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MINISTRY OF WATER DEVELOPMENT

THE STUDY

ON

THE NATIONAL WATER MASTER PLAN

SECTORAL REPORT
(R)

REMOTE SENSING ANALYSIS

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

Administrative Division of Districts

In this Study, the original 41 districts were considered and various statistical data, particularly socio-economic information, were collected for these districts. During the progress of the Study, six districts were detached from the original ones and established as new districts. In the report, the data on these new districts are grouped together with the corresponding original districts as shown below.

	Original Districts	New Districts	Data included in:
1.	Machakos	Makueni	Machakos/Makueni
2.	Kisii	Nyamira	Kisii/Nyamira
3.	Kakamega	Vihiga	Kakamega/Vihiga
4.	Meru	Tharaka-Nithi	Meru/Tharaka-Nithi
5.	Kericho	Bomet	Kericho/Bomet
6.	South Nyanza	Migori	South Nyanza/Migori

(Note: The last three Districts were established very recently.
The report refers only to the names of the original 41 districts.)

The administrative boundary map used in this Study is the latest complete map set covering the whole country (41 Districts, 233 Divisions and 976 Locations), prepared in 1986 by the Survey of Kenya, Ministry of Land, Housing and Physical Planning.

Data and Information

The data and information contained in the report represent those collected in the 1990-1991 period from various documents and reports made available mostly from central government offices in Nairobi and/or those analyzed in this Study based on the collected data. Some of them may be different from those kept in files at some agencies and regional offices. Such discrepancies if any should be collated and adjusted as required in further detailed studies of the relevant development projects.

THE STUDY ON THE NATIONAL WATER MASTER PLAN

SECTORAL REPORT (R)
REMOTE SENSING ANALYSIS

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NOTE

Separately from this report, the following study outputs were submitted to GOK:

1.	Vegetation/Landuse Map (North & South 2 sheets/set, colour)	1:1,000,000	40 sets
2.	Landform Map (North & South 2 sheets/set, colour)	1:1,000,000	4 sets
3.	Vegetation/Landuse Map (24 sheets/set, colour)	1:250,000	8 sets
4.	Landform Map (24 sheets/set, colour)	1:250,000	4 sets
5.	Landsat Data - False-color Image (31 sheets/set covering whole country)		1 set
6.	NOAA Data (1) 1982 dry season (2) 1982 wet season (3) 1989 wet season (4) 1990 dry season (5) 1982 dry - 1982 wet season comparison (6) 1990 dry - 1982 wet season comparison (7) 1990 dry - 1982 dry season comparison (8) 1989 wet - 1982 wet season comparison (8 sheets in total)	1:2,000,000	2 sets

R1. INTRODUCTION

This is a report on the remote sensing analysis based on Landsat data and NOAA AVHRR* data conducted in connection with the National Water Master Plan (hereinafter referred to as NWMP) as part of efforts for acquisition and integration of basic information. The analysis work was conducted over the period of January 1990 through March 1991, involving the following:

(1) Production of Landsat color infrared imagery covering the whole country : at 1:1,000,000 for the whole country and 1:250,000 for medium to high potential areas.

(2) Production of Reconnaissance Thematic Maps

(a) Whole country:

- Vegetation & Landuse Map	(1:1,000,000)
- Landform Map	(1:1,000,000)
- Watershed/Drainage Map	(1:1,000,000)

(b) Medium to High Potential Areas:

- Vegetation & Landuse Map	(1:250,000)
- Landform Map	(1:250,000)

(3) Field Survey (during August - October 1990)

(4) Compilation and Cartography of Thematic Maps

(5) Analysis of NOAA AVHRR data

(a) Production of Vegetation Cover Map (1:2,000,000)
- 1982 Dry season/Wet season
- 1989 Wet season
- 1990 Dry season

(b) Changes in Vegetation cover through time (1:2,000,000)
- 1982 Dry season/Wet season
- 1990 Dry season/1989 Wet season
- 1982 Dry season/1990 Dry season
- 1982 Wet season/1989 Wet season

(6) Report Writing

This report deals with Landsat data and NOAA AVHRR data in terms of observation systems, data contents, processing, analysis, and their results.

* AVHRR: Advanced Very High Resolution Radiometer

R2. LANDSAT SYSTEM CHARACTERISTICS AND IMAGE PRODUCTS

2.1 Characteristics of the Landsat System

The Landsat satellite (formerly called ERTS, Earth Resources Technology Satellite) could potentially acquire imagery of every point on the earth's surface, between 81 N and 81 S latitude, every 18 days for Landsat-1, -2, and -3 and every 16 days for Landsat-4 and -5. Five Landsat satellites have been launched since 1972 (Table R2.1), however, only Landsat -5 is operational as of February 1991. The Landsat satellites orbit the earth in a descending, sun-synchronous, polar orbit at an altitude of approximately 900 km for Landsat-1, -2, and -3 and approximately 700 km for Landsat-4 and -5.

Overpass time for all of the Landsat satellites is approximately 9:45 a.m. local time, although perturbations in the orbit have caused small variations in the time. An early morning sun-synchronous orbit was selected to take advantage of clear morning skies and to ensure repeatable illumination. Consistency in illumination is important for constructing image mosaics and in comparing changes through time. In addition, the moderately low sun angle at the time of overpass, particularly in the higher latitudes and during the winter months, enhances detail caused by relief differences.

The Multispectral Scanner Systems (MSS) on board the Landsat satellites are designed to measure solar radiation reflected from the earth's surface. The radiation data is telemetered to a number of ground receiving stations, where the data is processed and stored as images or on High Density Digital Tapes (HDDT).

The HDDT's are used to make Computer Compatible Tapes (CCT's) that are, in turn, used to produce the imagery.

Several of the satellites carried additional sensors to MSS. Landsat-1, -2, and -3 carried a Return Beam Vidicon (RBV) camera that produced black-and-white panchromatic imagery with 35m resolution. The RBV was successful only on Landsat-3. Landsat-3 also carried a thermal sensor, but it did not provide usable data because of technical difficulties. Landsat-4 and -5 carried a Thematic Mapper (TM) sensor in addition to the MSS; the TM has a spatial resolution of 30m on six of its seven bands. The data from the TM system is of high quality and the increased spatial resolution and expanded spectral capability are proving to be extremely valuable for a variety of applications.

Prior to Landsat-4 and -5, the Multispectral Scanner was the principal recording instrument on Landsat. The MSS records radiant energy from the earth in four spectral bands (Table R2.1), two in the visible portion of the electromagnetic spectrum at 0.5 to 0.6 micrometres (green) and 0.6 to 0.7 micrometres (red), and two in the reflected (not thermal) infrared at 0.7 to 0.8 micrometres and 0.8 to 1.1 micrometres. These bands have been designated as bands 4, 5, 6, and 7, respectively, for Landsats-1, -2, and -3 (1, 2, 3, and 4, respectively on Landsat-4 and -5). Each band can be used individually to produce a single band Landsat image or they can be color composited to produce a false-color image.

The MSS continuously scans the terrain line-by-line, with every line of data representing a strip on the earth's surface approximately 185 kilometres long by 79 metres wide. The continuous swath of Landsat data are partitioned into scenes that represent approximately 185 kilometres by 185 kilometres on the ground. Each individual scan line is sampled to give 3,240 reflectance values in each of the four bands. A single band Landsat MSS scene consists of approximately 2,340 scan lines, each scan line containing approximately 3,240, 57 metre by 79 metre resolution cells called pixels (abbreviation for picture element). Therefore, for each Landsat spectral band, there are approximately 7,500,000 pixels. Within each pixel, the intensity of reflected sunlight for each spectral band is recorded and stored as integers. Because there are four spectral bands, there are four integers per pixel, one for each band recorded on the CCT's. The spatial resolution of the imagery from the multispectral scanner is 79 metres.

The individual spectral bands can be color combined or composited photographically to produce a color "composite image" which greatly increases the interpretability of the final image product. The most common type of Landsat MSS color composite is the falsecolor composite. To produce a false-color composite image, transparencies for three of the four bands (MSS 4, MSS 5, MSS 7) are assigned a blue, green, and red color filter respectively and are optically superimposed onto color negative film. The spectral ranges of the color film pigments are different than the spectral ranges of the Landsat bands. Therefore, the color on the image is very different from the earth's true color, thus, the name "false-color image." This type of image is similar in spectral response to a color infrared photograph.

2.2 Multispectral Scanner (MSS) Imagery

Each band of landsat imagery contains some information that is unique or uniquely interpretable in that band. In general, bands 4, 5, and 7 are the most useful for interpretation of geography, geomorphology, and cultural features. The following brief discussion will indicate some of the reasons for this observation.

Band 4 responds to the green-yellow-orange portion of the spectrum. Green foliage, many cultural features, some soil types (e.g., white sand), and turbid water bodies reflect considerable light in this portion of the spectrum and thus are bright (light gray) on band 4 imagery. Many rock types and soil types reflect relatively little light in this portion of the spectrum and thus are a dark gray (usually with little contrast between lithologic or soil units) and are difficult to differentiate. The relatively short wavelengths detected by band 4 may be severely attenuated (absorbed and reflected) by dust particles and moisture in the atmosphere. This gives many band 4 images a hazy or foggy appearance and degrades the inherently better resolution of the shorter wavelength light. Despite this attenuation, band 4 is particularly good for picking out cities, towns, roads, and areas underlain by nearsurface aquifers.

Differentiation of lithologic units and separating bodies of water from their surroundings normally is difficult on band 4 imagery.

The short wavelength light recorded by band 4 penetrates water better than the longer wavelengths recorded by the other bands. Consequently, band 4 can be processed in order to infer relative water depth in near-shore or shallow areas and can be used to guide marine geophysical surveys in remote areas of the world.

Like band 4, band 5 (red) also detects light in the visible portion of the spectrum (red-orange to red). The longest wave-lengths of band 5 are about the longest detected by the human eye (700nm). In this portion of the spectrum, rocks and soils show a wide range of tones (gray and green rocks appear dark, red and yellowish rocks appear light, and dark brown and black rocks image dark gray to black). Green foliage is dark gray, clear deep water is very dark or black, and turbid or shallow water is light gray. This band is good for distinguishing between green vegetation and bare areas or dead vegetation. It also exhibits differences among rock types.

Bands 6 (700-800 nm) and 7 (800-1100 nm) record reflected light in the near infrared or "photographic infrared" portion of the spectrum in the region just beyond the human eye's sensitivity. Because these channels record wavelengths we do not see, their responses are more difficult to relate to our experience. At the same time, some distinctions we normally cannot see are apparent in the imagery of these bands. Green foliage reflects infrared light well and consequently is bright (the healthier, the brighter). Most rock types and many soils reflect light well in this region of the spectrum, but with considerable variation so that many subtle distinctions not seen in normal photography may become apparent. These differences may be related to variations in moisture content, grain size distribution of surficial material, rock color, minor differences in plant communities or different soils, etc. Water is uniformly black. A striking contrast between bodies of water (black) and lush foliage that grows near many of these water bodies (nearly white) is characteristic of band 6 and band 7 imagery. This characteristic makes these two bands excellent for mapping surface water distribution and accurately locating the shores of lakes, etc. In general, the types of tonal contrasts described above are more marked in band 7 than in band 6, but upon detailed examination there are some features that are more easily recognized in band 6 than in band 7. Overall, band 7 is somewhat more desirable for geologic interpretation.

2.3 Computer Processing of Landsat MSS

The Landsat CCT's contain the satellite data that has received some processing. From this data, Landsat imagery is produced by a series of computer algorithms that comprise the processing package. An interactive computer system is allowed for viewing and selection of various image algorithms and band combinations. The algorithms within the processing package can be divided into two broad types: "pre-processing" and "image processing".

2.4 Pre-processing

The Landsat MSS data contains some noise and distortion. Therefore, pre-processing of the data is necessary before image processing.

The pre-processings are:

(1) The radiometric correction adjustments for instrument noise and atmospheric distortion.

(2) The destripping algorithm equalizes scan line response imbalances prevalent in the multispectral scanner at the time of data correction.

(3) The geometric corrections compensate for distortion due to variations in orbital altitude, satellite orientation, Earth rotations, etc.

2.5 False-Color Composite Image

The algorithm used to produce a false-color composite image includes a modified Laplacian operator to enhance linear features and a contrast enhancement package to accentuate the most geographically important portions of the satellite data.

The false-color image is created on color film by compositing three of the four spectral bands (usually MSS 4, MSS 5, and MSS 7) as the three primary pigments of the film emulsions. The spectral ranges of the color film pigments are different from the spectral ranges of the Landsat bands. Therefore, the color on the MSS image is not the same as the Earth's true color, thus named, "false-color image".

Of all the image types, the false-color image usually provides the greatest variety of information. It is the major information source for the interpretation of regional geography, geomorphology, and cultural features. Furthermore, by using different combinations of bands or colors, color images can be produced that enhance features of particular interest to the analyst.

R3. LANDSAT DATA ANALYSIS

The purpose of Landsat data analysis in this project was to produce Vegetation & Landsat Map, Landform Map, and Watershed/Drainage Map, covering the whole country at 1:1,000,000 and Vegetation & Landuse Map and Landform Map at 1:250,000 for medium to high potential areas to serve as basic information for NWMP. The analysis was based on interpretation of color infrared imagery using Landsat MSS data.

3.1 Selection and Purchase of Landsat Data

Landsat data to be used for this project were selected by taking the following into account:

(1) Landsat scenes that cover the study area in its entirety. The areas covered by Landsat data are defined by Pass Numbers (East-West) and Row Numbers (North-South).

(2) Latest data available (from the latest observation dates)

(3) Good quality data with least cloud cover. A cloud cover of more than 30% makes the data impractical for interpretation because of the limited view of land surface.

By considering these factors, a total of 31 scenes taken during January-March 1987 period were selected and purchased as shown in Figure R3.1 with respect to their central locations and in Table R3.1 with respect to observation dates, cloud coverage, and data quality.

3.2 Production of Color Infrared Imagery

By pre-processing of the acquired Landsat imagery as discussed above, color infrared imagery was developed as a major source of information. The combination of spectral bands comprised band 4 blue, band 5 green, and band 7 red. Images were produced at scales of 1:1,000,000 for the whole country and 1:250,000 for medium to high potential areas.

3.3 Interpretation of Color Infrared Imagery

Colors of infrared imagery are greatly different from the actual colors as seen on the ground. In the processes of pre-processing and image-processing, color tones are adjusted among individual scenes while there actually exist minute differences in color tones, even between adjacent scenes of the same data, that reflect meteorological conditions. So that the analyst has to be aware of it in interpreting differences and changes in color tones in the imagery. Where color tones are different but look similar, they should be properly classified by referring to other information. The imagery analysis for this project was based on aerial photo interpretation (for landuse, landform, soils, etc) and the technology that has been proven in the field in Kenya.

General characteristics of typical landuse classifications as they appear on MSS data based color infrared imagery are as follows:

Forest : Usually red to dark red. Fine texture for dense forest; coarse texture for sparse forest. When trees are sparse, under-growths are seen in bright red (grass) mixed with gray white (earth). Coniferous trees appear darker in red than deciduous trees. In the typical climates of tropical rain forests and savannah, the dry season can be reflected in reddish brown but there is little change in color tone between dry and wet seasons. Whereas in the temperate climate zone, low temperature seasons appear reddish brown to brown mixed with gray white (earth) for under-growths seen through bare trees.

Grassland/Bushland: Generally bright red - red. Brighter than forests. Red dots are dense or coarse depending on the density of bushes. In the tropical rain forest climate zone and the savannah climate zone, the wet season is reflected in bright red, low temperature periods in reddish brown, and the dry season in reddish brown, possibly mixed with gray white (dry earth) - dark grayish blue (wet earth).

Because of the above characteristics, the best imagery for interpretation of grassland and bushland is the one taken immediately after the wet season is over for the tropical rain forest climate zone and the savannah climate zone, and that of high temperature seasons for the temperate climate zone.

Agricultural land : Color tones of agricultural land on the imagery differ widely according to the growth stages of crops. At the sowing stage, it appears gray white (dry earth) - dark grayish blue (wet earth) and, as crops grow with leaves, bright red - red. Grains right after harvesting appear in orange - yellowish brown. There is little difference in color tone between grassland and crops in the growing stage, so that artificial segmentations, water channels, or topography like slopes are sought as surrogates to differentiate them in interpretation.

Paddy : At planting time, it appears dark blue reflecting water surface, red as rice plants grow covering the water surface, and brown when they have grown.

Town : Generally bright blue. Dark blue where there are many tall structures. Parks appear red reflecting trees and white for roads. Towns and villages with few buildings show a mixture of light blue and red for agricultural land and gray white for open land, making it difficult to delineate their boundaries.

Road : Generally gray white lines. Roads with widths of 6 - 8m or more can be clearly recognized on the imagery. Norrower roads can be interpreted from differences with adjacent land use. But if they are located in the barren land, it becomes difficult to differentiate because both appear in gray white.

Bareland : Generally in irregular expanse appearing gray white. Very similar to those of agricultural land after harvesting and grassland during the dry season.

During the wet season, it appears in dark gray - dark grayish blue reflecting the wetness, making it clearly different from bright red grassland. In the dry or semi-dry zones, there is little vegetation cover so that bare land can be observed extensively. Rock outcrops if any are reflected in brownish colors in various shades with coarse texture while areas covered with weathered sand range from gray white to dark brown but uniformly smooth in texture making it relatively easy to interpret.

Waters : Generally black or dark blue. Deep clear water in black and shallow turbid water in blue. In the tropical rain forest climate zone and the savannah climate zone, rivers flood during the wet season and water remains in the flood plain. It is turbid and appears blue in color. Original river channels can be traced from riparian vegetation on both banks of the rivers appearing in red dots meandering in two parallel lines. The river channels are dark blue during the dry season and the flood plains white gray-white and, when wet, grayish blue.

Swamps have typically riparian vegetation growths which appear on the imagery as a mixture of blue for water and red for vegetation, with red varying depending on the density of vegetation.

Dams and reservoirs are represented in black-dark blue. It is easier to monitor changes in water levels during the wet and dry seasons. Water conduits can be recognized as black - dark blue straight lines.

Others : Other landuse features that are relatively easy to identify on the imagery include;
[Airport] Runways of 2 - 4 km appear in grayish white - grayish blue and are easily identifiable.
[Port facility] Berths and breakwaters extending more than 1,000 m are shown in gray white lines.
[Railroad][Power transmission line] Both can be identified in high quality images.

3.4 Production of Reconnaissance Thematic Maps

Prior to the field survey, reconnaissance thematic maps were produced based on color infrared imagery interpretations as well as existing data. The thematic maps thus made were:

(1) For whole country (1:1,000,000)
Landuse Map, Landform Map, Watershed/drainage Map

(2) For medium to high potential areas (1:250,000)
Landuse Map, Landform Map.

Based on these maps, what needed to be done in the field was defined in terms of items and locations to be identified or added, as well as other additional information as necessary.

3.5 Field Survey

The field survey was conducted for two months from the end of August 1990. The survey covered the following:

(1) Checking of the reconnaissance thematic maps with existing data (aerial photos and existing thematic maps for necessary correction).

(2) Field identification of uncertain items in the reconnaissance maps.

(3) Observation and aerial photographing aboard a light aircraft (for information to help interpretation to be done in Japan)

(4) Meeting to discuss and finalize the legends for thematic maps.

3.6 Compilation and Cartography of Thematic Maps

Based on the findings of the field survey, the color infrared imagery was interpreted again, and the thematic maps were compiled accordingly and completed after cartography. The types, scales, and volumes of the thematic maps produced were as follows:

(1) Whole country (1:1,000,000)
- Vegetation & Landuse Map (North/South 2 sheets - 1 set)
- Landform Map (Same as above)
- Watershed/Drainage Map (Same as above)

(2) Medium to high potential areas (1:250,000)
- Vegetation & Landuse Map (24 sheets, 1 set)
- Landform Map (Same as above)

Legends for Vegetation/Landuse Map and Landform Map are presented in Tables R3.2 and R3.3, respectively.

Landform classifications were based on the Exploratory Soil Map and Agro-Climatic Zone Map of Kenya, 1980, Kenya Soil Survey.

3.7 Results of Analysis

The thematic maps were digitized by a digitizer in terms of their boundaries, made into a data file and stored in a computer. As a typical thematic output, the Vegetation Landuse Map was produced from the file. Figure R3.2 is the map at a reduced scale and Table R3.4 shows sizes of the respective classifications in area.

From Table R3.4, it can be seen that the largest in area is "Bushland (Dense)" accounting for more than 40% of the nation's total land area. Combined with "Bushland (Sparse)", bushland amounts to 354,500 sq km occupying about 60% of the total land area. Areas associated with trees, namely, "Forest" and "Woodland", are about 14,600 sq km and 21,400 sq km, respectively, adding up to about 36,000 sq km or about 6.1% of the total land area. With respect to agricultural land, "Dense", "Sparse" and "Plantation" represent about 45,600 sq km, 32,150 sq km 16,350 sq km, respectively, totalling about 94,100 sq km or about 15.9% of the total land. "Barrenland (S/G)" and "Barrenland (R)", both with minimal vegetation cover, represent a combined area of about 76,500 sq km or about 12.9%.

These statistics were compared with those of 1983 land use map (by KREMU, based on 1980 Landsat data) shown in Table R3.5. The areas shown in the table are as per NWMP Progress Report (1), which were enumerated focusing mainly on agricultural landuses.

Precise analysis of land use changes appearing in both tables (Tables R3.4 and R3.5) is rather difficult since the information is based on 1:1,000,000 maps. It was presumed that more detailed attempt of the comparison of two maps seemed not meaningful in view of limited information on 1:1,000,000 maps. Therefore, no attempt had carried out to analyze the possible cause of vegetation/land use change through the comparison of the two maps. Nevertheless, the comparison of both figures would still be worthwhile for knowing a general trend, where the two tables represent the following information sources:

	Scale	Land Use Map By	Year	Landsat Data
Table R3.4	1:1,000,000	This Study (NWMP)	1990	1987
Table R3.5	1:1,000,000	KREMU	1983	1980

a. Forest and Woodland (F1+F2) decreases by about 900 sq km in Table R3.4 (1990 map) or about 2.5% of the total forest/woodland area. But allowing for possible differences in classification of these categories in the two mappings, it would be more appropriate to assume that there had been no much change in the area for 7 years under comparison.

b. With respect to agricultural land, a total of about 94,100 sq km of C1, C2, and C3 in Table R3.4 compares with 95,600 sq km of items 3 through 5 in Table R3.5, which represent a decrease of about 1,500 sq km or 1.5 % of the total agricultural area.

c. "Bushland" and "Grassland" in Table R3.4 can be considered to correspond to "Unimproved grazing land" in Table R3.5. If so, the area decreased substantially from 433,000 sq km in Table R3.5 to 354,540 sq km in Table R3.4. On the other hand, "Barrenland" increased sizably from 4,800 sq km of "Badland on barren" in Table R3.5 to 76,538 sq km in Table R3.4.

   However, "Barrenland" combined with "Bushland" and "Grassland" in Table R3.4 comes to 443,019 sq km, while "Badland and barren" and "Unimproved grazing land" in Table R3.5 amounts to 437,800 sq km. Both figures are very close to each other, though about 5,200 sq km larger in the former. This reflects differences in classifications and how they are looked at.

d. Water bodies represent 11,954 sq km in Table R3.4, which compares with 11,800 sq km in Table R3.5, a difference corresponding to the size of Waters (artificial).

e. Towns and Villages represented 430 sq km in Table R3.4 comparing with 300 sq km in Table R3.5. The difference is possibly because, in this NWMP 1990 survey, some open space in the surrounding areas and scattered farmlands inside towns and villages were included in the representation of this category. Expansion of urban areas may also be one of the reasons.

R4. NOAA AVHRR SYSTEM CHARACTERISTICS AND VEGETATION INDEX

4.1 NOAA AVHRR System Characteristics

The first meteorological satellite for practical application ever to be launched in the world was called ESS Satellite (Environmental Science Services administration satellite). After ESS 1 was launched in 1966, nine of them were put into orbit during the 1966 - 1969 period. They were followed by ITOS-1, 2, and 3, improved versions of ESSA. After ITOS-D, the name of such satellites was changed to NOAA (National Oceanic and Atmospheric Administration, USA). And presently NOAA 11 and 12 are operating. Those launched after October 1978 were collectively called TIROS-N/NOAA Series.

(1) NOAA Series satellites are in the Near Polar Sun Synchronous orbit at altitudes of 870 km and 833 km. As a rule, they are orbiting in a pair, each of them covering the same spot a minimum of twice a day or four times by the pair. Daytime observations were made twice at 7:30 am and 3:00 pm both local time.

(2) The satellite is equipped with a sensor system, AVHRR (Advanced Very High Resolution Radiometer), with 2 visible and near infrared bands and 2 thermal infrared bands. It continuously scans the ground surface at a width of approximately 3,000 km. The channels of AVHRR and their applications are as follows:

Description of AVHRR

Channel	Resolution at subpoint	Wave length (um)	Primary Use
1	1.1 km	0.58 - 0.68	Daytime Cloud & Surface Mapping
2	1.1 km	0.725 - 1.10	Coastline, Snow & Ice, Vegetation
3	1.1 km	3.55 - 3.93	Seasurface Temperature
4	1.1 km	10.3 - 11.3	Seasurface Temperature, Day/Night Cloud Mapping
5	1.1 km	11.5 - 12.5	Seasurface Temperature

(3) AVHRR data can be received directly from the satellites at the receiving stations across the world. They are available for purchase from NOAA.

(4) AVHRR data is available in two formats: Lac (Local Area Coverage) and Gac (Global Area Coverage). The former type of data is transmitted by HRPT mode

(High Resolution Picture Transmission - High resolution data to be transmitted in digital signals) and subject to the memory capacity therefore limiting the area to be covered.

Whereas the transmission mode of the latter type is APT (Automatic Picture Transmission) by which AVHRR data are processed into images of 4 km x 4 km ground resolution on board the satellite and after simple geometric corrections, the images are transmitted by facsimile. Since this type of data is available in photo images on a real time basis on a properly equipped receiving system for that purpose, an increasing number of fishing vessels are being equipped with such a receiving system to monitor the oceanic situations.

(5) Both data types were 10-bit data and channels 1 and 2 (Visible and IR, respectively) were used.

(6) The standard base projection of data was Polar-Stereographic from May 1982 through March 1985 (First Generation version), and is currently Plate Carree (or latitude/longitude) for the Second Generation version of the product, April 1985 through the present. This data is easily converted to UTM Projection.

4.2 Computer Processing of AVHRR Data

Since all of the processing of the AVHRR data was to be done on 8-bit data, each scene needed to be converted from raw 10-bit data. This conversion was needed to preserve the widest range of vegetative spectral reflectance possible. Since each image would be a mosaic of data taken on several dates within a short time period, the data to be used for the vegetative indices needed to be normalized to a common range.

4.3 Conversion of 10-bit Data

Each scene was initially converted to 8-bit data using a range of values equal to 10-bits (1024 values). The conversion routine performed a linear compression to produce a range of 0-255. The data set was then previewed and a range of 64 values was visually selected for having the greatest range of vegetative data.

Each scene was then converted a second time using the range of values previously selected. Since the initial range chosen was in a compressed format, the second conversion produces a decompressed range of 256 values. This data set represents the widest usable range of data and preserves the full radiometric resolution of the raw data set for the features of interest.

Each scene was then georeferenced, resampled to a common projection (UTM), and windowed to the area of interest.

4.4 Creation of Vegetation Indices

AVHRR data relate to vegetation based on reflectance and wave lengths as shown in Figure R4.1.

Based on these reflectance characteristics of vegetation, Channel 1 and Channel 2 data are mathematically combined to find out about presence of vegetation and its density where it exists.

The following are two mathematical formulas that are widely and effectively used:

(1) VI (Vegetation Index) = Channel 2 - Channel 1 .... (F.1)

Where vegetation is dense, reflectance in Channel 2 is greater than that of Channel 1 making the index value greater as vegetation gets denser. Index values are smaller for bare land (there is little difference in reflectance between Channel 1 and Channel 2), and minus for water in many cases. But index values as obtained from this formula are vulnerable to haze and vapor in the atmosphere so that the following formula has been introduced to cope with that deficiency.

(2) NDVI (Normalized Difference Vegetation Index)

$$\frac{\text{Channel 2} - \text{Channel 1}}{\text{Channel 2} + \text{Channel 1}} \quad \text{...} \quad (F.2)$$

NDVI is used for monitoring vegetation in large areas because in this formula, differences in reflectance due to localized light intensity, slopes on the ground surface, view angles of the satellite, etc. (differences being caused by the satellite as it cruises, between the spot directly below it and the peripheral areas) are removed and corrected assuming that they are common to both channels. Clouds, water, and snow have large reflectances in the visible range than in the near infrared, so for these features' NDVI is negative. Rocks and bare soils have similar reflectances in these two bands and result in vegetation indices near zero. In scenes with vegetation, the NDVI ranges from 0.1 to 0.6 ; the higher values are associated with greater density and greenness of the plant canopy.

(3) New Global Vegetation Index User's Guide was published from NOAA in May, 1990. In the Guide, both DVI and NDVI values are scaled to permit them to be represented by 8 bit integers (i.e., on a range of 0 to 255) over the range of DVI and NDVI values representative of vegetation.

The Scaled Difference Vegetation Index (DVI) is computed as follows:

Scaled DVI = Channel 2 - Channel 1+100 .... (F.1')
If the Scaled DVI is negative, it is set to be zero.

The NDVI (F.2) is then scaled according to the following criteria:

a. If the NDVI is less than -0.05, the Scaled NDVI is set to 255

b. If the NDVI is greater than 0.6, the Scaled NDVI is set to 0.

c. Between these limits (-0.05 and 0.6), the Scaled NDVI is computed from the equation:
Scaled NDVI = 240 - (NDVI+0.05)x350 .... (F.2')

4.5 Creation of Composite Data

A composite data (NDVI) is created by processing each computed index. The value of each pixel in each index are compared, and the highest value available is inserted into the new index. This composite data contains every available pixel containing vegetation data and less cloud cover.

4.6 Creation of Images

All of the final indices are then compared to find the best data ranges for some classes of vegetative cover. The result is a single band classified image, which identified some classes of vegetation density. Water and clouds are edited into the classification to produce the final images.

R5. NOAA AVHRR DATA ANALYSIS

In January through April of 1981, the central part of East Africa was hit by extensive drought resulting in heavy damages in Kenya, Uganda, Somalia, and Tanzania. Since then there has been no drought of such major proportions but desertification has emerged as a new problem for the sub-Sahara involving many countries in the region.

The purpose of the NOAA AVHRR data analysis in this project is to clarify the current status of vegetation cover in the whole country of Kenya and its changes due to seasons as well as to the lapse of time over years. As mentioned earlier, AVHRR data is commonly used to study vegetation cover over a wide area. The results of the present study could also be basic data for future monitoring of vegetation cover.

5.1 Selection and Purchase of AVHRR Data

As of January 1990, the oldest (1982) and the latest AVHRR data available for purchase was examined with respect to the dry season (January to February) and the wet season (June to July). And those that would make composite scenes with least cloud cover were selected and a minimum number purchased. The data of the 1989 dry season turned out to be impractical with sizable cloud cover so that those of the 1990 dry season were additionally acquired to replace them. All the data acquired are listed below in order of their dates:

List of AVHRR Data

1982	Dry Season	1989	Dry Season	1990	Dry Season
	24 January		12 January		4 January
	28 January		20 January		5 January
	5 February		11 February		6 January
	6 February		12 February		13 January
					14 January
					15 January
	Wet Season		Wet Season		
	10 June		20 June		
	19 June		18 July		
	15 July		19 July		
	19 July				

* The 1982 data are Gac (4kmx4km) and the 1989-1990 data Lac (1kmx1km)
** In Kenya, wet season is distinctive for the months from April to May. However, NOAA data in June-July were selected with two reasons:
(i) they represent vegetation of (or more precisely "after") the wet season.
(ii) cloud-free images are available (difficult to obtain cloud-free images for the months from April to May)

5.2 Data Processing

Acquired data were modified to the UTM projection (UTM Zone 37), and the NDVI values (F. 2) of individual pixels were obtained. Each pixel was studied in the order of dates for each season starting with the oldest, and the data with the highest NDVI value was inserted to make composite data.

Composite data of negative value was classified as water and clouds, those of 0 as outcrops/bare land, and 0.6 - 0.1 as vegetation, which were then compared with the topographic map and the Landsat imagery. As the result, it was found that the boundary was not clear between water/clouds and outcrops/bare land. So that water and clouds for each date were checked according to Channel 1 reflectances (175-255) with respect to clouds and Channel 2 reflectances (0 - 28) with respect to water, and composite data was edited accordingly.

NDVI values of individual pixels fell in the range of 0 - 0.6 except for clouds and water but since the range was small, it was rescaled by setting NDVI 0 to 0 and 0.6 to 255 and reassigning intermediate values proportionately on that scale. The values for individual pixels were then obtained based on the rearranged scale. After comparing these values with existing data (Landsat imagery, Vegetation/Landuse Map), they were classified as shown below.

Classification of Vegetative Cover

241 - 255	Very high vegetative cover
193 - 240	High vegetative cover
159 - 192	Moderate vegetative cover
126 - 158	Sparse vegetative cover
0 - 125	Scarce vegetative cover

This classification is compared with the vegetation/ landuse for the dry season as follows:

Vegetative Cover (NOAA)		Vegetation/Landuse
Very high vegetative cover	-	Forest, Plantation,
High vegetative cover	-	Woodland, Plantation
Moderate vegetative cover	-	Bushland, Agricultural land
Sparse vegetative cover	-	Grassland, Agricultural land
Scarce vegetative cover	-	Barrenland

The results of analysis are presented in 1:2,000,000 scale colour maps (separately submitted to MOWD). The reduced scale versions of the maps are attached as Figures R5.2 to R5.5.

5.3 Analysis of Seasonal and Yearly Changes in Vegetation Cover

The following four cases were studied in order to find out seasonal and yearly variations of vegetation cover:

(1) Comparison of data between 1982 dry season and 1982 wet season: to obtain seasonal variations in vegetation cover.

(2) Comparison of data between 1989 wet season and 1990 dry season: for the same purpose as (1) above.

(3) Comparison of data between 1982 dry season and 1990 dry season: to obtain yearly changes, namely, changes over years.

(4) Comparison of data between 1982 wet season and 1989 wet season: for the same purpose as (3) above.

Since the 1982 data was defined in terms of 4km x 4km units and the 1989/1990 data in 1km x 1km, the 1982 data was divided into 1km x 1km units (i.e. 16 grid cells, without changing the vegetation indices) before it was compared with the 1989/1990 data.

5.4 Comparison of Rainfall Data

Vegetation cover is subject to changes in weather conditions and human activities. Changes in weather conditions are considered to have a greater impact on vegetation cover than human activities. Therefore, rainfall data was obtained and compiled to provide base information for analysis of NOAA AVHRR data.

The rainfall data at 12 observatory stations having relatively long period records was collected. Location of the stations is shown in Figure R5.1. The rainfall data thus collected is shown in terms of monthly maximums/minimums and monthly averages in Table R5.1.

Assuming that vegetation cover had been affected by the rainfall for some time preceding the date of observation, the rainfall data of the preceding 2 to 3 months was studied as shown in Table R5.2. From the above two tables, seasonal rainfalls were characterized as follows:

a. For the period from November to December 1981, average rainfalls were little in the north and much in the south and the east. But in January and February 1982, there was nearly no rainfall in the north and the east except for the Lake Victoria area where there was average rainfall. That means that vegetation cover during this period most likely should have reduced in density excepting the Lake Victoria area.

b. The records covering March to July 1982 show that there was average rainfall in March, but in April to May there were large amounts of rainfall across the country, particularly in Marsabit and Moyale in the north, Kisumu in the west, and Mombasa in the southeast. In June and July, the rainfall was back to normal with little rain in the north and much in the Lake Victoria area and the coastal areas facing the Indian Ocean. It is supposed then that during this period vegetation cover was restored to the average wet season condition, except for some areas which were adversely affected for other reasons; say, flood or excessive moistures.

c. The records covering March to July 1989 show that in March to May the rainfall was below the average in the east and the coasts of the Indian Ocean but all other areas had more or less average rainfalls. In June to July, the rainfall was slightly less than the average nationwide. Therefore, the vegetation cover in 1989 wet season was assumed to be within the normal range or slightly below the average.

d. The records covering November 1989 to February 1990 show that there was average or slightly more rainfall nationwide. The trend continued in January and February with rainfalls far exceeding the average, especially in Marsabit, Mayale and Wajir in the north. Therefore, vegetation cover was relatively dense in the north, where the density is usually relatively low in this period. The density in other areas was assumed to be normal or slightly higher for this time of a year.

5.5 Results of Analysis

5.5.1 Vegetation cover in respective years/seasons

The results of analysis for each year/season are shown below and also shown graphically in Figure R5.6.

Vegetation Cover in Each Year/Season

Unit = sq.km (%)

Season / Vegetative cover	1982, Dry	1982, Wet	1989, Wet	1990, Dry
Very high	40,900 (6.91)	26,600 (4.49)	58,200 (9.83)	47,050 (7.94)
High	47,150 (7.96)	42,650 (7.20)	130,700 (22.07)	133,450 (22.54)
Moderate	76,450 (12.91)	112,150 (18.94)	117,000 (19.76)	121,300 (20.48)
Sparse	102,100 (17.24)	236,200 (39.88)	116,350 (19.64)	103,200 (17.43)
Scarce	308,400 (52.07)	151,500 (25.58)	134,850 (22.77)	173,100 (29.23)
Clouds	1,000 (0.17)	0 (0)	21,000 (3.54)	400 (0.06)
Water	16,250 (2.74)	23,150 (3.91)	14,150 (2.39)	13,750 (2.32)
Total Area	592,250 (100.00)	592,250 (100.00)	592,250 (100.00)	592,250 (100.00)

The results are presented by counting the areas in units of 50 sq km and fixing the country's total land to 592,250 sq km. From the table and figure, vegetation covers for the respective seasons can be characterized as follows:

a. Analysis of 1982 dry season data shows that areas with "scarce" vegetation cover account for 52% of the total land, followed by areas of "sparse" vegetation of 17%.

The total of both areas accounts for about 70%. This implies that a severe extent of drought prevailed in that period.

b. Analysis of 1982 wet season data shows that "sparse" vegetation areas represent about 40% of the total land, followed by "scarce (26%)" and "moderate (19%)". It is notable that the area classified as "scarce" in 1982 dry season turned into "sparce" in 1982 wet season, and similarly "sparse" areas turned into "moderate", each increasing their density. This can be attributed to the substantial rainfalls in April to May 1982, which helped the growth of vegetation (grasses in particular). Compared with the dry season, the "scarse" area was more than halved while the "sparse" area increased 2.3 times and the "moderate" area went up about 50%. This shows the great impact that rainfalls had on the vegetation cover.

c. Analysis of 1989 wet season data shows that areas tended to average among the categories at about 20% with an exception of 10% for "very high". Since the rainfall was an average for Kenya at this time of a year, it seems that this represents a typical areal pattern of vegetation cover for a wet season.

d. Analysis of 1990 dry season data shows that "scarce" is largest in area with about 29%. But, in can be noted that when compared with the wet season, there was little difference in the areas of "high" and "moderate" with 22% and 20%, respectively, while "sparse" area was reduced and "scarce" increased. This means that areal changes in the vegetation cover between the dry and wet seasons occur mainly in "sparse" and "scarce" categories.

e. "Very high" and "high" of both dry and wet seasons of 1982 were less in size than those of 1989 and 1990. This is partly because of the drought but more importantly due to the large data cell size of 4km x 4km which allowed denser vegetation occupying smaller portions to be absorbed by more dominant types of less density as they represented that particular cell as a whole. Therefore, it may be appropriate to assume that there actually existed more of "very high" and "high" vegetation areas.

5.5.2 Seasonal variation of vegetation cover

(1) 1982 dry season-wet season comparison

Vegetation cover was compared firstly between 1982 dry season and 1982 wet season as shown below. Figures R5.7 and R5.8 illustrate graphically how the vegetation cover observed in the dry season had changed in the subsequent rainy season.

Vegetation Cover Comparison between
1982 Dry Season and 1982 Wet Season

Unit : sq km

			1982 Dry Season							
			1 V.high	2 high	3 moderate	4 sparce	5 scarce	6 cloud	7 water	Total
	1	very high	5,800*	5,750	6,950	5,750	2,350	0	0	26,600
	2	high	10,400	9,500*	10,500	7,400	4,250	0	650	42,650
1982	3	moderate	15,350	15,950	24,200*	24,950	30,050	700	950	112,150
Wet	4	sparse	6,100	10,450	25,100	44,350*	149,650	250	300	236,200
Sea-	5	scarce	1,400	2,600	7,100	19,000	121,300*	0	100	151,500
son	6	clouds	0	0	0	0	0	0*	0	0
	7	water	1,850	2,900	2,600	650	850	50	14,250*	23,150
		Total	40,900	47,150	76,450	102,100	308,400	1,000	16,250	592,250

* Area unchanged in both seasons

From the table and figures above, seasonal variations can be characterized as follows:

a. In the dry season of 1982, "sparse vegetation cover accounted for 2/3 of the total land area reflecting the effects of a drought of the preceding year. But during the subsequent wet season, vegetation was significantly restored thanks to increased rainfall. As a result, approximately 2/3 of the "sparse" area in the dry season turned into denser vegetation categories. The vegetation became denser as a whole but, as a tendency, the denser the vegetation cover, the smaller the areas they occupied.

b. Decreases in vegetation density during the dry season were particularly noticeable in the vegetation areas of "very high", "high" and "moderate" classified in the dry season. This was due to either notable rainfalls (see Tables R5.1 and R5.2) before the start of the wet season in such highly vegetation areas as south central, west (Lake Victoria area) and the coastal areas on the Indian Ocean, which had adversely affected the growth of vegetation, or possibly because reflectance of Channel 2 (near infrared: absorbed by water) due to excessive humidity.

(2) 1989 wet season - 1990 dry season comparison

Vegetation cover was also compared between 1989 wet season and 1990 dry season as shown in table below. Figures R5.9 and R5.10 show graphically the changes of vegetation density between the two seasons.

As mentioned before, the NOAA data for the 1989 dry season were not available due to a large amount of cloud cover. Unlike the case of year 1982 wherein seasonal changes were compared between the preceding dry season and the following wet season, here the order of the seasonal comparison had to be reversed. An approach was taken to look at the vegetation cover of 1990 dry season first and then how it had been in 1989 wet season.

Vegetation Cover Comparison between
1990 Dry Season and 1989 Wet Season

Unit : sq km

			1990 Dry Season							
			1 V.high	2 high	3 moderate	4 sparce	5 scarce	6 cloud	7 water	Total
	1	very high	23,650*	28,200	4,550	1,000	700	0	100	58,200
	2	high	14,900	61,100*	39,700	11,400	3,350	100	150	130,700
1989	3	moderate	4,400	33,550	46,300*	25,350	6,150	100	1,150	117,000
Wet	4	sparse	1,550	7,900	23,150	40,300*	43,000	0	450	116,350
Sea-	5	scarce	750	1,950	4,850	15,350	111,600*	150	200	134,850
son	6	clouds	1,250	750	2,400	9,050	7,500	50*	0	21,000
	7	water	550	0	350	750	800	0	11,700*	14,150
		Total	47,050	133,450	121,300	103,200	173,100	400	13,750	592,250

* Area unchanged in both seasons

From the table, their seasonal variations can be characterized as follows:

a. Compared with the cases of changes in 1982 dry and wet seasons, areal changes in vegetation cover between 1990 dry and 1989 wet seasons were relatively small. But vegetation density was reduced at all levels, and changes from "sparse" to "scarce" were particularly extensive.

b. Some of the "high" and "moderate" vegetation during the dry season were denser than they were during the wet season. This is probably because during the period from November 1989 to February 1990, there was substantial rainfall in north central area where normally there was little rainfall, which had prompted the growth of vegetation.

Both Figures R5.7 and R5.9 show the same information; variations from dry season to wet season, but in different years. Comparison of both figures will indicate different variations by area which might be particular occurrences in the respective years.

5.5.3 Chronological variations of vegetation cover

In order to obtain over-year variations of vegetation cover, vegetation cover was compared (1) between 1982 dry season and 1990 dry season and (2) between 1982 wet season and 1989 wet season.

(1) Vegetation cover comparison between 1982 dry season and 1990 dry season.

Changes in areas of different vegetation levels between these two dry seasons were as shown below. Figures R5.11 and R5.12 show graphically the changes over the two years.

Vegetation Cover Comparison between
1982 Dry Season and 1990 Dry Season

Unit : sq km

		1990 Dry Season							
		1 V.high	2 high	3 moderate	4 sparce	5 scarce	6 cloud	7 water	Total
	1 very high	6,750*	21,150	9,050	2,800	450	150	550	40,900
	2 high	6,500	22,400*	11,050	4,950	1,500	50	700	47,150
1982	3 moderate	10,850	27,600	18,750*	10,800	7,250	50	1,150	76,450
Dry	4 sparse	9,500	24,150	24,800	19,800*	23,550	50	250	102,100
Sea-	5 scarce	13,150	36,650	56,600	64,800	136,850*	50	300	308,400
son	6 clouds	0	750	250	0	0	0*	0	1,000
	7 water	300	750	800	50	3,500	50	10,800*	16,250
	Total	47,050	133,450	121,300	103,200	173,100	400	13,750	592,250

* Area unchanged in both seasons

From these results, variations of vegetation cover between the two dry seasons in different years can be characterized as follows:

a. In the 1982 dry season, vegetation growth suffered due to drought causing more than half of the nation's land to be poor vegetation. But the vegetation was recovered substantially in the 1990 dry season. Compared with 1982, "high" area increased about three-fold and "moderate" 1.5 times, whereas "scarce" area was reduced nearly by half.

b. "Very high" increased from 40,900 sq. km in 1982 to 47,050 sq. km in 1990. The increase implies the recovery of vegetation, but it may partly due to the difference in size of grid cells; i.e. 4km x 4km grid cells in the 1982 data and 1km x 1km grid cells in the 1990 data, where in the former some of denser categories occupying smaller portions of a cell might be absorbed by other areally dominant categories.

(2) Vegetation cover comparison between 1982 wet season and 1989 wet season

Changes in areas of different vegetation levels between the two wet seasons were as shown below. Figures R5.13 and R5.14 show graphically the changes over the two years.

Vegetation Cover Comparison between
1982 Wet Season and 1989 Wet Season

Unit : sq km

			1989 Wet Season							
			1 V.high	2 high	3 moderate	4 sparce	5 scarce	6 cloud	7 water	Total
	1	very high	7,700*	11,950	3,800	650	350	1,850	300	26,600
	2	high	11,200	18,700*	8,200	1,400	200	2,350	600	42,650
1982	3	moderate	24,400	40,600	29,450*	13,200	1,600	2,300	600	112,150
Wet	4	sparse	13,200	51,750	61,600	74,950*	21,000	13,600	100	236,200
Sea-	5	scarce	1,150	6,050	9,700	24,550	109,250*	700	100	151,500
son	6	clouds	0	0	0	0	0	0*	0	0
	7	water	550	1,650	4,250	1,600	2,450	200	12,450*	23,150
		Total	58,200	130,700	117,000	116,350	134,850	21,000	14,150	592,250

* Area unchanged in both seasons

From the table and the figures, variations of vegetation cover between the two wet seasons in different years can be characterized as follows:

a. In 1989, "very high" and "high" areas increased about two times and three times respectively over 1982. On the other hand, "sparse" area was more than halved. This shows that the 1982 wet season was not yet free from the after-effects of the drought that preceded, and that the vegetation cover was completely restored in the wet season of 1989.

b. There was little areal change in vegetation cover over the years as far as judging of the two wet seasons, compared with those between the two dry seasons. There were many parts where no change was observed while there were few where vegetation density dropped. In other words, vegetation density is generally more stable during wet seasons.

c. As mentioned earlier, the 1982 data was in 4km grid cells whereas the 1900 data 1km grid cells, and therefore such density levels occupying smaller portions of a cell were absorbed by a areally dominant level. Specifically, "very high" and "high" might have been more extensive in 1982 than represented in the data.

5.5.4 Regional variations of vegetation cover

Kenya has a total land area of about 590,000 sq. km and its regional characteristics can not be defined by the preceding studies of nation-wide vegetation variations alone. Therefore the land was divided into regions according to the Thiessen Method to study their regional variations. Figure R5.15 shows the regional divisions which were tentatively defined by Thissen's polygon. In Table R5.3. are given the areas of vegetation cover by region to help comparison. Bar charts were generated to indicate components of vegetation cover by region as shown in Figure R5.16 (1) to (4).

From these figures and tables, regional characteristics of vegetation cover are characterized as follows:

(1) LODWAR

The area has little vegetation cover and therefore the after-effects of the drought of 1981 were not as conspicuous as in some other regions. The areas rated "very high" and "high" during the 1982 dry season were found to be reduced substantially in the later seasons. This might have been partly due to errors in analysis but quite possibly be that the vegetations have been actually reducing. The "moderate" area in the 1982 wet season expanded in the 1990 dry season but the increase was small. Overall the area has no much vegetation cover, and the vegetation cover varies little between dry and wet seasons.

(2) MARSABIT

During the 1982 dry season, "scarce" accounted for as much as 80% showing the extent of after-effects of the drought. For the 1982 wet season and afterwards, "scarce" remained more or less 50% of the vegetation cover with little seasonal change. On the other hand, "sparse" of 1982 wet season was halved in 1989 and 1990. There were no significant changes between dry and wet seasons in 1989 and 1990.

(3) MOYALE

There was little change in vegetation cover through four seasons. The cloud cover in the 1989 wet season corresponds mainly to "scarce" area.

(4) MANDERA

This region is characterized by a conspicuous change in vegetation cover between dry and set seasons that involves "sparse" and "scarce" areas. "Scarce" accounts for 60-70% during the dry season whereas in the wet season "sparse" represents more than 90% of the vegetation cover.

(5) WAJIR

About 87% of the vegetation cover was "scarce" during the 1982 dry season reflecting the after-effects of the drought. The "scarce" had decreased since that times, and in the 1982 and 1989 wet seasons, it dropped to about 20%. But in the 1990 dry season it was about 50%. Obviously, "scarce" area varies sizably between the dry and wet seasons in this region.

(6) GARISSA

Like WAJIR, "scarce" accounted for about 80% during the 1982 dry season, but decreased sharply subsequently. During 1982 wet season, it seemed that "scarce" was replaced by "sparse". In 1989 and 1990, "sparse" and "scarce" combinedly represented only 13-22% while "high" and "moderate" were more than 30% each. There was little change in the composition of vegetation cover between 1989 wet season and 1990 dry season.

(7) LAMU

Similar to GARISSA, "scarce" appeared only during the 1982 dry season, and it looked almost replaced by "sparce" during the 1982 wet season. In the 1989 wet season, "sparse" of 1982 wet season was replaced by "moderate" and it remained so during the 1990 dry season. There was little change between 1989 wet season and 1990 dry season. "Water" of 1982 wet season was due to a slippage of the coastline in the data, which was inevitable in data handling.

(8) MOMBASA

"Clouds" of 1989 wet season presumably correspond to "high" and "moderate" areas. If so, there was little change in vegetation cover between the dry and wet seasons in 1982. Between 1989 wet season and 1990 dry season, there was some growth of "high" area but basically little change between the two seasons.

(9) VOI

During the 1982 dry season, "scarce" accounted for 55% and, combined with "sparse", it came to about 80%. But in the 1982 wet season, there was nearly no "scarce" with "sparse" and "moderate" accounting for 37% and 42% respectively. In 1989 and 1990, "very high" and "high" sharply increased to account for about 60%. From 1989 wet season to 1990 dry season, there was some change with decreased "high" and increased "sparse".

(10) NAIROBI

Like VOI, there was substantial change in the composition of vegetation cover between 1982 and 1989/90. Between dry and wet seasons of 1982, decrease in "scarce" and increase in "sparse" were conspicuous. On the other hand, during the 1989/90 seasons, "very high" and "high" increased noticeably. From 1989 wet season to 1990 dry season, there was a decline in "high" and an increase in "moderate".

(11) KERICHO

From 1982 to 1989/90, particularly noticeable were the decrease in "very high" and increase in "high". But the differences between 1982 dry and wet seasons and between 1989 wet season and 1980 dry season were small.

(12) KISUMU

Large "very high" areas of 1982 dry season could possibly be due to noise of data. In terms of the total of "very high" and "high" combined, 1982 dry season and 1990 dry season were nearly the same while 1982 wet season and 1989 wet season were much alike. In this region, vegetation cover is reduced during June-July period (herein called wet season) and increases during January-February period (herein called dry season).

5.6 Conclusion

From the above analysis of NOAA AVHRR data, it can be concluded as follows:

a. The 1982 analysis results clearly show that vegetation in larger areas had reduced substantially due to drought specific in the preceding year.

b. It appears that in 1989 and 1990 vegetation had recovered from the effects of the 1982 drought. But in the northern part of the country, vegetation cover has remained low in density. Comparing the analysis results of 2 years and 2 seasons, there seems no excessive declining of vegetation density having occurred in the country as a whole, but this should be subject to further confirmation in the future similar evaluation.

c. The 1989 and 1990 data seem to represent most typical vegetation pattern in view of rainfalls prevailed in those years.

NOAA Data Center started distribution of new data from May 1990. And their data is available for purchase in a more time saving manner than before. It is hoped that on the basis of the present analysis data, monitoring will be continued in future stages to assist in development planning and environmental preservation efforts.