SATELLITE MONITORING OF VEGETATION AND GEOLOGY IN SEMI - ARID ENVIRONMENTS

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SUMMARY

The aim of the study has been to utilize different techniques for image manipulation of satellite registrations to evaluate their maximum practical usefullness within the applied fields of:

- Vegetation
- Geology
- Geomorphology
- Soils
- Ecology
- Hydrology

The study is part of an ecological project with the overall aim of assessing the impact on the environment of the flooding and regulation of the water in the Mtera reservoir in Tanzania.

Landsat registrations from different occasions were used to collect basic ground data within the listed fields of interest. Interpretation and mapping were carried out in black and white as well as in colour infrared images on the scale of 1:250 000.

Several computer techniques were also used, including:

- Contrast-stretched ratioing
- Differential edge enhancement
- Supervised classification
- Multitemporal classification and change detection

The results of the study show that *interpretation* of black and white Landsat photos is greatly facilitated by the use of the four different wave length bands. It is also extremely valuable to have access to different registrations from various seasons, since different information can be gained from each image. For interpretation purposes, the most useful image is made from band 5. Most of the additional information on band 5 is gained from one of the two near infrared bands 6 or 7. For interpretation of vegetation and geology, the use of black and white images is much more time-consuming and the result less reliable as compared with colour infrared images.

The conclusion is that the advantages of using colour infrared images are so great that they should be used basically for all interpretation, while black and white images should only be used to supplement the coloured images.

Contrast-stretched ratioing can often be used as a faster and less costly approach as compared with supervised classification. The method enables a larger area to be divided into sub-areas with uniform characteristics regarding, for instance, geology and vegetation. The technique could then be useful in the initial phase of a study where the determination of uniform areas simplifies the field survey.

Differential edge enhancement is particularly useful to detect tectonic features. Lineaments are exaggerated and thus possible to detect, while visual image interpretation gives the major tectonic pattern only.

The advantage of *supervised classification* is the very detailed nature of the information which becomes available for analysis. Tne characteristics of very small areas make it possible to distinguish even minor differences in large-scale patterns.

Multitemporal classification, using two or more registrations simultaneously in the classification, gives more varied separation of classes in comparison with the information from one single registration. *Change detection* is useful in the separation of changes between two occasions, for instance, a decrease in the cover as a result of forest clearance.

The result of the work certainly shows how immensely useful the Landsat technique may be within several fields of data acquisition and analysis. The advantages it has over many conventional methods in use at present are also clearly demonstrated.

RECOMMENDED USE

A brief discussion of the potential usefulness of the analysis techniques described is given below.

Colour infrared images

The Landsat colour infrared images on the scale of approximately 1:250 000 proved to be of a great use in the classification of, for example, vegetation as compared to the use of black and white aerial photos in conventional methods. This is especially the case when combining the data from images of different seasons. A great deal of detailed information was gained in this way.

This technique may be applied when the aim is to produce a large-scale map of vegetation, land-use, soil, etc. By using this method, it is also easy to map the various changes in plant cover of the ground as well as areas of pre-dominantly annual or perennial vegetation.

It is also possible to distinguish the extent of clearings and other man-made impact on, for example, forests, providing the possibility to monitor changes in the environment.

Contrast stretched ratioing

This is a very rapid method for exaggerating the contrast between areas with different characteristics. This method was applied to an area in the central part of the Mtera basin in order to study whether soils and vegetation classes could be separated or not.

The results showed that it was easy to separate the main classes. The advantage to be gained by the use of this method this method as compared to the more sophisticated computer techniques is mainly related to the fact that rapidly delineation between areas of different characteristics is possible. Thus, it should preferably be used during the initial phase of the analysis work.

This method, however, does not allow a detailed classification.

Differential edge enhancement

Landsat registrations contain information about linear features, which cannot be detected by the interpretation of aerial photos or satellite images. By edge enhancement it is possible to exaggerate linear changes and contrasts in the scene and thus detect lineaments.

This technique is especially applicable in tectonic studies and geological mapping, where the aim is to identify structural elements of the bedrock such as faults, joints, dikes, contacts or schistosity. For bedrock mapping it should be used in combination with contrast-stretched ratio data. The method is rapid in comparison with computer classification.

Differential edge enhancement for tectonic studies and geological mapping is limited to areas with small to moderate soil cover. Dense vegetation will hide much of the linear features while sparse to moderate vegetation cover often tends to exaggerate linear features, depending on the structural elements of the bedrock.

Supervised classification

Supervised classification identifies the characteristics of areas as small as 60x80 m. This method thus allows very detailed analysis. The results are dependent on the accuracy in selecting classes, which correspond to a particular type of vegetation, soils, etc.

This method allows the production of rather detailed maps of, for example, soils, vegetation, etc. over large areas with a minimum of field checks, a fact which cannot be overemphazied in areas where roads are few and where accessibility to vast areas is jeopardized by topography, soils or vegetation.

As in the case of the Mtera study, where information on the distribution and characteristics of the vegetation and soils was well-known from previous field surveys, the results of the supervised classification method proved to be very good.

Multitemporal classification

Normally, the growing season is the most suitable time to classify different vegetation types. To obtain a complete picture of the distribution of vegetation types, it is wise to use several registrations from the growing season. However, by also using registrations from the dry season, additional information on the vegetation is gained, resulting in more accurate mapping.

The method is thus most applicable in areas with a marked seasonal plant cover, for example, arid areas with their great differences between annual and perennial vegetation.

Change detection

Through comparison of two registrations, it is possible to detect certain changes that have taken place.

In the Mtera area, the forest cover registrations from the same season but seven years apart were compared by means of this method. The results showed that large areas which had lost their forest cover during the period were easily detected.

This method is thus of great value in the detection of, for example, changes in vegetation, man-made or natural. It is also important in the detection of overgrazing, soil erosion and desertification.

It is potential use is enormous. It can be applied to the monitoring of all sorts of changes in the environment. It is particularly useful in the monitoring of large areas and in areas where it is difficult to carry out field checks, for example, swamps, mountains and rain forests.

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PREFACE

The Swedish Space Corporation, SSC, with funding from the Swedish Board of Space Activities, has initiated a series of pilot projects with the aim of establishing the potential usefulness of data from earth resources satellites in a number of different fields. Special interest has been concentrated to the use of interactive image analyses systems to access the usefulness and to introduce the technique to different categories of users.

As part of this scheme, VBB has been entrusted to assess the potential use of the Landsat technique for physical planning in a semi-arid area in Tanzania. The area in question, the Mtera basin, has previously been thoroughly surveyed and mapped by VBB/SWECO as part of various studies in connection with the work of creating a storage reservoir by the damming of the Great Ruaha river. The pictures in the field, which were taken by Dick Johansson, all refer to that phase of the work.

VBB/SWECO's knowledge of field conditions has been an absolute necessity in establishing the best methods for use in the work of physical planning.

We have tried to assess the possibility of mapping various characteristics of the natural environment, for example, vegetation and soils, by different Landsat techniques, and to list not only the advantages and disadvantages of these as compared to conventional field investigation methods, but also to see where the different methods supplement each other.

The Swedish Space Corporation has actively participated throughout the work. The SSC has participated with operational personnel and its interactive analyses system. Sonny Lundin has as Project Manager handled the computer part of the project with Lars-Erik Gustafsson, Mats Rosengren and Per G Jönsson. Their efforts are much appreciated. The text on Landsat techniques has been written jointly with the staff on the Swedish Space Corporation.

In addition, the Swedish National Board for Technical Development ("Styrelsen för teknisk utveckling") has contributed funds to make possible a more detailed work procedure. We are greatly indebted to all contributors to and participants in the study.

There are very few Landsat registrations available of the Mtera area, as no ground station exists for Landsat in east Africa. Data has to be recorded on tape on the satellite at the time of registration and transmitted to the ground when the satellite is passing the USA. NASA carried out registrations in March 1979, at the end of the growing season, especially for this study. However, the Mtera area was completely covered with clouds at that time. Another registration was therefore carried out at the end of July 1979. We are most grateful to NASA for this contribution to the study.

1. BACKGROUND

1.1 Landsat

One objective of the Landsat programme has been to obtain one-time imaging of the land areas of the world. All data received and processed from Landsat are available to anyone throughout the world. Several data formats are available to match user needs, but the investigator can carry out additional processing to meet his specific requirements.

The Landsat data base comprises documentation of environmental conditions, documentation which will be of critical importance in as much as it will constitute a baseline for the recognition of environmental changes that may occur in the future. In order to be able to make continued comparable observations, it will be necessary to use this baseline information effectively and wisely. An objective, factual data base will be essential in large-scale resources studies to both developers and environmentalists.

Data from Landsat can be interpreted through analysis of photographic type images or through highly sophisticated computer procedures. This range of techniques opens the door to wide and extensive benefits in terms of a large number of applications.

The object of the Landsat satellites, which make up a series, is the study of the earth's surface. The satellites are placed in sun-synchronous, near-polar orbits. Each satellite passes over a certain location above the earth every 18 days at the same local time. The satellites are at an altitude of approximately 910 km and each is equipped with MSS and RBV instruments.

A Multi Spectral Scanner, MSS, scans the earth in four wave length bands from green to near-infrared. In order to obtain continuous images of the earth in the direction of the motion of the satellites, six lines are scanned at the same time. The length of a scan corresponds to 185 km on the ground and the detectors are read out at constant time intervals. The true ground resolution is considered to be 79x56 m. Scan lines are continuously read and telemetered to the ground, but artifical division into frames is produced by a computer system, in such a way that the final product consists of images which cover areas 185x185 km on the ground. Each frame consists of 2 340 scan lines and each scan line contains 3 240 resolution elements. The satellites produce vast amounts of data. A single Landsat scene actually consist of four pictures, each of which has some 7.6 million picture elements.

A set of three Return Beam Vidicon, RBV, tubes photograph the earth through filters, taking images in green, red and near-infrared light. The resolution of the vidicons was approximately 60 m on Landsat 1 and 2 and is approximately 30 m on Landsat 3. Due to the fact that no vidicon data exist from the first two satellites, the data is normally not very much used, nor is it received by receiving stations other than NASA's own. No RBV-data presently exist from the Mtera area.

1.2 The Mtera Pilot Project

The purpose of this pilot project has been to study the value of different Landsat MSS analysis techniques within the field of ecology and land-use, utilizing the Mtera Project for reference purposes. Studies of ecology and land-use similar to those carried out within the Mtera Project will be of increased importance in the future. This is particularly valid in the developing countries. Few current projects have the time or funds required to allow the carrying out of sufficiently detailed ecological studies. The utilization of Landsat must be regarded as an appropriate measure to find a more efficient and economical way of carrying out studies of this kind.

In this study we have compared different levels of Landsat use. At the basic level, black and white aerial photos and Landsat images have been interpreted. Band five has been mainly used. The second step has been the interpretation of colour infrared composite images, also a standard Landsat product. All images have been enlarged to 1:250 000. The following four registrations, Figs. 1-4 have been studied:

Fig.	Date	Season	Landsat identification number
1	1972-09-28	Dry season	E-1065-07132
2	1972-12-25	Early wet season	E-1155-07140
3	1974-01-07	Wet season	E-1533-07103
4	1979-07-25	Dry season	E-21645-06554

These are the only cloud-free registrations available over the area.

Computer techniques have been applied in several ways:

- contrast-stretched ratio enhancement
- differential edge enhancement

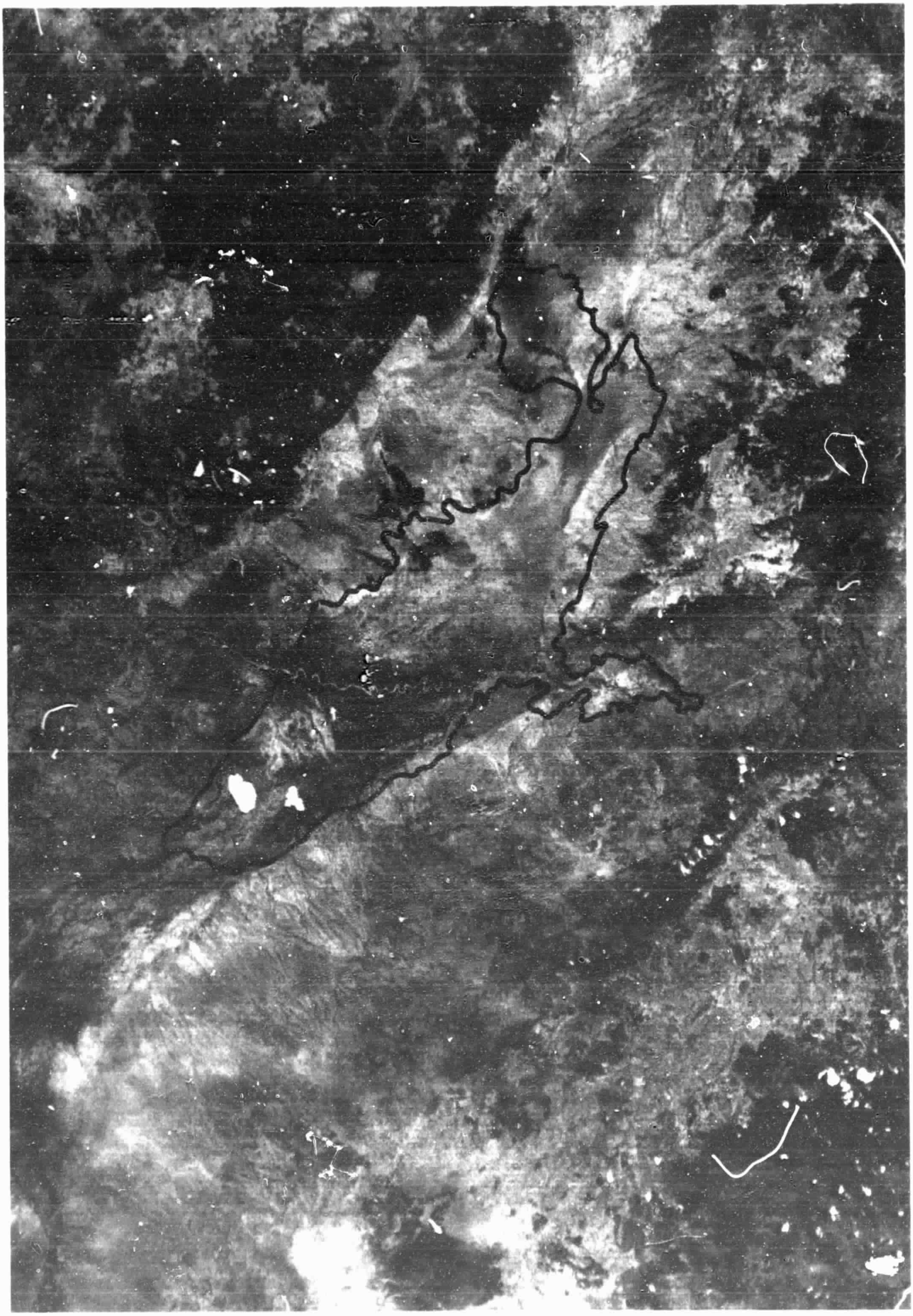

Fig. 1 Landsat colour infrared image 1972-09-28

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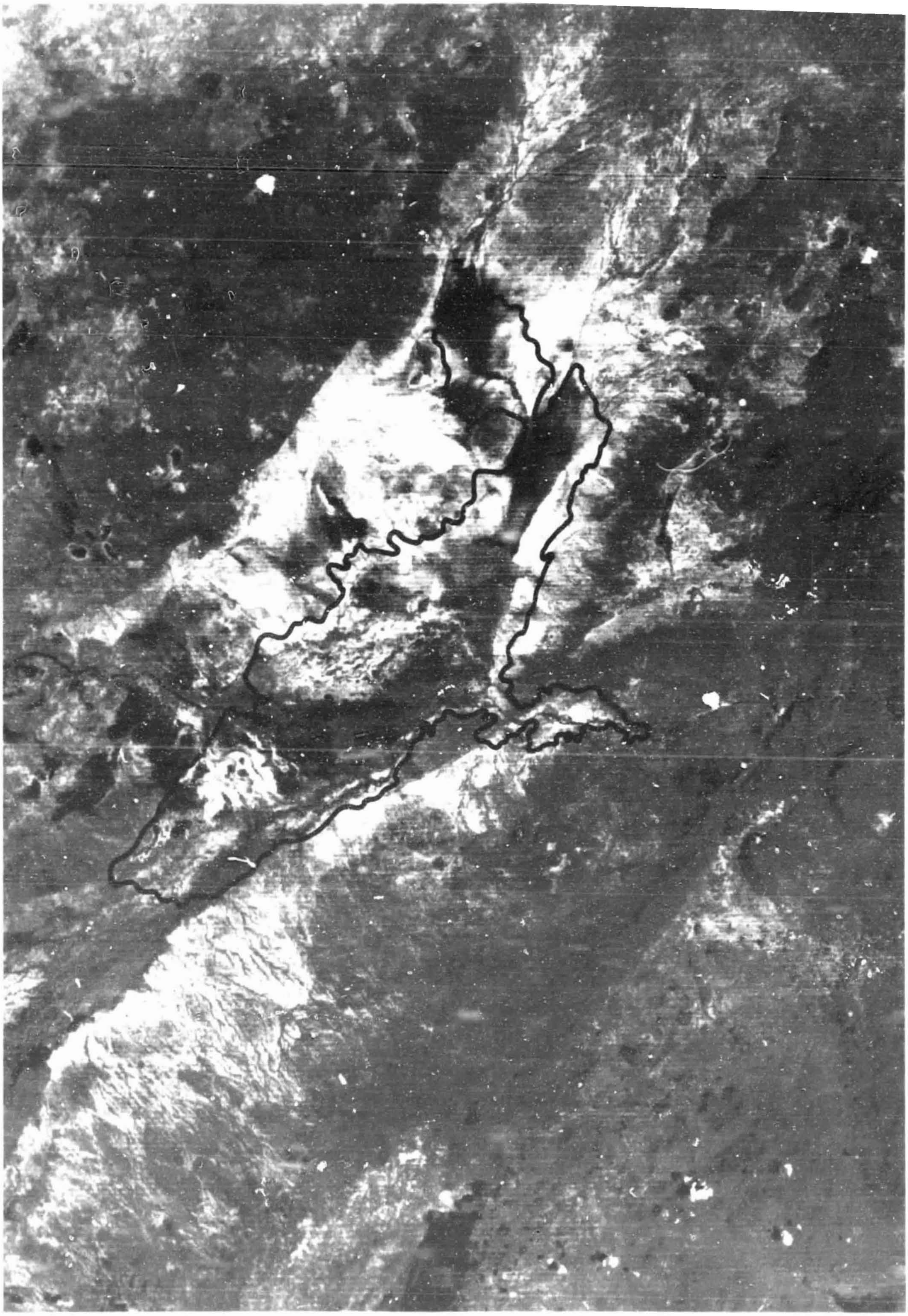

Fig. 2 Landsat colour infrared image 1972-12-25

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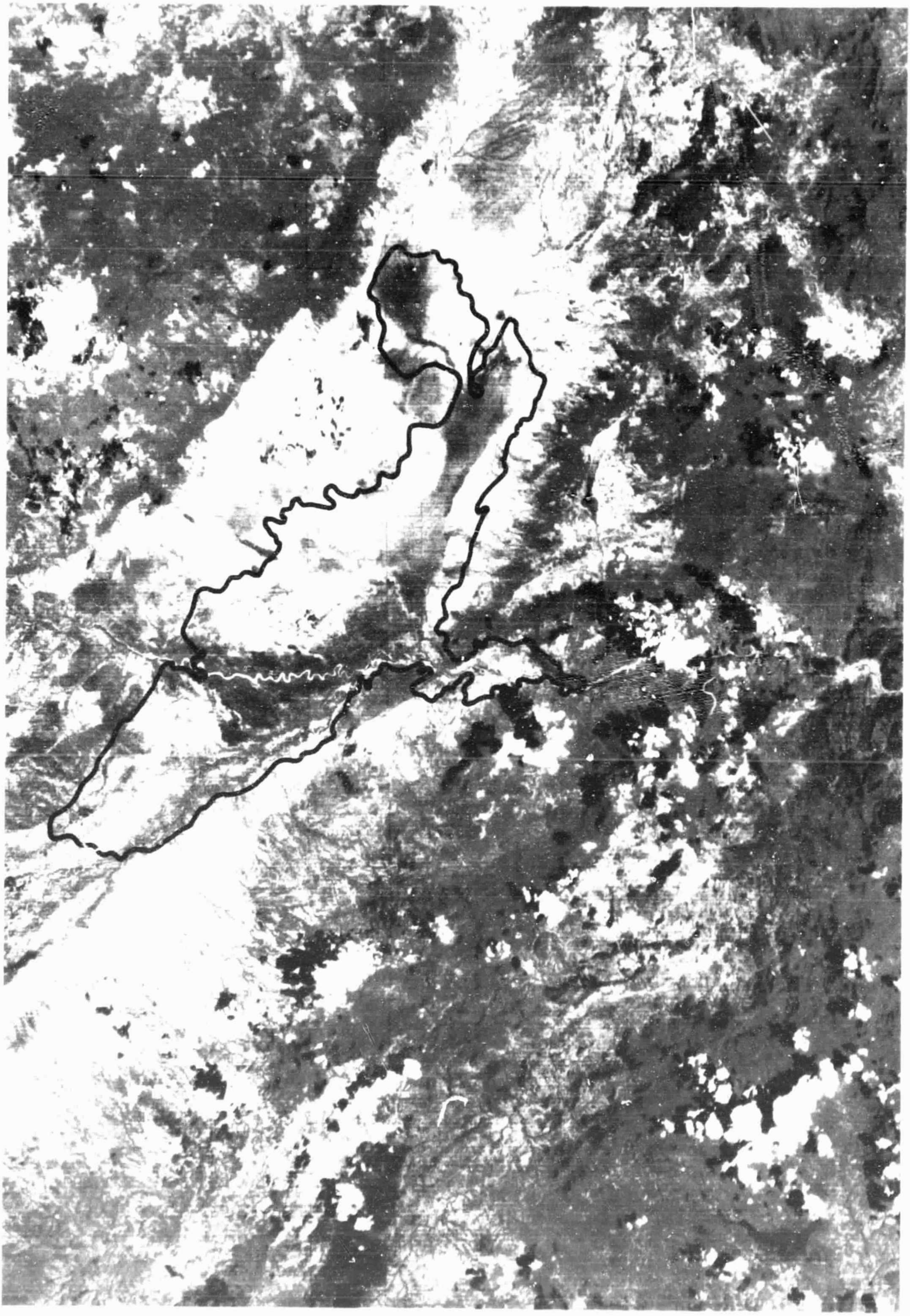

Fig. 3 Landsat colour infrared image 1974-01-07

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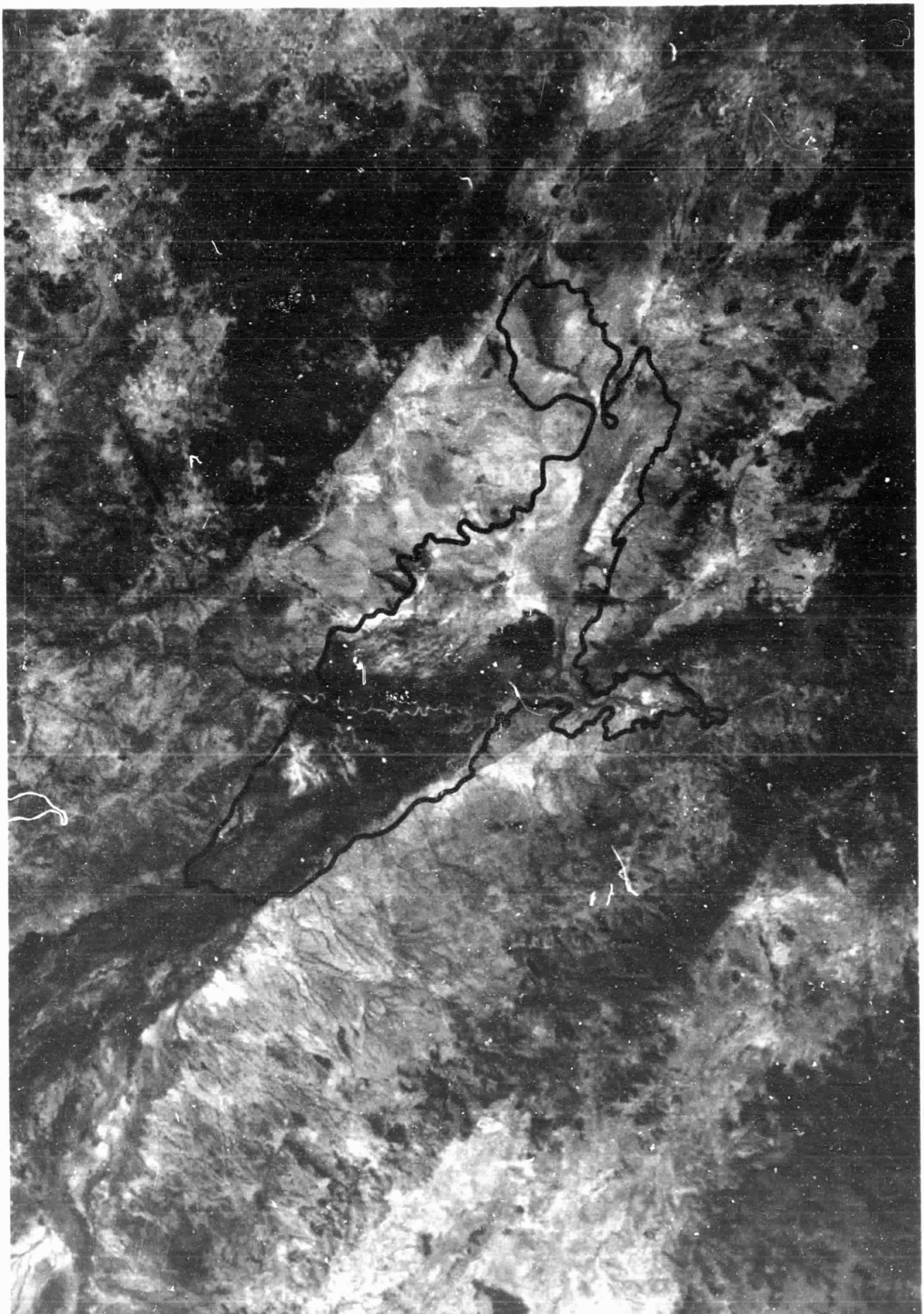

Fig. 4 Landsat colour infrared image 1979-07-25

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- supervised classification
- multitemporal classification and change detection

1.3 The Great Ruaha Power Project

On behalf of the Tanzania Electric Supply Company Ltd (TANESCO), a hydro-electric power plant has been constructed on the Great Ruaha River at Kidatu.

The volume of the reservoir at Kidatu is, however, rather small, and for this reason a main storage dam is planned and currently under construction at Mtera, which is situated 175 km upstream of the Kidatu reservoir.

At Mtera, the dam across the Great Ruaha river is being constructed about 6 km downstream of the Mtera bridge. The dam will be completed in late 1980. At full supply level the Mtera reservoir will be approximately 630 km^2 in area. The reservoir will be rather shallow because of the flatness of the terrain and large areas around the reservoir will be affected by the annual variations in the water level.

Several aspects relating to the environmental impact of the reservoir have previously been presented (SWECO 1976, 1977a, b, 1978 a, b, 1979).

Thus, the study area has been selected on the basis of accumulated knowledge on many aspects of the natural environment which allows a more thorough interpretation of signals from the Landsat satellites.

1.4 The Mtera basin

1.4.1 Geography

The Mtera basin is situated in central Tanzania approximately half way between the two towns of Iringa and Dodoma, Fig. 5. The basin lies within the Rift Valley at an altitude of approximately 675-725 m.

The land below an altitude of 690 m will be flooded when the Mtera storage reservoir is completed in late 1980. The outline of the reservoir is shown in Fig. 6, which also shows the road system and villages.

The area is sparsely populated, a state which, however, may change after the establishment of the reservoir.

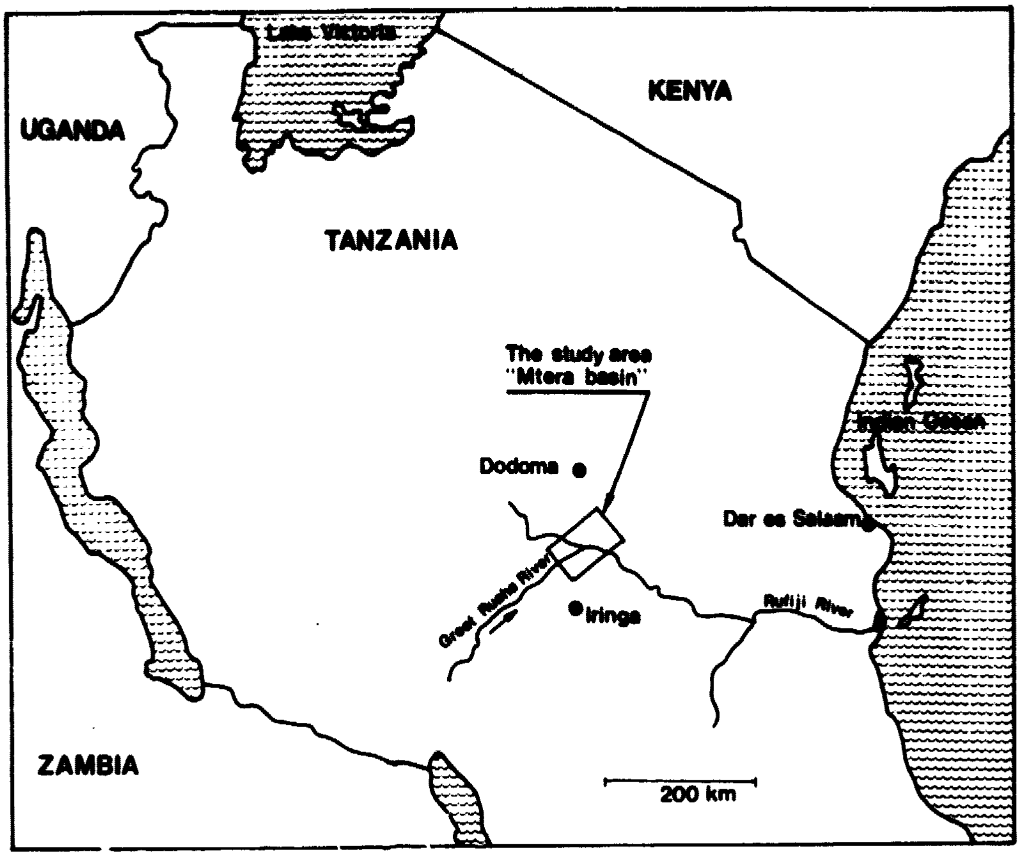

Fig. 5 The location of the Mtera area

1.4.2 Climate (from Strömquist 1976)

The Mtera basin is situated within a semi-arid belt which runs from north to south through the central portion of Tanzania. In this zone, the average annual rainfall is approximately 500 mm. The annual rainfall at Mtera (450 mm/year) is thus very low and concentrated in a rainy season between November and April. Most of the rain falls during December and January. The variability in rainfall is high, Fig. 7, and precipitation is often in the form of heavy showers, causing rapid surface run-off and sudden spates in the seasonal streams and rivers.

The climate is characterized by low humidity, Fig. 8. Evaporation always exceeds precipitation (3 260 mm/year) and is highest in October and November, Fig. 9. The air temperature is always high with a daily variation range of about 10-15°C, Fig. 10.

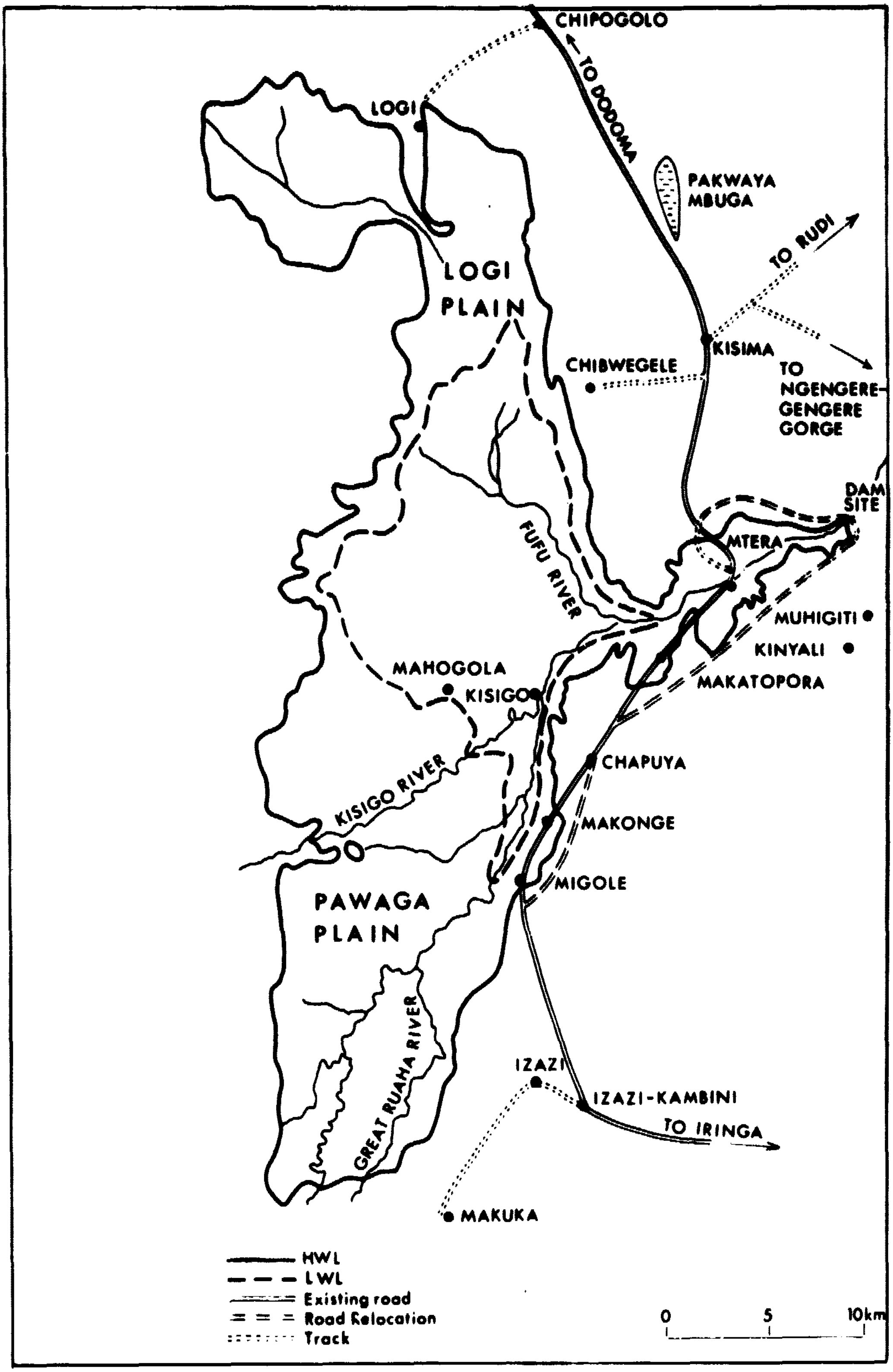

Fig. 6 The Mtera basin. The location and outline of the Mtera reservoir is shown at highest water level (HWL) and at lowest water level (LWL)

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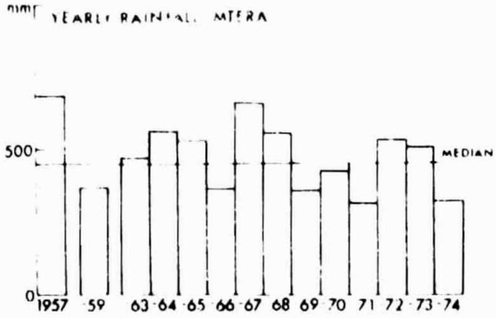


Fig. 7 Annual rainfall, Mtera

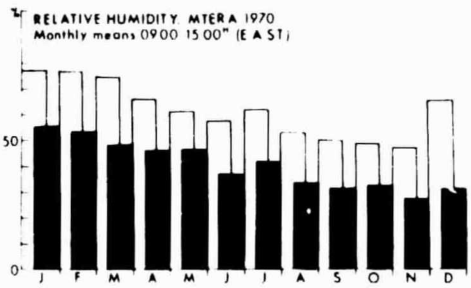


Fig. 8 Relative humidity, Mtera, 1970. Monthly means 09.00, 15.00^{H}. (E.A.S.T.)

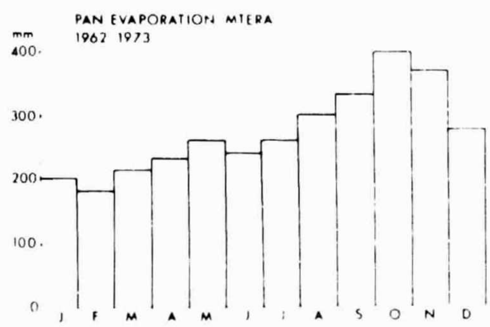


Fig. 9 Pan evaporation, Mtera, 1962-1973

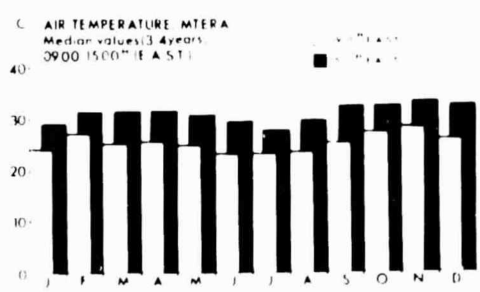


Fig. 10 Air temperature, Mtera. Median values (3-4 years), 09.00, 15.00^{H}. (E.A.S.T.)

2. LANDSAT TECHNIQUES

The aim of the study has been to utilize different techniques of image manipulation and interpretation to evaluate their maximum benefit within the fields of ecology, vegetation, geomorphology, soils, geology and hydrology. The techniques applied are briefly described in the following.

2.1 Image interpretation

The interpretation of Landsat images has much in common with the interpretation of aerial photographs. Much of the experience which exists in connection with the latter can easily be transferred to the study of satellite images. There are in fact many advantages connected with the use of Landsat images, an exception being the case of geometric resolution. Landsat makes black and white registrations of the ground in four different wave length bands, which greatly facilitates interpretation. Normally, it is possible to obtain a number of registrations over the same area at low cost. It is extremely valuable to have different registrations at various seasons, since different information can be gained from each image. Aerial photographs taken at different seasons are rarely available. The greatest advantage of Landsat images is that a colour infrared image can be produced from each registration. The cost involved is slightly higher as compared with that for black and white images, but where it is possible to order images from the US Geological Survey, the cost is not of great significance. The conclusion is that the advantages of using colour infrared are so great that this should be used for all interpretation, while black and white images should only be used to supplement the coloured images.

2.2 Contrast-stretched ratio enhancement

The image enhancement technique used in the Mtera study was applied to investigate the possibilities of discriminating various soil and vegetation classes. This approach is a considerably faster and less costly method than supervised classification. The image enhancement technique is a three-step procedure:

- the spectral values of any two Landsat MSS bands are divided pixel by pixel

- the resultant ratio values are rescaled in order to fill the entire dynamic range of the display medium

- the stretched data from three ratio sets are combined into a colour composite image.

The procedure is useful because the ratio values determined by combining data from MSS band pairs tend to remove first-order brightness differences attributable to topography. In addition, the ratio tends to normalize the response of similar materials with similar spectral response curves but varying albedos, (Blodget et al., 1978). The ratio also displays the slope of the reflectance spectrum of a material between two bands on a single black and white image. The ratios derived using this algorithm generally show a narrow range of values. The data must be contrast-enhanced before image construction to obtain the best display characteristics.

The colour composite image can be built up in a number of ways using any of twelve ratio alternatives, different colour-filters and stretch combinations. The best combination for discrimination of soils and vegetation was found to be ratio data of MSS 4/5, 5/6 and 6/7 projected through red, green and blue filters respectively.

To focus on the resolution of different soil classes, the three ratio sets, varying stretch combinations were tried. Two different stretch combinations are shown in Figs. 11 and 12.

2.3 Differential edge enhancement

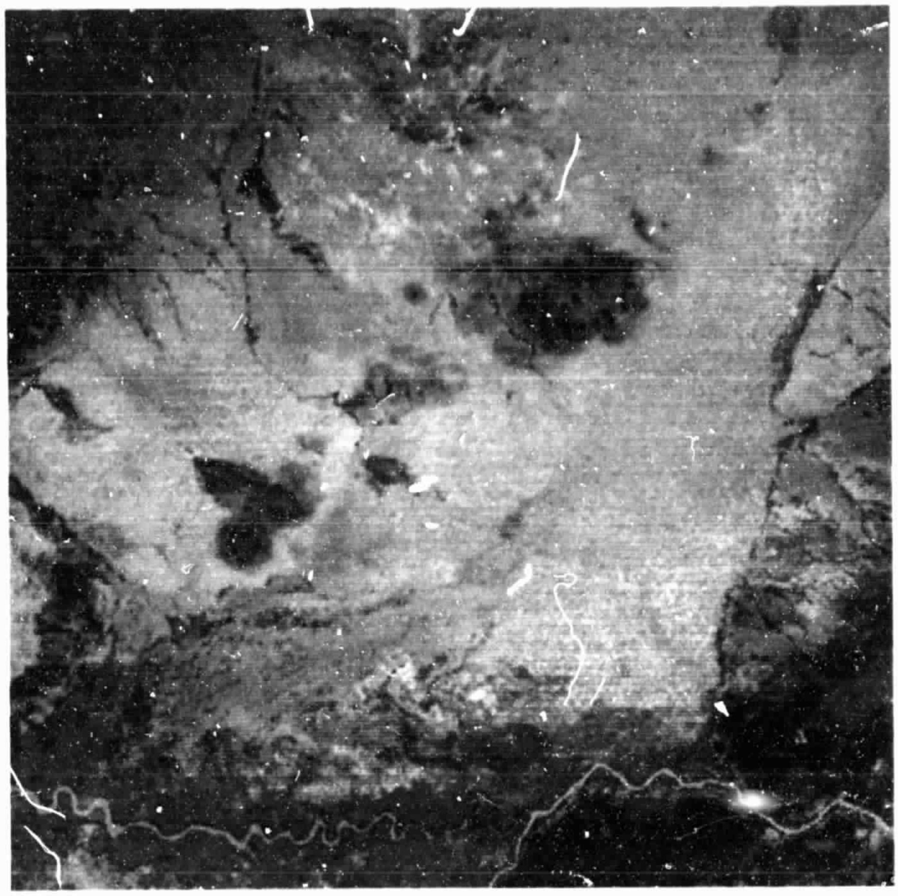
A method often used on photographs to enhance tectonic patterns is to overlay a negative image on the same positive image and to observe the result when the negative is moved on top of the positive.

The same operation can easily be performed with digital images. Mathematically, the image is moved in any desired direction and displacement.

In the resulting image, lineaments and other linear structures perpendicular to the displacement direction will be enhanced and all other features will disappear. Enhanced pictures are shown in 4.3 on tectonic features.

2.4 Supervised classification

There are two alternative methods available when classifying Landsat data into different types of vegetation, terrain etc.: supervised or unsupervised classification. The computer program that performs the actual classification is the same in both cases.



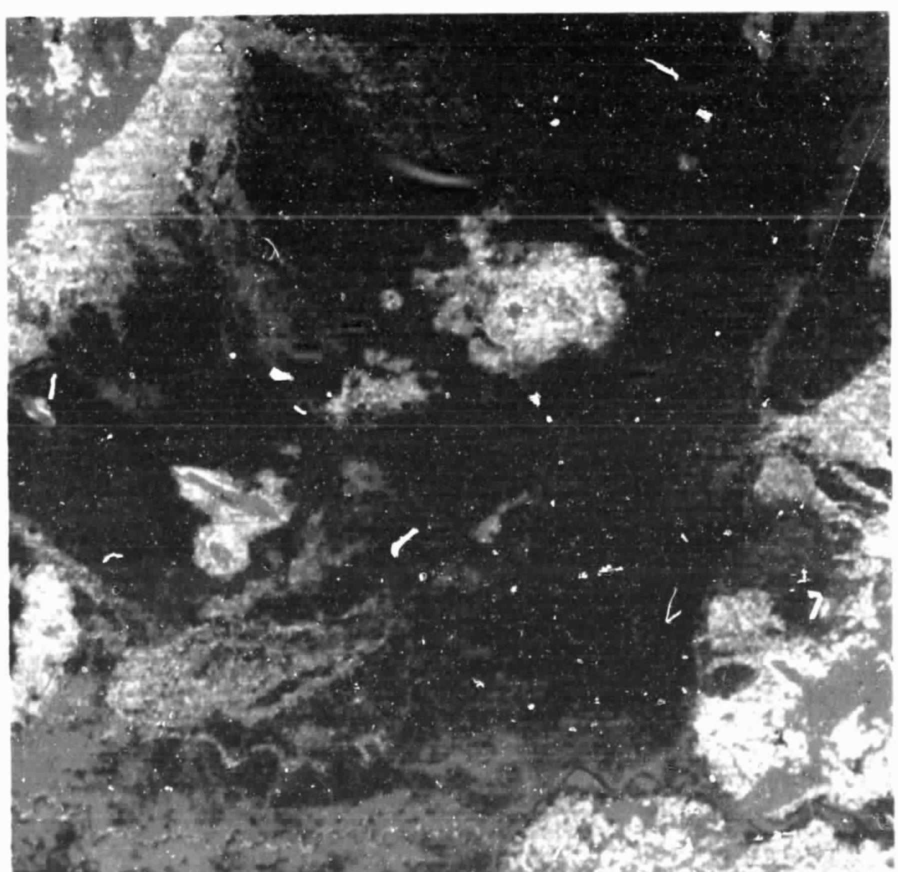


Fig. 11 and 12 Two different stretch combinations from the central parts of the Mtera basin. The top image discriminates in particular various types of vegetation, while the lower image separates the soil types.

In the case of supervised classification, the signatures used for classification are created by the user, whereas those used in the case of unsupervised case classification are created more or less automatically by the computer. Supervised classification has been used in the Mtera project. The signatures have been created from the statistics of different training areas.

For vegetation classification, it is especially important that there be a fairly large number of training areas to cover the variations within each class resulting from differences in growth, precipitation, altitude, soils etc.

In the image analysis system used, only 32 signatures from training areas could be used for supervised classification when the Mtera project was conducted. This is a strongly limiting factor. For normal use this should be increased to some 50-100 signatures in order to obtain the best result.

The main phases of supervised classification are as follows:

- Training area acquisition, which implies identifying the areas where ground truth is available.

- Calculation of multidimensional statistics for the training areas.

- Merging, splitting, editing and deleting of signatures to obtain distinct, gaussian normal-shaped statistics.

- Maximum-likelihood classification of all pixels.

- Generation of a thematic map.

- Colour-coding of the thematic map.

Marking of training areas was done with a trackball. Different types of presentation were used for marking the training areas, e.g. three band zoomed contrast stretched pictures in order in an optimized way to enhance the specific characteristics of the training area in question. Where possible, different training areas for the same signature were placed on different parts of the image. The training areas were studied and, where necessary, corrected, using all the different bands.

Generation of statistics involved automatic calculation and display of means, sigmas, covariances and histograms using pixels from the training areas. This was done for every band and signature.

The signatures were then corrected to distinct, gaussian-shaped one-feature signatures, by merging signatures with equal statistics, splitting signatures with more than one top in the histograms, and recalculating statistics without the influence of single pixels far from the mean values. Signatures with very broad non-distinct statistics were deleted.

Classification was done one pixel at a time, using the maximum likelihood classification.

To generate thematic maps, the following procedure was carried out:

- Each signature or class was given a separate grey tone.

- Merging of signatures was possible by transforming of signatures to the same grey tone.

- Colour coding, giving a desired colour to each grey tone, was done as the last step, pseudo-colouring.

The final maps were produced as photo-copies from the screen or using an ink-jet plotter.

2.5 Multitemporal classification

It is possible to use any number of different bands when performing classification. In the case of Landsat there are four bands. If we want to use more information, we must use data from other sources or from several different Landsat registrations of the same scene. In the Mtera project, we have used data from several different times of the year and from different years. Thus, when classifying data over the same geographical area but from different times, we call this a multitemporal classification.

The classification was done in the following steps:

- preparation of images

- supervised classification as described in 2.4.

Preparing the images in this case means geometrically registering the two images to each other so that each picture element in one image represents the same pixel in the other image.

Geometric correction of systematic errors was first done for one of the MSS images.

The other image was then registered to the systematic corrected image by using it as a reference for smoothed precision correction.

3. CLASSIFICATION OF VEGETATION

3.1 Types of vegetation

To provide data for land-use planning, soil conservation, bush clearing and utilization of arboreal species, the vegetation has previously been classified into eight types. (Johansson, 1976).

- I Acacia circummarginata - Commiphora bushland
- II Acacia tortilis - Cordia gharaf groundwater bushland
- III Bushland with mixed acacias
- IV Acacia kirkii bushland
- V Open grassland
- VI Acacia seyal wooded grassland
- VII Riparian vegetation
- VIII Land under cultivation in the past and at present

The types of vegetation are described and illustrated in the following, Figs. 13-21.

Fig. 13 Open bushland with Commiphora merkeri (to the left) and Acacia circummarginata trees near Chapuya. The seasonal grasses cover the stony ground, February 1977

I Acacia circummarginata - Commiphora bushland

The two tree-forming species Acacia circummarginata and Commiphora merkeri dominate totally. The field layer is sparsely developed and much of the soil surface is bare because of heavy grazing and trampling. A considerable number of herbs and shrubs occur, but none is particularly dominant, except for Duosperma crenatum. This bushland is associated with red-brown residual soils and is common on hills and inclined plateaus.

Fig. 14 Bushland with Acacia tortilis near Izazi. The picture was taken at the end of the wet season when the ground is covered by the annual grass Sporobolus ioclados

II Acacia tortilis - Cordia gharad groundwater bushland

In the Mtera basin, Acacia tortilis normally grows to a height of 5-7 m with a flat spreading crown. This vegetation type occurs on yellow or brown colluvial soils, and on grey alluvial soils where the groundwater table is relatively close to the surface. Vast areas of it surround the Kisigo and Great Ruaha rivers. Cordia gharaf is most common close to the rivers, and gradually gives way to Acacia tortilis.

Fig. 15 Bushland with mixed acacias. The shrub in the centre is a Cordia gharaf, and the trees surrounding it are Acacia mellifera. Migole

III Bushland with mixed acacias

Apart from the well-defined association in which a particular Acacia species is dominant (e.g. A. kirkii or A. seyal) or co-dominant, (e.g. A. circummarginata and A. tortilis), there are also loose associations of a number of Acacia species. This is here described as bushland with mixed acacias. It is composed of rather short and shrubby trees. The dominant species are Acacia tortilis and A. mellifera, which normally reach a height of 4-5 m. This vegetation type is associated with badly or slightly sorted sand and silty soils. It is mainly found on the gentle slopes which surround the Logi plain and the areas from Chapuya down to Izazi, and its occurrence is probably related to the heavy grazing pressure in these areas.

Fig. 16 Acacia kirkii bushland on the fringe of the Kisigo alluvial fan near Mahogola, May 1971

IV Acacia kirkii bushland

Acacia kirkii is a small tree, normally 3-4 m high in the Mtera area. It has a very short, thick trunk with branches close to the ground (Fig. 37) and grows in rather dense stands with the branches of the crowns interwoven. This type of bushland is found on clayey, 'mbuga'-like soils, and on sand and silty colluvial soils. Acacia kirkii is normally associated with alkaline soils. Although it is not an infallible indicator of alkalinity, it enables recognition of the main areas of alkaline soils. Acacia kirkii bushland occurs in the border zone of the 'mbugas' often in narrow strips with open grassland in between, as well as in the drainage channel from the northernmost 'mbuga'.

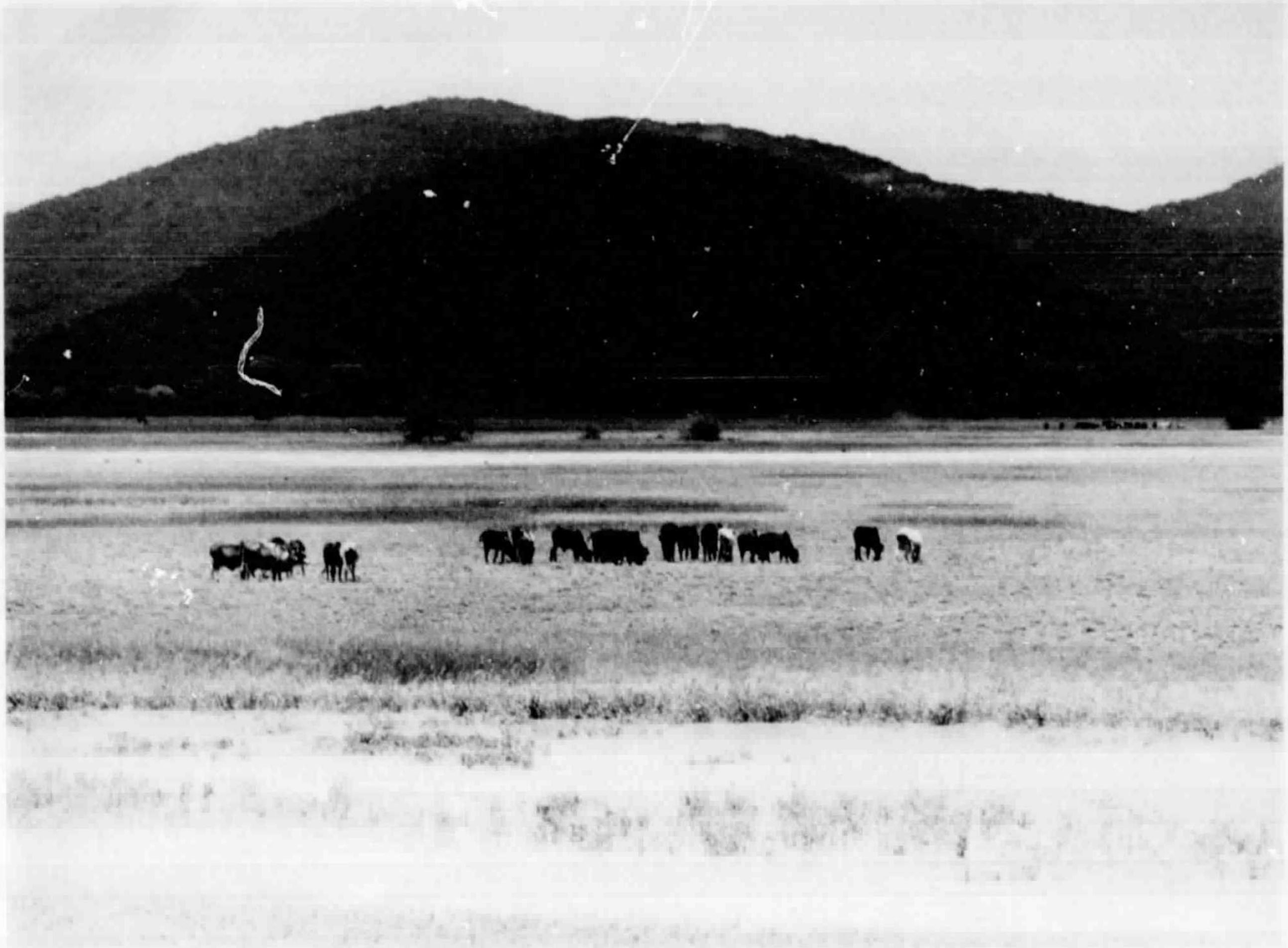


Fig. 17 The Pakwaya 'mbuga', which is located between Kisima and Chipogolo, is here partly flooded, at the end of the rainy season, February 1977

V Open grassland

The open grasslands are composed of short grasses which cover the ground completely; only occasional shrubs and widely scattered trees occur. The soils of this vegetation type are well-sorted clays. Black 'mbuga' soils are common in the central part of the plains, which are seasonally flooded. In somewhat higher sections grey 'mbuga'-like colluvial soils occur. Normally this vegetation is not subject to periodic burning. Open grasslands are found in the northern parts of the Mtera basin, their central part being known locally as Logi mbuga or Logi plain.

Fig. 18 Short Acacia seyal trees near Fufu river. Note the black clay soil below the trees, May 1971

VI Acacia seyal wooded grassland

Almost monospecific patches of Acacia seyal trees form a typical and easily recognized vegetation type. Acacia seyal is a rather tall tree, reaching up to 12 m in height. Acacia seyal is adapted to seasonally waterlogged, badly aerated soils, and occurs on well-sorted black clay soils ('mbuga soils'). This vegetation type occupies the lowest sections of the Logi plains around the Fufu river, where the water remains longest after the rainy season.

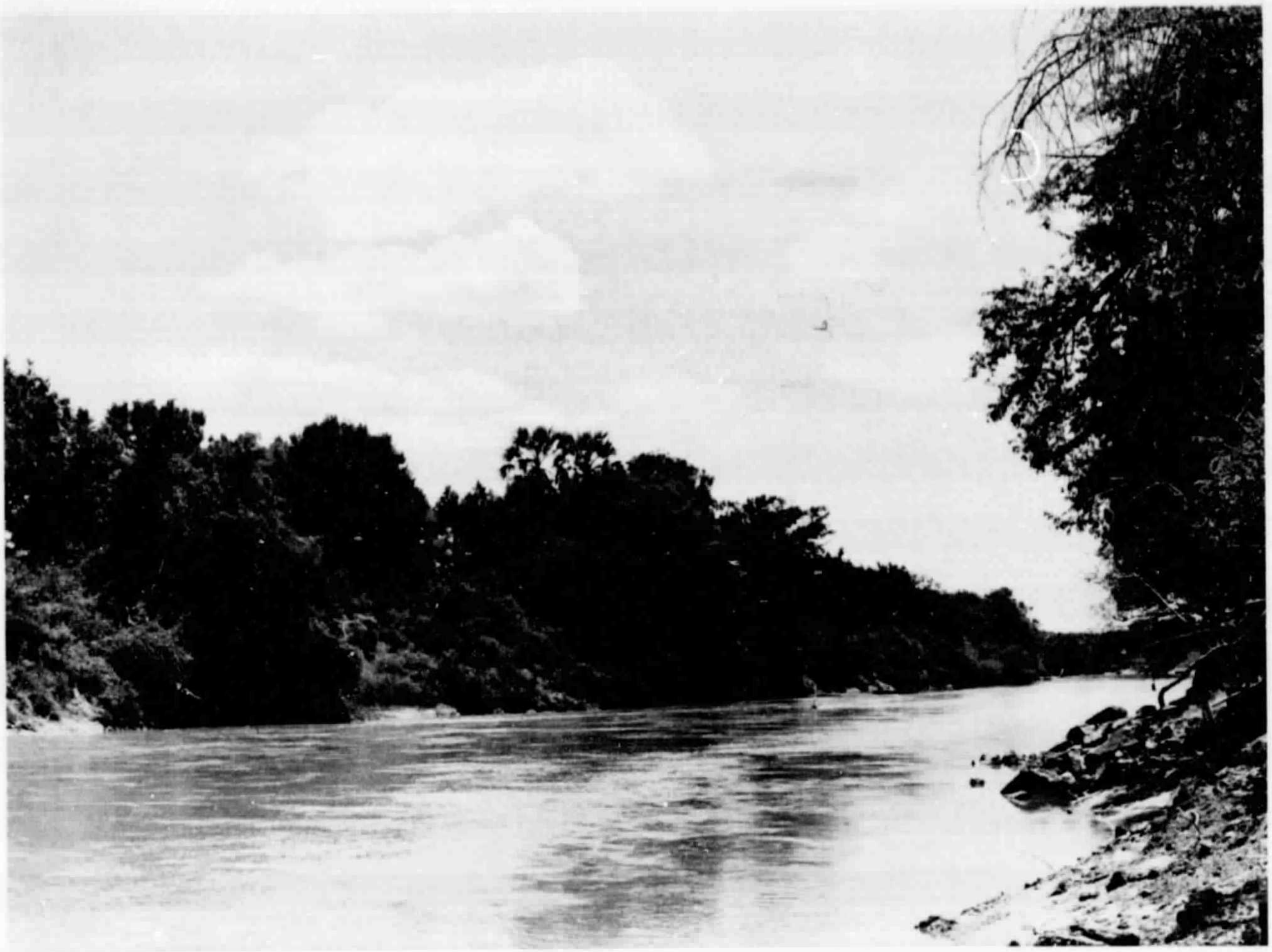


Fig. 19 Riparian vegetation at the Great Ruaha river near Makonge, May 1971

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VII Riparian vegetation

This vegetation is often referred to as riverine forest because of the dominating tall trees which reach heights of 15-20 m. However, there are also shrubs and herbs closely associated with it, and in several places the trees have been removed (felled for different purposes), leaving only the shrubs and herbs.

Among the trees, Acacia albida and A. clavigera are the dominants in certain areas and Tamarindus indica elsewhere. This vegetation is clearly limited to the alluvial grey soils with high water content in a narrow zone on both sides of the rivers. At some distance from the river, the riparian vegetation ends abruptly, being replaced by Acacia tortilis - Cordia gharaf groundwater bushland.

Riparian vegetation is found on both sides of the Kisigo and Great Ruaha rivers, except for the stretch from Mtera village downstream to the planned dam site.

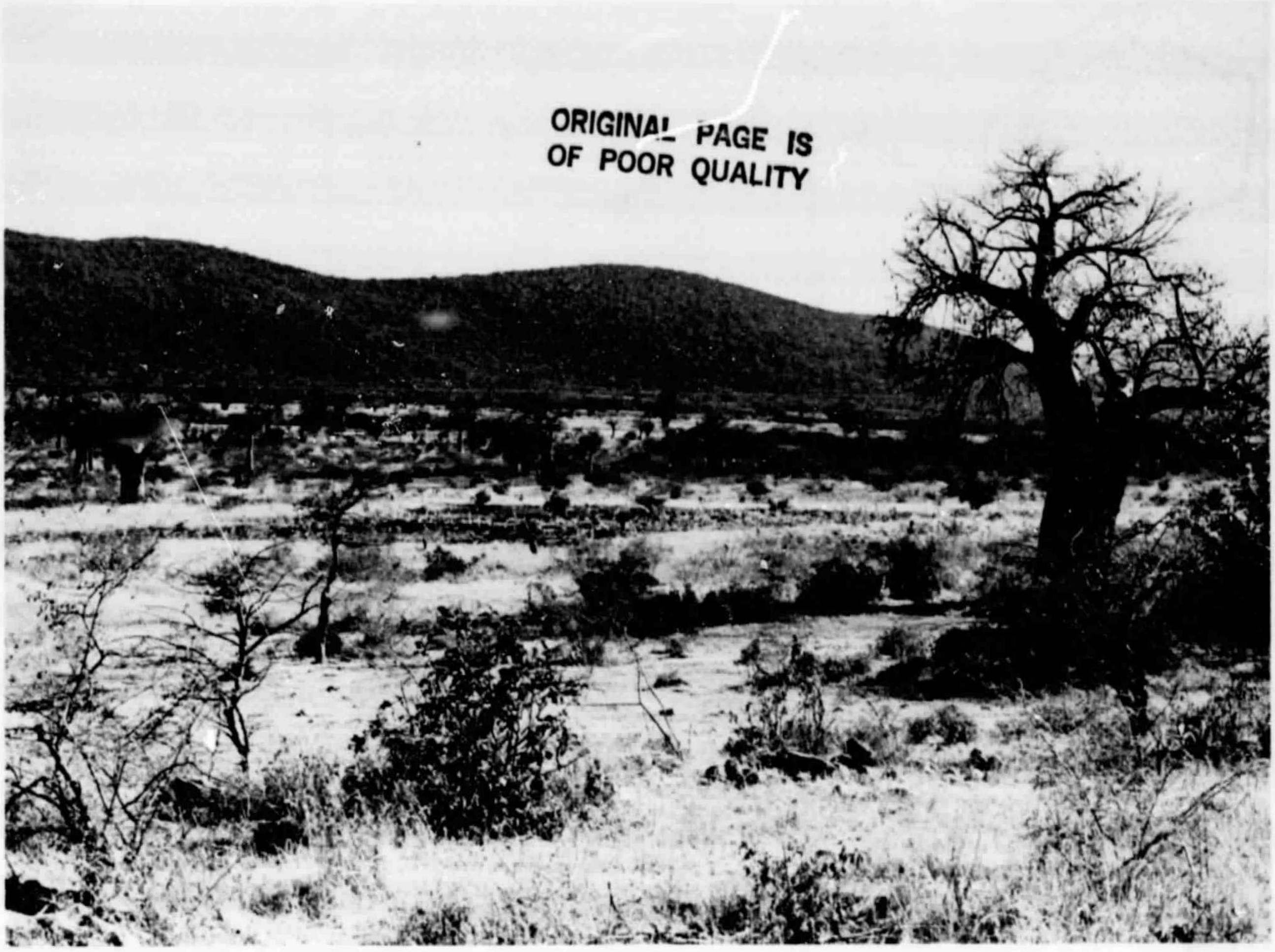

Fig. 20 Cultivated land near Kisima, May 1971

VIII Land under cultivation in the past and at present

The main areas of cultivation are round Kisima and Makatopora, and between Migole and Makonge. The areas which will be affected by the impoundment are part of the Makatopora and the Migole-Makonge cultivations. In the vicinity of Kisima, the cultivated land is mainly derived from cleared Acacia circummarginata - Commiphora bushland on grey colluvial soils or red residual soils. The cultivations in the Iringa region are all situated on grey colluvial soils.

Crops are planted at the beginning of the rainy season, December January, and harvested in May. The most common of these are maize, millet and groundnuts, which are cultivated as cash crops. During years with low rainfall, however, the maize fails to reach maturity.

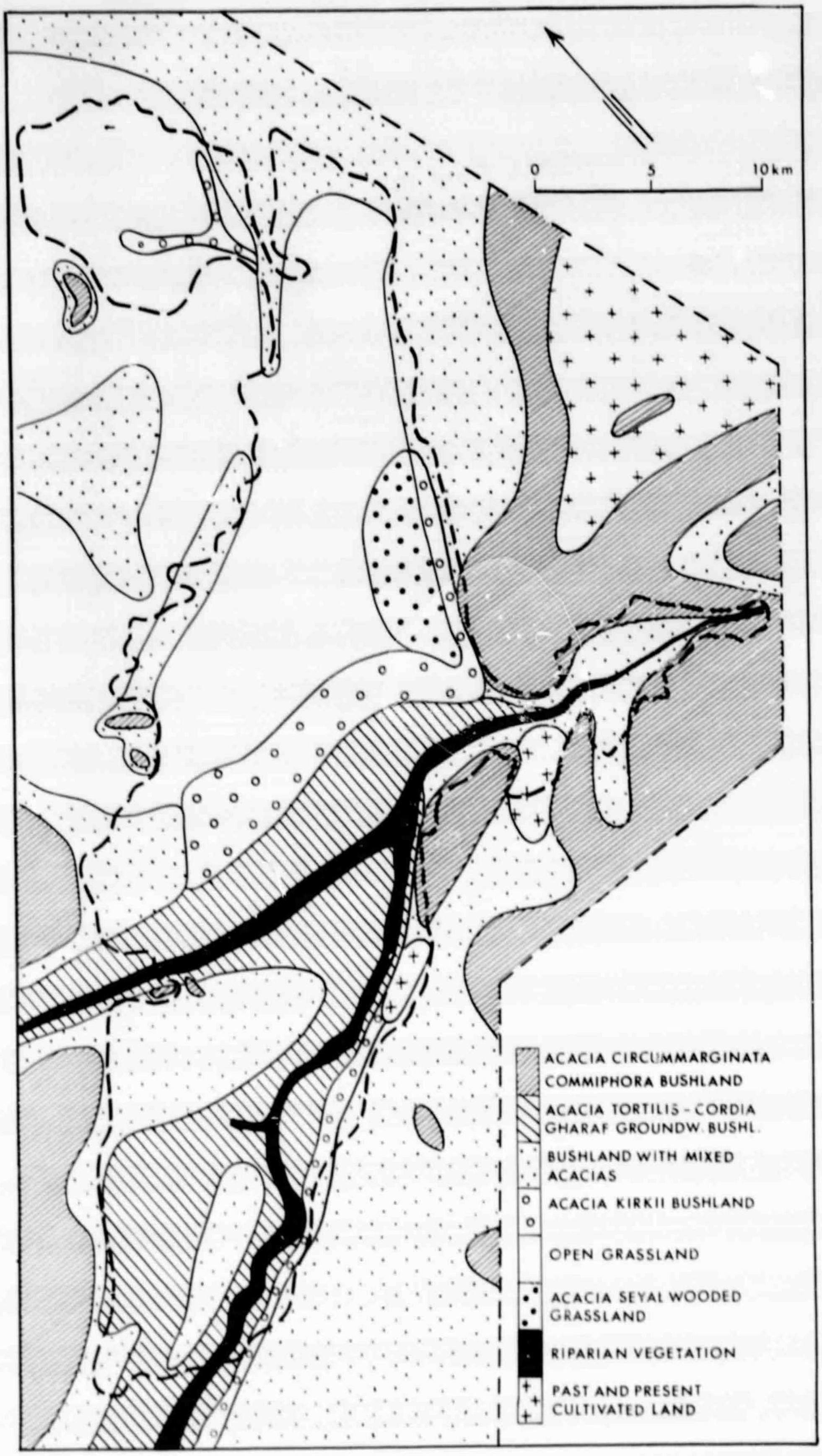

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Fig. 21 Vegetation types and their distribution in the Mtera basin

3.2 Interpretation of black and white aerial photos

The vegetation of the Mtera basin has previously been mapped on a scale of 1:200 000 (Johansson 1976). This map was based on interpretation of aerial photos on a scale of 1:34 000, dated June 1963. The mapping was checked in the field. The vegetation types which were distinguished by this method have been presented in the preceding Clause. It should be noticed that some of the vegetation types which were distinguished could not be traced on the aerial photos, their distribution being based entirely on the field reconnaissance.

The aerial photos, although detailed in the information provided, are sometimes difficult to interpret. This is related to the fact that, owing to the great area to be covered, the photos may be taken in different light conditions, which effects the grey tones of the photos. When the aim is to produce a vegetation map, on the scale of, let us say, 1:150 000-1:200 000, covering areas of 500-1 000 km², the use of aerial pictures is very laborious and the result is by no means better than can be achieved by the use of Landsat colour infrared images, which is a much faster method.

3.3 Interpretation of black and white Landsat images

The vegetation and geomorphology of the Mtera basin have previously been interpreted by means of information from satellite images (Johansson and Strömquist, 1978).

The original Landsat satellite images (No. E-1155-07140, 25th December, 1972) were enlarged from a negative 2.2x2.2 inches in size to a scale of 1:250 000, which proved to be the best working scale. Band five (spectral band 0.6-0.7 µm, one of four available) was used as the grey tones of the black and white images resemble those of conventional aerial photos, thus simplifying interpretation, Fig. 22. By using band 5, which is best suited for vegetation studies, the information on geomorphology, however, varies with terrain factors, vegetation and relief.

The distribution of the major vegetation types as determined by aerial photos and field reconnaissance could be traced on the Landsat images, Table 1. The wet grasslands, which sometimes are difficult to observe on conventional aerial photos, are particularly easy to distinguish on the Landsat images, Fig. 23.

Fig. 22 Landsat-1 image of the Mtera area

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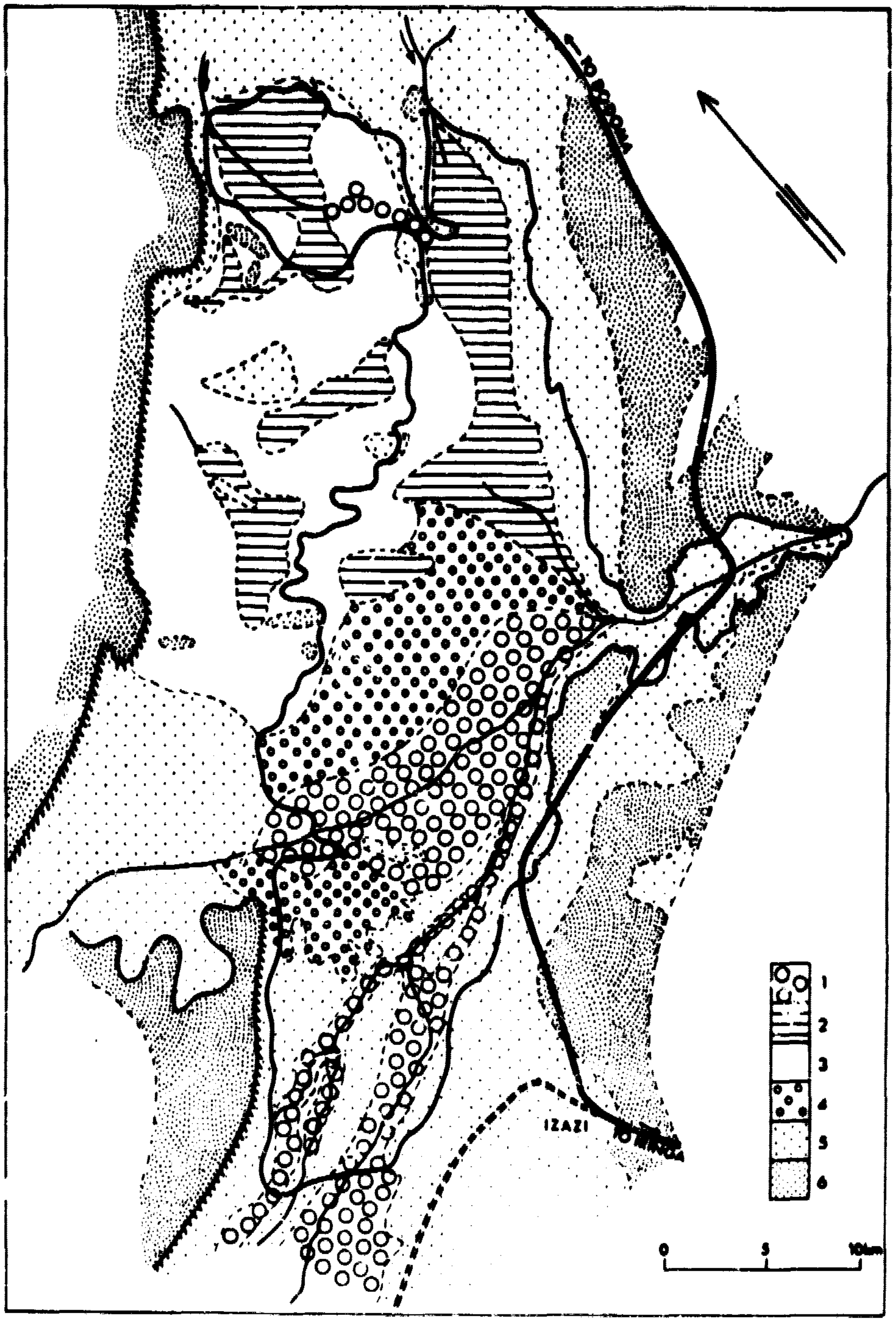

Fig. 23 Main vegetation types of the Mtera area as interpreted from Landsat-1 image (cf. Fig. 22). Legend: 1. Riparian forest and dense Riparian bushland, 2. Wet grassland, 3. Dry grassland, 4. Wooded grassland of the Kisigo river alluvial fan, 5. Bushland with mixed acacias, 6. Commiphora bushland/woodland

However, the occurrence of the Acacia kirkii - A. stuhlmannii bushlands and the Acacia seyal wooded grassland as determined by conventional aerial photos and ground surveys could not be accurately identified on the satellite images. The reason for this is their "patchy" distribution within other more extensive vegetation types.

It was also evident that more or less identical tones of the Landsat images sometimes represent totally different vegetation types, Table 1. For instance, the very light tones sometimes refer to dry grasslands, in other cases to badly eroded areas with very poor plant cover. Similarly the dark tones may either refer to riparian vegetation or Commiphora bushland. However, the marked catena arrangement of soils and vegetation proved to be of great value in the classification of vegetation types.

Table 1 Comparison between the tone of the satellite image and geomorphology and vegetation

Tone	Land Facets	Soils	Vegetation	Cover (%)			Remarks
				Canopy	Field layer		
					Wet season	Dry season	
Very light, almost white	Pediment slopes	Brown and grey colluvial soils, hardpan soils	Bushland with mixed acacias	5- 25	25- 75	(<5)	The strong reflection from bare earth gives a light tone
Very light, almost white	Pediment slopes	Brown and grey colluvial soils	Dry grassland	<5	75-100	(25-50)	The reflection from dry grass produces a light tone
Light grey	Alluvial fans	Well-sorted sand, silt and clay	Wooded grassland	5- 25	50-75	(5-25)	A mixture of trees, shrubs and fairly good cover of the field layer as well as the well drained soils results in various light grey tones
Dark grey	'Mbugas'	Alkaline clay	Wet grassland		100	(25-75)	The lush vegetation and humid soils is responsible for the darker tone
Very dark	Flood-plains	Grey alluvial soils	Riparian veg. or dense bushland	75-100	50-100	(5-25)	The canopy of the large trees and bushes gives a dark image. The dark areas compared with the band 7 image, also represent zones with a high soil moisture content
Very dark, almost black	Rift escarpments and tectonic hills	Red, coarse grained acidic residual soils	Commiphora bushland or woodland	75-100	25- 50	(<5)	The canopy and the very dark ground (rocks and red residual soils) both tend to give a dark tone

3.4 Interpretation of Landsat colour infrared images

The comparison is based on the vegetation classificatiom of Johansson, 1976, which in turn was based on conventional aerial photos (scale approximately 1:34 000) and ground reconnaissance, Fig. 23. The comparison is thus based on the known occurrence of the various vegetation types which could be delimited by this method.

Consideration must be given in comparison of the images to the fact that they are from three different years, namely September 1972, December 1974 and July 1979. Although the overall climatic conditions are very similar from year to year, large variations in the total amount of rainfall and lesser ones in the seasonal distribution of rainfall may occur between different years. The climatic difference is thus mainly related to the periods preceding or ending the "normal" wet season, which lasts from December to March.

The total rainfall at Mtera for the years 1972, 1973 and 1979 was 428, 605 and 506 mm respectively, which is rather close to the mean of 450 mm/year, except for the 1978/1979 wet season rainfall, which is considerably above the mean. The variations in the mean monthly rainfall at Mtera is shown in Fig. 24 and the monthly rainfall for the years 1972, 1973 and 1979 in Fig. 25-27. The seasonal variation in rainfall for the years 1972 and 1973 may be considered as quite normal, although high rainfall figures were recorded for February 1972 and January 1973. The Landsat images studied no doubt reflect normal environmental conditions in the periods of the years which they cover.

Below are some notes on the observations of the visibility of the different vegetation types on the Landsat images. A summary is given in Table 2.

3.4.1 I - Acacia circummarginata - Commiphora bushland

The denser types of this vegetation are easily recognized also on the July and September images. More open types with a great number of Acacia circummarginata are, however, not particularly distinct and may be difficult to delimit unless they can be related to topographical features, e.g. fault lines and escarpments. Owing to the dry conditions, the commiphoras are at this time of the year leafless. When they are in leaf, as in the images from December and January, they are more difficult to distinguish from other vegetation types in the surroundings.

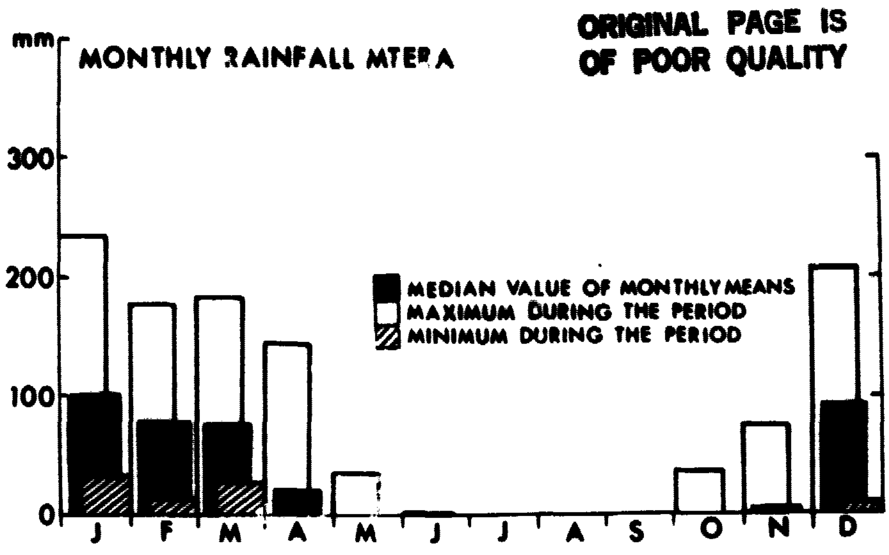

Fig. 24 The mean monthly distribution of rainfall at Mtera (Strömquist, 1976)

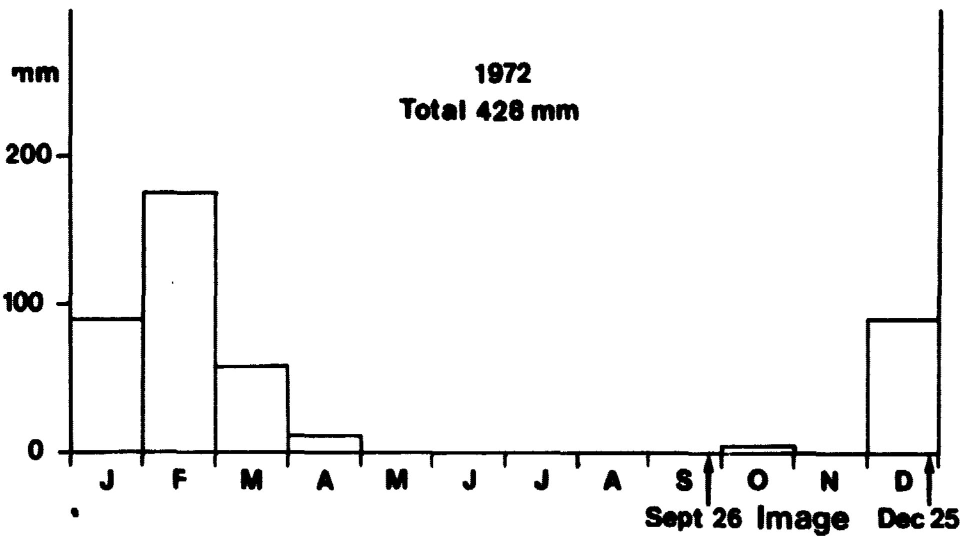

Fig. 25 The monthly distribution of rainfall at Mtera during 1972. There were 164 days without rain prior to the September 26 image. After the long dry season, 1972, a total of 60 mm rain had fallen prior to December 25, 1972

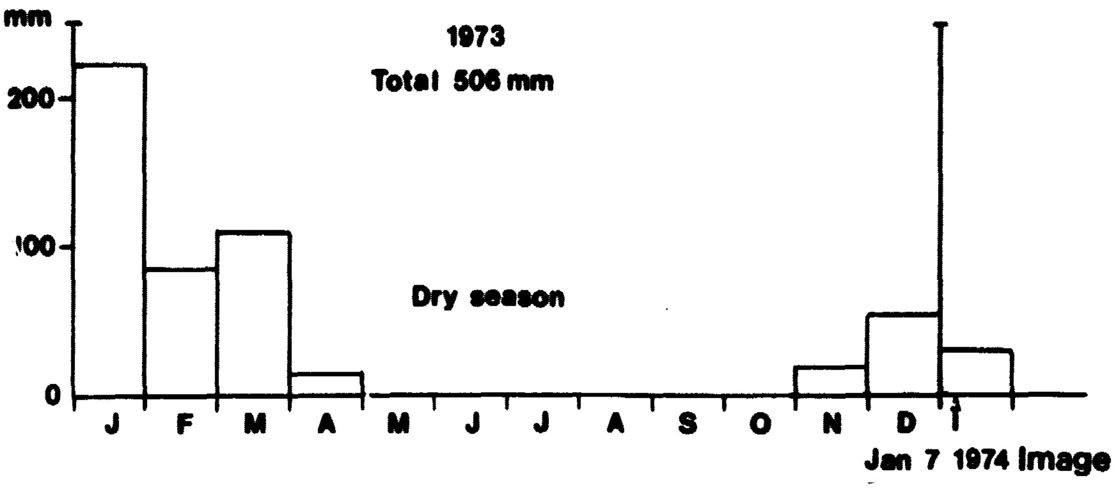

Fig. 26 The monthly distribution of rainfall during 1973 and January 1974. After the dry season of 1973, a rainfall of 81 mm in total was recorded prior to January 7, 1974.

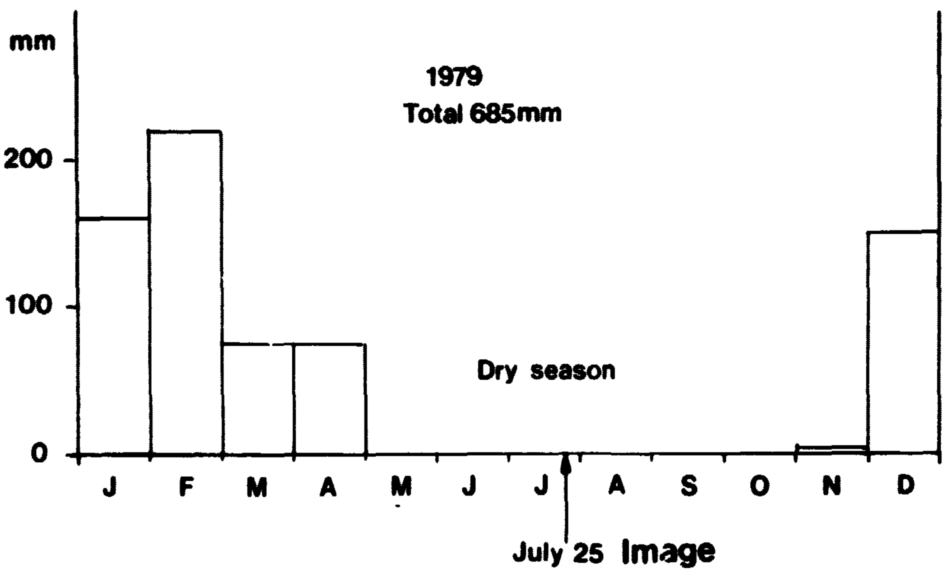

Fig. 27 The monthly distribution of rainfall at Mtera during 1979

Table 2 Interpretation potential with regard to vegetation in four Landsat colour infrared images.

Vegetation type		SATELLITE IMAGE			
		Dry season Sep 28th 1972	Early wet season Dec 25th 1972	Wet season Jan 7th 1974	Dry season Jul 25th 1979
I	Acacia circummarginata-Commiphora bushland	++	+	+	++
II	Acacia tortilis - Cordia gharaf groundwater bushland	++	+	+	++
III	Bushland with mixed acacias	-	+	+	-
IV	Acacia kirkii bushland	-	+	++	-
V	Open grassland	+	++	++	-
VI	Acacia seyal wooded grassland	-	-	-	-
VII	Riparian vegetation	++	+	+	++
VIII	Land under cultivation in the past and at present	-	+	+	-
Outside the Mtera basin					
Dense evergreen mountain rain forest		+	-	-	++

Legend:
- \- indistinct or impossible to trace
- \+ possible to trace
- ++ very distinct

3.4.2 II - The Acacia tortilis - Cordia gharaf groundwater bushland

This vegetation type appears as a very distinct red tone, for example, on the Pawaga flood plain and the alluvial fans of the Little Ruaha and the Kisigo rivers, on all images. In the July and September images, this colour stands out very distinctly towards the blue to greenish colours of the surrounding areas, where no green (chlorophyll) vegetation exists at this time of the year, since the trees and shrubs have shed their leaves and the herbs and grasses are entirely dried up.

The distribution of groundwater bushlands, as seen on the dry season images, is also a very good indication of the presence and distribution of a fairly rich supply of groundwater.

3.4.3 III - Bushland with mixed acacias

This is a rather heterogeneous type of vegetation. This is amply illustrated by the satellite images, which subdivide the areas of mixed acacia bushland into a number of tones, some with quite extended distribution. This bushland comes out very indistinctly on the July and September dry season images. It is in fact impossible to distinguish from many of the vegetation types in the surroundings.

In the wet season images from December and January, a number of areas with homogeneous and distinct tones may be distinguished. For instance, the pediment areas with considerable dominance of Acacia tortilis and subsequent large canopy cover comes out very clearly in a yellowish colour, while areas with low shrubs or trees, e.g. areas with a dominance of Acacia drepanolobium, appear as a light, almost white tone. The latter probably reflects the low canopy cover and the poor cover afforded by the field layer vegetation, typical of the most badly eroded pediments.

3.4.4 IV - Acacia kirkii bushland

It is not possible to distinguish this type of bushland on the images from July or September. It starts to appear on the images from December, but not very distinctly. However, on the image from January, the extent of more continuous belts of Acacia kirkii and the closely associated Acacia stuhlmannii is easily traceable. However, the growth habit of this vegetation type, which is often found in narrow strips, always makes it difficult to trace in heterogeneous plant communities.

3.4.5 V - Open grassland

The wettest parts of the open grasslands, which are seasonally flooded to form so-called 'mbugas', are easy to trace. They are very distinct on the wet season images, December and January, slightly more difficult to trace on the dry season image from September and much less distinct on the dry season July image.

The drier types of grassland are, however, somewhat more difficult to delimit, as they tend to merge with badly eroded pediment areas with poor arboreal cover.

In the December image, the grasslands in general and the drier parts in particular are quite distinct. This is related to the fact that most deciduous trees in this area tend to develop their foliage some weeks prior to the onset of the rains. In late December, the grasses and herbs have not developed any extensive ground cover, while the signals from the canopies of the trees are beginning to be strong. It is thus easy to trace the dividing line between areas with many trees and those with few. At the same time, the herbs and grasses of the wettest parts of the grassland are somewhat further developed, which also makes the boundary between the wet and dry grasslands more distinct. As the field layer vegetation develops towards the end of the rainy season, the difference between the grass-covered areas and bushland with few trees tends to lessen. This is already apparent on the image from the beginning of January.

3.4.6 VI - Acacia seyal wooded grassland

The Acacia seyal wooded grassland, although very easily recognized on the ground, is generally difficult to trace on aerial photos. This is mainly because of the small narrow crowns of the trees and the spacious distribution of the tress. On the satellite images it is not recognized on the July, September or December images, while the onset of new foliage seems to be reflected on the image from the beginning of January.

3.4.7 VII - Riparian vegetation

The riparian forest appears as a red, very distinct tone, on the July and September images. It thus merges with the surrounding groundwater bushland. However, the close association between the riparian vegetation and the drainage lines and water courses make delimiting easy, since the riparian vegetation is rarely found at any great distance from the water courses. In the December and the January images, the signals from the groundwater bushland and the riparian vegetation merge with the deciduous vegetation types in the surroundings, which at this time of the year trees leaves. This complicates mapping of the vegetation.

3.4.8 VIII - Land under cultivation in the past and at present

The land which has in the past been cultivated or is at present used as farmland is generally difficult to trace, because it occurs in rather small and dispersed areas. The regeneration of the plant cover of abandoned farmlands also occurs in many different stages, which furthermore gives rise to a complex pattern of signals. It is not possible to distinguish the farmlands on the images from July and September. However, on the December and January images, the denser leaf-bearing vegetation which surrounds the areas cleared for cultivation makes it easier to distinguish the light tones of areas under cultivation, since the crops at this time of the year have hardly begun to develop.

3.4.9 Dense evergreen mountain rain forest

The image from July also clearly distinguishes two vegetation types which do not occur in the Mtera basin. The dense, evergreen mountain rain forest which is found on the high mountains east of the Mtera basin appears as a very distinct purplish colour, while the surrounding vegetation, Brachystegia woodland and grasslands, which at this altitude still remain green at this time of the year, appear as an orange colour, Fig. 28. This in fact makes possible very exact delimiting of areas covered by rain forest, e.g. within the Mafomwero, Ukiwa, Mangalisa, Imoye and the West Kilimbero scarp forest reserves.

The exact distribution and encroachments on the forest can easily be registered and monitored by means of this type of satellite image. The differences between the dense mountain rain forest and surrounding vegetation types also appear on the image from September, although far less pronounced.

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Fig. 28 Evergreen mountain rain forest in bright red surrounded by Brachystegia woodland and man-made grasslands at Imoye on Landsat, July 1979. Scale 1:250 000.

3.4.10 Result of vegetation mapping

By combining the most useful data from a number of images, a quite detailed vegetation map may be compiled, Fig. 29. The information derived from the different images that were used to identify the vegetation types may be summarized as follows:

The dry season images (July and September) were used to delimit

- groundwater bushland and riparian forest
- denser Commiphora bushland
- wet grasslands

The early wet season image (December) was used to delimit

- Acacia tortilis bushland (part of the mixed acacia bushland)
- Acacia drepanolobium bushland (part of the mixed acacia bushland)
- Dry grasslands

The wet season image (January) was used to delimit

- Acacia kirkii/A stuhlmannii bushlands
- Areas with poor plant cover

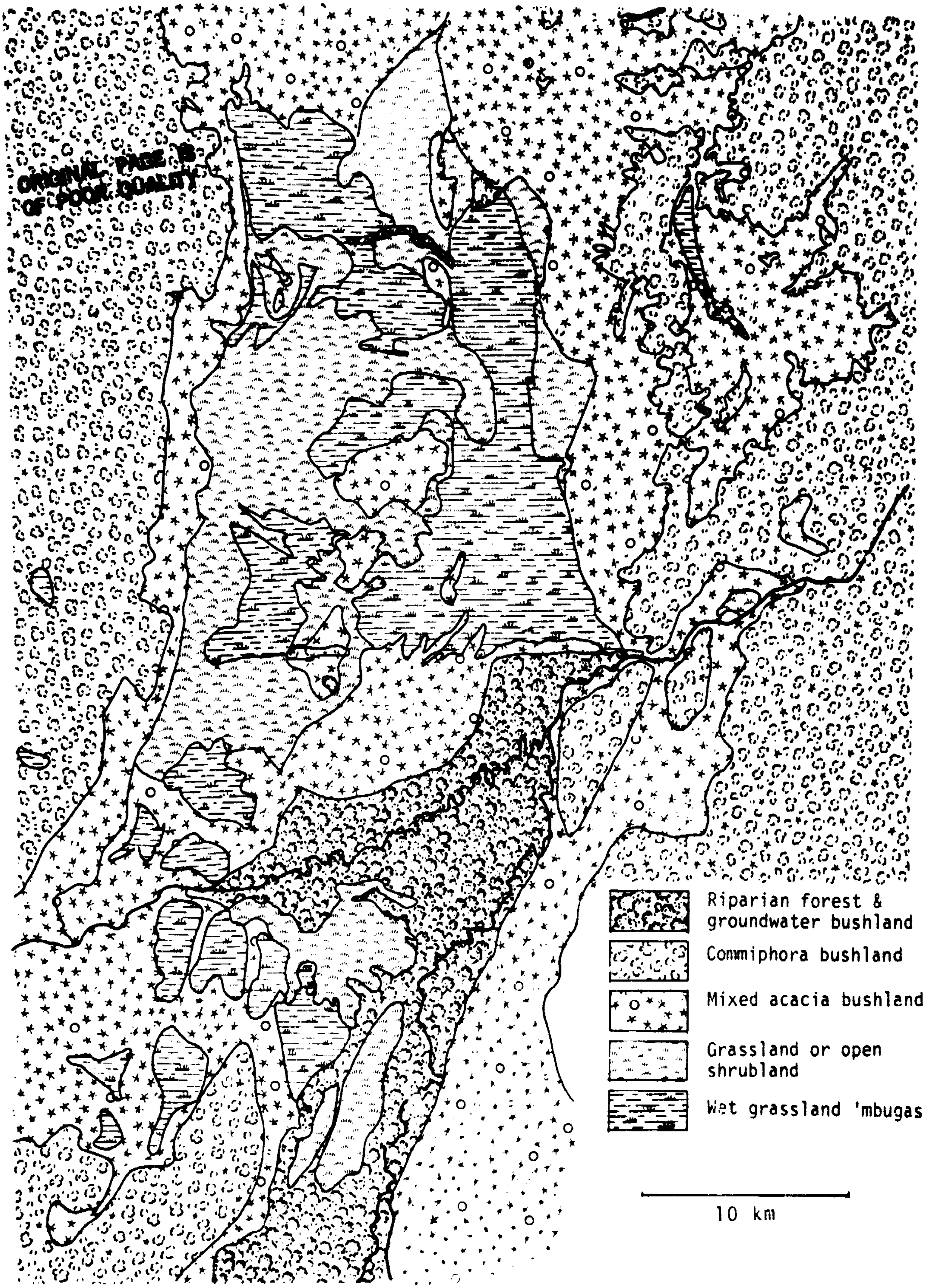


Fig. 2: Classification of vegetation of the Mtera basin based on interpretation of different colour infrared satellite images

3.5 Supervised classification of Landsat registrations

When comparing the results of interactive computer analysis in relation to interpretation of images, the following two observations are valid:

1. The general visibility of the different vegetation types is much increased. This is due to the fact that the signal from each 60x80 m area is grouped according to its characteristics into one of the selected classes. This represents a simplification of a complex pattern. Furthermore, by giving the selected classes different and distinct colours, the borders between the various vegetation types may also be accentuated.

2. The other obvious advantage of this method is the very detailed nature of the information which becomes available for analysis. The characteristics of areas as small as 60x80 m are clearly visible, which makes it possible, for example, to distinguish minor differences in large-scale patterns.

A colour image showing a preliminary analysis by this method of the vegetation of the northern part of the Mtera basin is presented in <u>Fig. 30</u>. The information of this image may be used directly as a vegetation map, or may in a generalized form be transferred to a map showing, for example the distribution of different vegetation types, <u>Fig. 31</u>.

The results of the computer analysis give the following conclusions:

I The Acacia circummarginata - Commiphora bushland or more homogeneous bushland of mainly Commiphora spp (olive or lighter green tones), are clearly separated from the surrounding bushlands of Acacia tortilis. For example:

Areas with poorer tree density, for example old farmland at various stages of regrowth, appear as lighter green tones within the Commiphora belt.

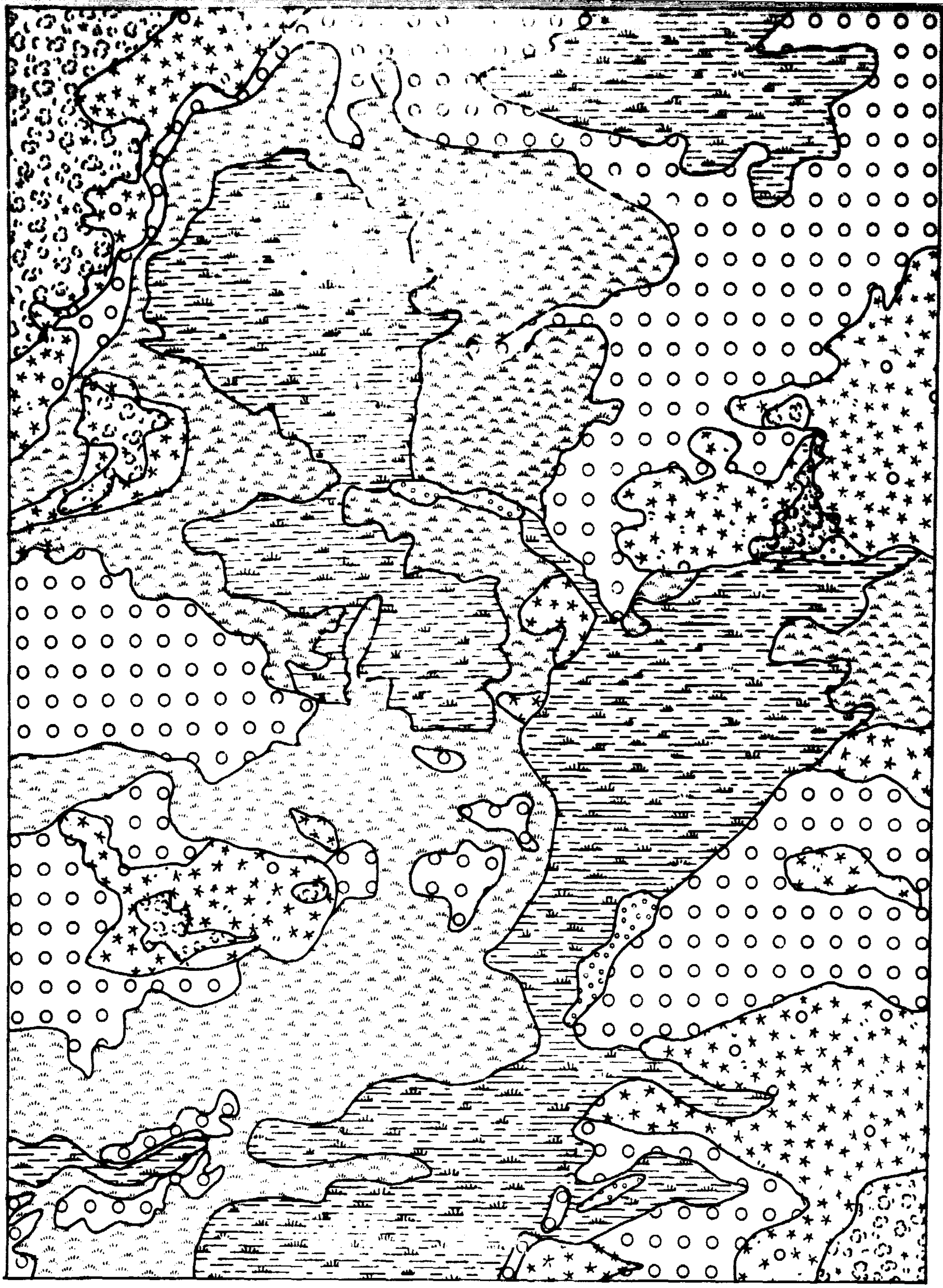
II The Acacia tortilis - Cordia gharaf groundwater bushland is delimited in the generalized vegetation map is presented in the computer analysis as a heterogeneous pattern of olive and light green tones. This reflects a mixture of riparian forest and trees and shrubs as Cordia gharaf and Acacia kirkii/A. stuhlmannii. The Acacia tortilis which is very common in the groundwater bushland near the Great Ruaha river, obviously does not occur in any great numbers on the Kisigo alluvial fan, as previously anticipated.

III Bushland with mixed acacias. The mixed Acacia bushland, which is a rather heterogeneous vegetation type, is subdivided in the computer analysis into two easily recognizable vegetation types:

1) an Acacia tortilis bushland of rather large trees, shown in brick-red;

2) a more open bushland with shorter trees and shrubs, for example, Acacia drepanolobium, Capparis sepiaria, Grewia bicolor and Balanites pedicellaris, in pale yellow colour.

IV The Acacia kirkii bushland, which shows up in pale brownish tones, is not easy to re-



10 KM

LEGEND

- COMMIPHORA BUSHLAND
- ACACIA TORTILIS BUSHLAND
- GROUNDWATER BUSHLAND
- RIPARIAN FOREST
- OPEN SHRUBLAND
- DRY GRASSLAND
- WET GRASSLAND "MBUGAS"

Fig. 31 Computer classification of vegetation in the northern part of the Mtera basin over the same area as on Fig. 30

Fig. 30 Computer classified vegetation map

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cognize when it is, as usual, associated with wet grasslands. However, it is very difficult to trace even on large scale aerial photos.

V The open grasslands stand out very distinctly. The wet grasslands, 'mbugas', i.e. seasonally flooded plains, (dark blue), are furthermore very easy to separate from the more dry types of grassland (light blue). The dividing line between the grassland and the bushland is also very distinct. This is of great value since other methods fail to provide any safe method of distinguishing the open grasslands from the more open types of bushland with mixed acacias.

VI The areas with Acacia seyal have not shown up in the images of the computer analysis. The reason for this is probably their patchy distribution and the low cover afforded by their canopies, which results in their "disappearance" in the signal from the wet grasslands in which they occur.

VII The riparian forest gives rise to a response, coded in olive on the map, similar to that of the Commiphora bushland. However, since the riparian forest is strictly limited to the water courses, it is easy to distinguish from the Commiphora bushland, which is associated with hills, ridges or rocky outcrops.

Only occasionally do these two vegetation types merge, for example, on the steep slopes of the narrow river valley downstream of Mtera village. However, in such a narrow valley, the riparian forest is for natural reasons of very limited distribution, which simplifies its separation from surrounding vegetation types.

VIII Land under cultivation in the past and at present is generally difficult to trace on the computer-analyzed images. There are two reasons for this:

1) the size of the cultivated plots is usually rather small;

2) the plots are often widely dispersed. They are therefore commonly surrounded by land with different plant cover, which tends to give a rather

complex signal, i.e. a mixture
of cleared areas, areas with
some regrowth and areas with
dense mature vegetation.

The regrowth of abandoned farmland, although easily recognized on the ground by the composition of its flora, may also be difficult to recognize on the images since it may resemble the natural vegetation in density and other characteristics. When the cultivations occur in denser vegetation types, they are, however, easier to detect. Cultivations in the rather dense Commiphora bushland north of Kisima are thus clearly visible.

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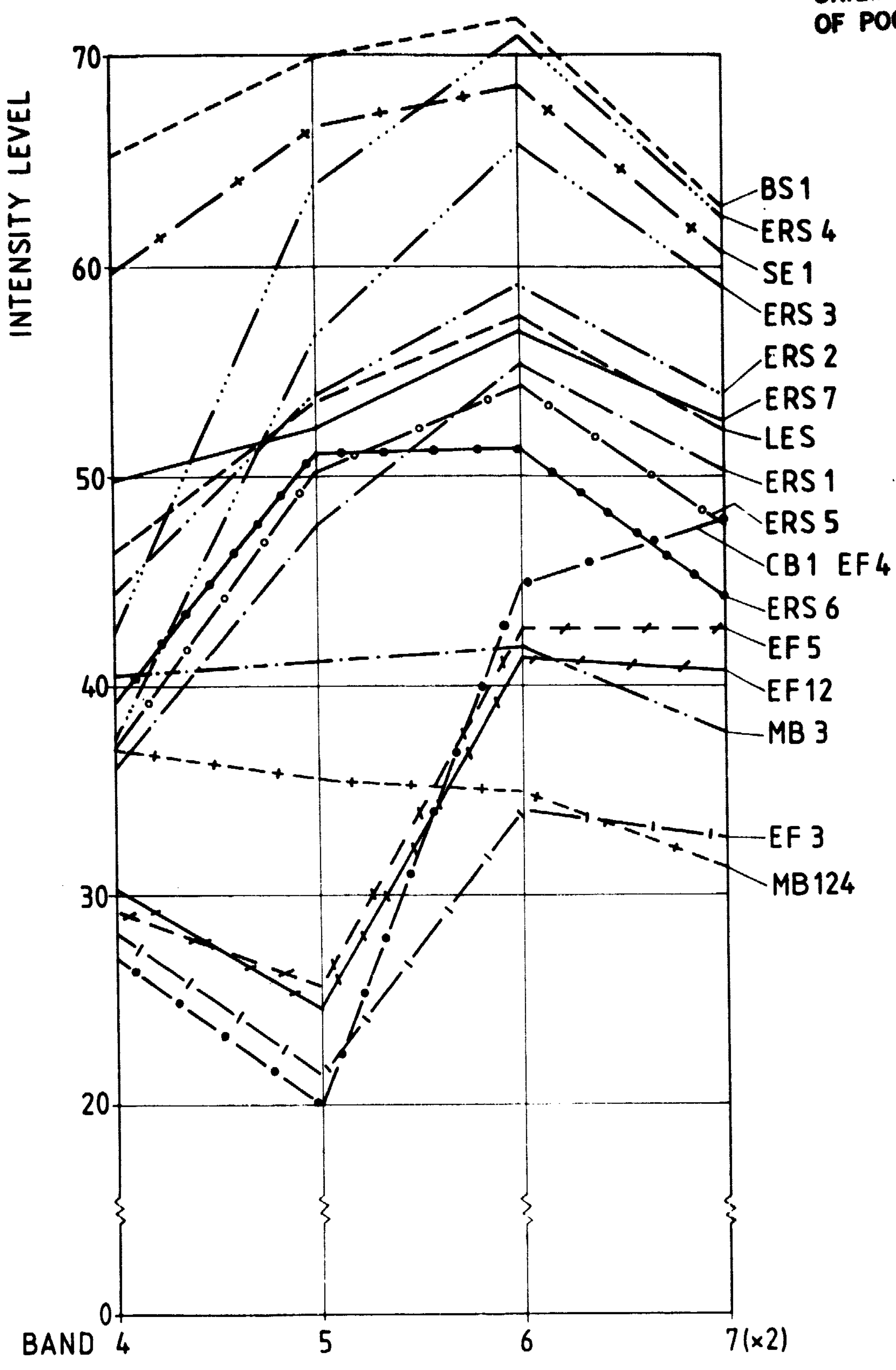

Fig. 32A Spectral mean values for 16 out of 31 soil and vegetation signatures from classification of the Mtera scene, 1974-01-07. The intensity levels of band 7 are multiplied by 2. The complete statistics are reported in Appendix 1

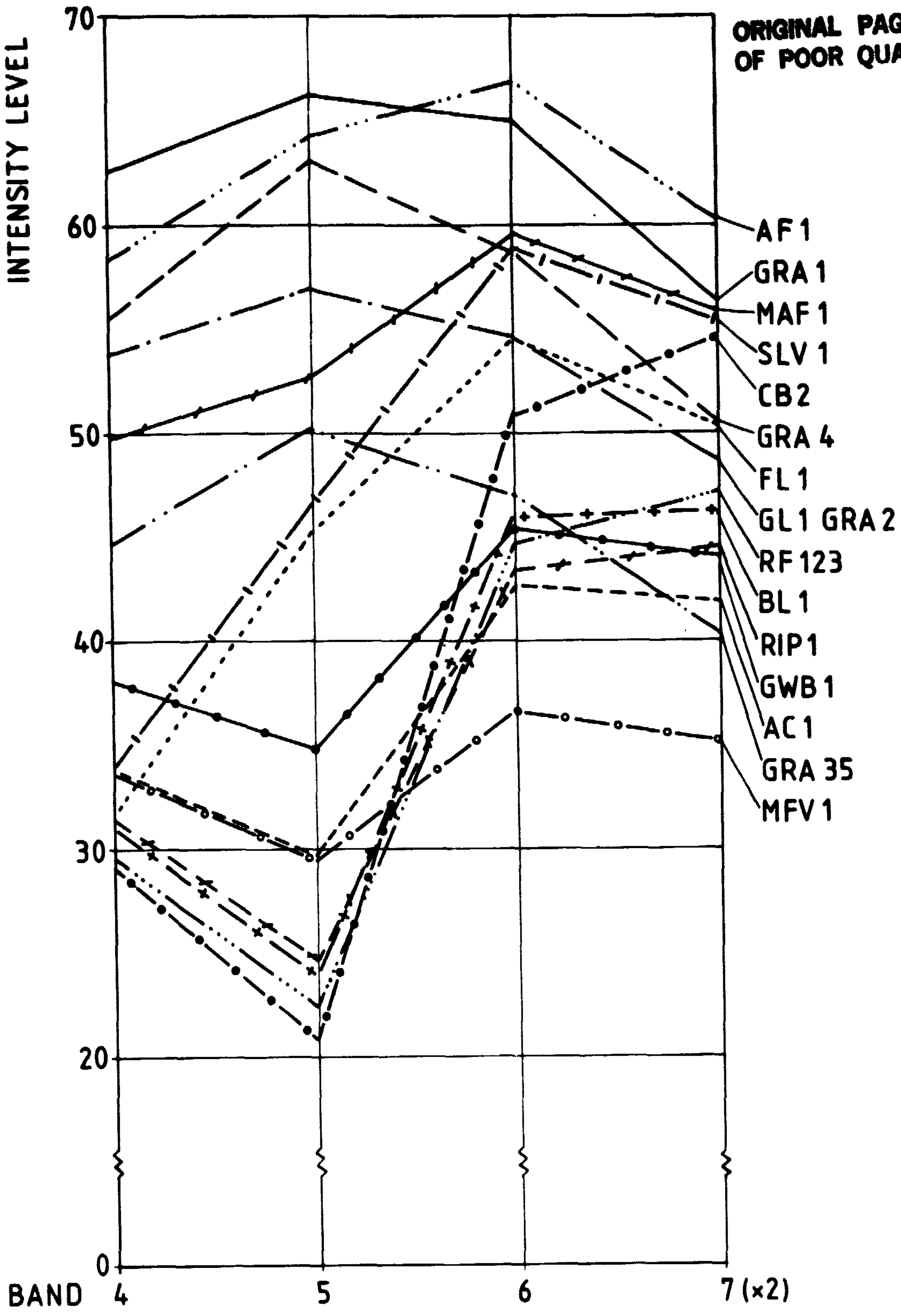

Fig. 32B Spectral mean values for 15 out of 31 soil and vegetation signatures from classification of the Mtera scene, 1974-01-07. The intensity levels of band 7 are multiplied by 2. The complete statistics are reported in Appendix 1

4. GEOMORPHOLOGY

4.1 Interpretation of black and white aerial photos and Landsat images

Landforms, erosion and sedimentation within the Mtera basin have been mapped on the scale 1:250,000 (Strömquist, 1976, Johansson and Strömquist 1978), Fig. 33. The map was based on interpretation of aerial photos and mosaics and was followed by field checks. Landsat images were used as a basis for the subdivision of the landscape into land systems and land facets. The images were also used for preliminary quantification of areas affected by severe erosion. The interpretation was carried out on a Landsat image from 25th December, 1972 which in this case is at the beginning of the wet season. Band 5 was mainly used but band 7 was also used to some extent. No colour infrared images were used.

In two papers from 1976 and 1978, it was pointed out that the greatest advantage in using Landsat images instead of conventional aerial photos or aerial photo mosaics for land systems mapping was that the same grey tones prevail over large areas representing the same type of terrain. The tones are good indicators of soil types and drainage conditions which are to differences in moisture content and vegetation.

The large-scale features of the landscape, such as faults, escarpments, erosional or depositional zones etc., were identified on the satellite images. However, it was impossible to observe on the images the details of the catena distribution of soils in relation to the local variation in vegetation pattern and geochemical environment.

The details of the drainage pattern could be identified. It was possible to map quite small streams (5-10 m wide) on the basis of the signals from the surrounding riparian vegetation or from the dry sandy river bottoms.

In the Mtera pilot study we have interpreted vegetation and geomorphological features in the four bands of the four available registrations over the area. The interpretation has not included vegetation or geomorphological maps as the use of the black and white images is much more time consuming and the result much more unreliable when compared with colour infrared images. We consider that the black and white images should only be used as a supplement to the coloured images. We have summarized our experience in Table 3. For interpretation purposes the most useful

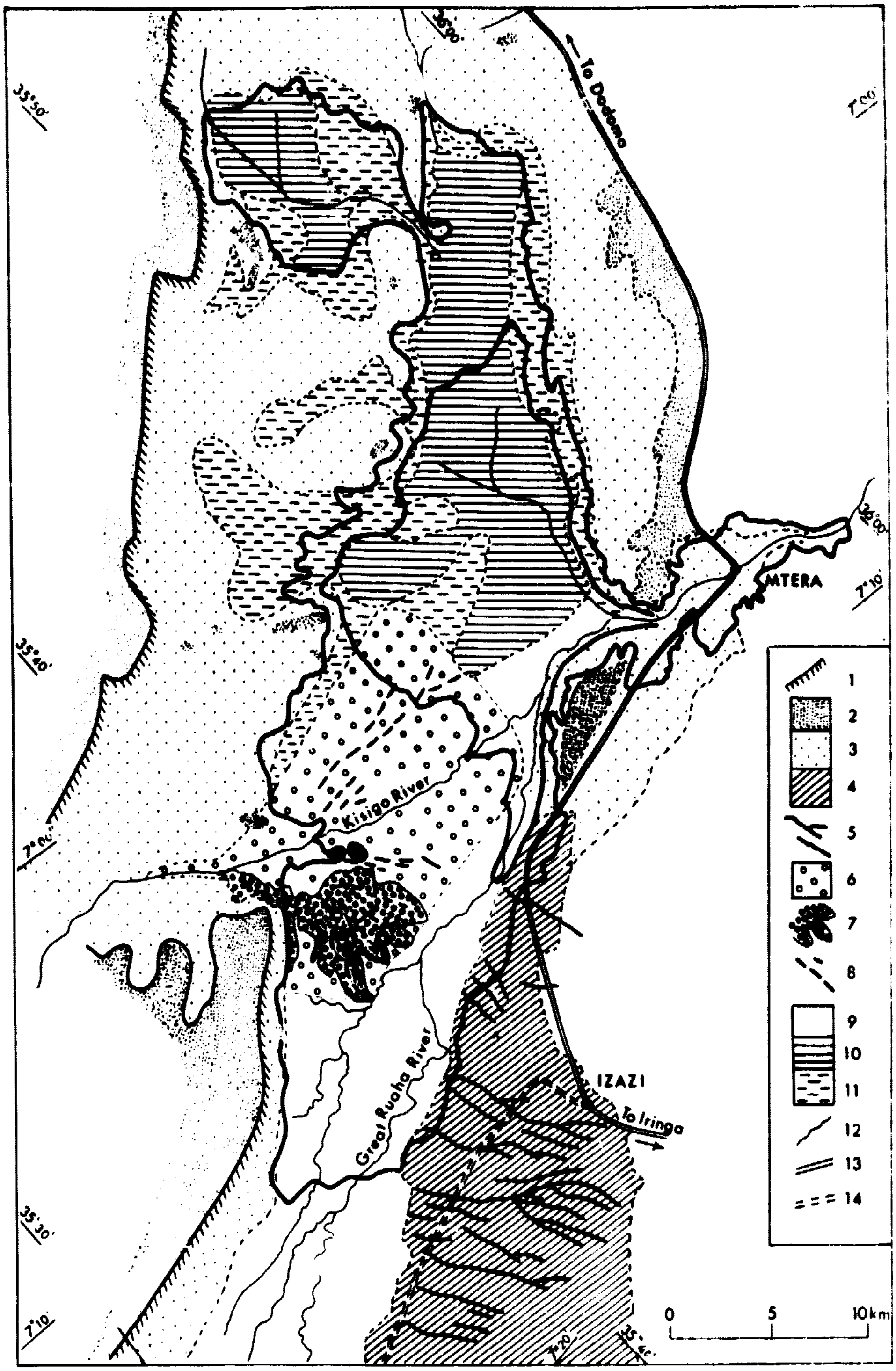

Fig. 33 Land forms, erosion and sedimentation within the Mtera area. Rift escarpments. 2. Tectonic hills and inclined plateaus. 3. Pediments with colluvium. 4. Eroded pediments. 5. Seasonal streams on pediments. Kisigo alluvial fan. 7. Recent bifurcate deposits. 8. Old stream channels. 9. Great Ruaha alluvial deposits. 10. Mbugas. 11. Mbuga-like colluvial deposits. 12. River. 13. Highway. 14. Track. (Strömquist, 1976).

Table 3. Interpretation potential in Landsat black and white images

Element	Spectral bands															
	4				5				6				7			
	Sep 72	Dec 72	Jan 74	Jul 79	Sep 72	Dec 72	Jan 74	Jul 79	Sep 72	Dec 72	Jan 74	Jul 79	Sep 72	Dec 72	Jan 74	Jul 79
General vegetation	+	++	++	++	+	++	++	++	+	+	+	+	+	-	-	+
Vegetation types	-	+	+	-	-	+	+	-	-	-	-	-	-	-	-	-
Moisture conditions	-	-	-	-	-	-	-	-	+	++	++	-	+	++	++	-
Rift escarpments	++	++	++	++	++	++	++	++	++	+	+	++	++	-	-	++
Tectonic hills and inclined plateaus	+	+	+	++	+	+	+	++	+	-	-	+	+	-	-	+
Pediments	-	++	++	+	+	++	++	++	+	++	+	+	+	+	-	+
Erosion	-	++	++	+	+	++	++	++	+	+	+	+	+	-	-	+
Farmland	+	+	+	-/+	++	++	++	+	++	+	+	-/+	++	-	-	-/+
Alluvial fans	+	-/+	+	++	+	-/+	-/+	++	+	+	+	++	+	+	+	++
Flood plains	++	++	++	++	++	++	++	++	+	++	++	++	+	+	+	++
Mbugas	-	+	+	-	+	+	+	+	+	++	++	+	+	++	++	+
Primary drainage ways	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
Secondary drainage ways in open terrain	++	++	++	++	++	++	++	++	+	++	+	++	+	++	++	++
Secondary drainage ways in forested terrain	++	++	++	++	++	++	++	++	-	-	-	+	-	-	-	+
Gullies in open terrain	+	++	++	++	+	++	++	++	-	+	+	+	-	-/+	-/+	+
Gullies in forested terrain	-	-/+	-/+	-/+	-/+	-/+	-/+	-/+	-	-/+	-	-/+	-	-	-	-/+
Major tectonic features	++	++	++	++	++	++	++	++	++	++	++	++	++	+	+	++
Minor tectonic features	-	+	+	+	+	++	+	+	+	+	+	+	+	+	-/+	+

Legend: - indistinct or impossible to trace ++ very distinct
+ possible to trace

useful image is made from band 5. To cover what cannot be interpreted from band 5, the two near-infrared bands Nos. 6 and 7 should be used. These two bands will primarily add information about the water and moisture conditions. As can be seen from the table, the information in the images varies with the season.

4.2 Interpretation of Landsat colour infrared images

The comparison is based on the classification of land facets carried out by Strömquist in the report by Johansson, 1976. The colour infrared images are shown in Fig. 1-4.

4.2.1 Rift escarpments

Major rift escarpments are found west and east of the Mtera basin which is located at the foot of the rift valley. Minor scarps and faults are found within the basin. The western rift is more distinct than the eastern. The major escarpments are easily identified in all four Landsat images. In fact, this feature is so large that it is easy to identify in any kind of Landsat material.

The identification of minor scarps and faults are discussed in more detail in the Clause Tectonic features.

4.2.2 Tectonic hills and inclined plateaus

Tectonic hills are common on the central plain while inclined plateaus are common in the eastern rift zone and delimited by faults and scarps. The tectonic hills are identified most easily on the December and January images as the hilltop is covered with dense vegetation in deep red in distinct contrast to the surrounding pediments which appear in tones of yellow on the images. The typical change in the tone of the pediments from higher to lower altitudes gives a "topographic" impression to the hills.

On the July and September images the tectonic hills are also clearly visible but they do not contrast with the surroundings to the same extent as on the images from the wet season. The "topographic" effect of the pediments is missing and the image looks rather flat. The drainage pattern on the slopes of the tectonic hills is poorly developed and the interpretation that the hills rise above the valley bottom cannot be easily made.

4.2.3 Pediments

The pediments in the area occur as gently inclined slopes below the rift escarpments and the tectonic hills. Their gradient very seldom exceeds 2-5^{o} and the relief is extremly low. The pediments are commonly affected by sheet and fluvial erosion by seasonal streams. In certain areas extensive gully erosion is found.

On the January, September and December images the pediments are easily recognized, as they appear in different nuances of yellow. In the two wet season images the effect of erosion can observed. With an increase in the portion of bare soil, the tone turns from dark yellow to light yellow and finally becomes whitish in areas with severe erosion. All white tones on the images do not, however, indicate eroded land, as dry vegetation and especially the dry grasslands are also represented in a rather similar way. On the July image, the pediments are quite difficult to delineate, although it is possible to draw the approximate boundaries. Only the most severely eroded areas appear very clearly.

4.2.4 Alluvial fans

The alluvial fans consist of fine- to coarse-grained sediments deposited by the intermittent flowing streams. The fan-like shape of the drainage pattern makes it possible to identify this land form. The great Kisigo alluvial fan at the confluence of the Great Ruaha and Kisigo rivers is particularly easy to recognize in any kind of Landsat material.

There are several alluvial fans and alluvial cones along the western escarpment. They are most easily observed north of the Kisigo river in the January and December images. It is also possible to detect these land forms in the September and March images, although this interpretation is more difficult. The small alluvial cones south of the Kisigo river can be observed in the dry season images, while it is difficult to locate them in the wet season images as the canopy covers the minor details that reveal their occurrence.

4.2.5 Flood Plains

The flood plains are areas along the main rivers which are flooded seasonally. Grain size in the soil ranges from sand to clay in a most complex way, a result of the historical build-up of the plain. The formation is identified from the drainage pattern as braided river systems, meanders, cut-off drainage ways, etc. It is possible to identify the general delineation of the plains in all four images. Vegetation will affect identification in more detailed studies of the minor parts of the flood plains as is discussed in the clause Drainage pattern.

4.2.6 Mbugas

Mbugas and mbuga-like deposits appear as the wettest parts of the open grasslands. They are formed on sedimentary clay plains, where the mbugas are located on the lowest parts of the terrain. The mbuga-like deposits are a transitional form against the surrounding pediments. Identification depends on the moisture and vegetation conditions. It is probably possible to identify this formation on Landsat images from any season due to the often distinct contrast with the surroundings. In the four available registrations over the Mtera area, the mbugas were easily recognized on the wet season images from December and January by their dark appearance during flood conditions. During the dry season, the mbugas were also clearly identifiable quite distinctly on the September scene, while in a less pronounced manner on the July image.

4.2.7 Drainage

The drainage pattern, including the main rivers and minor gullies, is quite easy to identify.

The primary drainage ways, the major rivers such as Great Ruaha river and Kisigo river within the Mtera basin, can be identified from the Landsat images with great accuracy independent of season. Water-filled streams are found most easily, but dry streams can also be traced without difficulty.

In the secondary drainage ways, and where the river system is spread out as braided rivers within the Pawaga plain in the southern part of the basin, the use of images from different seasons significantly increases the possibility of identifying the drainage ways. During the wet season, most of the drainage ways can be seen, but they are partly out of sight due to the dense canopy. In the dry season image of July 1979, the drainage ways are beautifully exposed in the Pawaga plain.

In order to identify the minor gully drainage ways, it is absolutely necessary to use multitemporal images. In open areas, very small gullies, 5-10 m wide, can be identified, since they appear in significant contrast to the surroundings due to changes in vegetation, soil conditions and slope. The identification is possible in both dry and wet season images, although the drainage pattern will appear in more detail during the growing season. Parts of the pattern may vanish in dry season as contrasts become weaker. In forrested areas, the dry season images are superior as the drainage pattern is visible even with regard to minor detail. During the wet season, the covering canopy hides much of the drainage ways which leads to an uncertain and schematic result. Thus, to obtain the best information about the drainage pattern several images from different seasons should be studied and interpreted.

The occurence of different drainage patterns can be found over the entire Mtera scene. An example of the effect of seasonal variability is the eroded soils east of the Great Ruaha river. In comparison with the best available map of the region, the geological map Izazi on the scale 1:125,000, the interpretation of Landsat images gives a more detailed drainage pattern. The topography on the geological map is derived from 1951 and 1959. The differences might reflect changes in the drainage ways during the period from the mapping to the Landsat registration. The varying amount of detail might also depend on different views about generalization of the maps. <u>Fig. 34</u> shows a comparison between the drainage pattern on the geological map and from Landsat for a small area in the southeastern part of the Mtera basin.

The drainage pattern provides information regarding the physical characteristics of the ground such as soil and erosion conditions. The overall view that Landsat provides gives us the opportunity to interpret and compare the conditions over large areas. However, the resolution of the present Landsat generation does not allow a careful analysis of the smallest element of the pattern, the very form of the gullies, that is the most useful criteria in the evaluation of erosion. During the seven year period of the ava[illegible] images, no significant change can be ob[illegible] drainage pattern indicating changes in [illegible]

By combining the most useful data from [illegible] able Landsat images, a rather detailed [illegible] can be compiled. The information used to p[illegible] drainage pattern of the figure is summarized [illegible] <u>Table 4</u>.

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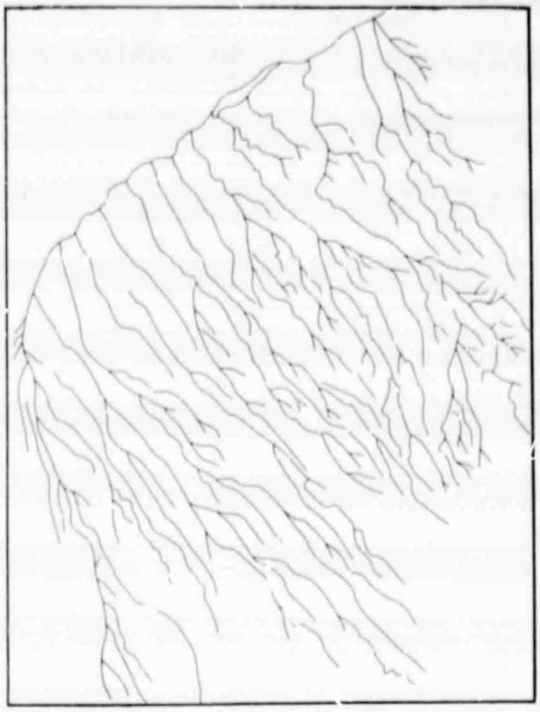

A. according to the geological map B. according to Landsat
   Izazi

Fig. 34 Drainage pattern on the eroded slope east of the Great Ruaha river

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Table 4. Interpretation potential with regard to geomorphological features in four Landsat colour infrared images

Geomorphological feature	Satellite image			
	Dry season Sep 28th 1972	Early wet season Dec 25th 1972	Wet season Jan 7th 1974	Dry season Jul 25 1979
Rift escarpments	+/++	+/++	+/++	+/++
Tectonic hills and inclined plateaus	+	++	++	+
Pediments	++	++	++	+/-
Alluvial fans	+	+/++	+/++	+
Flood plains	++	++	++	++
Mbugas	++	++	++	+
Primary drainage ways	++	++	++	++
Secondary drainage ways in open terrain	++	++	++	++
Secondary drainage ways in forested terrain	++	+/++	+/++	++
Gullies in open terrain	++	++	++	+
Gullies in forested terrain	+	-/+	-/+	++

Legend:
- \- indistict or impossible to trace
- \+ possible to trace
- ++ very distinct

4.2.8 Tectonic features

Linear features may reflect several structural elements of the bedrock such as faults, joints, dikes, contacts or schistosity. Aerial photos are superior for identification and for interpretation of the many linear features but as they only cover small areas many linearities may not be identified. The Landsat coverage of large areas facilitates the identification of a more structural pattern than the areal photos alone can achieve. The satellite images reveal several linear features around the Mtera basin which are not presented on available geological maps. In comparison with aerial photographs the Landsat images in this case have a great advantage as they are multitemporal

——— Detectable on all images
- - - " primarily on the image 1972-09-26
-.-.-. " " " " " 1972-12-25
. . . . " " " " " 1974-01-07
.... " " " " " 1979-07-25

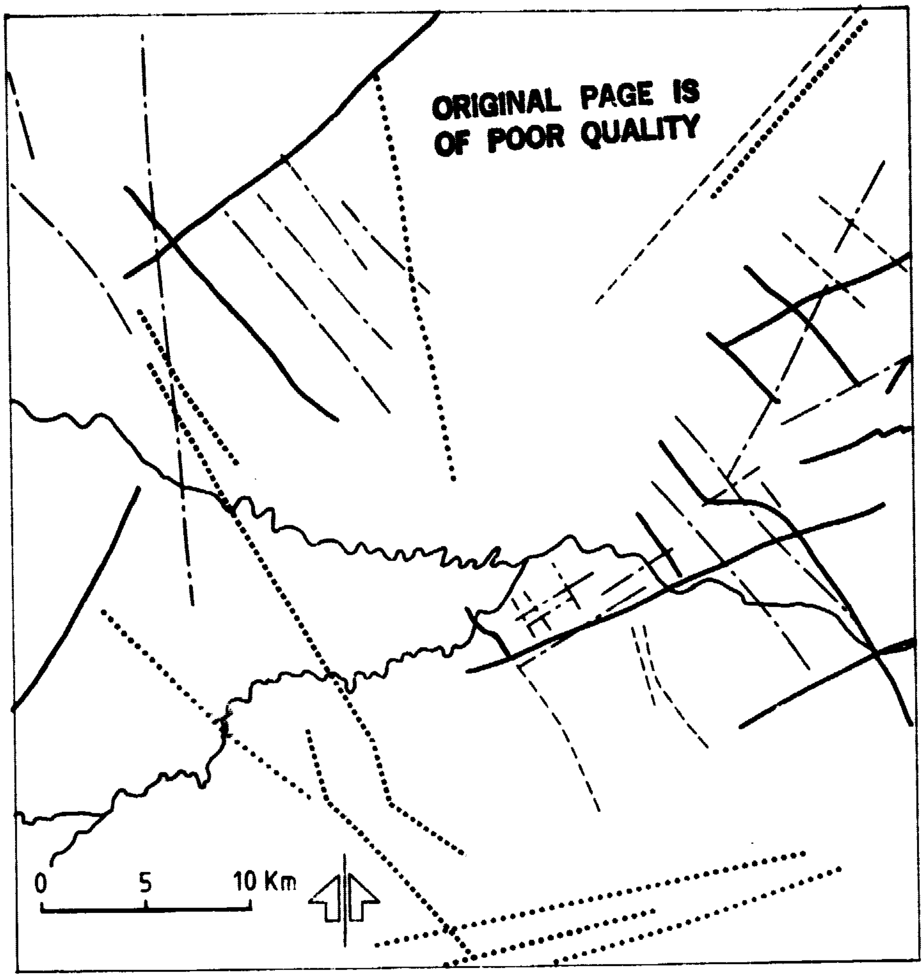

Fig. 35A Tectonic features interpretated from four Landsat colour infrared images

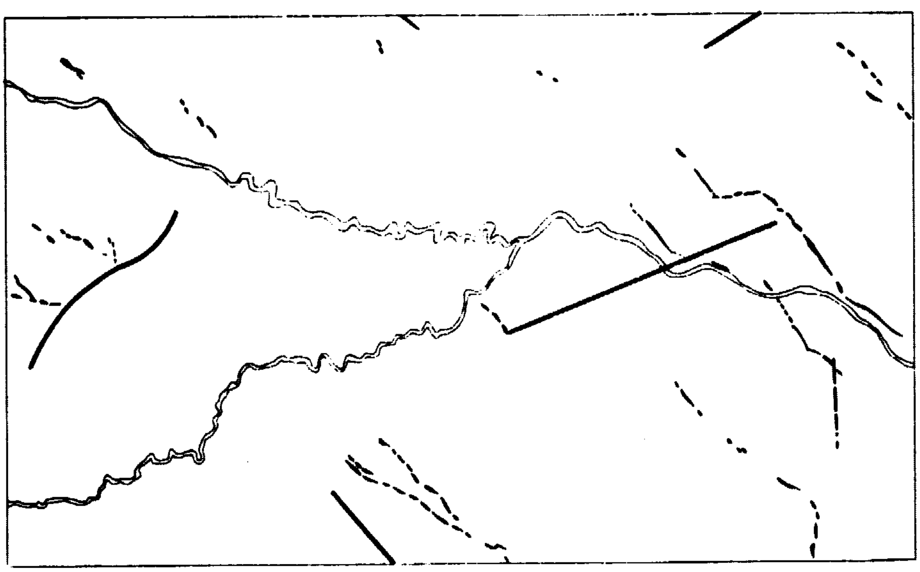

Fig. 35B Tectonic features, thick lines, and dykes according to the geological map Izazi which means that it is possible to collect information from different seasons with different conditions as regards vegetation, moisture, sun angle, etc. Aerial photos are normally taken during the dry season when the use of these parameters is at a minimum. In many areas, the aerial photos from one single occasion are only available in black and white.

The linear features have been interpreted in the four Landsat images. A number of major lineaments are clearly identified in all four images. However, most linear features are only visible in one or two of the images. This stresses the fact that the interpreter shall use multitemporal images in order to to achieve the best results. If only one image has to be selected, registrations from the growing season contain most of the information required.

The tectonic map on Fig. 35 has been compiled from the interpretation of all four images. Preference is given to the image in which the individual lineament is most easily identified. Comparison is also made with the information on the available geological map Izazi on the original scale 1:125 000.

4.3 Tectonic features through differential edge enhancement

The Landsat registrations contain information about linear features, which it is not possible to detect by interpretation of the satellite images. By edge enhancement it is possible to exaggerate changes in the scene and thus detect lineaments. On Fig. 36 enhancement is carried out by translation in four directions of band 5 from the January registration. The translation was carried out on an area of 512x 512 pixels. The Mtera dam site is located in the eastern central margin of the pictures. The translation directions are northwest-southeast, north-east-southwest, north-south and east-west. In all examples the translation is one pixel.

In the figures, many of the lineaments are derived from rivers and small streams. The major tectonic features which were interpreted from the false colour images and shown in Fig. 35 are all found in some of the enhanced pictures. In addition, three more linear systems reflecting tectonic features can be seen, as indicated in Fig. 36.

Fig. 36A Translation NW-SE

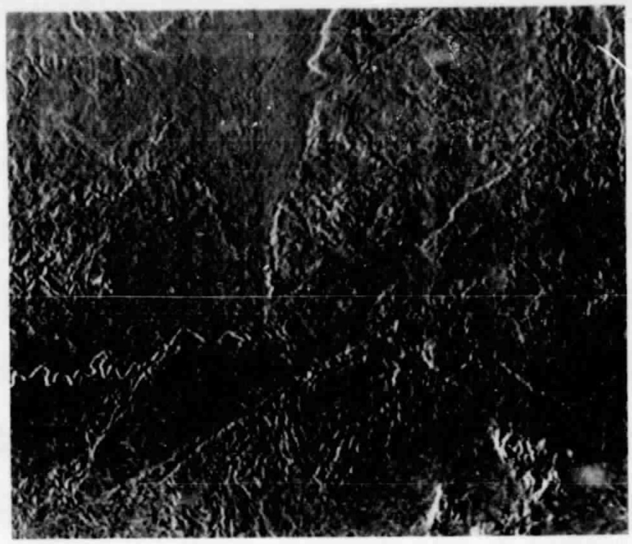

Fig. 36B Translation NE-SW

Fig. 36C Translation N-S

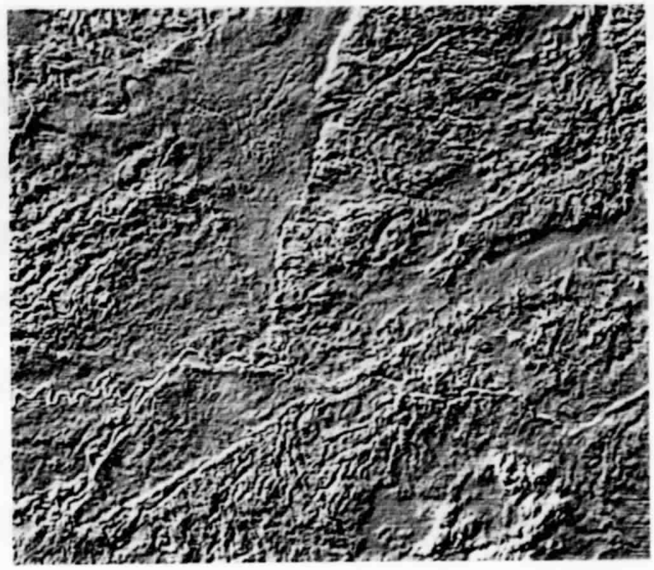

Fig. 36D Translation E-W

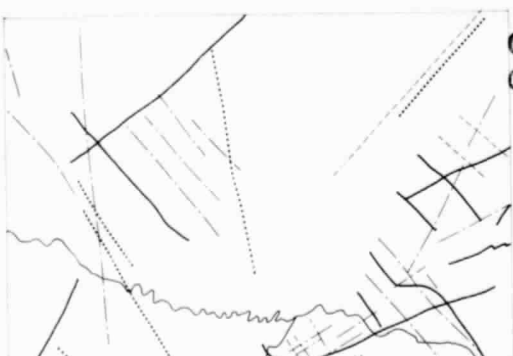

Fig. 36E Tectonic features as interpreted from Landsat colour infrared images

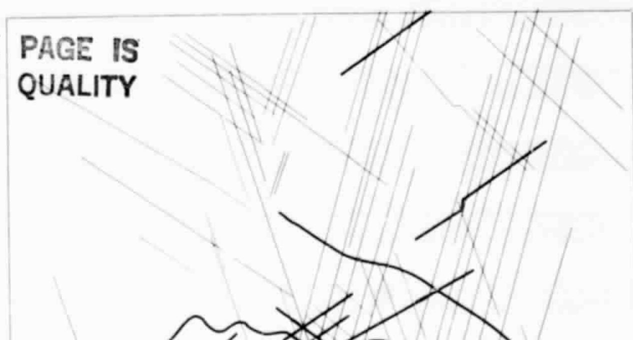

Fig. 36F Tectonic features derived from edge enhancement. Thick lines show major fracture lines. Thin lines indicate fracture pattern derived from edge enhancement accord-

5. MULTITEMPORAL CLASSIFICATION AND CHANGE DETECTION

5.1 Classification with eight spectral bands

The initial computer classification was carried out using four spectral bands of the wet season registrations of 1974-01-07. Normally, the growing season is the most suitable time to classify different vegetation types. However, to obtain a complete picture of the distribution of vegetation types it is wise to use several registrations from the growing season. This is normal procedure and thus not tested in this study. Instead in our tests we have used the eight spectral bands from one wet season and one dry season registration to study what could be gained from such contradictionary ground conditions.

There are certain difficulties locate to images to each other where this has to rely on terrain features such as rivers and vegetation boundaries. In semi-arid areas like in Mtera the images differ greatly from a wet to a dry season. This will influence upon the apperance of the terrain features and obviously change boundaries, river courses, etc.

Training areas were initially selected and refined from the January wet season registration. The 30 training areas finally selected were then transferred to and retrained on the September scene of 1972. These dry season training areas were then adjusted and refined until the new classes were satisfactorily clean with gaussian-shaped statistics. Finally, the adjusted training areas were retrained on the January scene to cover the same pixels. The spectral mean values for the 30 soil and vegetation signatures of the eight spectral bands are plotted on <u>Fig. 37A-C</u>. The complete statistics are presented in <u>Appendix 2</u>. The final map of the reservoir area is presented on <u>Fig. 38</u>

The results show a much more varied separation of classes in comparison with classification from one registration only. The grasslands and eroded soils in particular are more diversified, as are the vegetation classes but to a lesser extent, cf. Fig. 39. The number of unclassified pixels has also decreased.

The spectral mean values illustrated on Fig. 37A-C show that training areas of the different classes appear in distinct signatures both during wet and dry seasons. In the wet season diagrams, the denser vegetation shows a typical S-shaped signature curve, such as that associated with Commiphora bushland and Acacia kirkii. During the dry season, only the groundwater bushland and the riparian vegetation appear in S-shape, although the curves are much flatter.

The mbuga grassland is a complex class. In the wet season the training areas MBUG 4 and 6 represent growing areas. MBUG 2 and 3 are only slightly green, while MBUG 1 and 5 have still not started growing but are covered with dry, old grass. In the dry season all the mbuga training areas are covered with dry grass. There are still clear differences between the three groups of mbugas MBUG 4 and 6, 2 and 3, 1 and 5. In fact the differnces between the groups have increased, thus making it possible to better separate the different grasslands within the mbugas than in the wet season registration.

A similar pattern can be seen from the signatures of bushland with mixed acacias. The training areas AX 1 and BUSH 1 contain a rather large amount of vegetation while AX 2 contains more grass or bare soil during the wet season.

The signatures of the vegetation class acacia tortilis, TORT 1-3, show that the trees are quite widely spaced. The spectral values are strongly affected by the field layer which is dominated by grass. This can be seen from the wet season curves while the dry season curves reflect the dry vegetation.

The eroded pediments, ERP 1-3 and DREP 1-3, show almost identical signatures in both seasons. There is a slight tendency towards there being less sparse vegetation in the eroded pediments where acacia drepanolobium, DREP 1-3, can be traced during the wet season.

Legend: ERP = eroded pediments
MIM = brachystegia bushland
AX+BUSH = bushland with mixed acacia
GRWB = groundwater bushland

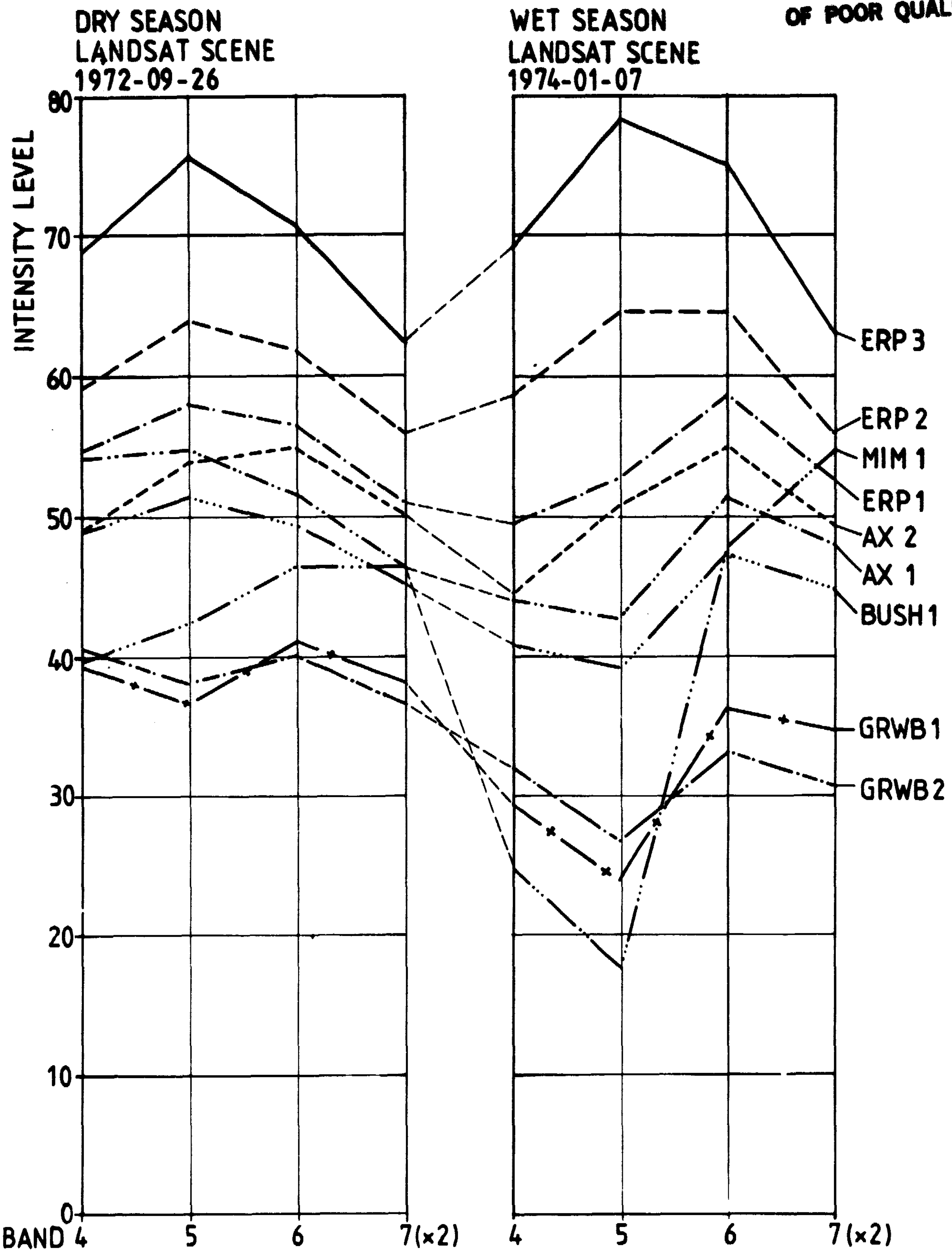

Fig. 37A Spectral mean values for soil and vegetation signatures of eight spectral bands used for multitemporal classification. The intensity levels of band 7 are multiplied by 2

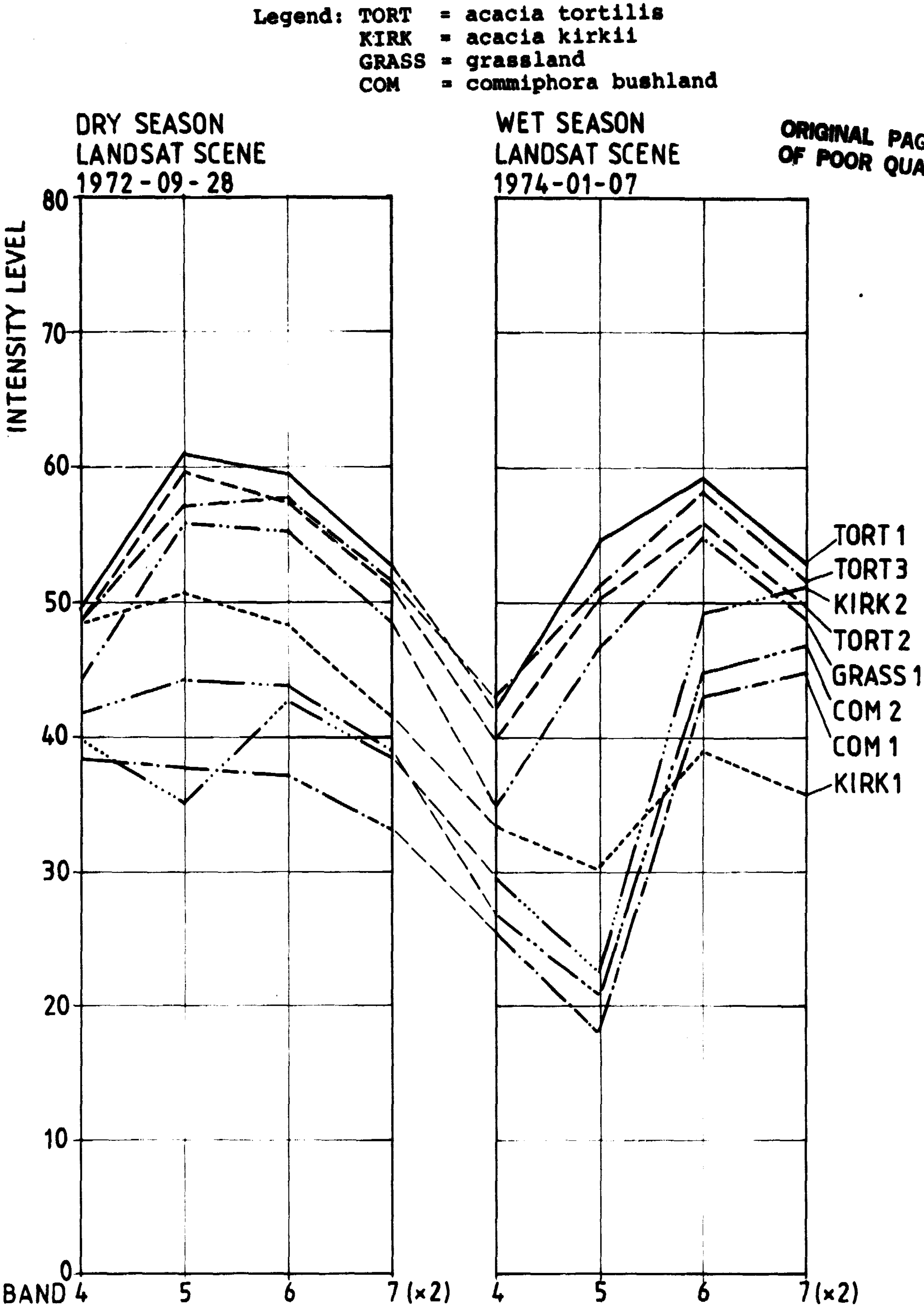

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Fig. 37B Spectral mean values for soil and vegetation signatures of eight spectral bands used for multitemporal classification. The intensity levels of band 7 are multiplied by 2

Legend: DREP = eroded pediments with Acacia drepanolobium
REP = riparian vegetation
MBUG = mbuga grassland

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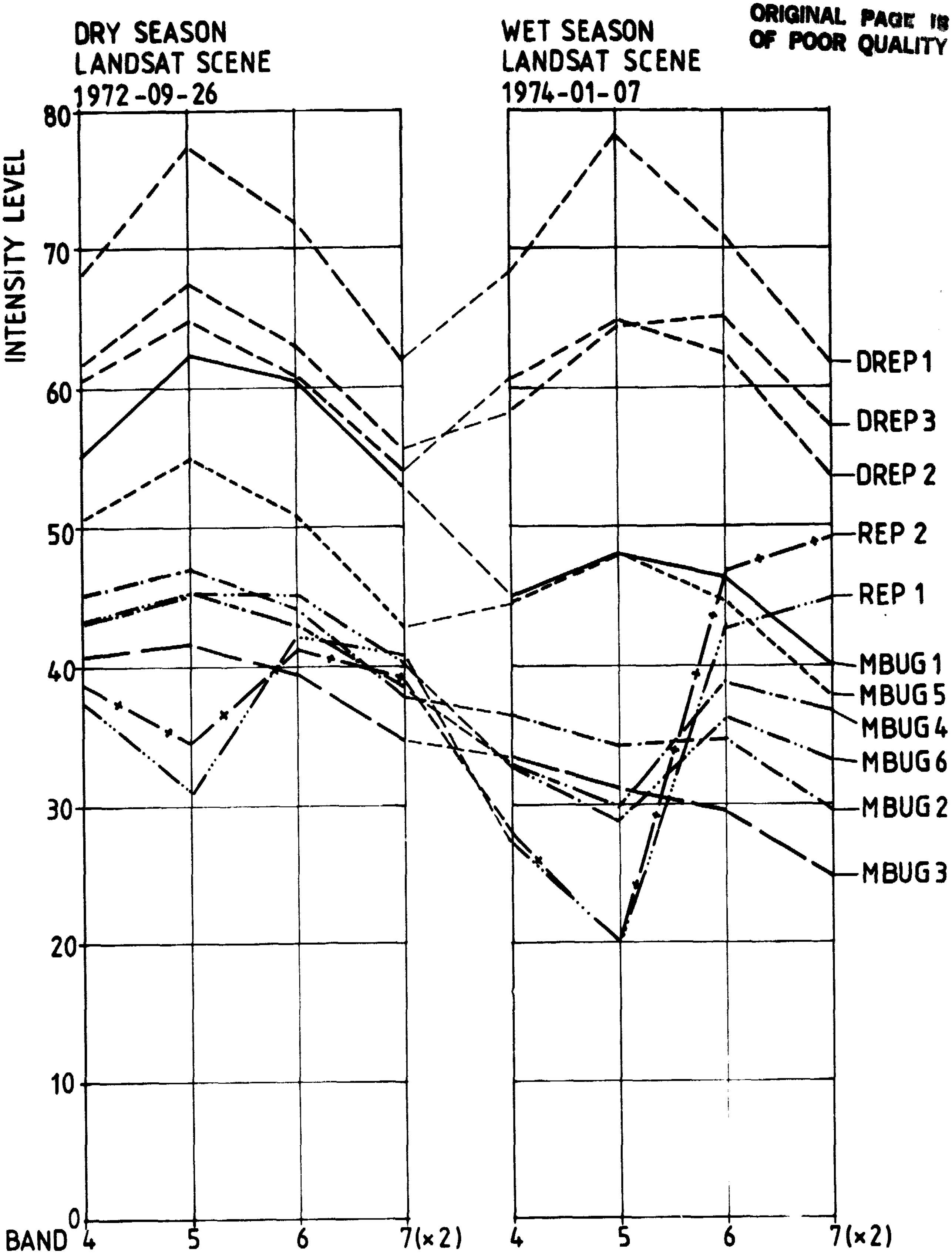

Fig. 37C Spectral mean values for soil and vegetation signatures of eight spectral bands used for multitemporal classification. The intensity levels of b·nd 7 are multiplied by 2

LEGEND

Dark red-red	=	Riparian vegetation
Pink	=	Acacia kirkii
Red	=	Brachystegia bushland
Purple	=	Bushland
Dark green	=	Commiphora bushland
Medium green	=	Acacia tortilis
Light green	=	groundwater bushland
Blue shades	=	open grassland
Yellow	=	eroded bushland
Bluish grey	=	eroded pediments with Acacia drepanolobium
Brown	=	severely eroded bushland

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Fig 38 Soil and vegetation map from multitemporal classification

5.2 Changes in forest cover 1972-1979

Through comparison of two registrations, it is possible to detect certain changes that have taken place. In Mtera it is especially interesting to register the changes in forest cover, as this is the first step towards land erosion. The speed of forest clear-cutting is high enough to permit detection of changes within a seven-year time interval. It is even more important to follow the phenomenon of active soil erosion. However, it has not been possible to detect the increase in soil erosion that has taken place within the period 1972-1979 as the speed of erosion seems to have been too low to permit detection from Landsat registrations.

To detect changes in forest cover registrations from the same season should be used. In the Mtera study, we have used two dry season registrations from 1972-09-28 and 1979-07-25.

The chlorphyll content is best visible in band 5. Changes to higher reflection in band 5 i.e., changes in chlorophyll content, could be mapped by digital subtraction of the 1972 image from 1979, and by addition, if necessary, of negative mean intensity changes from the 1972 to the 1979 image. The number of unclassified pixels has also decreased.

Clear-cut areas can now be defined as those that have been mapped as forest areas in the 1972 image and that have changed to higher intensity to a greater degree than changes in mean image intensity from the 1972 to the 1979 image.

The result of this procedure shows that large forested areas have been cleared over the seven year period. The clear cut areas are concentrated to the margins of the open farmlands above the escarpments. The changes are presented on Fig. 39. The image has been smoothed to remove isolated pixels. The changes in forest cover can also, to some degree, be interpreted from the photographic images but with less accuracy and with an increase in the amount of time required for two task, cf. Fig. 1-4.

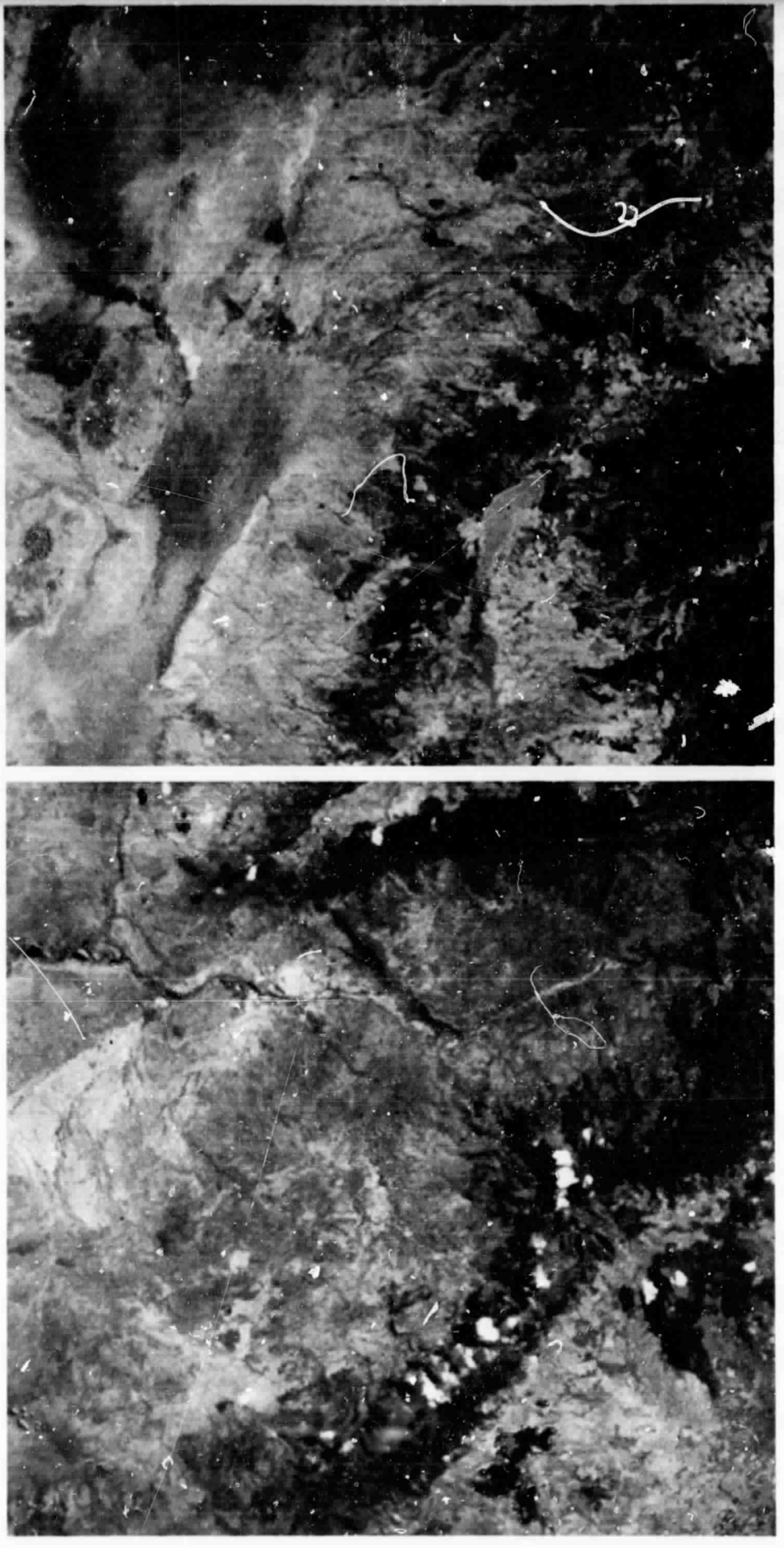

Fig. 39 Changes in forest cover 1972-1979 north (top) and south (bottom) of the Mtera dam site. The felling and burning of trees and shrubs to obtain farmland during the seven year period is shown in red on the pictures. The changes are clearly concentrated around the existing farmlands appearing in light grey-tones. The darker areas show the forest cover in 1979.

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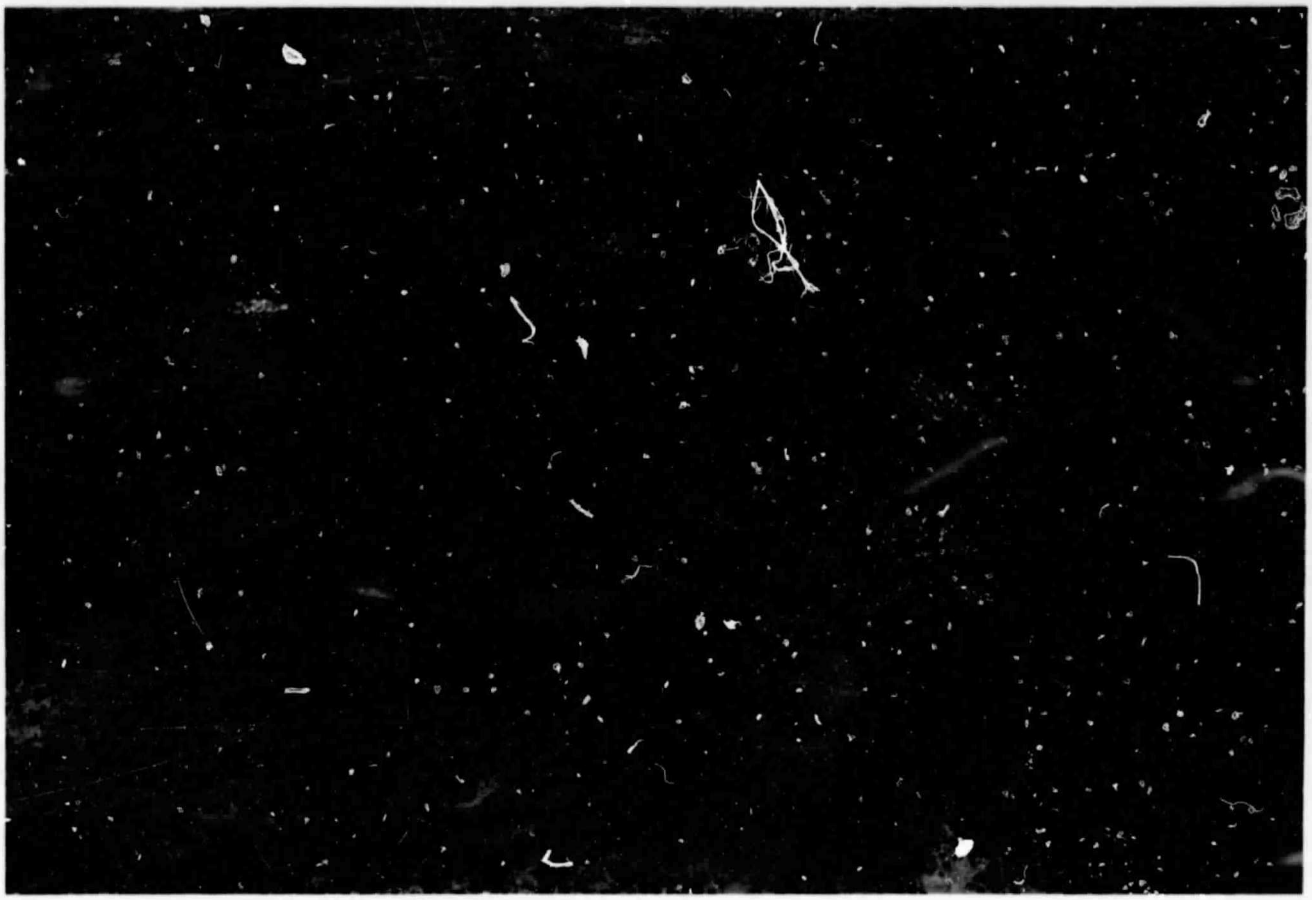

Fig. 40 Impact of shiftning cultivation practice on the landscape, Dodoma district, Nov. 1975.

Shifting cultivation, i.e. the felling and burning of trees and shrubs, to obtain farmland, is a very destructive land use practice. The forest which originally covered the whole landscape in the picture, now only remains on the steep hillsides and the peaks. The most recent clearings, to be cultivated in the comming wet season, are visible by their ash-grey tone. Lower down the slopes abandoned farmlands, which still are devoid of trees and shrubs are recognized by their pale lateritic soils. Old farming areas further down have been severely eroded. The numerous gullies can easily be traced by the dark stripes of bushes which colonize their bottoms.

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Appendix 1

Statistics
of 31 signatures selected from originally 49 training areas of the Mtera Landsat scene, 1974-01-07

Band 4	Band 5	Band 6	Band 7

FILE: MTERA 2375 , SIGNATURE: 1 , DESCRIPTOR: EF12
BASED UPON 3675 TRAINING SAMPLES
MEAN:

0.304438E+02	0.247676E+02	0.414444E+02	0.204207E+02

COVARIANCE:

0.255722E+01	0.394340E+01	0.124054E+01	0.185578E+00
0.394340E+01	0.104623E+02	0.310558E+01	0.509116E+00
0.124054E+01	0.310558E+01	0.154661E+02	0.805878E+01
0.185578E+00	0.509116E+00	0.805878E+01	0.384955E+01

FILE: MTERA 2375 , SIGNATURE: 2 , DESCRIPTOR: GWR1
BASED UPON 6020 TRAINING SAMPLES
MEAN:

0.382119E+02	0.349460E+02	0.455007E+02	0.220718E+02

COVARIANCE:

0.823455E+01	0.119854E+02	0.666578E+01	0.245847E+01
0.119854E+02	0.203877E+02	0.102148E+02	0.391794E+01
0.666578E+01	0.102148E+02	0.927741E+01	0.363239E+01
0.245847E+01	0.391794E+01	0.363239E+01	0.229568E+01

FILE: MTERA 2375 , SIGNATURE: 3 , DESCRIPTOR: MB3
BASED UPON 7330 TRAINING SAMPLES
MEAN:

0.405364E+02	0.410924E+02	0.418628E+02	0.189344E+02

COVARIANCE:

0.369822E+01	0.243046E+01	0.188947E+01	0.559137E+00
0.243046E+01	0.546777E+01	0.256586E+01	0.776904E+00
0.188947E+01	0.256586E+01	0.372538E+01	0.568401E+00
0.559137E+00	0.776904E+00	0.568401E+00	0.932306E+00

FILE: MTERA 2375 , SIGNATURE: 4 , DESCRIPTOR: EPS1
BASED UPON 4032 TRAINING SAMPLES
MEAN:

0.360745E+02	0.376379E+02	0.558827E+02	0.251994E+02

COVARIANCE:

0.101712E+02	0.824792E+01	0.385497E+01	0.12[illegible]E+01
0.824792E+01	0.218564E+02	0.126051E+02	0.3[illegible]E+01
0.385497E+01	0.126051E+02	0.125108E+02	0.333047E+01
0.120995E+01	0.360950E+01	0.333047E+01	0.1527[illegible]E+01

FILE: MTERA 2375 , SIGNATURE: 5 , DESCRIPTOR: EPS2
BASED UPON [illegible] TRAINING SAMPLES
MEAN:

0.44[illegible]E+02	[illegible]	0.[illegible]E+02	0.269940E+02

COVARIANCE:

0.11[illegible]E+02	[illegible]	0.4[illegible]E+01	[illegible]
0.[illegible]E+01	0.203362E+02	0.124924E+02	0.[illegible]E+01
0.4[illegible]E+01	0.124924E+02	0.119413E+02	0.338264E+01
0.199007E+01	0.387991E+01	0.338264E+01	0.1685[illegible]E+01

Band 4	Band 5	**Band 6**	**Band 7**

FILE: MIERA 2375 , SIGNATURE: 6 , DESCRIPTOR: GRA1
BASED UPON 1962 TRAINING SAMPLES

MEAN:

0.625708E+02	0.662370E+02	0.650464E+02	0.282615E+02

COVARIANCE

0.447452E+01	0.362130E+01	0.340520E+01	0.972987E+00
0.362130E+01	0.626147E+01	0.403517E+01	0.901121E+00
0.340520E+01	0.403517E+01	0.690622E+01	0.129969E+01
0.972987E+00	0.901121E+00	0.129969E+01	0.878695E+00

FILE: MIERA 2375 , SIGNATURE: 7 , DESCRIPTOR: RIP1
BASED UPON 1372 TRAINING SAMPLES

MEAN:

0.3159[illegible]E+02	0.246628E+02	0.434410E+02	0.223178E+02

COVARIANCE

0.719241E+01	0.929592E+01	0.255831E+01	-0.288311E+00
0.929592E+01	0.147966E+02	0.340525E+01	-0.100733E+01
0.255831E+01	0.340525E+01	0.446793E+01	0.202770E+01
-0.288311E+00	-0.100733E+01	0.202770E+01	0.274904E+01

FILE: MIERA 2375 , SIGNATURE: 8 , DESCRIPTOR: CB2
BASED UPON 1675 TRAINING SAMPLES

MEAN:

0.2920[illegible]E+02	0.208744E+02	0.509021E+02	0.273248E+02

COVARIANCE

0.372597E+01	0.489744E+01	-0.438209E+00	-0.828657E+00
0.489744E+01	0.920433E+01	-0.116298E+01	-0.156201E+01
0.438209E+00	0.116298E+01	0.803642E+01	0.365075E+01
-0.828657E+00	-0.156201E+01	0.365075E+01	0.257970E+01

FILE: MIERA 2375 , SIGNATURE: 9 , DESCRIPTOR: BS1
BASED UPON 1128 TRAINING SAMPLES

MEAN:

0.652[illegible]E+02	0.698005E+02	0.717638E+02	0.314349E+02

COVARIANCE

0.339644E+02	0.344099E+02	0.258631E+02	0.881970E+01
0.344099E+02	0.509416E+02	0.335551E+02	-0.108264E+02
0.258631E+02	0.335551E+02	0.318239E+02	0.952087E+01
0.881970E+01	0.108264E+02	0.952087E+01	0.333389E+01

FILE: MIERA 2375 , SIGNATURE: 10 , DESCRIPTOR: AF1
BASED UPON 1404 TRAINING SAMPLES

MEAN:

0.592[illegible]E+02	0.641750E+02	0.668535E+02	0.301558E+02

COVARIANCE

0.242845E+02	0.263874E+02	0.195918E+02	0.609531E+01
0.263874E+02	0.397575E+02	0.261913E+02	0.784068E+01
0.195918E+02	0.261913E+02	0.223087E+02	0.635277E+01
0.609531E+01	0.784068E+01	0.635277E+01	0.299929E+01

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Band 4	Band 5	Band 6	Band 7

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FILE: MTERA 23/5          , SIGNATURE: 11 , DESCRIPTOR: MAF1
BASED UPON     2311  TRAINING SAMPLES
MEAN:
 0.496716E+02  0.527257E+02  0.596335E+02  0.279546E+02
COVARIANCE:
 0.252264E+02  0.312298E+02  0.208377E+02  0.733492E+01
 0.312298E+02  0.440372E+02  0.286227E+02  0.963522E+01
 0.208377E+02  0.286227E+02  0.269628E+02  0.958416E+01
 0.733492E+01  0.963522E+01  0.958416E+01  0.453180E+01

FILE: MTERA 23/5          , SIGNATURE: 12 , DESCRIPTOR: FL1
BASED UPON     3714  TRAINING SAMPLES
MEAN:
 0.314459E+02  0.451169E+02  0.542935E+02  0.252141E+02
COVARIANCE:
 0.347981E+01  0.237695E+01  0.140576E+01  0.542003E+00
 0.237695E+01  0.109704E+02  0.546742E+01  0.665590E+00
 0.140576E+01  0.546742E+01  0.631637E+01  0.981691E+00
 0.542003E+00  0.665590E+00  0.981691E+00  0.677975E+00

FILE: MTERA 23/5          , SIGNATURE: 13 , DESCRIPTOR: CRIFF4
BASED UPON     8009  TRAINING SAMPLES
MEAN:
 0.270256E+02  0.199916E+02  0.448590E+02  0.240311E+02
COVARIANCE:
 0.971282E+00  0.841054E+00  0.181546E+00  0.124860E-03
 0.841054E+00  0.313884E+01  0.664253E-01 -0.171557E+00
 0.181546E+00  0.664253E-01  0.293158E+01  0.100287E+01
 0.124860E-03 -0.171557E+00  0.100287E+01  0.921588E+00

FILE: MTERA 23/5          , SIGNATURE: 14 , DESCRIPTOR: FF5
BASED UPON     4811  TRAINING SAMPLES
MEAN:
 0.293498E+02  0.257764E+02  0.428061E+02  0.214132E+02
COVARIANCE:
 0.115215E+01  0.119019E+01  0.318021E+00  0.742049E-01
 0.119019E+01  0.555352E+01  0.132363E+01  0.377053E+00
 0.318021E+00  0.132363E+01  0.285845E+01  0.870089E+00
 0.742049E-01  0.377053E+00  0.870089E+00  0.111370E+01

FILE: MTERA 23/5          , SIGNATURE: 15 , DESCRIPTOR: HK1
BASED UPON      799  TRAINING SAMPLES
MEAN:
 0.417972E+02  0.404581E+02  0.485269E+02  0.208417E+02
COVARIANCE:
 0.302165E+01  0.196371E+01  0.881101E+00  0.610138E+00
 0.196371E+01  0.511765E+01  0.244806E+01  0.833464E+00
 0.881101E+00  0.244806E+01  0.344934E+01  0.760013E+00
 0.610138E+00  0.833464E+00  0.760013E+00  0.705444E+00
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Band 4	Band 5	Band 6	Band 7

FILE: MTERA 23/5 , SIGNATURE: 16 , DESCRIPTOR: RF123
BASED UPON 2470. TRAINING SAMPLES
MEAN:

0.296818E+02	0.225514E+02	0.445571E+02	0.235871E+02

COVARIANCE:

0.361539E+01	0.403603E+01	0.156316E+01	0.121862E+00
0.403603E+01	0.699838E+01	0.216073E+01	0.179352E+00
0.156316E+01	0.216073E+01	0.702591E+01	0.299231E+01
0.121862E+00	0.179352E+00	0.299231E+01	0.209069E+01

FILE: MTERA 23/5 , SIGNATURE: 17 , DESCRIPTOR: SE1
BASED UPON 1251. TRAINING SAMPLES
MEAN:

0.595995E+02	0.666507E+02	0.686059E+02	0.303549E+02

COVARIANCE:

0.122934E+02	0.145212E+02	0.992166E+01	0.281535E+01
0.145212E+02	0.256603E+02	0.170040E+02	0.544924E+01
0.992166E+01	0.170040E+02	0.167538E+02	0.459472E+01
0.281535E+01	0.544924E+01	0.459472E+01	0.226699E+01

FILE: MTERA 23/5 , SIGNATURE: 18 , DESCRIPTOR: ERS7
BASED UPON 1499. TRAINING SAMPLES
MEAN:

0.498873E+02	0.523142E+02	0.569019E+02	0.263676E+02

COVARIANCE:

0.927618E+01	0.105317E+02	0.583255E+01	0.208206E+01
0.105317E+02	0.164156E+02	0.885457E+01	0.331888E+01
0.583255E+01	0.885457E+01	0.858906E+01	0.239026E+01
0.208206E+01	0.331888E+01	0.239026E+01	0.133472E+01

FILE: MTERA 23/5 , SIGNATURE: 19 , DESCRIPTOR: RL1
BASED UPON 1028. TRAINING SAMPLES
MEAN:

0.312140E+02	0.240768E+02	0.459562E+02	0.231936E+02

COVARIANCE:

0.261205E+01	0.207423E+01	0.886576E-01	-0.507053E+00
0.207423E+01	0.402073E+01	-0.892023E+00	-0.118580E+01
0.886576E-01	-0.892023E+00	0.415856E+01	0.158755E+01
-0.507053E+00	-0.118580E+01	0.158755E+01	0.139760E+01

FILE: MTERA 23/5 , SIGNATURE: 20 , DESCRIPTOR: MB124
BASED UPON 13422. TRAINING SAMPLES
MEAN:

0.369803E+02	0.354544E+02	0.349099E+02	0.156096E+02

COVARIANCE:

0.245567E+01	0.197050E+01	0.199076E+01	0.881463E+00
0.197050E+01	0.457637E+01	0.289763E+01	0.108620E+01
0.199076E+01	0.289763E+01	0.586105E+01	0.195597E+01
0.881463E+00	0.108620E+01	0.195597E+01	0.164958E+01

Band 4	Band 5	Band 6	Band 7

FILE: MTERA 2375 , SIGNATURE: 21 , DESCRIPTOR: LES
BASED UPON 4097 TRAINING SAMPLES
MEAN:

0.464457E+02	0.534918E+02	0.576837E+02	0.261418E+02

COVARIANCE:

0.105209E+02	0.149678E+02	0.938785E+01	0.300195E+01
0.149678E+02	0.283490E+02	0.167025E+02	0.544203E+01
0.938785E+01	0.167025E+02	0.150757E+02	0.448304E+01
0.300195E+01	0.544203E+01	0.448304E+01	0.199513E+01

FILE: MTERA 2375 , SIGNATURE: 22 , DESCRIPTOR: ACI
BASED UPON 464 TRAINING SAMPLES
MEAN:

0.331910E+02	0.297725E+02	0.426481E+02	0.210193E+02

COVARIANCE:

0.637715E+01	0.827910E+01	0.575121E+01	0.223002E+01
0.827910E+01	0.145059E+02	0.108211E+02	0.402146E+01
0.575121E+01	0.108211E+02	0.124211E+02	0.510743E+01
0.223002E+01	0.402146E+01	0.510743E+01	0.315590E+01

FILE: MTERA 2375 , SIGNATURE: 23 , DESCRIPTOR: GLIGRA2
BASED UPON 5273 TRAINING SAMPLES
MEAN:

0.536907E+02	0.568859E+02	0.546247E+02	0.244104E+02

COVARIANCE:

0.922709E+01	0.903184E+01	0.107015E+02	0.458885E+01
0.903184E+01	0.133335E+02	0.122097E+02	0.521089E+01
0.107015E+02	0.122097E+02	0.172118E+02	0.694159E+01
0.458885E+01	0.521089E+01	0.694159E+01	0.356667E+01

FILE: MTERA 2375 , SIGNATURE: 24 , DESCRIPTOR: MLV1
BASED UPON 5088 TRAINING SAMPLES
MEAN:

0.308445E+02	0.294694E+02	0.367748E+02	0.176301E+02

COVARIANCE:

0.234700E+01	0.210285E+01	0.137070E+01	0.537283E+00
0.210285E+01	0.456008E+01	0.165801E+01	0.425959E+00
0.137070E+01	0.165801E+01	0.807473E+01	0.284450E+01
0.537283E+00	0.425959E+00	0.284450E+01	0.216873E+01

FILE: MTERA 2375 , SIGNATURE: 25 , DESCRIPTOR: FRS3
BASED UPON 4271 TRAINING SAMPLES
MEAN:

0.374821E+02	0.566130E+02	0.657848E+02	0.295927E+02

COVARIANCE:

0.306767E+01	0.328939E+01	0.208640E+01	0.767727E+00
0.328939E+01	0.177310E+02	0.101777E+02	0.277078E+01
0.208640E+01	0.101777E+02	0.113195E+02	0.212081E+01
0.767727E+00	0.277078E+01	0.212081E+01	0.130743E+01

FILE: MTERA 2375 , SIGNATURE: 26 , DESCRIPTOR: FRS4
BASED UPON 3546 TRAINING SAMPLES
MEAN:

0.425093E+02	0.638486E+02	0.709298E+02	0.312250E+02

COVARIANCE:

[illegible]	0.112324E+02	0.794224E+01	0.210244E+01
0.112324E+02	0.240375E+02	0.168860E+02	0.485223E+01
0.794224E+01	0.168860E+02	0.180664E+02	0.467[illegible]E+01

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Band 4            Band 5            Band 6            Band 7

FILE: MTERA 23/5               , SIGNATURE: 27 , DESCRIPTOR: ERS5
BASED UPON      725. TRAINING SAMPLES
MEAN:
 0.370235E+02   0.502883E+02   0.543200E+02   0.239241E+02
COVARIANCE:
 0.565017E+01   0.597241E+01   0.468414E+01   0.198267E+01
 0.597241E+01   0.185007E+02   0.133366E+02   0.512845E+01
 0.468414E+01   0.133366E+02   0.140676E+02   0.503810E+01
 0.198267E+01   0.512845E+01   0.503810E+01   0.267431E+01

FILE: MTERA 23/5               , SIGNATURE: 28 , DESCRIPTOR: ERS6
BASED UPON      618. TRAINING SAMPLES
MEAN:
 0.391084E+02   0.510049E+02   0.512799E+02   0.221537E+02
COVARIANCE:
 0.130998E+02   0.122152E+02   0.680906E+01   0.251760E+01
 0.122152E+02   0.229628E+02   0.117104E+02   0.412915E+01
 0.680906E+01   0.117104E+02   0.907767E+01   0.288107E+01
 0.251760E+01   0.412915E+01   0.288107E+01   0.177437E+01

FILE: MTERA 23/5               , SIGNATURE: 29 , DESCRIPTOR: GRA4
BASED UPON     1125. TRAINING SAMPLES
MEAN:
 0.554080E+02   0.630907E+02   0.587138E+02   0.252880E+02
COVARIANCE:
 0.682933E+01   0.452889E+01   0.480622E+01   0.128000E+01
 0.452889E+01   0.735733E+01   0.622222E+01   0.199200E+01
 0.480622E+01   0.622222E+01   0.935467E+01   0.218489E+01
 0.128000E+01   0.199200E+01   0.218489E+01   0.998278E+00

FILE: MTERA 23/5               , SIGNATURE: 30 , DESCRIPTOR: GRA35
BASED UPON     5555. TRAINING SAMPLES
MEAN:
 0.445827E+02   0.502117E+02   0.470547E+02   0.202229E+02
COVARIANCE:
 0.919424E+01   0.822952E+01   0.785112E+01   0.389451E+01
 0.822952E+01   0.127054E+02   0.105455E+02   0.515824E+01
 0.785112E+01   0.105455E+02   0.120329E+02   0.515104E+01
 0.389451E+01   0.515824E+01   0.515104E+01   0.324356E+01

FILE: MTERA 23/5               , SIGNATURE: 31 , DESCRIPTOR: SLV1
BASED UPON      633. TRAINING SAMPLES
MEAN:
 0.336919E+02   0.463602E+02   0.580689E+02   0.277283E+02
COVARIANCE:
 0.180904E+01   0.340995E+01   0.157662E+01   0.327409E+00
 0.340995E+01   0.184550E+02   0.102717E+02   0.224634E+01
 0.157662E+01   0.102717E+02   0.992101E+01   0.175612E+01
 0.327409E+00   0.224634E+01   0.175612E+01   0.871347E+00

FILE: MTERA 23/5               , SIGNATURE: 32 , DESCRIPTOR: EF3
BASED UPON      512. TRAINING SAMPLES
MEAN:
 0.280918E+02   0.213809E+02   0.341426E+02   0.164023E+02
COVARIANCE:
 0.129028E+01   0.890869E+00   0.208691E+00   0.646973E-01
 0.890869E+00   0.213037E+01   0.102979E+01   0.165039E+00
 0.208691E+00   0.102979E+01   0.493091E+01   0.192700E+01
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ORIGINAL PAGE IS OF POOR QUALITY

Statistics of 30 signatures for multitemporal classification of the Mtera Landsat scenes 1972-09-26 and 1974-01-07

Description Legend:

MBUG	= mbuga grassland	MIM	= brachystegia bushland
DREP	= acacia drepano-lobium	GRWM	= groundwater bush-land
TORT	= acacia tortilis	AX + BUSH	= bushland with mixed acacias
KIRK	= acacia kirkii	GRASS	= grassland
COM	= commiphora bushland	REP	= riparian vegetation
FARM	= farm land		
ERP	= eroded pediments		

Landsat scene 1972-09-26				Landsat scene 1974-01-07			
Band 4	Band 5	Band 6	Band 7	Band 4	Band 5	Band 6	Band 7

FILE: MTERA , SIGNATURE: 1 , DESCRIPTOR: MBUG1
BASED UPON 492. TRAINING SAMPLES

MEAN:

50.7	55.0	50.8	21.6	44.6	48.0	46.5	19.8

COVARIANCE:

2.7	1.1	0.5	-0.4	0.7	1.1	0.3	-0.1
1.1	3.4	1.2	0.3	0.2	0.3	-0.2	-0.3
0.5	1.2	3.3	0.8	0.1	0.0	0.2	0.1
-0.4	0.3	0.8	1.2	-0.3	-0.8	0.0	-0.0
0.7	0.2	0.1	-0.3	8.6	10.1	7.3	2.3
1.1	0.3	0.0	-0.8	10.1	15.8	10.2	3.5
0.3	-0.2	0.2	0.0	7.3	10.2	9.9	3.1
-0.1	-0.3	0.1	-0.0	2.3	3.5	3.1	2.2

FILE: MTERA , SIGNATURE: 2 , DESCRIPTOR: MBUG2
BASED UPON 914. TRAINING SAMPLES

MEAN:

45.4	47.2	44.2	18.9	36.5	34.1	34.8	14.7

COVARIANCE:

3.0	2.0	1.3	0.4	1.1	1.6	1.9	0.8
2.0	3.5	2.1	0.9	0.9	1.5	2.0	0.8
1.3	2.1	3.9	1.3	0.6	0.9	1.4	0.8
0.4	0.9	1.3	1.2	0.2	0.3	0.5	0.3
1.1	0.9	0.6	0.2	2.0	1.4	1.5	0.6
1.6	1.5	0.9	0.3	1.4	3.4	2.3	0.9
1.9	2.0	1.4	0.5	1.5	2.3	4.4	1.3
0.8	0.8	0.8	0.3	0.6	0.9	1.3	1.4

FILE: MTERA , SIGNATURE: 3 , DESCRIPTOR: MBUG3
BASED UPON 1125. TRAINING SAMPLES

MEAN:

40.8	41.5	39.6	17.3	33.5	31.1	29.6	12.3

COVARIANCE:

3.3	2.9	2.3	0.7	0.1	0.3	0.2	0.1
2.9	6.4	5.0	2.1	0.6	0.9	0.5	-0.0
2.3	5.0	7.4	2.7	0.8	1.3	0.8	0.2
0.7	2.1	2.7	1.8	0.4	0.6	0.4	0.1
0.1	0.6	0.8	0.4	[illegible]	1.9	1.8	0.9
0.3	0.9	1.3	0.6	1.9	4.5	3.1	1.5
0.2	0.5	0.8	0.4	1.8	3.1	4.4	1.6
0.1	0.0	0.2	0.1	0.9	1.5	1.6	1.6

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Landsat scene 1972-09-26				Landsat scene 1974-01-07			
Band 4	Band 5	Band 6	Band 7	Band 4	Band 5	Band 6	Band 7

FILE: MTERA , SIGNATURE: 4 , DESCRIPTOR: MBUG4
BASED UPON 326. TRAINING SAMPLES
MEAN:

43. 5	45. 4	43. 2	19. 1	33. 0	29. 8	38. 8	18. 4

COVARIANCE:

2. 5	2. 0	1. 6	0. 5	1. 5	1. 9	0. 1	-0. 2
2. 0	4. 3	2. 7	1. 2	2. 3	3. 3	0. 9	-0. 3
1. 6	2. 7	4. 0	1. 2	2. 1	2. 8	1. 0	0. 0
0. 5	1. 2	1. 2	1. 1	0. 9	1. 3	1. 0	0. 3
1. 5	2. 3	2. 1	0. 9	4. 5	5. 1	1. 4	0. 3
1. 9	3. 3	2. 8	1. 3	5. 1	8. 4	2. 1	0. 3
0. 1	0. 9	1. 0	1. 0	1. 4	2. 1	4. 2	1. 1
-0. 2	-0. 3	0. 0	0. 3	0. 3	0. 3	1. 1	1. 3

FILE: MTERA , SIGNATURE: 5 , DESCRIPTOR: DREP1
BASED UPON 93. TRAINING SAMPLES
MEAN:

68. 2	77. 5	72. 0	31. 1	68. 3	78. 2	73. 3	30. 9

COVARIANCE:

18. 7	24. 2	20. 1	7. 8	6. 9	6. 2	6. 9	2. 0
24. 2	37. 5	29. 2	11. 8	7. 1	7. 6	9. 6	2. 6
20. 1	29. 2	27. 4	9. 8	7. 3	6. 9	9. 4	2. 5
7. 8	11. 8	9. 8	4. 6	2. 7	2. 8	3. 6	1. 0
6. 9	7. 1	7. 3	2. 7	12. 6	9. 2	8. 1	3. 2
6. 2	7. 6	6. 9	2. 8	9. 2	11. 9	8. 7	3. 7
6. 9	9. 6	9. 4	3. 6	8. 1	8. 7	11. 9	3. 3
2. 0	2. 6	2. 5	1. 0	3. 2	3. 7	3. 3	2. 0

FILE: MTERA , SIGNATURE: 6 , DESCRIPTOR: DREP2
BASED UPON 107. TRAINING SAMPLES
MEAN:

60. 6	65. 0	61. 0	27. 0	60. 7	65. 0	62. 7	26. 8

COVARIANCE:

2. 8	2. 5	1. 9	0. 8	1. 8	2. 0	2. 0	0. 5
2. 5	6. 2	3. 0	1. 3	3. 2	3. 5	3. 2	1. 0
1. 9	3. 0	4. 7	1. 2	2. 8	3. 0	2. 7	0. 9
0. 8	1. 3	1. 2	1. 0	1. 1	1. 1	1. 2	0. 3
1. 8	3. 2	2. 8	1. 1	6. 1	5. 3	5. 0	1. 7
2. 0	3. 5	3. 0	1. 1	5. 3	8. 5	6. 2	2. 0
2. 0	[illegible]	2. 7	1. 2	5. 0	6. 2	9. 7	2. 3
0. 5	1. 0	0. 9	0. 3	1. 7	2. 0	2. 3	1. 4

FILE: MTERA , SIGNATURE: 7 , DESCRIPTOR: DREP3
BASED UPON 926. TRAINING SAMPLES
MEAN:

61. 9	67. 7	63. 2	27. 9	58. 2	64. 7	65. 1	28. 6

COVARIANCE:

14. 6	14. 3	11. 5	4. 9	13. 5	12. 2	10. 3	4. 0
14. 3	21. 8	16. 7	7. 2	15. 2	18. 5	15. 2	5. 8
11. 5	16. 7	16. 7	6. 3	12. 3	15. 9	13. 6	5. 0
4. 9	7. 2	6. 3	3. 2	5. 3	7. 0	5. 9	2. 1
13. 5	15. 2	12. 3	5. 3	22. 8	23. 9	18. 6	6. 7
12. 2	18. 5	15. 9	7. 0	23. 9	37. 8	27. 1	9. 1
10. 3	15. 2	13. 6	5. 9	18. 6	27. 1	24. 7	7. 6
4. 0	5. 8	5. 0	2. 1	6. 7	9. 1	7. 6	3. 5

Landsat scene 1972-09-26				Landsat scene 1974-01-07			
Band 4	Band 5	Band 6	Band 7	Band 4	Band 5	Band 6	Band 7

FILE: MTERA , SIGNATURE: 8 , DESCRIPTOR TORT1
BASED UPON 1229. TRAINING SAMPLES
MEAN:

49.9	60.9	59.4	26.3	42.2	54.5	59.2	26.5

COVARIANCE:

5.0	4.8	4.8	2.1	2.4	5.3	3.2	1.0
4.8	9.1	7.7	3.1	4.6	10.1	6.0	2.2
4.8	7.7	10.3	3.5	4.6	10.4	6.7	2.4
2.1	3.1	3.5	1.9	1.9	4.2	2.8	1.0
2.4	4.6	4.6	1.9	7.0	12.9	8.5	2.8
5.3	10.1	10.4	4.2	12.9	30.1	19.1	6.0
3.2	6.0	6.7	2.8	8.5	19.1	17.2	4.7
1.0	2.2	2.4	1.0	2.8	6.0	4.7	2.2

FILE: MTERA , SIGNATURE: 9 , DESCRIPTOR: TORT2
BASED UPON 1497. TRAINING SAMPLES
MEAN:

48.4	59.6	57.9	25.7	39.8	50.3	55.9	24.9

COVARIANCE:

9.2	4.1	3.6	2.2	5.0	0.8	0.7	0.7
4.1	8.0	6.7	3.0	3.2	6.8	4.5	1.6
3.6	6.7	9.5	3.5	2.2	6.7	4.9	1.5
2.2	3.0	3.5	2.2	1.1	2.3	1.9	0.7
5.0	3.2	2.2	1.1	11.1	12.9	7.2	2.2
0.8	6.8	6.7	2.3	12.9	34.5	18.7	4.7
0.7	4.5	4.9	1.9	7.2	18.7	14.7	3.6
0.7	1.6	1.5	0.7	2.2	4.7	3.6	1.7

FILE: MTERA , SIGNATURE: 10 , DESCRIPTOR: KIRK1
BASED UPON 280. TRAINING SAMPLES
MEAN:

48.2	50.7	48.4	20.9	33.4	30.2	39.1	17.9

COVARIANCE:

5.6	5.7	4.9	2.4	1.4	1.7	0.3	-0.2
5.7	9.6	6.9	3.5	2.1	3.4	-0.0	-0.6
4.9	6.9	7.4	3.0	1.7	2.5	-0.2	-0.1
2.4	3.5	3.0	1.9	1.0	1.5	0.0	-0.1
1.4	2.1	1.7	1.0	2.9	3.7	1.4	0.2
1.7	3.4	2.5	1.5	3.7	8.7	1.6	-0.1
0.3	-0.0	-0.2	0.0	1.4	1.6	4.2	0.8
-0.2	-0.6	-0.1	-0.1	0.2	-0.1	0.8	1.4

FILE: MTERA , SIGNATURE: 11 , DESCRIPTOR COM1
BASED UPON 1400. TRAINING SAMPLES
MEAN:

38.3	37.8	37.3	16.6	25.7	18.0	43.0	22.4

COVARIANCE:

1.6	1.3	1.2	0.6	0.3	1.1	0.2	-0.2
1.3	5.1	3.8	1.6	1.1	3.3	0.3	-0.3
1.2	3.8	5.5	1.6	1.1	3.3	0.4	-0.7
0.6	1.6	1.6	1.1	0.5	1.4	0.2	-0.1
0.3	1.1	1.1	0.5	1.5	1.7	-0.1	-0.3
1.1	3.3	3.3	1.4	1.7	6.2	-0.0	-0.9
0.2	0.3	0.4	0.2	-0.1	-0.0	2.9	0.9
-0.2	-0.3	-0.7	-0.1	-0.3	-0.9	0.9	1.3

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Landsat scene 1972-09-26				Landsat scene 1974-01-07			
Band 4	Band 5	Band 6	Band 7	Band 4	Band 5	Band 6	Band 7

FILE: MTERA , SIGNATURE: 12 , DESCRIPTOR: MBUG5
BASED UPON 550. TRAINING SAMPLES
MEAN:

55.5	62.4	60.6	26.6	45.0	48.0	44.6	18.8

COVARIANCE:

3.9	4.1	4.6	2.0	2.4	2.8	2.3	0.8
4.1	9.6	9.7	4.7	3.5	4.4	3.9	1.5
4.6	9.7	15.3	6.7	3.4	4.4	4.7	2.0
2.0	4.7	6.7	3.9	1.4	1.7	2.2	1.0
2.4	3.5	3.4	1.4	6.3	7.2	5.0	1.9
2.8	4.4	4.4	1.7	7.2	11.2	6.8	2.6
2.3	3.9	4.7	2.2	5.0	6.8	6.9	2.2
0.8	1.5	2.0	1.0	1.9	2.6	2.2	1.8

FILE: MTERA , SIGNATURE: 13 , DESCRIPTOR: FARM1
BASED UPON 655. TRAINING SAMPLES
MEAN:

46.8	61.3	61.5	27.5	31.1	43.8	53.6	24.6

COVARIANCE:

10.6	8.3	8.4	4.0	2.9	2.1	-0.1	0.4
8.3	11.2	9.7	4.3	1.3	3.5	0.3	-0.1
8.4	9.7	12.1	4.7	1.0	3.8	0.6	-0.1
4.0	4.3	4.7	2.6	0.6	1.3	0.1	0.0
2.9	1.3	1.0	0.6	7.1	5.8	4.4	1.8
2.1	3.5	3.8	1.3	5.8	17.4	9.4	2.1
-0.1	0.3	0.6	0.1	4.4	9.4	9.9	2.5
0.4	-0.1	-0.1	0.0	1.8	2.1	2.5	1.5

FILE: MTERA , SIGNATURE: 14 , DESCRIPTOR: COM2
BASED UPON 441. TRAINING SAMPLES
MEAN:

41.8	44.2	43.9	19.6	26.9	20.8	44.7	23.4

COVARIANCE:

1.6	1.0	1.0	0.6	0.3	0.6	0.5	0.2
1.0	3.7	2.5	1.5	0.6	2.0	0.4	0.1
1.0	2.5	4.4	1.6	0.4	1.9	0.8	0.3
0.6	1.5	1.6	1.3	0.4	1.1	0.3	0.0
0.3	0.6	0.4	0.4	1.2	1.3	0.1	-0.2
0.6	2.0	1.9	1.1	1.3	4.7	0.3	-0.4
0.5	0.4	0.8	0.3	0.1	0.3	3.3	1.3
0.2	0.1	0.3	0.0	-0.2	-0.4	1.3	1.4

FILE: MTERA , SIGNATURE: 16 , DESCRIPTOR: TORT3
BASED UPON 517. TRAINING SAMPLES
MEAN:

48.9	57.4	57.8	25.9	43.0	51.3	58.2	25.9

COVARIANCE:

3.9	4.5	3.6	1.2	2.4	4.5	1.8	0.4
4.5	10.0	7.4	2.2	4.7	10.1	4.9	1.1
3.6	7.4	8.5	2.1	3.7	8.2	4.1	1.0
1.2	2.2	2.1	1.2	1.1	2.4	1.3	0.3
2.4	4.7	3.7	1.1	7.4	12.1	5.6	1.1
4.5	10.1	8.2	2.4	12.1	27.2	12.0	2.3
1.8	4.9	4.1	1.3	5.6	12.0	9.9	2.0
0.4	1.1	1.0	0.3	1.1	2.3	2.0	1.1

Landsat scene 1972-09-26				Landsat scene 1974-01-07			
Band 4	Band 5	Band 6	Band 7	Band 4	Band 5	Band 6	Band 7

FILE: MTERA , SIGNATURE: 17 , DESCRIPTOR: ERP1
BASED UPON 1825. TRAINING SAMPLES

MEAN:							
54.6	58.0	56.4	25.5	49.7	52.8	58.6	26.3
COVARIANCE:							
9.1	11.0	9.7	4.0	8.3	11.2	7.3	2.5
11.0	18.9	16.2	6.6	11.3	18.5	13.2	4.5
9.7	16.2	18.3	6.9	9.6	16.7	12.8	4.6
4.0	6.6	6.9	3.4	3.7	6.6	5.2	1.9
8.3	11.3	9.6	3.7	21.7	29.5	18.4	5.9
11.2	18.5	16.7	6.6	29.5	50.6	32.1	10.7
7.3	13.2	12.8	5.2	18.4	32.1	25.5	8.2
2.5	4.5	4.6	1.9	5.9	10.7	8.2	3.5

FILE: MTERA , SIGNATURE: 18 , DESCRIPTOR: ERP2
BASED UPON 899. TRAINING SAMPLES

MEAN:							
59.2	64.0	61.9	28.0	58.4	64.8	64.6	28.0
COVARIANCE:							
11.3	13.4	10.8	4.5	10.2	13.4	8.0	2.2
13.4	21.1	15.5	6.7	14.0	19.0	11.9	3.3
10.8	15.5	16.6	6.3	11.0	15.4	10.9	3.0
4.5	6.7	6.3	3.3	5.1	7.1	5.2	1.5
10.2	14.0	11.0	5.1	22.8	27.7	17.6	5.6
13.4	19.0	15.4	7.1	27.7	40.4	24.9	7.6
8.0	11.9	10.9	5.2	17.6	24.9	20.8	5.4
2.2	3.3	3.0	1.5	5.6	7.6	5.4	2.6

FILE: MTERA , SIGNATURE: 19 , DESCRIPTOR: MIM1
BASED UPON 562. TRAINING SAMPLES

MEAN:							
39.8	42.3	46.5	23.2	24.9	17.6	48.0	27.2
COVARIANCE:							
2.9	3.2	2.3	1.4	0.5	0.3	1.3	0.9
3.2	7.3	5.8	3.3	1.2	1.0	1.0	0.5
2.3	5.8	9.3	4.7	0.8	1.2	-2.3	-2.0
1.4	3.3	4.7	3.4	0.6	0.8	-1.2	-1.0
0.5	1.2	0.8	0.6	3.1	3.4	2.4	1.3
0.3	1.0	1.2	0.8	3.4	6.5	2.5	0.9
1.3	1.0	-2.3	-1.2	2.4	2.5	19.6	12.8
0.9	0.5	-2.0	-1.0	1.3	0.9	12.8	9.8

FILE: MTERA , SIGNATURE: 20 , DESCRIPTOR: GRWB1
BASED UPON 1063. TRAINING SAMPLES

MEAN:							
39.6	36.6	41.1	19.1	29.5	23.9	36.2	17.4
COVARIANCE:							
3.4	4.0	2.8	1.3	1.0	1.3	1.5	0.7
4.0	8.8	4.4	1.8	1.9	2.6	1.5	0.5
2.8	4.4	8.4	3.5	1.2	1.3	4.4	2.4
1.3	1.8	3.5	2.4	0.5	0.4	2.3	1.3
1.0	1.9	1.2	0.5	2.8	2.5	1.1	0.3
1.3	2.6	1.3	0.4	2.5	4.5	0.5	0.1
1.5	1.5	4.4	2.3	1.1	0.5	9.7	4.7
0.7	0.5	2.4	1.3	0.3	0.1	4.7	3.7

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Landsat scene 1972-09-26				Landsat scene 1974-01-07			
Band 4	Band 5	Band 6	Band 7	Band 4	Band 5	Band 6	Band 7

FILE: MTERA , SIGNATURE: 21 , DESCRIPTOR: BUSH1
BASED UPON 104. TRAINING SAMPLES
MEAN:

48.9	51.5	49.6	22.7	40.7	39.3	47.6	22.3

COVARIANCE:

2.6	1.1	0.6	0.4	1.2	0.4	0.3	-0.2
1.1	2.3	0.8	0.3	0.8	0.6	0.2	-0.0
0.6	0.8	2.2	0.3	0.9	0.8	0.8	0.4
0.4	0.3	0.3	0.7	0.4	0.3	0.5	0.1
1.2	0.8	0.9	0.4	4.0	1.9	0.6	0.2
0.4	0.6	0.8	0.3	1.9	4.5	1.7	0.8
0.3	0.2	0.8	0.5	0.6	1.7	3.4	0.9
-0.2	-0.0	0.4	0.1	0.2	0.8	0.9	1.0

FILE: MTERA , SIGNATURE: 22 , DESCRIPTOR: GRASS1
BASED UPON 411. TRAINING SAMPLES
MEAN:

44.3	55.9	55.6	24.4	34.6	46.5	54.9	24.5

COVARIANCE:

8.1	2.7	1.0	1.1	6.8	3.3	0.8	0.5
2.7	7.4	5.7	2.4	2.6	6.8	4.6	1.7
1.0	5.7	7.9	2.5	0.9	6.5	5.7	2.2
1.1	2.4	2.5	1.5	1.0	2.4	2.0	0.8
6.8	2.6	0.9	1.0	11.9	7.6	2.2	0.4
3.3	6.8	6.5	2.4	7.6	21.6	12.7	3.7
0.8	4.6	5.7	2.0	2.2	12.7	13.3	4.0
0.5	1.7	2.2	0.8	0.4	3.7	4.0	2.0

FILE: MTERA , SIGNATURE: 23 , DESCRIPTOR: AX1
BASED UPON 1011. TRAINING SAMPLES
MEAN:

54.1	55.0	51.8	23.2	44.0	42.8	51.7	24.2

COVARIANCE:

8.1	7.6	7.1	3.4	1.8	1.6	2.8	1.3
7.6	10.1	8.4	3.9	1.6	1.4	2.9	1.3
7.1	8.4	9.9	3.9	0.9	0.3	2.6	1.3
3.4	3.9	3.9	2.4	0.4	0.1	1.1	0.6
1.8	1.6	0.9	0.4	13.8	18.5	9.1	2.6
1.6	1.4	0.3	0.1	18.5	29.2	13.3	3.6
2.8	2.9	2.6	1.1	9.1	13.3	9.7	2.7
1.3	1.3	1.3	0.6	2.6	3.6	2.7	1.4

FILE: MTERA , SIGNATURE: 24 , DESCRIPTOR: ERP3
BASED UPON 303. TRAINING SAMPLES
MEAN:

69.0	75.7	71.0	31.3	69.3	78.4	75.8	31.8

COVARIANCE:

7.4	9.6	10.1	3.9	2.8	5.4	2.4	1.0
9.6	19.6	19.9	7.8	3.6	10.0	4.3	1.1
10.1	19.9	25.6	9.1	3.6	11.2	4.0	1.4
3.9	7.8	9.1	4.1	0.8	3.4	1.0	0.3
2.8	3.6	3.6	0.8	15.9	18.9	14.6	4.1
5.4	10.0	11.2	3.4	18.9	31.4	20.2	5.3
2.4	4.3	4.0	1.0	14.6	20.2	19.4	4.5
1.0	1.1	1.4	0.3	4.1	5.3	4.5	1.9

Landsat scene 1972-09-26				Landsat scene 1974-01-07			
Band 4	Band 5	Band 6	Band 7	Band 4	Band 5	Band 6	Band 7

FILE: MTERA , SIGNATURE: 25 , DESCRIPTOR: AX2
BASED UPON 251. TRAINING SAMPLES
MEAN:

49.3	53.9	55.0	25.1	44.4	50.9	55.2	24.7

COVARIANCE:

6.9	8.5	4.7	1.8	3.9	6.4	3.1	1.2
8.5	14.9	8.1	3.1	5.9	10.0	5.5	1.9
4.7	8.1	8.1	2.2	3.4	5.5	3.9	1.1
1.8	3.1	2.2	1.3	1.6	2.4	1.9	0.7
3.9	5.9	3.4	1.6	10.2	14.7	7.6	2.2
6.4	10.0	5.5	2.4	14.7	26.6	13.1	3.8
3.1	5.5	3.9	1.9	7.6	13.1	10.9	2.8
1.2	1.9	1.1	0.7	2.2	3.8	2.8	1.4

FILE: MTERA , SIGNATURE: 26 , DESCRIPTOR: MBUG6
BASED UPON 1691. TRAINING SAMPLES
MEAN:

43.6	45.7	45.1	20.1	33.3	29.0	36.1	16.6

COVARIANCE:

4.3	4.0	2.4	0.7	3.8	5.0	1.3	0.0
4.0	6.6	3.7	1.2	4.5	5.8	1.6	0.4
2.4	3.7	5.0	1.5	2.8	3.4	1.8	0.7
0.7	1.2	1.5	1.3	0.6	0.7	1.1	0.5
3.8	4.5	2.8	0.6	7.5	8.6	2.2	0.1
5.0	5.8	3.4	0.7	8.6	12.8	2.8	-0.1
1.3	1.6	1.8	1.1	2.2	2.8	5.2	1.4
0.0	0.4	0.7	0.5	0.1	-0.1	1.4	1.6

FILE: MTERA , SIGNATURE: 27 , DESCRIPTOR: KIRK2
BASED UPON 317. TRAINING SAMPLES
MEAN:

39.8	35.4	42.6	19.7	29.7	22.4	49.4	25.8

COVARIANCE:

3.7	4.9	2.6	1.2	2.7	4.6	-1.3	-1.4
4.9	10.5	4.2	1.6	5.8	9.4	-1.3	-2.1
2.6	4.2	6.0	2.1	2.3	3.9	-2.3	-1.8
1.2	1.6	2.1	1.6	0.7	1.4	-0.9	-0.8
2.7	5.8	2.3	0.7	8.7	13.0	-0.1	-2.0
4.6	9.4	3.9	1.4	13.0	23.0	-0.7	-3.4
-1.3	-1.3	-2.3	-0.9	-0.1	-0.7	8.5	4.0
-1.4	-2.1	-1.8	-0.8	-2.0	-3.4	4.0	3.2

FILE: MTERA , SIGNATURE: 28 , DESCRIPTOR: FARM2
BASED UPON 665. TRAINING SAMPLES
MEAN:

48.6	57.5	57.9	26.0	41.6	50.1	58.0	26.1

COVARIANCE:

4.2	3.7	2.8	1.0	1.9	2.1	0.9	0.4
3.7	9.2	6.5	2.0	1.2	3.4	2.0	0.8
2.8	6.5	8.7	2.0	0.9	3.2	2.3	0.7
1.0	2.0	2.0	1.1	0.1	0.9	0.5	0.2
1.9	1.2	0.9	0.1	7.7	9.1	4.3	1.0
2.1	3.4	3.2	0.9	9.1	19.1	9.6	2.4
0.9	2.0	2.3	0.5	4.3	9.6	8.7	2.1
0.4	0.8	0.7	0.2	1.0	2.4	2.1	1.2

ORIGINAL PAGE IS
OF POOR QUALITY

Landsat scene 1972-09-26				Landsat scene 1974-01-07			
Band 4	Band 5	Band 6	Band 7	Band 4	Band 5	Band 6	Band 7

FILE: MTERA , SIGNATURE: 29 , DESCRIPTOR: REP1
BASED UPON 1081. TRAINING SAMPLES
MEAN:

37.3	31.2	42.2	20.5	27.4	19.9	42.6	22.4

COVARIANCE:

2.5	2.7	1.1	0.6	1.0	1.4	0.0	-0.3
2.7	6.7	2.2	0.6	1.7	2.9	-0.4	-0.4
1.1	2.2	3.7	1.5	0.7	0.6	0.5	0.4
0.6	0.6	1.5	1.5	0.4	0.2	0.9	0.5
1.0	1.7	0.7	0.4	2.5	2.8	0.3	-0.4
1.4	2.9	0.6	0.2	2.8	5.8	-0.5	-1.2
0.0	-0.4	0.5	0.9	0.3	-0.5	3.9	2.1
-0.3	-0.4	0.4	0.5	-0.4	-1.2	2.1	2.4

FILE: MTERA , SIGNATURE: 30 , DESCRIPTOR: REP2
BASED UPON 444. TRAINING SAMPLES
MEAN:

38.8	34.4	41.7	19.6	27.9	19.9	46.6	24.6

COVARIANCE:

1.4	0.9	0.6	0.3	0.3	0.6	-0.5	-0.4
0.9	3.8	1.9	0.6	1.2	2.3	-1.2	-1.1
0.6	1.9	3.2	0.7	0.7	1.8	-1.3	-1.1
0.3	0.6	0.7	0.7	0.2	0.6	-0.8	-0.5
0.3	1.2	0.7	0.2	2.2	2.0	0.3	-0.1
0.6	2.3	1.8	0.6	2.0	4.7	-2.0	-1.8
-0.5	-1.2	-1.3	-0.8	0.3	-2.0	9.1	4.7
-0.4	-1.1	-1.1	-0.5	-0.1	-1.8	4.7	3.4

FILE: MTERA , SIGNATURE: 31 , DESCRIPTOR: GRWB2
BASED UPON 1444. TRAINING SAMPLES
MEAN:

40.6	38.0	40.0	18.3	31.0	26.6	33.3	15.3

COVARIANCE:

3.3	3.9	3.2	1.5	1.3	1.8	1.2	0.5
3.9	9.8	8.1	3.8	4.0	5.6	3.5	1.7
3.2	8.1	12.0	5.3	3.5	5.7	3.4	1.8
1.5	3.8	5.3	3.3	1.6	2.7	1.5	0.9
1.3	4.0	3.5	1.6	4.1	4.8	2.4	1.2
1.8	5.6	5.7	2.7	4.8	8.4	3.9	1.8
1.2	3.5	3.4	1.5	2.4	3.9	6.3	3.0
0.5	1.7	1.8	0.9	1.2	1.8	3.0	2.4