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AN EVALUATION OF MULTI–SENSOR SATELLITE IMAGERY FOR MONITORING RANGELANDVEGETATION IN NORTHERN KENYA

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1 INTRODUCTION

In many semi-arid regions of the world, the typically sparse vegetation cover is under pressure from a combination of man's activities and climatic factors. Both these influences interact over the short and long term to affect the productivity of the vegetation cover.

In order to increase our understanding of the complex interaction between these factors and to devise strategies for effective management of rangeland resources, efficient mapping techniques are required to monitor the changing condition of the vegetation cover. With the development of earth observation from orbiting satellites, there has been increasing interest in the use of satellite derived indices of vegetation productivity, particularly in remote and poorly mapped regions of the world.

The objectives of this study are to assess the potential of multi-date satellite imagery for monitoring rangeland vegetation and to compare the results from a number of sensors of varying spatial and spectral resolution and temporal frequency (Table 1). The project has been undertaken at the National Remote Sensing Centre (NRSC) as part of its remit to develop and demonstrate the potential of satellite remote sensing for environmental monitoring.

1.1 The Study Area

The semi-arid Hedad region of Marsabit District, Northern Kenya (Figure 1) was selected for analysis. The region formed the study area of the Integrated Project for Arid Lands (IPAL) between 1976-86 as part of the UNESCO programme on Man and the Biosphere (MAB). A major component of the IPAL project was to investigate the interactions between the livestock population and the carrying capacity of the rangeland vegetation.

The Hedad is an area of very low and variable rainfall (less than 150mm/year), and is consequently prone to drought (Edwards et al, 1979). This low rainfall combined with high average annual temperatures results in a sparse vegetation cover. Pratt & Gwynne (1977) describe the vegetation as primarily wooded and/or bushed grassland, replaced by barrenland and/or dwarf shrubland in the Chalbi desert and low-lying lavas. The Hedad is a predominantly nomadic area peopled by the Rendille group who are dependent traditionally upon their livestock and indirectly therefore, the productivity of the vegetation resources for their livelihood.

In addition to a low and variable rainfall, man-made factors have had an important effect upon the vegetation cover, particularly over the last 20 years. Drought in the early seventies, combined with a doubling of the Rendille population (Lusigi, 1981) and a transition from a largely nomadic to a sedentary lifestyle, has resulted in severe desertification at some locations and a general loss of rangeland productivity over more extensive areas.

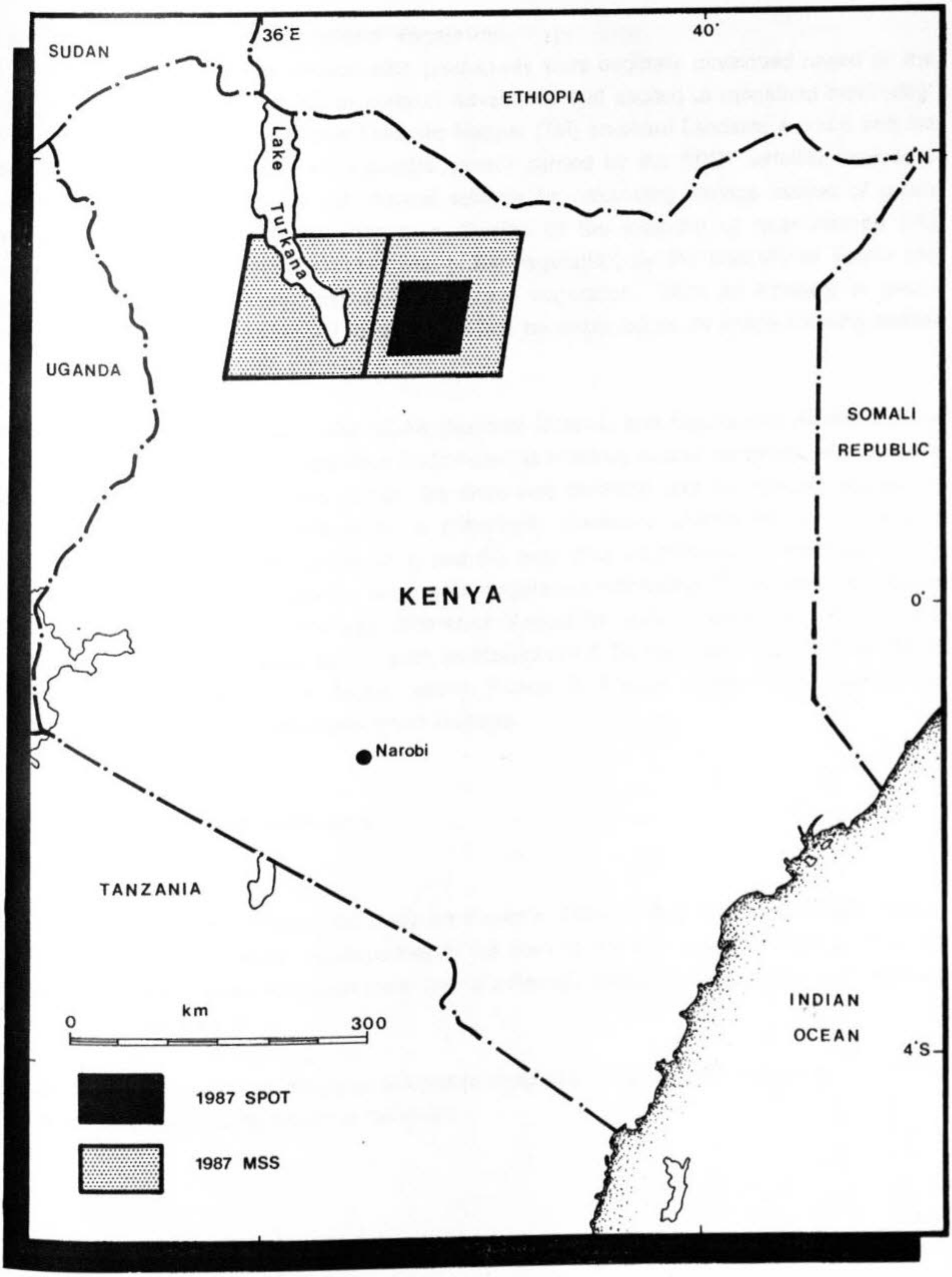

Figure 1 *Study area showing location of AVHRR, Landsat MSS and SPOT scenes.*

1.2 Remote Sensing of Rangeland Vegetation

A number of different indices of vegetation productivity were originally developed based on the Landsat multispectral scanner (MSS) spectral wavebands and applied to rangeland monitoring. In addition to Landsat MSS, both the Thematic Mapper (TM) on-board Landsats 4 and 5 and the High Resolution Visible (HRV) multi-spectral sensor carried by the SPOT satellite, include a near-infrared (IR) and a visible red channel suitable for calculating various indices of green vegetation. A simple vegetation ratio is a division of the intensity of near-infrared (IR) radiance, which is positively correlated with green vegetation, by the intensity of visible red radiance, which is negatively correlated with green vegetation. With an increase in green vegetation cover the ratio value will increase and can be displayed as an image showing spatial variations in green vegetation amount.

Although the spatial resolution of the NOAA (National Oceanic and Aeronautics Administration) AVHRR (Advanced Very High Resolution Radiometer) is relatively coarse compared with Landsat and SPOT (Table 1), the low cost of data, the large area coverage and the frequent acquisition capability of this sensor make it an a potentially attractive alternative for rangeland monitoring. The AVHRR visible (channel 1) and the near infra-red (channel 2) channels (Table 2) have been used increasingly for large area vegetation monitoring. Townshend & Justice (1986) used the AVHRR Normalised Difference Vegetation Index (NDVI) for studying the phenology of African vegetation. Others such as Henricksen & Durkin (1986) used AVHRR-NDVI for drought early warning in Africa, whilst Prince & Tucker (1986) investigated the correlation of NDVI with above ground green biomass.

2 SATELLITE AND GROUND DATA

2.1 Satellite Data.

The satellite data used in the present study are shown in Table 1. Both the Landsat MSS images and the SPOT (HRV) images are cloud-free in the area of interest. In the AVHRR scenes, the January and March images had cloud cover over the Hedad, although the December and February scenes were cloud free.

The data were purchased as computer compatible tapes (CCT's) and analysed using the GEMS image processing system at the NRSC.

Table 1 *Satellite image data for Hedad study area, Northern Kenya.*

Satellite	Path/row	Date acquisition
Landsat (1) MSS	181/058	31/01/1973
Landsat (2) MSS	181/058	02/06/1979
Landsat (5) MSS	168/058	24/01/1987
Landsat (5) MSS	169/058	15/01/1987
SPOT	138/345	10/02/1987
NOAA (9) AVHRR		30/12/1986
NOAA (9) AVHRR		07/02/1987
NOAA (9) AVHRR		04/02/1987
NOAA (9) AVHRR		04/03/1987

2.2 Ground Data

Ground data in the form of a vegetation map (Figure 2) and small format colour aerial photographs (Figure 3) were used to assist with the interpretation of the imagery. Additional information about the vegetation of the study area was obtained from the IPAL literature and from limited fieldwork (Griffiths, 1985).

The example of one of the small format vertical air photographs presented in Figure 3 illustrates the typical composition of the rangeland vegetation across much of the study area. In general, the rangeland consists of three components; bare soil, shrub and dwarf shrub vegetation and a herbaceous layer. The air-photograph was taken during the dry season; areas of bare soil appear reddish in colour, dwarf shrub and shrub plants give a characteristically rough texture and appear grey in colour and the ground layer of dry herbaceous species appear yellow. During and after rain the shrub and dwarf shrub understorey and the herbaceous ground layer develop green growth that can be detected using spectral ratios.

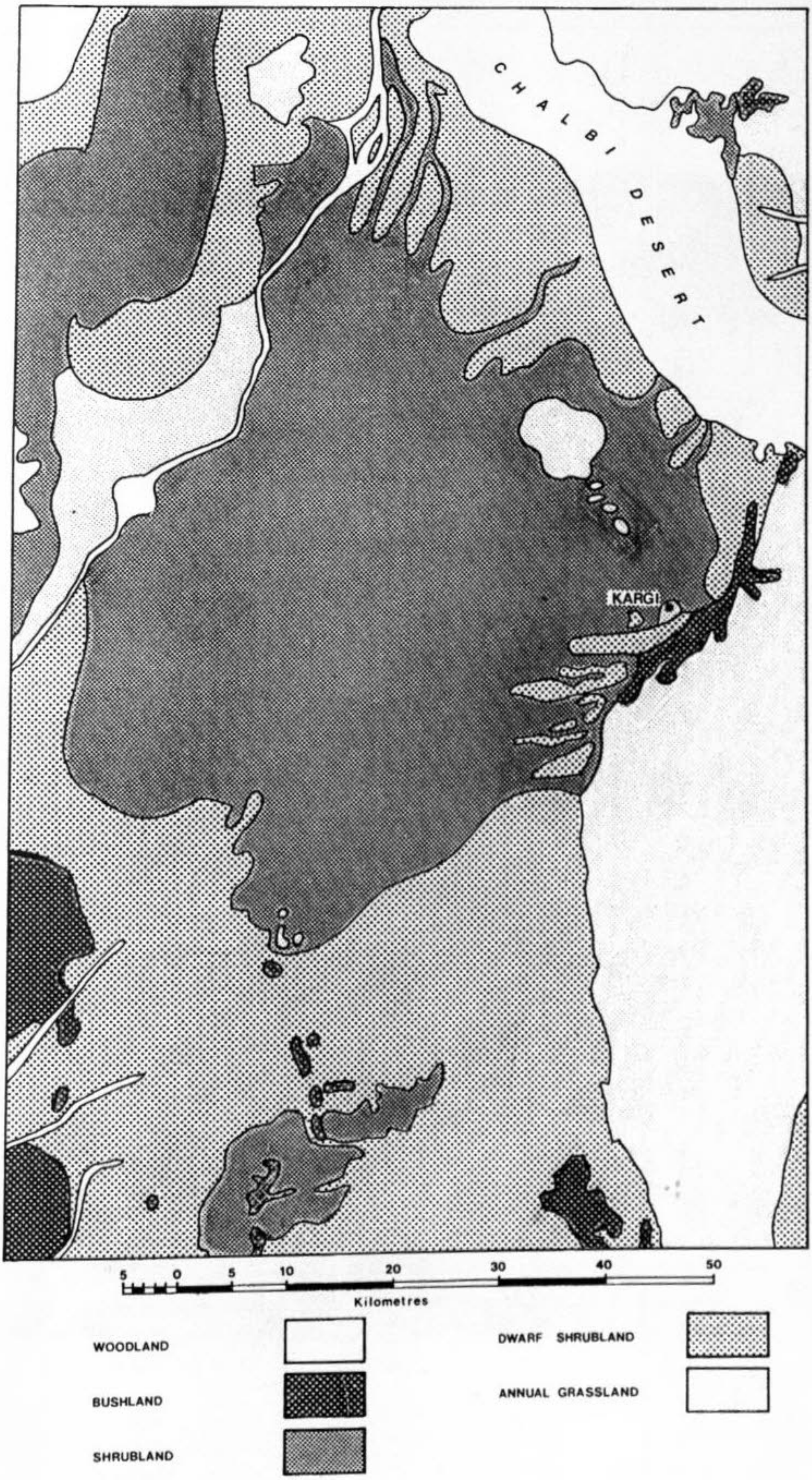

Figure 2 *Vegetation map of the IPAL study area (after Herlocker,1979)*

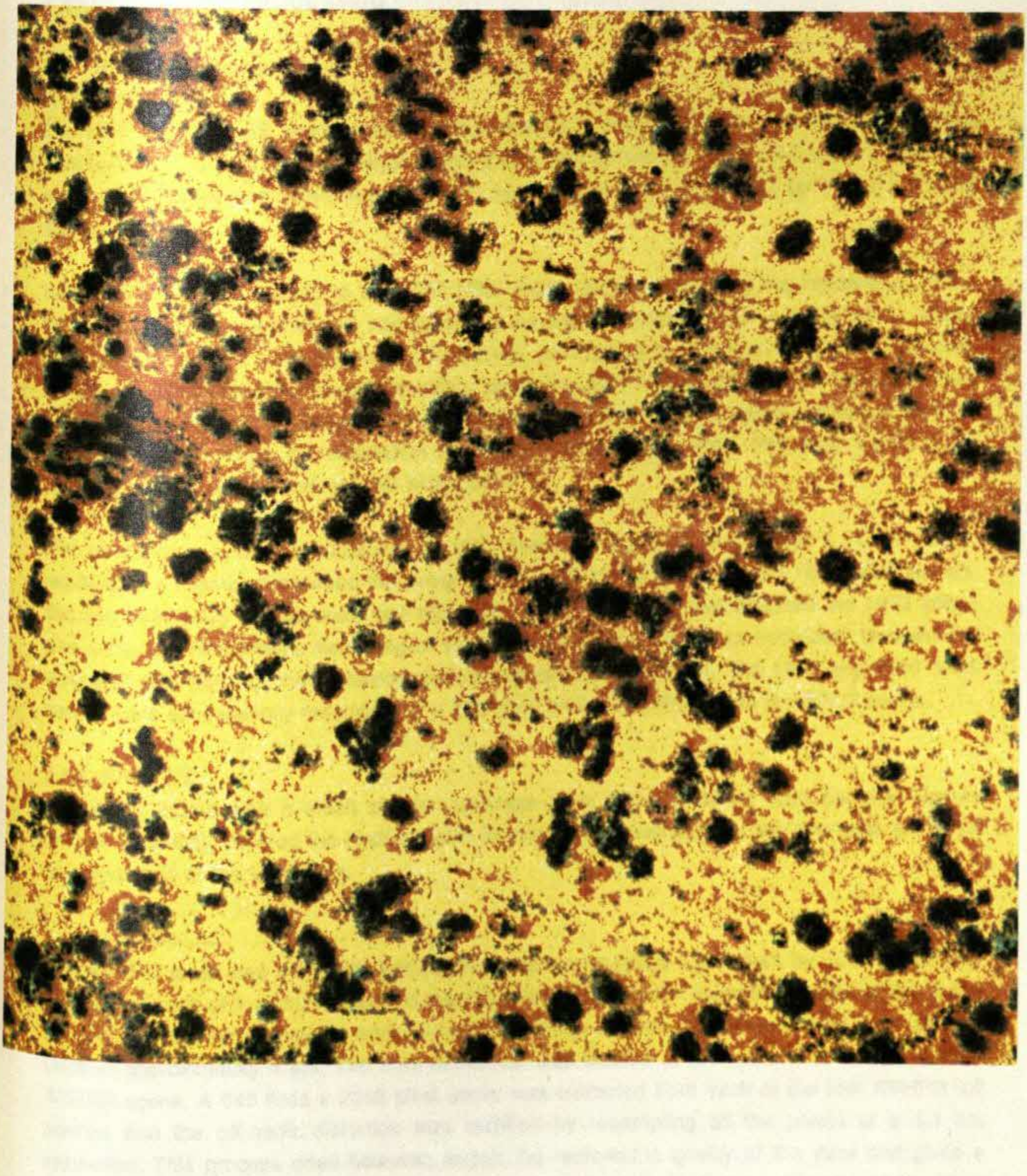

Figure 3 *Small format air-photograph of typical rangeland vegetation*

3 DIGITAL IMAGE PROCESSING

3.1 Pre-processing

3.1.1 Landsat MSS

The 1987 Landsat MSS image acquired by Landsat 5 is 8-bit data whilst the 1973 MSS image from Landsat 1 is 7-bit data for bands 1 and 2 and 6-bit for band 4. The 1973 MSS image data were subsequently converted into 8-bit data by multiplying the 7-bit data by 2 and the 6-bit data by 4.

Haze correction was applied to the 1987 MSS image data by analyisng the histograms of the visible red and near-IR channels and recording the lowest radiance value in each band. These minimum DN values were subtracted from their corresponding bands to yield much sharper images for interpretation and radiometrically corrected data for calculating ratio values. Where a major haze-induced additive effect is present in the image data, haze correction gives a greater dynamic range for vegetation ratios than uncorrected data. This was found to be necessary for the 1987 Landsat MSS image only.

The referencing system for Landsat 5 (1987 scene) is different to Landsat 1 (1973 scene) resulting in a mismatch between the geographical positions of the 1973 and 1987 MSS scenes. The two 1987 MSS scenes were first mosaiced and later an area that matched the 1973 image was extracted. Radiometric balancing of the two 1987 MSS scenes was necessary to make the west and east parts of the mosaiced extract radiometrically uniform. The 1973 and 1987 MSS scenes were subsequently resampled to a 20m pixel and co-registered with the SPOT scene.

3.1.2 SPOT-XS

The SPOT scene with a much smaller coverage area (60km x 60km) than Landsat scenes (185km x 185km), covered the Hedad region of interest and was used as the reference scene for co-registration of the MSS data.

3.1.3 AVHRR-LAC

The AVHRR local area coverage (LAC) data comprise an image 2048 lines by 5000 pixels with an IFOV at nadir of 1.1 km. The spatial resolution becomes coarser towards the edge of the scene as a result of earth curvature and off-nadir scanning, to give a maximum pixel size across-track of approximately 4 km. The area of interest was located at the extreme left edge of each AVHRR scene. A 640 lines x 2048 pixel scene was extracted from each of the four AVHRR full scenes and the off-nadir distortion was rectified by resampling all the pixels to a 1.1 km resolution. This process does however, impair the radiometric quality of the data and gives a slightly smoothed image of blurred appearance; in preference the image area should be taken from the central portion of each AVHRR scene. The four AVHRR image extracts of the study area were co-registered by resampling.

Since the image is scanned from south to north its orientation must be reversed by rotating the image 180 degrees. AVHRR data are in 10-bit format and cannot be displayed on the 8-bit GEMS image processing system without a division by 4 conversion to 8-bit format.

Table 2 *Radiometric and spatial resolution of sensors*

	Channel	Wavelength (micrometers)	Resolution (metres)
(a) AVHRR			
	1	0.58-0.60	1100
	2	0.76-1.10	1100
	3	3.55-3.93	1100
	4	10.30-11.30	1100
	5	11.50-12.50	1100
(b) Landsat MSS			
	1 green	0.5-0.6	79
	2 red	0.6-0.7	79
	3 red/ IR	0.7-0.8	79
	4 nearIR	0.8-1.1	79
(c) SPOT XS			
	1	0.50-0.59	20
	2	0.61-0.68	20
	3	0.79-0.89	20

3.2 Vegetation Mapping

3.2.1 False Colour Composite Imagery.

The SPOT false colour composite (FCC) image was created by displaying bands 1, 2 and 3 in blue, green and red respectively, whilst the FCC of the Landsat MSS scenes were created by assigning bands 1, 2 and 4 to the blue, green and red. In both cases the imagery was contrast enhanced to facilitate image interpretation.

The AVHRR FCC images were created by using channel 1 (visible red) and channel 2 (near-IR) and then displaying channel 1 in two colour guns and channel 2 in one colour gun. For example, displaying channel 1 in blue and red and channel 2 in green highlighted vegetation in green, or alternatively if channel 1 is displayed in blue and green and channel 2 in red, vegetation is highlighted in red. Displaying vegetation in red gave better contrast with the non-vegetated background image, but may not be a suitable display for a non-expert who is unfamiliar with the techniques of false colour display. The contrast enhanced FCC images were interpreted visually to monitor vegetation change between image dates.

3.2.2 Principal Component Analysis (PCA).

Principal components analysis (PCA) creates new uncorrelated components from the original correlated bands. Landsat bands 1, 2 and 4, SPOT bands 1, 2 and 3 and AVHRR bands 1 and 2 of the December and March AVHRR image data were used for PCA analysis. The information content expressed in per cent for each component and the contribution from each band on the component is given in Table 3.

Table 3 *The percent composition of the new transformed components and the contribution from each band on the new component*

(a) 1987 combined MSS extract

		1	2	3
1	95.4	0.39	0.63	0.67
2	3.9	0.77	0.18	-0.61
3	0.7	0.51	-0.76	0.41

(b) 1987 SPOT HRV whole scene

1	99.2	0.58	0.57	0.57
2	0.7	-0.75	0.10	0.66
3	0.1	-0.32	0.81	-0.49

(c) 1973 LANDSAT MSS

1	96.0	0.54	0.59	0.60
2	3.0	0.84	-0.31	-0.44
3	1.0	-0.07	0.75	-0.60

(d) 1986 DECEMBER AVHRR

1	89.5	0.64	0.76
2	10.5	0.76	-0.64

Principal component 1 (PC1) contains almost all the information in the original bands for the MSS, SPOT and AVHRR image data. Almost all the spectral information of the SPOT image data is contained in PC1 (99.2%) indicating a very high correlation between the three bands. For the less vegetated 1973 MSS scene, the contribution from vegetation is low (1 percent) and contained in PC3, in contrast to the much more densely vegetated 1987 MSS scene where the contribution from vegetation is much higher (3.9 percent) and is contained in PC2. The PCA transform was applied to the MSS, SPOT and AVHRR image data to produce enhanced imagery with PC1 assigned to the blue, PC2 to the green and PC3 to the red.

Figure 4a *Landsat MSS false colour composite imagery of the Hedad study area for January 1973*

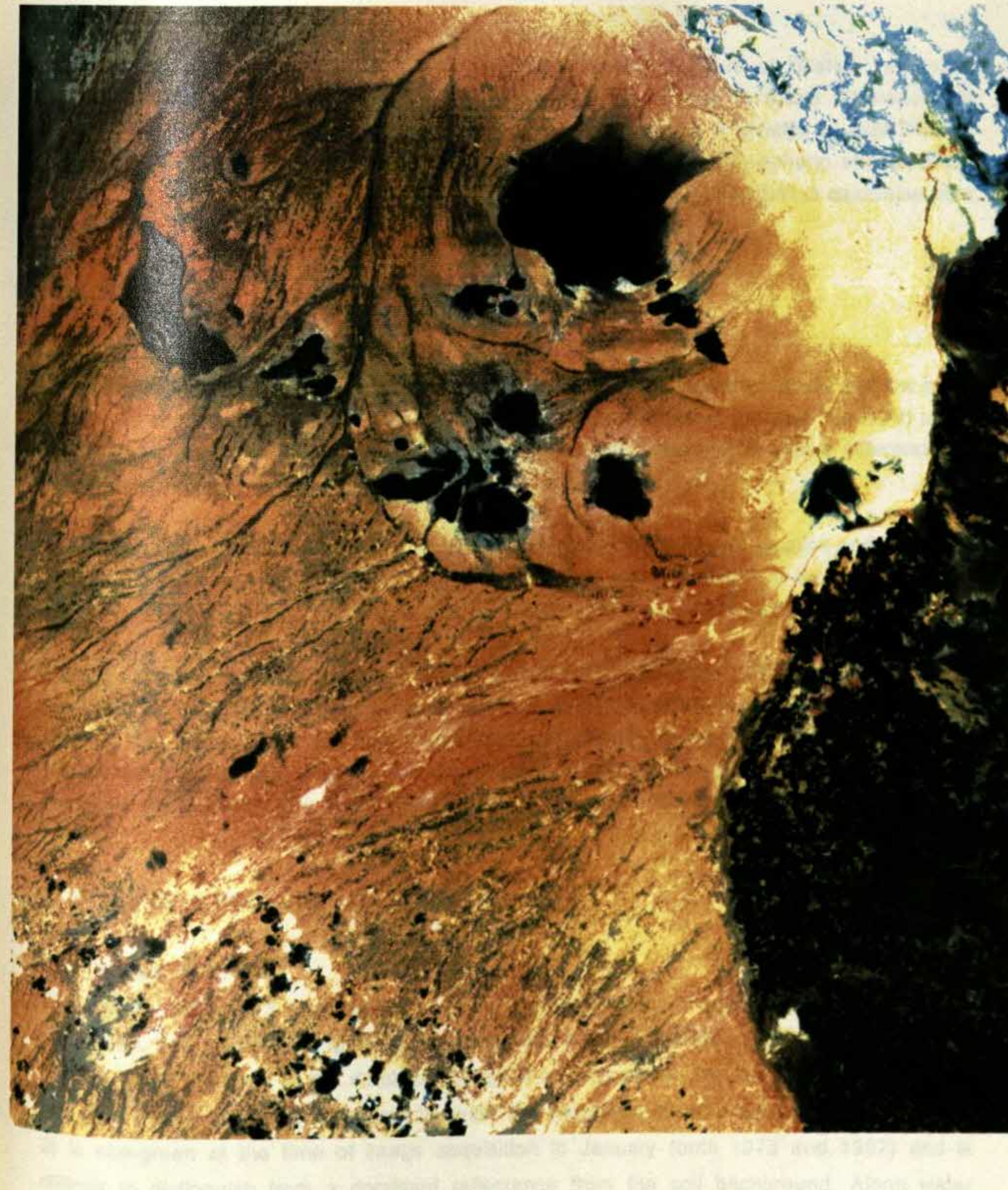

Figure 4b ***Landsat MSS false colour composite imagery of the Hedad study area for January 1987***

3.2.3. Normalised Difference Vegetation Index (NDVI)

Although a simple ratio of MSS7/MSS5 provides a useful measure of relative vegetation greenness, spatial differences in brightness within a scene and temporal differences in brightness between scenes introduces a large error component. A division of MSS7-MSS5 normalised over the sum of MSS7+MSS5 reduces multiplicative atmospheric effects which cause temporal and spatial variations in average scene brightness. The NDVI is calculated from the following expression:

$$\frac{\text{Near infrared - red}}{\text{Near infrared + red}}$$

High index values are associated with the presence of high green vegetation cover and low index values are obtained for bare soil, cloud and water, e.g., Lake Turkana. Although the NDVI is not an absolute measure of biomass, the index provides a useful measure of relative differences in green vegetation amount.

NDVI images were produced for all three image types using the standard equation and scaled by 100 with a constant (100) added to ensure positive numbers. The NDVI images were divided into 10 percentiles, to facilitate comparison between the different image types.

The SPOT, Landsat MSS (1973 and 1987) and AVHRR (December, January, February and March) NDVI images were density sliced for each percentile to enhance differences between areas of low, intermediate and high vegetation cover. Density slicing (level slicing) is a colour enhancement technique whereby the DN values distributed along the *x* axis of an image histogram are divided into a series of intervals or slices which are displayed in colour.

4 INTERPRETATION AND ANALYSIS OF IMAGERY

4.1 Landsat MSS

The Landsat MSS 1973 and 1987 false colour imagery (Figure 4 (a,b)) displays a number of vegetation and geological features very clearly. Mature riverine forest (mostly *Acacia Tortilis*) along the base of the Kulal and Marsabit lava (green on the image) appears in deep red. Over large parts of the study area however, the vegetation cover of sparse bush (see Figure 3) is non-green at the time of image acquisition in January (both 1973 and 1987) and is difficult to distinguish from a dominant reflectance from the soil background. Along water courses ('luggas') however, the bush cover is sufficiently dense to be clearly visible in grey tones.

The 1987 image displays a distinctive reddish tone characteristic of actively growing green vegetation over a restricted area of the scene. This is believed to be caused by an ephemeral annual grasses which 'green-up' in response to rainfall. This green 'flush' is absent from the 1973 image, which was acquired under drought conditions thst prevailed during the early 1970's. It is not clear why active green herbaceous vegetation is distributed in this way; the patterns may be related to soil or topographical control of sheetwash. Remaining areas on both images are either barren saline flats of the Chalbi-desert (blue-white) or severely degraded areas of negligible vegetation cover (orange) close to the settlement of Kargi.

The FCC of the 1987 MSS principal components (1,2 and 3) also enhanced the area of green vegetation, with green vegetation appearing more clearly in yellow on the transformed PCA imagery (Figure 5) than on the untransformed FCC imagery. .

4.2 SPOT False Colour Composite Imagery

The very high resolution of the SPOT false colour composite imagery enables a considerable amount of additional detail about the vegetation cover to be obtained compared with the MSS (Figure 6). In particular, variations in the distribution of the ephemeral herbaceous cover and the density of the bush cover are clearly visible. In some areas, resolution is sufficienly high to show that areas visible as green vegetation are composed of bush and shrub as well as herbaceous species. Imagery of this type would be useful for refining detail on vegetation maps, such as the one illustrated in Figure 2.

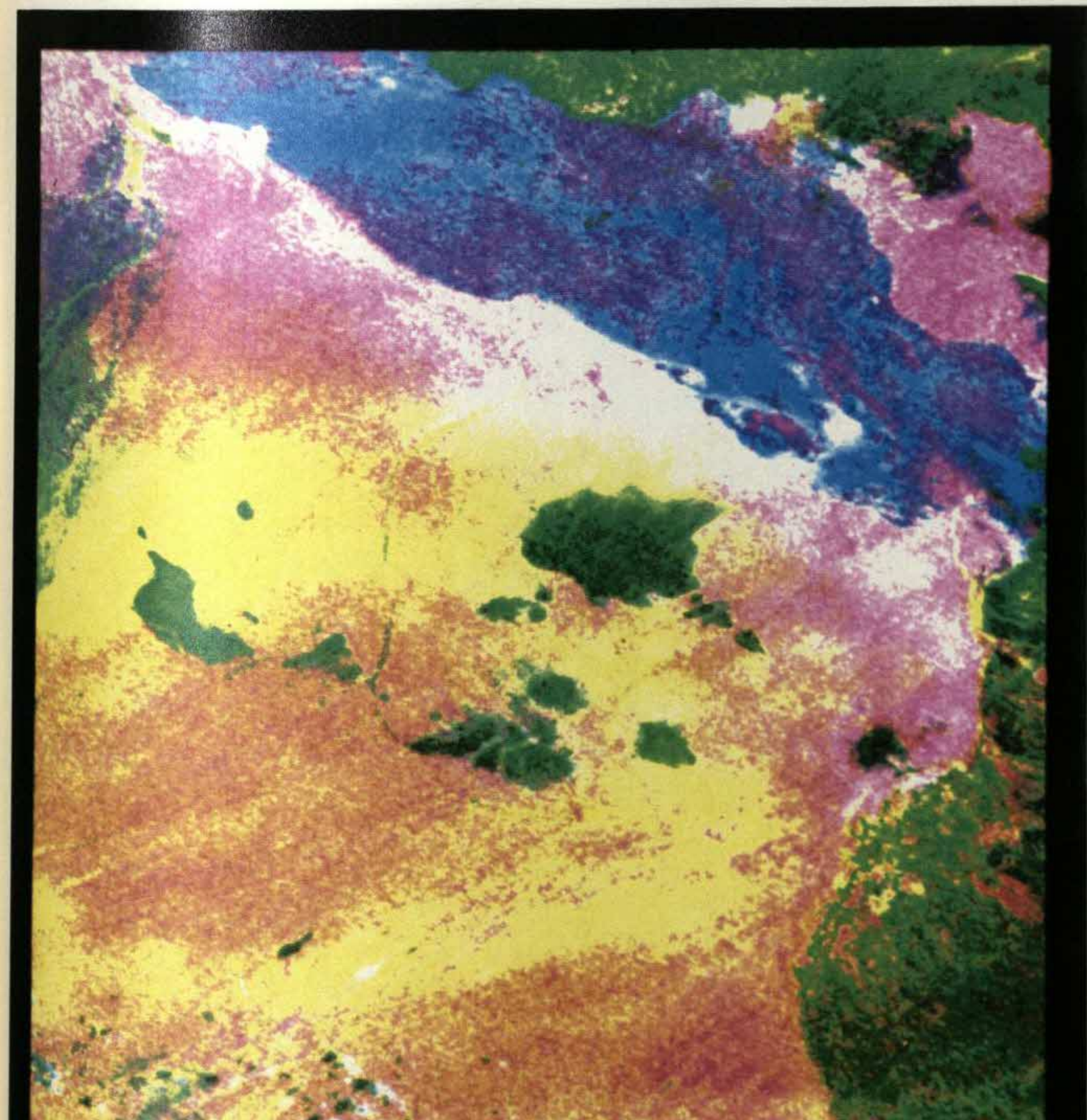

Figure 5 *Principal components transformed image of the January 1987 MSS scene*

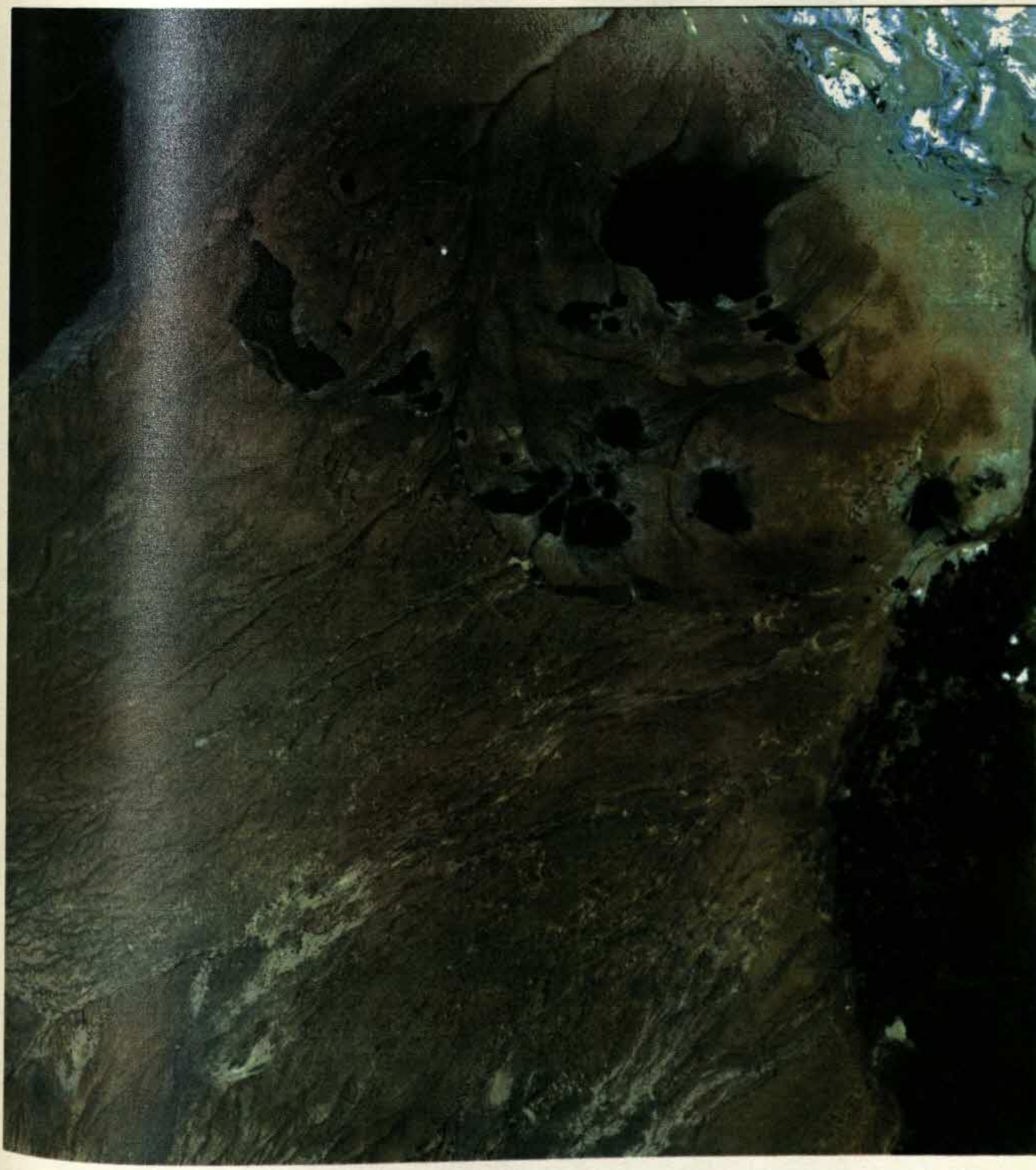

Figure 6 *SPOT-XS false colour composite image of the Hedad study area; February 1987 (Copyright Cnes 1987)*

4.3 Analysis of Change from AVHRR imagery

The false colour composite AVHRR images show a continuous decline in green vegetation (Figure 7 (a,b,c,d)) between December 1986 and and March 1987, both within the rangeland areas in the centre of the images and in the bush and grassland vegetation at higher altitudes on the slopes of Mount Kulal and Mount Marsabit. Only the evergreen montane forest crowning the summits of these two mountains remains productive during the dry months of January, February and March.

In the rangeland areas the light green tones of the productive vegetation is particularly obvious on the December image following the 'short-rains' in November, but these areas have almost disappeared by March at the end of the dry-season.

The decline in green vegetation within the rangeland is confirmed by reference to the colour density-sliced NDVI imagery of the same four AVHRR images (Figure 8 (a,b,c,d).

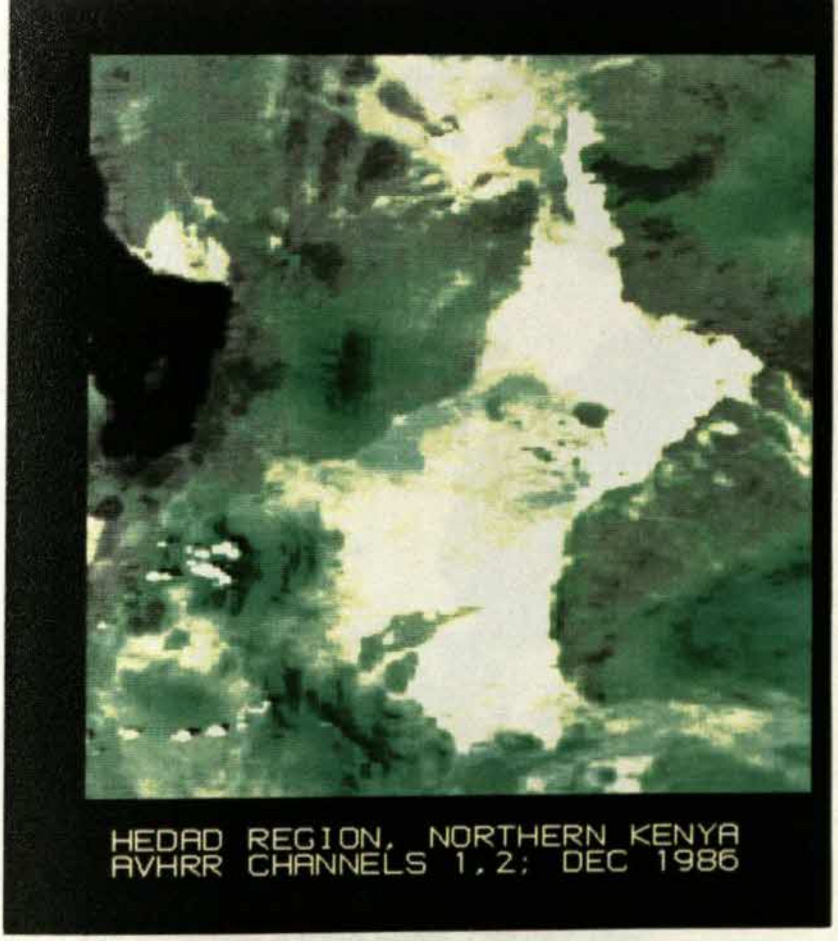

Figure 7a *False colour composite AVHRR image; December 1986*

Figure 7b *False colour composite AVHRR image; January 1987*

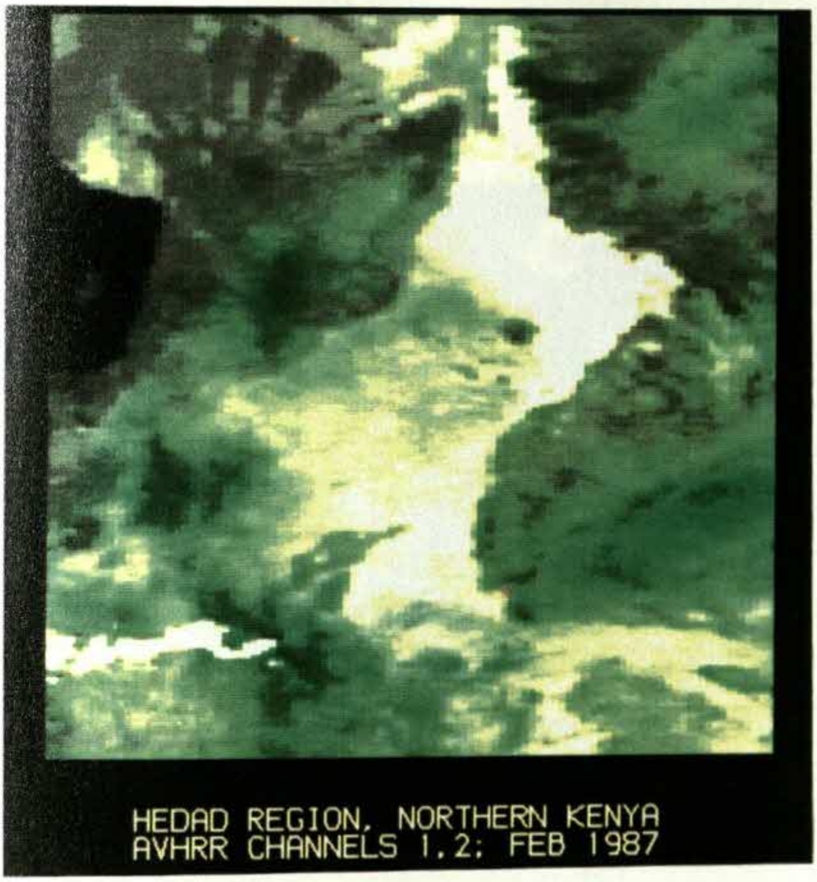

Figure 7c *False colour composite AVHRR image; February 1987*

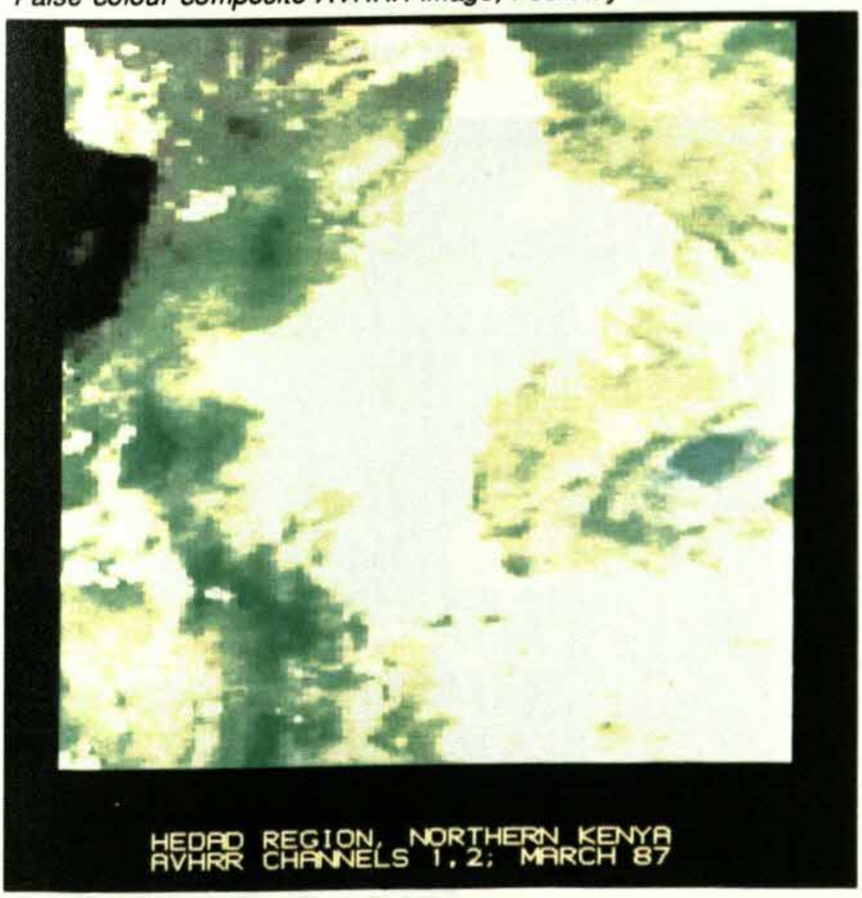

Figure 7d *False colour composite AVHRR image; March 1987*

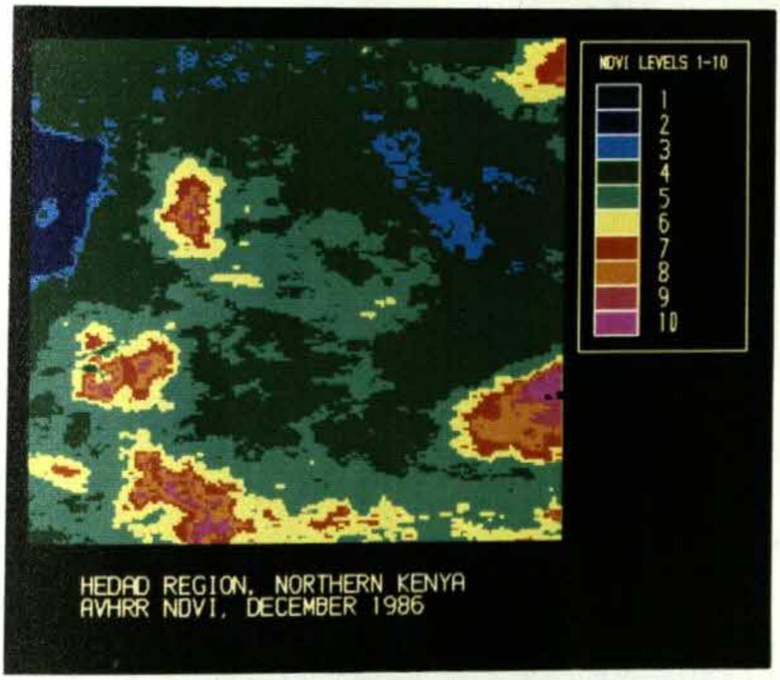

Figure 8a *AVHRR NDVI image; December 1986*

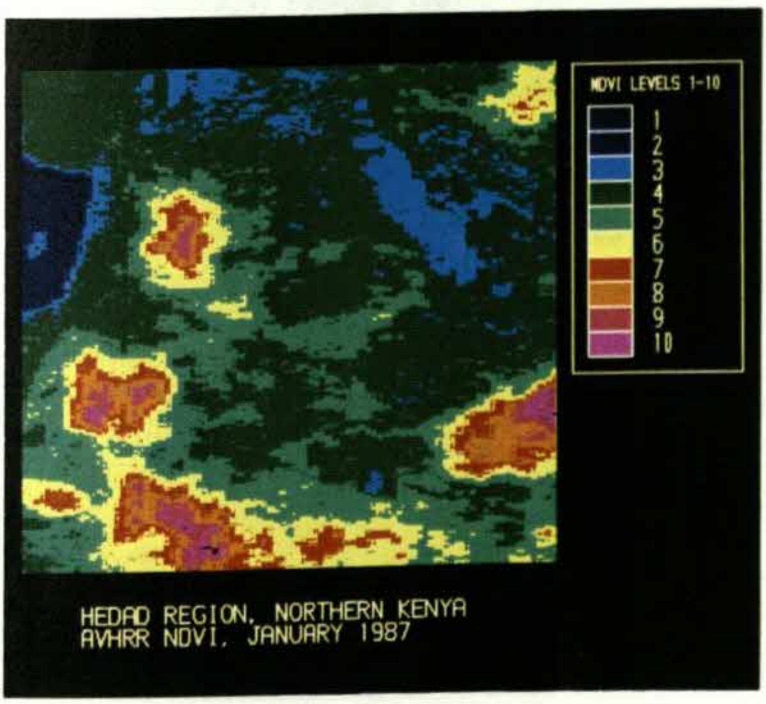

Figure 8b *AVHRR NDVI image; January 1987*

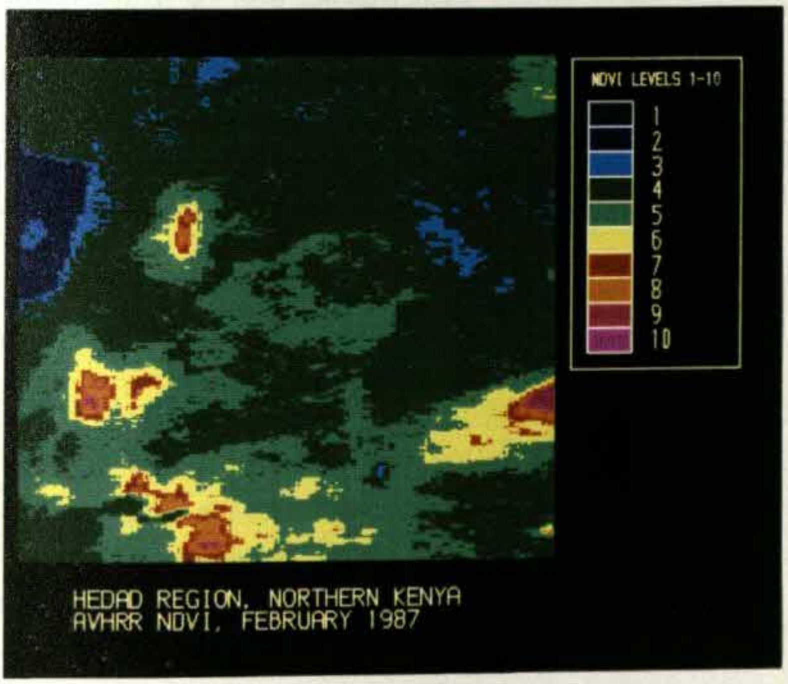

Figure 8c *AVHRR NDVI image; February 1987*

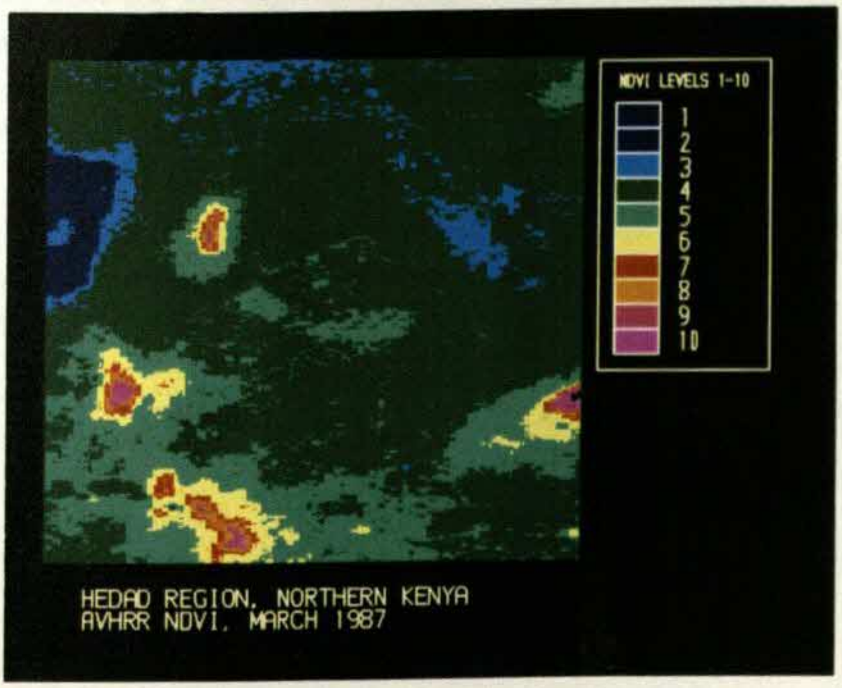

Figure 8d *AVHRR NDVI image; March 1987*

4.4 Comparison of AVHRR, MSS and SPOT NDVI imagery

To ensure that vegetation conditions were as similar as possible between scenes from different sensors, the AVHRR, SPOT and Landsat MSS scenes which corresponded most closely in acquisition time (04.02.87, 10.02.87 and 24.01.87 respectively) were selected for detailed study. The SPOT image was chosen as a reference image and the MSS and AVHRR image data were resampled to match the same geographic area as the 60km x 60km SPOT scene. A nearest neighbour resampling algorithm was used to minimise radiometric modification of the image data. This produces a rather blocky appearance to the coarse resolution AVHRR data.

A 512 x 512 pixel extract was selected for detailed comparison of the AVHRR, SPOT and MSS scenes.

The three NDVI images of the Kargi subscene (Figure 9) derived from the AVHRR (9a), MSS (9b) and SPOT (9c) image data show broadly similar patterns in their distribution of NDVI values. The encouraging aspect of this comparison is that, despite the relatively coarse resolution of the AVHRR sensor, the AVHRR-NDVI is sensitive to green vegetation even at the low density of cover which characterises this region.

However, whilst a broad correspondence is apparent for areas where green vegetation is widely distributed, at the coarse resolution of an AVHRR pixel many minor features, such as riverine *Acacia tortilis* woodland with high NDVI values, are not detected on the AVHRR-NDVI image. This was also apparent from a comparison of the standard false colour composite images for the SPOT, MSS and AVHRR imagery, in which small areas of dense green vegetation were not detected on the AVHRR colour composite image.

The spatial correspondence in the distribution of NDVI values is closer between the SPOT and MSS images than between either the SPOT and AVHRR or between the MSS and AVHRR-NDVI imagery (Table 3).

Table 3 *Correlation matrix for AVHRR, SPOT and MSS image pairs*

	AVHRR	SPOT	MSS
AVHRR	1.0	0.74	0.76
SPOT		1.00	0.81
MSS			1.00

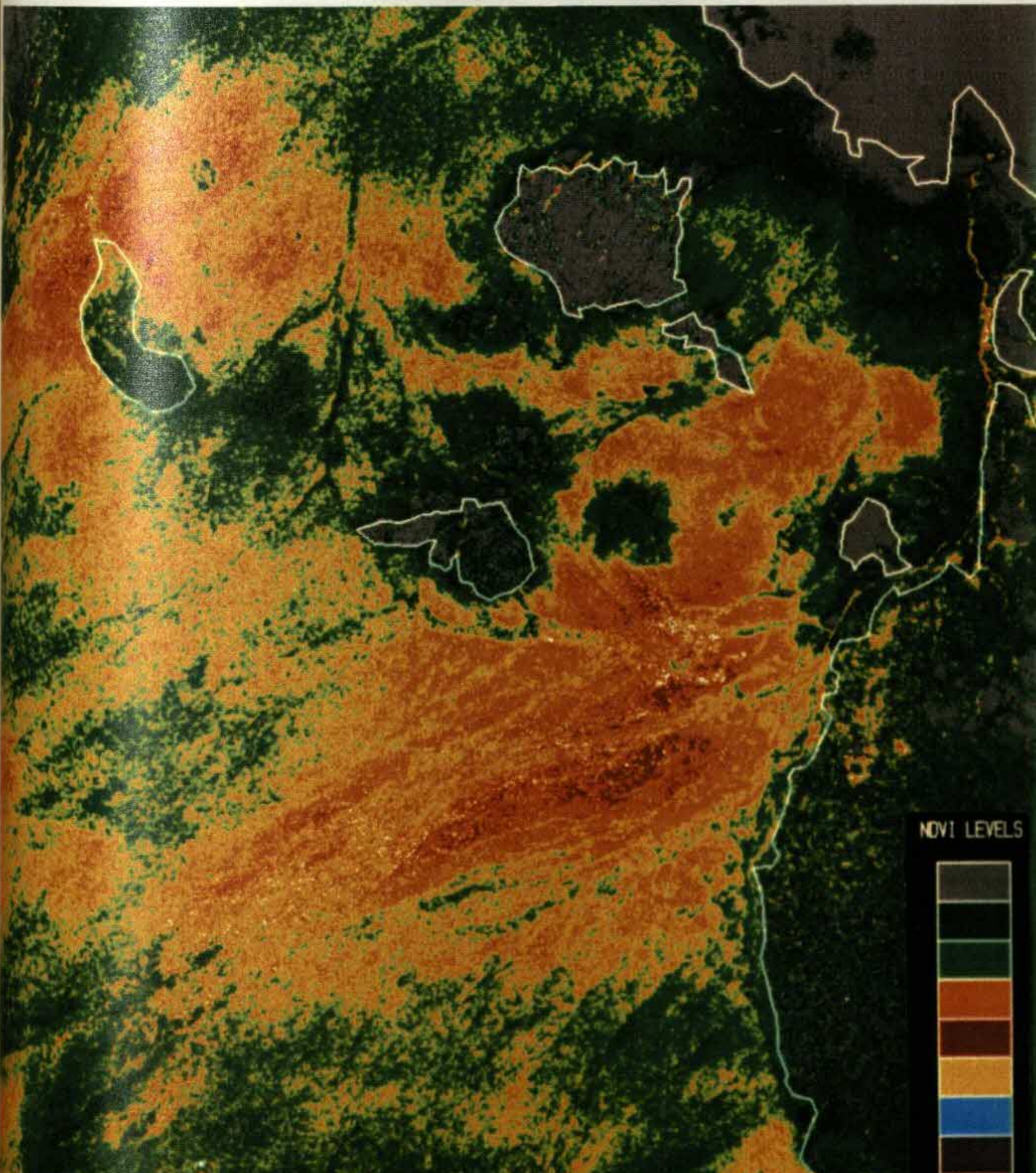

Figure 9a SPOT NDVI image for the Kargi subscene

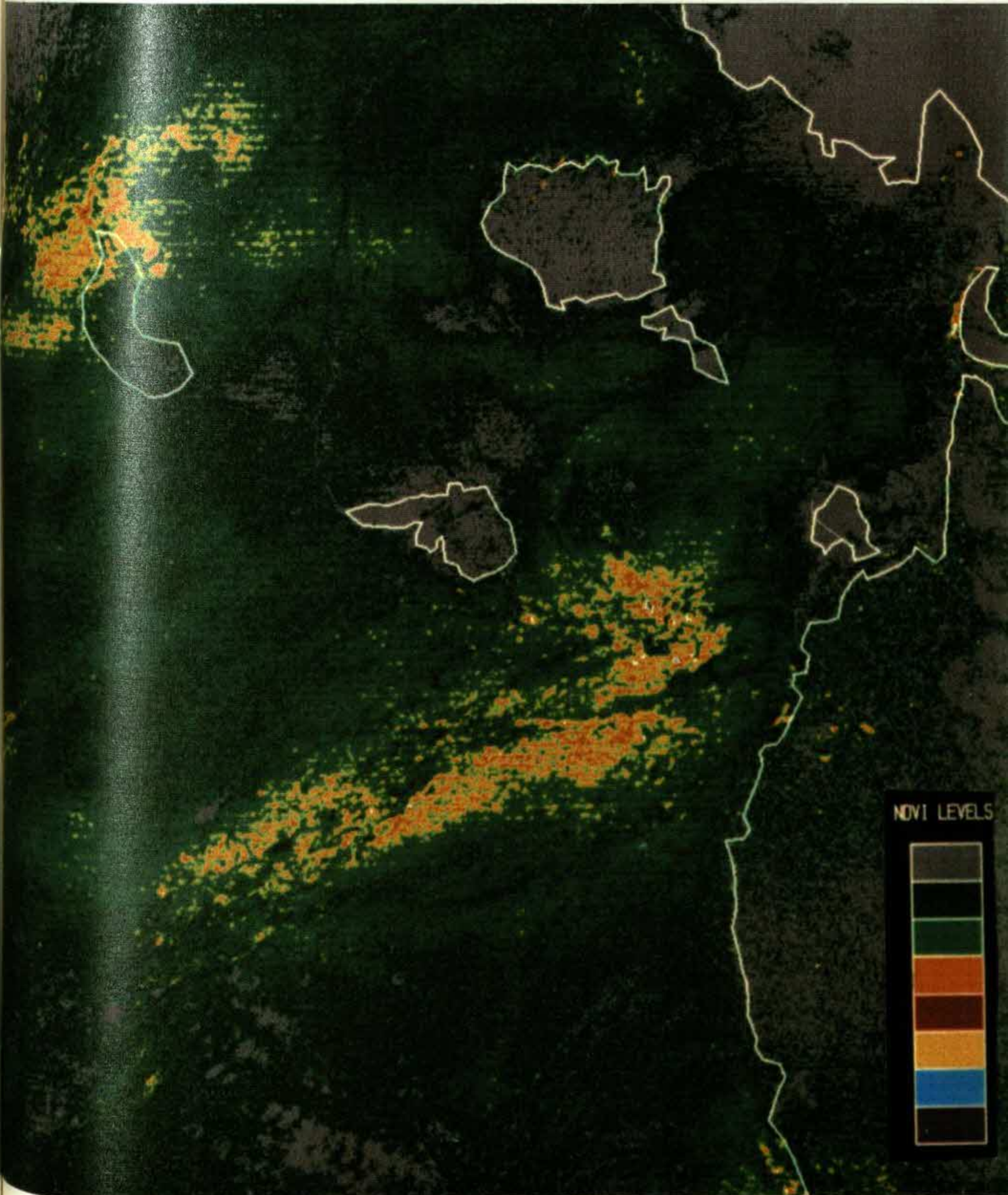

Figure 9b *MSS NDVI image for the Kargi subscene*

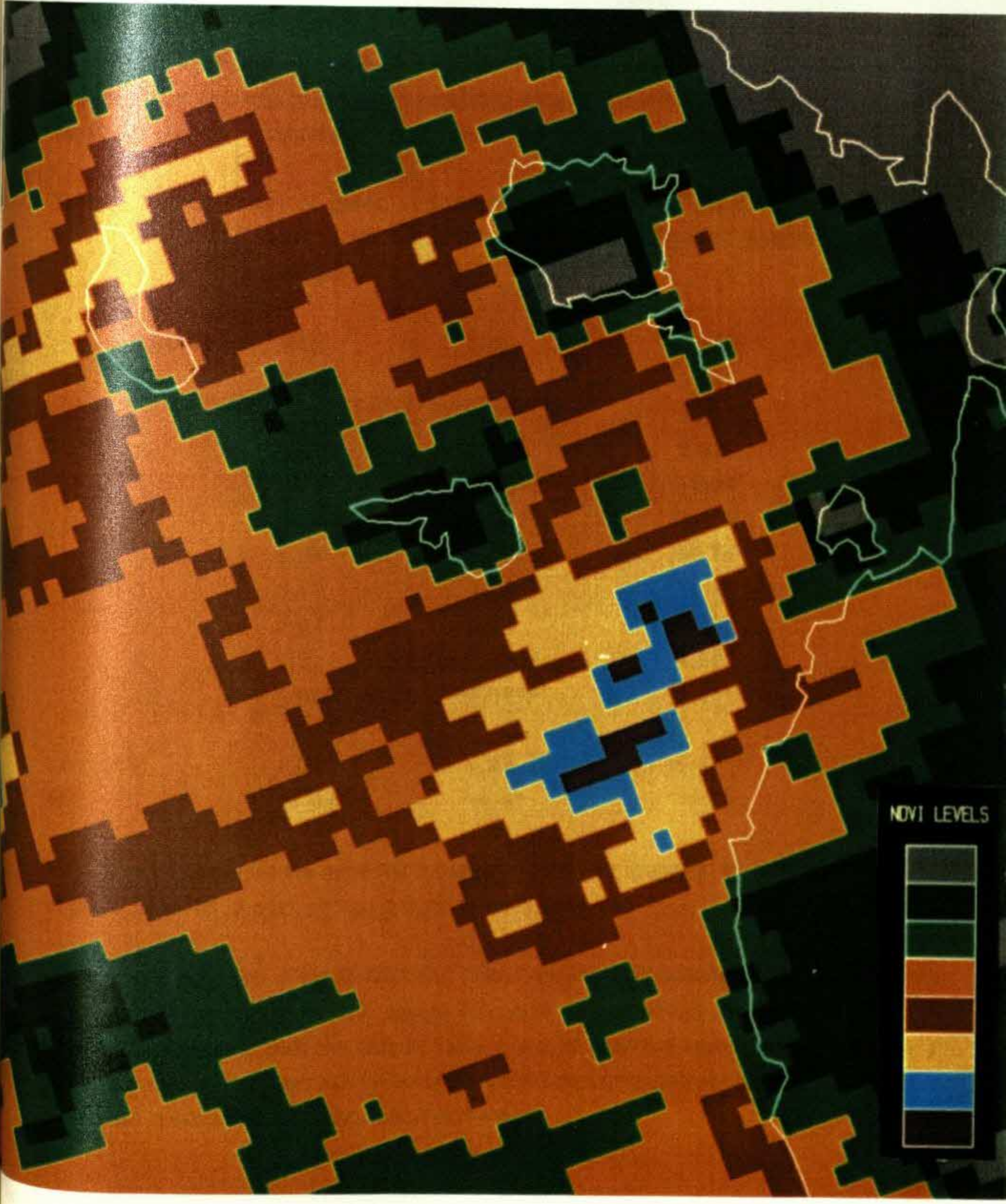

Figure 9c *AVHRR NDVI image for the Kargi subscene*

The estimates for the total area of green vegetation at each NDVI level differ considerably between the AVHRR-NDVI and the SPOT, MSS NDVI (Table 4). In particular, the AVHRR-NDVI underestimates the area of low green vegetation amount and overestimates areas of high green vegetation amount, in comparison with the SPOT and MSS-NDVI imagery.

Table 4 *Comparison of green vegetation cover estimates (percent) in each NDVI level (1-10) for SPOT, MSS and AVHRR-NDVI images in the Kargi subscene.*

NDVI level	SPOT	MSS	AVHRR
1	0.13	0.42	0.36
2	2.69	3.79	1.06
3	15.39	13.55	2.99
4	55.01	41.15	10.04
5	24.49	35.67	24.72
6	1.94	4.97	30.74
7	0.12	0.21	16.21
8	0.04	0.04	8.43
9	0.01	0.0009	4.02
10	0.0005	0.0009	1.25
Mean NDVI	4.08	4.23	5.89
S.D.	16.96	14.81	10.20

The differences between the three NDVI images can also be illustrated by plotting the frequency of pixels occurring at each of the 10 NDVI levels (Figure 10).

At the spatial resolution of the AVHRR LAC data, recorded reflectance is an integrated response from an area measuring 1.1 km. square compared with individual SPOT pixels which only measure 20m square. Both the data in Table 4 and its graphical representation in Figure 10, show an increase in the mean NDVI value of the AVHRR data compared with the SPOT and MSS and a decrease in the standard deviation about each mean.

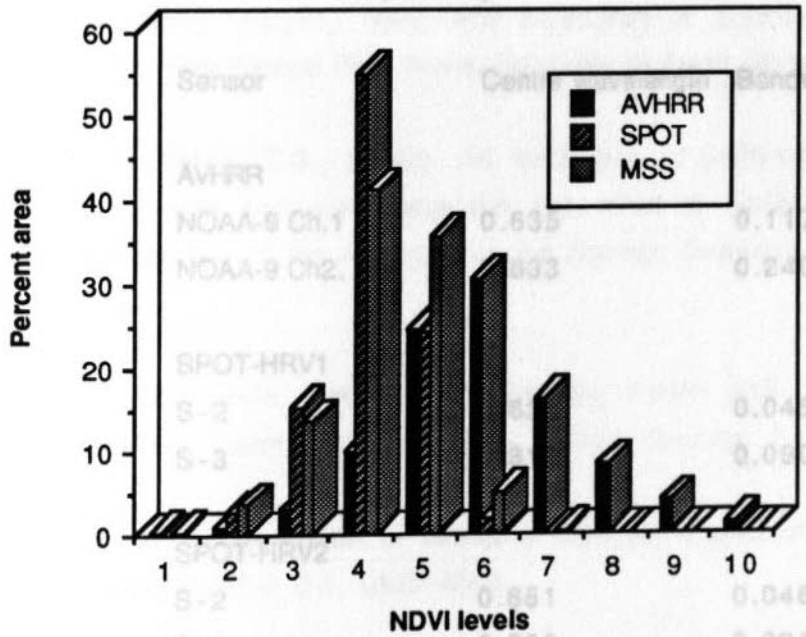

Figure 10 Comparison of NDVI estimates from SPOT, MSS and AVHRR

It is argued that there are two factors which explain these differences. Firstly, the coarse resolution AVHRR data is effectively smoothed compared with the fine resolution SPOT and MSS data. The smoothing results in the observed lower standard deviation about the mean NDVI value for the AVHRR data and, to a lesser extent, for the Landsat MSS data which has a pixel size of 80m square. Secondly, the bandwidth of the AVHRR near-IR channel (channel 2) is much broader than the SPOT (channel 3) and MSS (channel 4) near-IR bandwidths (Table 5). The wider bandwidth of AVHRR channel 2 means that more near-IR reflectance is sampled by the AVHRR sensor to give a higher NDVI value for the same green vegetation amount compared with SPOT and MSS with their narrower bandwidths in the near-IR spectral region.

Table 5 *Centre wavelengths and spectral bandwidths for AVHRR and SPOT data (microns)*

Sensor	Centre wavelength	Bandwidth
AVHRR		
NOAA-9 Ch.1	0.635	0.117
NOAA-9 Ch2.	0.833	0.240
SPOT-HRV1		
S-2	0.638	0.045
S-3	0.816	0.090
SPOT-HRV2		
S-2	0.651	0.046
S-3	0.836	0.091

5 DISCUSSION

The effectiveness of multi-date satellite imagery for mapping and monitoring rangeland vegetation was investigated in a semi-arid region of northern Kenya. In particular, the results obtained from sensors of varing spatial and radiometric including SPOT, Landsat MSS and AVHRR imagery, were compared.

Spatial variations in the distribution of green vegetation were apparent on all false colour composite SPOT, Landsat MSS and AVHRR scenes. For example, green vegetation which appears in red tones on false colour imagery, was clearly visible in the central area of the Hedad study area and along seasonal water courses in the Landsat MSS (1987), SPOT HRV (1987) and AVHRR images of December 1986, January, February and March 1987. Most importantly, the location of this mapped green vegetation was consistent between between sensors, with areas of green vegetation visible on the finer spatial resolution of the SPOT and Landsat MSS imagery also apparent at the much coarser resolution of the AVHRR sensor.

The visual interpretation of green vegetation was quantified using the NDVI index; quantification of the distribution of green vegetation enables exact comparisons to be made between imagery of different dates and types. The AVHRR images showed a rapid decline in green vegetation cover between December 1986 and March 1987, particularly in the sparsely vegetated rangeland areas. However, quantitative estimates of vegetation amount from the AVHRR imagery need to be calibrated with reference to higher resolution imagery; a procedure to do this is described in Griffiths and Tekie (1990).

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