat TM & SPOT HRV

Satellite	Type of Sensor	Band	Wave length range in m	Characteristics/Potential application
Landsat	MSS	4	0.5 - 0.6	Penetrates water turbidity determination possible. Green vegetation and other surface cover distinguishable geologic structures identification possible.
		5	0.6 - 0.7	Topographic features determination and differentiation of types of green vegetation.
		6	0.7 - 0.8	Differentiation in landuse, detection of bio-mass in vegetation.
		7	0.8 - 1.1	Land water boundary delineation and soil-crop contrasts.
Landsat	TM	1	0.45 - 0.52	Coastal water mapping, soil/vegetation differentiation,deciduous/coniferous differentiation (sensitive to chlorophyll concentration).
		2	0.52 - 0.60	Green reflectance by healthy vegetation.
		3	0.63 - 0.69	Chlorophyll absorption for the plant species differentiations.
		4	0.73 - 0.90	Biomass surveys, waterbody delineation.
		5	1.55 - 1.75	Vegetation moisture measurement, snow, cloud differentiation.
		6	10.40 - 12.50	Plant heat stress management, other than mapping.
		7	2.08 - 2.33	Hydrothermal mapping.
SPOT	HRV Panchromatic	1	0.51 - 0.73	Observation over a broad spectral band.
	HRV Multispectral	1	0.5 - 0.59	(Green) together ensure improved spectral response to chlororophyll and specifically to the response peak in the green band, strong absorption in red band and pronounced response in the near IR.
		2	0.61 - 0.68	(Red)
		3	0.79 - 0.89	(NIR)

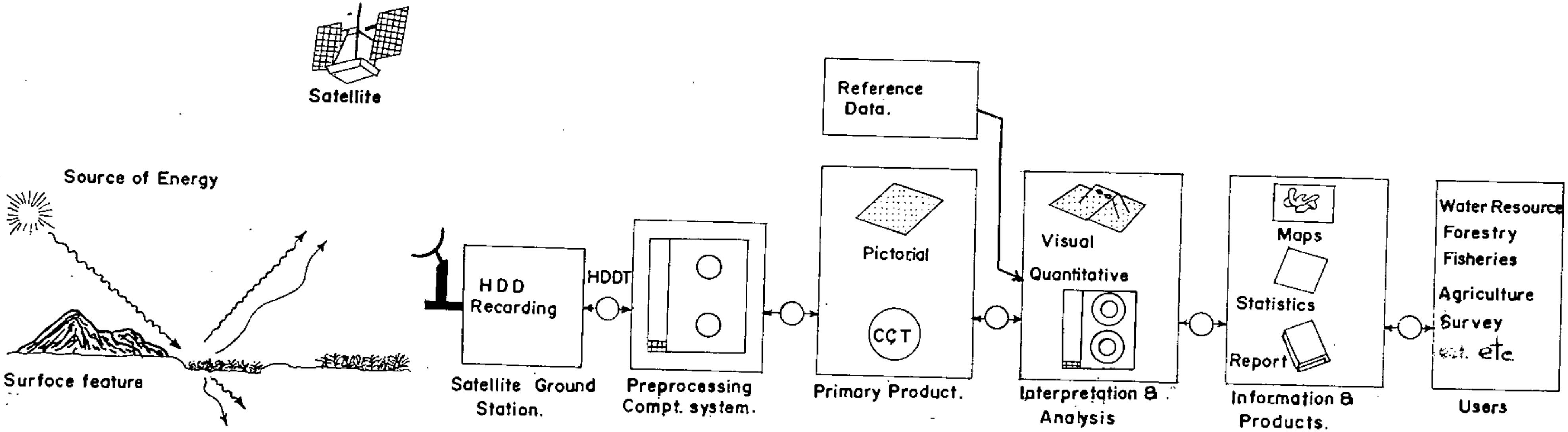


Figure 3: Satellite Sensing of the Resources of the Earth.

1.2 Present state of art of the research topic (with special reference to Bangladesh):

Although digital computers have a long history, digital image processing techniques have only been developed considerably in the last two decades. These could be achieved thanks to the development of Earth Resources Technology Satellites (later renamed as Landsat) and the digital computers. The speed, size and cost effectiveness of digital computers made it a popular application programme of satellite technology. Digital transmission of data from satellites to the ground receiving stations, processing of these data by digital techniques gained momentum. Thus in the developed world digital processing technique could be utilized fruitfully to a wide range of fields like agriculture, forestry, fisheries, water resources, oceanography, meteorology, geology, cartography, medical science, industries and so on. In the developed world production of digital computers, necessary peripherals for their various applications and the relevant application software is going on at a very large scale. But this high technology has also been travelling fast to reach developing nations like ours. Bangladesh has thus become one of the end users of this digital image processing systems through its remote sensing programme. Bangladesh Space Research and Remote Sensing Organization (SPARRSO) is the focal point of the activity and has been engaged in processing, analyzing and applying remote sensing satellite and airborne data to resource management and disaster monitoring in the country. Its march towards this goal started in 1968 through receiving analogue Automatic Picture Transmission

(APT) data from meteorological satellites under the auspices of the Space and Atmospheric Research Centre (SARC) of Bangladesh Atomic Energy Commission. Later at the launching of Earth Resources Technology Satellite (ERTS) in 1972 by NASA, Bangladesh took up ERTS programme which was subsequently renamed as Bangladesh Landsat Programme (BLP) with the change of nomenclature of the satellites from ERTS to Landsat by NASA, USA. Digital data processed and produced in the form of images were analyzed visually at BLP. Further developments occurred in Bangladesh with the establishment of Bangladesh Space Research and Remote Sensing Organization (SPARRSO) by merging SARC and BLP into a single organization in 1980. At the beginning Landsat MSS data in the form of Computer Compatible Tape (CCT) and Imagery were brought from USA, Thailand and India. Digital Processing of Satellite Images thus became a vital component of SPARRSO and attempts began to establish a SPOT/Landsat Ground Station in Bangladesh (SPOT-"Systeme Probatoire d'Observation de la Terre" is a French Satellite with higher ground resolution). Digital Image Processing System (computer) was thus installed. There is another system under the Agro-climatic Environmental Monitoring Project of SPARRSO which has been extensively used for processing and analysing meteorological satellite data. It is also capable of processing and analysing resource survey satellite data for various applications. The SPOT/Landsat Ground Station which is yet to be made fully operational will receive enormous amount of resource data over the country and the region encompassing a radius of 2500 km from Dhaka. These data will have to be processed digitally for their application in various fields for resource management and disaster monitoring in the country as well as in the neighbourhood. Attempts have been made to utilize digital processing techniques to certain fields. For better understanding of the characteristics of these data research work is needed.

1.3 Objective(s) of the Research:

Satellite data acquired over the earth's surface for resource sensing are multi-dimensional. These dimensions are (i) temporal i.e. variation in relation to time (ii) spatial i.e. variation in relation to space location and (iii) spectral i.e. variation with respect to the band (region of wavelength of the electromagnetic spectrum in which the image is taken). The variability in these three factors often lead to better results in understanding the features on the surface of the earth. The Multispectral Scanner (MSS, used in Landsat 1,2,3,4 & 5) data are of the resolution of 80m x 80m while Landsat 5 uses an improved facility of a sensor named Thematic Mapper (TM) which has a better resolution of 30m x 30m (Landsat 4 also had included TM). SPOT, a French Satellite, has even higher resolution of 10m x 10m. Thus, MSS data which was once most familiar have been surpassed apparently in resolution. Digital processing techniques were found very suitable in the developed world where homogeneous plots of land/feature are larger than the detectable/recognizable size or resolution of the satellite sensors. But those may not be very suitable in identifying the much fragmented land and heterogeneous mixture of features prevailing in Bangladesh.

Surface features have certain characteristic reflectances which are recorded by the satellite sensors. But if the fields are of mixed category then an averaging effect tells on the determination of the nature of the surface feature. In resource management, creation of authentic data base depends mostly on accurate identification of features through digital techniques. Thus, the present study has been an attempt to examine appropriate method or technique to identify spectral signatures of surface features and to compare effectiveness and suitability of MSS and TM data by using available - resources and software with special reference to Bangladesh.

1.4 Methodology

The topographic maps at scale 1:50,000 and the colour infrared aerial photographs would be required for the preparation of a Landuse map of the study area. This map would be consulted during the identification of spectral signatures of different surface features during digital processing of the satellite image.

The satellite data for two different years of the same area would be procured . The MSS data of size 512x512 pixels covering the study area would be read into the computer memory for spectral bands 4, 5, and 7 from the CCT of 1984. The TM data for 1988 would similarly be loaded into the computer memory for all the seven bands and the scene would be so chosen as to be of 1024 x 1024 pixel size approximately covering the same area.

These raw data would be studied carefully by displaying them on the VDU and appropriate bands for both MSS and TM would be selected for extraction of optimum information over the study area. The image enhancement functions like scale, histogram equalise, tlm, piece would be used to visually categorize the features of the area. Then unsupervised classification technique would be employed for digitally classifying the spectral signatures of the features. Also created would be a statistics file which could be used for classifying bigger areas if required. For the TM data a representative area of 512x512 pixels would first be chosen for unsupervised classification method and a statistics file would be prepared for subsequent processing of the other 3 quadrants of the 1024x1024 size image. After classification (unsupervised) a 'stash' file[4] would be created by choosing colours to be imposed for each class of the 512x512 original subscene. Then by fetching the 'stash' file uniform colour code would be maintained for all 4 quadrants of the TM Scene. This classification would be tried for obtaining spectral signatures of as many number of distinct classes as possible for both MSS and TM data. Next, the supervised classification technique would be utilized first by choosing training data sets on particular feature types and vertices file would be prepared to identify locations of the training sample areas on the image. With the help of this vertices-file, preparation of data sets would be carried out and with the help of this prepared file supervised classification would be possible to be done over the study area for both MSS & TM data sets. Colors would be added to the classified images. Both the images would then be compared by splitting the display screen into two halves. The statistical results would be obtained at the line printer and photographs would be taken from the VDU to show the results of each processing stage.

The next phase would be to compare the two images by bringing them to the same size. At this stage manipulation on the digital data sets would be carried out to bring both the images to proper size so that point to point registration between MSS and TM data could be made. This would prove the effectiveness or otherwise of TM data over those of MSS and provide a means for comparing data sets having different resolutions (data from SPOT and MOS - 1).

1.5 Selection of the Study Area and the Data Set:

A full Landsat scene covers 185 km x 185 km area consisting of generally 3548 pixels in a line having 2983 number of lines altogether in multispectral mode in each of its four bands and recorded in two Computer Compatible Tapes (CCTs). The Thematic Mapper of landsat 5, however, covers the same area having 7020 pixels in a line and 5729 number of lines per scene for each of its seven bands and the data for one complete scene is contained in three CCTs. For the digital processing techniques optimum results are usually obtained by studying two or three relevant bands depending on the nature of study. According to the need of the present study combination of three bands will hopefully suffice. To minimise the processing time and for sharing computer time with other research works data sets of the size of 512 x 512 pixels for MSS and 1024 x 1024 pixels of TM were chosen over the same area. For MSS data three bands and for TM all seven bands would be tried. Table 2 shows the particulars of the data sets utilized for the study.

Table 2: Description of Data Sets

Sl. No.	Type of data and format	Landsat path-row	Area coverage	Date of data set	Source	Frame
1	MSS (BIL) Band 4,5 & 7	137-045 two tapes	512X512 pixels	27-9-84	NRCT - TRSC	B_D
2	TM (BSQ) Band 1,2..7	137-045 three tapes	1024X1024 pixels	7-12-88	"	"

	SS	SL	NS	NL	SI	LI	BANDS
MSS	(1961),	513	512,	512,	1,	1 :	4,5,7)
TM	(4033,	4141,	1024,	1024,	1,	1 :	(1,2,3,4,5,6,7)

When desired results are obtained over this chosen area (subscene), the processing may be extended to the entire scene or any number of scenes through the available software of the system. The individual subscenes taken in definite order may be mosaiced if necessary. The particular location of the present study area was chosen at a place of which data sets were available at SPARRSO from two different type of sensors (MSS and TM) and of two different periods. The location map of the study area is shown in figure no. 4.

Figure 4: Location Map of Study Area.

The area chosen for the study lies in the coastal region of Bangladesh. The dynamic nature of the area, the ecological importance of it and the afforestation programme therein of mangrove forests attract much attention these days. There is an active erosion and accretion zone in the coastal region of Bangladesh. So, along with the spectral signature identification this study would come out with some by-product results on other aspects. This is why the Lower Patuakhali area particularly the islands of Rabanabad, Char Momtaz, Char Kasem, Anderchar, Char Hare, Sonarchar-Ruparchar etc. was chosen as the study area.

Colour infrared aerial photographs were used for preparation of the landuse map based on topographic sheets at scale 1:50,000, published by the Survey of Bangladesh. Table 3 shows particulars of the base data used for the study.

Table 3: Base Data Used in the Study.

Type of data & source	Scale	Identification	Number of sheets or photographs	Year
Topographic maps, Survey of Bangladesh	1:50,000	J	12	1972
		J	8	1973
		K	5	1978
		K	9	1977
Colour infrared aerial photographs, SPARRSO	1:50,000	61/84	30,32,33	1984
		62/84	6-12,14,16	
		63/84	31,33,34-38	

CHAPTER TWO
DIGITAL IMAGE PROCESSING TECHNIQUE

2. DIGITAL IMAGE PROCESSING TECHNIQUE

When solar radiation with a broad range of wavelength is incident on the surface of the earth, a portion of it is either reflected or radiated depending on the physical properties of the objects existing there. This reflected energy with its distinct spectral or wavelength distribution for each object is referred to as the spectral signature of the object. It is observed selectively by MSS in four small portions, called bands, of the electromagnetic spectrum. Digital image is an array of numeric depiction whose values represent the brightness of the sampled or quantized region in different spectral bands. While, Digital Image Processing involves the employment of a computer to digitally manipulate the matrix of numbers. The important operations are noise removal, geometric and radiometric correction, resampling the image data into a different scale, image display, enhancement of the image and information extraction (classification) etc.

2.1 Construction of Image

Digital image processing technique can be explained as the conversion of a continuous image into an equivalent digital form. Thus, the system usually deals with arrays of numbers obtained by spatially sampled points of a physical continuous image. After processing, another array of numbers is produced and this array of numbers is then used to reconstruct a continuous image at the output level for display and viewing. Image sampling is nothing but sensing the physical measurement of a continuous image field such as measurement of the image intensity or photographic density.

There are many software systems now available and are devoted mainly to image processing. A few of the systems are I^2S, VIPS, Comtal, ERDAS, MEASURONICS, LARSYS, MDAS and so on. In some systems, digitization of an image is done by electro optical scanner by measuring density/transmission and in some others a special camera is used by which the monochrome or colour images are instantaneously sensed and digitized.

Remote sensing data are acquired by observing and analysing the spatial, spectral, temporal and polarization variations of radiation emitted and reflected by the surface features of the earth or by the atmosphere in the optical region of the electromagnetic spectrum. This region extends from x-rays to microwaves which includes the ultraviolet, visible and infrared (.2 to 1,000 m).Remote sensing image devices may be photographic or nonphotographic sensors. Nonphotographic devices use the television systems and optical-mechanical scanners. The sensors, airborne or space borne, observe and measure the radiation coming from a scene modified on the way by the atmosphere. If we consider L as the spectral radiance of a target located at location x, y at time t,then emission and reflectance are the two components making the total radiance.

$L\ (x,y,\lambda,t,p) = (1-r)\ (x,y,\lambda,t,p)\ M\ (\lambda) + r\ (x,y,\lambda,t,p)\ i\ (x,y,\lambda,t)$. The function $r\ (x,y,\lambda,t,p)$ is the spectral reflectance of the object, $i(x,y,\lambda,t)$ is the spectral irradiance (incident illumination) on the object, and $M\ (\lambda)$ is the spectral radiant emittance of a black body. The parameter 'p' indicates the polarization and 'λ' indicates wavelength[5]. In the visible and near-infrared spectrum, where self-emission is negligible and reflected solar energy predominates, the radiance of an object consists of a reflectance and an illumination component while in the mid and far infrared regions emission is dominant. The illumination component is determined by the lighting of the scene and the reflectance component characterises the objects or materials in the scene.

The images that are to be analysed for remote sensing studies are considered to be of two dimensional spatial distributions. It can be represented by a real function of two spatial variables x and y which represent the value of a physical variable of the spatial location (x,y). The variable x,y are considered as basic variables and the spectral, temporal and polarization variables are considered as parameters.

Let $f_i(x,y) = L(x,y,\Delta\lambda j,t_m,p_n)$ be the spatial distribution for a given spectral band $\Delta\lambda j$, $J = 1,,\ .,P_1$ a given time t_m, $m= 1,,\ .,\ P_2$; and given polarization P_n, $n = 1,,.,\ P_3$. The $P = P_1 + P_2 + P_3$ functions $f_i(x,y)$ are combined into the real vector function:

$$f\ (x,y) = \begin{pmatrix} f_1(x,y) \\ \vdots \\ f_p(x,y) \end{pmatrix}$$

which will be called multi-image[5]. The measurements in several spectral bands for a given time, ignoring polarization, are called multispectral images. Measurements at different times in a given spectral band are called multi-temporal images.

Image functions are usually defined over a rectangular region R = { (x,y); $0<x\leq x_m$, $0<y\leq y_m$}. Because of the fact that the energy distributions are non-negative and bounded, every image function is non-negative and bounded; i.e. $0 \leq f_i (x,y) \leq B_i$; i = 1, ,., p for all x,y in R. The usual picture orientation of a Landsat scene is shown in figure 5.

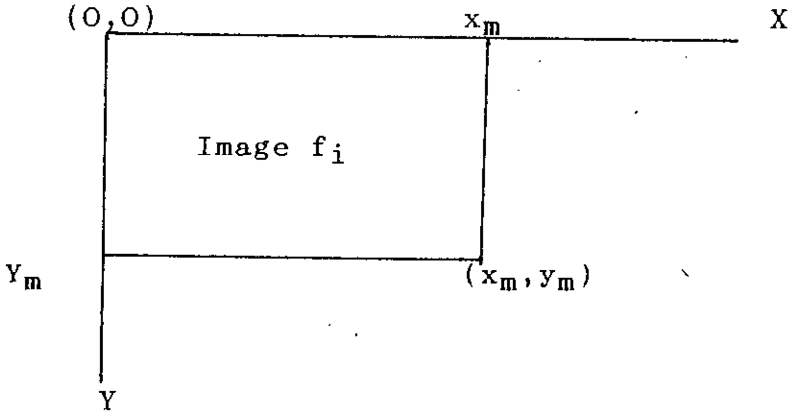


Figure 5: Landsat Image Orientation.

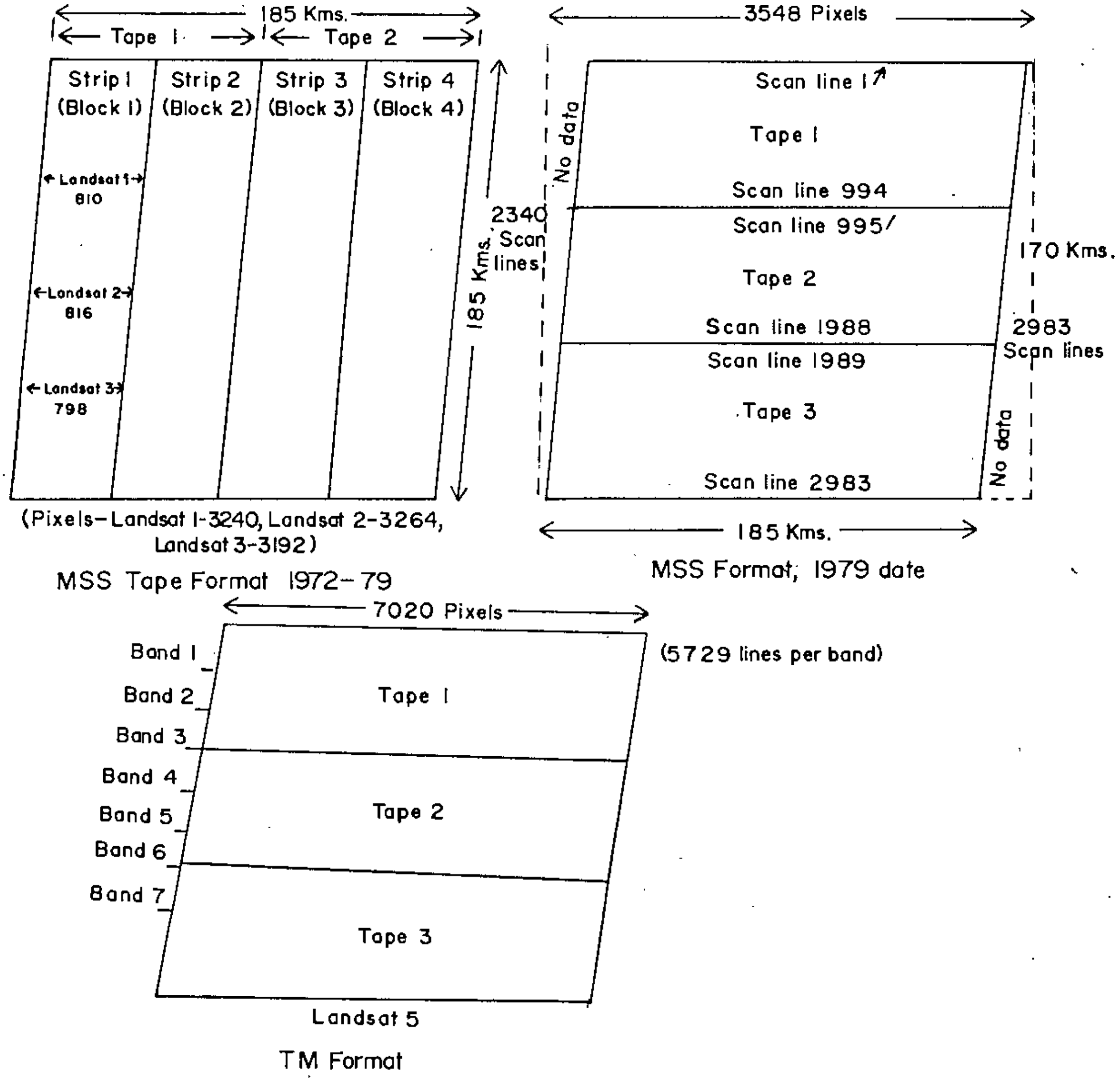
In figure (5) the x-axis is in the direction of increasing sample numbers and the y-axis is in the direction of increasing image line numbers. The value of the function f at a spatial location (x,y) is called the gray value of the image component at that point. A P = dimensional vector f(x,y), consisting of the values of f for a given location (x_o,y_o) is called a multidimensional picture element or pixel. The range of pixel values is called gray scale, where the lowest value (0) is black and the highest value (255) is white. All intermediate values represent shades of gray[5].

The remote sensing input data are to be digitized for processing by a digital computer. Digitization of an image consists of sampling the gray level in an image at an M by N matrix of points and of quantizing the continuous gray levels at the sampled points into K usually uniform intervals. The finer the sampling (M, N large) and the quantization (K large), the better the approximation of the original image. The purpose of sampling and quantization is to represent a continuous image by an array of numbers called samples, such that a continuous image can be reconstructed from the samples. A digital multi image with P components is represented by PMN samples. The operation of image digitizer and scanners imposes a sequential row structure on the sampled image data. Therefore, the fundamental unit of the data structure is one row of the image matrix. For multi-images the rows of different components may be stored as records in separate files, resulting in a band sequential (BSQ) storage format. Alternatively, corresponding rows from the P components may be concatenated and stored in one file in the band-interleaved by line (BIL) format. Finally the values from all components for a given raster point may be combined to a p-dimensional vector, and the vectors for one row are concatenated, resulting in one record of the digital image file known as band-interleaved by pixel (BIP) format.

The black/white or colour image may be digitized and stored in different pseudo-colour memories. Based on different sets of equations depending on the processing system different tables may be modified as required. For example, a monochrome image may be stored into three pseudo colour memories and a colour image may be obtained.

2.2 Preparation of input data set (digitization):

There are certain specific steps to be followed in digital image processing and they depend on the hardware structure of the processing system and also the software functions available under which the system operates. The process, though time consuming and quite complicated, can be mastered upon by practice and practical experience. The input data may be had from different sources such as either from a camera, or a digitizer or from Computer Compatible Tapes (CCT). The transparent films even photographs, monochrome or colour, may be digitized and stored in a CCT or a disc. The most usual process is to store a set of digitized data in CCTs. This enables the computer storage to be free from being overburdened. This digitization or preparation of input data may be termed as the first step in the digital data processing systems. The images/transparencies are digitized by cameras or electro-optical scanners. This information may be stored in a CCT or computer disc. However, we often find satellite data for resource survey in the form of a CCT. The CCTs are 7 or 9 track, 800, 1600 or 6250 bytes per inch, 2400 feet magnetic tape. To put these numbers in perspective, a 9 track 1600 BPI magnetic tape can store 3.2×10^8 bits and so can hold a Landsat image which contains about 2×10^8 bits[6]. These CCTs are also to be reformatted at times to make the format acceptable to the particular processing system. The usual tape formats are shown in figure 6.



MSS Tape Format 1972–79

MSS Format, 1979 date

TM Format

Figure 6: Landsat Tape Format

A TM image has about 7020 pixels and 5729 lines in each of its 7 bands which are arranged in BSQ format.

2.3 Sampling and quantization

The images are usually sampled at fixed increments $X = j\Delta x$, $Y = k\Delta y$ ($j = 1,.....m$, $k = 1,.....n$), where x and y are the sampling intervals in the x and y directions respectively. The matrix of samples $g\ (j\Delta x,\ k\Delta y)$ is the sampled or digital image.

The amplitude of the sampled image $g_s\ (j\Delta x,\ k\Delta y)$ must be divided into discrete values for digital processing. This conversion between analog samples and discrete numbers is called quantization.

In most digital image processing systems, a uniform quantization into k levels is used. Each quantized picture element is represented by a binary word. For natural binary code and word length of b bits, the number of quantization levels is $k_q = 2^b$[6].

2.4 Reconstruction and display

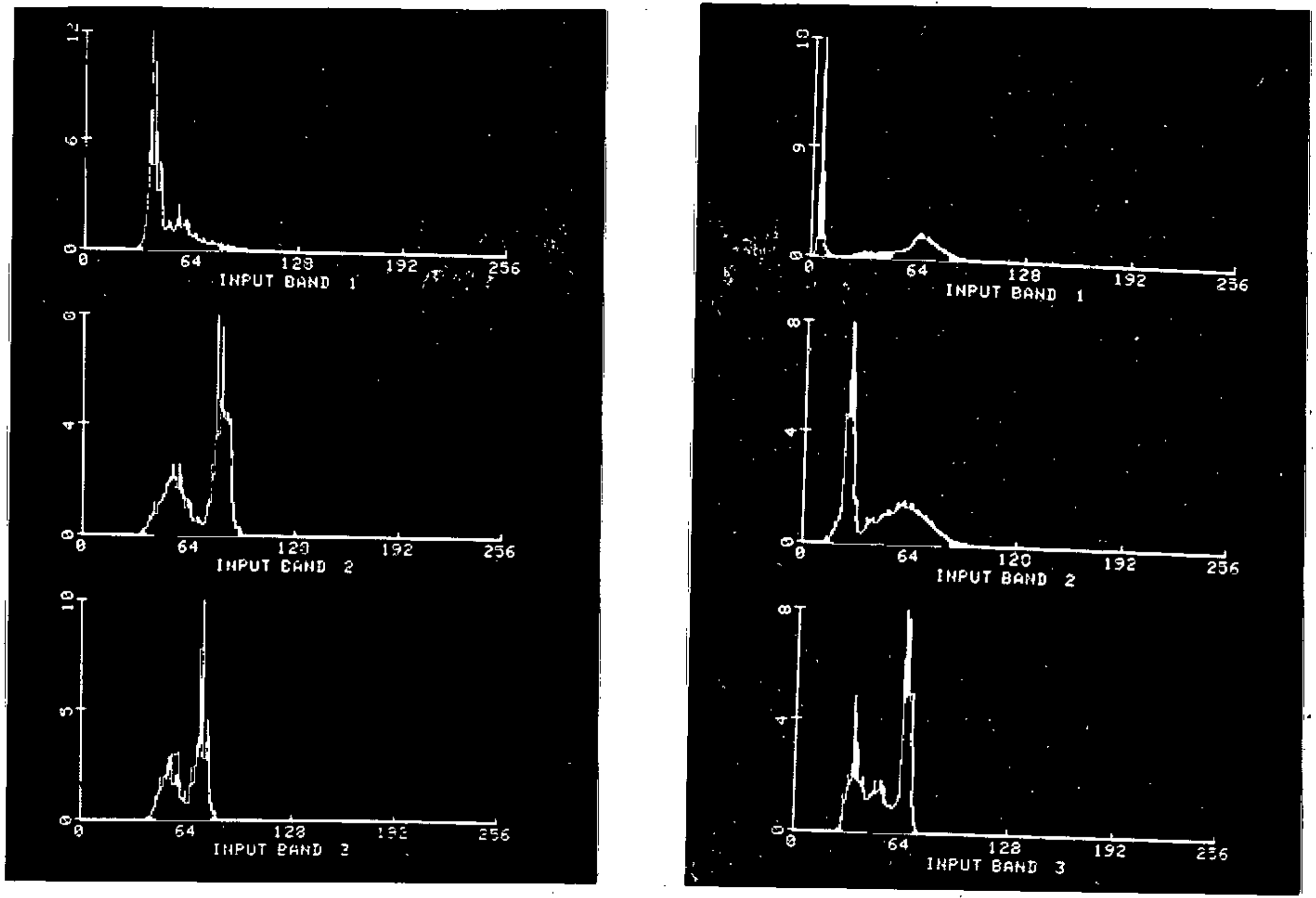
Sampled quantized images are to be reconstructed for display purposes required for visual interpretation. The usual display system is a CRT or a directly write-enable film. A light spot of finite size is focused and projected by optical means on to the film or CRT screen. The intensity of the spot is modulated and the spot sweeps across the display plane to create a continuous picture.

The second step is displaying of the data on the Video Display Unit (VDU) of the processing system for visual first hand observation of the set of data. The computer assisted devices are quite fast in displaying the desired sub-scene of the size 512 x 512 pixels of the original image. This limitation is due to the space available on the VDU screen.

The data is to be taken into the disc, if not already existing there, by a function command of the particular image processing system. If the interpreter has previous knowledge of the area then it may be possible to go straight for a particular subscene to be displayed on the VDU rather than observing the whole data set subscene by subscene. Once it is found that the subscene chosen is a satisfactorily representative sub-scene of the whole image then the histograms of one/three channel (s), as the case may be, can be displayed.

2.5 Histograms

Once the image is digitized or display resident the histogram may be obtained at the line printer to find out the gray level range of the image; histograms may also be displayed on the Video Display Unit of the system(figure 7). The histograms provide a basis for further processing in respect of manipulation of images by enhancement techniques[4].



(a) Histogram of MSS Band 7,5,4 (b) Histogram of TM Band 5,4,3

Figure 7 : Histogram of the images

2.6 Image enhancement techniques

A Landsat Image (MSS data) stored in digital form in the Computer Compatible Tapes (CCTs) contains a huge wealth of information for the researchers and the managers of natural resources. The image data as acquired by the sensors and recorded onboard are transmitted to the ground receiving stations where these are recorded in High Density Digital Tapes for their subsequent conversion to Computer Compatible Tapes after preprocessing. There are possibilities of data imperfections in the process of acquisition and transmission due to factors relating to the platform, sensor, scene effects and atmospheric effects. Most of these imperfections are reduced to a minimum at the Image Processing Facilities (PF) of the Ground Receiving Stations.

The CCTs are processed in different stages by digital computers for interpretation of the data. The first hand observations of the image is made on the screen of the Video Display Unit (VDU) of the processing systems. The images as they appear on the VDU screen may not be suitable for specific purpose of interpretation. Improvement of the image quality is necessary to have the image meet the requirements of the purpose. The image enhancement technique modifies the original image into a better state highlighting the features of specific interest. However, specific interest may be of diversified nature.

The operations involved in the processing of digital image data of Landsat scene include geometrical correction, rescaling, destriping, resampling, atmospheric correction, elimination of sensor noise, image restoration and improvement in the visual presentation. The image enhancement is performed prior to the visual interpretation of the data so that the suitable interpretability is achieved. Many of these corrective operations are done during preprocessing i.e. while converting HDDT into CCT. The image quality enhancement is usually done by the user. Geometrical correction is often necessary for correlating image features with maps. It becomes essential when attempts are made to prepare a Geographic Information System (GIS). Some of the enhancement techniques are as follows:

2.6.1 Contrast stretching (point operations)

Contrast stretching, usually called point operation, modifies the brightness values of each pixel in an image data set. The range of image values designed in a Landsat multispectral scanner is wide enough in covering the poorly illuminated arctic areas to the high reflectance desert areas. It is due to this reason that most of the Landsat data of a scene taken from Bangladesh occupy considerably small portion of this range.

The function of contrast stretching is to expand this range of image values, present in an input scene, to be wide enough to get spread over most of the available range at the output. If the output device (CRT, Line Printer or Laser Beam Recorder) of the processing system is capable of representing the range of data values from 0 to 255 which are the 256 levels of image values known as gray levels from dark to bright respectively, then contrast stretching may be explained in the following manner.

There are a wide variety of vegetation or crop cover with different reflectance values resulting in different gray levels in the output product. Visual interpretation is difficult with all those gray levels present in the scene within a narrower range and occupying places so closely resembling to each other. Thus if we can increase the contrast between individual or groups of pixels by enhancing the brightness of one or a group of pixels then those may be easily distinguishable from the others which are either retained at their original gray levels or whose gray level values have been diminished. Now to make a contrast stretch, if the range of gray levels (60-158) of a particular cover type is expanded to the entire range (0-255) as shown in Figure 8c, from 60 and 158 to 30 and 255, a better view of the land cover type will be obtained for interpretation. Otherwise unutilizing the remaining portion of the gray level range from 0 to 59 at the lower range and 159 and 255 at the higher range) will mean to have more radiometric details concentrated within narrow gray level range making distinction of reflectance values more difficult (figure 8b)[7].

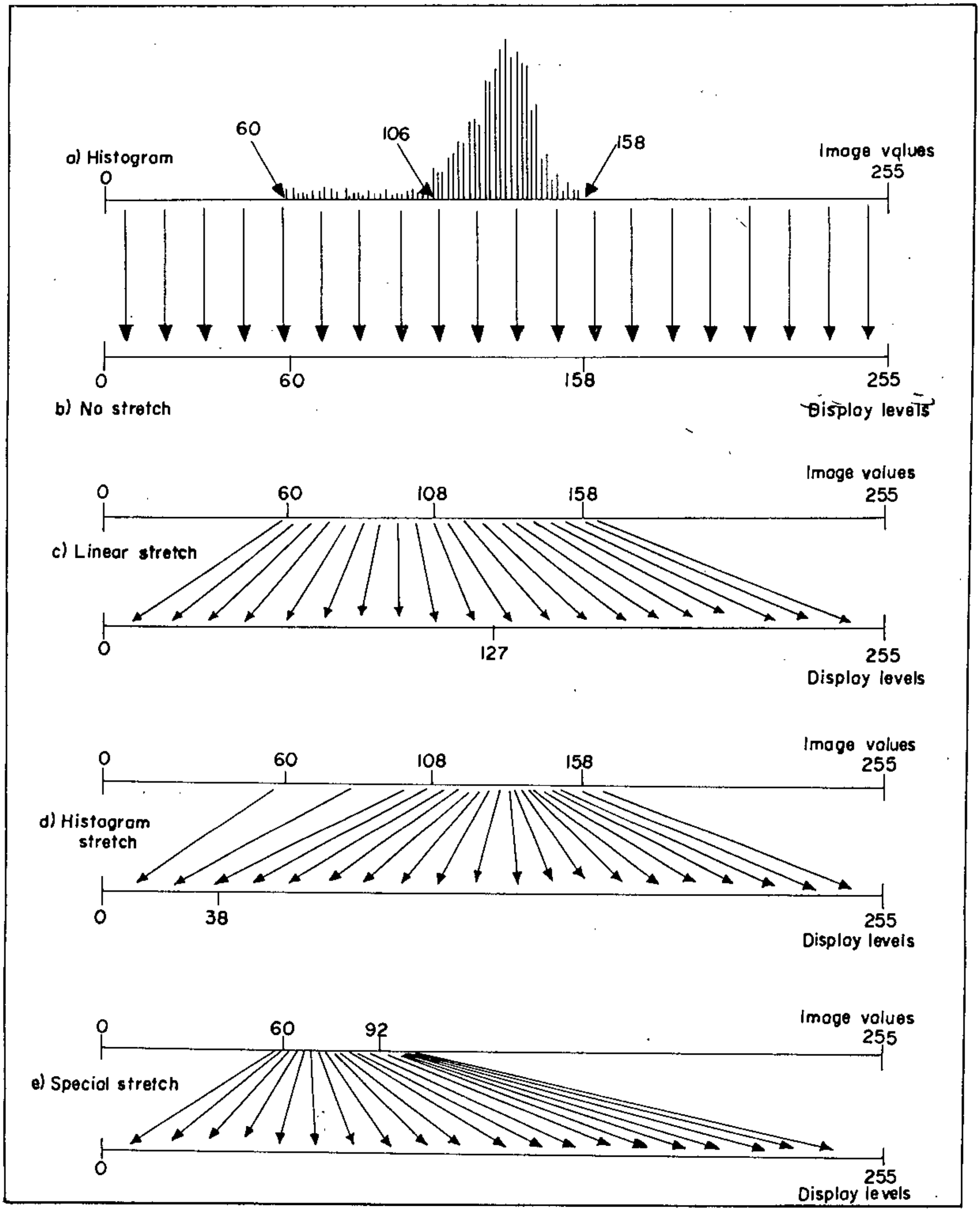


Figure:8 Principle of contrast stretch enhancement.

The limitation of this stretching is that it does not give the best fruitful output image because it assigns equal number of gray levels at the output for both the less and more frequently occurring data values. Thus the less frequently occurring data values between 60 to 108 occupies gray levels from 0 to 127 (for example), while the more frequently occurring values in the input data from 109 to 158 expands only between 128 and 255 at the output. This stretching is performed by the function "scale" of the S575 software.

A histogram-equalization method, however, can improve upon the above situation by allowing gray levels at the output in proportion to the frequency of occurrence of the input values. Figure 8d shows that the infrequently occurring data values have occupied lesser number of gray values at the output than the more frequently occurring input data values. The "Histogram Equalise" function of the S575 performs the same for image enhancement.

2.6.2 Histogram stretching

If, however, the interpreter is interested in any particular range of input image values say, those representing water to be greatly exaggerated at the output for better distinguishability of the radiometric detail, the range of image value at the input (60-92) may be represented by the whole range of output levels. This will put other input image values of 0 - 60 and 159 - 255 to become only two output values of black and white respectively (figure 8e). Similarly different segments of image values may be exaggerated/enhanced or suppressed by the function 'piece' of system 575[4].

2.6.3 Band ratioing

In a single band analysis the extraneous factors cause differential illumination across a scene thus effecting the results. Those extraneous factors are self compensated in a ratio enhancement. This band-ratio techniques are used by the geologists because of its great utility in analysing the spectral aspects of some ground features. The band ratio technique involves the division of the DN's of each pixel in one band by the DN's of the corresponding pixels in another. The quotient which results from this divisions may have values ranging from zero to infinity, but usually those are found between .3 and 3. Ratios may be obtained for bands 4 with 5, 4 with 6, 4 with 7, 5 with 7, and 6 with 7 and also their reciprocals for Landsat MSS data.

A ratioed image is formed by the pixel quotient values in the same way as in the case of a single band image. It is possible to combine three of the ratio images in a colour composite by using individual ratio images as inputs through red, green and blue colour tables. Two important properties of the ratio images are : (1) the strong differences in the spectral signatures of different features come out more prominent in certain ratios, (2) the differences in reflectance from surfaces composed of the same features caused by typographical variations, shadowing, or seasonal change in irradiance levels can be removed by band ratioing.

2.6.4 Pseudo-colour image processing

In a monochrome image the visual limitation of distinguishing 256 gray levels is inevitable. Pseudo-colour image processing provides a sort of enhancement of the image quality because the interpreters eye can easily distinguish more number of colours then the numbers of gray levels in monochrome images. The difference between pseudo-colour processing and false-colour processing is, however, to be borne in mind. The false colour is generally analogous to true-colour images while the pseudo colour is relevant to monochrome images. The objective of pseudo-colour processing is to assign a colour to a monochrome image pixel depending on its intensity. Density slicing is an example of pseudo-colour image processing. In this process, if we place parallel two-colour-slicing plane, having one colour on the upper side and another on the lower at a height above the monochrome image plane then the pixels above the slicing plane will be coloured say, red and the pixels whose gray levels below will be green (figure 9).

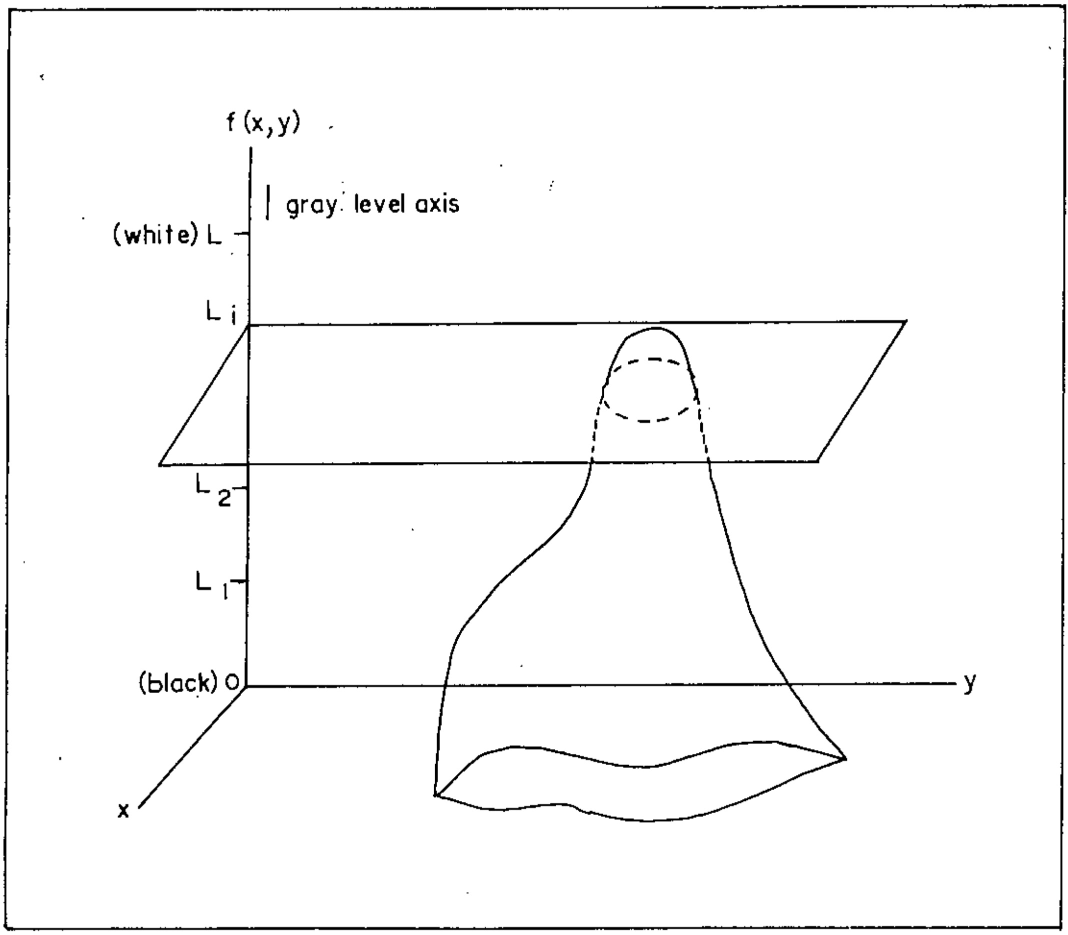


Figure 9 : Geometrical interpretation of the density slicing technique.

To expand the technique for many colour M number of planes may be defined at levels L_1, L_2, $\ldots L_i, L_m$; L_0 representing black [$f(x,y) = 0$] and L_1 representing white [$f(x,y) = L$]. Now that $0<M<L$, the M planes partition the gray scale into M+1 levels, colours are assigned according to the relation $f(x,y) = C_k$ where C_k is the colour associated with the K_{th} level. This technique has been surpassed by many other enhancement and classification techniques[6].

2.6.5 Filtering (local operations)

The techniques discussed so far handle only the data values from each pixel without taking the neighbourhood data into consideration. Those operations change only the textural values of individual pixels and thus of the scene. These changes could also be made considering the neighbourhood pixels for image enhancement.

The edge or boundary of an object in an image is usually an abrupt change in the gray value of a pixel from its nearest neighbour. These boundary discontinuities may be sharpened by a technique known as spatial filtering which is more commonly known as edge enhancement. The overall brightness of the entire image may either be emphasized or de-emphasized in this technique. The raw data may contain significant noise making the image snowy in appearance. These noises of high spatial frequency change more abruptly than the image data. The mathematical technique for separating an image into its various spatial frequency components is called Fourier Analysis.

After an image is separated into its component spatial frequencies, it is possible to emphasize certain group (or band) of frequencies with respect to others and combine the spatial frequencies to produce image enhancement. The algorithms to perform such enhancements are called filters. The filters which suppress high frequencies are known as low-pass filters. The simpler form of low pass filter replaces the value of a pixel by the average of a 5x5 pixel square area (keeping that pixel at the centre of the area) and are used in smoothing an image with a salt and pepper appearance[7]. In high pass filtering high spatial frequency values indicating small sub-resolution-sized features are emphasized to increase the apparent spatial resolution of the image. This is also referred to as edge enhancement. This technique is employed by (a) computing local average surrounding each pixel, (b) noting the deviation of the pixel from its surrounding average and (c) doubling that deviation, thus, a pixel that is brighter than its surroundings will be made brighter yet, and a relatively dark pixel even darker. Mathematically, this is done by doubling the value of a pixel and subtracting the local average from that.

The difference between the input image and the low-pass filtered image is the high-pass filtered output. High pass filtering is done for sharpening the boundaries of farms, roads, streams, rock strata and joints.

The Fourier transform of a function f(x,y) that has been sampled over an NxN grid of points is given by:

$$F(u,v)=\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f(x,y)\exp\left[-2\pi i(ux+vy)/N\right] \cdots\cdots (1)$$

and the inverse by:

$$f(x,y)=\sum_{u=0}^{N-1}\sum_{v=0}^{N-1} F(u,v)\exp\left[2\pi i(ux+vy)/N\right] \cdots\cdots (2)$$

Rearrangement of equation into the form:

$$F(u,v)=\sum_{y=0}^{N-1}\sum_{x=0}^{N-1} f(x,y)\exp(-2\pi i\,ux/N)\exp(-2\pi i\,vy/N) \cdots (3)$$

shows that the two-dimensional tgransformation can be performed by applying one-dimensional transforms to each of the rows (or columns) of the input array and then similarly transforming the columns (or rows) of the intermediate array [8].

Expanding the complex exponentials into sine and cosine terms and assuming that f(x,y) is real allows equation(1) to be decomposed into four components:

$$F(u,v) = (A - B) - i(C + D) \cdot \cdot \cdot \cdot \cdot \cdot (4)$$

where,

$A = \sum f(x,y)\ \mathrm{Cos}\ (u'x)\ \mathrm{Cos}\ (v'y)$

$B = \sum f(x,y)\ \mathrm{Sin}\ (u'x)\ \mathrm{Cos}\ (v'y)$

$C = \sum f(x,y)\ \mathrm{Sin}\ (u'x)\ \mathrm{Cos}\ (v'y)$

$D = \sum f(x,y)\ \mathrm{Cos}\ (u'x)\ \mathrm{Sin}\ (v'y)$

The sigma refers to the double summation performed in equation(1) and $u' = 2\pi u/N$, $v' = 2\pi v/N$.

2.7 Classification Techniques:

2.7.1 Image classifiers

For image classification the following classifiers may be talked about :

1. Minimum distance to means classifier,
2. Parallelepiped classifier,
3. Maximum likelihood classifier (MAXL),
4. Bayesian classifier.

Out of these classifiers the maximum likelihood classifier with Bayesian modification is mostly used in modern image processing algorithms [7].

1. The minimum distance to means method is simple and computationally efficient but it has the limitation that it is insensitive to different degrees of variance in the spectral response data. Figure 10a shows a two-channel distribution of class-wise pixel values in the feature space. 'W' represents pixels of water category, 'F' represents forest, 'H' represents hay, 'C' represents crops, 'U' represents urban and 'S' represents sands. The mean of each category is computed (shown by '+' sign). Now to classify an unknown pixel distance between its location and the location of the mean of each class is compared. The pixel is assigned to the class for which this distance is minimum. The pixel values indicated as 'point 2' would be assigned to the sand category despite the reason that the greater variability in the urban category suggests 'Urban' category as more appropriate.

A basic computer system implementation of the minimum-distance classifier[9]. is shown in figure 10.

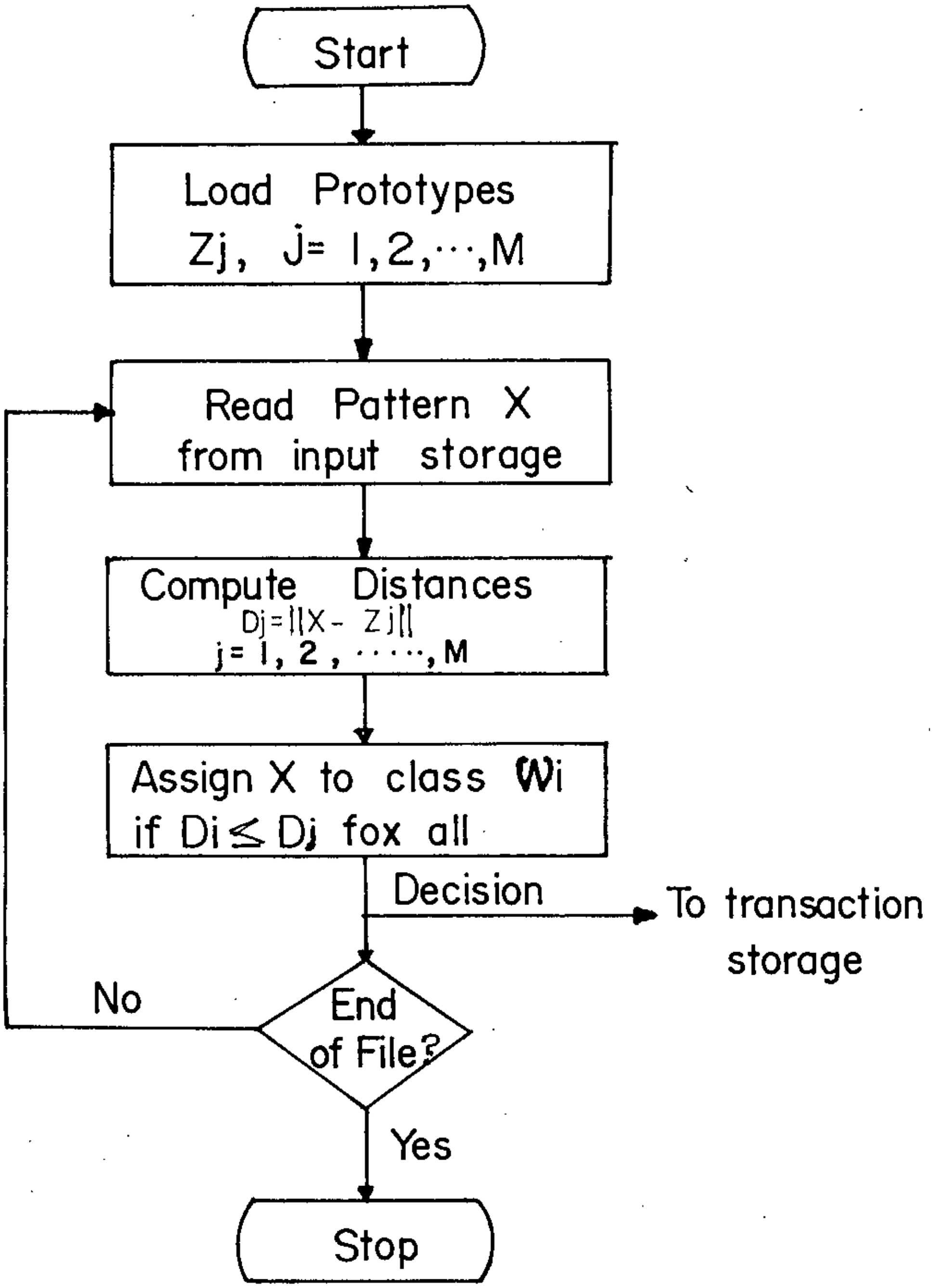


Figure 10: Minimum distance classifier basic software flowchart.

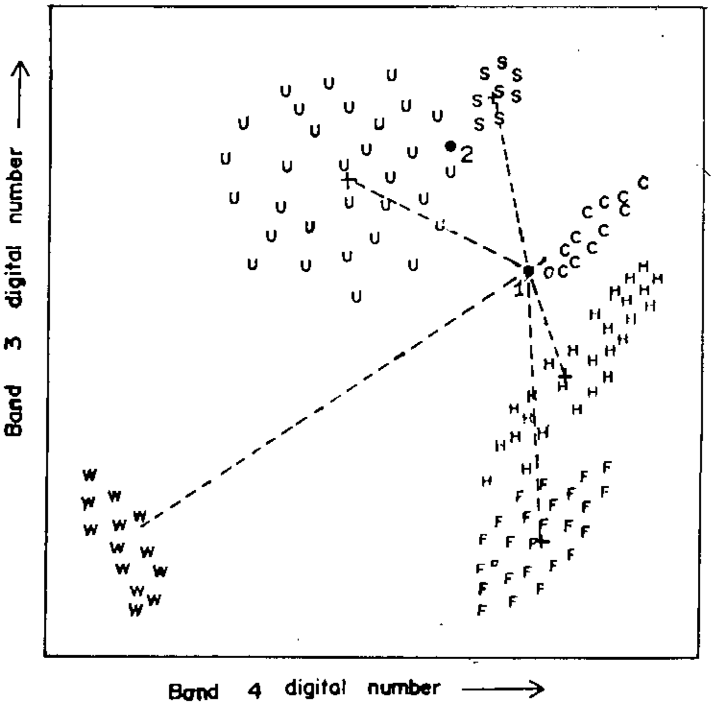
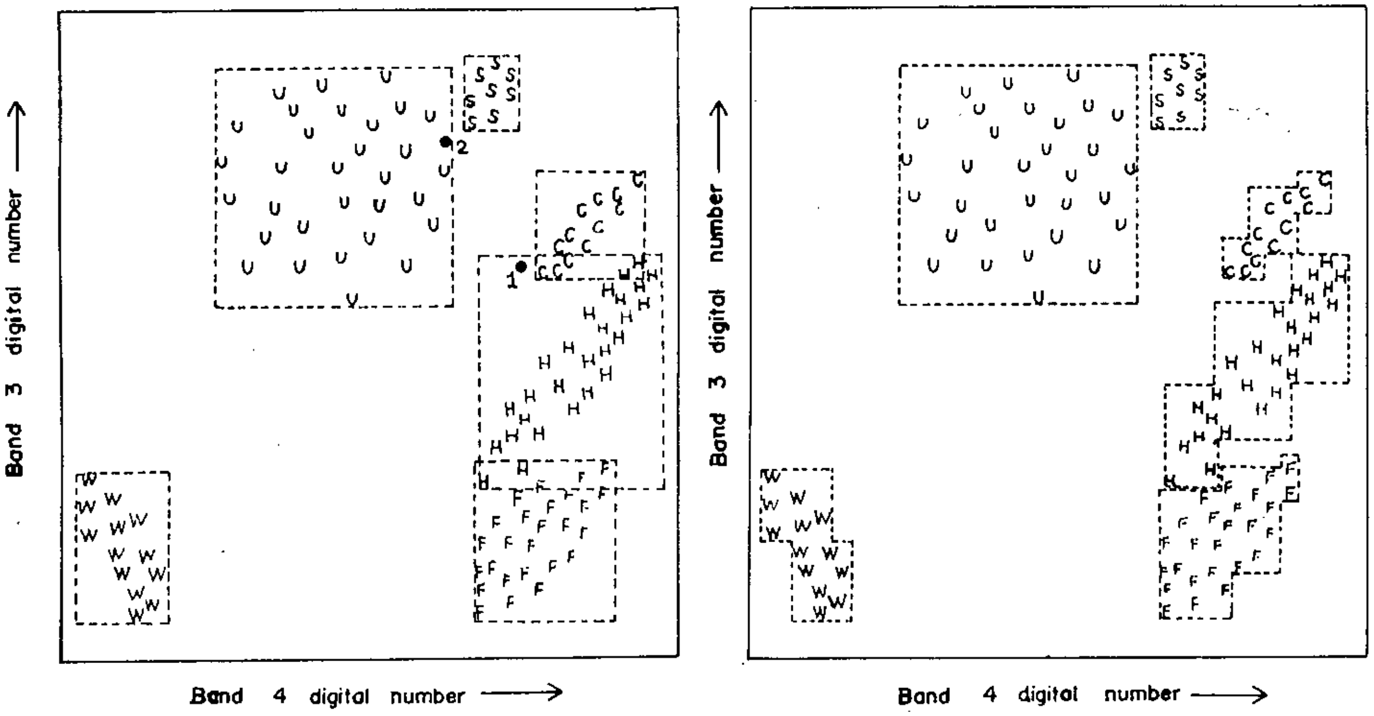


Figure 10a : Minimum distance to means strategy[7].

2. In the parallelepiped classification system rectangles are considered between the lowest and highest values of the pixel groups (as shown for water only in Fig. 11a).Any unknown pixel is classified according to the category range, or decision region, in which it lies, or termed as 'Unknown' if it lies outside all ranges.

The category distribution follows a correlation pattern either positive or negative. In positive correlations the pattern of the distribution is slanted towards right-hand-upperside and for negative downwards to the right. In the presence of correlation, the rectangular decision regions poorly fit, the category training data resulting in confusion for a parallelepiped classifier. If the category ranges overlap then



(a) Parallelepiped (b) Stepped

Figure 11 : Parallelepiped Classification[7].

the pixels are attributed to arbitrary group which is another handicap for this classifier. However, making smaller rectangles (Stepped decision regions) this may be avoided for better accuracy (figure 11b).

3. Gaussian MAXL Classifier: For classifying an unknown pixel this classifier evaluates both the variance and correlation of the category spectral response patterns quantitatively. In doing so, it is assumed that the distribution of the cloud of 'pixels' forming the category training data is Gaussian. Under this assumption the distribution of a category response pattern is described by the mean vector and covariance matrix. To classify an unidentified pixel the probability density functions are used by computing the probability of the pixel value belonging to each

category (figure 12). The function would test the likelihood of the pixel of occurring in any class one by one. After the test the category is attributed to the pixel in which its occurrence is most likely or label 'Unknown' if the probability values are all below the threshold.

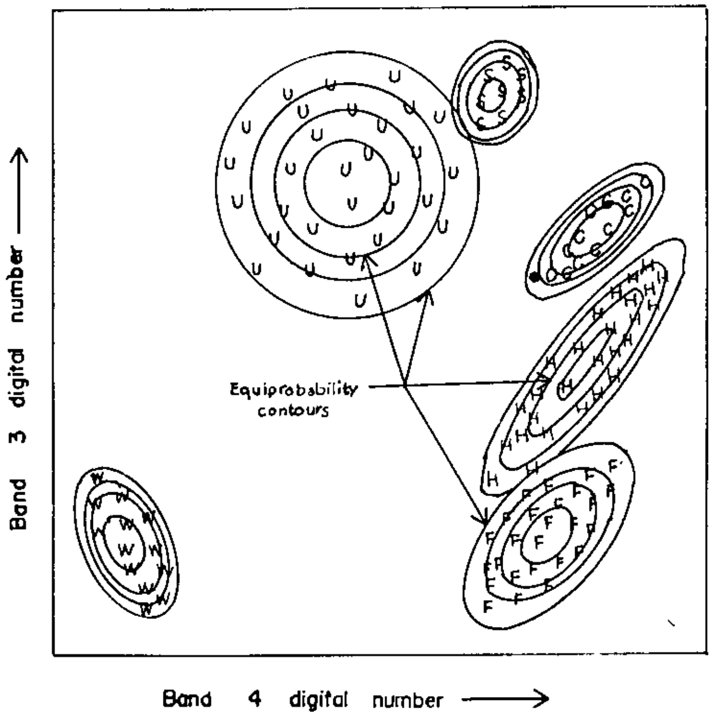


Figure 12: Equiprobability contours defined by a MAXL classifier[7].

4. Bayesian classifier is an extension of the MAXL approach. This technique applies two weighting factors to the probability estimate, first; 'a priori probability' and 2nd 'miscalculation probability'. This factor theoretically optimize the cost of miscalculation.

Though the MAXL classifier gives better accuracy, it involves longer computational processes.

The probability function of occurrence of any event could be estimated by simply having it occur practically in a set of data and tabulating the relative frequency with each occurrences. Suppose now that the data source were a single channel of multispectral scanner, could try to 'guess' which set of ground-cover classes was observed. Again the associated probability functions would be useful, and these could be estimated from training patterns. Given a set of measurements for a particular class, a tabulation would be made of the frequency with which each data value occurred for that class. The results could be displayed in the form of a histogram as shown by the square curves figure 12a. Similar histograms would be produced to estimate the probability function for each class as shown by the dotted curve.

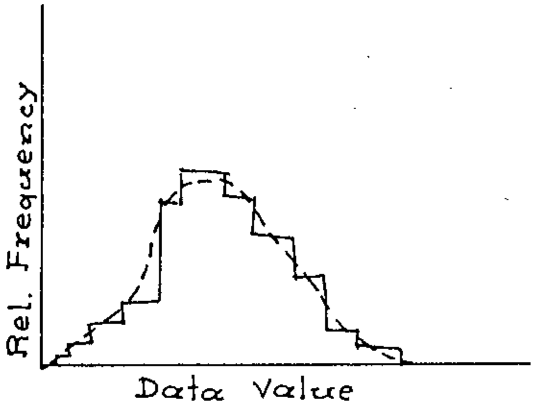


Figure 12a: Histogram.

If the number of possible data vlaues is large, storage in the computer of the histogram representation of the class probability function may require a considerable amount of memory. Furthermore, if we try to generalize this approach to handle additional wavelength bands, the memory requirements will rapidly get out of hand: the number of memory locations needed to save n-dimensional histogram in which each dimension can take on p values is p^n. One way to alleviate this problem is to assume that each histogram or probability function can be adequately approximated by a smooth curve having a simple functional form. In particular, we shall assume that the probability function for any class of interest can be approximated by a normal (or Gaussian) probability density function (dotted curve). For the one dimensional or univariate case, the normal density function for class i is given by :

$$P\,(x/\omega_i) = \frac{1}{(2\pi)^{1/2}\,\sigma_i}\exp\left[-\frac{1}{2}\frac{(x-\mu_i)^2}{\sigma_i^2}\right]$$

where $\exp\left[\;\cdots\;\right]$ = e (the base of the natural logarighms) raised to the indicated power.

$\mu_i = E\left[x/\omega_i\right]$ is the mean or average value of the measurement in class i.

$\sigma_i^2 = E\left[(x-\mu_i)^2/\omega_i\right]$ is the variance of the measurements in class i.

In practice μ_i and σ_i^2 are unknown and must be estimated from training samples. From statistical theory; unbiased estimators for μ_i and σ_i^2 are given by :

$$\hat{\mu}_i = \frac{1}{q}\sum_{j=1}^{q_i} x_j \quad ; \quad \hat{\sigma}_i^2 = \frac{1}{q_i-1}\sum_{j=1}^{q_i}(x_j-\hat{\mu}_i)^2$$

where q_i is the number of training patterns available for class i and x_j is the jth training pattern for class i. Then the estimated probability function for class i is :

$$\hat{p}\,(x/\omega_i) = \frac{1}{(2\pi)^{1/2}\,\sigma_i}\exp\left[-\frac{1}{2}\frac{(x-\hat{\mu}_i)^2}{\hat{\sigma}_i^2}\right]$$

Having made this parametric assumptions that the probability function for each class may be approximated by a normal density function, we need only store the mean and variance for each class in the computer rather than the entire histogram. When we need the value of the probability function associated with a data value, we can compute it, using the above equation. But, if there are two channels of multispectral data, the bivariate probability function for each class could be estimated by tabulating the frequencies of occurrence of all possible pairs of data values, each pair consisting of a value x_1 from channel 1 and a value x_2 from channel 2. The result would be a two-dimensional generalization of the figure with dotted curve above. But as in the one dimensional case, considerations based largely on computer-storage efficiency lead us again to make parametric assumption that the probability function can be approximated by a normal probability density function. The two dimensional or bivariate normal density function is given by :

$$P(x_1, x_2/\omega_2) = \frac{1}{2\pi(\sigma_{i_{11}}\sigma_{i_{22}} - \sigma_{i_{12}}^2)^{1/2}} \exp$$

$$\left[-\frac{1}{2} \frac{(x_1-\mu_{i_1})^2/\sigma_{i_{11}} - \frac{2\sigma_{i_{12}}(x_1-\mu_{i_1})(x-\mu_{i_2})}{\sigma_{i_{11}}\sigma_{i_{22}}} + \frac{(x_2-\mu_{i_2})^2}{\sigma_{i_{22}}}}{1 - \frac{\sigma_{i_{12}}^2}{\sigma_{i_{11}}\sigma_{i_{12}}}} \right.$$

where $\mu_{ij} = E\left[x_j/\omega_i\right]$ is the mean value of the data in channel j (for classi)

$\sigma_{ijk} = E\left[(x_j-\mu_{ij})(x_k-\mu_{jk})/\omega_i\right]$ is the covariance between channels j and k (for class i).

If the parameters μ_{ij} and σ_{ijk} are stored in the computer for each class (a total of five parameters for each class), the probability functions for the data can be computed as needed from the above equation. For adding more channels the quation becomes too much complicated, but can be represented by the use of vectors/metrix notation which provides for a very compact means of expressing formulas, such as the above equation. For the general case of n-dimensional data, if we let

$$X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix} \quad U_i = \begin{bmatrix} \mu_{i_1} \\ \mu_{i_2} \\ \mu_{i_3} \\ \vdots \\ \mu_{i_n} \end{bmatrix} \quad \sum_i = \begin{bmatrix} \sigma_{i_{11}} & \sigma_{i_{12}} & \cdots & \sigma_{i_{1n}} \\ \sigma_{i_{21}} & \sigma_{i_{22}} & \cdots & \sigma_{i_{2n}} \\ \vdots & \vdots & \vdots & \vdots \\ \sigma_{i_{n1}} & \sigma_{i_{n2}} & \cdots & \sigma_{i_{nn}} \end{bmatrix}$$

be the data vector, mean vector for class i and covariance matrix for class i respectively, then n-dimensional multivariate normal density function can be written as :

$$p\,(x/\omega_i) = \frac{1}{(2\mu)^{n/2}\left|\sum_i\right|^{1/2}} \exp\left[-\frac{1}{2}(x-u_i)^T \sum_i^{-1}(x-U_i)\right]$$

where $\left|\sum_i\right|^{1/2}$ is the determinant of the covariance matrix $\sum_i$. $\sum_i^{-1}$ is the inverse of $\sum_i$ and $(x-U_i)^T$ is the transpose of the vector $(x-U_i)$. When $n = 2$, it is straight forward to show that carrying out the operations implied by the above equation results in the expression given by the previous one.

For notational covnience it may be indicated that p (x/wi) is the normal density function with means vector V_i and covariance matrix $\sum_i$ by writing: $p\,(x/wi) \sim N(v_i, \sum_i)$.

2.7.2 Unsupervised classification approach :

In this approach a desired subscene is selected which is the best representative area of the whole image. On this subscene a search program is executed to obtain statistics of the spectral values of each pixel. For classification of raw data it is necessary to group spectrally homogeneous blocks of data. The search program examines 2 x 2 or 3 x 3 blocks of pixels to find spectrally homogeneous blocks. These blocks are examined sequentially to calculate a series of statistical measures such as the mean, standard deviation and covariance of the blocks. For example the Earth Resources Laboratory Application Software (ELAS) search program is designed to calculate a maximum of 60 classes. The VIZIR Image Processing Software Provides a branched tree which shows the results of the statistical search program on the subscene. The decision is obtained by the computation software itself to decide the maximum number of classes by truncating the tree at smaller number of branches. The S575 software has a possibility of determining user specified number of classes in its clustering process i.e. classification process.

In the ELAS programme if actually there exist more than sixty classes in the subscene then the 61st class will be accommodated by merging two of the classes having nearest statistical values. Once the entire data subscene is searched and statistics on 60 classes or less are obtained, a clustering algorithm is applied to the training data set. This algorithm clusters the most similar classes together. By adjusting some parameters and rerunning the program, a more manageable number of classes may be obtained. The final stage of training data collection process is to obtain a two-channel plot which enables the operator to view the means of all classes in the statistics file for any two MSS channels. The X-axis represents band 7 value for each desired class and the Y-axis represents the band 5 values. From this two-channel plot it would be evident that the mean values of certain classes group together in certain locations. This plot help naming the classes which represent corresponding ground fractures. Generally the group of symbols on the two channels plot representing water occupies the lower left areas, symbols representing vegetation occupy the lower centre area, and the symbols for barren land are found along the diagonal extending far in the upper corner of the plot.

After competing the training data process and search for the whole image and having obtained the two-channel plots the data are ready to be classified. The ELAS employs a maximum likelihood, classifier. This classifier quantitatively evaluates the statistical parameters of each spectral category when classifying an unknown pixel. In doing so it is assumed that the distribution of the cloud of pixels forming the training category is Gaussian. Under this assumption, the distribution of a category's response pattern can be completely described by the mean vector and covariance matrix. The probability density functions are used to classify an unidentified pixel by computing the probability of the pixel value belonging to each category. The function tests the likelihood of the pixel occurring in any class, one by one. After the test the pixel is assigned to the category in which its occurrence is most likely.

The S575 software prompts the user to decide certain parameters like number of iterations, number of classes, maximum classes, input statistics, bandmask, migrationquit, sizemax, sizemin, monitor, line printer, button and extrema. This clustering process estimates the "seed" locations statistically in the feature space for a specified number of classes prompted by the user and performs the classification examines the results and modifies it by itself and repeats (iterates) the process upto the number of times the system has been prompted to. This statistics may be saved in the disk file for classifying an image[4]. A classified image may be given colour "keys" so that the classes appear in distinct colours. The colour assignment to each class is made by the user himself by combining various proportion of three fundamental colours (red, green and blue). According to the assigned colours the image is displayed in the monitor and may also be stored in the disk. If larger areas are to be processed by unsupervised method then, a 'stash' file may be created by storing the desired colour table in the disk. On any other image after running the statistical calculations 'stash' file may be imposed on the classed image so that colour of the entire image remain in the same order of assignment of colour for each class. Although there is a limitation that the display of an image may be made at 512x512 pixel size. But bigger images (multiple of 512x512 size) may be classified and given colour according to the stash file as subscenes. These subscenes may be mosaiced to make a complete image of bigger size which is non-display resident (i.e. disk image).

2.7.3 Supervised classification approach:

This classification technique is adopted when the user has a first hand knowledge of the study area and the surface features existing there in. By displaying the image and by applying the enhancement techniques if distinct signatures of various features are identifiable on the subscene with regard to colour, tone, texture and location then training data sets (usually more than one and upto five regions of the same type may be obtained for each class of feature. The number of classes has to be determined by visual analysis or estimation. In S575 system this training data set is stored in a vert-file in the disk. The vertices of the regions are translated to the disk file for the location of each feature region. Then a 'prepare' program is run on the subscene to obtain statistics of each class as preparation to classifications. Then this statistics is applied to the data set (disk resident) for classification of the image and class map is obtained. This may be given a 'key' for assigning colour to individual classes[4].

In the supervised classification process the limitation of processing only a subscene may be avoided. But there is a danger of including pixels of other classes in selecting the regions of a specific class. In that case the result would be anomalous.

CHAPTER THREE

IMAGE ANALYSIS OF MSS AND TM DATA

3. IMAGE ANALYSIS OF MSS AND TM DATA

An analyst or an interpreter enjoys the liberty of choosing this line of action for achieving the desired result from the processing of an image. Here again, the objectives of the researchers vary quite widely. According to the aim of the study a particular process of image analysis is employed. For this particular study the following methodology was adopted :

3.1 Surface Feature Delineation Map

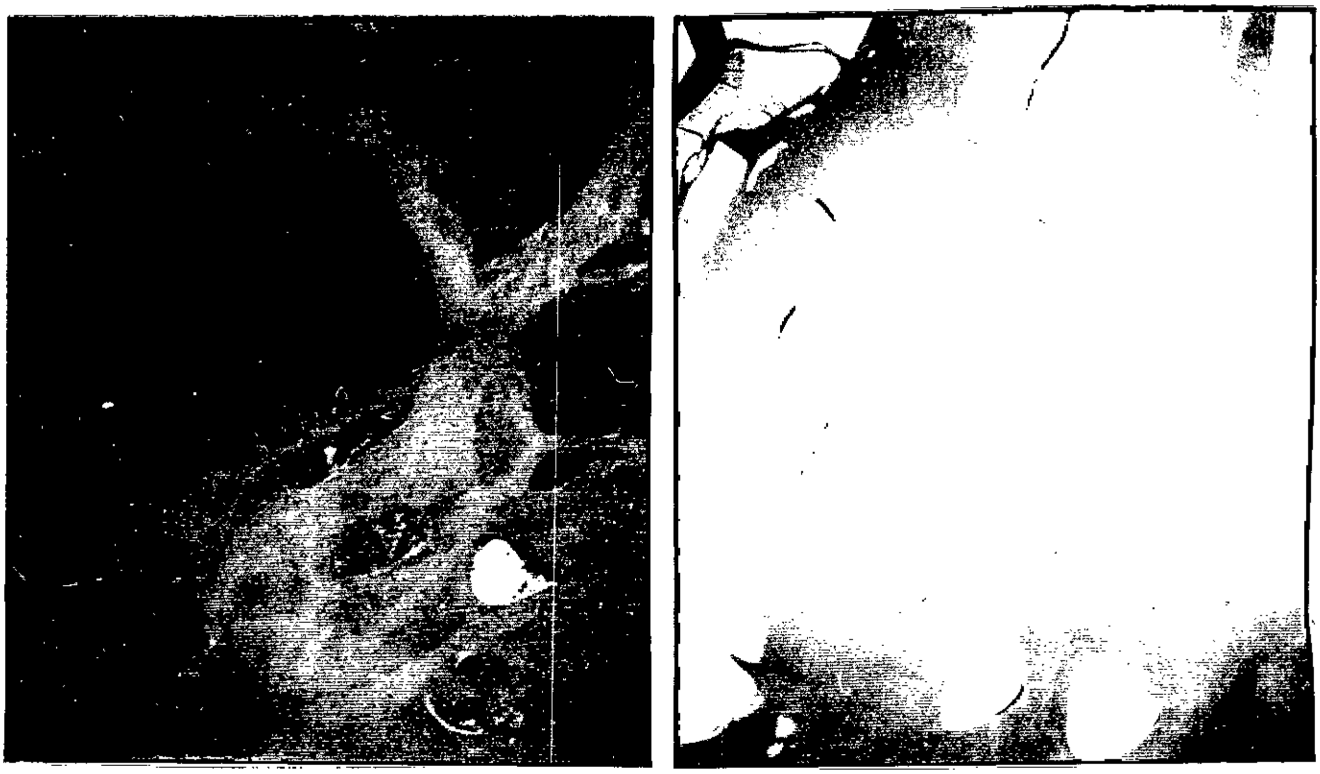
Although spectral reflectances of the surface features provide ample information about its type, it is all the more better if supporting documents are available beforehand. The study area being a dynamic zone in the coastal region often undergo changes. The area is covered by four topographic maps prepared by the Survey of Bangladesh at scale 1:50,000. Since these maps were drawn long ago, they needed updating. This updating was done from the interpretation of the colour infra-red aerial photographs. Major surface features were delineated from the aerial photographs and a surface feature delineation map was drawn with the interpretation keys (Figure 13).

This map being too big to be accommodated here, a photographic replica is presented only while an ammonia-print of the map is given in the Appendix-I.

Figure 13: Surface feature delineation map.

3.2 Enhancement techniques

All the enhancement techniques were not essentially required for the processing of the data set. However, before analysing the data set, it is wise to employ the enhancement techniques to obtain the knowledge on the nature of the surface features of the study area. The normal (unenhanced) display image (Figure 14) do not clearly show all the features available.



1984 (MSS) Data 1988 (TM) Data

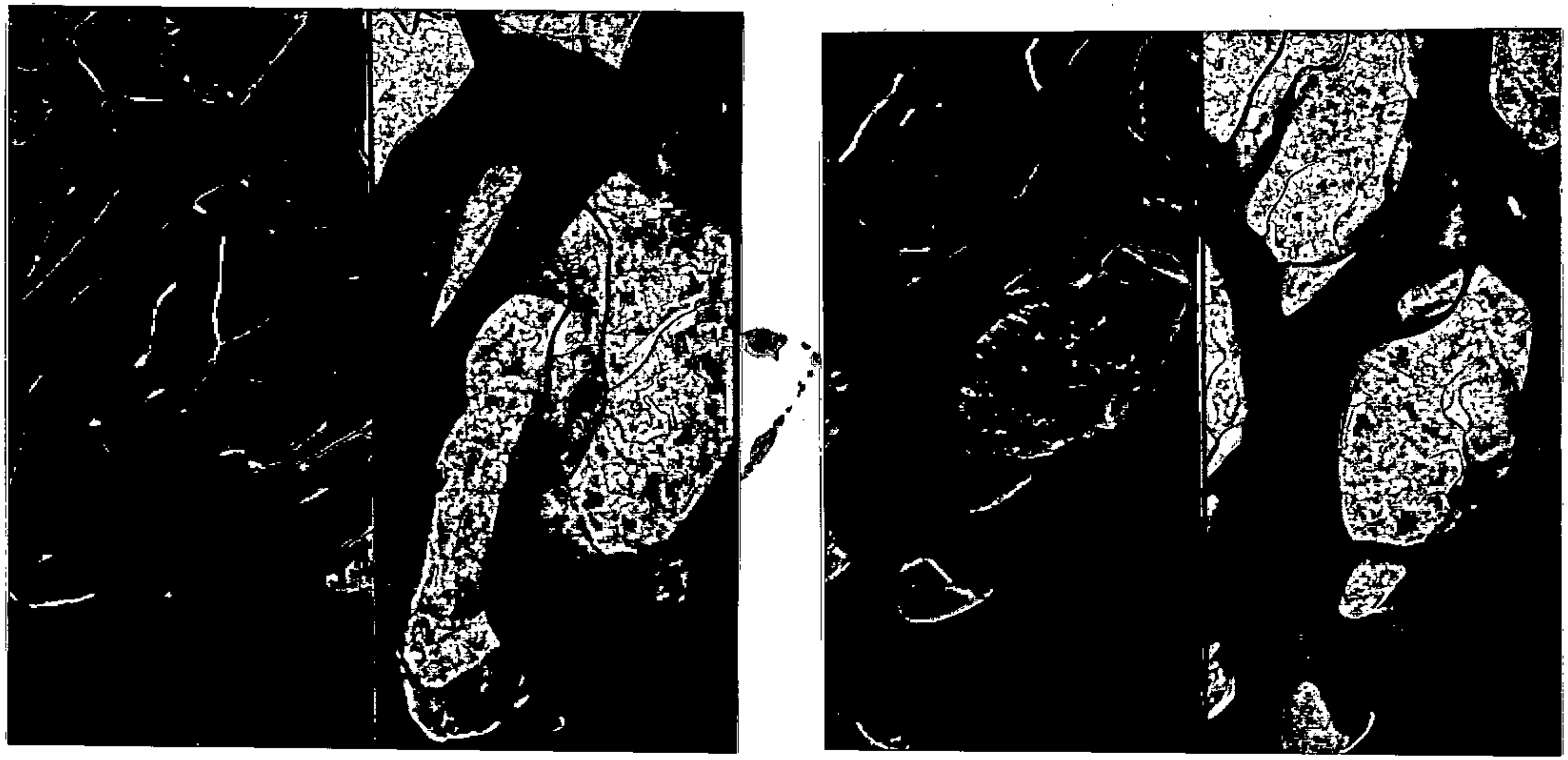
Figure 14: Unenhanced image.

Thus the first enhancement was made by utilizing a function 'scale' of S575 software of the system. The enhanced images are shown in figure 15.

1984 Data 1988 Data

Figure 15: Enhanced images of the study area.

The two sets of data were displayed side by side by splitting the screen into two halves to get a comparative idea about the surface features and image quality. The two photographs figure 16 a & b show left & right portions respectively. The TM scene has been represented as a subsampled image (by a step 2) thus making the apparent resolution 30x2=60m. While the MSS scene has been represented at full scale but without geometric correction. Thus it seems to be squeezed and incomparable to the TM scene.



(a) Lefthand portions of the study area

(b) Righthand portions of the study area

Figure 16 : Comparative representation of 1984/88 data.

But a full-scale TM image (i.e. without subsampling & with resolution 30m x 30m shows much details of the study area.

Figure 17:Full resolution TM Image

Different other combinations of bands were tried but the results were not better than those obtained for bands 3,2,1 of MSS & 5,4,3 of TM. Photographs of another combination of bands are displayed in the figure 18.

(a) (b)

Figure 18: (a) MSS bands 1 2 3 (b) TM bands 4 3 2

Figure 18 shows some other combination of TM bands. Figure 19(a) is a photograph of band display which characterises itself by separating vegetation from soils.

Figure 19(b) shows an image of bands 6,4 & 2 (TM) where healthy vegetation is showing up as green and the pink colour may represent moist vegetation.

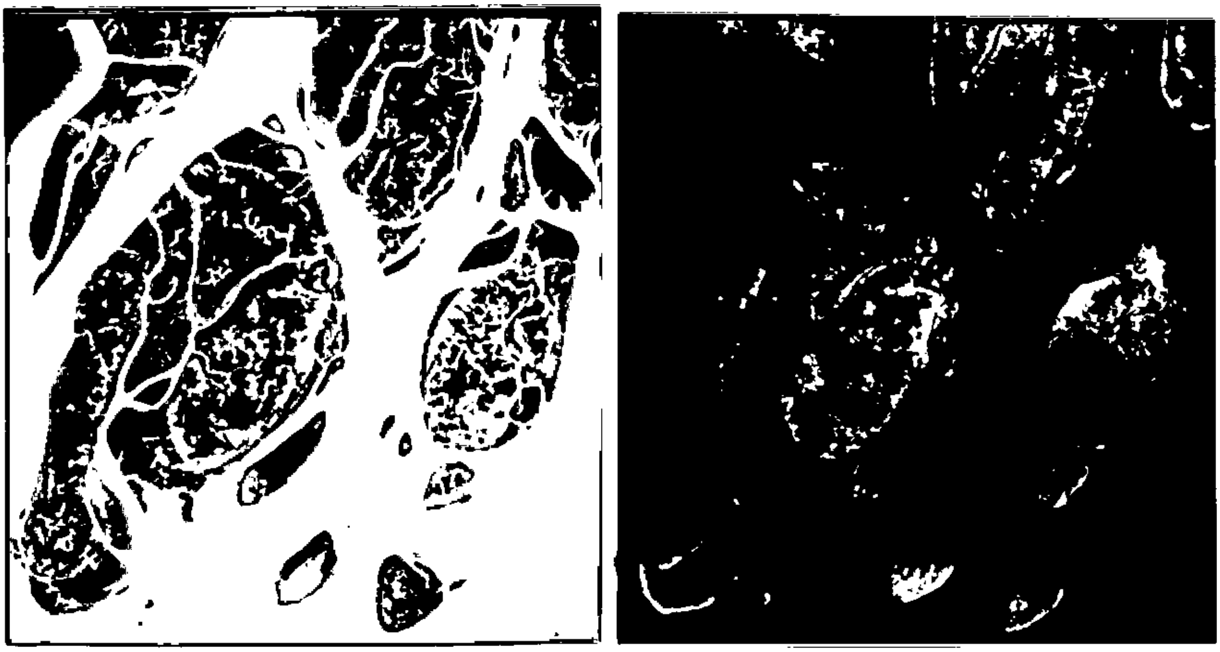


Figure 19: (a) TM bands 3 2 1 & (b) TM bands 6 4 2.

Other image enhancement techniques were used and the results are shown in the following figures. The tlm of 88 TM data and piece of '84 MSS data are represented in figure 20 a & b respectively.

(a) TLM of 1988 data (b) Piece of 1984 data

Figure 20: Results of other enhancements.

From these enhancement techniques strategy for making decision about the classification could be chalked out. This could also provide a background information which would be required while supervised classification technique is adopted.

The enhancement techniques contribute much towards feature extractions depending on combination of bands and type of enhancement.

3.3 Ground-Truth Information

In utilizing remote sensing techniques for feature identification ground-truth information plays a vital role particularly in the context of Bangladesh because there are features which show up in the unclassified images as same category but in the real world they may be of different nature. In the present study area, the island in the bottom right corner is a mixed class of mangroves and creepers which are intermingled in such a way that they really become inseparable. Figure 21 shows the actual situation on the ground.

Figure 21: Ground truth data showing mixtue of two categories.

The sandy accreted areas are shown in figure 22(a & b). In figure 22(b) a stress in the mangrove forest is observed.

(a) Bare sandy soil. (b) Bare sandy soil adjacent to vegetation

Figure 22: Ground truth data showing sandy accreted land.

The other important aspect is that there are certain areas in the coastal region where the tide condition make much difference in the resultant images. During high-tide even some mangrove plantations or the just surfacing islands/mud flats go under water. While during low-tide their existence is clearly identifiable.

3.4 Classification stages

3.4.1 Unsupervised classification of 1984 data

An unsupervised approach of classification of the 1984 data set was undertaken by assigning different number of classes. It was observed that the data set being of the month of September showed ample resemblance between mangrove and agricultural crops. (Points 1's and 2's respectively in figure 23(a & b)).

(a) (b)

Figure 23: Pseudo colour - clustered image.

By choosing higher and higher number of classes it was observed that those two were inseparable which means that the class statistics obtained through this classification will be erroneous. The classified image can be imposed colours in two methods. Simple approach is to apply pseudo-colour[4]. By the movement of the track-ball the colour may be interactively changed until an acceptable colour is obtained. The other process is to construct an interpetation key and make a 'stash' file. During clustering process a statistics file can optionally be created to apply the same statistics over other areas if the study area is bigger than and is a multiple of the size 512x512. In doing this a series of clustering process was undertaken. The number of classes were chosen to be 6, 8, 10, 16 & 32 and the results of each clustering process was evaluated. It was found that the results obtained from clustering i.e. unsupervised classification with 16 classes was the best. Although apparently result obtained by assigning 32 classes is supposed to have been

Figure 24: Colour coded unsupervised classification of 1984 image.

the best but after clustering it shows only 27 classes. The results of these clustering processes are shown in appendix-II. The statistics created while processing data set were applied on the MSS data and it was observed that almost no information loss occurs.

3.4.2 Unsupervised classification of 1988 data

The data set was of the size of 1024x1024 thereby comprising four subscenes of 512x512 size.

Figure 25: Colour coded unsupervised classification of 1988 image.

The first quadrant of 512x512 size was displayed and clustered for various number of classes. Then ultimately 16 classes were chosen. During the clustering process a statistics file was created to obtain similar classification of the rest of the quadrants. Then colour was imposed on the image (first quadrant) by constructing a key for the colour codes (Fig. 25). After attaining suitable colour code a stash file was created which could be fetched to colour other subscenes (quadrants) in the same colour code. Then these four quadrants were mosaiced together to constitute the full data set of the study area (figure 26). Statistics for each quadrants are given in table-4. Interpretation key was added to provide colour code for all the classes. Nine distinguishable classes were detected.

Figure 26 : Colour Coded unsupervised classification of 1988 data (mosaiced)

Table 4

(Statistics generated for unsupervised classification of TM data)

Class	Bands (M/STD)		
1	13.33	18.15	26.81
	7.72	10.64	6.82
2	6.08	26.62	66.25
	7.72	10.64	6.82
3	29.72	38.57	39.52
	7.72	10.64	6.82
4	42.29	42.43	44.93
	7.72	10.64	6.82
5	24.27	33.47	59.74
	7.72	10.64	6.82
6	39.95	56.78	33.52
	7.72	10.64	6.82
7	42.28	37.95	54.10
	7.72	10.64	6.82
8	61.02	51.41	40.54
	7.72	10.64	6.82
9	52.61	41.31	51.80
	7.72	10.64	6.82
10	64.32	68.44	35.38
	7.72	10.64	6.82
11	65.17	46.55	50.49
	7.72	10.64	6.82
12	71.55	62.59	42.78
	7.72	10.64	6.82
13	78.36	57.63	52.98
	7.72	10.64	6.82
14	77.36	83.42	36.12
	7.72	10.64	6.82
15	91.08	69.19	57.22
	7.72	10.64	6.82

3.4.3 Supervised classification of 1984 (MSS) data

From the careful observations on colour and tone of the image obtained after various enhancements and from the study of aerial photo interpretation results as many as nine classes could be chosen visually as identifiable spectral classes. Thus two training areas for each of the nine classes were chosen on the displayed image and a "vert-file" was constructed. With this vert-file preparation programme was run to construct a "prepare file" which was subsequently utilised for making the classification of the image. The prepare file was run on the disk-resident image for calculating the statistical results and a classified disk image was obtained. From this classified image statistics could be obtained for the nine classes. The classified image was then assigned an interpretation key (figure 27). The statistical results are shown in table 5.

Table 5

(Statistical results of supervised classification of MSS (1984) data)

Table of coverage by class type (in hectares)

Class	Hectares	%Cover	Npixels	
0	4605.38	3.9%	10410.	Reject class
1	6262.61	5.4	14156.	
2	6799.68	5.8	15370.	
3	11108.66	9.5	25110.	
4	19797.84	17.0	44751.	
5	558.30	.4	1261.	
6	25914.02	22.3	58576.	
7	15586.19	13.4	35231.	
8	1386.03	1.1	3133.	
9	7728.72	6.6	17470.	
10	16225.01	13.9	36675.	

Total area = 115972.50 hectares 262143. PIXELS

Figure 27 : Colour Coded Supervised classification of 1984 Image.

3.4.4 Supervised classification of 1988 (TM) data

With the inherent improved spatial resolution and a temporal variation to the MSS data set, the TM data set provided better tonal and textual variations for choosing the spectral classes. Ten distinguishable features could be identifiable from the enhanced image. But since training areas were required to be taken from the whole study area, a subsampling of the image was done at a rate of 2. Thus the entire image of the study area could be displayed on the screen and two training areas were chosen for each feature category. Then in the similar manner as supervised classification for MSS, the classification results were obtained for the TM data. From the classified image the statistics were obtained as shown in table 6.

The classified image was then given a colour code (key & colour) for interpretation Figure 28 shows the colour classified subsampled image of TM data.

3.4.5 Interpretation 'Key' and Colour

The system S575 provides facilities to colour-code a classified image. An interpretation 'Key' can be added where the number of total classes and the position of the 'Key' are to be defined by the user. Then colour is added to each class one after another by interactive manipulation of the colour table. Values between 0 & 1 are to be assigned by the user for each of the red, green and blue channels for each class category. One such colour code is represented in table 6a.

Table 6

(Supervised classification results of TM data)

Table of coverage by class type (in hectares)

Class	Hectares	%Cover	Npixels	
0	20888.35	18.0%	47216.	Reject class
1	433.10	.3	978.	
2	315.87	.2	714.	
3	2641.57	2.2	5971.	
4	13667.50	11.7	30894.	
5	3059.63	2.6	6916.	
6	19486.83	16.8	44047.	
7	9671.30	8.3	21861.	
8	4139.53	3.5	9357.	
9	41405.10	35.7	93592.	
10	263.67	.2	596.	

Total area = 115972.50 hectares 262143. PIXELS

Figure 28: Colour-Coded Supervised classification of 1988 Image.

Table 6a

(Example of colour-code generation)

```
  2) MSSCLASS\DISP\$A;


  3) $A\KEY ?;

 m chr *016 CLASSNAMES (128) = ?
 0 1 2 3 4
 int SMALLBOXVALUES (128) = ?
 "0" "1" "2" "3" "4"
 int BOXVALUE = 128?
 1
 int LABELVALUE = 255?

 int KLOCATION (4) = 2 80 100 350?
 450 350 30 150
 int NUMBEROFCOLUMNS = 1?
 1

  4) $A\COLOR ?;

 m int NSTEPS = ?
 5
 int MINIMUM = 0?

 int MAXIMUM = 10?

 chr *016 OBLOTCH = ?


 [  1] Enter color weights :
 .3 .3 .3
 Enter classes to be assigned color :
 1
 Continue, repeat or exit, type C, R or E:
 C

 [  2] Enter color weights :
 .4 .5 .6
 Enter classes to be assigned color :
 2
 Continue, repeat or exit, type C, R or E:
 R

 [  2] Enter color weights :
 .2 .4 .5
 Enter classes to be assigned color :
 2
 Continue, repeat or exit, type C, R or E:
 C

 [  3] Enter color weights :
 .2 .7 .0
 Enter classes to be assigned color :
 3
 Continue, repeat or exit, type C, R or E:
 C

 [  4] Enter color weights :
 .6 .9 .2

 Enter classes to be assigned color :
 4/5
 Continue, repeat or exit, type C, R or E:
 E
```

3.5 Comparison of MSS and TM data

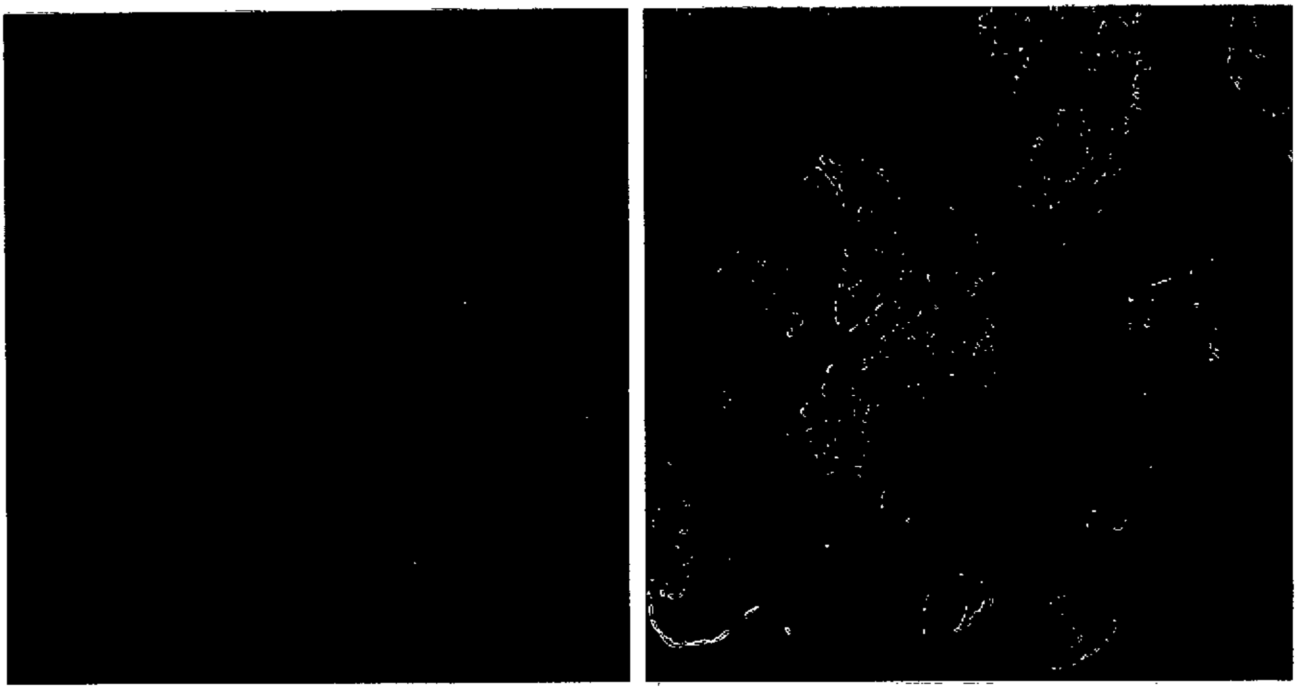
Although there is a fundamental difference in the data type of MSS and TM, an attempt was made to bring the two images to an identical scale by employing processing manipulations to register the two images as accurately as possible. The display size being 512x512, the images should be restricted within 512x512 pixel size. The TM image was subsampled at a step of '2' and it was kept unchanged as a display image. Then the MSS image was subjected to geometrical correction until a proper point to point match was obtained during image registration. It was found after many operations of geometrical correction[4] of MSS data and its subsequent comparison with TM data that angular rotation of the image was not necessary. For matching the pixel size of MSS with those of TM (60m x 60m in this subsampled image) the sample was reduced .95 times while the line was expanded 1.38 times. Thus by choosing the appropriate position of the MSS image for subjecting to geometric correction (starting sample 1, starting line 40, number of samples 512, number of lines 365) a properly registered image was obtained. Thus a comparison could be easily made on the colour classified images.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4. RESULTS AND DISCUSSIONS

During the image analysis a great deal of care was taken to identify the spectral signatures of various surface features. In a bid to do that the number of classes were chosen to be six at the beginning and clustering was done. The result was not satisfactory and thus the number of classes of features were increased gradually during the processing options as 8, 10, 16 & 32 (Appendix-II). Although spectrally, identification and separation of even more classes are possible but in the study area it was observed that only 27 types or groups of features were present. The result of the option of 16 classes are given in table 7. Then by studying the classified images one after another by imposing pseudo colour it was found that 16 would be the optimum number of identifiable classes (surface features) for this study area. The results of clustering process have been shown in figures 24 & 26 for 1984 (MSS) and 1988 (TM) data respectively.

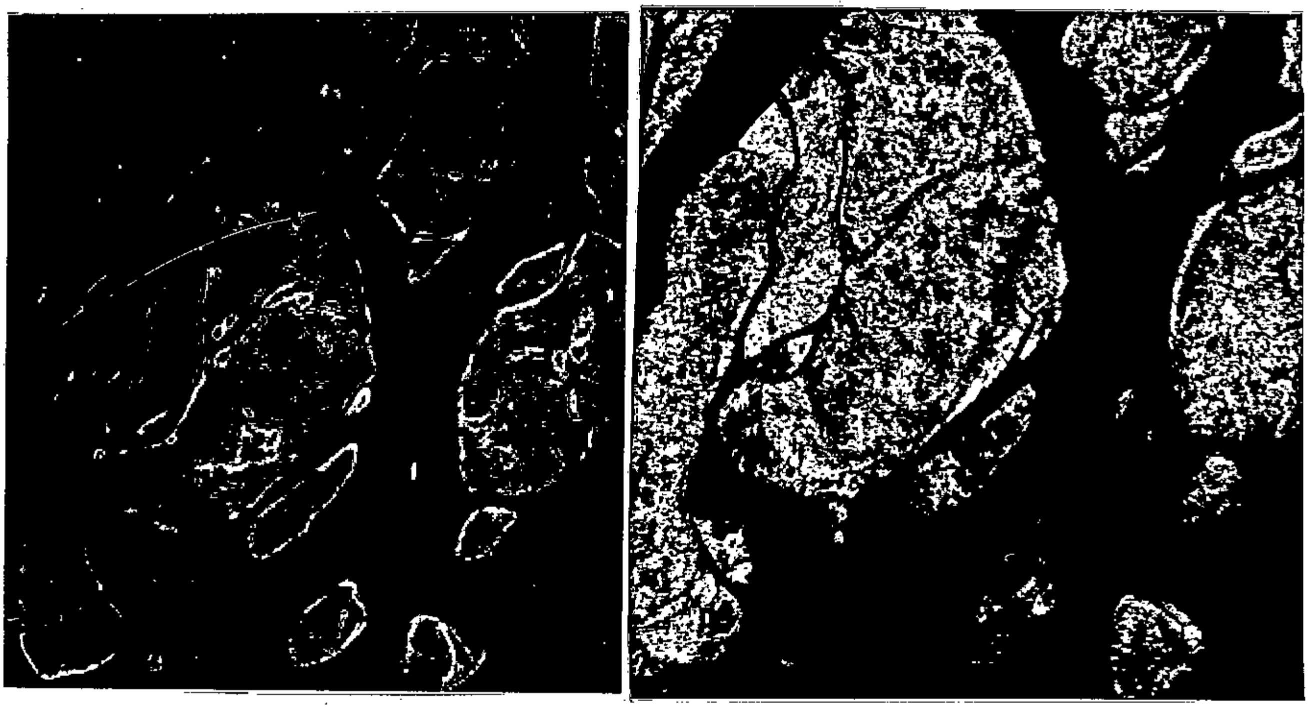
Since the TM data set was of the size of 1024 x 1024, those were processed quadrant by quadrant by preparing a statistics file with the first quadrant. The unsupervised classification done with this statistics file shows marked closeness to the normal clustering results (Table 8a & 9). Now, since the data sets were of different pixel sizes, those could not be physically compared. Thus by geometrically correcting the MSS data sets a comparable size could be attained and the images could be registered with the corresponding TM data set which was subsampled at a step of 2 (Figure 29 a & b) shows the unsupervised classification (clustering) results while figure 30 (a & b) represents the supervised classification results. The



(a) 1984 data (MSS)   (b) 1988 data (TM)

Figure 29: Corrected results of clustering process.

registered images at different stages are shown in fig. 30 a. During unsupervised classification, although sixteen classes were desired on both MSS and TM data sets only 15 classes were finally obtained during clustering (unsupervised processing) of TM data



(a) MSS (1984) (b) TM (1988)

Figure 30: Corrected image of supervised classification.

sets. But in both MSS and TM data sets merging of classes had to be done on the basis of the ground truth information and the surface feature delineation map. Ultimately nine distinct classes rather spectrally separable signatures could be identified (Table 10).

Figure 30 a: Different stages of registered images.

Table 7
Statistical results of unsupervised classification of MSS (1984) Data (clustering process)

```
Starting seed table

CLASS    BANDS (MEAN)
-----------------------------------------------
   1     41.99      55.00      60.00          .
   2     41.99      55.00      74.00          .
   3     51.00      55.00      60.00          .
   4     51.00      55.00      74.00          .
   5     41.99      71.00      60.00          .
   6     41.99      71.00      74.00          .
   7     51.00      71.00      60.00          .
   8     51.00      71.00      74.00          .
   9     41.99      82.00      60.00          .
  10     41.99      82.00      74.00          .
  11     51.00      82.00      60.00          .
  12     51.00      82.00      74.00          .
  13     41.99      87.00      60.00          .
  14     41.99      87.00      74.00          .
  15     51.00      87.00      60.00          .
  16     51.00      87.00      74.00          .


Results of iteration     1

CLASS    BANDS (MEAN)                     Pixels
-----------------------------------------------
   1     41.99      55.00      60.00      8524.
   2     41.99      55.00      74.00        14.
   3     51.00      55.00      60.00     61983.
   4     51.00      55.00      74.00        17.
   5     41.99      71.00      60.00      7627.
   6     41.99      71.00      74.00      4229.
   7     51.00      71.00      60.00     10928.
   8     51.00      71.00      74.00       737.
   9     41.99      82.00      60.00      6264.
  10     41.99      82.00      74.00     71552.
  11     51.00      82.00      60.00       243.
  12     51.00      82.00      74.00      2492.
  13     41.99      87.00      60.00       623.
  14     41.99      87.00      74.00     61567.
  15     51.00      87.00      60.00        12.
  16     51.00      87.00      74.00      3477.


Input statistics to iteration     2

CLASS    BANDS (MEAN)                  Migration
-----------------------------------------------
   1     40.46      53.98      54.25         8.
   2     37.46      60.06      71.33        12.
   3     59.36      55.03      54.74        13.
   4     58.47      60.88      69.47        17.
   5     41.40      71.24      64.15         4.
   6     41.08      74.59      70.47         8.
   7     53.68      67.13      61.38         7.
   8     51.91      72.70      69.70         6.
   9     40.02      80.14      66.23        10.
  10     40.85      81.60      72.73         2.
  11     50.06      78.95      65.84         9.
```

Table 7 (cont'd)

```
     12      49.10      81.23      73.63          3.
     13      39.90      86.63      66.40          8.
     14      41.28      87.86      75.15          2.
     15      47.83      87.08      65.16          8.
     16      48.50      88.66      76.97          7.

 Results of iteration    2

 CLASS    BANDS (MEAN)                         Pixels
 ------------------------------------------------------
      1      40.46      53.98      54.25      12094.
      2      37.46      60.06      71.33        542.
      3      59.36      55.03      54.74      58867.
      4      58.47      60.88      69.47       1639.
      5      41.40      71.24      64.15       5179.
      6      41.08      74.59      70.47      10210.
      7      53.68      67.13      61.38      16156.
      8      51.91      72.70      69.70       1568.
      9      40.02      80.14      66.23      12892.
     10      40.85      81.60      72.73      55312.
     11      50.06      78.95      65.84       1296.
     12      49.10      81.23      73.63       6576.
     13      39.90      86.63      66.40       4230.
     14      41.28      87.86      75.15      49984.
     15      47.83      87.08      65.16        214.
     16      48.50      88.66      76.97      11908.

 Input statistics to iteration    3

 CLASS    BANDS (MEAN)                      Migration
 ------------------------------------------------------
      1      42.89      52.23      52.85          5.
      2      38.31      61.92      63.93         10.
      3      62.66      53.45      53.55          6.
      4      59.07      60.70      63.16          7.
      5      42.02      70.70      64.01          1.
      6      41.03      76.12      69.97          2.
      7      53.25      64.65      60.00          4.
      8      52.46      72.60      67.45          2.
      9      39.89      79.89      67.61          1.
     10      40.50      82.15      73.07          1.
     11      48.13      78.05      67.06          4.
     12      46.72      81.72      74.61          3.
     13      39.44      86.00      68.78          3.
     14      40.80      87.54      75.08           .
     15      46.28      86.57      67.58          4.
     16      45.93      89.70      78.32          4.

 Results of iteration    3

 CLASS    BANDS (MEAN)                         Pixels
 ------------------------------------------------------
      1      42.89      52.23      52.85      13449.
      2      38.31      61.92      63.93       3158.
      3      62.66      53.45      53.55      48062.
      4      59.07      60.70      63.16      12184.
      5      42.02      70.70      64.01       5013.
```

Table 7 (cont'd)

```
   6     41.03     76.12     69.97     13016.
   7     53.25     64.65     60.00     14612.
   8     52.46     72.60     67.45      2720.
   9     39.89     79.89     67.61     13608.
  10     40.50     82.15     73.07     45269.
  11     48.13     78.05     67.06      2120.
  12     46.72     81.72     74.61     11733.
  13     39.44     86.00     68.78      9522.
  14     40.80     87.54     75.08     40281.
  15     46.28     86.57     67.58      1124.
  16     45.93     89.70     78.32     16066.


Input statistics to iteration    4

CLASS    BANDS (MEAN)               Migration
---------------------------------------------
   1     44.98     51.04     51.93        4.
   2     40.49     61.35     60.47        6.
   3     65.63     51.68     52.28        6.
   4     58.65     59.66     59.28        5.
   5     42.89     70.72     64.03         .
   6     40.84     76.60     70.19         .
   7     52.87     63.74     58.86        2.
   8     53.14     71.61     65.98        3.
   9     39.86     80.22     68.00         .
  10     40.25     82.27     73.20         .
  11     47.03     77.87     67.56        1.
  12     45.33     82.20     75.33        2.
  13     39.23     85.85     70.25        1.
  14     40.80     87.36     74.93         .
  15     45.77     86.45     69.69        2.
  16     44.43     90.15     78.32        1.


Results of iteration    4

CLASS    BANDS (MEAN)                  Pixels
---------------------------------------------
   1     44.98     51.04     51.93     13846.
   2     40.49     61.35     60.47      5018.
   3     65.63     51.68     52.28     38994.
   4     58.65     59.66     59.28     23445.
   5     42.89     70.72     64.03      5324.
   6     40.84     76.60     70.19     14405.
   7     52.87     63.74     58.86     11493.
   8     53.14     71.61     65.98      3490.
   9     39.86     80.22     68.00     14108.
  10     40.25     82.27     73.20     36975.
  11     47.03     77.87     67.56      2984.
  12     45.33     82.20     75.33     15906.
  13     39.23     85.85     70.25     14802.
  14     40.80     87.36     74.93     33225.
  15     45.77     86.45     69.69      3093.
  16     44.43     90.15     78.32     17279.


Input statistics to iteration    5

CLASS    BANDS (MEAN)               Migration
```

Table 7 (cont'd)

```
------------------------------------------------------
    1      46.33      50.22      51.37          2.
    2      41.89      60.50      59.21          3.
    3      68.97      49.92      51.19          6.
    4      58.31      58.47      57.30          3.
    5      42.88      70.64      64.16           .
    6      40.73      76.85      70.31           .
    7      53.02      63.90      59.24           .
    8      53.91      70.57      64.83          2.
    9      39.94      80.50      68.23           .
   10      40.03      82.18      73.17           .
   11      46.57      77.70      67.98          1.
   12      44.39      82.65      75.68          1.
   13      39.24      85.74      71.03           .
   14      40.84      87.39      75.17           .
   15      45.54      86.41      71.05          1.
   16      43.87      90.30      78.14           .


Results of iteration    5

CLASS    BANDS (MEAN)                       Pixels
------------------------------------------------------
    1      46.33      50.22      51.37      14203.
    2      41.89      60.50      59.21       5942.
    3      68.97      49.92      51.19      33076.
    4      58.31      58.47      57.30      29078.
    5      42.88      70.64      64.16       5470.
    6      40.73      76.85      70.31      14292.
    7      53.02      63.90      59.24      12028.
    8      53.91      70.57      64.83       3749.
    9      39.94      80.50      68.23      14047.
   10      40.03      82.18      73.17      35820.
   11      46.57      77.70      67.98       3761.
   12      44.39      82.65      75.68      18207.
   13      39.24      85.74      71.03      16809.
   14      40.84      87.39      75.17      28068.
   15      45.54      86.41      71.05       4868.
   16      43.87      90.30      78.14      17013.


Input statistics to iteration    6

CLASS    BANDS (MEAN)                    Migration
------------------------------------------------------
    1      47.47      49.64      50.95          2.
    2      42.61      59.64      58.47          2.
    3      72.33      48.51      50.30          5.
    4      58.63      57.43      56.42          2.
    5      42.57      70.63      64.36           .
    6      40.62      76.91      70.35           .
    7      53.69      63.83      59.53          1.
    8      54.22      69.91      64.18          1.
    9      39.96      80.62      68.24           .
   10      40.13      82.02      73.01           .
   11      46.46      77.44      68.11           .
   12      43.78      83.16      75.94          1.
   13      39.11      85.77      71.45           .
   14      40.81      87.63      75.42           .
   15      45.38      86.40      71.83           .
   16      43.69      90.44      78.06
```

```
Results of iteration    6

CLASS   BANDS (MEAN)                     Pixels
-----------------------------------------------
  1      47.47     49.64     50.95     14117.
  2      42.61     59.64     58.47      7087.
  3      72.33     48.51     50.30     28865.
  4      58.63     57.43     56.42     32122.
  5      42.57     70.63     64.36      5609.
  6      40.62     76.91     70.35     14190.
  7      53.69     63.83     59.53     13205.
  8      54.22     69.91     64.18      3933.
  9      39.96     80.62     68.24     15394.
 10      40.13     82.02     73.01     31732.
 11      46.46     77.44     68.11      4087.
 12      43.78     83.16     75.94     19321.
 13      39.11     85.77     71.45     20148.
 14      40.81     87.63     75.42     26295.
 15      45.38     86.40     71.83      6256.
 16      43.69     90.44     78.06     15566.


Input statistics to iteration    7

CLASS   BANDS (MEAN)                  Migration
-----------------------------------------------
  1      48.43     49.10     50.55          1.
  2      43.47     58.91     57.91          2.
  3      75.30     47.36     49.56          4.
  4      59.33     56.59     55.81          2.
  5      42.38     70.46     64.38           .
  6      40.58     76.96     70.37           .
  7      54.27     63.52     59.53           .
  8      54.22     69.60     63.82           .
  9      40.04     80.86     68.35           .
 10      40.39     81.73     73.10           .
 11      46.55     77.24     68.16           .
 12      43.15     83.45     76.26          1.
 13      39.06     85.55     71.71           .
 14      40.82     87.92     75.49           .
 15      45.26     86.28     72.29           .
 16      43.83     90.60     78.11           .


Results of iteration    7

CLASS   BANDS (MEAN)                     Pixels
-----------------------------------------------
  1      48.43     49.10     50.55     14004.
  2      43.47     58.91     57.91      8360.
  3      75.30     47.36     49.56     25733.
  4      59.33     56.59     55.81     32981.
  5      42.38     70.46     64.38      5673.
  6      40.58     76.96     70.37     13945.
  7      54.27     63.52     59.53     14803.
  8      54.22     69.60     63.82      4184.
  9      40.04     80.86     68.35     15308.
```

Table 7 (cont'd)

10	40.39	81.73	73.10	30814.
11	46.55	77.24	68.16	4342.
12	43.15	83.45	76.26	18673.
13	39.06	85.55	71.71	22790.
14	40.82	87.92	75.49	25856.
15	45.26	86.28	72.29	6949.
16	43.83	90.60	78.11	14442.

Premature quit because of minimum migration limit

Table 7a

(Statistical Results of Unsupervised classifciation of MSS data using statistics file)

Summary table

Class	Bands (M/STD)			Pixels
1	48.43	49.10	50.55	13359.
	7.47	3.92	5.19	
2	43.47	58.91	57.91	8692.
	7.47	3.92	5.19	
3	75.30	47.36	49.56	28798.
	7.47	3.92	5.19	
4	59.33	56.59	55.81	33716.
	7.47	3.92	5.19	
5	42.38	70.46	64.38	6008.
	7.47	3.92	5.19	
6	40.58	76.96	70.37	14258.
	7.47	3.92	5.19	
7	54.27	63.52	59.53	14250.
	7.47	3.92	5.19	
8	54.22	69.60	63.82	4066.
	7.47	3.92	5.19	
9	40.04	80.86	68.35	14956.
	7.47	3.92	5.19	
10	40.39	81.73	73.10	31895.
	7.47	3.92	5.19	
11	46.55	77.24	68.16	4840.
	7.47	3.92	5.19	
12	43.15	83.45	76.26	17264.
	7.47	3.92	5.19	
13	39.06	85.55	71.71	23147.
	7.47	3.92	5.19	
14	40.82	87.92	75.49	24458.
	7.47	3.92	5.19	
15	45.26	86.28	72.29	8019.
	7.47	3.92	5.19	
16	43.83	90.60	78.11	14414.
	7.47	3.92	5.19	

Table 8

(Statistical results of unsupervised classification of TM data (1st quadrant) using statistics file)

Class	Bands (M/STD)			Pixels
1	13.33	18.15	26.81	819.
	7.72	10.64	6.82	
2	6.08	26.62	66.25	100294.
	7.72	10.64	6.82	
3	29.72	38.57	39.52	2420.
	7.72	10.64	6.82	
4	42.29	42.43	44.93	3997.
	7.72	10.64	6.82	
5	24.27	33.47	59.74	3705.
	7.72	10.64	6.82	
6	39.95	56.78	33.52	8232.
	7.72	10.64	6.82	
7	42.28	37.95	54.10	6490.
	7.72	10.64	6.82	
8	61.02	51.41	40.54	23709.
	7.72	10.64	6.82	
9	52.61	41.31	51.80	7655.
	7.72	10.64	6.82	
10	64.32	68.44	35.38	32652.
	7.72	10.64	6.82	
11	65.17	46.55	50.49	9953.
	7.72	10.64	6.82	
12	71.55	62.59	42.78	15684.
	7.72	10.64	6.82	
13	78.36	57.63	52.98	9927.
	7.72	10.64	6.82	
14	77.36	83.42	36.12	29545.
	7.72	10.64	6.82	
15	91.08	69.19	57.22	6461.
	7.72	10.64	6.82	

Table 8 (cont'd)
(b) 2nd quadrant.

Summary table

Class	Bands (M/STD)			Pixels
1	13.33	18.15	26.81	67.
	7.72	10.64	6.82	
2	6.08	26.62	66.25	91525.
	7.72	10.64	6.82	
3	29.72	38.57	39.52	1896.
	7.72	10.64	6.82	
4	42.29	42.43	44.93	5012.
	7.72	10.64	6.82	
5	24.27	33.47	59.74	4356.
	7.72	10.64	6.82	
6	39.95	56.78	33.52	16565.
	7.72	10.64	6.82	
7	42.28	37.95	54.10	6144.
	7.72	10.64	6.82	
8	61.02	51.41	40.54	17245.
	7.72	10.64	6.82	
9	52.61	41.31	51.80	8197.
	7.72	10.64	6.82	
10	64.32	68.44	35.38	41384.
	7.72	10.64	6.82	
11	65.17	46.55	50.49	11435.
	7.72	10.64	6.82	
12	71.55	62.59	42.78	14760.
	7.72	10.64	6.82	
13	78.36	57.63	52.98	12905.
	7.72	10.64	6.82	
14	77.36	83.42	36.12	25057.
	7.72	10.64	6.82	
15	91.08	69.19	57.22	5590.
	7.72	10.64	6.82	

Table 8 (cont'd)
(c) 3rd quadrant.

Summary table

Class	Bands (M/STD)			Pixels
1	13.33	18.15	26.81	53.
	7.72	10.64	6.82	
2	6.08	26.62	66.25	121175.
	7.72	10.64	6.82	
3	29.72	38.57	39.52	1684.
	7.72	10.64	6.82	
4	42.29	42.43	44.93	5203.
	7.72	10.64	6.82	
5	24.27	33.47	59.74	3439.
	7.72	10.64	6.82	
6	39.95	56.78	33.52	17113.
	7.72	10.64	6.82	
7	42.28	37.95	54.10	4067.
	7.72	10.64	6.82	
8	61.02	51.41	40.54	15956.
	7.72	10.64	6.82	
9	52.61	41.31	51.80	8970.
	7.72	10.64	6.82	
10	64.32	68.44	35.38	23538.
	7.72	10.64	6.82	
11	65.17	46.55	50.49	13731.
	7.72	10.64	6.82	
12	71.55	62.59	42.78	11474.
	7.72	10.64	6.82	
13	78.36	57.63	52.98	14169.
	7.72	10.64	6.82	
14	77.36	83.42	36.12	14379.
	7.72	10.64	6.82	
15	91.08	69.19	57.22	7186.
	7.72	10.64	6.82	

Table 8 (cont'd)
(d) 4th quadrant.

Summary table

Class	Bands (M/STD)			Pixels
1	13.33	18.15	26.81	33.
	7.72	10.64	6.82	
2	6.08	26.62	66.25	187664.
	7.72	10.64	6.82	
3	29.72	38.57	39.52	763.
	7.72	10.64	6.82	
4	42.29	42.43	44.93	2424.
	7.72	10.64	6.82	
5	24.27	33.47	59.74	2805.
	7.72	10.64	6.82	
6	39.95	56.78	33.52	8090.
	7.72	10.64	6.82	
7	42.28	37.95	54.10	2727.
	7.72	10.64	6.82	
8	61.02	51.41	40.54	9213.
	7.72	10.64	6.82	
9	52.61	41.31	51.80	3846.
	7.72	10.64	6.82	
10	64.32	68.44	35.38	12301.
	7.72	10.64	6.82	
11	65.17	46.55	50.49	8924.
	7.72	10.64	6.82	
12	71.55	62.59	42.78	11464.
	7.72	10.64	6.82	
13	78.36	57.63	52.98	5892.
	7.72	10.64	6.82	
14	77.36	83.42	36.12	4461.
	7.72	10.64	6.82	
15	91.08	69.19	57.22	1534.
	7.72	10.64	6.82	

Table 9

(Statistical Results of Unsupervised Classification of TM Data (clustering)

```
Starting seed table

CLASS    BANDS (MEAN)
-----------------------------------------------
    1       7.00      28.99      41.00         .
    2       7.00      28.99      65.00         .
    3       7.00      60.00      41.00         .
    4       7.00      60.00      65.00         .
    5      30.00      28.99      41.00         .
    6      30.00      28.99      65.00         .
    7      30.00      60.00      41.00         .
    8      30.00      60.00      65.00         .
    9      63.00      28.99      41.00         .
   10      63.00      28.99      65.00         .
   11      63.00      60.00      41.00         .
   12      63.00      60.00      65.00         .
   13      71.99      28.99      41.00         .
   14      71.99      28.99      65.00         .
   15      71.99      60.00      41.00         .
   16      71.99      60.00      65.00         .


Results of iteration     1

CLASS    BANDS (MEAN)                     Pixels
-----------------------------------------------
    1       7.00      28.99      41.00      778.
    2       7.00      28.99      65.00   101090.
    3       7.00      60.00      41.00       10.
    4       7.00      60.00      65.00         .
    5      30.00      28.99      41.00     7287.
    6      30.00      28.99      65.00     4973.
    7      30.00      60.00      41.00     7866.
    8      30.00      60.00      65.00      130.
    9      63.00      28.99      41.00     8032.
   10      63.00      28.99      65.00     2727.
   11      63.00      60.00      41.00    55357.
   12      63.00      60.00      65.00      884.
   13      71.99      28.99      41.00      473.
   14      71.99      28.99      65.00      256.
   15      71.99      60.00      41.00    60526.
   16      71.99      60.00      65.00     8503.
```

Table 9 (cont'd)

Input statistics to iteration 2

CLASS	BANDS (MEAN)			Migration
1	11.66	19.09	28.88	26.
2	6.16	26.65	66.22	4.
3	15.70	48.00	45.10	24.
4	38.14	37.61	46.51	72.
5	33.12	34.99	58.72	26.
6	36.95	54.66	35.55	62.
7	39.86	48.29	56.74	37.
8	55.45	40.77	48.76	60.
9	53.97	39.15	55.85	34.
10	61.31	60.07	38.53	59.
11	59.68	51.73	56.27	26.
12	71.50	42.16	49.68	41.
13	73.04	42.03	56.02	29.
14	75.08	72.55	39.62	72.
15	84.42	61.78	58.09	31.

Results of iteration 2

CLASS	BANDS (MEAN)			Pixels
1	11.66	19.09	28.88	961.
2	6.16	26.65	66.22	101210.
3	15.70	48.00	45.10	465.
4	38.14	37.61	46.51	6080.
5	33.12	34.99	58.72	3901.
6	36.95	54.66	35.55	8779.
7	39.86	48.29	56.74	1543.
8	55.45	40.77	48.76	10692.
9	53.97	39.15	55.85	4674.
10	61.31	60.07	38.53	45989.
11	59.68	51.73	56.27	2477.
12	71.50	42.16	49.68	8446.
13	73.04	42.03	56.02	1922.
14	75.08	72.55	39.62	52579.
15	84.42	61.78	58.09	11954.

Table 9 (cont'd)

```
Input statistics to iteration     3

CLASS   BANDS (MEAN)                    Migration
-------------------------------------------------
    1    14.92      19.49      27.79         4.
    2     6.18      26.66      66.22          .
    3    20.71      38.08      45.62        15.
    4    39.73      38.77      47.34         3.
    5    30.25      34.38      58.86         3.
    6    38.24      54.67      34.11         2.
    7    42.88      42.02      54.62        11.
    8    56.46      44.09      46.62         6.
    9    50.96      38.94      54.62         4.
   10    62.29      60.59      37.49         2.
   11    62.60      53.09      53.14         7.
   12    69.76      49.58      48.52        10.
   13    74.26      48.19      55.34         8.
   14    74.99      78.04      37.26         7.
   15    86.25      64.58      56.09         6.


Results of iteration     3

CLASS   BANDS (MEAN)                       Pixels
-------------------------------------------------
    1    14.92      19.49      27.79       964.
    2     6.18      26.66      66.22    100920.
    3    20.71      38.08      45.62      1077.
    4    39.73      38.77      47.34      4728.
    5    30.25      34.38      58.86      3505.
    6    38.24      54.67      34.11      9029.
    7    42.88      42.02      54.62      4225.
    8    56.46      44.09      46.62     12028.

    9    50.96      38.94      54.62      5164.
   10    62.29      60.59      37.49     43548.
   11    62.60      53.09      53.14      3282.
   12    69.76      49.58      48.52     11297.
   13    74.26      48.19      55.34      4430.
   14    74.99      78.04      37.26     46312.
   15    86.25      64.58      56.09     11387.
```

Table 9 (cont'd)

```
Input statistics to iteration     4

CLASS    BANDS (MEAN)                        Migration
------------------------------------------------------
    1     15.35      19.63      27.48               .
    2      6.14      26.64      66.23               .
    3     24.01      36.52      44.89              5.
    4     40.00      39.67      46.72              1.
    5     27.96      34.01      59.54              3.
    6     38.82      55.03      33.95              1.
    7     43.51      39.33      53.96              3.
    8     58.02      45.94      44.74              5.
    9     51.48      39.24      53.65              1.
   10     63.07      61.97      37.01              2.
   11     63.05      52.59      52.37              1.
   12     69.65      52.70      46.82              4.
   13     75.94      51.42      54.28              5.
   14     75.22      80.03      36.53              2.
   15     87.20      66.51      55.51              3.


Results of iteration     4

CLASS    BANDS (MEAN)                           Pixels
------------------------------------------------------
    1     15.35      19.63      27.48            941.
    2      6.14      26.64      66.23         100709.
    3     24.01      36.52      44.89           1306.
    4     40.00      39.67      46.72           4337.
    5     27.96      34.01      59.54           3588.
    6     38.82      55.03      33.95           9060.
    7     43.51      39.33      53.96           5156.
    8     58.02      45.94      44.74          14912.
    9     51.48      39.24      53.65           5885.
   10     63.07      61.97      37.01          41181.
   11     63.05      52.59      52.37           4339.
   12     69.65      52.70      46.82          11775.
   13     75.94      51.42      54.28           6502.
   14     75.22      80.03      36.53          42007.
   15     87.20      66.51      55.51          10245.
```

Table 9 (cont'd)

```
Input statistics to iteration     5

CLASS    BANDS (MEAN)                    Migration
-------------------------------------------------
   1     15.07      19.47      27.27           .
   2      6.12      26.63      66.24           .
   3     26.25      36.71      43.30          4.
   4     40.36      40.52      46.15          1.
   5     26.51      33.77      59.79          1.
   6     39.20      55.46      33.86           .
   7     43.31      38.46      53.88          1.
   8     59.24      47.47      43.19          4.
   9     52.24      40.07      53.02          2.
  10     63.57      63.77      36.50          2.
  11     63.55      49.33      52.35          3.
  12     70.03      55.61      45.40          4.
  13     76.84      53.66      53.60          3.
  14     75.68      81.09      36.33          1.
  15     88.13      67.80      55.58          2.


Results of iteration     5

CLASS    BANDS (MEAN)                       Pixels
-------------------------------------------------
   1     15.07      19.47      27.27        900.
   2      6.12      26.63      66.24     100555.
   3     26.25      36.71      43.30       1525.
   4     40.36      40.52      46.15       4297.
   5     26.51      33.77      59.79       3690.
   6     39.20      55.46      33.86       8902.
   7     43.31      38.46      53.88       5558.
   8     59.24      47.47      43.19      17430.
   9     52.24      40.07      53.02       6380.
  10     63.57      63.77      36.50      38860.
  11     63.55      49.33      52.35       6275.
  12     70.03      55.61      45.40      12152.
  13     76.84      53.66      53.60       7765.
  14     75.68      81.09      36.33      38645.
  15     88.13      67.80      55.58       9056.
```

Table 9 (cont'd)

```
Input statistics to iteration     6

CLASS    BANDS (MEAN)                        Migration
--------------------------------------------------------
    1     14.46      19.06      27.06           1.
    2      6.10      26.62      66.25            .
    3     27.84      37.20      41.66           3.
    4     40.99      41.21      45.71           1.
    5     25.48      33.63      59.75           1.
    6     39.47      55.91      33.73            .
    7     43.01      38.17      54.03            .
    8     60.00      49.01      41.97           3.
    9     52.36      40.62      52.44           1.
   10     63.90      65.45      36.06           2.
   11     64.41      46.80      51.67           4.
   12     70.52      58.48      44.37           4.
   13     77.53      55.46      53.26           2.
   14     76.21      81.88      36.26           1.
   15     89.17      68.55      56.02           2.
```

```
Results of iteration     6

CLASS    BANDS (MEAN)                           Pixels
--------------------------------------------------------
    1     14.46      19.06      27.06        853.
    2      6.10      26.62      66.25     100448.
    3     27.84      37.20      41.66       1860.
    4     40.99      41.21      45.71       4151.
    5     25.48      33.63      59.75       3708.
    6     39.47      55.91      33.73       8666.
    7     43.01      38.17      54.03       5923.
    8     60.00      49.01      41.97      19845.
    9     52.36      40.62      52.44       6830.
   10     63.90      65.45      36.06      36545.
   11     64.41      46.80      51.67       7759.
   12     70.52      58.48      44.37      13337.
   13     77.53      55.46      53.26       8639.
   14     76.21      81.88      36.26      35418.
   15     89.17      68.55      56.02       8035.
```

Table 9 (cont'd)

Input statistics to iteration 7

CLASS	BANDS (MEAN)			Migration
1	13.72	18.52	26.90	1.
2	6.09	26.62	66.25	.
3	28.96	37.79	40.33	3.
4	41.63	41.89	45.31	1.
5	24.77	33.55	59.73	.
6	39.72	56.36	33.63	.
7	42.63	38.02	54.11	.
8	60.57	50.33	41.14	2.
9	52.45	41.04	52.03	.
10	64.11	67.03	35.67	2.
11	64.86	46.34	51.00	1.
12	71.04	60.77	43.53	3.
13	78.03	56.70	53.09	1.
14	76.79	82.65	36.19	1.
15	90.17	68.97	56.61	2.

Results of iteration 7

CLASS	BANDS (MEAN)			Pixels
1	13.72	18.52	26.90	826.
2	6.09	26.62	66.25	100355.
3	28.96	37.79	40.33	2171.
4	41.63	41.89	45.31	4039.
5	24.77	33.55	59.73	3732.
6	39.72	56.36	33.63	8428.
7	42.63	38.02	54.11	6193.
8	60.57	50.33	41.14	22150.
9	52.45	41.04	52.03	7267.
10	64.11	67.03	35.67	34546.
11	64.86	46.34	51.00	8895.
12	71.04	60.77	43.53	14416.
13	78.03	56.70	53.09	9387.
14	76.79	82.65	36.19	32439.
15	90.17	68.97	56.61	7209.

Table 9 (cont'd)

```
Input statistics to iteration     8

CLASS   BANDS (MEAN)                 Migration


-----------------------------------------------
    1     13.33      18.15      26.81          .
    2      6.08      26.62      66.25          .
    3     29.72      38.57      39.52         2.
    4     42.29      42.43      44.93         1.
    5     24.27      33.47      59.74          .
    6     39.95      56.78      33.52          .
    7     42.28      37.95      54.10          .
    8     61.02      51.41      40.54         2.
    9     52.61      41.31      51.80          .
   10     64.32      68.44      35.38         1.
   11     65.17      46.55      50.49         1.
   12     71.55      62.59      42.78         3.
   13     78.36      57.63      52.98         1.
   14     77.36      83.42      36.12         1.
   15     91.08      69.19      57.22         1.


Results of iteration     8

CLASS   BANDS (MEAN)                    Pixels
-----------------------------------------------
    1     13.33      18.15      26.81       820.
    2      6.08      26.62      66.25    100303.
    3     29.72      38.57      39.52      2432.
    4     42.29      42.43      44.93      4141.
    5     24.27      33.47      59.74      3711.
    6     39.95      56.78      33.52      8218.
    7     42.28      37.95      54.10      6369.
    8     61.02      51.41      40.54     23898.
    9     52.61      41.31      51.80      7641.
   10     64.32      68.44      35.38     32782.
   11     65.17      46.55      50.49      9847.
   12     71.55      62.59      42.78     15600.
   13     78.36      57.63      52.98      9949.
   14     77.36      83.42      36.12     29776.
   15     91.08      69.19      57.22      6587.
```

Table - 10

Features for which spectral signatures were identified

Sl.No.	Name of identified features	Class No.s of TM unsupervised classification	Class No.s of TM supervised classification	Class No.s of MSS unsupervised classification	Class No.s of MSS supervised classification
1.	Mangrove - High crown density	6,7	1	3	5
2.	Mangrove	-	2	-	-
3.	Mangrove - Low crown density	3	3	4	7
4.	Fallow land/Agri. land (current fallow)	8,9	4	4	3
5.	Accreted land	4,5	5	8	4
6.	Agri. land with winter crop	10	6	3/7	6
7.	Settlement with bushes	11,12	7	1	8
8.	Bare/Sandy soil	13-15	8	-	9
9.	Sea water	2	9	5,6,9-15	2
10.	River/Stagment water	1	10	-	1
				2 *	

* May be some crop

The comparison of MSS and TM data sets thus made shows that TM data has its marked distinction over the MSS data because of its greater number of bands and smaller size of the pixels. And that the use of multi-temporal data are essential for classification at times is proved beyond doubt by the fact that for the MSS data of the month of September separation of agricultural vegetation from mangrove became impossible both in unsupervised and supervised approach. While for TM data of another date (December) this separation was possible because during that time of the year crop fields were harvested and left bare for sometime. Thus temporal data sets are essential for spectral signature identification in an area of mixed surface features.

Supervised classifications in this particular study area or in any similar area was not very suitable for spectral signature identification. Because during the process of choosing training data sets there might have been heterogeneous pixels within the polygon. Thus a confusing statistical average would be obtained which would tell upon the results of classification. But it cannot be denied that supervised process of classification is very useful in places of homogenous features and in finding out area statistics of certain homogenous features.

It was ascertained that unsupervised classification has a distinct advantage over supervised classification because the recognition of features are done digitally and this is much accurate and precise. In the present study a supervised-unsupervised classification has been found most suitable.

Because, out of 16 classes merging of several groups of spectral values could be imposed wherever it was found essential.

The process of geometrical correction and registering technique could be applied for comparing images of different pixel sizes. Formation of new land or erosion, particularly in the coasts, could be detected from this type of studies. Increase or decrease of area of a particular feature type may also be detected by applying same colour code for corresponding classes in different images.

The present study shows, as a by product, accretion of land in certain areas (Fig. 31). The study and the study area have been of very importance these days because of the ecological aspects.

Figure 31 : Land Accretion.

A group of environmentalists and Professors of the Uppsala University of Sweden has shown keen interest in this deltaic coast and is trying to take up a study on the area. A TM quarter scene of Jan 12, 1989 of bands 2, 3 & 4 as processed and obtained through the courtesy of Professor T. Lyndell is shown in figure 32.

Figure 32 : TM image (120 m resolution) of Jan 12, 1989.

The image is histogram stretched and sub-sampled to a ground resolution of 120 meters. The full resolution (30 m) contrast stretched TM image as processed by the same Professor is shown in figure 33. Here, mangrove and coastal eco-system was given preference.

Figure 33: TM image (30m resolution) of Jan 12, 1989.

CHAPTER FIVE
FURTHER SCOPE OF STUDY

5. FURTHER SCOPE OF STUDY

This study will pave the way to compare data sets of SPOT (French Satellite), MOS1 (Japanese Satellite) and Landsat TM (i.e. data sets of different pixel sizes. Multitemporal data sets can be studied to monitor crops, mangroves, land accretion and land erosion etc. In short the ecological changes can be monitored. Correlations would also be tested between the digital values of satellite data and the reflectance of surface feature on real-time basis with the availability of multitemporal data from the SPOT/Landsat Ground Station of SPARRSO for accurately identifyinjg the spectral signatures of the surface features of Bangladesh.

Another aspect of the study is that it will expose digital processing technique of satellite data to the researchers to imbibe an urge in them to undertake research works in the field. One such researcher is a student of the Applied Physics Department of Dhaka University who is trying to modify some software for Fast Fourier Transformation (FFT) and its inverse which would improve upon the filtering of images for image enhancements. This kind of studies will add to the science of digital image processing and create a technological base in the country.

Further works and indepth study of digital image processing technique will develop expertise in the country so that appropriate software and processing-system design may be possible in future. Also possible will be construction of GIS based on remote sensing data.

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SURFACE FEATURE
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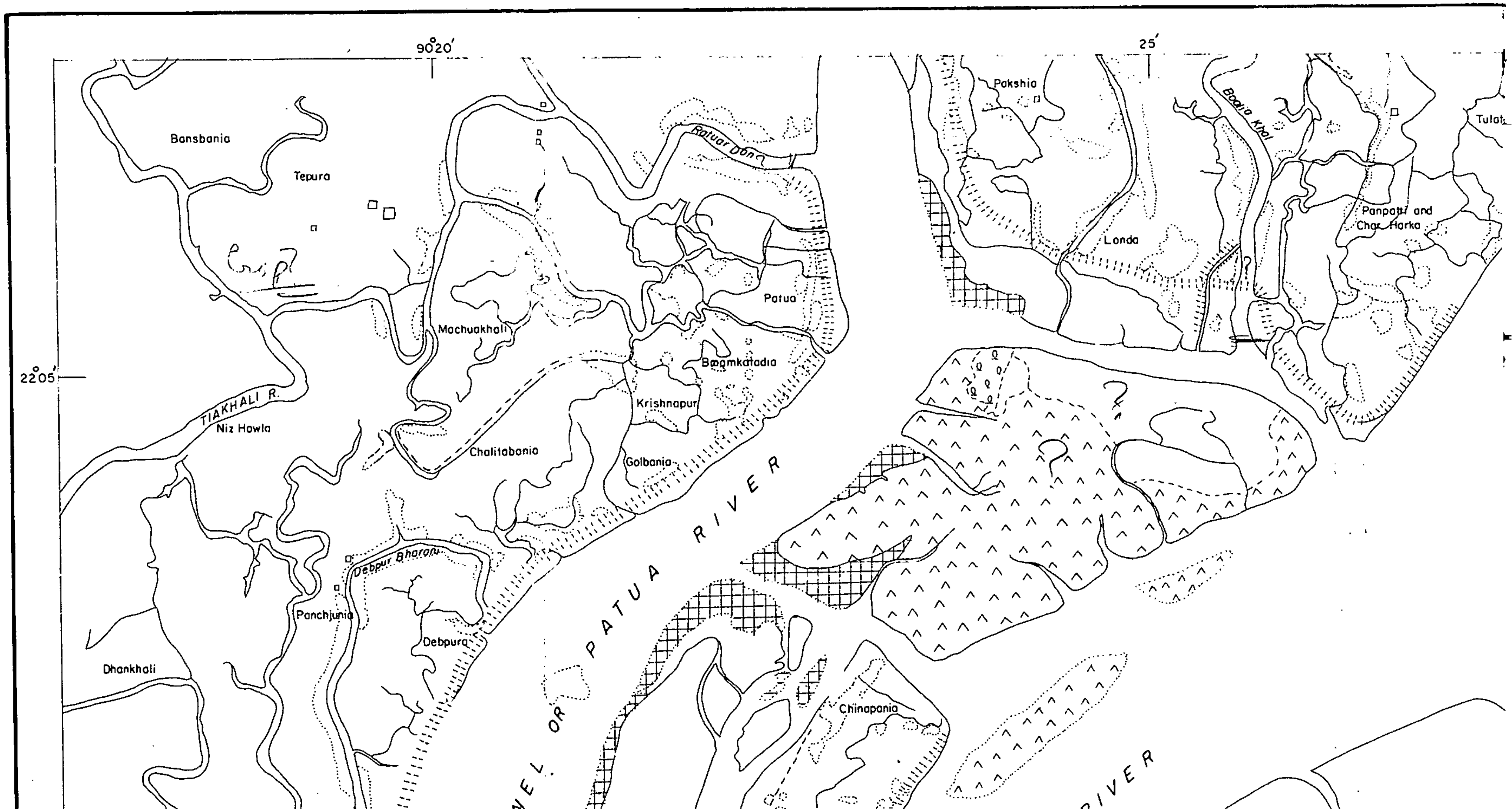

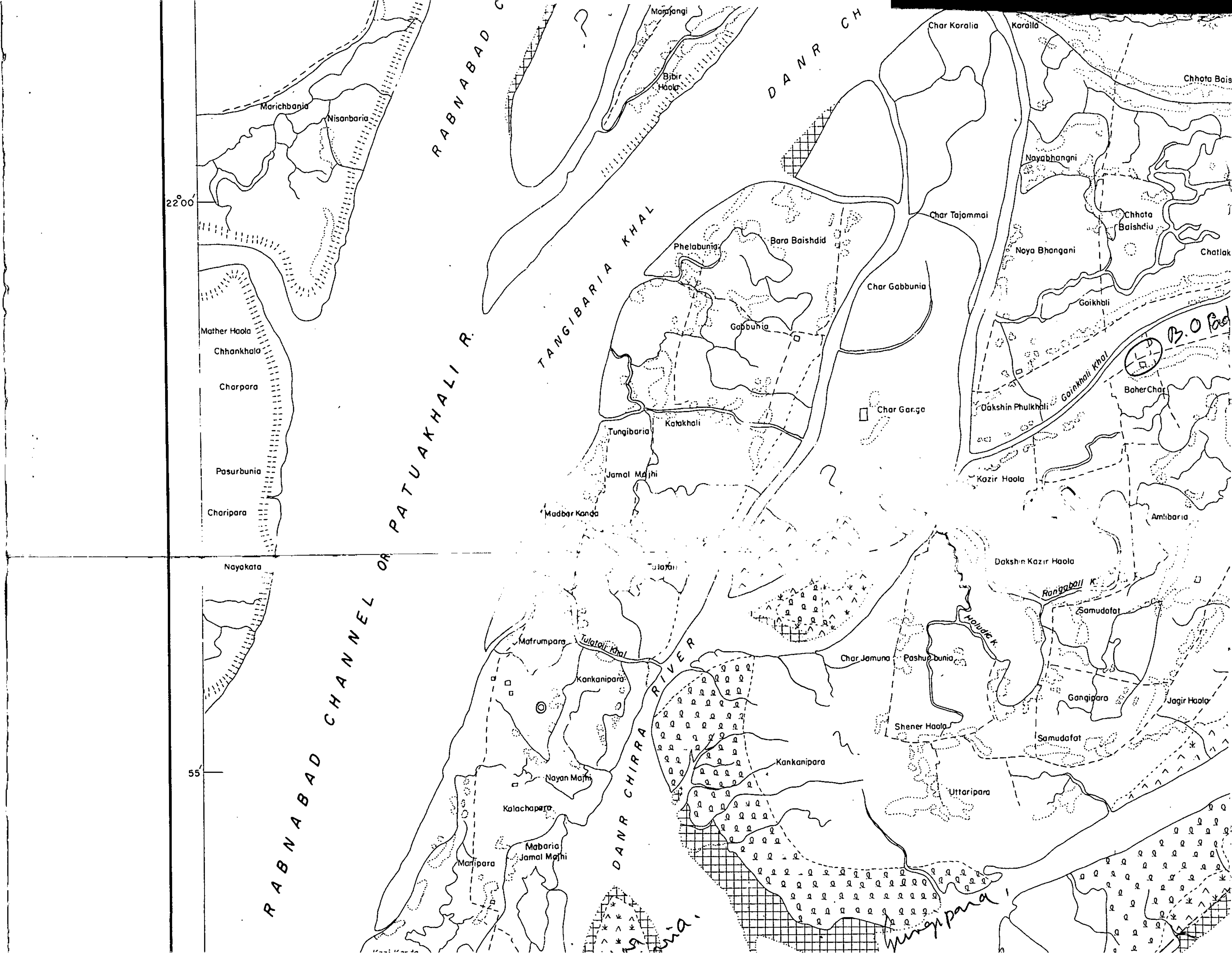
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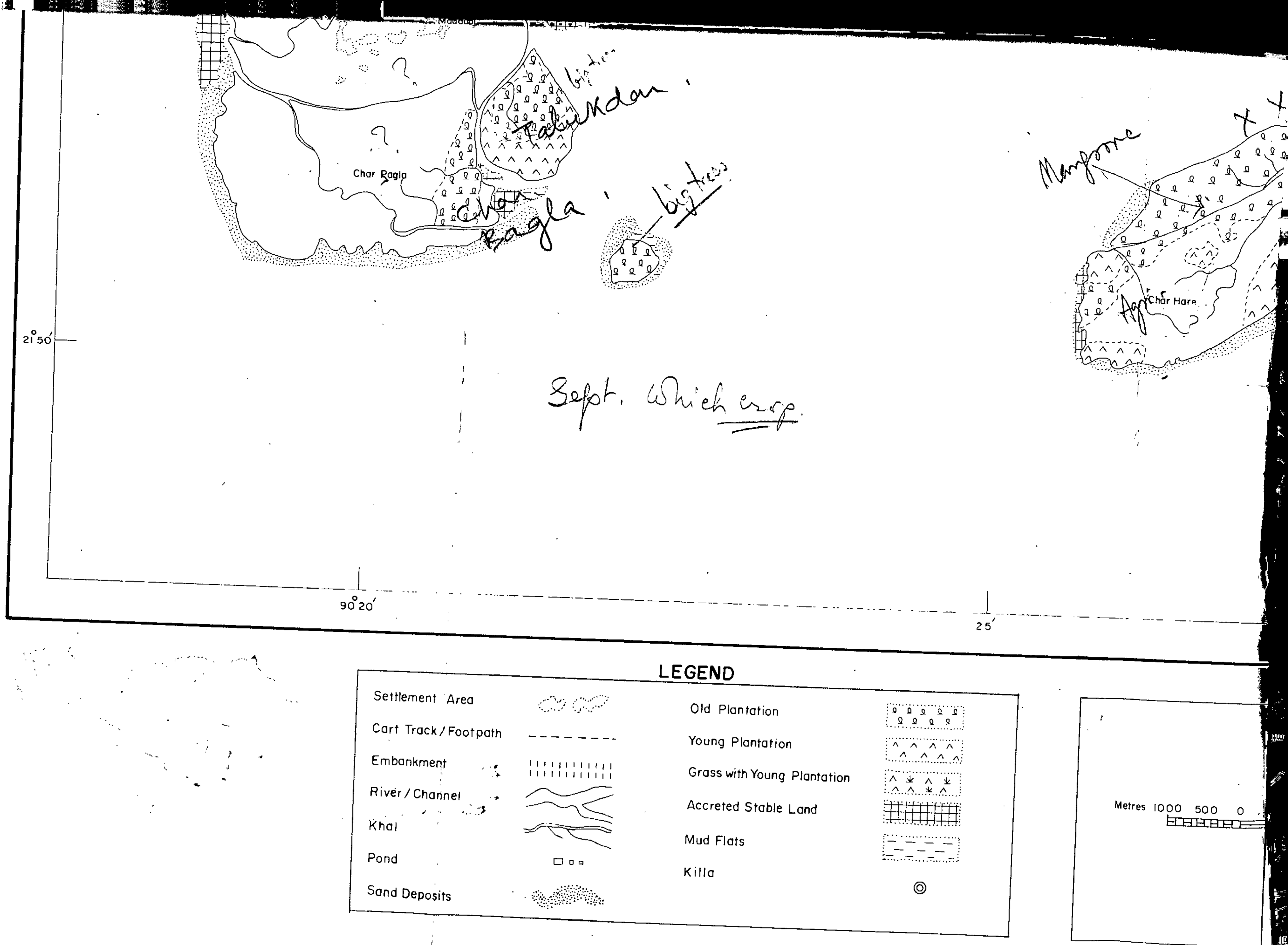

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big trees

Char Ragla

big trees

Sept. Which crop.

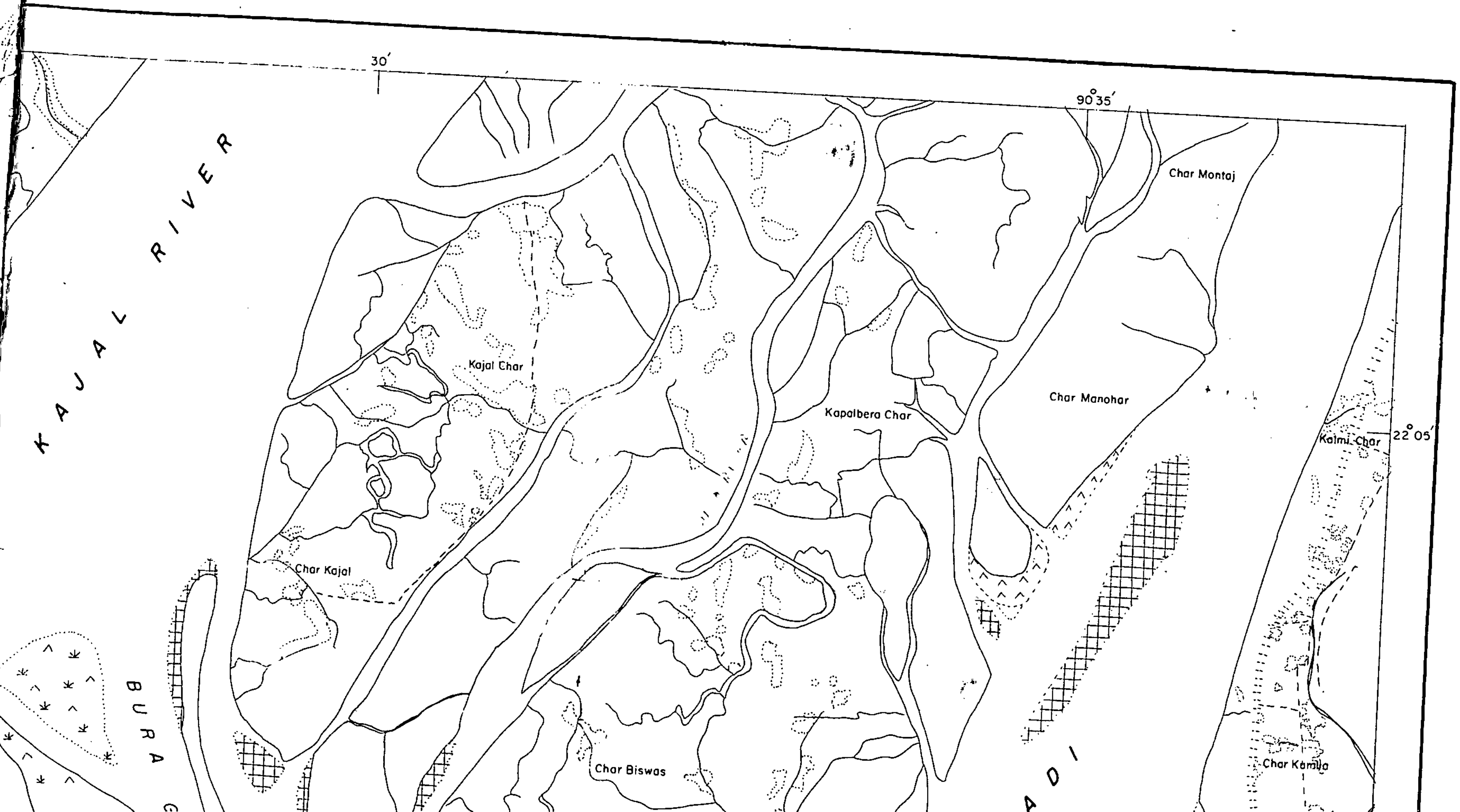
Mangrove

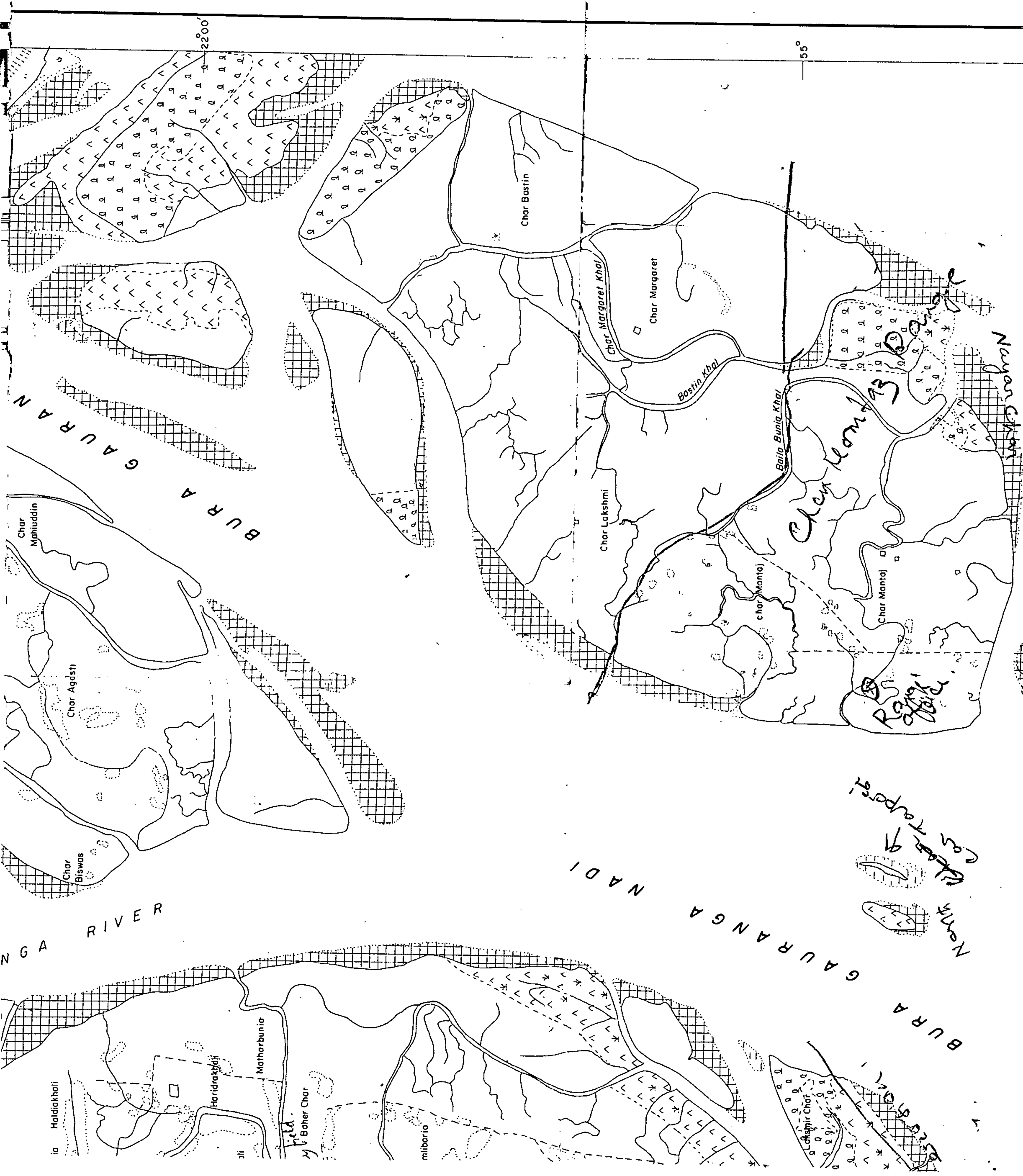
Agri

DELINEATION MAP

AREA

ROUNDING ISLAND)

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Char Margaret
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Nayar Char
Char Kamlag 3 Range
Rangabali
North
Char Tapasi
BURA GAURAN
Char Mohiuddin
Char Agasti
Char Biswas
NGA RIVER
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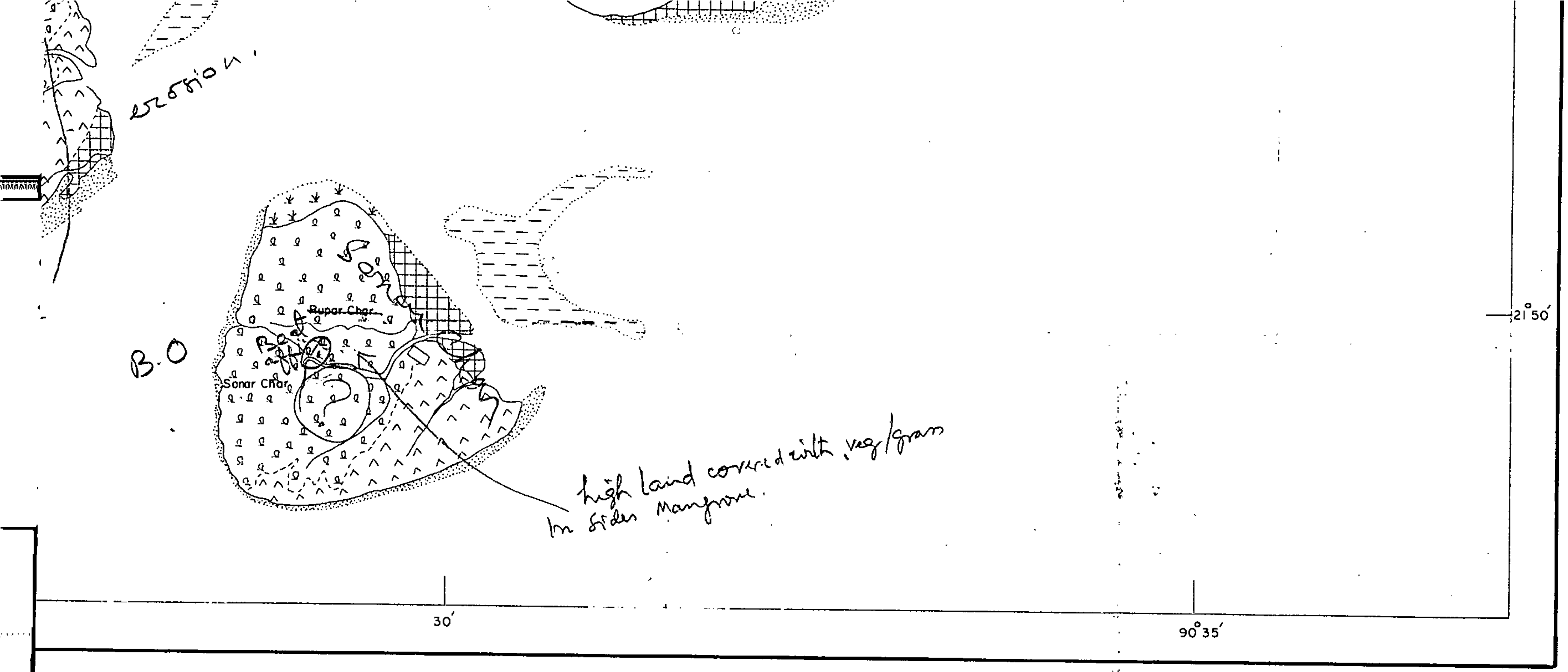
Baher Char
mlibaria



Scale 1: 50,000

1 2 3 4 5 Kms

SOURCE:

Topographic sheets of scale 1:50,000, Survey of Bangladesh

Colour IR aerial photographs, 1984, SPARRSO.

SURFACE FEATURE
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STUDY
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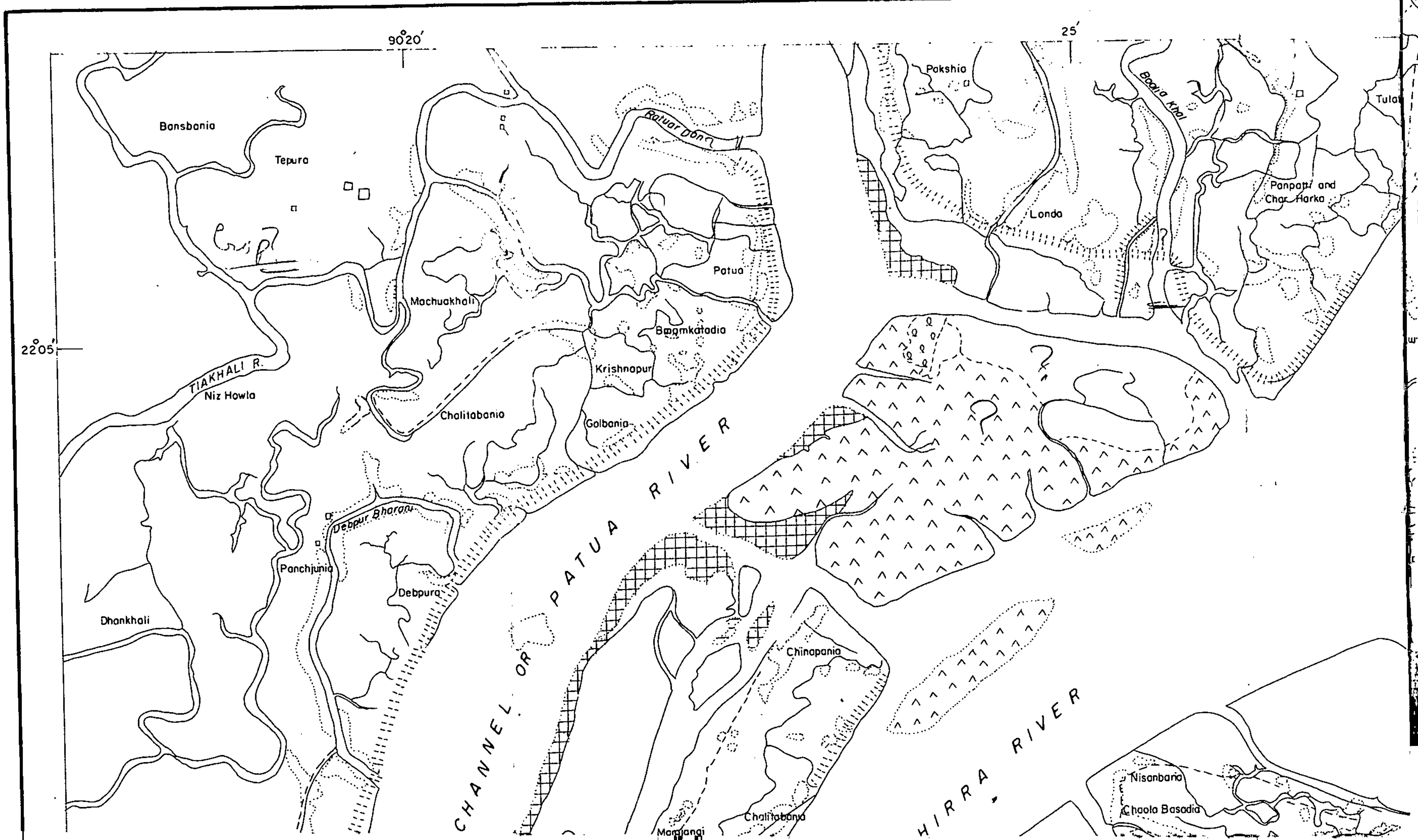
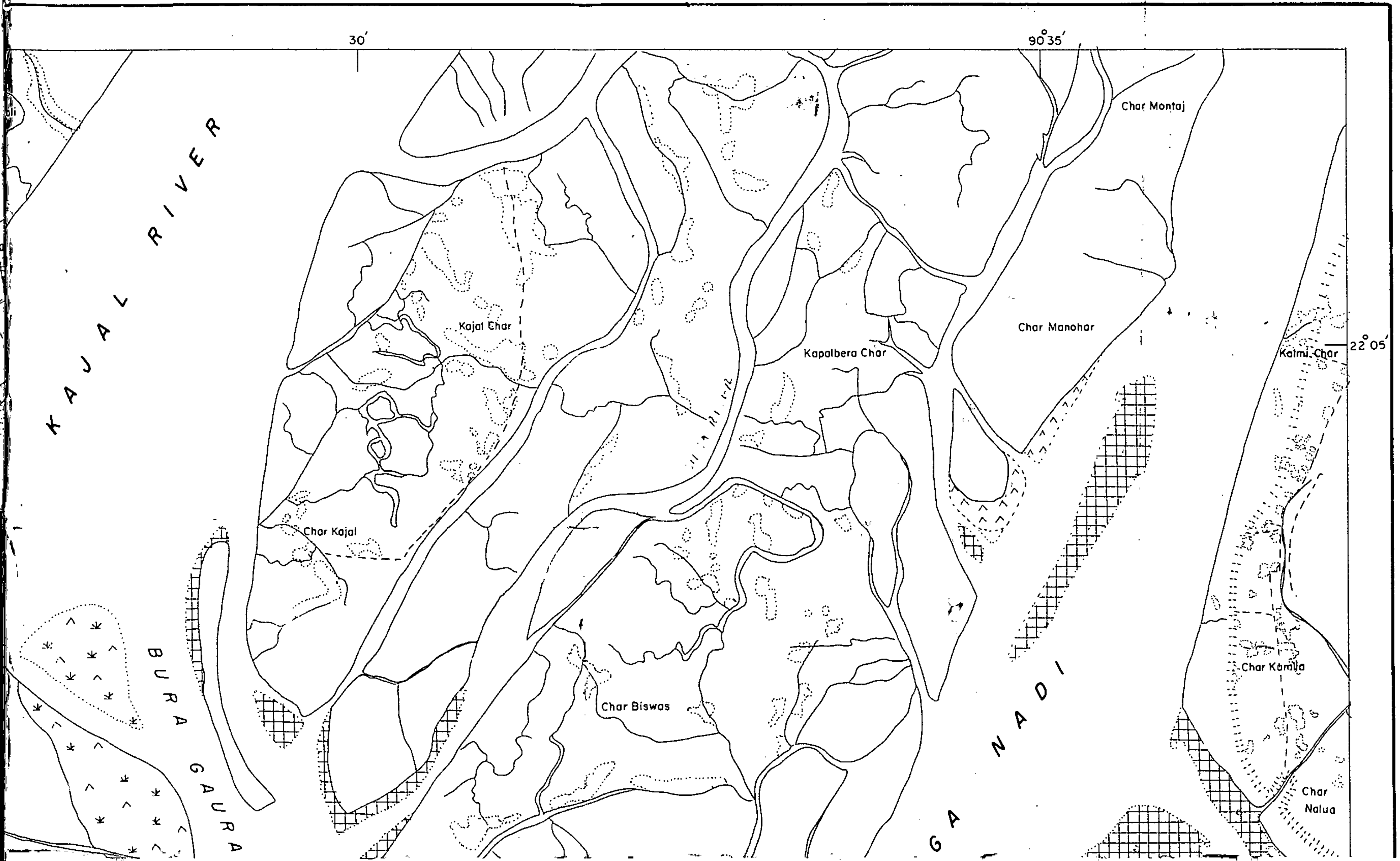
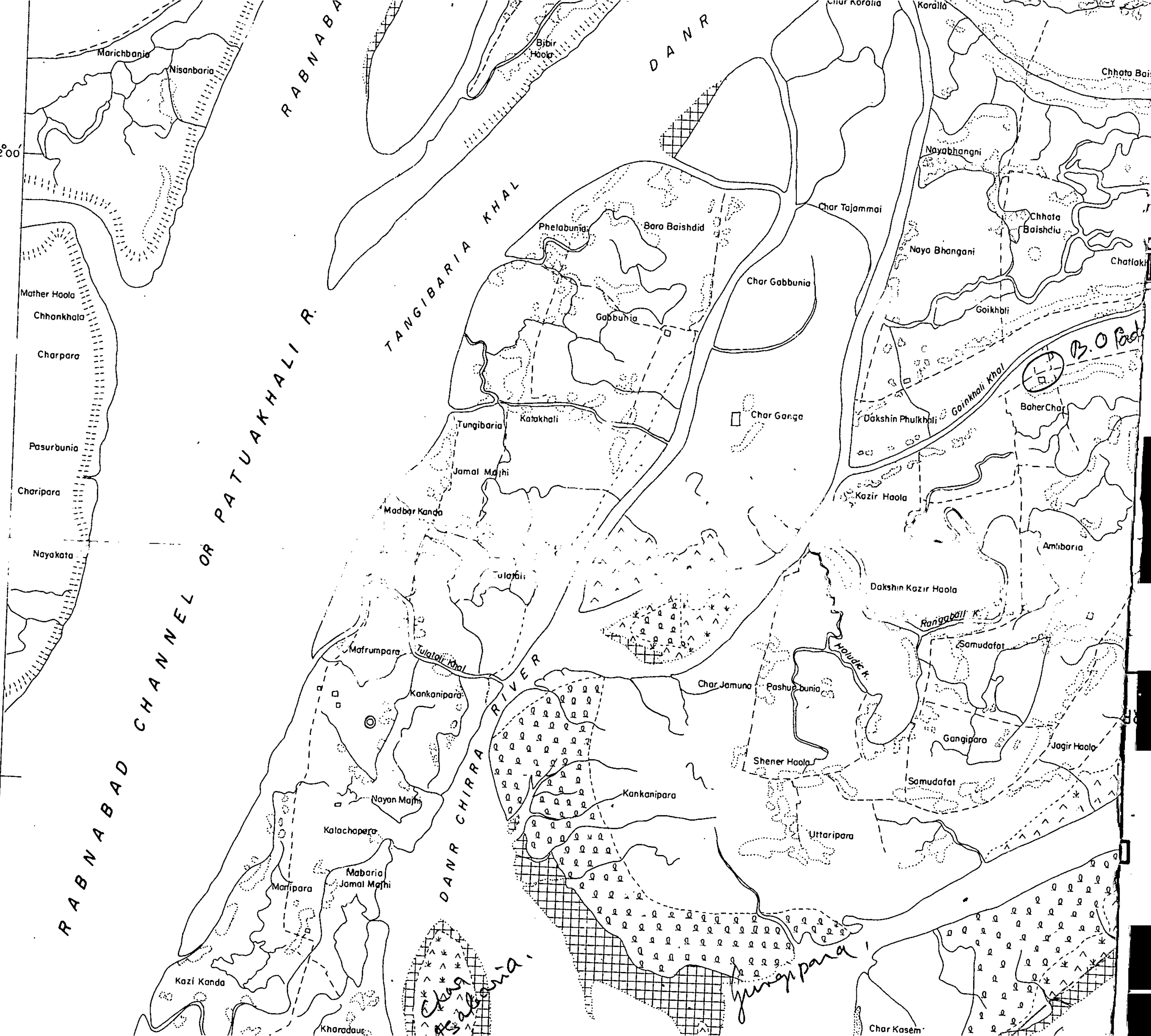


DELINEATION MAP

AREA

RROUNDING ISLAND)

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Nisanbaria
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Chhankhola
Charpara
Pasurbunia
Charipara
Nayakata
Bibir Haola
Chur Koralia
Koralia
Chhota Bais
Nayabhangni
Char Tajammai
Chhota Baishdia
Naya Bhangani
Chatlakh
Phelabunia
Baro Baishdid
Char Gabbunia
Gabbunia
Goikhali
B. O Pad
Goinkhali Khal
Baher Char
Dakshin Phulkhali
Char Ganga
Tungibaria
Katakhali
Jamal Majhi
Madbar Kanda
Kazir Haola
Amlibaria
Tulatali
Dakshin Kazir Haola
Rangabali K.
Samudafat
Mafrumpara
Tulatali Khal
Holudi K.
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Char Jamuna
Pashu bunia
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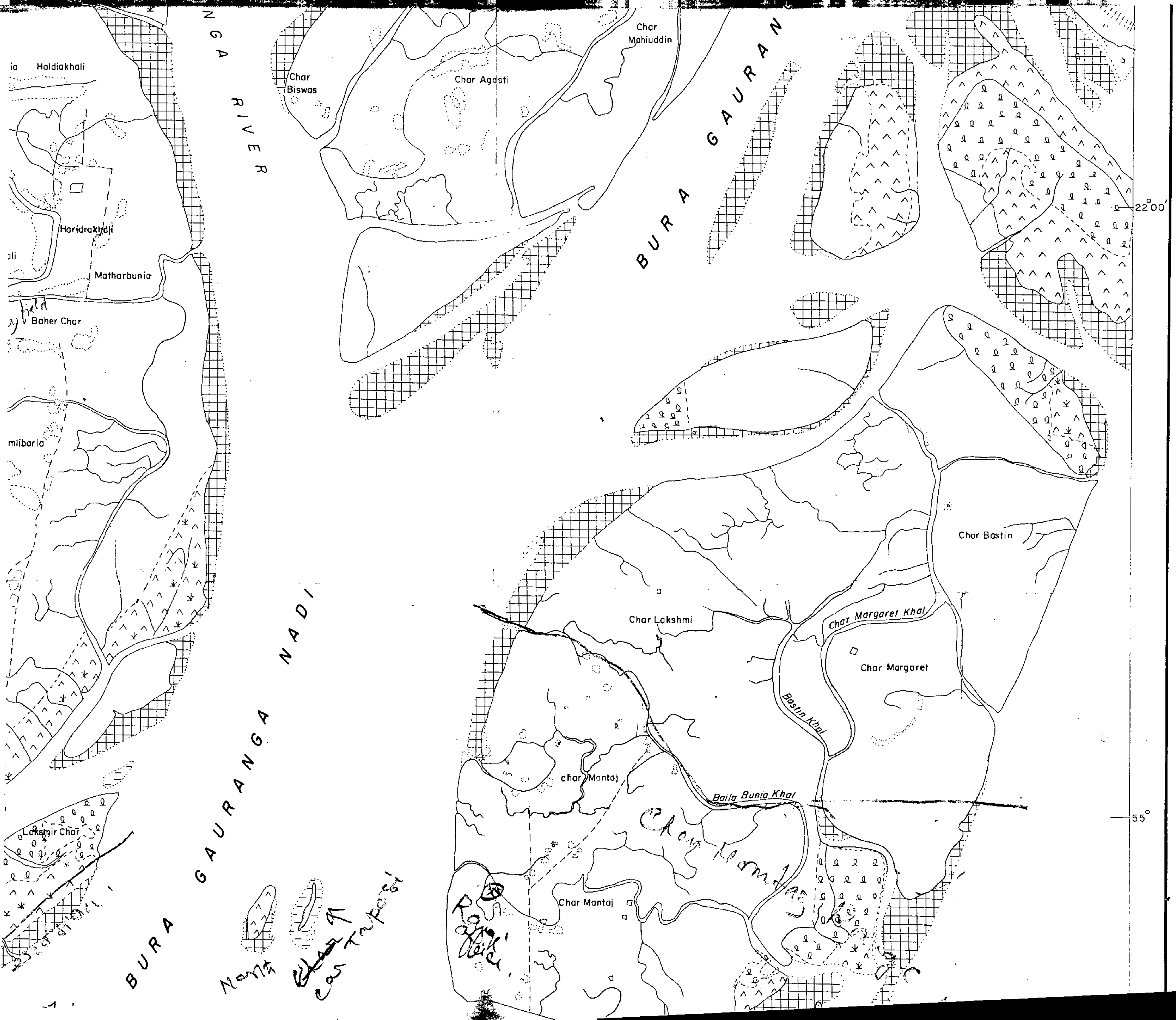
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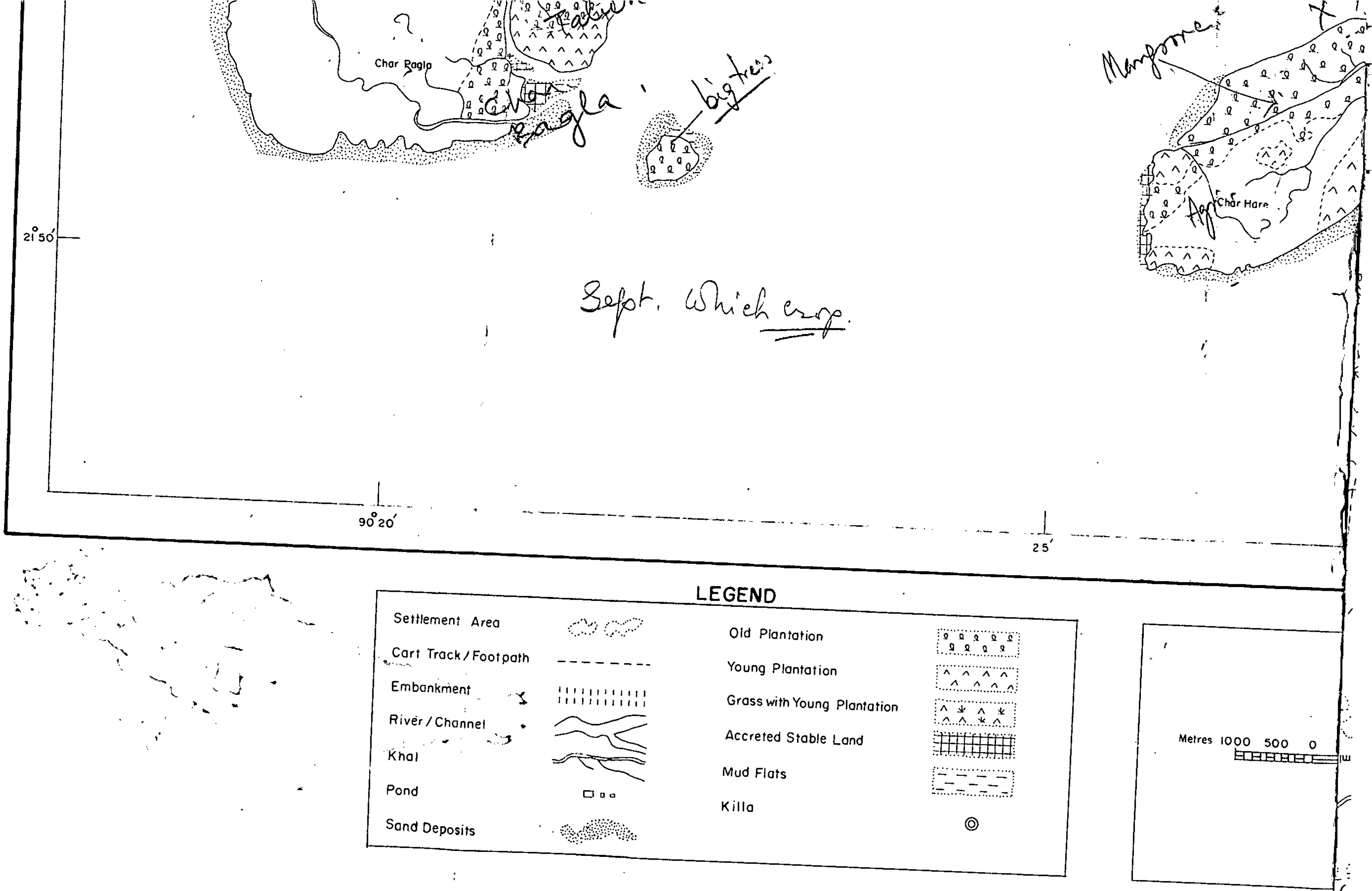

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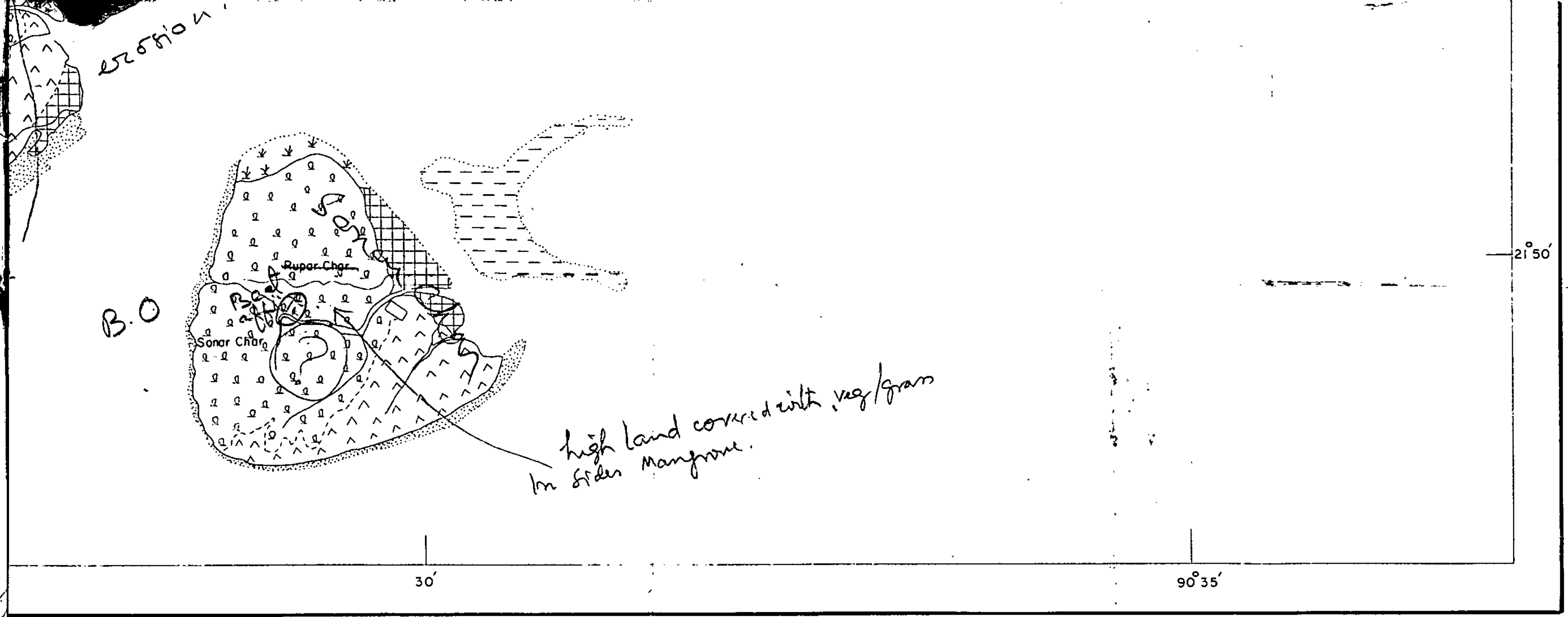
Char Ragla

big trees

Mangrove

Agri

Sept. Which crop.



Scale 1: 50,000

1 2 3 4 5 Kms

SOURCE:

Topographic sheets of scale 1:50,000, Survey of Bangladesh

Colour IR aerial photographs, 1984, SPARRSO.

Appendix-II
(Clustering results with various number of classes)
(a) Six classes.

Starting seed table

CLASS	BANDS (MEAN)		
1	41.99	57.99	71.00
2	51.00	57.99	71.00
3	41.99	81.00	71.00
4	51.00	81.00	71.00
5	41.99	86.00	71.00
6	51.00	86.00	71.00

Results of iteration 1

CLASS	BANDS (MEAN)			Pixels
1	41.99	57.99	71.00	11534.
2	51.00	57.99	71.00	70536.
3	41.99	81.00	71.00	69454.
4	51.00	81.00	71.00	5274.
5	41.99	86.00	71.00	79811.
6	51.00	86.00	71.00	4012.

Input statistics to iteration 2

CLASS	BANDS (MEAN)			Migration
1	40.76	56.50	55.84	17.
2	58.56	56.31	55.42	24.
3	40.85	79.87	71.25	2.
4	50.76	75.66	68.19	8.
5	41.14	87.01	74.74	5.
6	48.62	88.13	76.78	10.

Results of iteration 2

CLASS	BANDS (MEAN)			Pixels
1	40.76	56.50	55.84	15397.
2	58.56	56.31	55.42	72872.
3	40.85	79.87	71.25	67244.
4	50.76	75.66	68.19	11298.
5	41.14	87.01	74.74	69695.
6	48.62	88.13	76.78	14670.

Appendix-II
(a) cont'd

```
Input statistics to iteration     3

CLASS    BANDS (MEAN)                              Migration
------------------------------------------------------------
   1     42.64      55.23      54.90               4.
   2     61.89      54.47      54.20               6.
   3     40.76      80.20      71.36                .
   4     48.99      71.26      64.90               9.
   5     40.53      86.68      74.47               1.
   6     46.35      88.71      77.21               3.

Results of iteration     3

CLASS    BANDS (MEAN)                              Pixels
------------------------------------------------------------
   1     42.64      55.23      54.90      19268.
   2     61.89      54.47      54.20      64567.
   3     40.76      80.20      71.36      67189.
   4     48.99      71.26      64.90      18357.
   5     40.53      86.68      74.47      63984.
   6     46.35      88.71      77.21      20392.


Input statistics to iteration     4

CLASS    BANDS (MEAN)                              Migration
------------------------------------------------------------
   1     44.98      54.32      54.33               3.
   2     64.34      53.18      53.40               4.
   3     40.90      80.29      71.42                .
   4     49.37      68.35      62.90               5.
   5     40.37      86.27      74.29                .
   6     45.20      89.40      76.99               2.


Results of iteration     4

CLASS    BANDS (MEAN)                              Pixels
------------------------------------------------------------
   1     44.98      54.32      54.33      22679.
   2     64.34      53.18      53.40      57059.
   3     40.90      80.29      71.42      68678.
   4     49.37      68.35      62.90      22244.
   5     40.37      86.27      74.29      59764.
   6     45.20      89.40      76.99      24818.
```

Appendix-II
(a) cont'd

```
Input statistics to iteration     5

CLASS    BANDS (MEAN)                        Migration
-----------------------------------------------------
  1      46.89      53.90      54.07           2.
  2      66.38      52.11      52.75           3.
  3      41.01      80.14      71.32            .
  4      50.82      66.36      61.52           4.
  5      40.35      85.92      74.19            .
  6      44.31      89.66      76.74           1.
```

```
Results of iteration     5

CLASS    BANDS (MEAN)                          Pixels
-----------------------------------------------------
  1      46.89      53.90      54.07      26980.
  2      66.38      52.11      52.75      48677.
  3      41.01      80.14      71.32      67080.
  4      50.82      66.36      61.52      26280.
  5      40.35      85.92      74.19      60377.
  6      44.31      89.66      76.74      26971.
```

```
Input statistics to iteration     6

CLASS    BANDS (MEAN)                        Migration
-----------------------------------------------------
  1      48.72      53.62      53.86           2.
  2      68.76      50.97      52.02           4.
  3      41.14      79.89      71.18            .
  4      52.12      64.91      60.65           3.
  5      40.34      85.64      74.07            .
  6      43.87      89.70      76.67            .
```

```
Results of iteration     6

CLASS    BANDS (MEAN)                          Pixels
-----------------------------------------------------
  1      48.72      53.62      53.86      30281.
  2      68.76      50.97      52.02      42146.
  3      41.14      79.89      71.18      63327.
  4      52.12      64.91      60.65      29672.
  5      40.34      85.64      74.07      62399.
  6      43.87      89.70      76.67      29686.
```

Appendix-II
(a) cont'd

```
Input statistics to iteration     7

CLASS    BANDS (MEAN)                          Migration
---------------------------------------------------------
   1     50.09      53.30      53.66               1.
   2     71.18      49.86      51.28               4.
   3     41.21      79.54      70.94                .
   4     53.18      63.86      60.04               2.
   5     40.40      85.30      73.94                .
   6     43.48      89.63      76.56                .

Results of iteration     7

CLASS    BANDS (MEAN)                            Pixels
---------------------------------------------------------
   1     50.09      53.30      53.66       33220.
   2     71.18      49.86      51.28       36610.
   3     41.21      79.54      70.94       60667.
   4     53.18      63.86      60.04       32339.
   5     40.40      85.30      73.94       62954.
   6     43.48      89.63      76.56       32615.

Input statistics to iteration     8

CLASS    BANDS (MEAN)                          Migration
---------------------------------------------------------
   1     51.45      52.97      53.46               1.
   2     73.57      48.81      50.59               4.
   3     41.17      79.23      70.75                .
   4     53.85      63.12      59.59               1.
   5     40.60      85.00      73.81                .
   6     43.08      89.55      76.45                .

Results of iteration     8

CLASS    BANDS (MEAN)                            Pixels
---------------------------------------------------------
   1     51.45      52.97      53.46       35641.
   2     73.57      48.81      50.59       32348.
   3     41.17      79.23      70.75       59914.
   4     53.85      63.12      59.59       34242.
   5     40.60      85.00      73.81       61426.
   6     43.08      89.55      76.45       35418.
```

Appendix-II

(b) Clustering 8 classes

```
Starting seed table

CLASS   BANDS (MEAN)
----------------------------------------

  1     41.99     63.00     60.00          .
  2     41.99     63.00     74.00          .
  3     51.00     63.00     60.00          .
  4     51.00     63.00     74.00          .
  5     41.99     83.99     60.00          .
  6     41.99     83.99     74.00          .
  7     51.00     83.99     60.00          .
  8     51.00     83.99     74.00          .


Results of iteration    1

CLASS   BANDS (MEAN)                  Pixels
----------------------------------------

  1     41.99     63.00     60.00   13458.
  2     41.99     63.00     74.00     712.
  3     51.00     63.00     60.00   72645.
  4     51.00     63.00     74.00     398.
  5     41.99     83.99     60.00    9937.
  6     41.99     83.99     74.00  136702.
  7     51.00     83.99     60.00     765.
  8     51.00     83.99     74.00    6345.


Input statistics to iteration    2

CLASS   BANDS (MEAN)               Migration
----------------------------------------

  1     40.92     58.65     57.04       8.
  2     40.82     70.90     69.96      13.
  3     58.47     56.63     55.63      18.
  4     52.86     70.05     69.22      13.
  5     40.19     79.01     66.10      12.
  6     41.05     84.26     73.76       1.
  7     50.89     76.29     65.21      13.
  8     48.95     85.01     75.30       4.


Results of iteration    2

CLASS   BANDS (MEAN)                  Pixels
----------------------------------------

  1     40.92     58.65     57.04   15664.
  2     40.82     70.90     69.96    6818.
  3     58.47     56.63     55.63   72066.
  4     52.86     70.05     69.22    3928.
  5     40.19     79.01     66.10   23292.
  6     41.05     84.26     73.76  105160.
  7     50.89     76.29     65.21    5062.
  8     48.95     85.01     75.30   19753.
```

Appendix-II
(b) cont'd

```
Input statistics to iteration    3

CLASS   BANDS (MEAN)                    Migration

-------------------------------------------------
   1     42.97     56.22     55.33          6.
   2     41.24     73.55     69.41          3.
   3     62.16     54.04     53.85          8.
   4     54.23     67.42     65.40          7.
   5     40.16     79.46     67.70          2.
   6     40.57     84.69     73.95          1.
   7     49.64     71.69     63.48          7.
   8     46.12     87.14     77.17          6.


Results of iteration    3

CLASS   BANDS (MEAN)                       Pixels
-------------------------------------------------
   1     42.97     56.22     55.33     19747.
   2     41.24     73.55     69.41     11174.
   3     62.16     54.04     53.85     62003.
   4     54.23     67.42     65.40     10097.
   5     40.16     79.46     67.70     27024.
   6     40.57     84.69     73.95     87512.
   7     49.64     71.69     63.48      7855.
   8     46.12     87.14     77.17     29243.


Input statistics to iteration    4

CLASS   BANDS (MEAN)                    Migration
-------------------------------------------------
   1     45.12     54.73     54.31          4.
   2     41.49     74.99     69.61          1.
   3     65.01     52.55     52.85          5.
   4     55.79     64.34     62.08          7.
   5     40.21     80.49     68.45          1.
   6     40.50     84.49     73.71           .
   7     47.93     69.01     62.10          5.
   8     44.41     87.94     77.69          3.


Results of iteration    4

CLASS   BANDS (MEAN)                       Pixels
-------------------------------------------------
   1     45.12     54.73     54.31     20815.
   2     41.49     74.99     69.61     13876.
   3     65.01     52.55     52.85     50402.
   4     55.79     64.34     62.08     20172.
   5     40.21     80.49     68.45     26717.
   6     40.50     84.49     73.71     80362.
   7     47.93     69.01     62.10      9840.
   8     44.41     87.94     77.69     34077.
```

Appendix-II
(b) cont'd

```
Input statistics to iteration     5

CLASS   BANDS (MEAN)                 Migration
----------------------------------------------
   1     46.49     53.36     53.26         3.
   2     42.10     75.64     69.55         1.
   3     67.95     50.92     51.74         5.
   4     56.69     61.79     59.68         5.
   5     40.08     80.99     68.68          .
   6     40.62     84.26     73.55          .
   7     46.64     67.67     62.11         2.
   8     43.52     88.13     77.69         1.


Results of iteration     5

CLASS   BANDS (MEAN)                    Pixels
----------------------------------------------
   1     46.49     53.36     53.26    21035.
   2     42.10     75.64     69.55    17650.
   3     67.95     50.92     51.74    40642.
   4     56.69     61.79     59.68    29122.
   5     40.08     80.99     68.68    23027.
   6     40.62     84.26     73.55    77019.
   7     46.64     67.67     62.11    11935.
   8     43.52     88.13     77.69    37295.


Input statistics to iteration     6

CLASS   BANDS (MEAN)                 Migration
----------------------------------------------
   1     47.66     52.19     52.34         3.
   2     42.29     76.31     69.48          .
   3     71.39     49.39     50.71         5.
   4     57.34     60.05     58.33         3.
   5     39.78     81.44     68.65          .
   6     40.70     84.17     73.40          .
   7     46.35     66.79     62.01         1.
   8     43.10     88.00     77.63          .


Results of iteration     6

CLASS   BANDS (MEAN)                    Pixels
----------------------------------------------
   1     47.66     52.19     52.34    20250.
   2     42.29     76.31     69.48    20393.
   3     71.39     49.39     50.71    34261.
   4     57.34     60.05     58.33    35261.
   5     39.78     81.44     68.65    22202.
   6     40.70     84.17     73.40    73085.
   7     46.35     66.79     62.01    13830.
   8     43.10     88.00     77.63    39528.
```

Appendix-II
(b) cont'd

```
Input statistics to iteration    7

CLASS   BANDS (MEAN)                       Migration
----------------------------------------------------
  1     48.20      51.33      51.66            2.
  2     42.40      76.75      69.44             .
  3     74.42      48.23      49.97            4.
  4     58.09      58.83      57.41            2.
  5     39.57      81.82      68.73             .
  6     40.70      84.04      73.40             .
  7     46.67      66.00      61.71            1.
  8     42.95      88.02      77.49             .

Results of iteration    7

CLASS   BANDS (MEAN)                          Pixels
----------------------------------------------------
  1     48.20      51.33      51.66      18959.
  2     42.40      76.75      69.44      22538.
  3     74.42      48.23      49.97      29765.
  4     58.09      58.83      57.41      39317.
  5     39.57      81.82      68.73      21846.
  6     40.70      84.04      73.40      71069.
  7     46.67      66.00      61.71      15830.
  8     42.95      88.02      77.49      40061.

Input statistics to iteration    8

CLASS   BANDS (MEAN)                       Migration
----------------------------------------------------
  1     48.36      50.65      51.14            1.
  2     42.43      76.95      69.42             .
  3     76.82      47.40      49.46            3.
  4     58.81      57.87      56.72            2.
  5     39.44      81.99      68.82             .
  6     40.70      84.05      73.43             .
  7     47.25      65.32      61.35            1.
  8     42.90      88.04      77.46             .

Results of iteration    8

CLASS   BANDS (MEAN)                          Pixels
----------------------------------------------------
  1     48.36      50.65      51.14      17731.
  2     42.43      76.95      69.42      22988.
  3     76.82      47.40      49.46      26839.
  4     58.81      57.87      56.72      41354.
  5     39.44      81.99      68.82      22624.
  6     40.70      84.05      73.43      70079.
  7     47.25      65.32      61.35      17999.
  8     42.90      88.04      77.46      40120.
```

Appendix-II

(c) Clustering with 16 classes

```
Starting seed table

CLASS    BANDS (MEAN)
------------------------------------------------------------
    1    41.99      55.00      60.00
    2    41.99      55.00      74.00
    3    51.00      55.00      60.00
    4    51.00      55.00      74.00
    5    41.99      71.00      60.00
    6    41.99      71.00      74.00
    7    51.00      71.00      60.00
    8    51.00      71.00      74.00
    9    41.99      82.00      60.00
   10    41.99      82.00      74.00
   11    51.00      82.00      60.00
   12    51.00      82.00      74.00
   13    41.99      87.00      60.00
   14    41.99      87.00      74.00
   15    51.00      87.00      60.00
   16    51.00      87.00      74.00


Results of iteration     1

CLASS    BANDS (MEAN)                             Pixels
------------------------------------------------------------
    1    41.99      55.00      60.00       8524.
    2    41.99      55.00      74.00         14.
    3    51.00      55.00      60.00      61983.
    4    51.00      55.00      74.00         17.
    5    41.99      71.00      60.00       7627.
    6    41.99      71.00      74.00       4229.
    7    51.00      71.00      60.00      10928.
    8    51.00      71.00      74.00        737.
    9    41.99      82.00      60.00       6264.
   10    41.99      82.00      74.00      71552.
   11    51.00      82.00      60.00        243.
   12    51.00      82.00      74.00       2492.
   13    41.99      87.00      60.00        623.
   14    41.99      87.00      74.00      61567.
   15    51.00      87.00      60.00         12.
   16    51.00      87.00      74.00       3477.
```

Appendix-II
(c) cont'd

```
Input statistics to iteration     2

CLASS    BANDS (MEAN)                        Migration
-------------------------------------------------------
    1    40.46       53.98       54.25             8.
    2    37.46       60.06       71.33            12.
    3    59.36       55.03       54.74            13.
    4    58.47       60.88       69.47            17.
    5    41.40       71.24       64.15             4.
    6    41.08       74.59       70.47             8.
    7    53.68       67.13       61.38             7.
    8    51.91       72.70       69.70             6.
    9    40.02       80.14       66.23            10.
   10    40.85       81.60       72.73             2.
   11    50.06       78.95       65.84             9.



   12    49.10       81.23       73.63             3.
   13    39.90       86.63       66.40             8.
   14    41.28       87.86       75.15             2.
   15    47.83       87.08       65.16             8.
   16    48.50       88.66       76.97             7.
```

```
Results of iteration     2

CLASS    BANDS (MEAN)                       Pixels
---------------------------------------------------
    1    40.46       53.98       54.25     12094.
    2    37.46       60.06       71.33       542.
    3    59.36       55.03       54.74     58867.
    4    58.47       60.88       69.47      1639.
    5    41.40       71.24       64.15      5179.
    6    41.08       74.59       70.47     10210
    7    53.68       67.13       61.38     16156
    8    51.91       72.70       69.70      1568.
    9    40.02       80.14       66.23     12892.
   10    40.85       81.60       72.73     55312.
   11    50.06       78.95       65.84      1296.
   12    49.10       81.23       73.63      6576.
   13    39.90       86.63       66.40      4230.
   14    41.28       87.86       75.15     49984.
   15    47.83       87.08       65.16       214.
   16    48.50       88.66       76.97     11908.
```

Appendix-II
(c) cont'd

```
Input statistics to iteration     3

CLASS    BANDS (MEAN)                       Migration
-----------------------------------------------------
    1     42.89      52.23      52.85          5.
    2     38.31      61.92      63.93         10.
    3     62.66      53.45      53.55          6.
    4     59.07      60.70      63.16          7.
    5     42.02      70.70      64.01          1.
    6     41.03      76.12      69.97          2.
    7     53.25      64.65      60.00          4.
    8     52.46      72.60      67.45          2.
    9     39.89      79.89      67.61          1.
   10     40.50      82.15      73.07          1.
   11     48.13      78.05      67.06          4.
   12     46.72      81.72      74.61          3.
   13     39.44      86.00      68.78          3.
   14     40.80      87.54      75.08           .
   15     46.28      86.57      67.58          4.
   16     45.93      89.70      78.32          4.


Results of iteration     3

CLASS    BANDS (MEAN)                         Pixels
-----------------------------------------------------
    1     42.89      52.23      52.85      13449.
    2     38.31      61.92      63.93       3158.
    3     62.66      53.45      53.55      48062.
    4     59.07      60.70      63.16      12184.
    5     42.02      70.70      64.01       5013.



    6     41.03      76.12      69.97      13016.
    7     53.25      64.65      60.00      14612.
    8     52.46      72.60      67.45       2720.
    9     39.89      79.89      67.61      13608.
   10     40.50      82.15      73.07      45269.
   11     48.13      78.05      67.06       2120.
   12     46.72      81.72      74.61      11733.
   13     39.44      86.00      68.78       9522.
   14     40.80      87.54      75.08      40281.
   15     46.28      86.57      67.58       1124.
   16     45.93      89.70      78.32      16066.
```

Appendix-II
(c) cont'd

```
Input statistics to iteration    4

CLASS    BANDS (MEAN)                      Migration
------------------------------------------------------
   1     44.98      51.04      51.93            4.
   2     40.49      61.35      60.47            6.
   3     65.63      51.68      52.28            6.
   4     58.65      59.66      59.28            5.
   5     42.89      70.72      64.03             .
   6     40.84      76.60      70.19             .
   7     52.87      63.74      58.86            2.
   8     53.14      71.61      65.98            3.
   9     39.86      80.22      68.00             .
  10     40.25      82.27      73.20             .
  11     47.03      77.87      67.56            1.
  12     45.33      82.20      75.33            2.
  13     39.23      85.85      70.25            1.
  14     40.80      87.36      74.93             .
  15     45.77      86.45      69.69            2.
  16     44.43      90.15      78.32            1.


Results of iteration    4

CLASS    BANDS (MEAN)                         Pixels
------------------------------------------------------
   1     44.98      51.04      51.93      13846.
   2     40.49      61.35      60.47       5018.
   3     65.63      51.68      52.28      38994.
   4     58.65      59.66      59.28      23445.
   5     42.89      70.72      64.03       5324.
   6     40.84      76.60      70.19      14405.
   7     52.87      63.74      58.86      11493.
   8     53.14      71.61      65.98       3490.
   9     39.86      80.22      68.00      14108.
  10     40.25      82.27      73.20      36975.
  11     47.03      77.87      67.56       2984.
  12     45.33      82.20      75.33      15906.
  13     39.23      85.85      70.25      14802.
  14     40.80      87.36      74.93      33225.
  15     45.77      86.45      69.69       3093.
  16     44.43      90.15      78.32      17279.
```

Appendix-II
(c) cont'd

```
 Input statistics to iteration    5

 CLASS   BANDS (MEAN)                  Migration




 ------------------------------------------------
    1     46.33     50.22     51.37          2.
    2     41.89     60.50     59.21          3.
    3     68.97     49.92     51.19          6.
    4     58.31     58.47     57.30          3.
    5     42.88     70.64     64.16           .
    6     40.73     76.85     70.31           .
    7     53.02     63.90     59.24           .
    8     53.91     70.57     64.83          2.
    9     39.94     80.50     68.23           .
   10     40.03     82.18     73.17           .
   11     46.57     77.70     67.98          1.
   12     44.39     82.65     75.68          1.
   13     39.24     85.74     71.03           .
   14     40.84     87.39     75.17           .
   15     45.54     86.41     71.05          1.
   16     43.87     90.30     78.14           .

 Results of iteration    5

 CLASS   BANDS (MEAN)                   Pixels
 ------------------------------------------------
    1     46.33     50.22     51.37     14203.
    2     41.89     60.50     59.21      5942.
    3     68.97     49.92     51.19     33076.
    4     58.31     58.47     57.30     29078.
    5     42.88     70.64     64.16      5470.
    6     40.73     76.85     70.31     14292.
    7     53.02     63.90     59.24     12028.
    8     53.91     70.57     64.83      3749.
    9     39.94     80.50     68.23     14047.
   10     40.03     82.18     73.17     35820.
   11     46.57     77.70     67.98      3761.
   12     44.39     82.65     75.68     18207.
   13     39.24     85.74     71.03     16809.
   14     40.84     87.39     75.17     28068.
   15     45.54     86.41     71.05      4868.
   16     43.87     90.30     78.14     17013.
```

Appendix-II
(c) cont'd

```
Input statistics to iteration    6

CLASS   BANDS (MEAN)                 Migration
-------------------------------------------------
   1    47.47     49.64     50.95          2.
   2    42.61     59.64     58.47          2.
   3    72.33     48.51     50.30          5.
   4    58.63     57.43     56.42          2.
   5    42.57     70.63     64.36           .
   6    40.62     76.91     70.35           .
   7    53.69     63.83     59.53          1.
   8    54.22     69.91     64.18          1.
   9    39.96     80.62     68.24           .
  10    40.13     82.02     73.01           .
  11    46.46     77.44     68.11           .
  12    43.78     83.16     75.94          1.
  13    39.11     85.77     71.45           .
  14    40.81     87.63     75.42           .
  15    45.38     86.40     71.83           .




  16    43.69     90.44     78.06           .
```

```
Results of iteration    6

CLASS   BANDS (MEAN)                   Pixels
-------------------------------------------------
   1    47.47     49.64     50.95     14117.
   2    42.61     59.64     58.47      7087.
   3    72.33     48.51     50.30     28865.
   4    58.63     57.43     56.42     32122.
   5    42.57     70.63     64.36      5609.
   6    40.62     76.91     70.35     14190.
   7    53.69     63.83     59.53     13205.
   8    54.22     69.91     64.18      3933.
   9    39.96     80.62     68.24     15394.
  10    40.13     82.02     73.01     31732.
  11    46.46     77.44     68.11      4087.
  12    43.78     83.16     75.94     19321.
  13    39.11     85.77     71.45     20148.
  14    40.81     87.63     75.42     26295.
  15    45.38     86.40     71.83      6256.
  16    43.69     90.44     78.06     15566.
```

Appendix-II
(c) cont'd

```
Input statistics to iteration     7

CLASS    BANDS (MEAN)                          Migration
-------------------------------------------------------
   1      48. 43      49. 10      50. 55          1.
   2      43. 47      58. 91      57. 91          2.
   3      75. 30      47. 36      49. 56          4.
   4      59. 33      56. 59      55. 81          2.
   5      42. 38      70. 46      64. 38           .
   6      40. 58      76. 96      70. 37           .
   7      54. 27      63. 52      59. 53           .
   8      54. 22      69. 60      63. 82           .
   9      40. 04      80. 86      68. 35           .
  10      40. 39      81. 73      73. 10           .
  11      46. 55      77. 24      68. 16           .
  12      43. 15      83. 45      76. 26          1.
  13      39. 06      85. 55      71. 71           .
  14      40. 82      87. 92      75. 49           .
  15      45. 26      86. 28      72. 29           .
  16      43. 83      90. 60      78. 11           .


Results of iteration     7

CLASS    BANDS (MEAN)                          Pixels
-------------------------------------------------------
   1      48. 43      49. 10      50. 55      14004.
   2      43. 47      58. 91      57. 91       8360.
   3      75. 30      47. 36      49. 56      25733.
   4      59. 33      56. 59      55. 81      32981.
   5      42. 38      70. 46      64. 38       5673.
   6      40. 58      76. 96      70. 37      13945.
   7      54. 27      63. 52      59. 53      14803.
   8      54. 22      69. 60      63. 82       4184.
   9      40. 04      80. 86      68. 35      15308.



  10      40. 39      81. 73      73. 10      30814.
  11      46. 55      77. 24      68. 16       4342.
  12      43. 15      83. 45      76. 26      18673.
  13      39. 06      85. 55      71. 71      22790.
  14      40. 82      87. 92      75. 49      25856.
  15      45. 26      86. 28      72. 29       6949.
  16      43. 83      90. 60      78. 11      14442.

Premature quit because of minimum migration limit
```

Appendix-II

(d) Clustering with 16 classes and migration limit 0.5.

```
Starting seed table

CLASS   BANDS (MEAN)
--------------------------------------------------
   1     41.99      55.00      60.00
   2     41.99      55.00      74.00
   3     51.00      55.00      60.00
   4     51.00      55.00      74.00
   5     41.99      71.00      60.00
   6     41.99      71.00      74.00
   7     51.00      71.00      60.00
   8     51.00      71.00      74.00
   9     41.99      82.00      60.00
  10     41.99      82.00      74.00
  11     51.00      82.00      60.00
  12     51.00      82.00      74.00
  13     41.99      87.00      60.00
  14     41.99      87.00      74.00
  15     51.00      87.00      60.00
  16     51.00      87.00      74.00
```

```
Results of iteration     1

CLASS   BANDS (MEAN)                        Pixels
--------------------------------------------------
   1     41.99      55.00      60.00       8524.
   2     41.99      55.00      74.00         14.
   3     51.00      55.00      60.00      61983.
   4     51.00      55.00      74.00         17.
   5     41.99      71.00      60.00       7627.
   6     41.99      71.00      74.00       4229.
   7     51.00      71.00      60.00      10928.
   8     51.00      71.00      74.00        737.
   9     41.99      82.00      60.00       6264.
  10     41.99      82.00      74.00      71552.
  11     51.00      82.00      60.00        243.
  12     51.00      82.00      74.00       2492.
  13     41.99      87.00      60.00        623.
  14     41.99      87.00      74.00      61567.
  15     51.00      87.00      60.00         12.
  16     51.00      87.00      74.00       3477.
```

Appendix-II
(d) cont'd)

Input statistics to iteration 2

CLASS	BANDS (MEAN)			Migration
1	40.46	53.98	54.25	8.
2	37.46	60.06	71.33	12.
3	59.36	55.03	54.74	13.
4	58.47	60.88	69.47	17.
5	41.40	71.24	64.15	4.
6	41.08	74.59	70.47	8.
7	53.68	67.13	61.38	7.
8	51.91	72.70	69.70	6.
9	40.02	80.14	66.23	10.
10	40.85	81.60	72.73	2.
11	50.06	78.95	65.84	9.
12	49.10	81.23	73.63	3.
13	39.90	86.63	66.40	8.
14	41.28	87.86	75.15	2.
15	47.83	87.08	65.16	8.
16	48.50	88.66	76.97	7.

Results of iteration 2

CLASS	BANDS (MEAN)			Pixels
1	40.46	53.98	54.25	12094.
2	37.46	60.06	71.33	542.
3	59.36	55.03	54.74	58867.
4	58.47	60.88	69.47	1639.
5	41.40	71.24	64.15	5179.
6	41.08	74.59	70.47	10210.
7	53.68	67.13	61.38	16156.
8	51.91	72.70	69.70	1568.
9	40.02	80.14	66.23	12892.
10	40.85	81.60	72.73	55312.
11	50.06	78.95	65.84	1296.
12	49.10	81.23	73.63	6576.
13	39.90	86.63	66.40	4230.
14	41.28	87.86	75.15	49984.
15	47.83	87.08	65.16	214.
16	48.50	88.66	76.97	11908.

Appendix-II
(d) cont'd)

```
Input statistics to iteration     3

CLASS   BANDS (MEAN)                      Migration
---------------------------------------------------
   1     42.89     52.23     52.85            5.
   2     38.31     61.92     63.93           10.
   3     62.66     53.45     53.55            6.
   4     59.07     60.70     63.16            7.
   5     42.02     70.70     64.01            1.
   6     41.03     76.12     69.97            2.
   7     53.25     64.65     60.00            4.
   8     52.46     72.60     67.45            2.
   9     39.89     79.89     67.61            1.
  10     40.50     82.15     73.07            1.
  11     48.13     78.05     67.06            4.
  12     46.72     81.72     74.61            3.
  13     39.44     86.00     68.78            3.
  14     40.80     87.54     75.08
  15     46.28     86.57     67.58            4.
  16     45.93     89.70     78.32            4.


Results of iteration     3

CLASS   BANDS (MEAN)                       Pixels
---------------------------------------------------
   1     42.89     52.23     52.85      13449.
   2     38.31     61.92     63.93       3158.
   3     62.66     53.45     53.55      48062.
   4     59.07     60.70     63.16      12184.
   5     42.02     70.70     64.01       5013.




   6     41.03     76.12     69.97      13016.
   7     53.25     64.65     60.00      14612.
   8     52.46     72.60     67.45       2720.
   9     39.89     79.89     67.61      13608.
  10     40.50     82.15     73.07      45269.
  11     48.13     78.05     67.06       2120.
  12     46.72     81.72     74.61      11733.
  13     39.44     86.00     68.78       9522.
  14     40.80     87.54     75.08      40281.
  15     46.28     86.57     67.58       1124.
  16     45.93     89.70     78.32      16066.
```

Appendix-II
(d) cont'd)

```
Input statistics to iteration     4

CLASS    BANDS (MEAN)                          Migration
-------------------------------------------------------
    1      44. 98      51. 04      51. 93          4.
    2      40. 49      61. 35      60. 47          6.
    3      65. 63      51. 68      52. 28          6.
    4      58. 65      59. 66      59. 28          5
    5      42. 89      70. 72      64. 03           .
    6      40. 84      76. 60      70. 19           .
    7      52. 87      63. 74      58. 86          2.
    8      53. 14      71  61      65. 98          3.
    9      39. 86      80. 22      68. 00           .
   10      40. 25      82. 27      73. 20           .
   11      47. 03      77. 87      67. 56          1.
   12      45. 33      82. 20      75. 33          2.
   13      39. 23      85. 85      70  25          1.
   14      40. 80      87. 36      74. 93           .
   15      45. 77      86. 45      69. 69          2.
   16      44. 43      90. 15      78. 32          1.


Results of iteration     4

CLASS    BANDS (MEAN)                             Pixels
-------------------------------------------------------
    1      44. 98      51. 04      51. 93      13846.
    2      40. 49      61. 35      60. 47       5018.
    3      65. 63      51. 68      52. 28      38994.
    4      58. 65      59. 66      59. 28      23445.
    5      42. 89      70. 72      64. 03       5324.
    6      40. 84      76. 60      70. 19      14405.
    7      52. 87      63. 74      58. 86      11493.
    8      53. 14      71. 61      65. 98       3490.
    9      39. 86      80. 22      68. 00      14108.
   10      40. 25      82. 27      73. 20      36975.
   11      47. 03      77. 87      67. 56       2984.
   12      45. 33      82. 20      75. 33      15906.
   13      39. 23      85. 85      70. 25      14802.
   14      40. 80      87. 36      74. 93      33225.
   15      45. 77      86. 45      69. 69       3093.
   16      44. 43      90. 15      78. 32      17279.
```

Appendix-II
(d) cont'd)

```
Input statistics to iteration     5

CLASS   BANDS (MEAN)                       Migration




-----------------------------------------------------------
   1      46.33       50.22       51.37             2.
   2      41.89       60.50       59.21             3.
   3      68.97       49.92       51.19             6.
   4      58.31       58 47       57.30             3.
   5      42.88       70.64       64.16              .
   6      40.73       76.85       70.31              .
   7      53.02       63.90       59.24              .
   8      53.91       70.57       64.83             2.
   9      39.94       80.50       68.23              .
  10      40.03       82.18       73.17              .
  11      46.57       77.70       67.98             1.
  12      44.39       82.65       75.68             1.
  13      39.24       85.74       71.03              .
  14      40.84       87.39       75.17              .
  15      45.54       86.41       71.05             1.
  16      43.87       90.30       78.14              .


Results of iteration     5

CLASS   BANDS (MEAN)                          Pixels
-----------------------------------------------------------
   1      46.33       50.22       51.37      14203.
   2      41.89       60.50       59.21       5942.
   3      68.97       49.92       51.19      33076.
   4      58.31       58.47       57.30      29078.
   5      42.88       70.64       64.16       5470.
   6      40.73       76.85       70.31      14292.
   7      53.02       63.90       59.24      12028.
   8      53 91       70.57       64.83       3749.
   9      39.94       80.50       68.23      14047.
  10      40.03       82.18       73.17      35820.
  11      46.57       77.70       67.98       3761.
  12      44.39       82.65       75.68      18207.
  13      39.24       85.74       71.03      16809.
  14      40.84       87.39       75.17      28068.
  15      45.54       86.41       71.05       4868.
  16      43.87       90.30       78.14      17013.
```

Appendix-II
(d) cont'd)

Input statistics to iteration 6

CLASS	BANDS (MEAN)			Migration
1	47.47	49.64	50.95	2.
2	42.61	59.64	58.47	2.
3	72.33	48.51	50.30	5.
4	58.63	57.43	56.42	2.
5	42.57	70.63	64.36	.
6	40.62	76.91	70.35	.
7	53.69	63.83	59.53	1.
8	54.22	69.91	64.18	1.
9	39.96	80.62	68.24	.
10	40.13	82.02	73.01	.
11	46.46	77.44	68.11	.
12	43.78	83.16	75.94	1.
13	39.11	85.77	71.45	.
14	40.81	87.63	75.42	.
15	45.38	86.40	71.83	.
16	43.69	90.44	78.06	

Results of iteration 6

CLASS	BANDS (MEAN)			Pixels
1	47.47	49.64	50.95	14117.
2	42.61	59.64	58.47	7087.
3	72.33	48.51	50.30	28865.
4	58.63	57.43	56.42	32122.
5	42.57	70.63	64.36	5609.
6	40.62	76.91	70.35	14190.
7	53.69	63.83	59.53	13205.
8	54.22	69.91	64.18	5933.
9	39.96	80.62	68.24	15394.
10	40.13	82.02	73.01	31732.
11	46.46	77.44	68.11	4087.
12	43.78	83.16	75.94	19321
13	39.11	85.77	71.45	20148.
14	40.81	87.63	75.42	26295
15	45.38	86.40	71.83	6256.
16	43.69	90.44	78.06	15566.

Appendix-II
(d) cont'd)

```
Input statistics to iteration     7

CLASS    BANDS (MEAN)                    Migration
--------------------------------------------------
   1     48.43      49.10      50.55          1
   2     43.47      58.91      57.91          2.
   3     75.30      47.36      49.56          4.
   4     59.33      56.59      55.81          2.
   5     42.38      70.46      64.38           .
   6     40.58      76.96      70.37           .
   7     54.27      63.52      59.53           .
   8     54.22      69.60      63.82           .
   9     40.04      80.86      68.35           .
  10     40.39      81.73      73.10           .
  11     46.55      77.24      68.16           .
  12     43.15      83.45      76.26          1.
  13     39.06      85.55      71.71           .
  14     40.82      87.92      75.49           .
  15     45.26      86.28      72.29           .
  16     43.83      90.60      78.11           .


Results of iteration     7

CLASS    BANDS (MEAN)                       Pixels
--------------------------------------------------
   1     48.43      49.10      50.55     14004.
   2     43.47      58.91      57.91      8360.
   3     75.30      47.36      49.56     25733.
   4     59.33      56.59      55.81     32981.
   5     42.38      70.46      64.38      5673.
   6     40.58      76.96      70.37     13945.
   7     54.27      63.52      59.53     14803.
   8     54.22      69.60      63.82      4184.
   9     40.04      80.86      68.35     15308.




  10     40.39      81.73      73.10     30814.
  11     46.55      77.24      68.16      4342.
  12     43.15      83.45      76.26     18673.
  13     39.06      85.55      71.71     22790.
  14     40.82      87.92      75.49     25856.
  15     45.26      86.28      72.29      6949.
  16     43.83      90.60      78.11     14442.
```

Appendix-II
(d) cont'd)

```
Input statistics to iteration     8

CLASS    BANDS (MEAN)                              Migration
-------------------------------------------------------------
   1      49.28      48.63       50.21                 1.
   2      44.25      58.37       57.45                 1.
   3      77.68      46.47       49.03                 3.
   4      60.19      55.89       55.32                 2.
   5      42.28      70.24       64.33                  .
   6      40.48      76.99       70.34                  .
   7      54.80      63.08       59.35                 1.
   8      54.06      69.38       63.60                  .
   9      40.06      80.92       68.33                  .
  10      40.78      81.48       73.08                  .
  11      46.45      76.92       68.05                  .
  12      42.75      83.70       76.50                  .
  13      39.08      85.39       71.98                  .
  14      40.82      88.18       75.46                  .
  15      45.17      86.12       72.61                  .
  16      44.03      90.64       78.28                  .
```

```
Results of iteration     8

CLASS    BANDS (MEAN)                              Pixels
-------------------------------------------------------------
   1      49.28      48.63       50.21          13583.
   2      44.25      58.37       57.45           9602.
   3      77.68      46.47       49.03          23305.
   4      60.19      55.89       55.32          33083.
   5      42.28      70.24       64.33           5698.
   6      40.48      76.99       70.34          13335.
   7      54.80      63.08       59.35          16174.
   8      54.06      69.38       63.60           4574.
   9      40.06      80.92       68.33          14735.
  10      40.78      81.48       73.08          31754.
  11      46.45      76.92       68.05           4441.
  12      42.75      83.70       76.50          18127.
  13      39.08      85.39       71.98          23636.
  14      40.82      88.18       75.46          25018.
  15      45.17      86.12       72.61           8960.
  16      44.03      90.64       78.28          13337.
```

Appendix-II

(e) Clustering with 32 classes.

```
Results of iteration    1

CLASS   BANDS (MEAN)                         Pixels
---------------------------------------------------
   1    41.00      57.99      56.99       6431.
   2    41.00      57.99      71.00        421.
   3    41.00      57.99      74.99          7.
   4    45.00      57.99      56.99      14739.
   5    45.00      57.99      71.00        769.
   6    45.00      57.99      74.99          6.
   7    56.99      57.99      56.99      56060.
   8    56.99      57.99      71.00        691.
   9    56.99      57.99      74.99          7.
  10    41.00      81.00      56.99       1290.
  11    41.00      81.00      71.00      43129.
  12    41.00      81.00      74.99      14453.
  13    45.00      81.00      56.99       1360.
  14    45.00      81.00      71.00       8609.
  15    45.00      81.00      74.99       4412.
  16    56.99      81.00      56.99        519.
  17    56.99      81.00      71.00        830.
  18    56.99      81.00      74.99         70.
  19    41.00      86.00      56.99         48.
  20    41.00      86.00      71.00      23945.
  21    41.00      86.00      74.99      39513.
  22    45.00      86.00      56.99         14.
  23    45.00      86.00      71.00       3469.
  24    45.00      86.00      74.99      16502.
  25    56.99      86.00      56.99          1.
  26    56.99      86.00      71.00         37.
  27    56.99      86.00      74.99        175.
```

```
Starting seed table

CLASS   BANDS (MEAN)
----------------------------------------------
   1    41.00      57.99      56.99
   2    41.00      57.99      71.00
   3    41.00      57.99      74.99
   4    45.00      57.99      56.99
   5    45.00      57.99      71.00
   6    45.00      57.99      74.99
   7    56.99      57.99      56.99
   8    56.99      57.99      71.00
   9    56.99      57.99      74.99
  10    41.00      81.00      56.99
  11    41.00      81.00      71.00
  12    41.00      81.00      74.99
  13    45.00      81.00      56.99
  14    45.00      81.00      71.00
  15    45.00      81.00      74.99
  16    56.99      81.00      56.99
  17    56.99      81.00      71.00
  18    56.99      81.00      74.99
  19    41.00      86.00      56.99
  20    41.00      86.00      71.00
  21    41.00      86.00      74.99
  22    45.00      86.00      56.99
  23    45.00      86.00      71.00
  24    45.00      86.00      74.99
  25    56.99      86.00      56.99
  26    56.99      86.00      71.00
  27    56.99      86.00      74.99
```

Appendix-II
(e) cont'd

Results of iteration 2

CLASS	BANDS (MEAN)			Pixels
1	38.41	55.80	55.40	6730.
2	39.31	66.63	66.69	1844.
3	38.71	66.14	75.00	115.
4	48.35	58.46	56.69	16557.
5	48.01	66.89	66.07	3244.
6	46.33	67.83	76.66	50.
7	60.09	55.91	55.19	50124.
8	57.13	65.57	65.90	2981.
9	62.14	64.71	75.28	24.
10	39.94	74.59	62.70	3893.
11	39.94	79.65	70.15	30691.
12	40.63	81.40	75.04	25794.
13	47.53	72.08	62.24	3499.
14	45.75	78.16	69.84	7393.
15	45.59	81.32	75.57	7530.
16	56.33	71.32	61.88	3562.
17	57.08	74.52	67.93	559.
18	60.98	80.54	75.34	124.
19	40.58	86.00	61.97	653.
20	39.65	86.02	71.57	24404.
21	40.41	87.28	76.03	28420.
22	46.40	86.93	61.46	53.
23	45.34	86.38	71.75	8223.
24	45.64	88.13	77.29	16672.
25	55.99	83.99	64.00	25.
26	63.13	86.28	71.39	111.
27	61.93	89.72	78.45	165.

Input statistics to iteration 2

CLASS	BANDS (MEAN)			Migration
1	38.41	55.80	55.40	6.
2	39.31	66.63	66.69	14.
3	38.71	66.14	75.00	10.
4	48.35	58.46	56.69	4.
5	48.01	66.89	66.07	16.
6	46.33	67.83	76.66	12.
7	60.09	55.91	55.19	6.
8	57.13	65.57	65.90	12.
9	62.14	64.71	75.28	12.
10	39.94	74.59	62.70	13.
11	39.94	79.65	70.15	3.
12	40.63	81.40	75.04	.
13	47.53	72.08	62.24	16.
14	45.75	78.16	69.84	4.
15	45.59	81.32	75.57	1.
16	56.33	71.32	61.88	15.
17	57.08	74.52	67.93	9.
18	60.98	80.54	75.34	4.
19	40.58	86.00	61.97	5.
20	39.65	86.02	71.57	1.
21	40.41	87.28	76.03	2.
22	46.40	86.93	61.46	6.
23	45.34	86.38	71.75	1.
24	45.64	88.13	77.29	5.
25	55.99	83.99	64.00	10.
26	63.13	86.28	71.39	6.
27	61.93	89.72	78.45	12.

Appendix-II
(e) cont'd

```
Results of iteration     3

CLASS     BANDS (MEAN)                           Pixels
-------------------------------------------------------
   1      39.18       51.68       52.40          7875.
   2      39.05       67.45       65.10          2523.
   3      36.20       69.50       73.26           364.
   4      50.10       58.11       56.53         19198.
   5      48.43       66.66       64.62          3421.
   6      46.35       71.11       75.54           281.
   7      62.35       53.82       53.71         42291.
   8      58.08       63.16       63.23          5327.
   9      68.95       67.50       70.95           284.
  10      39.79       74.77       64.66          5339.
  11      39.78       79.87       69.94         24551.
  12      40.49       81.98       74.34         25461.
  13      47.66       69.85       61.87          3971.
  14      44.92       78.21       69.67          8202.
  15      45.33       81.93       75.27         10409.
  16      56.54       66.44       60.15          7273.
  17      56.07       74.32       67.83           875.
  18      61.53       80.49       74.30           147.
  19      39.66       83.88       64.94          4153.
  20      39.17       85.84       71.86         22050.
  21      40.28       87.79       76.15         26346.
  22      46.07       84.64       63.20           231.
  23      44.77       86.13       72.41         11229.
  24      45.01       88.84       78.22         15356.
  25      54.52       81.28       65.47           114.
  26      68.17       82.57       71.00           119.
  27      65.97       92.36       80.64           190.
```

```
Input statistics to iteration     3

CLASS     BANDS (MEAN)                          Migration
---------------------------------------------------------
   1      39.18       51.68       52.40              7.
   2      39.05       67.45       65.10              2.
   3      36.20       69.50       73.26              7.
   4      50.10       58.11       56.53              2.
   5      48.43       66.66       64.62              2.
   6      46.35       71.11       75.54              4.
   7      62.35       53.82       53.71              5.
   8      58.08       63.16       63.23              6.
   9      68.95       67.50       70.95             13.
  10      39.79       74.77       64.66              2.
  11      39.78       79.87       69.94               .
  12      40.49       81.98       74.34              1.
  13      47.66       69.85       61.87              2.
  14      44.92       78.21       69.67              1.
  15      45.33       81.93       75.27              1.
  16      56.54       66.44       60.15              6.
  17      56.07       74.32       67.83              1.
  18      61.53       80.49       74.30              1.
  19      39.66       83.88       64.94              5.
  20      39.17       85.84       71.86               .
  21      40.28       87.79       76.15               .
  22      46.07       84.64       63.20              4.
  23      44.77       86.13       72.41              1.
  24      45.01       88.84       78.22              2.
  25      54.52       81.28       65.47              5.
  26      68.17       82.57       71.00              9.
  27      65.97       92.36       80.64              8.
```

Appendix-II
(e) cont'd

Results of iteration 4

CLASS	BANDS (MEAN)			Pixels
1	41.02	49.47	50.60	8151.
2	38.67	66.03	63.32	2899.
3	36.55	72.51	72.16	1348.
4	51.50	57.59	56.28	20431.
5	48.87	66.25	64.32	3945.
6	44.70	73.51	74.34	1261.
7	64.66	52.06	52.46	36362.
8	59.23	60.72	61.40	8178.
9	72.76	66.83	64.55	1126.
10	39.96	75.46	65.78	7051.
11	39.77	80.07	70.35	20722.
12	40.41	81.97	74.11	23879.
13	47.41	68.66	61.11	4386.
14	44.50	78.12	69.76	7592.
15	44.97	82.33	75.57	12059.
16	56.69	64.05	58.89	8602.
17	54.88	73.00	67.17	1275.
18	59.78	81.62	74.02	212.
19	39.31	82.62	66.53	6730.
20	38.84	85.82	72.03	21488.
21	40.24	87.78	76.20	22634.
22	45.07	83.15	63.98	563.
23	44.21	86.45	72.68	14093.
24	44.78	89.23	78.57	14889.
25	52.64	79.53	66.37	371.
26	71.03	81.03	71.02	130.
27	68.67	95.04	82.56	185.

Input statistics to iteration 4

CLASS	BANDS (MEAN)			Migration
1	41.02	49.47	50.60	5.
2	38.67	66.03	63.32	3.
3	36.55	72.51	72.16	4.
4	51.50	57.59	56.28	2.
5	48.87	66.25	64.32	1.
6	44.70	73.51	74.34	5.
7	64.66	52.06	52.46	5.
8	59.23	60.72	61.40	5.
9	72.76	66.83	64.55	10.
10	39.96	75.46	65.78	1.
11	39.77	80.07	70.35	.
12	40.41	81.97	74.11	.
13	47.41	68.66	61.11	2.
14	44.50	78.12	69.76	.
15	44.97	82.33	75.57	1.
16	56.69	64.05	58.89	3.
17	54.88	73.00	67.17	3.
18	59.78	81.62	74.02	3.
19	39.31	82.62	66.53	3.
20	38.84	85.82	72.03	.
21	40.24	87.78	76.20	.
22	45.07	83.15	63.98	3.
23	44.21	86.45	72.68	1.
24	44.78	89.23	78.57	.
25	52.64	79.53	66.37	4.
26	71.03	81.03	71.02	4.
27	68.67	95.04	82.56	7.

Appendix-II
(e) cont'd

```
Results of iteration     5
CLASS   BANDS (MEAN)                       Pixels
--------------------------------------------------
   1     42.22     48.65     49.84     7954.
   2     38.36     63.64     61.42     3358.
   3     37.87     74.65     71.56     2746.
   4     52.42     56.57     55.60    20829.
   5     49.47     66.17     64.06     4368.
   6     44.10     75.89     73.60     2940.
   7     66.95     50.73     51.47    30948.
   8     60.13     59.14     59.93    11169.
   9     74.90     62.71     60.61     2319.
  10     40.28     75.38     66.30     7366.
  11     39.83     80.39     70.70    19605.
  12     40.35     81.89     74.04    22527.
  13     47.41     67.33     60.35     4980.
  14     44.44     78.44     69.93     7209.
  15     44.64     82.89     75.80    11442.
  16     56.59     62.96     58.19     9062.
  17     54.73     71.58     66.38     1589.
  18     59.34     82.17     74.00      242.
  19     39.26     82.27     67.14     7651.
  20     38.72     85.95     72.22    19929.
  21     40.06     87.87     76.41    19648.
  22     44.46     82.03     64.74     1122.
  23     43.76     86.59     72.92    17540.
  24     44.64     89.45     78.69    14658.
  25     50.66     77.68     66.62     1025.
  26     71.63     80.17     71.39      165.
  27     70.64     97.34     84.36      190.
```

```
Input statistics to iteration     5
CLASS   BANDS (MEAN)                    Migration
--------------------------------------------------
   1     42.22     48.65     49.84          2.
   2     38.36     63.64     61.42          4.
   3     37.87     74.65     71.56          4.
   4     52.42     56.57     55.60          2.
   5     49.47     66.17     64.06           .
   6     44.10     75.89     73.60          3.
   7     66.95     50.73     51.47          4.
   8     60.13     59.14     59.93          3.
   9     74.90     62.71     60.61         10.
  10     40.28     75.38     66.30           .
  11     39.83     80.39     70.70           .
  12     40.35     81.89     74.04           .
  13     47.41     67.33     60.35          2.
  14     44.44     78.44     69.93           .
  15     44.64     82.89     75.80          1.
  16     56.59     62.96     58.19          1.
  17     54.73     71.58     66.38          2.
  18     59.34     82.17     74.00          1.
  19     39.26     82.27     67.14          1.
  20     38.72     85.95     72.22           .
  21     40.06     87.87     76.41           .
  22     44.46     82.03     64.74          2.
  23     43.76     86.59     72.92           .
  24     44.64     89.45     78.69           .
  25     50.66     77.68     66.62          4.
  26     71.63     80.17     71.39          1.
  27     70.64     97.34     84.36          6.
```

Appendix-II
(e) cont'd

```
Results of iteration    6

CLASS   BANDS (MEAN)                        Pixels
---------------------------------------------------
   1    42.79     48.14     49.41     7499.
   2    38.58     61.46     59.98     3776.
   3    38.46     75.64     71.25     4067.
   4    53.40     55.57     54.80    20822.
   5    49.84     66.02     63.79     4249.
   6    43.83     77.17     73.36     5080.
   7    68.94     49.54     50.59    25614.
   8    60.79     58.01     58.62    13401.
   9    76.76     58.55     57.86     4151.
  10    40.38     75.03     66.29     7118.
  11    39.87     80.86     70.86    16519.
  12    40.25     82.06     74.05    21485.
  13    47.65     65.89     59.76     5720.
  14    44.16     78.83     70.15     7580.
  15    44.56     83.05     76.19    10877.
  16    56.11     62.62     58.14    10292.
  17    55.63     70.32     65.61     1776.
  18    59.26     82.34     73.91      284.
  19    39.10     82.12     67.32     8678.
  20    38.59     86.13     72.31    20273.
  21    39.86     87.86     76.66    18602.
  22    44.02     81.34     65.51     1896.
  23    43.46     86.73     73.18    17938.
  24    44.63     89.50     78.71    14131.
  25    49.18     75.75     66.66     2068.
  26    72.03     78.68     70.87      200.
  27    71.32     98.79     85.54      188.
```

```
Input statistics to iteration    6

CLASS   BANDS (MEAN)                      Migration
---------------------------------------------------
   1    42.79     48.14     49.41         1.
   2    38.58     61.46     59.98         3.
   3    38.46     75.64     71.25         1.
   4    53.40     55.57     54.80         2.
   5    49.84     66.02     63.79          .
   6    43.83     77.17     73.36         1.
   7    68.94     49.54     50.59         4.
   8    60.79     58.01     58.62         3.
   9    76.76     58.55     57.86         8.
  10    40.38     75.03     66.29          .
  11    39.87     80.86     70.86          .
  12    40.25     82.06     74.05          .
  13    47.65     65.89     59.76         2.
  14    44.16     78.83     70.15          .
  15    44.56     83.05     76.19          .
  16    56.11     62.62     58.14          .
  17    55.63     70.32     65.61         2.
  18    59.26     82.34     73.91          .
  19    39.10     82.12     67.32          .
  20    38.59     86.13     72.31          .
  21    39.86     87.86     76.66          .
  22    44.02     81.34     65.51         1.
  23    43.46     86.73     73.18          .
  24    44.63     89.50     78.71          .
  25    49.18     75.75     66.66         3.
  26    72.03     78.68     70.87         2.
  27    71.32     98.79     85.54         3.
```

Appendix-II
(e) cont'd

Results of iteration 7

CLASS	BANDS (MEAN)			Pixels
1	43.02	47.67	49.03	6903.
2	38.93	59.71	58.93	4105.
3	38.68	76.31	71.01	5106.
4	54.37	54.67	53.98	19972.
5	49.88	65.97	63.61	4143.
6	43.72	78.27	73.21	7385.
7	70.66	48.36	49.71	20462.
8	61.52	57.22	57.49	15664.
9	78.86	54.97	55.66	6484.
10	40.22	74.54	66.14	6787.
11	39.83	81.22	71.01	16450.
12	40.17	82.18	74.09	20708.
13	47.86	64.50	59.32	6468.
14	43.89	79.43	70.33	7039.
15	44.50	83.19	76.44	10706.
16	55.72	62.11	58.52	11832.
17	57.00	69.08	64.80	2111.
18	59.39	82.38	73.81	314.
19	38.97	81.94	67.58	8864.
20	38.55	86.31	72.41	18790.
21	39.84	87.75	76.93	18287.
22	43.50	80.88	66.06	2898.
23	43.38	86.88	73.26	17813.
24	44.77	89.57	78.65	13321.
25	48.18	74.30	66.58	2822.
26	72.55	76.83	69.63	247.
27	72.34	99.98	86.58	185.

Input statistics to iteration 7

CLASS	BANDS (MEAN)			Migration
1	43.02	47.67	49.03	1.
2	38.93	59.71	58.93	3.
3	38.68	76.31	71.01	1.
4	54.37	54.67	53.98	2.
5	49.88	65.97	63.61	
6	43.72	78.27	73.21	1.
7	70.66	48.36	49.71	3.
8	61.52	57.22	57.49	2.
9	78.86	54.97	55.66	7.
10	40.22	74.54	66.14	
11	39.83	81.22	71.01	
12	40.17	82.18	74.09	
13	47.86	64.50	59.32	2.
14	43.89	79.43	70.33	1.
15	44.50	83.19	76.44	
16	55.72	62.11	58.52	1.
17	57.00	69.08	64.80	3.
18	59.39	82.38	73.81	
19	38.97	81.94	67.58	
20	38.55	86.31	72.41	
21	39.84	87.75	76.93	
22	43.50	80.88	66.06	1.
23	43.38	86.88	73.26	
24	44.77	89.57	78.65	
25	48.18	74.30	66.58	2.
26	72.55	76.83	69.63	3.
27	72.34	99.98	86.58	3.

Appendix-II
(e) cont'd

Results of iteration 8

CLASS	BANDS (MEAN)			Pixels
1	43.00	47.26	48.72	6317.
2	39.16	58.44	58.01	4332.
3	38.96	76.60	70.74	6124.
4	55.08	53.90	53.28	19257.
5	49.50	66.24	63.40	4519.
6	43.72	79.09	73.26	11916.
7	71.74	47.30	48.88	16131.
8	62.33	56.52	56.59	16697.
9	81.64	51.64	53.36	9303.
10	39.95	74.24	65.98	6258.
11	39.77	81.66	71.16	16040.
12	39.97	82.31	74.08	20820.
13	48.07	63.32	58.89	7051.
14	43.90	79.71	70.44	6058.
15	44.45	83.40	76.66	10119.
16	55.69	61.37	58.60	13352.
17	57.98	67.84	64.09	2536.
18	59.67	82.42	73.73	355.
19	38.92	81.89	67.69	9220.
20	38.52	86.63	72.52	16698.
21	39.83	87.65	77.07	17884.
22	43.14	80.47	66.54	3362.
23	43.40	87.02	73.34	16557.
24	44.85	89.77	78.64	13044.
25	47.86	73.43	66.40	3164.
26	73.28	74.32	67.95	333.
27	72.97	100.48	86.96	183.

Input statistics to iteration 8

CLASS	BANDS (MEAN)			Migration
1	43.00	47.26	48.72	.
2	39.16	58.44	58.01	2.
3	38.96	76.60	70.74	.
4	55.08	53.90	53.28	2.
5	49.50	66.24	63.40	.
6	43.72	79.09	73.26	.
7	71.74	47.30	48.88	2.
8	62.33	56.52	56.59	2.
9	81.64	51.64	53.36	8.
10	39.95	74.24	65.98	.
11	39.77	81.66	71.16	.
12	39.97	82.31	74.08	.
13	48.07	63.32	58.89	1.
14	43.90	79.71	70.44	.
15	44.45	83.40	76.66	.
16	55.69	61.37	58.60	.
17	57.98	67.84	64.09	2.
18	59.67	82.42	73.73	.
19	38.92	81.89	67.69	.
20	38.52	86.63	72.52	.
21	39.83	87.65	77.07	.
22	43.14	80.47	66.54	1.
23	43.40	87.02	73.34	.
24	44.85	89.77	78.64	.
25	47.86	73.43	66.40	1.
26	73.28	74.32	67.95	4.
27	72.97	100.48	86.96	1.