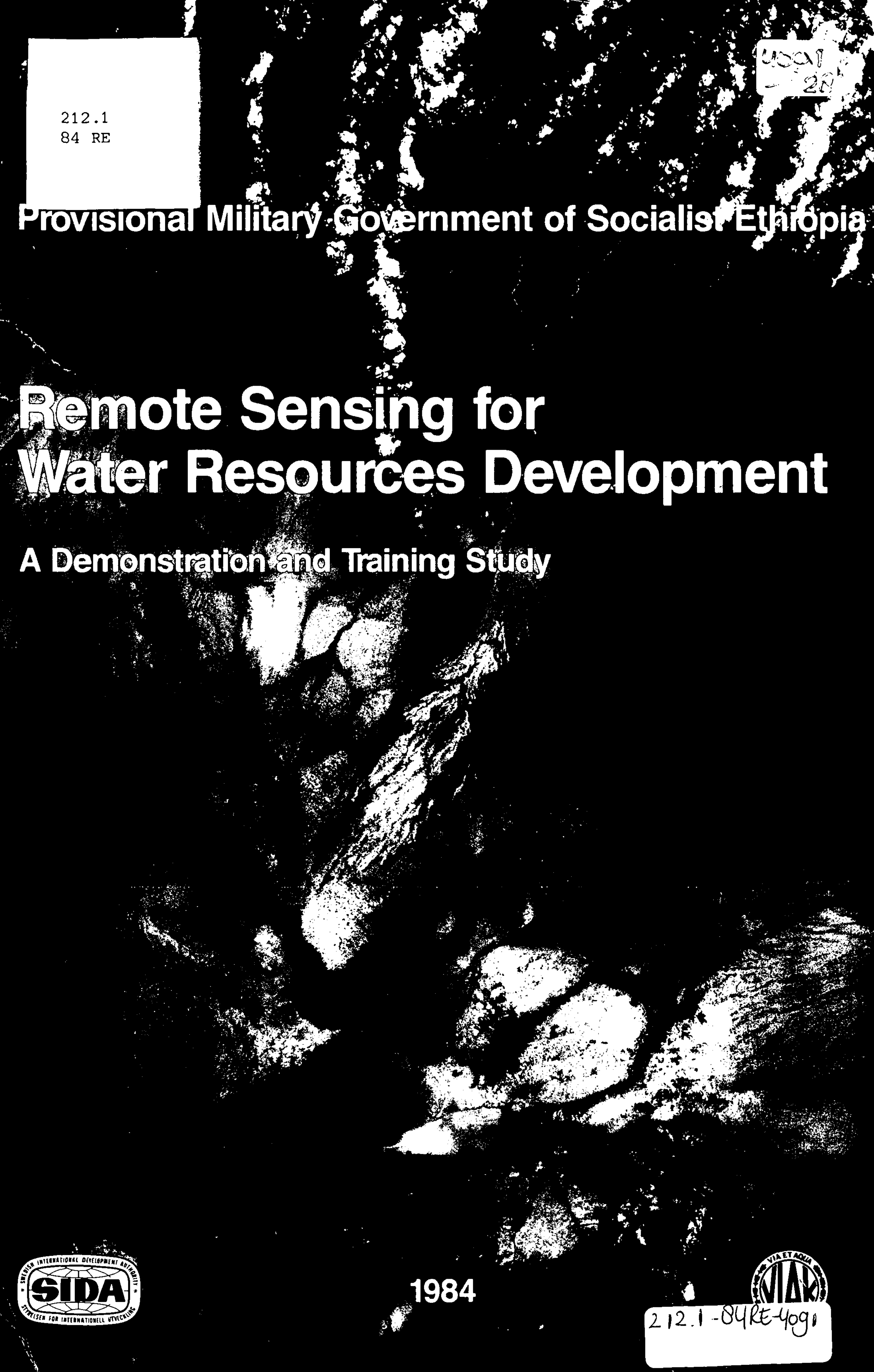

Provisional Military Government of Socialist Ethiopia

Remote Sensing for Water Resources Development

A Demonstration and Training Study

SIDA

1984

VIAK

Front cover:
LANDSAT False Colour Composite
of the Dire Dawa area.

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Preface

This demonstration and training study of the utilization of remote sensing techniques in water resources studies has been carried out jointly by VIAK AB, Consulting Engineers, Sweden and the Ethiopian Water Works Construction Authority (EWWCA) of the National Water Resources Commission (NWRC), Ethiopia. The study has been financed by the Swedish International Development Authority (SIDA).

The project team has been:

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Remote Sensing Specialist: Dr Rolf Å Larsson, Geomorphologist, VIAK AB
Training and Liason Officer: Mesfin Aytenffisu, M.Sc., Hydrogeologist, EWWCA

The following geologists from EWWCA participated in the training courses.

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Tibebe Beyene	- Eastern Region
Haile Hagos	- Eastern Region
Gebru Hailu	- North-western Region
Negash Awoke	- South-western Region
Zerihun Berhanu	- Southern Region

We wish to thank Comr. Alem Alazar, Commissioner of the National Water Resources Commission of Ethiopia for his encouraging support at all stages of the project.

We also very much appreciated the support and services rendered to us by the Ethiopian Mapping Agency.

1 SUMMARY AND RECOMMENDATIONS

Progress in the field of remote sensing is rapid and it is to be expected that the technique will have many applications in the future. The aim of this study has been to test the applicability of satellite image interpretation for exploration of water resources and to train Ethiopian geologists in remote sensing techniques.

The study is one of three research and development projects that the Swedish International Development Authority (SIDA) is financing in the Hararghe (Eastern) Region of Ethiopia, apart from its regular support to the water development of the region. The other two projects concern the development of appropriate methods and means for spring cappings, groundwater dams, shallow wells and pump devices. The idea is that, by using remote sensing techniques, the exploration of suitable sites for inexpensive water supplies could be facilitated.

The test area selected covers an area of 5500 km^2 around the city of Dire Dawa in eastern Ethiopia. It contains parts of the southern escarpment, slopes and floor of the Ethiopian Rift, where it meets with the Aden Rift and the Afar Rift System.

In this study the inventory method used was based on a visual analysis of LANDSAT images from both dry and wet seasons (bitemporal analysis), studied in an analogue stereoplotter that permits direct mapping to a base map scale of 1:250 000.

Six different terrain features, or interpretation elements, have been studied and mapped. These elements are of two kinds: dynamic or season-dependent elements, such as drainage conditions, vegetation cover and land-use, and static, less season-dependent elements such as drainage patterns, lineaments and geomorphology (land form).

These elements are shown on two physiographic-hydrographic maps, one showing drainage conditions (Map 1), and the other a classification of Land Units (Map 2). These two maps form the basis for an evaluation of the water and land-use potential of the area as summarized in Map 3.

Visual inspection of bitemporal satellite images is a simple, rapid and cost-effective method. One advantage is that it can be performed using existing equipemnt and facilities; another that it can be handled and used by many professionals in the geo- and bio-scientific fields, after only a short period of training.

The advantages of visual inspection of images compared to purely computerized data analysis will become even more evident with the introduction of high resolution systems like the Thematic Mapper on LANDSAT 4 and 5 and the 1985 SPOT satellite. It may be assumed that data-handling costs will rise drastically with the rapidly increasing number of picture elements to be handled.

The cost of images, mapping, analysis, and geohydrological evaluation for the project is less than 2 Birr/km^2 (1 US $) of the test area. If a complete LANDSAT scene (31 450 km^2) were to have been studied, the cost would have decreased to well below 1 Birr/km^2. If the same project were to have been based on aerial photo interpretation, the cost would have been 50% higher for the test area and nearly three times as high for a full LANDSAT scene.

Recommendations

In order to establish a realistic approach for a water resources inventory based on remote sensing on a national level, we suggest that certain regions or areas of the country, be given priority. In these areas inventories could be carried out along the lines presented in this report. As the method employs existing facilites we suggest the project to be carried out in close collaboration with the Ethiopian Mapping Agency in Addis Abeba.

The study has shown that there are great benefits to be gained from remote sensing techniques on a regional level as well. We therefore suggest that satellite image analysis be added to the routines for water exploration and siting at the regional offices of the National Water Resources Commission. For these applications it is necessary to acquire relevant satellite images, to select and install adequate viewing instruments and to organize the training of staff.

A ground receiving station, which will also cover Ethiopia, may be established in Kenya. It is essential that this station and data-handling facilities can be also used by Ethiopia. In 1985, it will be possible for Ethiopia to receive data from the SPOT satellite and also order special registrations from the two receiving stations in Sweden and France.

We suggest that SPOT images be studied, as soon as registrations are available in mid-1985. The possibilities of ordering special registrations from areas of interest in Ethiopia ought to be investigated.

2 INTRODUCTION

2.1 BACKGROUND

The Swedish International Development Authority (SIDA) has sponsered rural water development activities in the Hararghe (Eastern) Region of Ethiopia since 1976. The strategies for the development have been based on a Master Plan prepared by VIAK AB in 1977. (Rural Water Development Study for the Hararghe Region, Vol. I - III). The irrigation potential of the Dire Dawa area was assessed in a simultaneous study (VIAK 1977:2). In these studies, satellite images were studied on a reconnaissance level for the whole region (245 000 km^2) and proved to be very useful because of the large areal extent, the inaccessibility of many parts of the region and also because of the general deficiency of detailed, topographical and geological maps. Because of hostilities in the region the project was not operational most of time between 1977 and 1978.

At a seminar held in Dire Dawa in November 1979 the foundation was laid for a continuation of the SIDA project. At this time the original 5-year plan was reviewed and a 3-year development plan was formulated. During this seminar the first proposal for utilizing satellite image interpretation for water exploration was presented to SIDA and the Ethiopian Government.

It was, however, not until 1983 that this project could be realized, when SIDA initiated three research and development projects with the aim of introducing new methods and technologies which could later be incorporated into the regular water activities of SIDA in the Hararghe region and elsewhere in Ethiopia.

This project is the first of the three projects to be finalized, the other two concern development of groundwater dams, shallow wells and various means of water abstraction. The projects are linked in that the remote sensing shall be used to identify suitable areas and sites for inexpensive water supplies, such as springs, shallow wells and groundwater dams.

2.2 RESEARCH IDEA

The idea behind this work is that satellite information could be used for water resources exploration. Advantages with satellite images compared to aerial photographs are the large coverage, the possibility of selecting registrations from different seasons and the fact that registrations are also made in the infrared part of the spectrum, which facilitates interpretation of water bodies, soil moisture and vegetation. The disadvantage with satellite information is object identification as features less than 80 x 80 m cannot usually be traced. However, in this respect there will be improvements with satellites to be launched, e.g. the SPOT satellite in 1985.

In an area like the Hararghe Region, which covers 245 000 km^2, virtually thousands of aerial photos would be required for photo interpretation, but only 7 LANDSAT-scenes are required. Thus, the amount of work and costs involved in aerial photo interpretation were discouraging.

Improvements in the selection of water sources and water supply techniques are very much required. Unnecessary money is sometimes spent on deep drillings because of lack of information on the possibilities of using shallow groundwater.One major aim of this project has been to verify that by the use of advanced satellite technology (but not difficult or expensive), the most appropriate sources of water supply could be identified and inexpensive supplies planned.

Because of the lack of computer facilities in Ethiopia for processing satellite information a method was chosen whereby visual inspection is used. In this way existing instruments have been used and a number of Ethiopian geologists have been trained so that similar work can be carried out in other parts of the country.

3 METHODOLOGY

3.1 APPROACH

<u>Traditional Approach</u>

The traditional way of collecting information on the ground, water, plants, etc. of a region has been to travel in the area, make field observations and indicate features of interest on more or less primitive maps. After a certain number of traverses, a general idea of the qualities of the area could be presented.

A tighter network of observations gave greater understanding of even detailed terrain features, which could facilitate location and the exploitation of the natural resources of the area (Fig. 1a).

<u>Two-level Approach</u>

With a more general use of aerial photographs, the initial field observations could be reduced drastically. The experienced photo interpreter may in a short time identify and deliniate features that required weeks or months to discover during exploratory travels.

One of the most important advantages of aerial photographs is the synoptic view provided of a rather large area, while permitting study of details of the terrain.

Photo studies usually require checking in the field, especially when actual siting is required. This way of making a terrain inventory can be called a two-level approach, where the analysis of the aerial photographs allows an early concentration to areas of specific interest (see Fig. 1b).

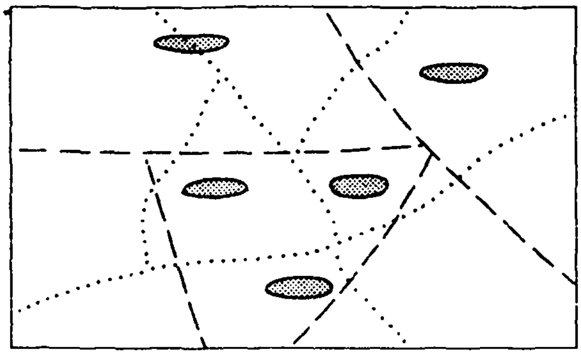


Fig 1 a Traditional inventory of geology and mineral resources

Field observation tracks

Land unit borders

Exploration sites

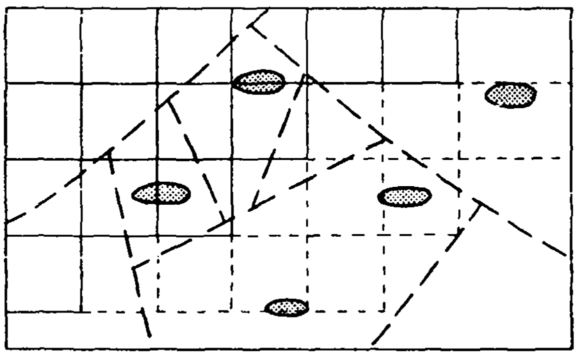


Fig 1 b The two-level approach

Aerial photographs

Field checks

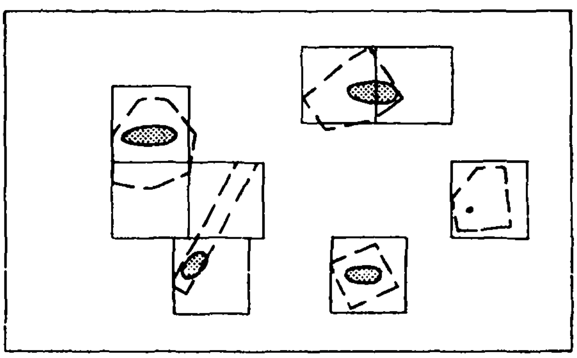


Fig 1 c The three-level approach

Satellite imagery

Aerial photographs

Field checks

Figure 1 Exploration of natural resources. Development of approaches.

Three-level Approach

A third step in the development of terrain inventory techniques has been taken with the introduction of the earth resources satellites, the LANDSAT series. Since 1972, LANDSAT data and imagery has been available for all regions of the globe, without political restrictions, and at moderate cost.

The LANDSAT system and its use in this project will be described later. Here we just wish to point out some of the options that can make terrain studies more cost-effective and afford higher quality using these facilities.

One important factor is the area coverage. One single LANDSAT scene covers 185 x 185 km, i. e. app. 34 000 km^2. To cover the same area with aerial photographs to a scale of 1:50 000 (stereo overlap 60%, side overlap 20%), more than one thousand photographs are needed, at a considerably higher cost.

Another advantage is the possibility of repeating coverage of an area. This multitemporal option is of the utmost value during dynamic studies, such as when following changes in land use, drought effects, erosion-siltation processes, etc. For inventories of a more static character, such as of the geology, geomorphology, soils, drainage, etc., the multitemporal recordings are also of a great value, as the terrain objects may stand out more or less clearly due to the differences in season or sun angle.

A third factor, and perhaps the most important one, is the multispectral scanning of the Earth's surface that permits sophisticated and rapid detection, analysis and presentation of terrain information. The LANDSAT system is described in more detail in Section 3.3.1.

The first stage in a three level regional terrain analysis is to study the satellite images delineating areas or spots of specific interest and to eliminate other parts of the region. In order to get a more detailed view of the areas selected, aerial photographs are studied in the second stage. The photo interpretation will indicate a number of limited areas or sites, some or all of which must be visited, depending upon which types of information are required (third stage; Fig. 1c and Section 3.2).

The future development of other remote sensing techniques, such as high resolution stereo imagery, satellite radar imagery and thermal registrations, will undoubtedly increase the benefits of "The Three-level Approach" for regional studies.

3.2 SATELLITE IMAGERY INVENTORIES

The recent development in the field of remote sensing, touched upon in the previous section, is already of the utmost importance to the developing countries and can be expected to be of still more importance in the future. The need for up-to-date knowledge on population distribution and land use, the existence of natural resources such as minerals and groundwater, early warnings for severe effects of droughts, crop infestations, land erosion and degradation, etc. is urgent and growing.

To make effective and rewarding use of remote sensing in a developing country in the near future, the ambition must be to introduce and apply methods which can have an immediate impact and rapidly become operational. The technical approach must rely to a high degree on existing instrumentation and facilities and it must be capable of being handled and used by many professionals in the geo- and bio-scientific fields, even after only a short period of training.

With these prerequisites as a background, a realistic way to carry out a terrain inventory based on LANDSAT imagery is to apply much the same technique used in conventional aerial photo interpretation. This involves studying the images visually in a stereoscope or stereoplotter and plotting observations or transferring them accurately onto a base map.

Computers may be used to a limited extent for the preprocessing of the LANDSAT data, to enhance terrain features of special interest. After such a procedure, however, the geometric quality of the image can often no longer compete with the geometrically corrected original image produced by the LANDSAT recording stations. The possibilities for direct mapping from the images have thereby been reduced.

As with conventional aerial photo interpretation, the visual studies of LANDSAT images is an indirect way of collecting information about the surface as well as subsurface features of the ground. Conclusions on the potential presence of subsurface water bodies and flows, infiltration, recharge and discharge areas, etc. can be drawn from indications or interpretation elements in the images.

These interpretation elements may be of two types:

1 Static elements (less dependent on the season):

DRAINAGE PATTERN (hydrology, lithology, topography)
ALIGNMENTS (faults, folds, joints, structural geology)
LAND-FORM (relief, morphology)

2 Dynamic elements (dependent on the season):

DRAINAGE CONDITIONS (natural, dry, moist, wet, irrigation)
VEGETATION (character, species, changes with season)
LAND USE (forestry, farming, grazing, etc.)

The interpretation elements are studied one by one and transferred to the base map. These element maps are integrated and summarized in a physiographic-hydrographic analysis forming the basis for the hydrogeological evaluation.

As has been pointed out earlier, LANDSAT imagery has definite advantages in the domain of multispectral and multitemporal scanning of the Earth's surface, compared to small-scale aerial photography. The multispectral registrations from LANDSAT show the Earth's surface in four separate wave-length bands. This increases the possibility of detecting and recognizing different objects in the LANDSAT scene compared with that of aerial photography.

Multitemporal image analysis is of a great value, especially in areas with pronounced dry and wet seasons. Dry season images are usually the best for observations of alignments, landform, relief, drainage conditions, and land use. Drainage patterns, irrigated farmland, and natural vegetation are usually better represented in registrations made during or shortly after a moist or wet period.

Selection of the time for imagery is thus of vital importance and careful consideration must be given to the following factors: Image quality, cloud cover, climate, soil moisture regions, and vegetation crop cycles.

3.3 THE LANDSAT SYSTEM

Among the different satellite systems active today, the LANDSAT programme is one of the most interesting in land resource studies. Images from the five US satellites, LANDSAT 1-5, have been available for non-military purposes since 1972. This means that most areas of the world are now well covered, with several registrations from different seasons. As mentioned in Section 3.2, the repeated coverage is an important advantage of this technique. Frequencies and the effects of rainfall, flooding, droughts, etc. can now be determinated by analysis of bitemporal or multitemporal registrations.

LANDSAT MSS (Multispectral Scanning) registrations are produced in two principle forms, photographs in black and white or in colour FCCs (False Colour Composites) or as CCTs (Computer Compatible Tapes). The former can be studied and analysed in much the same way as conventional aerial photographs, while the CCTs can be processed and used in a more flexible manner.

Figure 2 gives a generalized idea of how the multispectral scanning (MSS) of the LANDSAT system works. The oscillating mirror scans the ground along lines, receiving light from areas roughly 80 x 80 m on the ground. The light is directed in sensors recording the intensity of the radiation for four different wave-lenght bands. These registrated spectral bands correspond to what our eyes see as green and red colours and to near

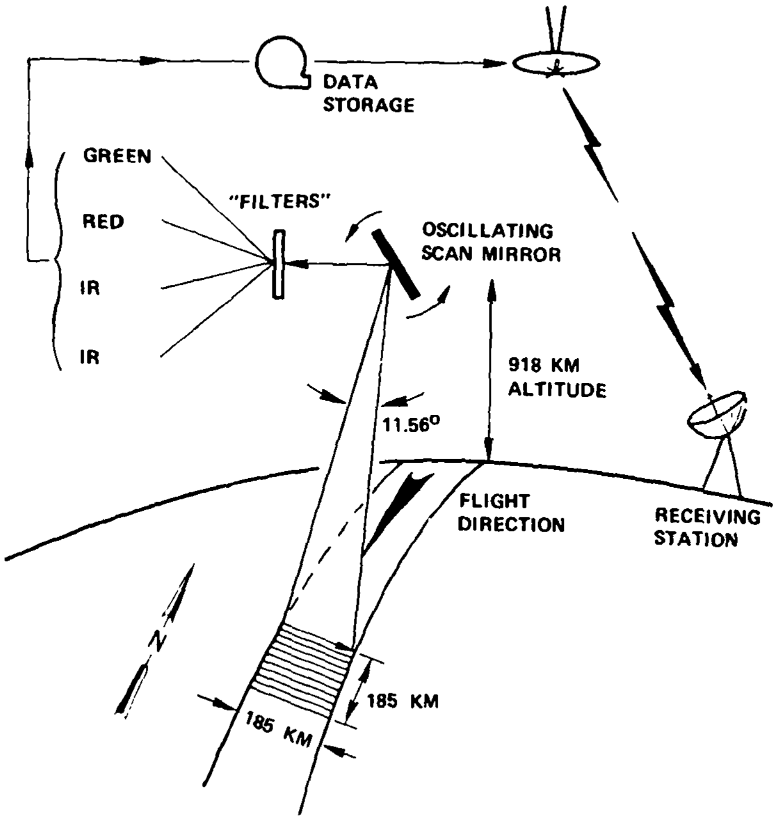


Figure 2 LANDSAT multispectral scanner (MSS). For each terrain scene, four images are transmitted to a receiving station. (From NASA, 1976.)

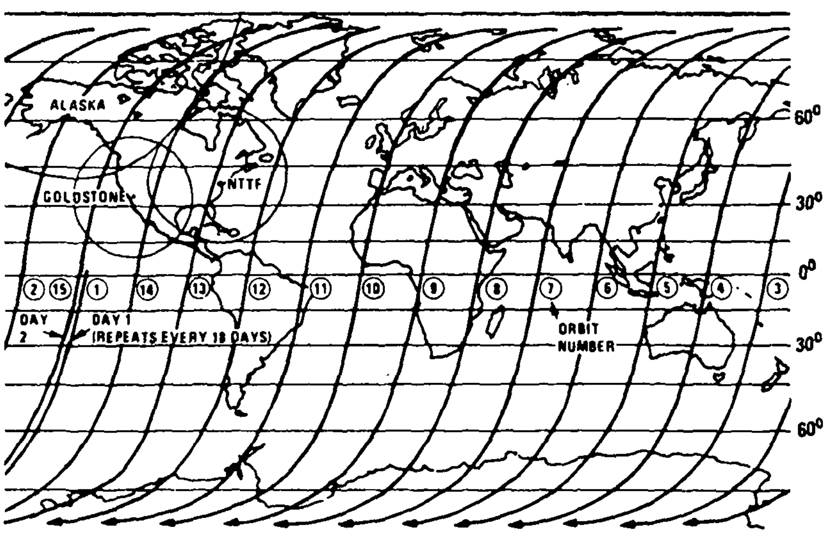


Figure 3 Typical daytime LANDSAT 1-3 orbit paths. Images are acquired between 09.30 and 10.00 AM local suntime. (From NASA, 1976.)

infrared radiation, which is "invisible" to the eye.

Each scanning line contains several thousand 80 x 80 m areas called picture elements or pixels. Each pixel can be located geographically and shows a certain intensity of the four separate spectral bands. This means that from the pixel-mass recorded on the CCT any part of the complete registration (185 x 185 km) can be presented to the required scale and in colours that enhance the terrain objects of special interest most effectively.

Registrations from two or more occasions can be compared, pixel by pixel, allowing multitemporal studies such as change detection, studies of trends, detection of time-related features for the whole LANDSAT scene or parts of it. Figure 3 shows the LANDSAT orbit paths over the Earth.

The CCTs can also be used for automatic terrain classification. This way of using the satellite data is based on a number of small test areas with known characteristics of groundwater, vegetation, land use, etc. A computer analyses the satellite registrations for these test areas, after which it can indicate all terrain in the area with the same spectral properties. A limited check of the classification result is usually made from aerial photographs or, more satisfactorily, on the ground.

A LANDSAT image covers about 34 000 km^2, in which major terrain features as well as minor details of a size around 80 m in diameter can be studied. This means that the deliniation and general geological-hydrographic description of principal and also secondary drainage basins can be based to a considerable extent on studies of satellite images and aerial photographs. The main surface drainage networks can usually be identified in LANDSAT scenes to a scale of around 1:1 000 000.

An important, but perhaps somewhat neglected, advantage of LANDSAT images is the very good geometrical properties. With sufficient geodetic support on the ground, the overall accuracy of image details has been shown to be app. 60 m in image scales of 1:250 000.

In our experience of this project in Ethiopia and from other projects in Kenya and Botswana, the discrepancy between point locations on 1:250 000 scale maps and system-corrected LANDSAT images to a scale of 1:1 000 000 seldom exceeds 1 - 1.5 mm on the map, i.e. less than 250 - 400 m on the ground.

The best way of examining LANDSAT images is usually by stereoscopic viewing. As there is a very limited overlap between images from two adjacent tracks, at least at low latitudes, an ordinary three-dimensional stereoscopic model cannot be achieved. The main advantage of stereo-viewing is, instead, the greatly increased optical resolution obtained compared to single image analysis. Using our stereoscopic vision we double the resolution of our eyes. To attain this, two copies of the same image may be used.

It is more rewarding, however, in a terrain analysis of the present type to obtain a stereoscopic view of images from two seasons. There, the season-dependent terrain differences are easily detected and a bitemporal study can be performed.

Ordinary mirror stereoscopes or other types of simple stereo-viewing equipment can be used for this kind of image inspection. They have, however, definite drawbacks when it comes to the transfer of information from the images to a base map of some kind.

It is our opinion that this transfer is best and most accurately done in an analogue stereoplotting instrument of the same type as used for conventional mapping. For this LANDSAT inventory, we have used WILD A8 and B8 stereoplotters. In connection with the field-check during the actual project, we had the opportunity of using the Kern PG2-plotter at the Ethiopian Mapping Agency in Addis Ababa. The arrangement for this bitemporal stereoscopic LANDSAT analysis is shown in Figure 4.

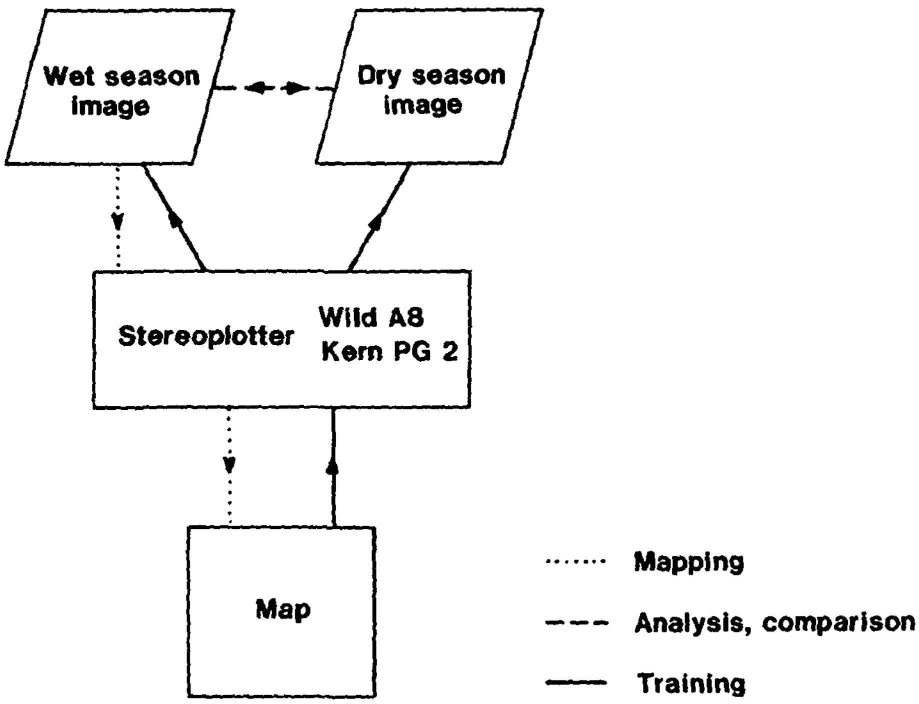


Figure 4 The bitemporal LANDSAT interpretation system used.

The different steps in the orientation of the images, scaling and mapping are described in Appendix 3.

The analysis and evaluation of image content is done by merely closing each eye alternately and comparing the colour, shape, texture, etc. of the same area in the two images (indicated by dashed arrows in Fig. 4).

The dotted arrows indicate plotting onto a base map. Normally, this cannot be done directly from the the stereoscopic model due to the difficulties of fusing together bitemporal images perfectly. Instead all transfer (mapping) of information must be done from one of the two images.

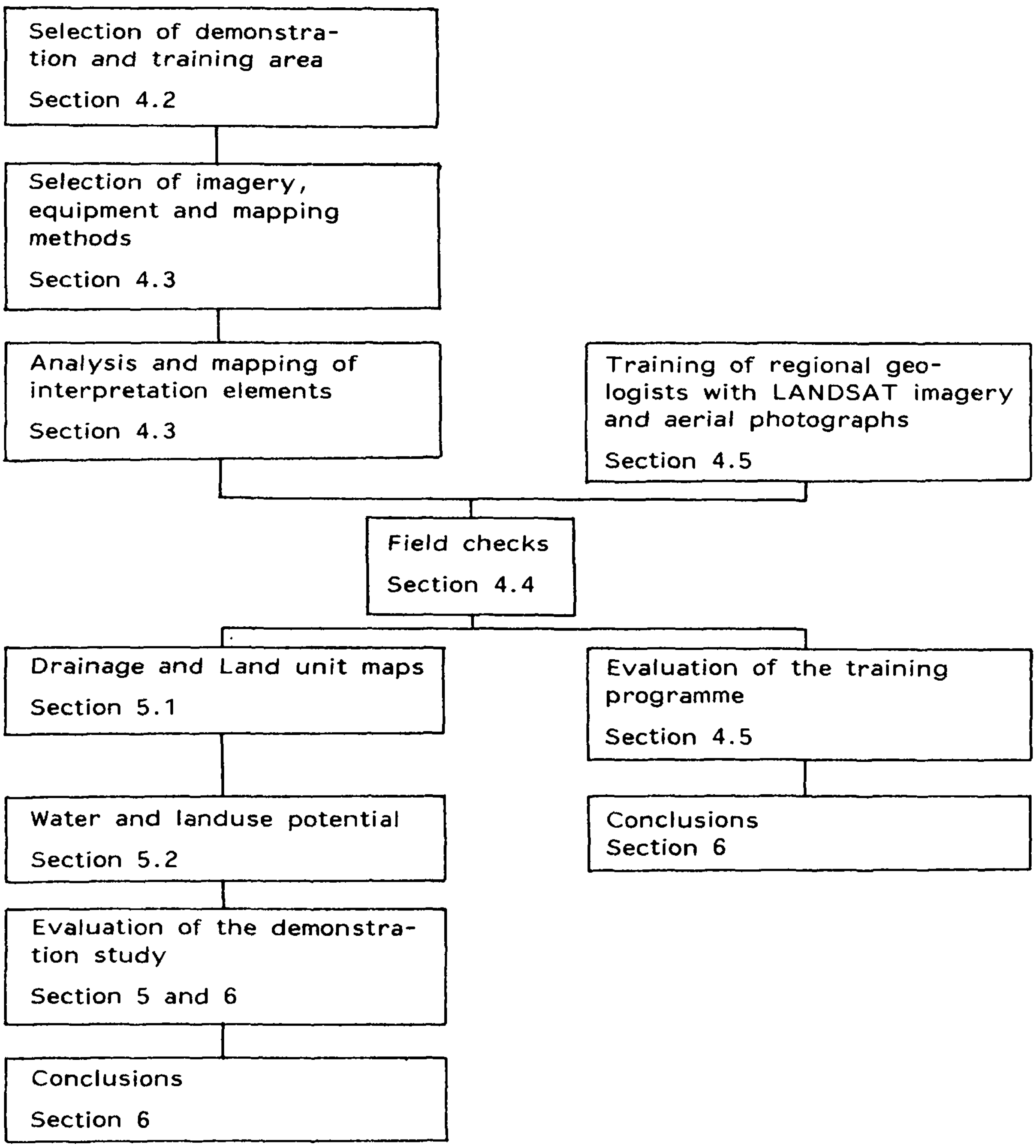
A most useful application of the system is shown by the full-line arrows. A geological map, a vegetation map or any other type of thematic map can be placed on the plotting table and the floating dot of the optics can be made to fall on the corresponding point of the image, giving excellent and precise image location.

This option has been very useful during the initial phase of the LANDSAT studies as well as for the training operations of the project.

4 PROJECT DESCRIPTION

4.1 WORK PROGRAMME

The following work programme was established after discussions with EWWCA officials to demonstrate the potentials of remote sensing in applied geohydrological studies.



4.2 DEMONSTRATION AND TRAINING AREA

Initially, two areas were chosen for the project, one around Dire Dawa and one in the Degahabour area, both in eastern Ethiopia (Fig. 5). The latter one had to be excluded, however, due to the lack of good quality dry-and-wet season images and to problems with access to the area for field checks.

The following description of the physical properties of the Dire Dawa area is mainly based on work by Mesfin Aytenffisu, (1981).

The area studied is in the southern part of the Afar Rift System. It contains parts of the Rift escarpment, the foothill area (mainly step faults) and the Rift floor. The project area covers app. 5500 km^2. To the southeast, the area meets the wide plateau that extends to the northern part of the Ogaden plains.

Geology

Precambrian granites and gneisses are the oldest rocks outcropping in the region (older than 600 million years). Often, however, they are covered by sedimentary rock of Mesozoic age (100 - 200 million years old), such as sandstones and limestones.

During the last 50 million years, the East African Rift faulting has developed a system of mostly rather narrow, straight and deep valleys, usually containing volcanic rocks and loose volcanic deposits. In eastern Ethiopia, the East Africa Rift meets the Afar Rift System and the Aden Rift causing a widening and funnelling out of the Ethiopian Rift.

This junction of three rift systems can be traced in the rock structures and lineaments of the area. Lineaments on a bearing of app. 30^o represent the main direction of the Ethiopian Rift. Lineaments on a bearing of app. 70^o are caused by tectonic movements parallel to the Aden Rift and a third system on a bearing of app. 320^o runs parallel to the Red Sea direction of the Afar Rift System.

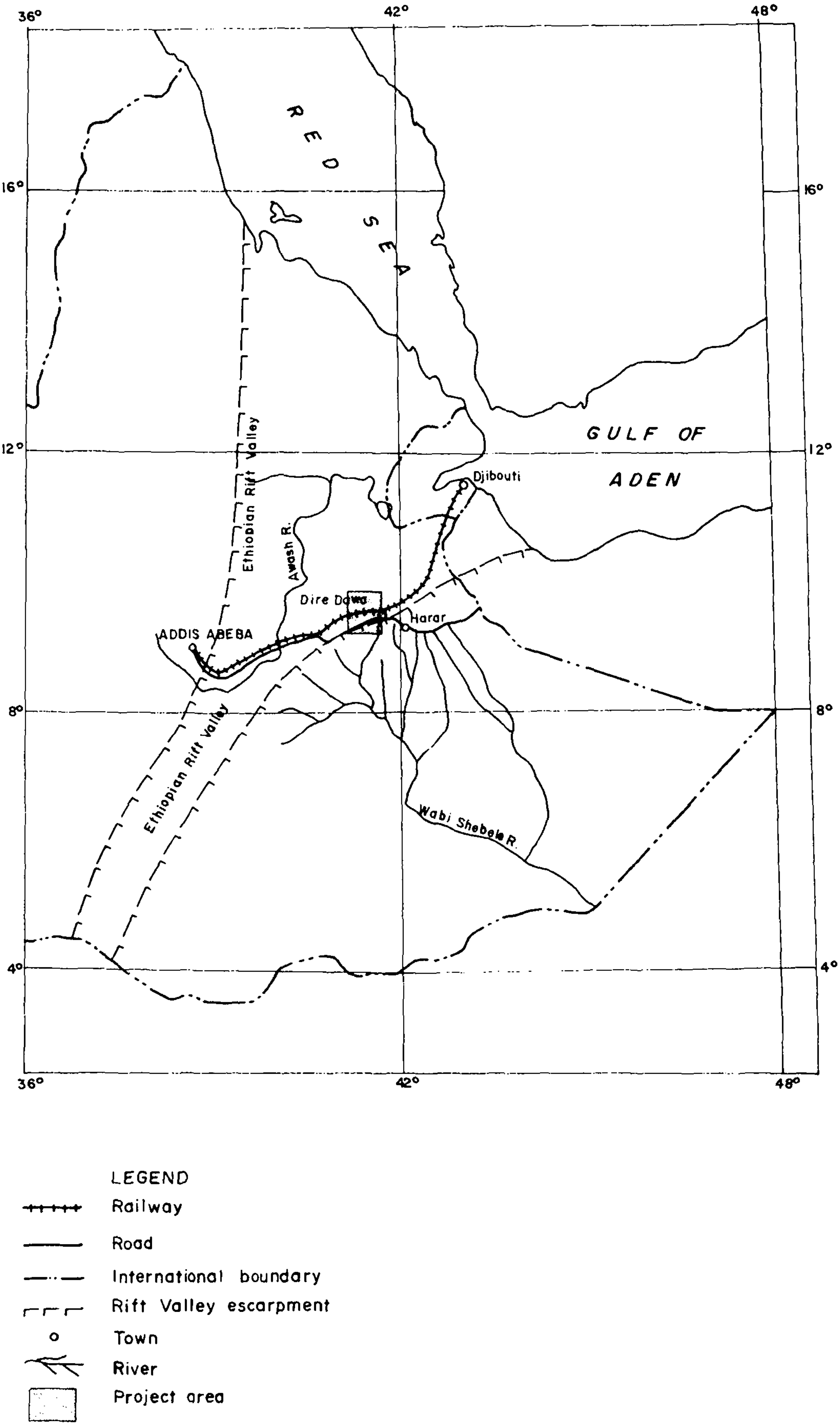


Figure 5 The project area.

During recent geological times, volcanic activity has been concentrated to the Rift floor, developing vast flood lava sheets from fissure-eruptions and also to more local deposits due to activity around volcanic crater centres.

In the LANDSAT images, these late volcanic rocks show no distinct lineaments in accordance with the systems mentioned earlier. Such tectonic features may exist, but are of such a limited size that they cannot be observed on the images. It can also be assumed that no major tectonic movements have taken place after the most recent lava outflow. These late lava fields may, however, cover old fault line systems or other tectonic features of great hydrogeological importance.

Quarternary Deposits - Geomorphology

The series of fault scarps from the plateau down to the foothills slopes generally at app. 35 - 40^{o}. At the foot of the escarpment, the general slope is usually gentle, app. 5^{o}, decreasing towards the rift floor.

Abrupt changes in slope gradient may allow for deposition of sediments in ephemeral streams, possibly forming fans or filling up valleys and depressions. In parts of the area, alluvial deposits of this kind are now being reworked as a result of tectonic or erosional changes in threshold levels.

Land erosion due to damaged vegetation cover caused by overgrazing, fuel wood harvesting, drought effects, etc. is frequent in the foothill area. The sediments are carried down into the rift floor, mainly along sand rivers. With few exceptions, the streams in the area are ephemeral, carrying water only during torrential rains.

When the streams reach the rift floor their ability to transport sediment ceases and depositional terrain-forms build up. Single or complex alluvial fans (bajadas) form as well as more featureless alluvial plains.

At the toe of the fans or in depressions in the alluvial plains, groundwater outflow and surface water may form temporary saline lakes (playas) or pans.

On the rift floor, wind probably has a significant erosional effect (deflation) on the fine, usually relatively loose alluvial deposits. There seem, however, to be few signs of more significant deflation and dune-formation in the test area.

4.3 METHODS, IMAGERY AND INSTRUMENTATION

LANDSAT MSS Imagery and Data Used

The area chosen for the study is covered by the LANDSAT 1 - 3 scene 179/153 centred around the city of Dire Dawa. Table 1 shows the types of imagery used.

Table 1 LANDSAT material used

Date	LANDSAT No.	Type	MSS bands	Season
Nov. 18, 1972	L1	FCC	4, 5, 6	Dry
Apr. 7, 1979	L2	FCC	4, 5, 6	Wet
Oct. 31, 1972	L1	B/W	5	Dry
Apr. 7, 1979	L2	B/W	5	Wet
Apr. 7, 1979	L2	CCT	4, 5, 6, 7	Wet

B/W = Black and white film, negative, scale 1:1 000 000
FCC = False colour composite, positive, scale 1:1 000 000
CCT = Computer Compatible Tapes
Band 4 = registration of green light 500-600 nanometer
Band 5 = registration of red light 600-700 nanometer
Band 6 = registration of IR light 700-800 nanometer
Band 7 = registration of IR light 800-1100 nanometer

The black and white negatives and the false colour images are corrected for system distortions such as scan skew, variation in scanner mirror velocity and scanner distortion. The geometry of the images may also be affected by non-system distortions caused by variations in space craft altitude, velocity and attitude. To correct for this type of geometric error a rather large number of ground control points visible in the image are needed. On this geodetic basis, the images can be reconstructed with a geometrical accuracy as good as ±60 m (Talts, 1979).

This latter type of laborious correction has not been found necessary during this project, as the demand for very accurate mapping is limited.

As pointed out in Section 3.2, the choice of registration date for the different scenes is extremely important for the results. The image quality, and the weather conditions, the seasonal changes in climate, etc. must be considered in detail to obtain optimum data quality.

In areas with pronounced dry and wet seasons it is often rewarding to use registrations from both situations. For instance, images from a dry season are usually preferable when it comes to studies of alignments, landform, relief, and drainage patterns, while drainage conditions, land use, and natural vegetation are usually represented better in registrations made during, or shortly after, a moist or wet period.

As was described in Section 3.3, stereoscopic viewing of two images from different seasons has been shown to be most valuable in a terrain analysis. The bitemporal stereoscopic view usually reveals very distinct changes in natural vegetation, land use, drainage conditions, etc. in the scene from one registration to another.

For the test area, two registrations of good quality from the dry season in 1972 and shortly after a wet period in 1979 were ordered (Table 1). Most of the analysis work has been performed on the false colour transparencies to a scale of 1:1 000 000, from which colour enlargements to a scale of 1:400 000 were also made for the training programme and for the field checks.

Due to local disturbances in the 1972 band 7 registration, the FCCs from both 1972 and 1979 were printed from bands 4, 5 and 6. Black and white negatives ordered only for band 5 were merely intended for enlargements to a scale of 1:400 000, for the training course and for the field work.

One computer compatible tape containing all the four bands of the 1979 scene was ordered in case the visual analysis of the images should lead to a need for some type of more general terrain classification, such as closer analysis of the vegetation cover, land use, rock types, soil erosion related textures, etc. It has, however, only been used for some limited vegetation classification tests.

Methods - Instrumentation

The principal work has followed the programme discussed in Section 4.1.

The interpretation elements of interest for the geohydrological evaluation of the area were:

- Drainage pattern
- Drainage conditions
- Rock outcrops
- Lineaments
- Landforms
- Dry-season vegetation

These elements have been mapped to a scale of 1:250 000 from a bitemporal LANDSAT model in a steroplotter of type Wild A8 at VIAK AB, Sweden. The optical magnification of the plotter was 6.

A Drainage map containing drainage features and dry-season vegetation areas (Map 1) and a Land Unit map, with geological-geomorphological information (Map 2) have been produced. Most plotting has been performed from the wet season image. For mapping of dry-season vegetation areas, lineaments and, in areas covered by clouds in the wet season image, the dry-season image was used.

The mapping was performed by an experienced geomorphologist with no direct acquaintance with the test area. The most detailed background information on the area available was that presented by Aytenffisu, (1981) as summarized in Section 4.2.

A preliminary analysis and a delineation of catchment areas and subareas with typical drainage patterns was done before visiting the area. Based on the Drainage map and the geological observations made, a Preliminary Land Unit map was prepared. A short written description was made for each drainage subarea and Land Unit area.

During the field visit to the area, it was possible to make "on the spot" comparisons between the terrain and the LANDSAT images. False colour transparencies to a scale of 1:1 000 000 and a 6 power magnifier were used during the field checks.

Some complementary information to the preliminary maps was obtained by comparisons with aerial photographs of limited parts of the area. It was the intention to make a detailed aerial photo - LANDSAT imgage comparison over selected parts of the area before reporting on the project. For various reasons it has not yet been possible to make this comparison.

At the Ethiopian Mapping Agency in Addis Ababa a Kern PG2 plotter was used for training and for complementary mapping following the field visit.

Throughout the project, conventional stereoscopes on light tables have been used for visual inspection of the images for interpretation discussions, planning and training purposes.

4.4 FIELD INSPECTION

Inventories based on remote sensing techniques usually have to be checked in the field.

The aim of the field inspection during this demonstration and training study has been twofold. One aim has been to check the preliminary mapping of the interpretation elements, performed at VIAK AB in Sweden. The other aim was to let the team of Ethiopian geologists participating in the remote sensing training programme carry out field checks of their preliminary LANDSAT inventories.

The visit to the Dire Dawa area lasted eight days and involved field trips in various types of terrain. Two vehicles and drivers were placed at the team's disposal by the EWWCA in Addis Abeba.

4.5 TRAINING PROGRAMME

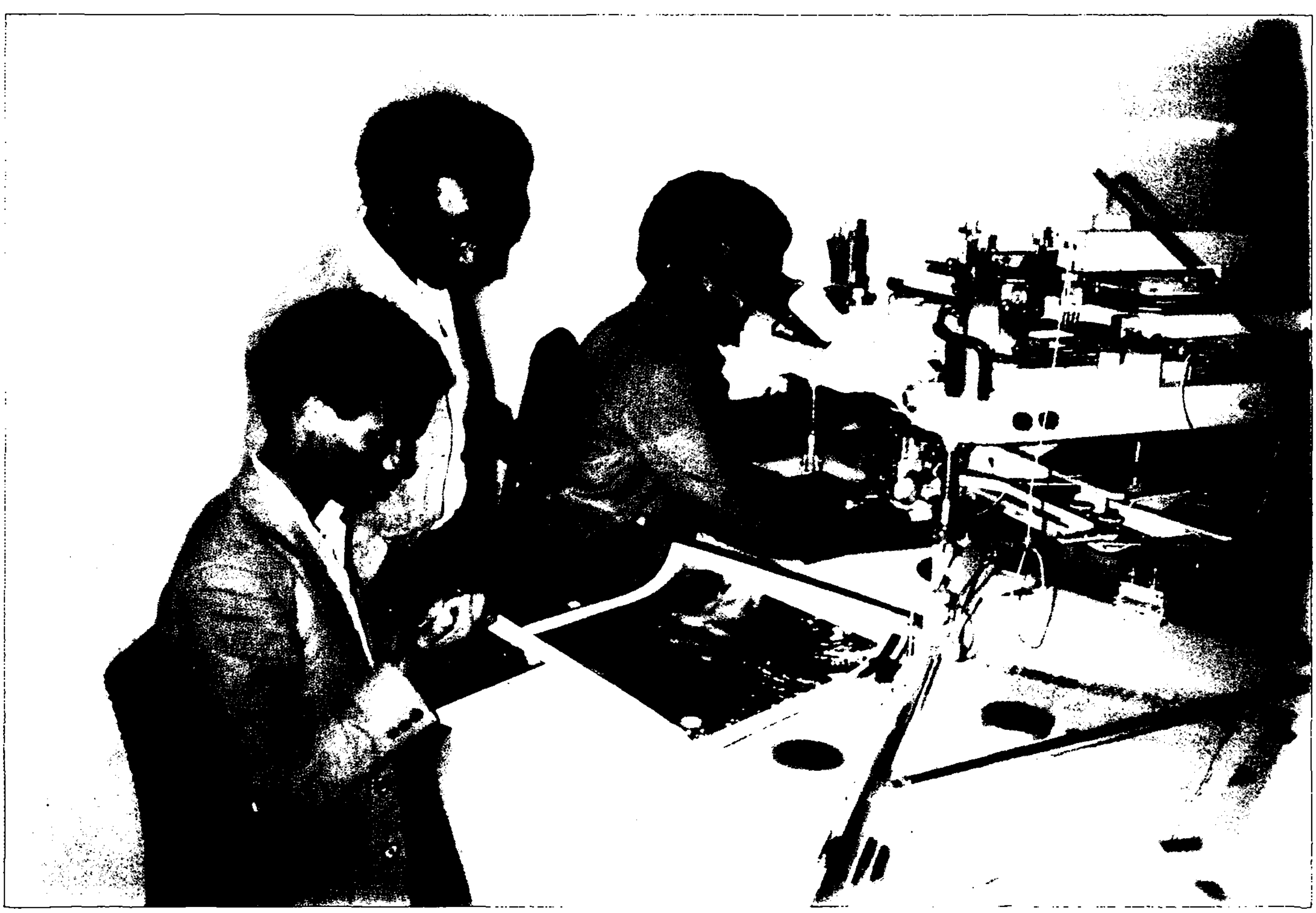
The VIAK team provided information on the bitemporal, stereoscopic mapping method for natural resources inventories based on LANDSAT images. The basic photogrammetric background and the plotting technique was presented.

Each participant had the opportunity to work with LANDSAT images in a Kern PG2 type stereoplotter at the Ethiopian Mapping Agency. The dual optics of the instrument (instruction eyepieces; see photo below) permitted the most effective training.

Aerial photographs to a scale of 1:50 000, studied in mirror stereoscopes, supported the LANDSAT inventory.

Areas of specific interest or where major interpretation difficulties occurred were chosen for field inspections (Section 4.4). As interpretation of aerial photographs or satellite images is very largely a question of experience, it is essential that field inspections can be included to a considerable degree in remote sensing training.

The team of Ethiopian geologists during a field inspection.



Analysis of LANDSAT images in a stereoplotter for identification of water resources.

After the field visit each participant used the stereoplotter for a comparison between the bitemporal LANDSAT images and the experiences gained during the field trip.

Written reports on the experiences of the training programme and on the possibility to use bitemporal LANDSAT images for geohydrological investigations were submitted by the participants. This evaluation covered the technique in general as well as how it can be applied on a regional level in Ethiopia.

5 NATURAL CONDITIONS AND RESOURCE EVALUATION

5.1 LAND UNIT MAPPING

As described in Section 4.3, the various interpretation elements were analysed and summarized in a Drainage map (Map 1) and a Land Unit map (Map 2). In Appendices 1 and 2 a corresponding, written summary of observations and conclusions from the LANDSAT studies is presented. Condensed editions of these descriptions are found beside Map 1 and Map 2 and also in connection with the LANDSAT stereo images for the six main Land Unit areas (See Section 9).

Six major physiographic regions can be identified, each containing a number of land units. The delineation of these land units is based on an analysis of the Drainage map and on the observations on geology and landforms presented in Appendix 2.

Compared to the preliminary mapping during the initial project phase in Sweden, only minor changes and additions to the maps have been made after the field inspection.

The following interpretation elements have been identified

Drainage Patterns and Drainage Conditions

There is normally a good correlation between the drainage network in the 1:250 000 scale base map and the drainage paths shown in the 1:1 000 000 scale LANDSAT False Colour Composites. In general, most streams in the maps can be directly or indirectly detected in the satellite images from the tone, texture, vegetation signs, land use, etc. (see Fig. 6).

When additions to the map are made, it is usually a question of rather vague stream channels in areas covered by loose deposits.

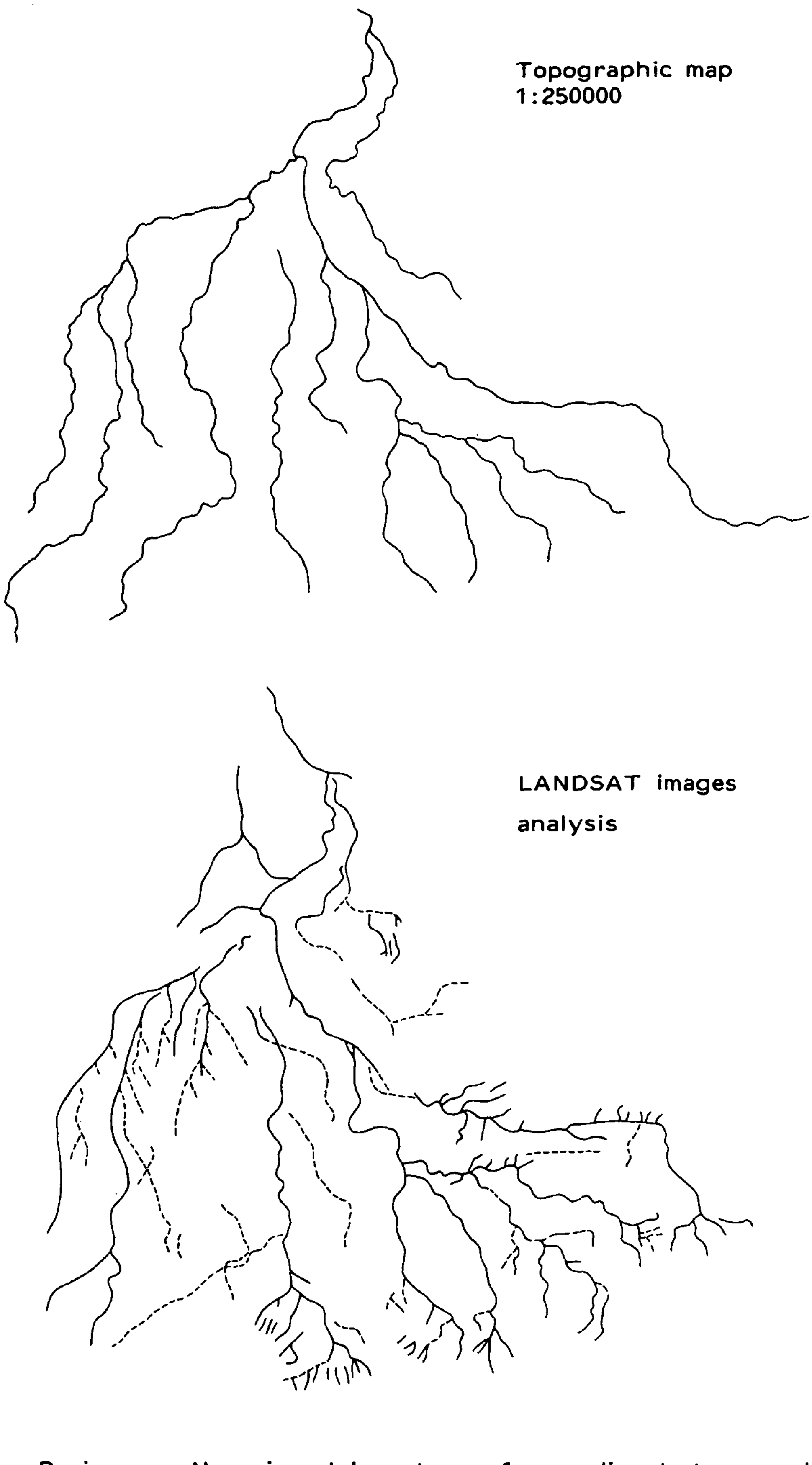


Figure 6 Drainage pattern in catchment area 1 according to topographic maps to scale 1:250 000 (above) and the LANDSAT images analysis (below)

Almost no free water surfaces can be observed in the area. Most streams are ephemeral and no larger dams have been identified. If dams are to be detected the size must be at least 2 - 4 pixels, i.e. cover an area of app. 2 hectares according to experience from Botswana (VIAK 1984:2).

Vegetation - Land Use

Overall natural vegetation types, density, status, etc. may to a large extent be studied in the LANDSAT images. In a climate with wet and dry seasons, the bitemporal, stereoscopic viewing of the images opens good possibilities for the detection of changes in the vegetation cover, land use, and irrigation through the year. For the actual project, no discrimination between vegetation units has been found necessary. It is more interesting instead to compare the vegetation distribution in wet and dry season images of the same area.

As water is often the most controlling factor, the vegetation showing up in the dry season images may indicate the presence of springs, seeps, a high groundwater table, etc. Conclusions may be drawn about the nature of the green area from the geographical position, the colour, the size and form of the vegetation spots. Vegetation, which is also green during the dry season is shown on Map 1.

The land use of the area has only been studied to a minor extent. Based on the tone and texture of the images, intensive cultivation on alluvial soils can be assumed in some parts of the area. Position and form imply that several vegetation spots are irrigated plantations and farming areas.

Geology and Landforms

The main rock outcrops or rock with shallow soil cover have been outlined on Map 2. An area with scattered outcrops is treated as one unit. Normally, the diameter of the outcrops has to be 3 - 4 pixels (app. 250 m) to allow accurate identification.

It has been possible to separate the main rock groups: Sedimentary, metamorphic-igneous and volcanic rocks. Among the volcanic rocks the following types have been outlined:

- Young flood or plateau basalts
- Vast sheets of very dark, young lavas (possibly rhyolitic)
- Rhyolite domes
- Older, faulted basalts.

In most cases, the rock outcrops stand out most clearly and distinctly in the dry season image.

The loose deposits are mainly of alluvial character. Along parts of the Rift escarpment there is a slope of old, trapped alluvial deposits (areas 1:3 and 5:1). Due to changes in threshold levels, fluvial erosion has started and the sediments are fed into wadis or sand rivers. In the lower sections, deposition occurs on flood plains, outwash surfaces, fan complexes (bajadas) or as alluvial plains. In the lowest parts of the area, playas have developed.

The sand rivers are characteristic drainage features of the area. They are usually well reproduced in images from the wet as well as from the dry season. For the major sand rivers, it is usually possible to give a rough estimate on the bank to bank width, existence of rock thresholds, flood plains, water-carrying channels and pools, tell the nature of sediments in the main channel and tributaries, etc.

Tone and texture indicate more or less distinctly land erosion and stream bank and gully erosion in various parts of the area studied. In elevated terrain, these signals are usually caused by coarse, stony erosion pavements, while in lower parts, tones are lighter due to finer sediments. In most erosional areas, a faint, dense drainage network can be observed. Usually, the wet season image gives the best representation of the landforms mentioned.

Along cliffs and steep rock outcrops, screes can occasionally be observed.

Lineaments

Because of the large area covered in a single image, the major rock structures and lineaments may be detected and followed for long distances. Even minor lineaments may come out clearly due to differences in vegetation type and growth, shadowing, tone, texture, etc.

The mapping of alignments has been focused on straight features or curved features with straight segments such as faults, fractures and dykes. Other rock structures such as gneissic striation, beddings or foliation have not been plotted though often visible in LANDSAT images. These features are usually less well correlated to subsurface water conditions than the former types of structure.

The three main tectonic directions can all be identified in the images:

- The Ethiopian Rift, app. bearing of 30^o
- The Aden Rift, app. bearing of 70^o
- The Afar Rift System, app. bearing of 320^o.

In large areas, however, the related lineaments are obscured by young flood or plateau basalts, showing no signs of faulting.

Other, more or less distinct, lineament directions have also been plotted. For instance, in areas 3:1, 4:1 - 4:3, several well-marked lineaments with a bearing of app. 100^o can be observed.

Lineaments are usually best shown in the dry season image.

5.2 WATER AND LAND-USE POTENTIAL

The water in and land-use of the Dire Dawa area are shown on Map 3, with detailed descriptions of each subarea in the legend. In Section 9, Maps and photos, each subarea is described both as regards its physiography and water availability, with stereo images and photos showing various physiographic and water-related features.

The aim has been not only to indicate the water sources but also to make suggestions as to the most suitable means of abstracting the water and on the water demand and possibilities of utilizing the water.

The water and land-use information obtained from the satellite imagery interpretation are described below. (See legend of Map 3.)

Perennial Rivers

As can be seen on the map some perennial surface waters have been identified, based mainly on the dry season image. Some irrigated agriculture is supported by these sources.

Springs and Groundwater Outflow Areas

Some larger springs and outflow areas have been identified. This is very useful information which can mainly be detected from vegetation spots. One identified outflow area was inspected and large quantities of groundwater appeared on an otherwise dry river bed. A photo of the site is shown in Section 9 (Area 1, photo 3). Springs and outflow areas are good indicators of the presence of groundwater which can normally be cheaply exploited.

Groundwater Flow Direction

The general direction of flow of the shallow groundwater is shown on the map, and follows the general topography of the area. It is not possible to obtain any clear opinion of the direction of flow of deeper groundwater but it is likely that it follows the general groundwater flow direction.

Groundwater Recharge

Major areas of groundwater recharge are indicated on the map. In area 1:6 the recharge area was identified through the disappearance of a major stream with abundant dry season vegetation in that particular site. This vegetation-covered area (red tones) is clearly shown on the satellite image in Section 9, (Area 1, photo 2).

The alluvial fans of areas 6:1 and 6:2 contain recharge areas, especially around the apex of the fans. These areas are likely to be rich in groundwater of good quality.

Evaporation Areas

In some places in the northern part of Map 3 there are areas where the flood water from the highland becomes impounded and to a large extent evaporates, causing salt enrichment in the soil and increased groundwater salinity. Such areas are shown on the satellite images as dark tones in the alluvial fan sediments.

Thresholds

A feature which is not commonly shown on hydrogeological maps is thresholds as inferred from narrow passages in the stream courses. These are shown here because there are reasons to expect a groundwater reservoir upstream of these places. While inspecting the sites in the field, large trees are often found in the middle of the dry river bed just upstream of these narrow passages indicating the presence of shallow groundwater.

Potential for Groundwater Dams

The whole of area 1:4 and parts of area 5:1 have a good potential for groundwater dams in the dry sand rivers (wadis). The major sand rivers can be clearly seen on the satellite image of Area 1. From the drainage pattern it can be concluded that a dense network of smaller sand rivers must be present. However, they can not be directly observed in the images. Sand rivers in other parts of the Dire Dawa area have been considered not suitable for groundwater dams, mainly because the sediments are deep and extensive causing construction problems for groundwater dams.

Land Irrigable by Surface Water

The areas with potential for irrigation by surface water throughout the year have been briefly indicated along perennial rivers. The size of these irrigable areas cannot be estimated since stream flow calculations can not be based on analysis of the LANDSAT images.

Land Irrigable by Groundwater

The potential of Areas 1:6 and 6:1 is especially good for irrigation by groundwater. At the junction of the two areas there is an extensive outflow area for groundwater as described above. Surrounding areas are also favourable for irrigation because of high recharge rates to the groundwater and flat land suitable for cultivation.

5.3 SOURCE SELECTION AND APPROPRIATE WATER SUPPLY TECHNOLOGIES

For domestic water supply purposes in the studied area the main source of supply is from shallow to medium deep groundwater. The water could be obtained from springs, which often need protection, or from shallow hand-dug wells and drilled, medium deep wells mainly in alluvial sediments. Apart from these traditional methods of rural water supply, groundwater reservoirs could also be artificially created by constructing groundwater dams in the numerous sand rivers of the area.

In areas where shallow or medium deep groundwater is not available, deep groundwater from drilled wells may be the only source of supply. Suitable sites for deep drillings are often along lineaments and especially at intersections between lineaments. As described in Section 4.2 the Study area has been intensely faulted and the lineaments follow the directions of the East Africa Rift, the Afar Rift System and the Aden Rift. Some lineaments are shown on Map 3 but areas suitable for drilling have not been mapped mainly because of the low priority of deep drilling as a result of high costs and problems incurred in maintaining pumps powered by engines.

It should be noted, however, that in a similar study in Botswana, (VIAK 1984:1) it was found feasible to locate suitable areas for deep drilling and subsequent drillings have proven very successful.

The recommendation to emphasize spring protection and construction of shallow wells and groundwater dams for rural water supplies in the study area is in line with the national priorities of Ethiopia, as expressed in the 10-year plan for rural water supply.

6 CONCLUSIONS

6.1 METHODOLOGY

For effective and rewarding use of the remote sensing technique in water development studies in Ethiopia, it is essential to introduce and apply methods which can have an immediate impact and rapidly become operational.

Visual analyses of LANDSAT MSS images from a dry and a wet season, studied in a stereoplotter, allowing accurate transfer of information onto a base map, have shown to be a reliable, simple, and cost-effective method (see Section 6.2) for making general, synoptic terrain inventories.

The method presented in this report can be applied and used by professionals in many geo- and bio-scientific fields, even after a short period of training. Suitable instruments are already available in Ethiopia, although they are normally used for conventional topographic mapping.

Analysis Based on Six Terrain Elements

For water resources development projects on a regional basis (map scales 1:200 000 and smaller), the inventory and analysis of six terrain elements (drainage pattern, drainage conditions, landform, lineaments, vegetation, and land use) have shown to be adequate for a general, synoptic evaluation of the water and land-use potential.

Under certain conditions, detailed terrain information as well as direct siting can also be based on LANDSAT images.

The image analysis usually has to be followed by a limited field check.

Visual Contra Digital Analysis

Visual inspection and analysis of LANDSAT MSS images is a rapid and reliable method of making an inventory. For this type of regional study of six different terrain elements, computerized handling of digital data can hardly compete with the human eye and brain. In many situations, however, a digital preprocessing of the images can be most valuable, increasing the quality and efficiency of the visual study.

In our opinion, the advantage of visual inspection of images for this type of study will be still more evident with the introduction of high resolution systems like the Thematic Mapper on LANDSAT 4 and 5 and the 1985 SPOT satellite. It may be assumed that data handling costs will rise drastically with the rapidly increasing number of picture elements to be handled.

Access to Images

The selection of images for this type of regional study is of the utmost importance. The various terrain features appear more or less clearly in the images depending on the season.

There is rather good coverage of Ethiopia from LANDSAT 1-3 during the period 1972 - 1982. LANDSAT 4-5 (since 1982) have limited storage capacity on board, and only few scenes are recorded outside the area covered from the ground receiving stations. As Ethiopia, as well as other parts of eastern Africa, is not reached from any operating ground receiving station, very few scenes are available after 1982.

To benefit from the dynamic evolution of satellite remote sensing, it is essential for many African countries that a well equipped receiving and data handling centre be established in eastern Africa.

Geometric Quality

The geometric quality of standard corrected LANDSAT MSS images has shown to be extraordinarily good for the images used in this project. The observed, judged mean discrepancy between the position of details in the base map (scale 1:250 000) and the images is 200 - 400 m measured on the ground.

The bitemporal, stereoscopic vision was usually undisturbed by vertical parallaxes, and when such occurred, they were of the magnitude of 2-5 pixels.

One drawback with the LANDSAT images is the impossibility of three-dimensional viewing. One is fully dependent on a correct topographic map for determination of heights, slopes, etc.

6.2 COST ANALYSIS

The cost of the various steps of the project can be given with good reliability. However, the cost of a corresponding project based on aerial-photo interpretation has to be an estimate of the time needed and the subsequent costs incurred (see Table 2, Cost Comparison between LANDSAT and Aerial-Photo Interpretation).

To elucidate the effect of the size of the area studied, an estimate of the costs for mapping, describing, and evaluating a complete, geometrically corrected LANDSAT scene (app. 31 450 km^2) is also presented.

The analysis and description of the terrain elements, land units and the hydrogeological discussion can also be more profound, using detailed aerial photos to a scale of 1:50 000 compared to 1:1 000 000 for LANDSAT MSS images.

As the objective of this study has been to show the potentials of LANDSAT MSS material for a general, synoptic inventory of potential water resources of a region, the cost comparison of alternative methods has to be related to the LANDSAT level of information. Even if the observer can go into further detail in the aerial photos, we assume in the following discussion, the results (maps showing drainage conditions and land units as well as the evaluation of water resources and land-use potentials) to be of a quality equal to those based on LANDSAT studies.

Inventory Speed and Costs

The mapping of the six terrain elements essential for the hydrogeological evaluation has been performed at a rate of approximately 140 km^2/hour.

For a full, geometrically corrected LANDSAT MSS scene, the mapping rate can be increased to approximately 200 km^2/hour, as there is usually a limited degree of variation in the terrain.

The cost of images, mapping, analysis, and geohydrological evaluation for the project is less than 2 Birr/km^2 (1 US $) for the test area (5500 km^2). If a complete LANDSAT scene (31 450 km^2) were to have been studied, the cost would have decreased to well below 1 Birr/km^2. Thus there is a clearly documented scale advantage in a regional study based on LANDSAT images.

If the same project were to have been based on aerial-photo interpretation, the cost, it is estimated, would have been 50% higher for the test area and nearly three time as high for a full LANDSAT scene area.

Table 2 Cost Comparison between LANDSAT and Aerial-Photo Interpretation

Type of cost (Ethiopian Birr)[1]		LANDSAT Test area 5500 km^2	LANDSAT Full scene 31450 km^2	Aerial photos Test area 5500 km^2	Aerial photos Full scene 31450 km^2
1	Images or aerial photos	1250	1250	1000	5900
2	Extra prints, enlargements	500	700	500	700
3	Selection of images, ordering	750	750	500	750
4	Mapping of six terrain elements	2000	7800	6900	39300
5	Plotter, mapping instruments	300	1250	1100	6300
6	Subtotal	4800	11750	10000	52950
7	Cost Birr/km^2	0.91	0.41	1.91	1.78
8	Terrain analysis, description of drainage conditions, Land unit mapping	1800	4000	1800	4000
9	Hydrogeological evaluation	2400	6000	2400	6000
10	Subtotal	4200	10000	4200	10000
11	Cost Birr/km^2	0.76	0.32	0.76	0.32
12	Total cost	9000	21750	14200	62950
13	Cost excluding field inspection, drawing, and printing, Birr/km^2	1.63	0.69	2.58	2.00

1) Birr 1 = US $ 0.483 (June 1984)

Comments on the Cost Comparison between LANDSAT and Aerial-Photo Interpretation

The numbers below refer to Table 2

1 Two LANDSAT MSS transparencies, one from a dry and one from a wet season to a scale of 1:1 000 000, at a cost of Birr 625 each, have been used.

These images are compared to aerial photos in the form of paper prints to a scale of 1:50 000, with 60% stereo-overlap and 20% side-overlap. The effective stereoscopically covered area is approximately 40 km^2. 140 photos are needed to cover the test area and 790 photos to cover a full LANDSAT scene, at an estimated cost of Birr 7.50 each.

2 During the inventory, planning, and carrying-out of the field inspection, etc, colour enlargements and extra black and white prints are usually needed.

3 Fees are based on a rate of pay of 50 Birr/hour.

4 According to the experience from this project, the time needed for mapping and compilation of the drainage condition map and the land unit map of the test area (5500 km^2) is approximately 40 hours, i.e. 140 km^2/hour. With the area increased to a full LANDSAT scene, the mapping can be more effective and is estimated to proceed at a rate of 200 km^2/hour.

With aerial photographs considerable time is spent on handling the photos and arranging them in the mapping instrument or stereo viewer. It is unlikely that more than one stereomodel can be treated per hour, which means an inventory and mapping rate of 40 km^2/hour.

5 The inventory and mapping from the LANDSAT images is best performed in an ordinary stereoplotter of the Wild A8 or B8 type or a Kern PG2. The instrument cost is approximately 8 Birr/hour.

An inventory based on aerial photos in a simple instrument faces problems with the transfer of information from the viewing facilities to the base map. The most reliable method is to use the same type of plotting instrument as mentioned above, but simpler equipment may also be used (for example Bausch & Lomb Zoom transfer scope, Zeiss Jena Kartoflex, etc.).

The lack of good reference points may cause problems in addition to the transfer itself. Even if the cost per hour is lower for a simpler instrument, the transfer cost may be higher compared to a more sophisticated stereoplotter.

In the calculation, an instrument cost of 8 Birr/hour has also been used for the aerial-photo analysis.

7 The cost per unit area decreases rapidly when a full LANDSAT scene is studied, compared to a minor part of it. According to our estimate, the full-scene-cost/km^2 is less than half of that for the test area, which covers less than 20% of a full scene.

This scale advantage is not present when it comes to the corresponding aerial-photo inventory method.

A comparison between a LANDSAT-based inventory and the same aerial-photo study is clearly in favour of the former method. The mapping cost for the test area is approximately 1 Birr/km^2 when LANDSAT images are used and 2 Birr/km^2 if aerial photos had been used. The same cost relation for a full scene is approximately 1:4, (0.41 Birr/km^2 to 1.78 Birr/km^2).

8 The terrain analysis involves a delineation and description of catchment areas and land units of the region. The effective time needed for this work was 36 hours, i.e. almost the same time as for the mapping.

Due to a limited degree of variation in the terrain, the corresponding time needed for the full scene does not follow the increase in area, but is estimated to be approximately 80 hours.

36 hours and 80 hours respectively have been assumed to be required totals for the corresponding analysis of the aerial-photo inventory.

9 The hydrogeological evaluation of the test area requires approximately 48 hours. It is estimated that 120 hours are required for the corresponding evaluation of a full LANDSAT scene.

The same figures are used for the evaluation of the aerial-photo inventory.

11 As for the interpretation and mapping phase of the project, there is also a similar and very evident scale advantage during the analysis and evaluation phases.

The cost per unit area decreases to approximately 40% of that of the test area cost when a full scene is treated.

13 Costs for field inspection, travel, drawing, printing, etc. are not included in the total costs presented, as, to a great extent, these factors usually vary from project to project.

The basic inventory, mapping, analysis, and evaluation is usually less variable implying that these cost estimates can be used as more reliable indications of the costs for this type of water resources study.

The approximate cost of a study of the present type, based on a visual interpretation of LANDSAT MSS images, varies between 1 and 2 Birr/km^2, with the lower figure for a full scene study and the higher cost for the test area study.

Compared to aerial-photo interpretation, the use of LANDSAT images reduces the cost to a half or a third of the full-scene study. For the test area size, the gain with LANDSAT is more limited, with a cost reduction of approximately 50%.

6.3 APPLICABILITY OF REMOTE SENSING FOR WATER RESOURCES DEVELOPMENT IN ETHIOPIA

National Level

For the planning of a nation's economy it is essential that the water resources and the land-use potentials are known. Remote sensing techniques could undoubtedly be a quick and cost-effective method of obtaining such information on a national level.

This study has proven that satellite image analysis is a useful tool for water resources assessment and planning. The method discussed in this report, visual interpretation and mapping from LANDSAT colour transparencies, is simple to apply and is especially suitable for a country like Ethiopia, with distinct dry and wet seasons.

In order to establish a realistic approach to a water resources inventory on a national level, we suggest that certain regions or areas of the country, be given priority. In these areas inventories could be carried out along the lines presented in this report. As the method to a great extent relies upon existing facilities we suggest that the project be carried out in collaboration with the Ethiopian Mapping Agency in Addis Abeba.

Initially, training and map production could be a cooperative effort between the Ethiopian staff and the Swedish Consultant. When the programme is running the consultant's contribution can be reduced.

Regional Level

The study has shown that there are great benefits to be gained from remote sensing techniques on a regional level as well. We therefore suggest that satellite image analysis be added to the routines for water exploration and siting at the regional offices of the National Water Resources Commission. For these applications it is necessary to acquire relevant satellite images, to select and install adequate viewing instruments and to organize the training of personnel.

Today the most useful satellite images are positive film transparencies of LANDSAT False Colour Composites from both wet and dry seasons. In 1985 the French-Swedish SPOT satellite will be launched. There is good reason to believe that the information content of SPOT images will allow more profound and qualified analysis, than that possible with the LANDSAT material.

It may be mentioned that Swedish institutions and companies will have an easy access to SPOT data, since Sweden is jointly financing the project.

As regards instrument quipment we suggest, at least to begin with, that ordinary mirror stereoscopes (or eqvuivalent) are used. Many regional offices are already equipped with these instruments and they are not very expensive to acquire.

Today there is, however, a rapid development of simple imgage interpretation equipments in the world. It is essential to follow and evaluate this development to find the most suitable and efficient equipment for the regional offices.

The training of personnel to use satellite image analysis on a regional and even local level is best performed at the regional offices, where the training can be adapted to regional-local conditions. It is essential that several officers at each office take part in the training, as will this hopefully speed up the acceptance of the method and allow a continuity of its use in the future.

Availability of Satellite Images

Unfortunately, there is yet no ground receiving station for LANDSAT and other satellite systems in eastern Africa. Since the registrations on LANDSAT 4 and 5 cannot usually be stored on a tape recorder on-board the satellite, data can only be obtained if they are directly transmitted to a ground receiving station. Thus, Ethiopia can only obtain data from earlier LANDSAT satellites. This is a clear disadvantage especially when studying dynamic processes like drought effects, land degradation, changes in vegetation, landuse, etc.

A ground receiving station, which will also cover Ethiopia, may be established in Kenya. In 1985, it will be possible for Ethiopia to receive data from the SPOT satellite (and also order special registrations) from the two receiving stations in Sweden and France.

We suggest that the potentials of SPOT images be studied, as soon as registrations are available in 1985. The practical and technical problems involved in ordering special registrations over areas of interest in Ethiopia should also be looked into.

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8 APPENDICES

DRAINAGE PATTERNS AND DRAINAGE CONDITIONS OF THE DIRE DAWA AREA AS DEPICTED FROM LANDSAT IMAGES

The main direction of flow is northwards, concordant with the general slope. The large area of basalt in the Rift floor blocks the flow towards north in the western part of the area, diverting the streams towards the east or west. Most streams are ephemeral.

There are five main drainage areas identified in the images. These areas are divided into a number of subareas that show specific characteristics and are delineated in Map 1. The following section contains a short description of each subarea. All information given is based on visual inspection of the LANDSAT images.

Description of subareas

1a

Short, parallel stream channels have cut into the escarpment and a faint system of dendritic character can be traced in the foothill area. The tone and texture give reason to expect a much denser drainage network in the foothill area than that directly revealed by the satellite images. Sand rivers can be found in parts of the alluvial slope.

1b

This is a parallel or subparallel, tectonically adjusted system with definite angularity in general terms as well as in detail. There are few tributaries joining the main stream. Mainly sand rivers can be observed. In the northern, lower part of the area, the westernmost stream branches on a flood plain and cannot be followed further in the images. Some sections show meandering tendencies without developing distinct meandering forms. This implies rock control of incised meanders in rather narrow, asymmetrical valleys. Minor areas of dry-season vegetation show up in some channel sections. The extensive flood plains in the lower part of the area are covered by dense, dry-season vegetation.

1c

Parallel major streams flow in an east-west direction, with frequent, parallel and usually short tributaries. Sand river sections may be present but cannot be observed reliably in the images. Limited flood plains are indicated by areas of vegetation (possibly irrigated areas).

1d

Very few and faint stream channels can be observed.

1e

Several short, parallel stream channels have cut into the escarpment slope. Few larger stream channels can be observed, especially upstream of the railway. Frequent, smaller drainage paths can be expected. Observable streams are arranged in a parallel system, concordant with the general slope, until distinctly diverted towards the northeast, blocked by lava Area 3:1. The tone and texture indicate a dense drainage network and intensive land erosion. There is presumably an extensive, irrigated area along the railway.

1f

Ephemeral streams of different character concentrate into one major sand river.

1g

Widely spaced bending streams are found in a subparallel pattern with few tributaries.

1h

The main river branches over a wide fan area, where most of the drainage paths cease or can be observed only occasionally. Overland flow occurs during flood periods. Green vegetation can be observed in areas of limited groundwater outflow.

2a

There are few major streams of parallel, non-sandy character, concordant with the general slope. Few tributaries are visible in the images. Flood plains or irrigated areas may be present where larger areas of vegetation are observed. The tone and texture indicate a considerably denser drainage pattern than that directly visible in the images. Much the same character as Area 1e.

2b
Subparallel, rock controlled pattern with three distinct directions N-S (general slope), NW-SE and NNE-SSW. Flood plains and sand rivers can be observed in the lower sections. Dry-season vegetation along several river sections may indicate perennial flow.

2c
The parallel system, concordant with the general slope, changes to the west of the mapped area, to a dense, pinnate pattern of minor streams joining the main stream. Larger areas of vegetation may be irrigated farming and plantation areas.

2d
Two major stream channels are incised into the basalt. The southern one has meandering tendencies, while the one to the north is more angular, with several tributaries joining mainly from the north, at almost right angles. Sectional sand river character. Dry-season vegetation is common in the main valleys.

2e
This dense network of faint stream paths, sometimes in a braided pattern, concentrates into some few major streams flowing north to north-east. Flooding, with overland flow, occurs.

3a
Bending, rather widely spaced parallel pattern, with distinct subparallel tributaries mainly joining from the west. No signs of vegetation.

3b
Subparallel to radial pattern of distinct stream channels, usually of sand river character at their lower sections. Very few tributaries are visible in the images. No vegetation can be observed in the area.

3c

This radial pattern has a dense system of straight, distinct channels. There are slight signs of a collector stream along the eastern periphery.

3d

Faint disintegrating channels are found in the central area, the streams are more distinct at the western and eastern margins. Infiltration and recharge of surface water occurs as well as occasional flooding. In lower sections of the area, groundwater outflow may take place as indicated by areas of vegetation.

4a

Only few distinct channels are visible.

4b

This medium to finely textured, parallel pattern has distinct rectangular features in the eastern part of the area. The main direction is NW-SE. Sand river sections occur in the lower part of the area. Large areas of dry-season vegetation are possibly irrigated.

4c

Distinctly rock-controlled pattern, with channels in three directions. The main direction of streams is NW-SE and tributaries join from the east (direction E-W) and from the south (direction S-N).

4d

Some few parallel major channels are found in the lower parts of the area. Few visible tributaries may indicate infiltration into alluvial deposits. The upper parts of the drainage system seem to be rock-controlled, with few distinct channels. Here, vegetation fed by springs may be observed.

4e

Several major streams spread over alluvial fans, rejoining in one major channel further downstream. Infiltration and flooding take place, as well as groundwater outflow in the lower sections.

5a

A mainly rock-controlled pattern with NE-SW directions repeated in several channels. The drainage pattern is presumably dense in certain parts, where the system shows up faintly in the images. Wide areas of dry-season vegetation may be found in the main valleys.

5b

A major sand river, fed by several rock-controlled tributaries. Extensive flood plains with dense vegetation occur in lower sections.

5c

Fan area, with the main stream branching into several disintegrating stream systems. Infiltration and flooding occur. A distinct parallel pattern, together with areas of dense vegetation, can be seen in the eastern part of the area.

LANDSAT INVENTORY OF GEOLOGY, LANDFORMS AND LINEAMENTS IN THE DIRE DAWA AREA

Description of land units (Map 2)

1:1

Plateau with level or slightly sloping ground. Moderately - slightly eroded. Shallow overburden of loose deposits. Poorly drained in parts.

1:2

Fault scarps (escarpment) with steep slopes. Very shallow or no loose deposits. Strongly eroded.

1:3

Slightly sloping area, with rock outcrops, colluvial and alluvial deposits, moderately eroded. The tone and texture indicate a considerably denser drainage networks than that directly visible. Sand rivers, fed from re-worked alluvial deposits, are distinct in the images. Streams are often bending, or main tributaries are joining, when the major stream enters an area of rock (Area 1:4), indicating a change in threshold level since the alluvium was deposited.

1:4

Hilly area of sedimentary rocks, dissected by valleys running mainly in the N-S and E-W directions and filled by alluvial sediments. The E-W valleys curve slightly. Indistinct lineaments run at approx. 340^{o}, mainly in the eastern part of the area. The rocks in the area may dip towards the west, mainly in the eastern part, as shown by river directions. Ingrown meanders in asymmetrical valleys have been developed by the westernmost streams. The streams of the area are sand rivers with minor flood plains. The hills are strongly eroded.

1:5

Hilly area of sedimentary rocks with dominating, slightly curving valleys running E-W. Valleys appear with the same spacing as within Area 1:4. Lineaments show the same frequency and direction as in Area 1:4. The hills are strongly eroded. Strong-moderate land erosion in the valleys.

1:6

Slightly sloping sediment transportation area, with sand rivers and extensive flood plains containing braided stream channels. Few, small rock outcrops may cause the changes in direction of the sand rivers. Downstream of the main flood plain section, several river channels join to form one major channel. Undisturbed meandering occurs for a short distance. The curved scar in the basalt area 3:4 may be caused by fluvial erosion, indicating a lowering of the threshold level in the narrow pass downstream.

2:1

Mountainous area of presumably metamorphic or igneous types of rock, with distinct valleys, probably due to faulting parallel to the general direction of the escarpment. Another, not so distinct, system of minor valleys can be identified between North and 20^{o}. Some permanent streams draining into the Rift are well adjusted to the latter system.

2:2

A moderately-gently sloping area, covered with rather shallow loose deposits, contains outcrops, presumably basaltic rocks, and minor hills. Sedimentary rocks, from Area 1:4 are affecting the easternmost part of the area. The tone and texture indicate that land erosion takes place in the whole area, but seems to be most active on the lower side of the railway. This part is slightly sloping with rather deep loose deposits.

2:3

Steep to moderate slopes close to area 2:1, with more gently slopes in the downstream sections. Extensive rock-controlled areas with only shallow alluvial or colluvial deposits. Moderate erosion takes place in the upper parts, but is more frequent in the lower areas (especially downstream of the railway). The increase in land erosion seems to take place along a straight zone, roughly parallel to the main direction of the tectonic features of Area 2:1. The transition may be caused by a change in levels along a fault line. Limited flood plains can be expected along the more or less permanent main streams.

3:1

Low, basaltic sheet trenched by widely spaced stream valleys, little affected by tectonic movements as only few signs of faulting or fracturing can be observed in the images. The major valleys in the eastern part of the area make a distinct bend along a straight line connecting the northern rhyolite border of Area 3:2 with a straight drainage path in Area 3:4. The line is almost parallel to the straight fault-line separating Areas 4:1 and 4:2. The change in stream direction may be indicative of a change in levels along a fault-line in the substratum. While there are hardly no alluvial deposits in the valleys of the eastern part, there is more valley fill in the west, due to transport from Areas 2:2 and 2:3. Two minor basaltic hills with colluvial fringes occur outside the main lava area. The bigger one, to the south, has a mesa character, with a flat upper surface and sides, and colluvial deposits cut by short, straight stream channels.

3:2

Two rhyolite domes, heavily dissected by stream erosion and gullying, leaving a dense network of sharp planezes. There are sections of short-transported alluvium and colluvium at the fringes. The easternmost part of the largest dome has a darker appearance than the rest, presumably due to different mineral composition. The outwash from the area shows the same characteristics. As there are few distinct stream channels leaving the area in a northerly direction, infiltration of water is high, possibly due to a faulted or fractured substratum.

3:3

Elongated (WNW-ESE), low sheet of dark lava outflow with few distinct valleys and only shallow loose deposits.

3:4

Low, young basaltic outflow area, earlier connected to Area 3:1, coarsely trenched by stream channels. Few or no direct signs of faulting or other tectonic movements were observed. However, see the description of Area 3:1 concerning faulting of the substratum. Only very shallow, loose deposits can be seen in the area. The connection with Area 3:1 has been cut off by fluvial erosion in Area 1:6. Traces of an erosion cliff can be seen in the southern part of the area.

4:1

Low, hilly area of presumably basaltic rock with a very shallow overburden of loose deposits. To the west, limited outwash areas are found. Between the strongly eroded hills, shallow alluvial deposits occur. Distinct tectonic lines on a bearing of app. 340° (the same direction as in Areas 1:4 and 1:5) are visible. There is also a marked and narrow transition zone from nearly bare rock in Area 4:1 to ground with loose deposits in Area 4:2. The directions of the lineaments of this zone are app. 60° and 100°.

4:2

Slightly sloping area, with a shallow overburden of alluvial deposits surrounding outcropping basalt arranged parallel to the direction of lineament of the Areas 1:4, 1:5 and 4:1, app. 340°. Especially in the central part of the area, the drainage is strictly rock-controlled with directions of app. 20° and 100°. In the easternmost part, there is a low lying transportation area of slightly sloping alluvial deposits surrounding outcropping basalt. Sediments are fed from neighbouring areas and are deposited temporary. A low cliff, due to faulting, is found in the southern part (transition to Area 4:1). Sand river sections and limited flood plains occur.

4:3

Low ridge of faulted or fractured basalt blocking drainage from the upstream area. The direction of lineament is app. 100°. Four or five tectonically adjusted gorges have developed where the streams enter the area. At the points of entry, there are reasons for expecting rock thresholds.

5:1

Mountainous area built of presumably metamorphic or igneous rock. The drainage pattern is tectonically affected and runs, together with several lineaments, in a main direction of app. 340°. Alluvial pockets are found, now being reworked as in the neighbouring Areas 1:3 and 1:4, due to change in threshold levels. Flood plains, possibly irrigated, can be observed. The dense drainage pattern on many hillsides indicates a low infiltration capacity; so does the land and fluvial erosion indicated by the light, speckled tones in the valleys. The general character of the valleys can be expected to be much the same as in Area 1:3. But only few signs of sand river transport have been observed.

5:2

Low, rather flat basaltic sheet with few and limited traces of loose deposits. Highly eroded surface. The sand river leaves the area to the north. Rivers widen and develop flood plains when entering from Area 5:1.

5:3

To the west, there is a low, rather flat, basaltic area with very limited pockets of loose material. The rock surface is highly eroded. To the east, there is a slightly sloping erosion surface with few, small rock outcrops. Sand river channels enter the area, forming a wide, sandy surface with a braided channel system and flood plains, possibly irrigated. Rock thresholds may be assumed to exist where the stream enters Area 4:3. Where Area 5:3 meets 4:1, some rather wide dry-season green areas can be observed. They are probably minor flood plains, but may also be areas of vegetation fed by springs. The low cliff running at a bearing of app. 60^{o} seems to continue into the western part of Area 5:3. Otherwise, few lineaments can be observed.

6:1

Several major ephemeral streams deposit large sediment loads on a complex of well developed alluvial fans (bajada area). Undulating terrain with seasonally flooded areas where fine, dark sediments can settle. There are generally darker tones in the eastern part of the area due to the basaltic parent rock. Light ridge-like features are common all over the depositional Area of 6:1-3. They are probably caused by dry grass growing in strips perpendicular to the direction of the overland flow during periods of flooding. Outflow of groundwater occurs in depressions allowing vegetation to establish itself and survive. Temporary salty marshes and pans (playas) may develop during periods of flooding.

6:2

Complex of weakly developed alluvial fans or outwash plains. Few distinct streams from the rocky Area 3:1 and 3:2 can be observed. This is possibly due to high infiltration in the area where faulting in the substratum may have taken place (see the description of Area 3:1). Some very bright tones on the bajada may be due to deflation or salt deposition on the surface in connection with flooding and evaporation.

6:3

Slightly sloping or flat alluvial plain, with fine, dark sediments in low, seasonally flooded areas. Light, subparallel ridge-like features in the LANDSAT images are probably dry grass as described in Area 6:1. The main stream channels do not branch out.

IMAGE ORIENTATION FOR BITEMPORAL STEREOSCOPIC ANALYSIS AND MAPPING FROM LANDSAT IMAGES IN ANALOGUE PLOTTERS

1 Indicate the centre line of one of the images by marks in the frame. Superimpose the other image to make the best possible fit, using details, and transfer the centre line.

2 Place the images in the projectors of the instrument so that the centre lines coincide with the photo base indicated by crosses or lines on the plate holders. No centring of the images on the centre crosses is needed. In order to be viewed stereoscopically, the images must usually be placed closer than for conventional aerial photographs.

To obtain optimal viewing conditions, shadows from terrain features should fall towards the viewer.

If the centre points of the left and right images do not coincide, i.e. they are not registered exactly along the same track, the images should be placed in the same left-and-right manner as for aerial photographs with conventional stereo-overlap.

3 Set the tilt (phi and omega) and swing (kappa) of each projector as well as the model tilt (common phi) to zero.

4 Set the principal distance (c; any) and adjust the z-column value (z) of the instrument in the correct c:z ratio. A ratio of 1:2 will give a model scale of 1:500 00, with images to a scale of 1:1 000 000.

5 Set the photo base until the images can be viewed stereoscopically. If this is not possible with the base distance available, displace one of the images parallel to the photo base until both images coincide.

6 Obtain optimal stereoscopic viewing in the area around the central cross of each image holder by turning the kappa wheel of the opposite projector. Adjust the base until the floating dot is on or slightly above the ground. Minor residual parallaxes may appear in the outer parts of the model and are eliminated as described in 9 below. Conventional relative orientation procedures cannot be applied as the images are not central projections of the ground.

7 Mount proper gears to obtain the required plotting scale. If the map scale is 1:250 000 and the model scale is 1:500 000, use gears 1:2.

8 Adjust the map on the plotting table according to the images. Check three or four control points found in the map as well as in the image from which the plotting is done. If necessary, adjust the scale by changing the z-value until the best possible fit on the control points is achieved. The z-value must not be changed during mapping as this will change the map scale. Clamp the z-column. Some adjustment of the model tilt may be needed (common phi and/or omega).

Adjust the base until the floating dot is close to the ground. Adjust the map according to the plotting image.

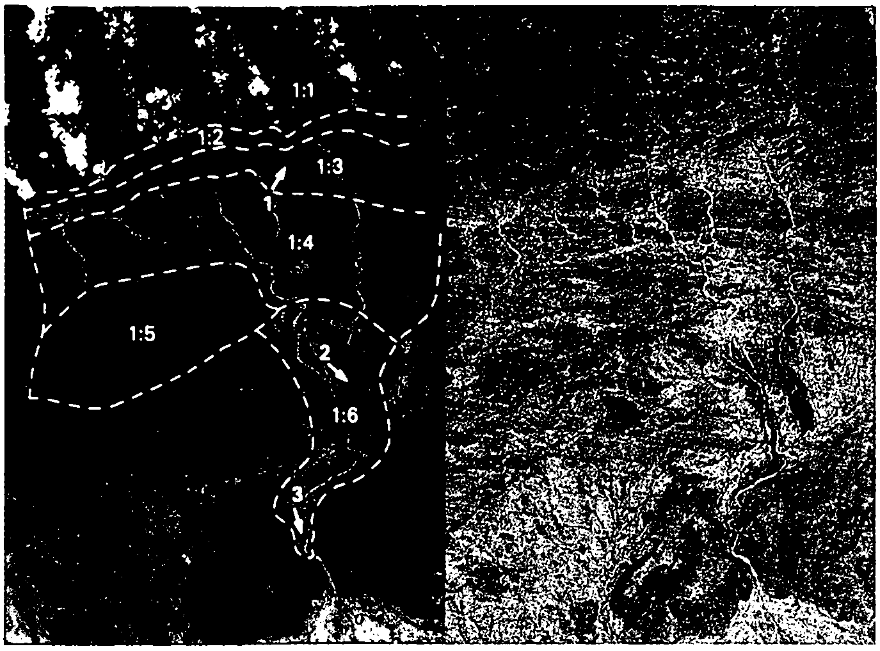
9 Plotting is always done from one and the same image. If the stereoscopic view is disturbed by vertical parallax, eliminate these using the omega adjustment (or if available b-y) of the other projector.

9 MAPS AND PHOTOS

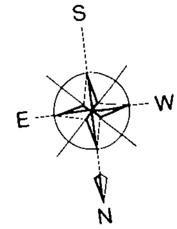
Note: The wet and dry season satellite images of Areas 1-6 are stereo-mounted and should preferably be viewed by using a lens stereoscope.

Alluvial slope — sand rivers Area 1

Wet season **Dry season**



33 km



1 → Photo number and directic

Physiography

1:1
Plateau with shallow overburden of loose deposits. Moderate or slight erosion damage.

1:2
Escarpment with steep slopes and short, parallel streams. Very shallow or no loose deposits. Strongly eroded.

1:3
Moderately eroded, reworked alluvial and colluvial deposits. Faint dendritic drainage pattern. Start of several major sand rivers.

1:4
Hilly area of eroded sedimentary rocks, with E-W and N-S valleys filled with alluvial material. Parallel or subparallel, tectonically modified drainage. Few tributaries. There are ingrown meanders in asymmetrical valleys and minor flood plains with areas of vegetation (possibly irrigated).

1:5
The strongly eroded hilly area of sedimentary rocks has slightly curving E-W valleys. Limited sand river sections and minor flood plains with vegetation. Strong to moderate land erosion in the valleys.

1:6
This is a sediment transportation area, with sand rivers and extensive flood plains containing braided channels. Small rock outcrops may affect stream courses. Signs of fluvial erosion are found in basalt area 3:4. There are wide areas of dry-season vegetation.

Water availability

1:1
The potential for shallow groundwater lies in depressions. In many places surface water could be stored in dams and ponds. Drilling for deep groundwater is not advisable because of the proximity to the Rift Valley escarpment.

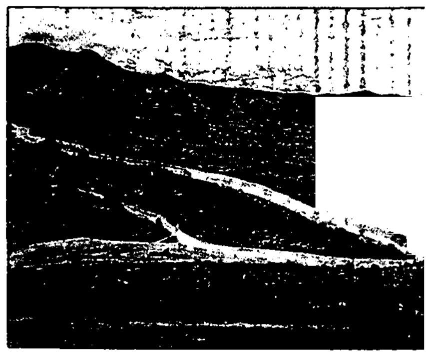
1:2
This is an outflow area characterized by the presence of springs at the foot of the escarpment.

1:3
Shallow groundwater is present in wadis and associated alluvial deposits. Suitable areas for development are upstream of the thresholds or narrow passages where the sand rivers enter area 1:4. Groundwater could be abstracted using shallow wells and groundwater dams. The area seems to consist of basement rocks, indicating only limited possibilities for deep drilling.

1:4
The valleys contain alluvial deposits and are suitable for development of shallow groundwater through wells and construction of groundwater dams. Bedrock consists of sedimentary rocks. Potential sites for deep drilling are at intersections of fault and fracture zones.

1:5
The potential for shallow groundwater lies in two extensive areas of alluvial fill. Rugged terrain restricts deep drilling, which would otherwise have a medium potential. There is probably some potential in the construction of groundwater dams.

1:6
There is a very high potential for shallow to medium groundwater development from alluvial aquifers and underlying sedimentary rocks.



1 Alluvial slopes with sand rivers. The R. Valley escarpment in the background.

2 Flood plain with dry-season vegetatic

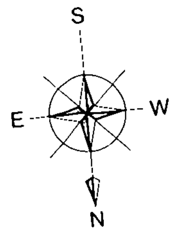
3 Outflow of groundwater in a sand river.

Eroded foothill area

Area 2

Wet season **Dry season**

58 km



1→ Photo number and directio

Physiography

2:1
Mountainous area of metamorphic or igneous rocks with distinct valleys due to faulting parallel to the escarpment. Another tectonic system runs at a bearing of 20°. Perennial or almost perennial streams fed by springs.

2:2
Sloping foothill area with eroded, shallow, overburden, outcropping of mainly basaltic rocks, and minor hills. The main erosion is most active on the lower side of the railway, where loose deposits are deeper and the drainage pattern dense. Irrigated farmland stretches along the railway.

2:3
The upper part is a sloping foothill area of mainly basaltic rocks covered by loose deposits. Almost parallel drainage in three main directions (N-S, NW-SE and NNE-SSW). Downhill of a faint zone parallel to the major escarpment direction, sediments are deeper and erosion is more intense. Sand rivers with vegetation may indicate perennial flow. A dense pinnate pattern of minor streams has developed to the west. Irrigated farmland stretches along the railway.

Water availability

2:1
Springs and seepages may occur in valleys near the escarpment. In other parts storing of surface water in dams and ponds has the greatest potential.

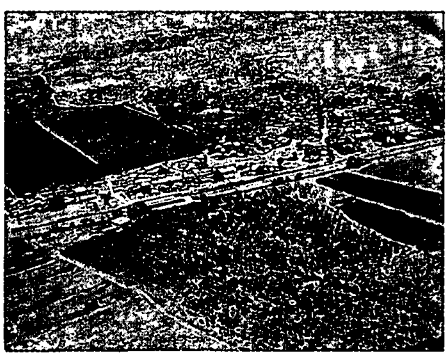
2:2
Perennial springs appear at the foot of the escarpment. Groundwater could be developed by shallow wells in some parts, and through deep drilling. At some places groundwater dams are an alternative.

2:3 Same as 2:2.
Perennial springs appear at the foot of the escarpment. Groundwater could be developed by shallow wells in some parts, and through deep drilling. At some places groundwater dams are an alternative.

1 Settlement in a highly eroded area.

2 Stock watering from wells dug in a san river.

3 Badlands with basalt plateau in the background.



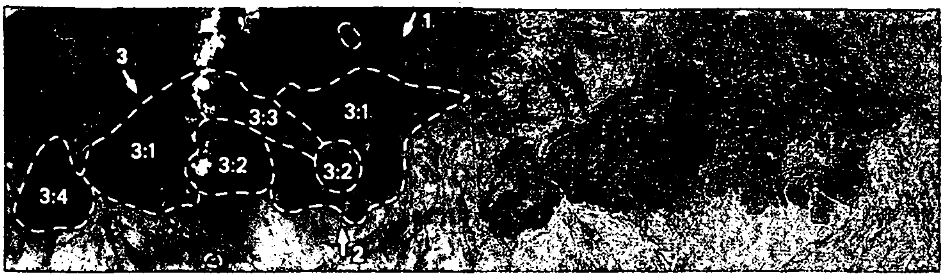
4 Irrigated farmland and orchards.

5 Spring-fed stream used for irrigation.

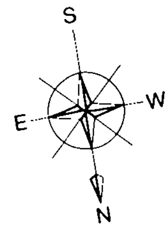
Young volcanic outcrops

Area 3

Wet season **Dry season**



62 km



1→ Photo number and directic

Physiography

3:1
Low, basaltic sheet with parallel to radial, widely distributed valleys, with few or no signs of tectonic movement and only limited alluvial deposits. Two major, incised sand river valleys, one meandering and one with more angular characteristics, are located to the SW. Minor basaltic hills occur outside the main area.

3:2
Two rhyolite domes, heavily dissected by radial streams. The eastern part is of darker appearance than the rest. There is a fringe of colluvium and alluvium at the base.

3:3
Elongated (WNW-ESE), low sheet of dark lava outflow, with few distinct valleys and only shallow loose deposits.

3:4
Low, unfaulted basaltic sheet that was earlier connected to area 3:1. There are few or no effects of faulting, and only shallow, loose deposits in widely spaced valleys. Signs of earlier fluvial erosion are present in the southern part.

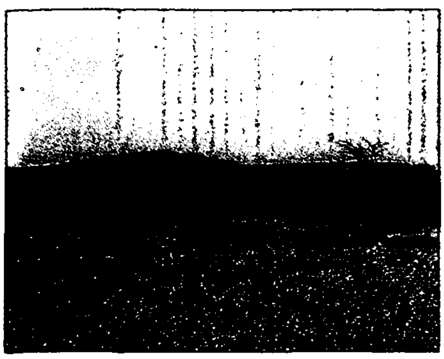
Water availability

3:1
Possibilities for groundwater development in incised valleys with sand rivers. Otherwise rugged topography inhibits water development.

3:2
Volcanic rock (rhyolite) with dense drainage network, indicating low groundwater recharge and high surface runoff. No potential for groundwater development.

3:3
Area with two major sand rivers. The rest of the area contains valleys with shallow alluvial sediments. There is potential for shallow well development and groundwater dams in the area.

3:4
Outcropping rocks with no soil cover. Drilling for deep groundwater is the only possibility for a water supply in the area. However, the accessibility is very poor.



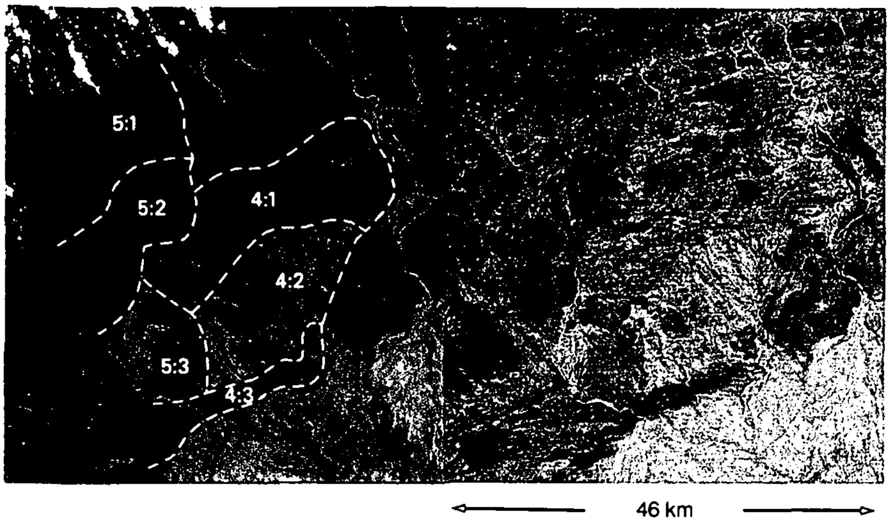
1 Basalt plateau and rhyolite dome. Stony erosion pavement in the foreground.

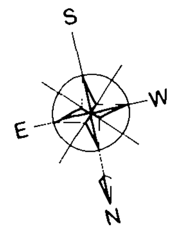
2 Rhyolite dome with dense drainage network indicating high surface runoff.

3 Young basalt plateau and flood plain wi riverine vegetation.

Faulted volcanic outcrops — Area 4
Alluvial pockets — sand rivers — Area 5

Wet season **Dry season**





Physiography

4:1
Highly eroded, hilly area of basaltic rock, with very shallow overburden of loose deposits and distinct tectonic lineaments on a bearing of app. 340° (major lineaments) and others, less distinct, on bearings of app. 60° and 100°.

4:2
Shallow overburden of alluvial deposits on outcropping basalt. Finely textured, subparallel pattern with distinct, rectangular features. Three main directions: NS-SE, NNE-SSW and E-W. To the south there is a low fault cliff. The northern part contains sand river sections and limited flood plains.

4:3
Low ridge of faulted basalt, with a main lineament bearing of app. 100°, blocking drainage of areas 4:1 and 4:2. Several tectonically modified gorges have developed.

5:1
Mountainous area of metamorphic or igneous rock. The main tectonic bearing is app. 340°. Reworked alluvium in valley pockets feeds into sand rivers and flood plains. The drainage in valleys is dense.

5:2
Low, young sheet of highly eroded lava covering tectonic lineaments passing through the area. Flood plains and sand rivers can be expected along main river channels.

5:3
Low, highly eroded basaltic area with limited pockets of loose deposits. Wide sand rivers and flood plains fed from several rock-controlled tributaries. A low fault cliff on a bearing of app. 60° enters from areas 4:1 and 4:2. Vegetation is fed from springs in the upper part.

Water availability

4:1
Hilly area with shallow pockets of alluvial sediments in the western part, with some potential for groundwater development through shallow wells. Springs are found in the border zone with areas 4:2 and 5:3.

4:2
High potential for groundwater development in alluvial sediments. The central area contains rock outcrops where deep groundwater could be exploited.

4:3
Rocky area. There is a potential for groundwater development in the transition zone to 6:1.

5:1
Metamorphic or igneous rock. Groundwater to be found in valleys and some sand rivers. Extensive erosion. Various abstraction methods could be utilized, i.e. drilled wells, groundwater dams and shallow wells.

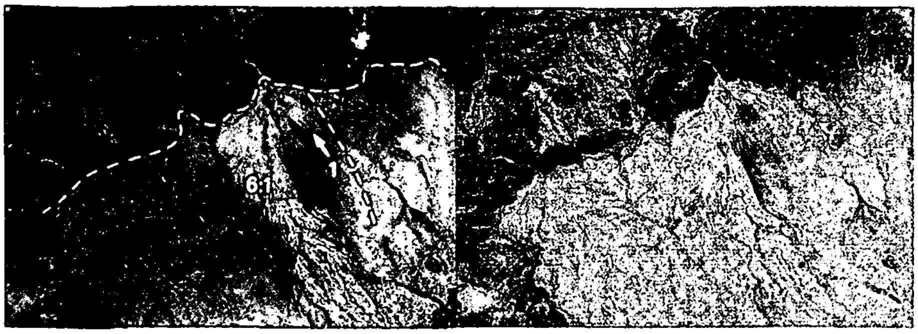
5:2
Basalt area with two large flood plains along two major drainage zones. Otherwise the area contains only small alluvial deposits. Deep drilling is the most feasible means for groundwater exploration.

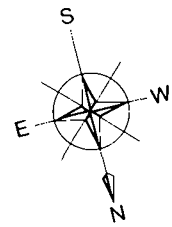
5:3
Sediments in the eastern part have a potential for shallow groundwater development.

Alluvial plain and fan complex — Area 6

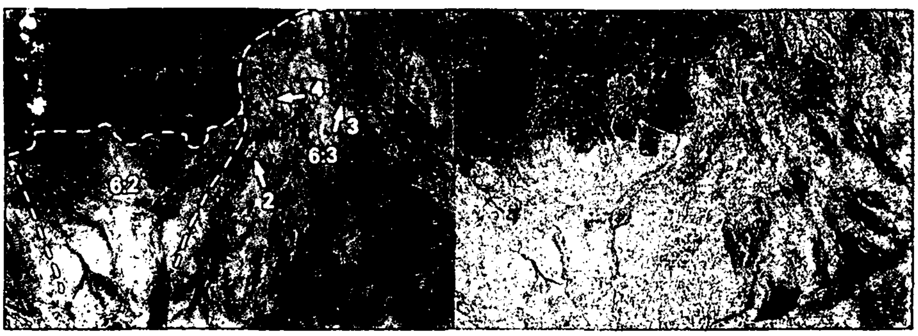
Wet season | **Dry season**

Area 6:1





Area 6:2, 6:3



60 km

1 ⟶ Photo number and directic

Physiography

6:1
Several major ephemeral streams deposit large sediment loads on a complex of alluvial fans (bajada area). Seasonal flooding occurs with settling of fine, dark sediments. In depressions, the outflow of groundwater permits vegetation to establish itself and survive. Temporary salty marshes and pans (playas) may develop during periods of flooding.

6:2
As area 6:1, but possibly with a higher infiltration capacity. Very bright tones may indicate superficial salt deposition.

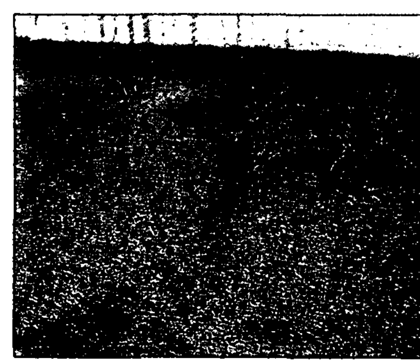
6:3
Mainly an alluvial plain with fine, dark sediments in low, seasonally flooded areas. A dense network of faint, partly braided streams joins to form a few major channels.

Water availability

6:1
Alluvial fan complex with some wadis. The area has high potential for groundwater development.

6:2
Alluvial fan — outwash. Outflow area with relatively high salinity in the groundwater.

6:3
Alluvial plain with definitive courses of rivers passing through the area. There is a potential for shallow wells and also surface water development, since the major rivers seem to flow during most of the year.



1 Occasionally flooded area on an alluvi fan with a faint channel system and cracked dark soil.

2 Alluvial plain with intense gully erosion along the sand river.

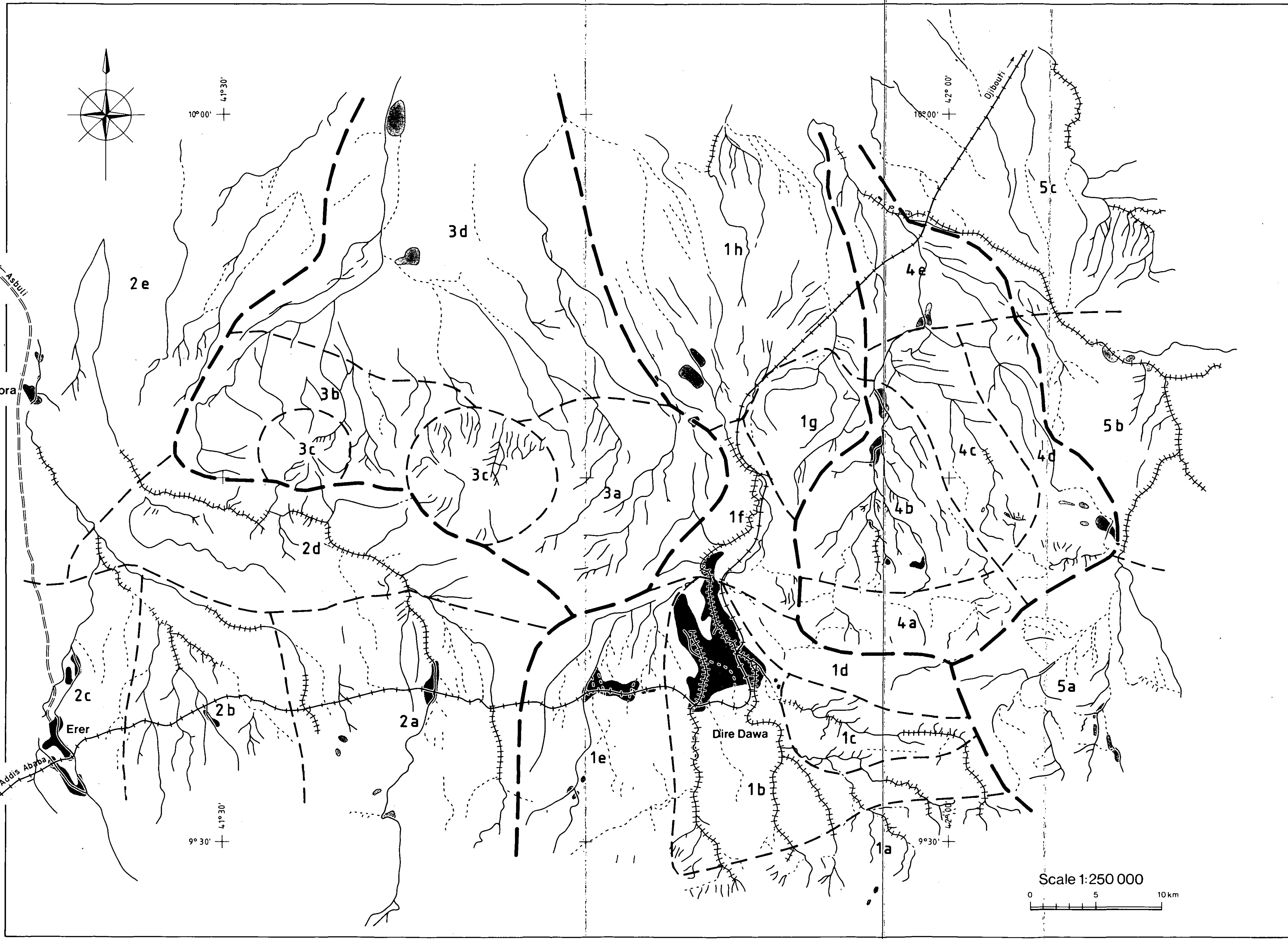
3 Spring-fed stream with light tones, indicating salt deposits.

4 Perennial stream with intensive bank er sion in alluvial deposits.

Map 1

DRAINAGE CONDITIONS IN THE DIRE DAWA AREA

Based on analysis of bitemporal LANDSAT images



1a
Short, parallel streams cut into the escarpment and a faint, dense dendritic system along the base. Sand rivers rise in the area.

1b
Parallel or subparallel tectonically modified system with few tributaries. Sand rivers show incised meandering characteristics. There are several minor, possibly irrigated, areas of vegetation. The lower part contains extensive flood plains with dry-season vegetation.

1c
Parallel major streams flow in the E-W direction, with frequent, short and parallel tributaries. Sand river sections and limited flood plains are covered by vegetation.

1d
Very few and faint stream channels can be observed.

1e
Short, parallel stream channels cut into the escarpment. Few visible larger, parallel streams concordant with the general slope. Downstream of the railway, the tone and texture indicate a dense drainage pattern and intensive land erosion. There may be extensive irrigation along the railway.

1f
Several ephemeral streams join to form one major, meandering sand river. Flood plains occur.

1g
This is a widely spaced, curving subparallel pattern with few tributaries. There are no signs of vegetation.

1h
The main river branches out over a wide fan area and disintegrates, due to infiltration into coarse sediments. Flooding occurs over vast areas. Dry-season vegetation indicates a groundwater outflow.

2a
There are a few main streams of parallel, non-sandy character. Few tributaries are visible, but the tone and texture indicate a dense drainage network. Large dry-season, green areas may be irrigated farmland.

2b
This subparallel, rock-controlled pattern has three main directions, N-S (general slope), NW-SE and NNE-SSW. Sand rivers are found in lower sections. Vegetation may indicate perennial flow.

2c
The parallel drainage is concordant with the general slope, but changes to the west into a dense, pinnate pattern of minor streams. Larger areas of vegetation may be irrigated farming and plantation areas.

2d
There are two major channels incised into basalt. The southern one shows meandering characteristics, while the northern one is more angular, with tributaries joining almost perpendicularly. The character of the area is that of a sand river. Dry-season vergetation is common in the main valleys.

2e
This is a dense network of small streams, sometimes braided, joining into some few major N-NE channels. Flooding occurs.

3a
This bending, widely spaced, parallel pattern contains distinct, subparallel tributaries joining mainly from the west. There are no signs of vegetation.

3b
This subparallel to radial, widely spaced pattern of distinct stream valleys is usually of sand river character in lower sections. There are few tributaries and no vegetation is visible.

3c
This radial pattern with a dense system of straight, distinct channels shows signs of a collector stream along the eastern periphery.

3d
Faint, disintegrating channels occur in the central area, while at the eastern and western edges the streams are more distinct and continuous. Flooding and infiltration occur. Groundwater outflow may take place as indicated by areas of vegetation.

4a
Few distinct and continuous channels are visible.

4b
A medium to fine textured, subparallel pattern, with distinct rectangular features in the eastern part of the area. Sand river sections occur to the north. Flood plains with areas of dry-season vegetation are irrigated.

4c
This pattern is rock-controlled and runs in three main directions, SE-NW (major stream) and E-W and S-N (tributaries).

4d
Parallel major channels are found in the northern, lower parts of the area. The small number of tributaries may indicate infiltration into alluvial deposits. The upper part of the drainage system is rock-controlled and the vegetation may by fed by springs.

4e
Major streams spread over alluvial fans and rejoin in one major channel further downstream. Flooding and infiltration occur as well as groundwater outflow in the lower sections.

5a
A pattern, mainly rock-controlled, with several channels running SW-NE. The tone and texture indicate dense drainage in valleys where wide areas of dry-season vegetation are also found.

5b
Major sand rivers here are fed by several rock-controlled tributaries. The lower sections contain extensive flood plains with dense vegetation. Areas of vegetation fed by springs are found in the upper, hilly part.

5c
This fan area contains a major channel which branches into several disintegrating stream systems. Flooding and infiltration occur. There is a very distinct, parallel pattern in the eastern part of the area.

LEGEND

- Road
- Railway
- Drainage path
- Drainage path (faint)
- Sand river
- Catchment area
- Catchment sub-area
- Dry-season vegetation
- Dry-season vegetation (scattered)

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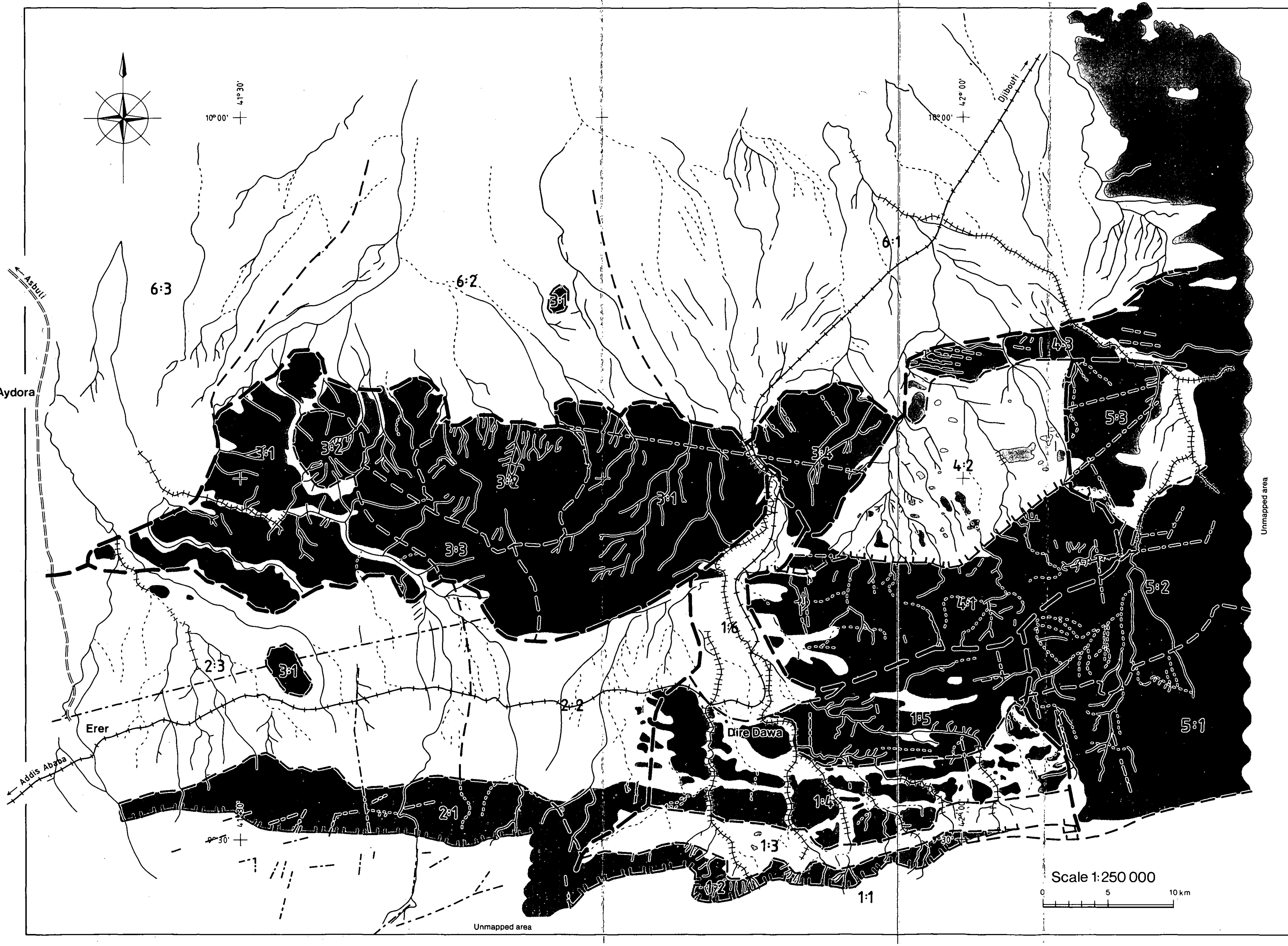
Map 2

LAND UNITS IN THE DIRE DAWA AREA

Based on geological, landform and lineament analysis of LANDSAT images



1:1
Plateau with shallow overburden of loose deposits. Moderate or slight erosion damage.

1:2
Escarpment with steep slopes. Very shallow or no loose deposits. Strongly eroded.

1:3
Moderatly eroded, reworked alluvial and colluvial deposits. The start of several major sand rivers.

1:4
Hilly area of eroded sedimentary rocks with E-W and N-S valleys filled with alluvial material. The E-W valleys curve slightly. Indistinct lineaments run at app. 340°. Ingrown meanders in asymmetrical valleys and minor flood plains occur in the western part.

1:5
Strongly eroded hilly area of sedimentary rocks have slightly curving E-W valleys. Strong to moderate land erosion has occurred in the valleys.

1:6
Sediment transportation area with sand rivers and extensive flood plains containing braided channels. Small rock outcrops may affect stream courses. Signs of fluvial erosion in basalt are found in area 3:4.

2:1
Mountainous area of metamorphic or igneous rocks, with distinct valleys due to faulting parallel to the escarpment and with another system running on a bearing of 20°.

2:2
Sloping foothill area with eroded, shallow overburden and outcropping rocks and minor hills. The main erosion is most active on the lower side of the railway, where the loose deposits are deeper.

2:3
The upper part is a sloping foothill area mainly in basaltic rocks covered by shallow loose deposits. On the downhill side *of a faint, light zone parallel to the major escarpment direction,* the sediments are deeper and erosion is more intensive.

3:1
Low, basaltic sheet with widely distributed stream valleys, with few or no signs of tectonic movement. Only limited alluvial deposits can be observed. *The change in stream direction in the* eastern part of the area may be indicative of a change in levels along a fault line in the substratum. Minor basaltic hills occur outside *the main area.*

3:2
Two rhyolite domes, heavily dissected by stream erosion. The eastern part is of darker appearance than the rest. A fringe of *colluvium and alluvium is found at the base of the domes.*

3:3
Elongated (WNW-ESE), low sheet of dark lava outflow with few distinct valleys and only shallow loose deposits.

3:4
Low, unfaulted basaltic sheet that was earlier connected to area 3:1. Few or no effects of faulting can be observed. Only shallow loose deposits in widely spaced valleys. Signs of earlier fluvial erosion are present in the southern part.

4:1
Highly eroded, hilly area of basaltic rock with very shallow overburden of loose deposits and with distinct tectonic lineaments on a bearing of app. 340° (major lineament) and others, less distinct, on bearings of app. 60° and 100°.

4:2
Shallow overburden of alluvial deposits on outcropping basalt with main lineaments on a bearing of app. 340°. Other tectonic directions in the area are app. 20° and 100°. To the south there is a low cliff, presumably due to faulting. Sand river sections and limited flood-plains occur in the northern part.

4:3
Low ridge of faulted basalt, with a main lineament bearing of app. 100°, blocking drainage of areas 4:1 and 4:2. Several tectonically modified gorges have developed.

5:1
Mountainous area of metamorphic or igenous rock. The main tectonic bearing is app. 340°. Reworked alluvium in valley *pockets is fed into sand rivers and flood plains.*

5:2
Low, young sheet of highly eroded lava with few areas of sediment. Tectonic lineaments are covered by lava where they pass through the area. Flood plains and rivers can be expected along the main river channels.

5:3
Low basaltic area with limited pockets of loose deposits. The rock surface is highly eroded. Wide sand rivers and flood plains exist in the lower, eastern part. A low fault cliff on a bearing of app. 60° enters from areas 4:1 and 4:2.

6:1
Several major ephermal streams deposit large sediment loads on a complex of well developed alluvial fans (bajada area). Undulating terrain with seasonally flooded areas, where fine, dark sediments settle. In depressions the outflow of groundwater permits vegetation to establish itself and survive. Temporary salty marshes and pans (playas) may develop during periods of flooding.

6:2
As area 6:1 but possibly with a higher infiltration capacity. Superficial salt deposition may occur.

6:3
Mainly an alluvial plain with fine, dark sediments in low, seasonally flooded areas. A dense network of faint, partly braided streams join to form a few major channels.

LEGEND

- Road
- Railway
- Drainage path
- Drainage path (faint)
- Sand river
- Rock outcrops
- Escarpment, cliff
- Land-unit area
- Land-unit sub-area
- Lineaments

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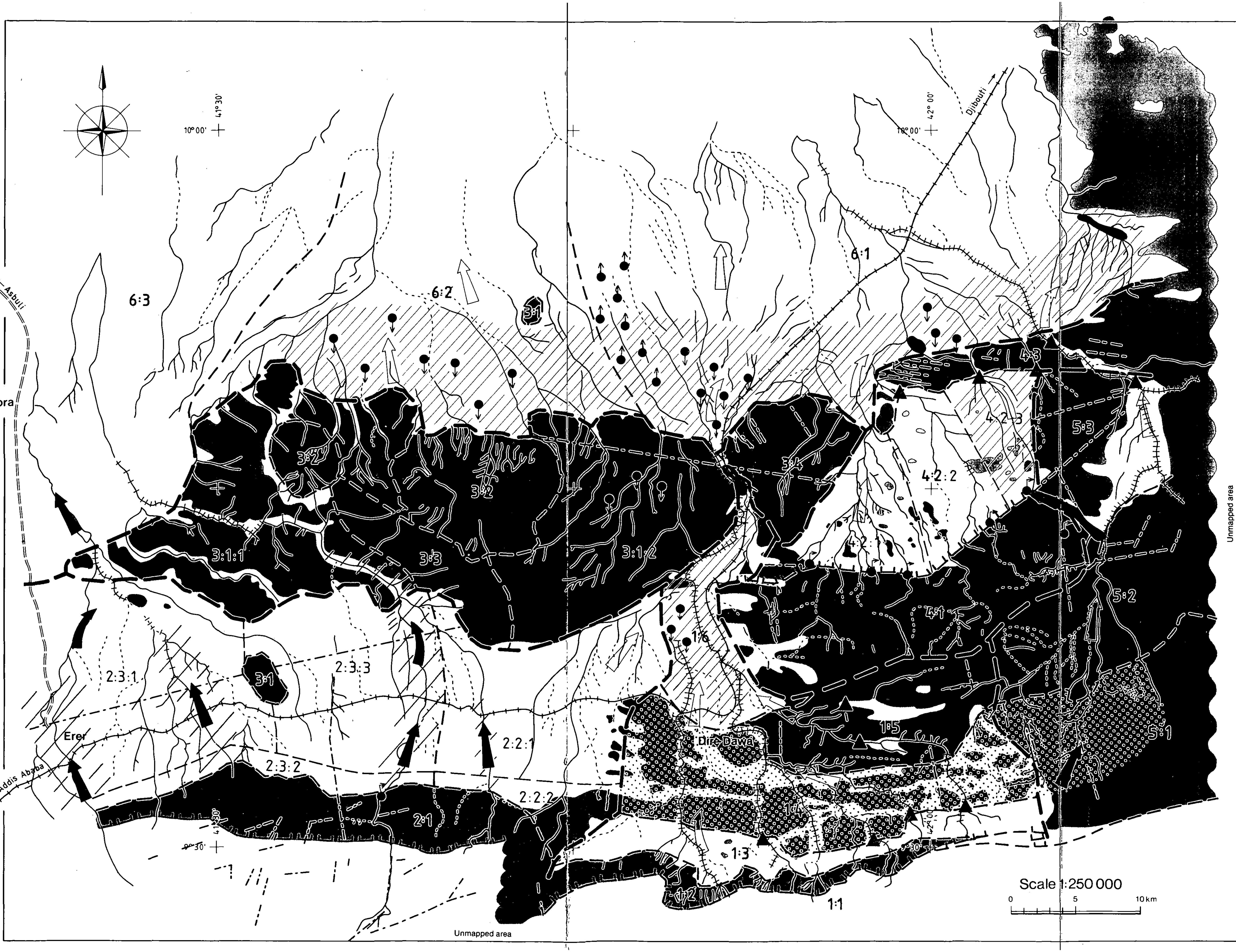

WATER AND LAND USE POTENTIAL IN THE DIRE DAWA AREA

Map 3

Based on geological, landform and lineament analysis of LANDSAT images

AREA 1

There are generally good prospects of finding groundwater in alluvial aquifers, wadis and in most places, including the rock, which can support irrigated agriculture.

1:1
The potential for shallow groundwater lies in depressions. In many places surface water could be stored in dams and ponds. Drilling for deep groundwater is not advisable because of the proximity to the Rift Valley escarpment.

1:2
This is an outflow area characterized by the presence of springs at the foot of the escarpment.

1:3
Shallow groundwater is present in wadis and associated alluvial deposits. Suitable areas for development are upstream of the thresholds or narrow passages, where the sand rivers enter area 1:4. Groundwater could be abstracted using shallow wells and groundwater dams. The area seems to consist of basement rocks, indicating only limited possibilities for deep drilling. Area suitable for agriculture supported by rain.

LEGEND

- Perennial river
- Groundwater flow
- Groundwater recharge
- Evaporation area
- Spring
- Groundwater outflow area
- Threshold
- Potential for groundwater dams
- Irrigable land, surface water
- Irrigable land, groundwater
- Road
- Railway
- Drainage path
- Drainage path (faint)
- Sand river
- Rock outcrops
- Escarpment, cliff
- Land-unit area
- Land-unit sub-area
- Lineaments

1:4
The valleys contain alluvial deposits and are suitable for development of shallow groundwater through wells and construction of groundwater dams. Bedrock consists of sedimentary rocks. Potential sites for deep drilling are at intersections of fault and fracture zones.

1:5
The potential for shallow groundwater lies in two extensive areas of alluvial fill. Rugged terrain restricts deep drilling, which would otherwise have a medium potential. There is probably some potential in construction of groundwater dams.

1:6
There is a very high potential for shallow to medium groundwater development from alluvial aquifers and underlying sedimentary rocks. Suitable land for irrigation is available.

AREA 2

The prospects for shallow groundwater are generally poor. There are some prospects for deep groundwater but surface water is basically the most feasible source of supply. Some large perennial springs exist which support irrigated agriculture.

2:1
Limited potential for shallow groundwater. Perennial springs and surface water are the main sources of supply in the area.

2:2:1
Area with some wadis, where groundwater dams and shallow wells could be developed. Deep groundwater is an alternative source of supply.

2:2:2
Area with perennial springs.

2:3:1
Relatively deep deposits, with sand rivers. Potential for shallow to medium deep wells and, probably, groundwater dams.

2:3:2
Area with perennial springs.

2:3:3
Shallow soil cover. Perennial streams exist in the area which could support irrigated agriculture. Other parts of the area could be worth drilling for deep groundwater.

AREA 3

Mountainous area of limited interest for water development. Some prospects for shallow water development through wells and groundwater dams in deeply incised rivers.

3:1:1
There are possibilities for shallow wells and groundwater dam development in deeply incised valleys with sand rivers. Otherwise the area is inaccessible.

3:1:2
Inaccessible area. The drainage pattern indicates a high rate infiltration. Possibly some potential for deep groundwater development but only limited use.

3:2
Volcanic rock with dense drainage network, indicating low groundwater recharge and high surface runoff. No potential for water development.

3:3
The drainage pattern indicates a high infiltration rate. Rugged topography. Limited potential for water development. Area with two major sand rivers.

3:4
Outcropping rocks with no soil cover. Drilling for deep groundwater is the only possibility for water supply in the area. However, the accessibility is very poor.

AREA 4

Area with good groundwater poten sibilities for small-scale irrigation.

4:1
Hilly area with shallow pockets of alluvial s western part, with some potential for groun ment through shallow wells. Springs are fou zone with areas 4:2 and 5:3.

4:2:1
Area with dense drainage network. Numero zone bordering area 4:1. Good potential fo groundwater and surface water.

4:2:2
Area with rock outcrops and little loose dep groundwater potential.

4:2:3
Deep alluvial sediments with good potential abstraction. The groundwater is probably dan hold in the river course at the border zone to

4:3
Rocky area. There is good potential for grour ment in a major sand river, probably with la groundwater at shallow depth which could b watering and irrigation in area 6:1.

AREA 5

Area with potential for shallow gro velopment and some small-scale

5:1
Groundwater can be found in some wadis a stracted using groundwater dams or shallow

5:2
Basalt area with two large flood plains along age zones. Otherwise the area contains only posits. Deep drilling is the most feasible me water exploration.

5:3
Sediments appear in the eastern part where a constitutes a high groundwater potential for gation.

AREA 6

Alluvial fans and outwash plain wi pects for groundwater developme tion. However, water quality (salinit restriction in the northern part.

6:1
Alluvial fan complex with some wadis. The a tential for groundwater development and irri

6:2
Alluvial fans and outwash plain. Probably go in the southern part because of groundwater creasing salinity to the north.

6:3
Alluvial plain with rivers passing through the a to flow during most of the year. Possibilities deep groundwater development through wells Salinity of groundwater is probably high.

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