# A Methodology for Assessment and Mapping of Desertification

## Report of the Kenya Pilot Study

(FP/6201-87-04)
January 1990

Government of Kenya (GOK)
epartment of Resource Surveys and Remote Sensing (DRSRS)
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## PREFACE

This report presents the results of the joint Government of Kenya (GOK) and United Nations Environment Programme (UNEP) project on the Evaluation of the FAO/UNEP Provisional Methodology for Assessment and Mapping of Desertification. The objectives of the project were:-

1. To evaluate the FAO/UNEP (1984) methodology for use in the assessment and mapping of desertification and recommend simplified methodology that could be used elsewhere with appropriate modification.

2. To strengthen the capability of Government of Kenya agencies to undertake desertification assessment, the planning of control measure and good land management; and

3. To contribute towards the preparation of a World Thematic Atlas of Desertification.

Many persons contributed at various stages to the completion of this report. This included staff of UNEP-DC/PAC, UNEP-GEMS/PAC and from the civil service of the Government of Kenya. Technical staff members of the Department of Resource Surveys and Remote Sensing (DRSRS) and project consultants greatly contributed towards the preparation of this report.

The most significant contributors and their fields were:

Mr. W.K. Ottichilo, Technical Coordinator
Mr. R.K. Sinange, Vegetation Expert
Mr. J.H. Kinuthia, Climate Expert
Ms. M.K. Kamar, Soils Expert
Mr. H.A. Mwendwa, Human Ecology Expert
Mr. J. Grunblatt, Systems Analyst

Assisted by:

Mr. S. Oduor, Vegetation
Mr. F. Msafiri, Vegetation
Mr. F. Waliaula, Vegetation
Mr. P.W. Wargute, Human Ecology
Mr. D.K. Ronoh, Human Ecology
Mr. S.M. Ng'ang'a, Data Analyst
Mr. P. Aoko, Cartography

It is hoped that the methodology and desertification indicators proposed in this report plus the conclusions arising from the study will form a basis for assessment and mapping desertification in affected countries.

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## EXECUTIVE SUMMARY

This report presents the results of the joint Government of Kenya (GOK) and United Nations Environment Programme (UNEP) evaluation of the FAO/UNEP (1984) Provisional Methodology for Assessment and Mapping of Desertification. The main objective of the project was to evaluate the FAO/UNEP (1984) methodology for use in the assessment and mapping of desertification and provide recommendations that would assist in its application at local and national levels. This entailed the choosing of appropriate desertification indicators and the identification of methods that could be used for data collection, and analysis in a rapid and cost effective manner. The project was undertaken at a pilot level in two study areas. The study areas were located in Baringo and Marsabit districts of Kenya.

Initial evaluation of the FAO/UNEP methodology showed that most of the indicators and methods proposed could only be used in assessment and mapping of desertification at a local or pilot level. It would be very expensive and time consuming to use most of the proposed indicators and methods for assessment and mapping of desertification at regional or national level. It was also noted that most countries do not have detailed data to the level proposed in the methodology. Recent past or long-term data required for determination of rate of desertification is also lacking.

In this study, detailed data was collected on selected desertification indicators using remote sensing techniques and field surveys. The detailed data was then evaluated for use at local level. Selected data elements and other ancillary data were used in the geographic information system (GIS) to develop generalized models that could be used in the assessment and mapping of desertification at regional or national level. Five models were developed. These are:

1. Water Erosion Model
2. Wind Erosion Model
3. Range Carrying Capacity Model
4. Vegetation Degradation Model
5. Human Population Model

These models can be used in assessment of desertification at a national level using basic data on climate, landform, soil, vegetation, animal numbers and human population. Based on the experience gained in this study, it is recommended that in areas where this basic data required for the models does not exist, remote sensing techniques - particularly the use of satellite imagery and systematic reconnaissance flights (SRF) can be used in the baseline resource inventory. The use of remote sensing is relatively cost-effective, rapid and the information can be obtained on a periodic basis and consequently these remote sensing techniques should further be used in the long - term monitoring and assessment of desertification.

Lastly it is recommended that socio-economic data should be included in any assessment of desertification since desertification processes are largely induced by human activities.

# 1. INTRODUCTION

## 1.1 THE GENERAL OUTLINE OF THE PROBLEM

Desertification is not a recent process. It has been proceeding - sometimes rapidly, sometimes slowly- for more than a thousand years (Dregne 1983). It commonly appears as degradation of plant, animal, soil and water resources and general loss of biological productivity in areas under ecological stress (FAO/UNEP, 1984). In fragile ecosystems such as those on desert margins, this degradation can severely reduce the capacity of the area affected to support human life.

Until recently, attention was not focused on desertification in part because the desertification process was an insidious one that went unrecognized in the early stages or was seen as a local problem affecting only a small population (Dregne, 1983). In addition, new land was always available to start over again. As long as remedial action could be deferred by moving to the new frontiers, land conservation had little appeal. It was not until the 20th Century - when easy land expansion came to an end - that governments and people finally realized that continued careless degradation of natural resources threatened their future (Dregne, 1983).

More than one-third of the earth's land area belong to the sub-humid, semi-arid and arid climatic zones where the process of desertification has intensified in recent decades (Mabbutt, 1984). According to the estimates available, desertification threatens the future of more than 785 million people, or 17.7 percent of the world's population who live in these drylands (United Nations Conference on Desertification (UNCOD) 1977, Mabbut 1984). Of this number between 60 and 100 million people are affected directly by decreases in productivity associated with the current desertification process.

It is also estimated that between 50,000 and 70,000 square kilometers of useful land are going out of production every year, through desertification. The World Map of Desertification, at a scale of 1:25,000,000 prepared for the UN Conference on Desertification in 1977 gives an impression of the present situation (UNCOD, 1977).

The situation as presented above on the current magnitude of the desertification problem has been evaluated in general terms. However, more precise data and methods are required on areas affected, or likely to be affected in the future by desertification processes at national and local scales (FAO/UNEP, 1984). Such analysis are required to obtain more precise figures on desertification and to assist in future action in planning and guiding anti-desertification activities at national and regional levels as a basis for international action to combat desertification, for co-ordination of research and for transfer of the appropriate technology. For this purpose, the FAO/UNEP project entitled 'Desertification Assessment and Mapping' was initiated (FAO, 1980)

In 1987, the United Nations Environment Programme (UNEP) in collaboration with the Government of Kenya (GOK) launched a project entitled "Desertification Assessment and Mapping Pilot Study in Kenya". The aim of this study was to evaluate FAO/UNEP (1984) methodology for use in the assessment and mapping of desertification and recommend simplified methodology that could be used elsewhere with appropriate modification.

## 1.2 THE BACKGROUND OF THE DESERTIFICATION ASSESSMENT AND MAPPING PILOT STUDY IN KENYA

The "Desertification Assessment and Mapping Pilot Study in Kenya" is the follow-up of a joint FAO/UNEP project which culminated in the publication of the "Provisional Methodology for the Assessment and Mapping of Desertification" in 1981 (FAO 1981). The publication describes the processes leading to desertification, details the factors to be considered in assessing each process, considers the combination of processes to quantify four aspects of desertification (status, rate, inherent risk and hazard) and suggests map compilation methods. Although the FAO methodology was revised in 1984 in the light of field-tests in 9 countries, the major criticism remained that the application of the proposed methodology was impractical (FAO/UNEP 1984). The lack of sufficient data, even in developed countries was a major handicap and the cost of acquiring such data could be very high. Consequently, it was recommended at a UNEP meeting on desertification assessment and mapping in Nairobi (11-14 March 1985) that a simpler, refined methodology should be tested in a pilot study project in Kenya.

The project formulation and preparation started in late 1985 and in April 1987, a memorandum of understanding was signed between the Government of Kenya and the United Nations Environment Programme for the implementation of the pilot study project (FP/6201-87-04 (2702)). The pilot study was to be undertaken in parts of Baringo and Marsabit districts. The criteria for selection of the pilot study areas were:

(a) The areas should be situated in arid or semi-arid zones of Kenya and should represent major ecological features of drylands e.g. vegetation, water etc. as well as being used in typical ways of dry areas through agriculture and range management;

(b) All areas should show typical catena from higher rainfall to drier parts, thus enabling the establishment of typical transacts. The areas should show signs of desertification at various stages, and;

(c) Accessibility by road and air both in the dry and in wet season should be good. The areas should have a good cover of LANDSAT and Systems Probatoire d'Observation de la Terre (SPOT) images and resource inventories are an added advantage.

The Department of Resource Surveys and Remote Sensing (DRSRS) - formerly known as KREMU which had earlier shown both interest and willingness to assist in the testing of refined methodology was mandated to implement the project on behalf of the Government of Kenya and in conjunction with UNEP because of its long-term experience in the ecological monitoring of the Kenya rangelands.

The planning for the implementation of the project commenced in September 1987 with the recruitment of required experts/consultants and ordering of project vehicles, and SPOT images. The study design was undertaken between September 1987 and February 1988. During the study design, a simplified set of indicators for degradation of vegetation cover, water erosion, wind erosion and human factors were defined and conceptual outline of the model to give status of desertification developed. The data on selected desertification indicators was collected between February 1988 and March 1989. Data analysis and report writing was carried out between March 1989 and July 1989. The results of the study were presented to a meeting of experts in Nairobi from 24 to 25 July 1989.

## 1.3 DEFINITIONS

In order to avoid misunderstanding, ambiguity and confusion, the main terms used in this study are defined as accurately as possible. This has become necessary because the literature is full of contradicting definitions on the same subject. Here below is a review of some popular definitions of desertification from the literature and working definition used in this study.

### 1.3.1 Desertification

There are numerous definitions of the word desertification in literature. According to the 1977 United Nations Conference on Desertification (UNCOD 1977) desertification was defined as:

> the diminution or destruction of the biological potential of the land, which can lead ultimately to desert-like conditions.

Though, this definition is acceptable for the purposes of a political UN conference, it is inadequate from the technical point of view, as it is not an operative definition in precise scientific terms (Rozanov and Zonn, 1984). First it is not clear what "desert-like conditions" are. There are wide variations between natural deserts, with some being completely devoid of plant cover and others having fairly well-developed plant cover (UNESCO 1977). Second, any degradation of biological potential is understood as desertification even in arctic and humid environments. Third, there is no clarification as the significance of natural phenomenon to desertification such as period droughts. Finally, there is no clear-cut measurable and objective criteria of desertification. Thus this definition does not provide concrete and precise parameters for quantitative assessment, monitoring and control of the process.

Apart from the above definition adopted by the 1977 United Nations Conference on Desertification, other examples of popular definitions of the term desertification are:

(a) Rozanov and Zonn (1984) based on their experiences in desertification in Russia have defined desertification as:

A natural or man-induced process of irreversible changes of soil and vegetation of dryland in the direction of aridization and diminution of biological productivity, which in extreme cases, may lead to total destruction of biological potential and conversion of land into desert.

(b) Sabadell et al (1982) in their final report on, "Desertification in the United States" have defined desertification as:

the sustained decline and/or destruction of the biological productivity of arid and semi-arid lands caused by man-made stresses, sometimes in conjunction with extreme natural events. Such stresses, if continued or unchecked, may lead to ecological degradation and ultimately to desert-like conditions.

(c) Dregne (1983) defined desertification as:

the impoverishment of terrestrial ecosystems under the impact of man. It is the process of deterioration in these ecosystems that can be measured by reduced productivity of desirable plants, undesirable alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy.

(d) Dregne (1977) has also defined desertification as:

the impoverishment of arid, semi-arid and sub-humid ecosystems by the combined impact of man's activities and drought. It is the process of change in these ecosystems that can be measured by reduced productivity of desirable plants, alteration in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil degradation, and increased hazards of human occupancy.

(e) The Food and Agricultural Organisation (FAO) and the United Nations Environment Programme (UNEP) - FAO/UNEP, 1984) define desertification as:

a comprehensive expression of economic and social processes as well as those natural or indu ced ones which destroy the equilibrium of soil, vegetation, air and water in the areas subject to edaphic and/or climatic aridity.

(f) The World Resources Institute (1989) defines desertification as:

the deterioration of soil, severely reduced productivity of desirable plants and declining diversity of flora and fauna because of the activities of both people and livestock.

(g) Kharin and Petrov (1977) define desertification as:

a complex of physiographical (natural) and anthropogenic processes, causing the destruction of arid, semi-arid and sub-humid ecosystems and the degradation of all forms of organic life, which, in turn, results in the diminished natural - economic potential of these territories.

(h) Kassas (1988) defines desertification as:

a process of ecological degradation by which economically bio-productive land becomes less productive. In extreme instances the final scene is a desert-like landscape incapable of sustaining communities that once depended on it.

In this Study the definition of the term desertification is based on the following criteria:

(i) Desertification has the same meaning as land degradation except the term is specifically used for land degradation processes occurring in arid, semi-arid and sub-humid lands.

(ii) Land degradation is defined here as degeneration or deterioration (loss of qualities that are normal or desirable or proper to its kind); process which takes place over relatively short periods (less than 100 years), it is not necessarily continuous, can be reversed and can occur in all climates. The main forms of land degradation in arid zones are: Vegetative cover and soil degradation.;

(iii) Desertification is either caused by a natural phenomenon (i.e. drought), or by human - indu ced activities or both; and

(iv) Desertification is to a large extent a reversible process (Spooner and Man, 1982, World Resources Institute, 1989)

Based on the above criteria, desertification is defined in this Study as:

a complex of natural and mainly man-induced land degradation processes which lead to the decline of biological productivity of arid, semi-arid and sub-humid lands and in turn, results in the diminished natural and economic potential of these lands.

1.3.2 Aspects of Desertification

For the purposes of assessment and mapping it is necessary to study, describe, quantify and codify the various aspects of desertification. The aspects proposed in the, "Provisional Methodology for Assessment and Mapping of Desertification" (FAO/UNEP 1984) were found adequate and have been adopted with slight modifications for use in this Study. The aspects are: risk, status, rate and hazard of desertification. Here below are definitions of these terms as used in this study:

1.3.2.1 Risk of Desertification

It is the vulnerability of an area to desertification. It should be noted that areas with a high risk are not necessarily areas with a severe status of desertification and vice versa. Risk of desertification is assessed through the analysis of physical and human factors of an area. The factors are: climate, soil and physiography or topography, human population and animal numbers. This aspect of desertification was not directly tackled in this study. It was incorporated in the status aspect.

1.3.2.2 Status of Desertification

Status of desertification is defined here as being the present, former or future situation of desertification indicator(s) for an area in relation to its natural state. Status therefore has to be assessed against an estimate of the natural state of the area.

1.3.2.3 Rate of Desertification

Rate is the measure with which desertification spreads or intensifies in a certain area or region over a defined period of time. It can be positive or negative. Positive meaning increase in desertification and negative meaning decrease. A rate is established through comparison of two different status, divided by the period of time. The first status can be a natural or undisturbed one, but it is often difficult to reconstruct. Thus, ideally status of desertification is compared over a period of time in order to establish rate.

1.3.2.4 Desertification Hazard

Is the summation of various status of desertification indicators for an area. It indicates the actual danger of an area being desertified.

1.3.2.5 Rating for Desertification Assessment and Mapping

The "Provisional Methodology for the Assessment and Mapping of Desertification (FAO/UNEP 1984)" uses a four point rating. The scale ranges from slight to very severe. In the case of this study it was found necessary to expand this rating to a five point one, so that the rating NONE which is not uncommon in Kenya, and elsewhere can be included (Table 1). However, in all cases except for desertification hazard, it was found practical to use only a three-point rating scale.

Table 1 RATING SCALE FOR ASSESSMENT AND MAPPING OF DESERTIFICATION

| RATING | 5-Point | 4-Point | 3-Point | 2-Point |
|---|---|---|---|---|
| | None | None | | |
| | Slight | Slight | Slight | |
| | Moderate | Moderate | Moderate | Slight |
| | Severe | Severe | Severe | Severe |
| | Very severe | | | |

## 1.4 SELECTED DESERTIFICATION FACTORS AND INDICATORS

In this study the term factor is used to describe particular data collected while indicator refers to something that provides information about the condition being investigated. In some cases a factor can be used directly as an indicator, i.e. soil salinity. In other cases factors are combined to provide an indicator, i.e. water erosion potential.

Prior to study implementation, a series of consultative meetings were held by scientific staff of DRSRS, DC/PAC, GEMS and project consultants to discuss and select desertification assessment methods and indicators to be assessed. The desertification assessment methods and indicators proposed in the FAO/UNEP Provisional Methodology for Assessment methods and Mapping of Desertification were critically evaluated for their practicality, rapidness and cost-effectiveness.

A set of factors were selected for desertification assessment. The factors were categorized into three types: physical, biological and social or socio-economic factors. The details of the factors chosen for each type are given in Table 2. Based on selected desertification assessment factors, a number of indicators were chosen for assessing and mapping desertification at both local and national levels. The details of the chosen indicators are given in Table 3.

In this study human impacts in desertification processes were considered to be very important. Thus a number of socio-economic factors which were not considered in the FAO/UNEP methodology, have been incorporated in this study.

## 1.5 STUDY APPROACH

The main objective of the Kenya Desertification assessment and mapping Pilot Study was to evaluate the FAO/UNEP (1984) methodology for use in the assessment and mapping of desertification and recommend a cost-effective, simplified methodology that could be used elsewhere with appropriate modification. To achieve this objective, a hierarchical study approach was adopted.

In this approach, detailed data was collected at a local level on selected desertification assessment factors using different methods. The detailed data was then evaluated and selected data elements given in Section 3.5 were used in Geographic Information System (GIS) to develop simple models that could be used in the assessment and mapping of desertification at a national or regional level.

The aim of this approach was to use the detailed data collected in the pilot study to develop simple models that could be used in the assessment and mapping of desertification at local and national levels using available basic data and without or with very limited field work. Also the detailed data was necessary for validating the models. This approach was deemed necessary in order to reduce the cost, time and manpower that would otherwise be required for national desertification assessment and mapping using conventional procedures yet provide reliable assessment.

Table 2 **DESERTIFICATION ASSESSMENT FACTORS**

| TYPE | Factors | |
|---|---|---|
| Physical | Climate | |
| | a. | Rainfall |
| | b. | Temperature |
| | c. | Wind speed, direction and frequency |
| | d. | Rainfall erosivity (calculated) |
| | e. | Sunlight duration |
| | f. | Potential Evapotranspiration PET - (Calculated) |
| | g. | Sandstorm/dust storm |
| | h. | Vorticity |
| | Soils | |
| | a. | Surface status (rockiness) |
| | b. | Texture |
| | c. | Fertility (organic matter) |
| | d. | Structure |
| | e. | Permeability |
| | f. | Erodibility (calculated) |
| | g. | Alkalinazation/Salinization |
| | h. | Soil unit map |
| | Topography | |
| | a. | Slope |
| Biological | Vegetation | |
| | a. | Canopy cover of herbaceous and woody plants (%) |
| | b. | Above ground biomass production (standing crops) of herbaceous/woody cover (kg/ha/yr) |
| | c. | Plant composition and desirable or key species |
| | d. | Potential herbaceous production (calculated) |
| | e. | Vegetation unit map |
| | Animals | |
| | a. | Animal population estimates and distribution |
| | b. | Herd composition |
| | c. | Herbaceous consumption (calculated) |
| Socio-Economic | Land and Water Use | |
| | a. | Land use |
| | b. | Fuel wood consumption |
| | c. | Water availability and requirements |
| | Settlement Patterns | |
| | a. | Settlements |
| | b. | Infrastructure |
| | Human Biological Parameters | |
| | a. | Population structure and growth rate |
| | b. | Measures of nutritional status |
| | c. | Feeding habits |
| | Social Process Parameters | |
| | a. | Conflicts |
| | b. | Migration |
| | c. | Transhumance |
| | d. | Environmental perception |

Table 3 **DESERTIFICATION ASSESSMENT INDICATORS**

| Category | Indicator | Level of Application | |
|---|---|---|---|
| Physical | Climate | | |
| | a. Aridity index | L | N |
| | b. Rainfall variability | L | N |
| | c. Wind deposition and deflection areas | L | - |
| | d. Wind erosion potential (calculated) | L | N |
| | Soil | | |
| | a. Crusting and compaction | L | - |
| | b. Soil salinization/Alkalinization | L | - |
| | c. Water erosion areas | L | - |
| | d. Water erosion potential (calcuated) | L | N |
| Biological | Vegetation | | |
| | a. Vegetation degradation (herbaceous and woody) - (calculated) | L | N |
| | b. Range carrying capacity (calculated) | L | N |
| | c. Desirable and undesirable plant species | L | - |
| Social | Human Factors | | |
| | a. Human settlements | L | N |
| | b. Land Use | L | N |
| | c. Fuel wood consumption (calculated)* | L | N |
| | d. Nutritional status | L | N |
| | e. Migration | L | N |
| | f. Environmental perception | L | - |

L = Local
N = National
* = Was not undertaken in this study but data is available at DRSRS

# 2 STUDY AREAS

## 2.1 BARINGO STUDY AREA

The study area is predominantly a low or bottom land and lies between 0° 15' and 1° N and 35° 30' and 36° 30'E (Figure 1). It is located between the Laikipia escarpment to the east and Tugen hills to the west. The altitude ranges from 900m on Njemps flats to 2500m in the Puka and Tangulbei/Pokot highlands in the north. The size of the area is approximately 3600km$^2$.

### 2.1.1 Drainage

The Perkerra and Molo rivers are the only permanent rivers which drain into Lake Baringo via the Njemps flats.

### 2.1.2 Rainfall

The climate of the region is generally wet. There is one dry season and three wet seasons. The region experiences trimodal type of rainfall occurring in the periods March - May, June - September and October - December. The dry season occurs in the months of January and February. Even during dry periods some significant rainfall amounts have been received mainly on the high ground. The highest rainfall of up to 1900mm is received in areas around the mountains. The rainfall amounts decrease with the decreasing altitude. The mountain ranges in Baringo extend from North to South. The rainfall increases from north to south. The annual rainfall in the project area is about 600mm.

### 2.1.3 Land Use

The main land use in the study area is livestock keeping. Irrigated agriculture is practised using Perkerra and Molo rivers. The water from the recently constructed Chemeron gorge dam is also being used for irrigation in the Endao area. The main crops grown under irrigation are vegetables, fruits and maize.

## 2.2 MARSABIT STUDY AREA

The study area in Marsabit lies between 2° 00' and 3° 00'N. and 37° 00' and 38° 00" E. and covers an area of about 14,000km$^2$ (see figure 2). The major part of the area lies within the arid lowlands of the Kaisut, Koroli and Hedad plains. To the south west, it is bounded by the Ndoto Mountains and to the west by Kulal Mountains. Towards the east it rises to 1500m on Mt. Marsabit which is covered by tropical rain forest. The lowest point is the Chalbi desert (salt desert) which is about 400m above sea level. Vast parts mainly the slopes of Mt. Marsabit and Kaisut and Hedad lowlands are covered with lava. Vegetational characteristics vary from desert halophytes, scattered woodland, dwarf shrub and shrubland to rain forest.

### 2.2.1 Drainage

Seasonal rivers originate from the hill masses and drain into the central plain where their water evaporates or sinks. Water from most of the area drains into old saline lake bed of the Chalbi desert.

### 2.2.2 Rainfall

The general climate of the region of Marsabit is generally dry but marked with two rainy seasons. Some short rain may occur during the dry months although quite irregular and unreliable. The region experiences a bimodal type of rainfall which occurs in the periods March - May (long rains) and October - December (short rains).

The remaining months are dry. The region is characterized by a highly variable spatial distribution of annual rainfall. The area around the mountains receive up to 800mm or more annually, while the low lying areas receive an annual average of less than 250mm. Besides this areal variability, there exists large year to year or seasonal variations.

2.2.3 Land Use

The lower plateau on Mt. Marsabit on which Marsabit town is situated is used for mixed farming of cattle, and small stock and arable agriculture. Numerous waterholes on the plateau have facilitated the sedentarization of the local pastoralists. The rest of the Marsabit study area is under extensive pastoralism and partly covers the home ranges of the Rendille, Gabbra, Boran and Samburu pastoral tribes.

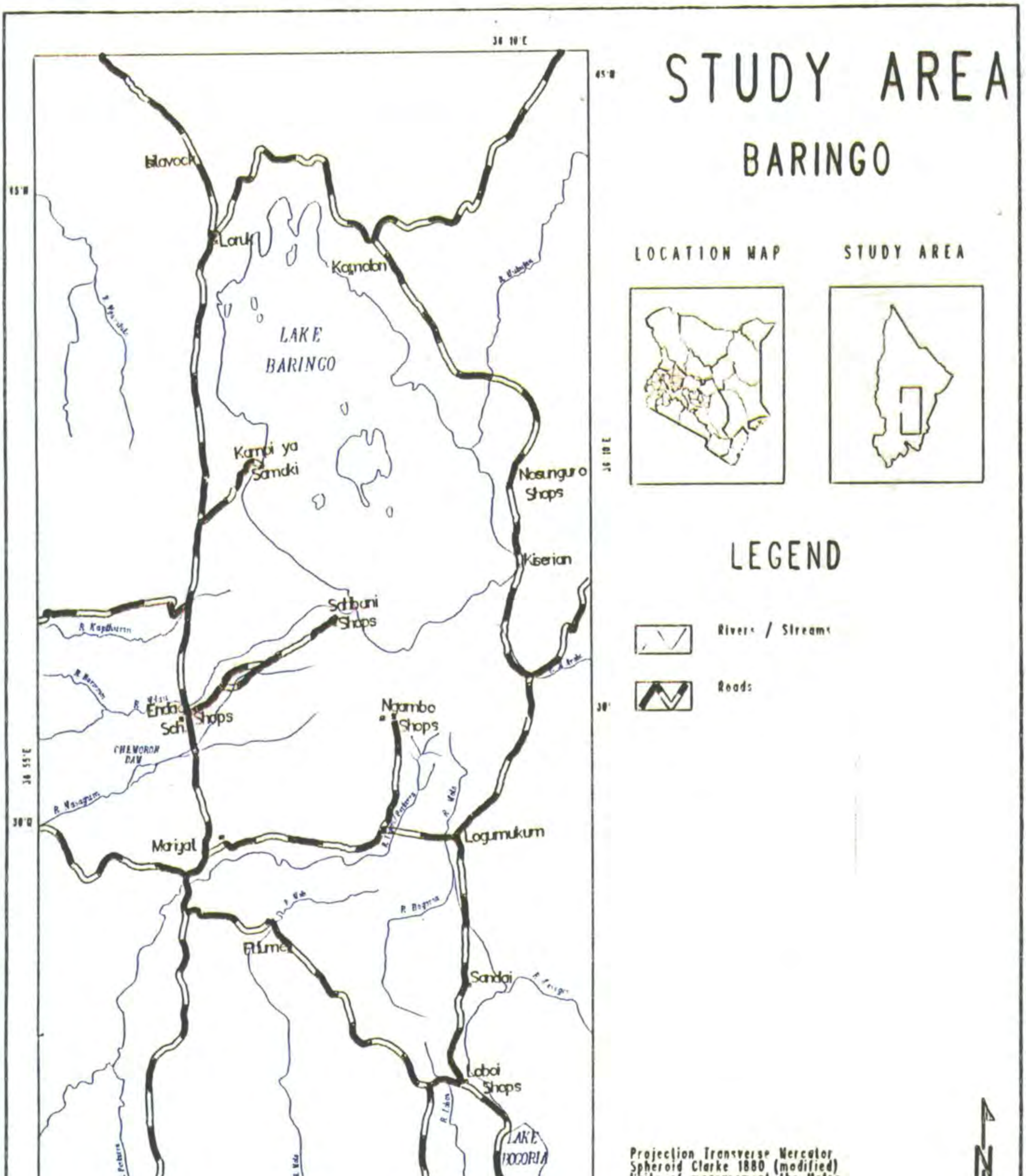
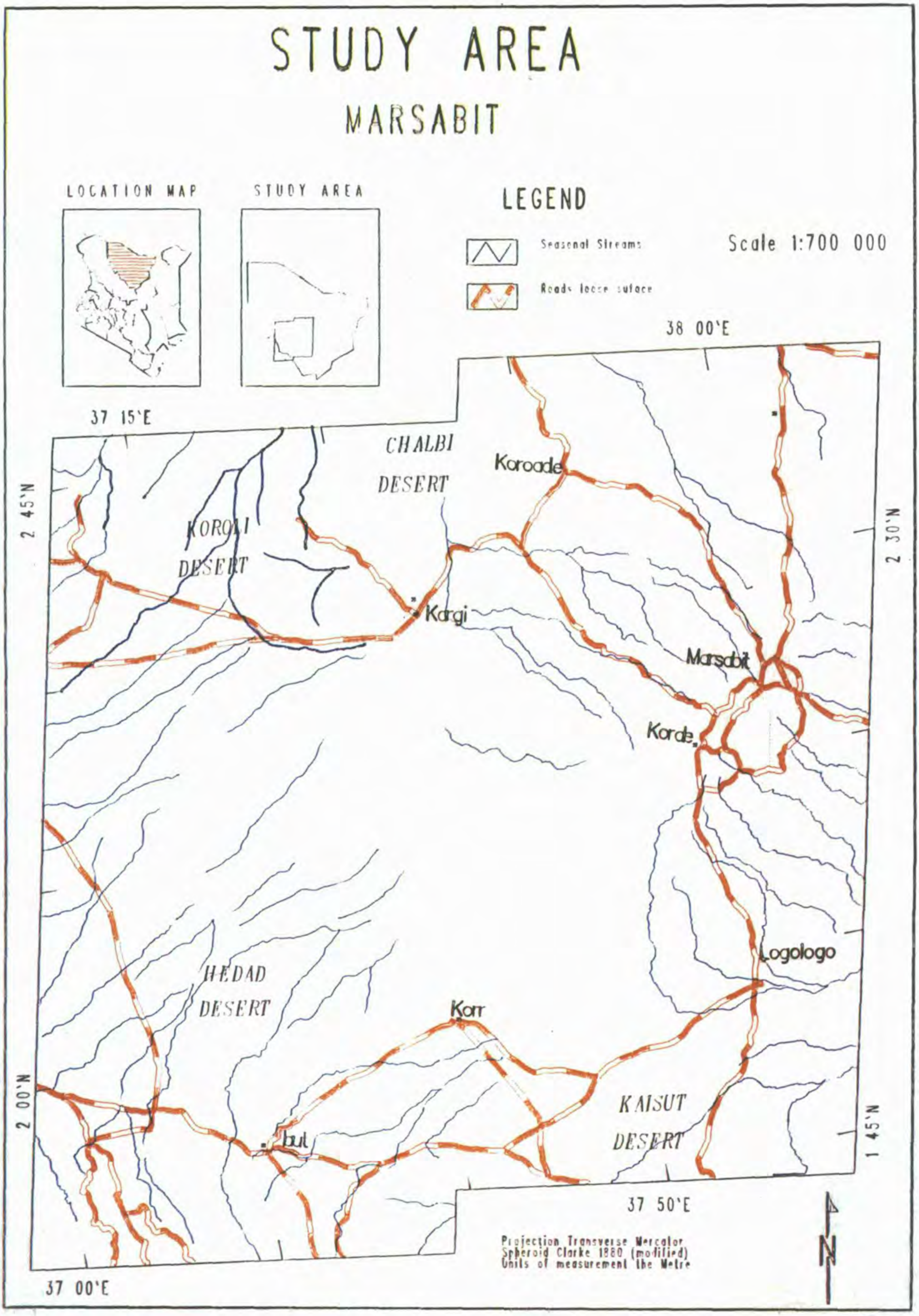

STUDY AREA
BARINGO
LOCATION MAP
STUDY AREA
LEGEND
Rivers / Streams
Roads
Projection Transverse Mercator
Spheroid Clarke 1880 (modified)
Units of measurement the Metre
Scale 1 250 000
LAKE BARINGO
LAKE BOGORIA
Bilavock
Loruk
Kamalon
Kampi ya Samaki
Nosunguro Shops
Kiserian
Salabani Shops
Endao Sch. Shops
Ngambo Shops
CHEMORON DAM
Marigat
Logumukum
Sandai
Loboi Shops
Radat
Maji Moto

Figure 2


STUDY AREA
MARSABIT
LOCATION MAP
STUDY AREA
LEGEND
Seasonal Streams
Roads loose suface
Scale 1:700 000
38 00'E
37 15'E
2 45'N
2 30'N
CHALBI DESERT
KOROLI DESERT
Koroade
Kargi
Marsabit
Korde
Logologo
HEDAD DESERT
Korr
KAISUT DESERT
Ilaut
2 00'N
1 45'N
37 50'E
37 00'E
Projection Transverse Mercator
Spheroid Clarke 1880 (modified)
Units of measurement the Metre
N

# 3 METHODS AND MATERIALS

## 3.1 INTRODUCTION

A number of methods were used to collect data on the factors and indicators given in Tables 2 and 3. The methods used were those that were believed to be feasible and appropriate for the type of data being collected and period of time allocated for field data collection. Due to the limited period of time allocated for field work, a number of factors which could have required a long period for data collection were not considered in this study. These include soil crusting and compaction, biomass production of woody plants (trees and shrubs), complete cover analysis of recent past photos for determination of rate of desertification, and digital image analysis of SPOT imagery etc.

Below is a brief description of the methods used to collect data for different types of factors. For details the reader is referred to individual consultant reports to the project (see Appendix 1 for list) which are available at the UNEP - Desertification Control Programme Activity Centre (DC/PAC).

## 3.2 PHYSICAL FACTORS/INDICATORS

Data on physical factors were acquired through field surveys, laboratory analysis and literature review. Below is a brief description of each of the methods used.

### 3.2.1 Climate and Physiography

Data on rainfall was obtained from the Kenya Meteorological Department. Further information (analyzed data) on rainfall was obtained from Farm Management Handbook of Kenya (Jaetzold and Schimdt 1982). Different rainfall stations were digitized and their rainfall records used to generate rainfall isohyets.

For the Baringo study area, the isohyets generated by Jaetzold and Schmidt (1982) were used.

The rainfall erosivity index or Fournier index (R) was calculated using the following equation.

$$R = \sum_{1}^{12} (p^2/P)$$

Where P = Annual Rainfall
p = Monthly Rainfall

Rainfall stations within the study areas were selected and their monthly and annual rainfall used to calculate the erosivity index. The erosivity index was then related to the annual rainfall for each of the rainfall stations by regression equations relating erosivity index (R) to annual rainfall (y).

Finally, a map of the erosivity index was generated using a computer by relating the digitized annual rainfall isohyets to their appropriate erosivity value using the regression equation.

Terrain information i.e. slope was derived from 1:250,000 topographic sheets (Republic of Kenya 1972). The contours at an interval of 60m were digitized and used in generating slope maps using a computer. The slope data was used in the analysis of water erosion status.

### 3.2.2 Soil Factors/Indicators

A preliminary soil unit map for each study area was produced through visual interpretation of enhanced dry season SPOT imageries which were taken on 12th September, 1986 for Baringo and on 10th February, 1987 for Marsabit. The visual interpretation was augmented by field checks which were undertaken during both the dry and wet season.

During the dry season field visit, the preliminary soil unit maps derived from the visual interpretation of the SPOT images were checked, verified and modified where necessary. Earlier soil unit maps for the areas (Republic of Kenya 1982, Van Kekem 1984) were used to verify the soil units derived from the SPOT images. The final field-checked and corrected soil unit maps were used in collecting information on soil degradation factors. Thus each soil unit (or polygon) formed a basis for collecting detailed data on the chosen factors. The final soil unit maps were digitized and used during the data analysis and modelling phase.

The data on the chosen soil degradation factors was acquired through the analysis of soil samples taken at different depths (0-25 cm, 25-50 cm, 50-75 cm) in each soil unit. The samples were analyzed at the Kenya National Agricultural laboratories for: soil structure, soil permeability, soil texture class, soil salinization (EC), soil alkalinization (ESP) and soil organic matter.

The analyzed data on organic matter, soil texture, soil structure and permeability was used to calculate soil erodibility for each soil type using the soil erodibility nomograph developed by Wischmeter and Smith (1978). Data on rockiness was collected in the field during the dry season. The rockiness surface cover percent was estimated ocularly using quadrats each measuring 1m x 1m. Quadrats were randomly laid in each soil unit and percent cover rockiness was estimated visually. Five quadrats were laid in each soil unit and an average percent was calculated.

3.2.3 Water Erosion

Data on water erosion was collected during the wet season. Due to shortage of time and manpower, only qualitative information on various stages of water erosion was collected in each soil unit. The principle assumption followed in collecting the data was that water erosion begins by splash, then as water run-off builds up we have sheet erosion. As run-off increases, concentration of water in small well defined channels form rills. More removal of soil by higher water flow in the rills leads to gully formation and continued gully development ultimately leads to the formation of badlands. In brief, the process is as follows:

None - Sheet erosion - Rill erosion - Gully erosion - Badland.

Each soil unit in each study area was visited during the wet season and the water erosion status was qualitatively determined through field observations based on the above water erosion processes.

3.2.4 Wind Erosion

Data on wind erosion was obtained from Kenya Meteorological Dearptment. Data on rainfall, potential evapotranspiration (PET), wind speed, direction and frequency for four years (1982 - 1985) was obtained from the Kenya Meteorological Department records (1984). The wind direction data was used to draw wind roses for each study area; while wind speed and frequency data was used for calculating erosivity wind index.

3.2.4.1 Calculation of wind erosivity.

Three formulae were used for the calculation of the erosivity wind index (FAO/UNEP/UNESCO 1979). They are given as follows:

$$C_1 = \frac{V^3}{2.9(P/E)^2} \quad .... \quad (1)$$

$C_1$ = Erosivity wind index $(m/s)_n^3$

Where V = Mean monthly wind speed at 2m height (m/sec)
(P/E) = Precipitation effectiveness of Thornthwaite
P = Mean monthly rainfall (cm)
E = Mean monthly potential evapotranspiration (cm)

$$C_2 = \frac{V^3}{2.9(P-E)^2} \quad .... \quad (2)$$

$C_2$ = Erosivity wind index $(m/s)^3$

Where V = Mean monthly wind speed at 2m height (m/sec)
P = Mean monthly rainfall (cm)
E = Mean potential evapotranspiration

These two indexes C1 and C2 were developed from the wind index of Chepil (1962) and were recommended to be used for assessment of wind erosion at detailed level (1:20.000 - 1:100,000)

$$C_3 = \frac{v^3}{100} \quad (\frac{E - P}{E} \times n) \quad ............ \quad (3)$$

$C_3$ = Erosivity wind index $(m/s)^3$

Where V = Mean monthly wind speed at 2m height (m/sec)
E = Mean monthly potential evapotranspiration (mm)
P = Mean monthly rainfall (mm)

(E-P)/E x n = number of erosive days per month

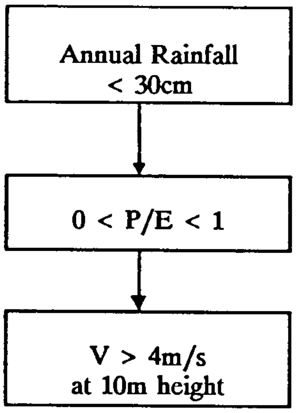
Where the number of days on which erosion occurs is assumed to be proportional to (E-P)/E times the total number of days in a month. This formula was recommended to be used for wind erosion assessment at general level (less than 1.1,000,000). The above formulae were used in computing the erosivity indexes for the study areas

The rainfall (P) and wind speed (V) are easily calculated. The calculation of potential evapotranspiration (E) is tedious and complicated. It can be calculated directly from empirical formula as shown in Appendix 2. Tables developed by Mather (1954) are used in the correction of this formula. Apart from this formula, the procedure given in Appendix 2 can be followed to calculate (E). In Kenya, Penman's equation is used to calculate the potential evapotranspiration (E). Penman's equation needs observations of radiation, temperature, humidity and wind, and whose combination is normally sparse.

Although the Penman equation is the one recommended for use in Kenya it cannot be used if one of the parameters mentioned above is missing. Criticisms of Thorntwaites indexes are well known, but nevertheless they constitute very useful empirical measures which are most successful in "continental" climates similar to those of the central U.S.A., in which areas they were first developed. Only the observations of temperature are required for the use of this formula.

In the arid areas either the Penman equation or Thornthwaite formula can be used for the calculation of PET as the rate of movement of sand will not vary much. In the sub-humid areas, it is recommended to apply a correction factor of 0.75 on E obtained from the Penman equation before using it in the formula for rate of movement of sand. In the humid areas the Penman equation does not give accurate values of erosivity index particularly in the areas where the wind speed is high.

The following conditions as given in the flow chart below are recommended for determining whether wind degradation is taking place in an area:




NB. The wind speed at 10 meter height is multiplied by a ratio of 0.78 to obtain the wind speed at 2m height (McCulloch, 1965).

3.2.4.2 Calculation of Sand load

The load of sand carried by wind was calculated using Chepil and Woodruff (1957) method. Chepil and Woodruff showed that the relationship between the visibility and dust load (assuming that mass of dust above one mile is negligible is:

$$C_m = \frac{29.5}{V^{1.25}}$$

Where $V$ = Visibility in miles
$C_m$ = Dust load in tons per cubic mile

Banoub (1970) notes that the relationships between suspended particles and visibility can lead to the definition "that a dust-storm occurs when the horizontal visibility is reduced to less than 1km." The World Meteorological Organisation (WMO) gives the same definition for the dust-storm and sand-storm (WMO, 1988). The visibility codes are given at steps of 100 meters for the first 5 km and then in steps of 1 km, up to 9 km. The actual distance for horizontal visibility beyond 10km is not given. In this study the WMO codes (Table 4) were used in the calculation of the load of sand.

The surface area affected by wind erosion was visually estimated from the dry season SPOT image. The SPOT image, was used to identify and delineate sand deflation and deposition areas. Hummocks/sand dunes were predominantly found in the deposition areas. The percent cover of hummocks and sand dunes in each delineated unit was verified in the field. The field checked units were digitized and the exact area calculated using the GIS.

Table 4 **WMO CODES AND CORRESPONDING LOAD OF SAND**

| Code | Distance(m) | Load of sand tons/mile$_3$ |
|---|---|---|
| 0100 | 100 | 944.02 |
| 0200 | 200 | 396.90 |
| 0300 | 300 | 239.10 |
| 0400 | 400 | 166.89 |
| 0500 | 500 | 126.26 |
| 0600 | 600 | 100.52 |
| 0700 | 700 | 82.90 |
| 0800 | 800 | 70.16 |
| 0900 | 900 | 60.55 |
| 1000 | 1000 | 53.09 |
| 2000 | 2000 | 22.31 |
| 3000 | 3000 | 13.44 |
| 4000 | 4000 | 10.62 |
| 5000 | 5000 | 7.11 |
| 6000 | 6000 | 5.65 |
| 7000 | 7000 | 4.66 |
| 8000 | 8000 | 3.94 |
| 9000 | 9000 | 3.39 |

NOTE: The values of the distance are converted from meters to miles before use in the formula.

## 3.3 BIOLOGICAL FACTORS/INDICATORS

The main biological factors chosen were vegetation and livestock. Data on them was obtained using rapid, and reliable methods, among which were SPOT image interpretation and field checking, recent past photo interpretation and field checking, field vegetation sampling, administration of a questionnaire and literature review. Details on these methods are given below:

### 3.3.1 Vegetation Factors

Data was collected on vegetation factors given in Table 3. Prior to data collection, a vegetation unit map for each study area was drawn through visual interpretation of the enhanced dry season SPOT imageries augmented by field checks. A vegetation classification system suggested by Grunblatt et al (1989) was used.

This was necessary because the map formed a basis for collecting data on the chosen factors for the assessment of degradation of vegetation cover i.e. each vegetation unit formed the primary sampling stand or stratum.

#### 3.3.1.1 Determination of Canopy Cover of Trees and Shrubs

The canopy cover determination of trees and shrubs was done using both the line intercept method (McIntrye 1953, CanField 1941, Heady 1983 and Westmand 1984) and the Ocular or Releve method (Zonnoveld et al 1979). The measurements were done during both the dry and wet season.

In each vegetation unit at least two trained vegetation experts made independent visual or ocular estimation of the canopy cover from an elevated point, a Land Rover top, and or by moving around and inside the vegetation cover type.

After ocular estimates, at least three transacts were randomly laid within each vegetation type and canopy cover estimates made using the line intercept method. The length of the line transect varied according to plant density, distribution and plant homogeneity in each cover type. For example, cover types of low density had longer transects than those of high plant density or even distribution. However, the minimum, length of the transect was 100m with an average of 300m. Along the transect line, the canopy cover of each shrub or tree intercepted was measured using a measuring tape. The shrubs or trees intercepted were identified and recorded. The bare and herb areas were also measured. Apart from data on canopy cover, the line-intercept method was also used to derive data on plant frequency and composition.

The canopy cover of the woody (trees and shrubs), herb cover and bare area were used in the analysis of vegetation degradation and water erosion status.

#### 3.3.1.2 Primary Biomass Production

Only the primary biomass production (standing crop) of the herbaceous cover was determined. Time available was inadequate to collect data on the biomass production of trees and shrubs. The biomass production was determined using the quadrat method (Grig-Smith 1964, Kershaw 1973, Southwood 1978 and Krebs 1978). The data was collected both in dry and wet season. The data for the wet season was collected immediately after the rains when production was at its peak.

A quadrat of 0.5x0.5m was used and in every vegetation type, a total of 15 quadrats were laid at an interval of 10m along a transect. First, in each quadrat laid, the percent cover of vascular plants, bryophytes, litter, bareground (mineral soil), and rocks or gravel or stones were ocularly estimated and recorded on data sheets. Second, each plant species (less than 0.5m in height) in each quadrat was identified and clipped for drying and weighing. The clipped plant materials were oven-dried for three days at a temperature of 70°C before weighing. The oven dry weight for each vegetation type was calculated in (kg/ha/yr) to obtain the primary biomass production.

The data was used to produce general primary production maps and in estimating carrying capacities for the two study areas.

#### 3.3.1.3 Desirable Species

A detailed plant checklist for each vegetation cover type was made by an experienced taxonomist. In each vegetation type, the taxonomist randomly recorded as many plant species as he came across through the tallying system. The plant species were recorded on the basis of either being rated rare, frequent, common or abundant. The checklist was enriched by new hits made during sampling using both the quadrat and line intercept sampling methods.

The plant checklist was used in the mapping of desirable plant species. Desirable plant species in this context are those plants that provide the bulky forage material for both livestock and wildlife. The desirable species listing was compiled from literature especially from previous studies by Integrated Project for Arid Lands (IPAL) (Lusigi et al 1986,) and also from field interviews with the local people.

A ratio of desirable species to the total species was calculated for each vegetation type and used in the derivation of vegetation degradation status.

#### 3.3.1.4 Recent Past Photo Interpretation

To determine the rate of vegetation degradation, recent past photos dating as far back as 1950, were acquired for certain selected areas in the study areas. The areas selected were those where it was apparent that vegetation degradation had occurred and are currently heavily settled as well as control areas. The photos were interpreted using both a stereoscope and dot grid. The analysis aimed at demonstrating changes in the woody vegetation in terms of area and percent cover, agricultural activities and human settlements. The vegetation maps emanating from this exercise were digitized and using the overlay capabilities of the GIS, vegetation changes over the years under consideration were discerned.

### 3.3.2 Animal Factors

Animal (livestock) numbers and their distribution in the study areas were derived from two main sources. From the Department of Resource Surveys and Remote Sensing and from a questionnaire administered at the study areas. The department has been collecting information on livestock and wildlife numbers and distribution in the Kenya rangelands since 1977 using systematic reconnaissance flights (SRF) (Norton-Griffiths 1978) and the data is kept in the department's data bank.

The questionnaire was designed to provide among other things information on animal numbers, and herd composition at a household level. Information was also collected on the general grazing systems and on local views about historical conditions of the range and the number of animals that used it as compared to the present.

Information on both economic and social values attached to each livestock species was also collected. Information on the perceived impact of livestock on the environment was also solicited. Livestock numbers were used to calculate the present stocking rate of the study areas, and to determine population trends. Using the data collected, it was possible to comment on the economic and social values of livestock as perceived by pastoralists, including their impact on environmental degradation.

## 3.4 SOCIAL FACTORS

Data on social factors (see Table 3) was predominantly collected through the administration of a questionnaire except for the data on agriculture, settlement expansions and human population trends and measures of nutrition status.

The data on agriculture, settlements and sedentarization was obtained after analysing recent past photos and SPOT imagery. Data on human population trends was extracted from the district administration files and from the 1969 and 1979 population census records (Central Bureau of Statistics (CBS), 1969, 1979). Information on population structure at a household level was collected through the administration of a questionnaire. Nutritional status was determined from measurements of the circumference of the mid-upper arm on children between ages 1-5 years. A circumference of less than 13.5cm meant the child and indeed the household was suffering from some form of nutritional stress (Caldwell 1975).

## 3.5 DATA ANALYSIS (MODELLING)

Preliminary analysis focused on a review of the FAO/UNEP methodology to select data elements appropriate for a national level desertification assessment. Data was gathered through field studies and by review of the available literature. Data was entered in the GIS by digitizing maps and entry of tabular datasets. A preliminary desertification assessment using the FAO methodology was performed in Marsabit and was evaluated using the field data. On the basis of this evaluation a revised methodology was selected for application in Baringo and later in Marsabit. The results for Marsabit are given in a different report (see Appendix 1 - Report No. 5).

The revised methodology focused on the development of models that could be used in desertification assessment and mapping at national and regional levels. Five models of assessment of desertification status were developed:

The titles are:

1. Water erosion status
2. Wind erosion status
3. Vegetation degradation status
4. Range carrying capacity status
5. Human population density status

These models were developed using the detailed data collected in the study areas. Thus field data on the status of water and wind erosion and vegetation degradation were used to cross-check and validate the simulated status of these aspects. Information on desirable/undesirable species was used to validate vegetation degradation models. The range carrying capacity status was based on the present stocking rates and available forage, while the human population status was based on the density of human settlements. A methodology was developed whereby model output was cross-checked by comparison with other data. Consequently, output could be quantitatively evaluated and models could be fine-tuned to reflect a true picture of the field condition.

The development of these models was only possible through the use of the overlay capabilities of the geographic information system (GIS). The details on how the models were developed and the algorithms used are given in a separate report (see Appendix 1). Below is a brief discussion on each model and data elements used.

3.5.1 Water Erosion Status

The simulated water erosion status was generated using the Universal Soil Loss Equation (USLE) (Wishchmeir and Smith 1965) which was modified to suit the local conditions. Thus the land management and conservation factors in the U.S.L.E. were substituted with vegetation and rockiness factors. This was necessary because the study areas were predominantly used for extensive grazing and are located in semi-arid and arid areas where very little cultivation is practised. Rockiness factor is based on coarse fragments values used by Olderman (1988). The water erosion status was therefore analyzed using the following equation:

Status = Slope * Erosivity * Erodibility factors * Vegetation cover (%) * Rockiness factor (%).

Based on this analysis and field data, it was found feasible to rate water erosion status into a three-point scale: slight, moderate and severe. The rating was based on soil deformation features caused by water. Thus water erosion status was rated slight if the area had only rills and was rated as being moderate if it was experiencing sheet erosion and had moderate gullies. It was rated severe if the area was extremely gullied and had developed into badland.

The details on the data elements used in the analysis of water erosion status are given under sub-section 3.2.2 and 3.3.1.

3.5.2 Wind Erosion Status

The data required for the analysis of wind erosion status were: vegetation cover (%), rockiness cover (%) and potential wind erosion in the study areas. The rockiness and vegetation cover (%) data was collected in the field (see sub-sections 3.2.2 and 3.3.1.1).

The potential wind erosion in the study areas was calculated as explained in subsection 3.2.4.1 of this report.

As for the water erosion status, it was found feasible to rate wind erosion into a three-point scale: slight, moderate and severe based on vegetation and rockiness cover. The following equation was used in wind erosion status analysis.

Status = Vegetation cover (%) * Rockiness factor (%) * Wind erosivity index

### 3.5.3 Vegetation Degradation status

The vegetation degradation status for herbaceous biomass was derived by subtracting actual vegetation production from potential vegetation production of the study areas.

The potential herbaceous vegetation production was calculated using rainfall use efficiency (RUE) values given by Pratt and Gwynne (1977) as detailed in Le Houeroux (1984). The RUE factor is the quotient of annual primary production by annual rainfall, i.e. the number of kilograms of aerial dry matter biomass produced over 1 ha in one year per millimetre of total rainfall. A rockiness factor was included to reflect varying site productivity. The actual vegetation production was determined from field data (see sub-section 3.3.1.2). The vegetation degradation status was therefore determined using the following equation:

Status = Actual Herb Production - Potential Herb Production
Potential Herb Production = Annual Rainfall * RUE * Rockiness factor

The vegetation degradation status was further analysed by calculating the ratio of desirable species to the undesirable species in each vegetation type (sub-section 3.3.1.3). Both the vegetation degradation status and the ratio of desirable species to the undesirable species were rated using a 3-point scale: slight, moderate and severe.

### 3.5.4 Range carrying capacity status

The range carrying capacity status was derived by subtracting the predicted livestock herbaceous consumption from the actual herbaceous biomass available in each study area.

The actual herbaceous biomass (standing crop) was determined as explained in sub-section 3.3.1.2. This biomass was reduced by about 25 per cent to provide for the usual errors associated with vegetation sampling using small plots or quadrats (Pratt and Gwynne 1977).

The data on livestock numbers and their distributions for each study area was obtained from the Department of Resource Surveys and Remote Sensing (DRSRS). The body weights used in the calculation of annual consumption requirements for each livestock species were: camel 301 kg, cattle 180 kg, donkeys 150 kg, and shoats (sheep and goats) 24 kg.

These body weights were obtained from Lusigi (1984). In calculating consumption for each animal species the following assumptions were made:

1. Each animal consumes forage material equivalent to about 2.5% of its body weight daily (Pratt & Gwynne 1977); and

2. That animals consume only about 66% of the available forage material without damaging range condition. This is a proper use factor which has been adopted for use in range science.

In addition the percent of diet of herbaceous material for each livestock type was considered. Based on Lusigi (1984), the diet of cattle, shoats, donkeys and camels consist of 99%, 80%, 99% and 71% of herbaceous material respectively.

Using the above data and assumptions the range carrying capacity status for each study area was determined. The status was rated into a 3-point scale: slight, moderate and severe.

The slight rating represents areas where the stocking rates fails to exceed the range carrying capacity, while moderate represents areas where stocking rates almost exceed the range carrying capacity. Finally severe rating represents areas where the range carrying capacity is exceeded and range deterioration is apparent. The range carrying capacity was determined using the following equation:

Status = Available Herb Biomass - Predicted Livestock Consumption
where Available Herb Biomass = Field Data

### 3.5.5 Human Settlement Density Status

The human settlement density status was generated using SRF data collected by the Department of Resource Surveys and Remote Sensing on permanent human settlements (or dwellings). The dwellings were classified into three categories and then rated as follows:

| Category | Rating |
| --- | --- |
| 0 to 10 dwellings/$km^2$ | Slight |
| 10 to 20 dwellings/$km^2$ | Moderate |
| 20 dwellings/$km^2$ | Severe |

### 3.5.6 Desertification Hazard Map

A final desertification hazard map was generated by overlaying the results of the above analysis and adding up the individual status scores. The desertification hazard map which represents the actual danger of an area or region being desertified was rated into a 4-point scale rating: none, slight, moderate and severe.

# 4 RESULTS

## 4.1 INTRODUCTION

Detailed results for the soils, vegetation, wind erosion and human components of this study are given in separate individual reports (Appendix 1). In this report only a summary of the results of each individual report are given. The results are given in both tabular and map form. The maps were generated using the geographic information system technology. Most of the maps have not been printed on hard copies but are available in the GIS at DRSRS and can be produced when needed. For the purpose of this report, it was found necessary to produce only the status and hazard maps.

## 4.2 THE SOILS COMPONENT

The following maps and tabular data for both Baringo and Marsabit study areas were produced:

Maps

a. Soil unit maps
b. Rockiness cover maps
c. Water erosion maps
d. Soil erodibility maps
e. Soil salinization and alkalinization maps

Tabular

a. Revised criteria for assessing water erosion
b. Revised criteria for assessing salinization and alkalinization
c. Results of soil analysis for Baringo study area
d. Results of soil analysis for Marsabit study area.

The above generated maps (b to e) were transformed into 5 qualitative ratings of desertification (none, slight, moderate, severe and very severe) and the output are status maps for each factor indicator. The revised criteria for the assessment of water erosion and salinization and alkalinization are based on the detailed data collected in the study areas. The criteria may be applicable elsewhere where such detailed assessment may be undertaken.

## 4.3 THE VEGETATION COMPONENT

The following maps and tabular data for both Baringo and Marsabit study areas were produced:

Maps

a. Vegetation/land use maps cover
b. Vegetation canopy cover (including ground bareness, herb layer cover, shrubs/trees)
c. Biomass production (standing crop)
d. Distribution of desirable plant species.

Tabular

a. Seasonal Biomass production in different vegetation types
b. Plant frequency and density
c. Plant community associations
d. Data for correlation analysis (releve method versus line intercept method).

The above generated maps (b and d) were transformed into 5 qualitative rating of desertification and the output are status maps. Vegetation communities in the same ecological zones were considered together and the cover classes suggested by Grunblatt et al (1989) of closed, dense, open, sparse and barren (or bare) were employed in the severity rating.

The results on rate, analysed from recent past photographs are summarised in Tables 5, 6 and 7. The dot grid methodology proved useful in the case of Baringo where photographs available were at scales of 1:20,000 and 1:40,000. It was possible to delineate vegetation community boundaries, cultivated areas, and count settlements. However, for Marsabit the photographs available were at scales of 1:50,000 and 1:80,000. At these scales the smaller trees and shrubs which are common in these areas are hardly discernable. It was, however, possible to draw broad areas of different canopy covers by visual estimation and therefore changes in boundaries were possible but not their actual canopy covers. At these scales of Marsabit it was also possible to delineate cultivated areas and settlements could be identified and counted. The time span considered was 32 years (1950 - 1981) for Baringo and 16 years (1956 - 1972) for Marsabit.

In Baringo, it was found that some vegetation communities expanded in area as well as improved in canopy cover, while others also expanded in area and degraded in canopy cover (see Table 5). The causes of improvement were mainly due to irrigation in Perkerra at Marigat. The area downstream the irrigation scheme changed from sparse vegetation to closed forest due to water percolating downstream and providing enough soil moisture. Other areas are frequently flooded and changed into grasslands. In some other sites the course of rivers changed and created new and better vegetation cover at their deltas on Lake Baringo.

It is, therefore, difficult to give one single rate of change on vegetation cover. However, on average the area which improved was 11%, the area which degraded was 14% and that which remained the same was 70%. The area under cultivation increased from a negligible area to occupy an average of 5% of the study sites.

The settlements (and therefore population) increased tremendously in all the study sites (Table 7). The large increase in Kampi Samaki was due to tourism activities and fishing and fish processing industry at the centre; while in Marigat it was due to irrigation scheme activities at Perkerra.

The general picture for Marsabit is that no significant degradation occurred during the 16 years except for Logologo and a little for Illaut. Agriculture except for around Marsabit mountain was negligible and settlements increased but not as much as Baringo. Because the degradation was apparent only at Illaut and Logologo, it would not be fair to derive a rate and generalise it to the whole study area.

Table 5

**CHANGES IN VEGETATION COVER AND AGRICULTURE FOR SIX SITES IN BARINGO 1950 - 1981.**

| Site | Period | Areas that Improved to a better cover class | | Areas that degraded to a worse cover class | | Areas slightly degraded or improved but remained in same cover class | | % Area that changed into agriculture |
|---|---|---|---|---|---|---|---|---|
| | | % Area | % Change in cover | % Area | % Change in cover | % Area | % Change in cover | |
| Marigat | 1950-1981 | 3.9 | +30 | 5.0 | 15 | 73.0 | -2 | 18.1 |
| K. Samaki | 1950-1981 | 2.0 | +8 | 4.5 | -15 | 91.5 | -4 | 2.0 |
| Sandai | 1950-1981 | 6.5 | +10 | 14.9 | -32 | 72.8 | -9 | 5.8 |
| Komolion | 1950-1981 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Ngambo | 1950-1981 | 43.2 | +60 | 27.7 | -10 | 25.0 | -6 | 4.1 |
| Salabani | 1950-1981 | 11.0 | +20 | 31.6 | -13 | 55.9 | +3 | 1.5 |
| Average | | 11.1 | | 14.0 | | 69.7 | | 5.3 |

Table 6

**CHANGES IN VEGETATION COVER AND AGRICULTURE FOR SIX SITES IN MARSABIT 1950 - 1981.**

| Site | Period | Areas that Improved to a better cover class | | Areas that degraded to a worse cover class | | Areas slightly degraded or improved but remained in same cover class | | % Area that changed into agriculture |
|---|---|---|---|---|---|---|---|---|
| | | % Area | % Change in cover | % Area | % Change in cover | % Area | % Change in cover | |
| Illaut | 1956-1972 | 0 | 0 | 18.0 | -15 | 82 | 0 | 0 |
| Balesaa | 1957-1972 | 0 | 0 | 5.0 | -25 | 95 | 04 | Negligible |
| Logologo | 1956-1972 | 0 | 0 | 100 | -20 | 0 | 09 | 0 |
| Kargi | 1957-1972 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Korr | 1956-1972 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Karale | 1957-1972 | 0 | 0 | 0 | 0 | 100 | 0 | Negligible |
| Average | | 0 | | 20.5 | | 79.5 | | Negligible |

Table 7 **CHANGES IN SETTLEMENTS IN THE 12 SITES OF BARINGO AND MARSABIT**

| Site | Year | No. of settlements | Year | No. of settlements | % change in settlements |
|---|---|---|---|---|---|
| BARINGO | | | | | |
| Marigat | 1950 | 36 | 1981 | 668 | 1756 |
| K. Samaki | 1950 | 2 | 1981 | 463 | 23000 |
| Sandai | 1950 | 5 | 1981 | 100 | 1900 |
| Ngambo | 1950 | 20 | 1981 | 136 | 580 |
| Salabani | 1950 | 13 | 1981 | 132 | 915 |
| Komolion | 1950 | 6 | 1981 | 12 | 50 |
| MARSABIT | | | | | |
| Ilaut | 1956 | 97 | 1972 | 147 | 52 |
| Balesa | 1957 | 30 | 1972 | 43 | 43 |
| Kargi | 1957 | 19 | 1972 | 36 | 89 |
| Logologo | 1956 | 15 | 1972 | 67 | 347 |
| Koir | 1957 | 7 | 1972 | 58 | 729 |
| Karalle | 1957 | 15 | 1972 | 21 | 40 |

## 4.4 WIND EROSION

The following maps and tabular data for both Baringo and Marsabit study areas were produced:

Maps

a. Wind deflation and deposition areas
b. Wind roses

Tabular

a. Wind erosion assessment using mean wind speed at 2m height (m/sec)
b. Wind erosion assessment using the frequency of active wind (V>6m/sec) expressed as % of total number of wind observations for 1982 - 1985
c. Annual ratings of movements of sand
d. Load of sand carried by wind in tons per cubic mile.

The major finding on wind erosion in Marsabit were:

a. The rate of soil/sand flow is negligible at the windward site of Mt. Marsabit but increases with distance at the leeward side until it reaches a maximum that a given wind can carry.

b. The deflation areas are found to exist in the north and south of Mt. Marsabit. These are the areas where cyclonic and anticylonic vortices have been found to exist.

c. Severe wind erosion occurs during dry season due to high frequency of severe sand-storms/dust-storms and also due to the wind deflation areas having little or no vegetation cover.

In the Baringo study area the main findings were:

a. No wind action was observed during the time of field study (wet season). The ground was bare in many places.

b. In the dry season, (December, January, February and March), it was reported that wind speeds are very high and during this period severe dust-storms occur. This is the period when the ground is dry and bare.

## 4.5 HUMAN ECOLOGY

Social-cultural and socio-economic data were collected in the two study areas in both map and tabular form:

Maps

a. Livestock grazing system

Tabular

a. Human feeding habits
b. Livestock herd composition, numbers and ranking of species importance.
c. Water availability
d. Human population
e. Measures of nutrition
f. Main constraints to livestock sales
g. Settlement types
h. Reasons for migrating
i. The socio-economic status
j. Factors for socio-economic development
k. Whether there is pressure on land resources and reasons for land degradation
l. Traditional methods of environmental conservation and the status of the environment as it is now compared to what it was 20 years ago.

Table 8 **HUMAN POPULATION BARINGO LOWLANDS (NJEMPS LOCATION)**

| Sub-Location | 1979 Population | % Increase since 1962 | 1979 Population (per km$^2$.) |
|---|---|---|---|
| Ngambo | 3116 | 101 | 66 |
| Loiminange | 1523 | 62 | 8 |
| Eldume | 808 | 57 | 19 |
| Mukutani | 1541 | 46 | 8 |
| Salabani | 1793 | 31 | 50 |
| Marigat Trading Centre | 987 | - | 160 |

Source: LBS 1962 and 1979 Population census, and Little (1981)

Table 9 **TOTAL POPULATION OF THE GABRA, RENDILLE AND BORAN IN 1962, 1969, AND 1979 IN MARSABIT DISTRICT**

| | 1962 | 1969 | 1979 |
|---|---|---|---|
| Gabra | 10,734 | 15,890 | 23,410 |
| Boran | 3,283 | 13,432 | 30,444 |
| Rendille | 13,638 | 17,686 | 19,856 |

Source: CBS population census 1962, 1969, and 1979

The details of the data are presented in a separate report (see Appendix 1). The major findings of the human ecology aspect of this study were:

1. The human population has drastically increased in the two study areas since 1962 (Tables 8 and 9). The average inter-censal population growth rate between 1969 and 1979 in Marsabit has been estimated at 6.4% per year. The high population growth rate is mainly attributed to the migration of people from other areas into the district. Between 1969 and 1979 the Boran population grew by 6.8%, the Gabbra 6.2% and the Rendille 1.5% per annum. Based on the 1979 population census, the Njemps location population in Baringo was 9768. Out of this, 6800 were Ilchamus (Njemps) and the rest were Tugen who came in from the hills in search of arable land. The Ilchamus population increased more than 300% between 1929 and 1979 (Little 1981); this gave an annual increase of about 2%.

2. There is increasing pressure on land resources in both areas. About 80% of the respondents were of the opinion that pressure on land resources was increasing. The main factors responsible for this pressure were said to be increase in both human and livestock population and decrease in rainfall. This situation has been compounded by sedentarization in certain centres where there is water, shops, dispensaries, schools, famine relief e.g. at Korr, Maikonna, Kargi, Marsabit town, Logologo and Illaut in Marsabit and Kampi Samaki, Marigat, Loboi, Sandai in Baringo.

3. Cattle were singled out by the pastoralists (80% of those interviewed) as being the main agents of environmental degradation - mainly through overgrazing and trampling. Sheep and goats also play an important role in environmental degradation. The camel was singled out as the least destructive animal in both respects. Most respondents were willing to sell excess livestock, but due to low prices offered and the long distances to markets, they cannot sell their livestock.

4. About 70% of the respondents said that the environment is more degraded now than it was in the past. This is because settlements have been set up which encourage families to settle permanently in an area, leading to a breakdown in the pastoral grazing system. The cutting of vegetation for construction of *manyattas* (temporary houses) and for firewood has greatly reduced vegetation cover around the settlement areas.

5. The environmental degradation due to overgrazing is likely to continue because this study confirmed that among the Pokot, Rendille, Gabbra and Samburu, their diet is still largely meat, milk and blood from livestock, with minimal diversification of dietary tendencies.

## 4.6 RESULTS OF DATA ANALYSIS

Using the geographic information system technology, a set of selected data sets from the above results plus other ancillary data were integrated and used in developing five models for desertification assessment and mapping. Figures 3 to 9 give the modelling results for the Baringo study area. These models have been validated through field checks. Figures 3 and 4 give both the actual and simulated water and wind erosion respectively.

The details about models are given in a separate report (Appendix 1) but a general discussion is given in section 3.5 of this report. The developed models can be used to assess and map desertification at a national level. However, it should be noted that the models can still be developed further or modified if need be for a national study. For example, during the review meeting it was recommended that for national or global assessment, the following integrated models should be considered:

1. Soil degradation: including water and wind erosion;
2. Vegetation degradation;
3. Land-use: Livestock stocking rates, crops, and agricultural marginalization;
4. Societal/Population impact:socio-economic data and land tenure;
5. Climate: Index of aridity and rainfall variability.

# 5 DISCUSSIONS AND RECOMMENDATIONS

## 5.1 INTRODUCTION

The main objectives of this study were:

1. To evaluate the applicability of the FAO/UNEP Provisional Methodology for Assessment and Mapping of Desertification.

2. Develop a simplified methodology that could be used for the assessment and mapping of desertification at local and national and regional levels;

Based on the results and experience gained in this study, the following conclusions and recommendations are made:

## 5.2 APPLICABILITY OF THE FAO/UNEP METHODOLOGY

A detailed evaluation of the methodology indicated that it was extremely expensive to collect the detailed data on the proposed desertification indicators.

It was also noted that most of the data required was not available even in developed countries (Sabadell, et al 1982, Babaev et al 1984). It was therefore concluded that the proposed methodology is only applicable at a local or pilot study level and cannot be used in assessing and mapping desertification at a national and regional level. However, it should be noted that quite a number of indicators could be used to assess and map desertification at a national or regional level if only generalized data on them was used. Details on which indicator can be used at a local or national level are given in Table 3.

Concerning the methods proposed in collecting data, it was felt that for the collection of the detailed data, it is inevitable that the methods have to be mainly field - based and consequently are expensive. The proposed use of remote sensing in collecting more generalized data was considered more appropriate and of wider application.

## 5.3 HIERARCHICAL STUDY APPROACH FOR ASSESSING AND MAPPING DESERTIFICATION

In this study an hierarchical study approach was adopted in an attempt to develop a simplified methodology for assessing and mapping desertification at local, national and regional level. The principle behind this approach was to collect detailed data at local level and then select from it generalized data elements which could then be analyzed and used in developing desertification assessment and mapping models. The models could then be used to assess and map desertification at national level using basic data which may readily be available or can be collected quickly.

This approach entailed collection of detailed data on the chosen factors and indicators (Table 2 and 3) using mainly ground based methods. Thus this approach initially is quite expensive but once the models have been developed it becomes less expensive. Based on the models developed in this study, it is apparent that detailed data on a number of parameters considered in this study can only be used at local level.

## 5.4 DESERTIFICATION INDICATORS

There are many types of indicators that can be used in desertification assessment and mapping. The choice of indicators to be used will depend on the objectives of the assessment and level of detail required. For example if the assessment is undertaken at a pilot study level, detailed data on a variety of indicators may be required. However, if the study is undertaken at regional level, only general data on selected indicators may be required.

In this study, data was collected on varied types of factors/indicators. During the data analysis it became apparent that some of the indicators could suitably be used for desertification assessment at a pilot or local level only.

However, some of the indicators were found to have wider application and could successfully be used in developing models that could be used in national assessments (See Table 3). The data elements used in the development of desertification assessment and mapping models for this study are given in section 3.5.

The developed models are considered as being suitable for desertification assessment - particularly at a national level for they can be easily verified through field observation.

## 5.5 METHODS USED IN DATA COLLECTION

A variety of methods were used in collecting data in this study. The methods include use of remote sensing, field surveys, administration of questionnaire and literature review. The SPOT satellite imagery was used to produce preliminary vegetation and soil unit maps. This was also used to map areas of intensive water erosion.

The field surveys were used to collect detailed data on both soil and vegetation parameters. The questionnaire was used to collect socio-economic data.

All the above methods have their advantages and disadvantages. The remote sensing techniques give generalized data but at a lesser cost, while the field surveys give detailed data but at a very high cost. The choice of what method to use in collecting data will depend mainly on the objective of the study. However, if the objective is to provide generalized data at a smaller scale then remote sensing techniques are suitable, rapid and relatively cost-effective. For example in this study, about two days of satellite image analysis were required to produce preliminary soil and vegetation unit maps for the two study areas. However, it took about 10 days in each study area to collect detailed vegetation and soil data using field survey methods described in section 3.0. The time needed to collect detailed data was actually double because the data was collected during both the dry and wet seasons. Based on the financial expenditure of this study (see Appendix 4) it can be said that this study became expensive mainly because of the field surveys and administration of a questionnaire.

To reduce the cost of collecting data at national level, it is proposed that remote sensing be used in collecting more generalized data and simpler methods be used in collecting the more detailed data. It is recommended that ocular or visual estimation should be used in collecting data on vegetation and human settlements rather than the use of ecological methods as long as the person making the visual estimates is experienced in making of consistent estimates. In this study, ocular estimation of vegetation canopy cover was found to be as good as the data derived from line-intercept measurements. Equally visual estimation of rockiness was found to be as good as that determined using quadrats.

It should be noted that reliable visual estimation depends on the experience of the estimator and consistence of estimators depends on training, experience and calibration. It is further recommended that SRF methods be used in collecting data on livestock, human settlements and other environmental attributes i.e., vegetation.

## 5.6 THE USE OF GEOGRAPHIC INFORMATION SYSTEM IN DESERTIFICATION ASSESSMENT AND MAPPING

The GIS is an important tool in the assessment and mapping of desertification because of its capabilities in supporting modelling. The GIS allows for the integration of a number of data elements and has a wider scope of data manipulation. Its capability to produce and update maps and tabular data makes it a very important tool for desertification assessment. In this study the GIS was used in the digitization and analysis of data and in the development of desertification models, and final products.

## 5.7 APPROACH TO NATIONAL DESERTIFICATION ASSESSMENT AND MAPPING

The models developed in this study can be used to assess and map desertification at national level. The models require only generalized data. A number of institutions in Kenya collect the data that is required for the developed models. Though most of the data for the use in the models may be available, the need for further collection of data in the field to augment the existing one cannot be over-emphasized. Also there is a need to validate assessments generated using the models.

## 5.8 DESERTIFICATION ASSESSMENT OF THE STUDY AREAS

### 5.8.1 Introduction

The results of this study show that desertification which is land degradation in arid, semi-arid and sub-humid areas is a major problem in the study areas. The main forms of desertification identified were soil and vegetation degradation. The soils are being degraded through water and wind erosion, while vegetation degradation is through tree and shrub cutting and overgrazing.

Both soil and vegetation degradation are very severe around settlement areas. Apart from experiencing common land degradation problems, the study areas differ in a number of aspects i.e., climate, land use, socio-economic, degree of land degradation and potential for land rehabilitation.

### 5.8.2 Climate

The details on climate for the two study areas are given in chapter 2. In general the Marsabit study area is located in an arid environment (with exception of areas around Mt. Marsabit) where the average annual rainfall is less than 250mm. The area has seasonal rivers which originate from hill masses and drain into the central plain where their water evaporates or sinks.

In contrast, the Baringo study area is located in a semi-arid/sub-humid environment where the average annual rainfall is about 600mm. The area is drained by two permanent rivers which drain into Lake Baringo via the Njemps flats.

### 5.8.3 Land Use

As a result of difference in climate, the land use patterns in the two areas differ in a number of ways..

In Marsabit, the land is predominantly used for extensive grazing, with only areas around Mt. Marsabit being used for both arable agriculture and grazing. The area is inhabited by three nomadic tribes: the Rendille, Gabbra and Boran. The Gabbra occupy the northern and north west, the Rendille south and south-west and Boran occupy the eastern and south-eastern parts of the study area. The grazing system in the district is governed by rainfall regime. Thus during wet season (March to May) most of the grazing is confined in the lowlands. During the dry season, the animals are moved to the mountain areas i.e, the Gabbra move to the Huri Hills and Mt. Kulal, the Rendille move further southwards into Ndoto Mts. in Samburu district, and the Boran more or less confine grazing around Mt. Marsabit throughout the year. The availability of water is the most crucial factor in this grazing system.

Thus a number of areas are not grazed at all due to lack of water. There is a tendency for animals to graze around areas where there are boreholes or wells. These areas are being over utilized and consequently heavily degraded. Due to the harsh climate, the camel is the most important livestock species in this area, followed by goats.

Unlike Marsabit, the land use practice in Baringo is different and diversified. First, the grazing system is not as extensive as in Marsabit, though seasonal grazing is practised. There are three ethnic groups in the area. These are the Njemps, Tugen and Pokot. The Njemps inhabit the central lowlands or what is commonly known as Njemps flats (area between L. Bogoria and L. Baringo).

The Tugen inhabit the Tugen hills and the Pokot occupy the northern parts of the district - Muktany/Nginyang/Tanguilbei areas. The Njemps practice arable agriculture using irrigation. They are also fishermen and predominantly lead a sedentary life. They also keep livestock which is mainly grazed in the lowlands in the wet season and moved into Laikipia escarpment during the dry season.

The Tugen are basically agriculturists, though some of the families have livestock in the lowlands. The Pokot are solely pastoralists and their grazing system is well-coordinated and controlled by elders. Since the Pokot inhabit the drier parts of the study area, the camel is increasingly becoming a very important animal in their community.

Unlike Marsabit, where land is predominantly owned by tribal communities, in Baringo the land tenure system is different. In the highland areas (Tugen Hills) the land has been adjudicated and is individually owned. The lowland areas (Njemps flats) are currently being adjudicated. It is only the Pokot territory which is still being owned communally.

### 5.8.4 Socio-Economic

The economic activity of Baringo is more diversified than that of Marsabit. In Baringo both pastoralism and arable agriculture are very important while in Marsabit pastoralism is the most important. Apart from pastoralism and arable agriculture, the people in Baringo are also involved in other economic activities i.e., fishing, business and tourism activities. This is possible because Baringo has a good communication network and is near to major towns, the marketing of both livestock-mainly goats and agriculture produce is not a major problem.

As a result of its strategic position and diversity in economic activities, the population in the Baringo Study area is increasing very fast. Based on the 1979 population census, the Njemps location population was 9768 out of this 6800 were Ilchamus (Njemps) and the rest were Tugen who came from the hills in search of arable land.

In contrast, the economic activities in Marsabit are very limited due to a number of factors, the main ones being its location far away from major towns and its poor communication network. Also its harsh climatic conditions does not allow diversification in land use. As a result the major economic activity in the area is pastoralism. Thus livestock products form the major diet of the people who inhabit this area. Due to its location and poor communication, marketing of livestock is a major problem. In spite of the previously mentioned factors, the population is increasing particularly around market centres and towns. The average inter-censal population growth rate between 1969 and 1979 has been estimated at 6.4% per year. Most of the population is found in market centres i.e., Marsabit town, Kargi, Maikonna, Korr, Illaut and Logologo where there are shops, schools, missions, dispensaries and other social amenities.

### 5.8.5 Degree of Land Degradation

Land in Baringo is more prone to degradation than in Marsabit. This is mainly due to the type of soil, and the amount of rainfall received - mainly rain water from the Tugen hills. The soil in the lowlands or flats is friable and therefore liable to both water and wind erosion. Thus during the rainy season, soil is eroded and the consequence is the formation of gullies and badlands.

The areas in the study area where water erosion is very severe are Loboi, Eldume, Marigat and Endao. Water erosion is being accelerated in these areas due to increasing human and livestock population. Due to overgrazing, trampling and cutting of trees, especially around settlement areas the soils are bare and loosened and this increases their vulnerability to both wind and water erosion. Also due to increasing use of fertilizers in the irrigation schemes, the problem of salinization is increasingly becoming important. Wind erosion in Baringo, occurs only during the dry season (January - March) when most of the areas are bare. During this period, heavy dust-storms occur and a lot of soil is blown away.

Lastly as a result of overgrazing especially around settlement areas, most of the desirable plant species have disappeared and have been replaced by undesirable ones e.g., Heliotropium Spp, Portulaca Spp etc.

Due to the practice of extensive grazing in Marsabit, the land degradation is not a problem in many areas except around the settlements and trading centres. Marsabit being located in an arid environment, water erosion is not very important except on the slopes of Mt. Marsabit and the southern areas bordering the Ndoto Mountains. However, wind erosion in this area is more important than Baringo. Wind erosion is severe in the flat areas where the channel separating the Ethiopian Highlands and Ndoto and Marsabit Mountains is narrow. The winds occur in this channel throughout the year but they are very severe during the dry season. Due to vegetation cover on Mt. Marsabit and other hills and lava and rock cover in the lowlands, the wind erosion effect is minimized, otherwise the area is prone to very serious wind erosion.

### 5.8.6 Potential for Land Rehabilitation

Although land degradation is more severe in Baringo than Marsabit, the land in Baringo has a higher potential for rehabilitation than Marsabit. This is mainly because the area receives ample rainfall, the soils are fertile (alluvial sediments) and there are permanent rivers. The current land rehabilitation programmes in the area have shown that degraded land can be rehabilitated through revegetation and the potential for plant regeneration is very high. As a result of the on going adjudication programme, it is expected that land rehabilitation will be speeded once land is owned individually. The people in the area are already aware of the need for soil conservation. The potential for rehabilitation of degraded areas in Marsabit is there but not as high as in Baringo. This is mainly because the area is located in an arid environment and already some areas i.e., Chalbi desert, have attained desert conditions. However, rehabilitation programmes particularly around settlement areas have shown that vegetation can recover and thrive in some of the areas.

In both the Baringo and Marsabit study areas, land degradation has been aggravated mainly by ever-increasing human population (see Tables 8 and 9).

## 5.9 RECOMMENDATIONS

Based on the findings of this study the following recommendations are made:

1. Remote sensing techniques (Satellite Data and Systematic Reconnaissance Flights (SRF) should largely be used in the gathering of data for assessment and mapping of desertification at national level. The techniques are simple, rapid and relatively cost-effective. It is recommended that the use of visual interpretation of satellite image should be adopted with minimum digital image analysis.

2. The development and use of models in desertification assessment and mapping at regional or national level should be encouraged and strengthened. Further improvement and validation of the developed models is essential.

3. Visual or ocular estimation methods should largely be used in collecting data from the field particularly for the data to be used at a national or regional level. This will allow for rapid gathering of detailed data from the field and reduce costs.

4. The socio-economic data in desertification assessment is very important and should not be ignored. However, most of it is applicable at local or management level.

5. The desertification indicators given in Table 3 are recommended for desertification assessment and mapping at local, and national levels.

6. Because of the large amounts of data required for the modelling process and for generating tabular and cartographic products use of GIS is recommended. The use of GIS will allow establishment of data base for further or long-term evaluation. Development of standard methods of data analysis will enhance the usefulness of the GIS.

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Appendix 1

LIST OF INDIVIDUAL CONSULTANT REPORTS

1. Report on Soils in the UNEP/DRSRS Desertification Assessment and Mapping Project by M. J. Kamar

2. Vegetation Assessment and Mapping in Baringo and Marsabit Areas by W. K. Ottichilo and R. K. Sinange.

3. Human Ecology as a Factor in the Desertification Process in Baringo and Marsabit Districts Pilot Study Areas by H. A. Mwendwa.

4. Assessment of Applicability of FAO/UNEP Methodology on Wind Erosion in Selected Areas in Marsabit and Baringo and Recommended Wind Degradation. Indicators by J. H. Kinuthia.

5. Desertification Assessment Modelling: Kenya Pilot Study by Jess Grunblatt

Appendix 2

CALCULATION OF PET BY THORNTHWAITE EQUATION (1948):

$E = 1.6(10t/I)^a$ .................... (i)

where

E = potential evapotranspiration (cm/month)

t = mean monthly temperature (°C)

I = heat index of the year which is the summation of 12 monthly indices ...... (i)

$i = (t/5)^{1.514}$.................................... (ii)

$a = 6.75 \times 10\text{-}7I^3 - 7.71 \times 10^{-5}I^2 + 1.79 \times 10^{-2}I + 0.49$...... (iii)

The formula gives unadjusted rates of PET.

## PROCEDURE FOLLOWED TO CALCULATE ADJUSTED POTENTIAL EVAPOTRANSPIRATION (E) BY USE OF TABLES:

The unadjusted E is adjusted for day and month length, taking a month of 30 days of 12 hours each as standard. The relationship between temperature and evapotranspiration in several areas tend to converge where potential evapotranspiration is 13.5 cm and temperature is 26.5°C. At lower temperatures there is increasing divergence in potential evapotranspiration.

The procedure followed is outlined below:

1. Obtain mean monthly temperatures for the whole year in °C from the meteorological publications where available.
2. Obtain the values of i from Table A corresponding to monthly mean temperatures.
3. Obtain I (annual heat index) by summing i in Appendix 1 for 12 months.
4. Use I to get unadjusted monthly PET from Table B (a) and multiply the value obtained from table by 30. The values obtained are in mm and are converted to cm before use.
5. For mean monthly temperatures above 26.50°C obtain the unadjusted monthly PET from Table Bb. Multiply the value obtained by 30. The values obtained are in mm and are converted to cm before use.
6. Use the latitude of the station and from Table C obtain the correction factor.
7. Multiply the unadjusted monthly PET by correction factor to get the corrected value of PET.

Note: Tables A, B and C were reproduced from the measurement of Potential Evapotranspiration, Publication in Climatology Volume VII No.1 edited by Mather (1954).

Appendix 4

# FINANCIAL ANALYSIS FOR APPLICATION OF THE METHODOLOGY

## 1.0 INTRODUCTION

This financial analysis covers the costs incurred in implementing the methodology used to assess and map desertification in the study areas. The analysis only considers the costs of collecting and analysing detailed data at local level. It does not consider the costs for the purchase of vehicles and administrat ion of the project. This financial analysis approach was deemed appropriate in order to evaluate the actual cost per $Km^2$ of applying the methodology at the local level. It is hoped that the actual cost would act as a guide when budgeting for similar projects elsewhere.

## 1.1 LOCAL ASSESSMENT

The study components considered were vegetation, soils, wind erosion and human ecology. Also included in the study components is the data analysis and modelling. The details on personnel, time, field allowances, cost of maintaining and running vehicles are given in individual reports of each study component. In this analysis, the aggregated cost for each component is given as well as the cost of collecting and analysing the same data in one square kilometre ($km^2$). This information is given in Table 1. The aggregated cost covers the two study areas with a total area of 17,600 $km^2$.

The aggregated cost for each component includes consultant's fees, field allowances, cost of running and maintaining vehicles. Included also are costs for the purchase of SPOT images for vegetation, soil and wind erosion mapping, the purchase of aerial photos for the vegetation mapping, the cost of analysing soil samples and the payment to field enumerators for the human ecology component. For data analysis, the cost includes computer time, computer paper and pens and cost of hiring a systems analyst and data analyst.

Table 1 **THE AGGREGATED COST OF EACH STUDY COMPONENT.**

| Study Component | Total cost (US Dollars) | Cost per $km^2$ (US Dollars) |
|---|---|---|
| Vegetation | 33,848 | 1.92 |
| Soils | 28,418 | 1.62 |
| Wind Erosion | 11,085 | 0.63 |
| Human Ecology | 13,310 | 0.76 |
| Data Analysis | 34,500 | 1,96 |
| Total | 121,161 | 6.89 |

From the information given in Table 1, it is apparent that the costs of collecting data are different for each study component. The cost of collecting vegetation data was the highest and was followed by the soils data. However, it should be noted that the cost of collecting human ecology data would have been equally higher had the data been collected during both dry and wet season.

Based on this analysis, it can be concluded that the cost of collecting and analysing data on all the study components was about US$7/km$^2$ at local level. This is expensive particularly if the assessment was to be undertaken at national level. However, at local level, this cost is considered to be modest given that detailed data necessary for management are collected and analysed.

## 1.2 NATIONAL ASSESSMENT

For national desertification assessment and mapping, less detailed data is required. As proposed in this study, only generalized data is required for the development of assessment and mapping models. In the case of Kenya, most of the data required for national assessment is available. The climatic data is readily available at the Kenya Meteorological Department. The exploratory soil map and agro-climatic zone map of Kenya (1:1,000,000) has been produced by Kenya Soil Survey and has already been digitized by GEMS-GRID (UNEP). The data on vegetation, livestock and wildlife numbers and on human settlements for the Kenya rangelands are available at DRSRS. And data on human ecology for a number of areas in Kenya can be found at the Central Bureau of Statistics, Institute of Development studies (University of Nairobi), Ministry of Planning and National Development (ASAL Project) and in existing literature.

Therefore a national desertification assessment project in Kenya will require very limited field data collection. The main task would be to collate and analyze all the required data from different government departments and institutions and integrate it in the proposed models. However, limited field work will have to be undertaken to gather missing data and to validate the desertification maps that would be produced through modelling exercise.

Given that most of the required data for desertification assessment and mapping in Kenya is available, it envisaged that the overall cost of collecting and analysing data per km$^2$ will be much less than at the pilot or local level. It is estimated that the cost per km$^2$ will be about an eighth of the cost per component in this study. (Table 2).

Table 2

**ESTIMATED COST FOR NATIONAL DESERTIFICATION ASSESSMENT AND MAPPING**

| Study Component (US Dollars) | Total Cost (US Dollars) | Per $km^2$ |
|---|---|---|
| Vegetation | 136,080 | 0.24 |
| Soils | 113,400 | 0.20 |
| Wind | 45,360 | 0.08 |
| Human Ecology | 56,700 | 0.10 |
| Data Analysis | 141,750 | 0.25 |
| Total | 493,290 | 0.87 |

Based on this estimate, it would cost about US$ 0.90 per $Km^2$ in Kenya. Given that the total land area of Kenya is about 567,000 $km^2$, the total cost would be about US$ 510,300.

Figure 3a

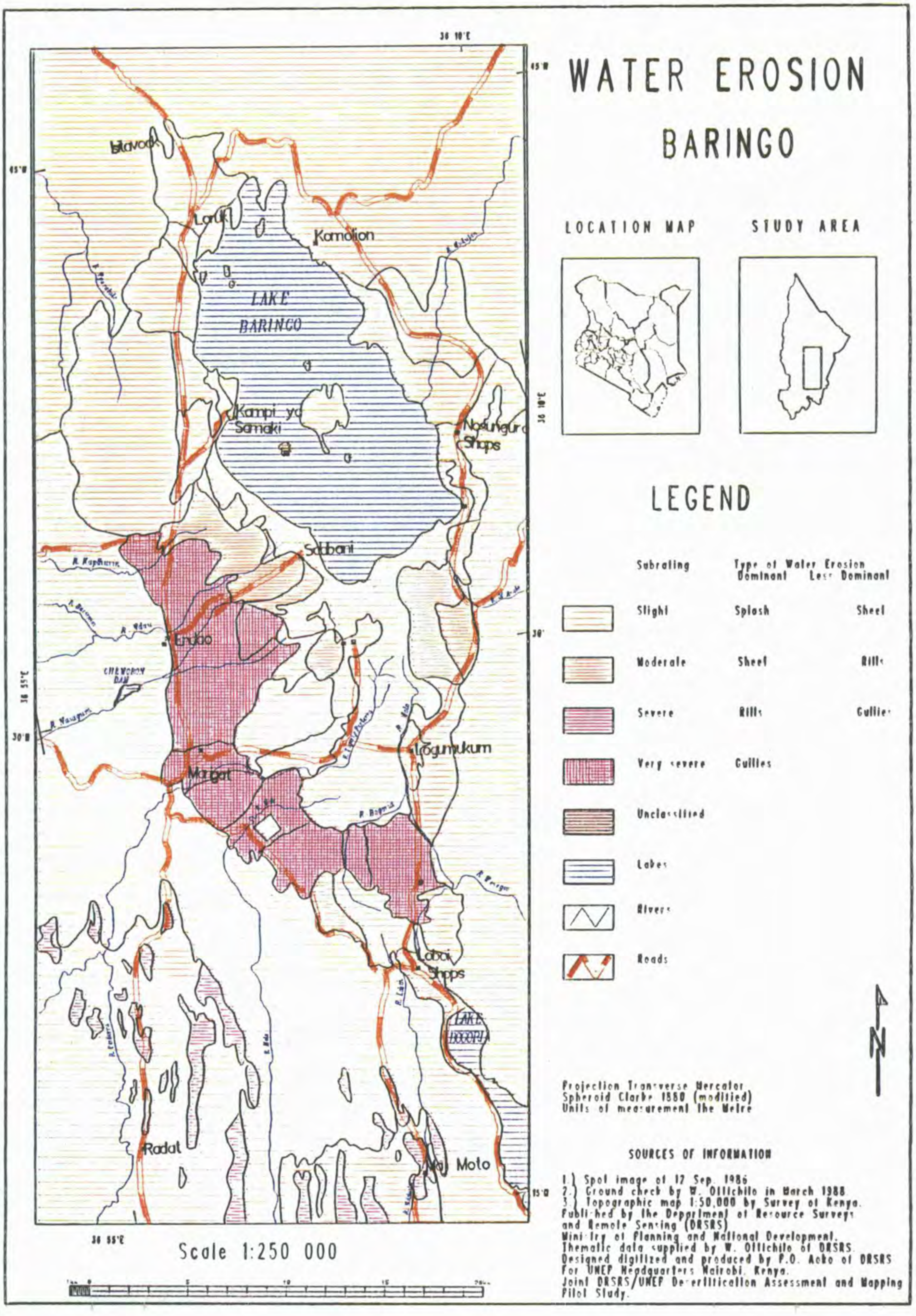

WATER EROSION
BARINGO
LOCATION MAP
STUDY AREA
LEGEND
Subrating
Type of Water Erosion
Dominant
Less Dominant
Slight
Splash
Sheet
Moderate
Sheet
Rills
Severe
Rills
Gullies
Very severe
Gullies
Unclassified
Lakes
Rivers
Roads
LAKE BARINGO
Loruk
Kampi ya Samaki
Kamolion
Nosunguro Shops
Salabani
Marigat
Loboi Shops
Radat
Maji Moto
Scale 1:250 000
Projection Transverse Mercator
Spheroid Clarke 1880 (modified)
Units of measurement the Metre
SOURCES OF INFORMATION
1.) Spot image of 12 Sep. 1986
2.) Ground check by W. Ottichilo in March 1988
3.) Topographic map 1:50,000 by Survey of Kenya.
Published by the Department of Resource Surveys
and Remote Sensing (DRSRS)
Ministry of Planning and National Development.
Thematic data supplied by W. Ottichilo of DRSRS.
Designed digitized and produced by P.O. Aoko of DRSRS
For UNEP Headquarters Nairobi, Kenya.
Joint DRSRS/UNEP Desertification Assessment and Mapping Pilot Study.

Figure 3b

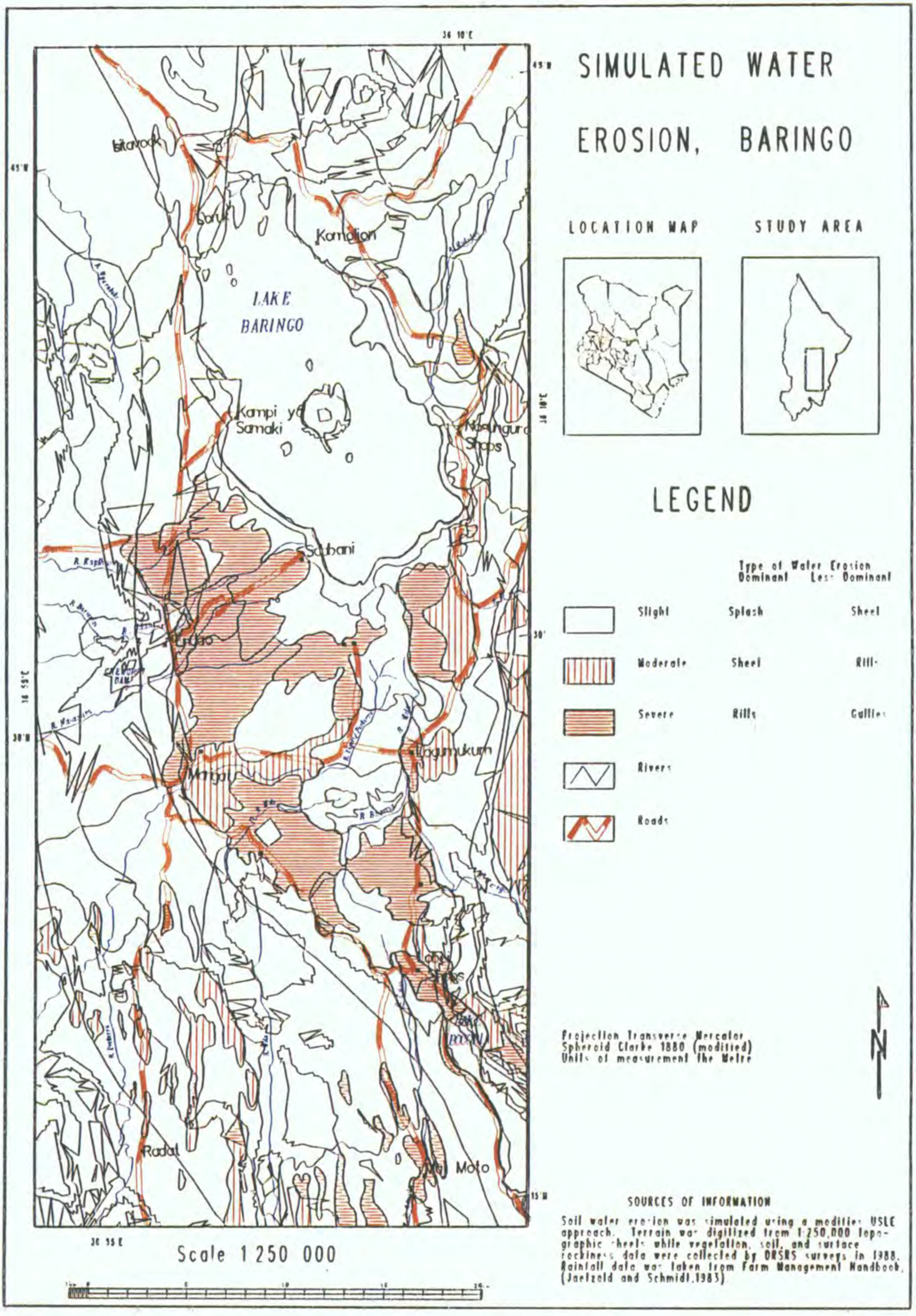
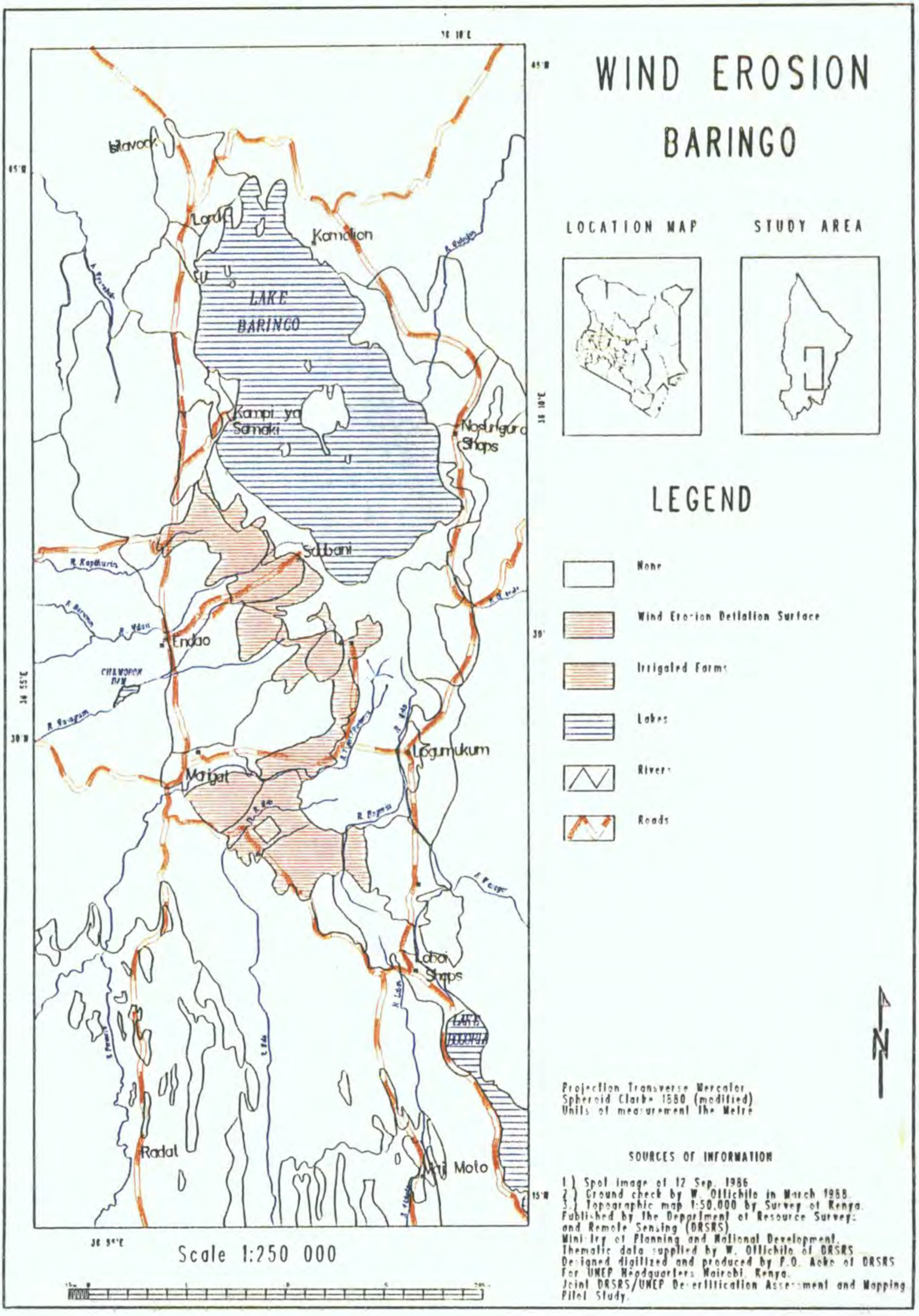
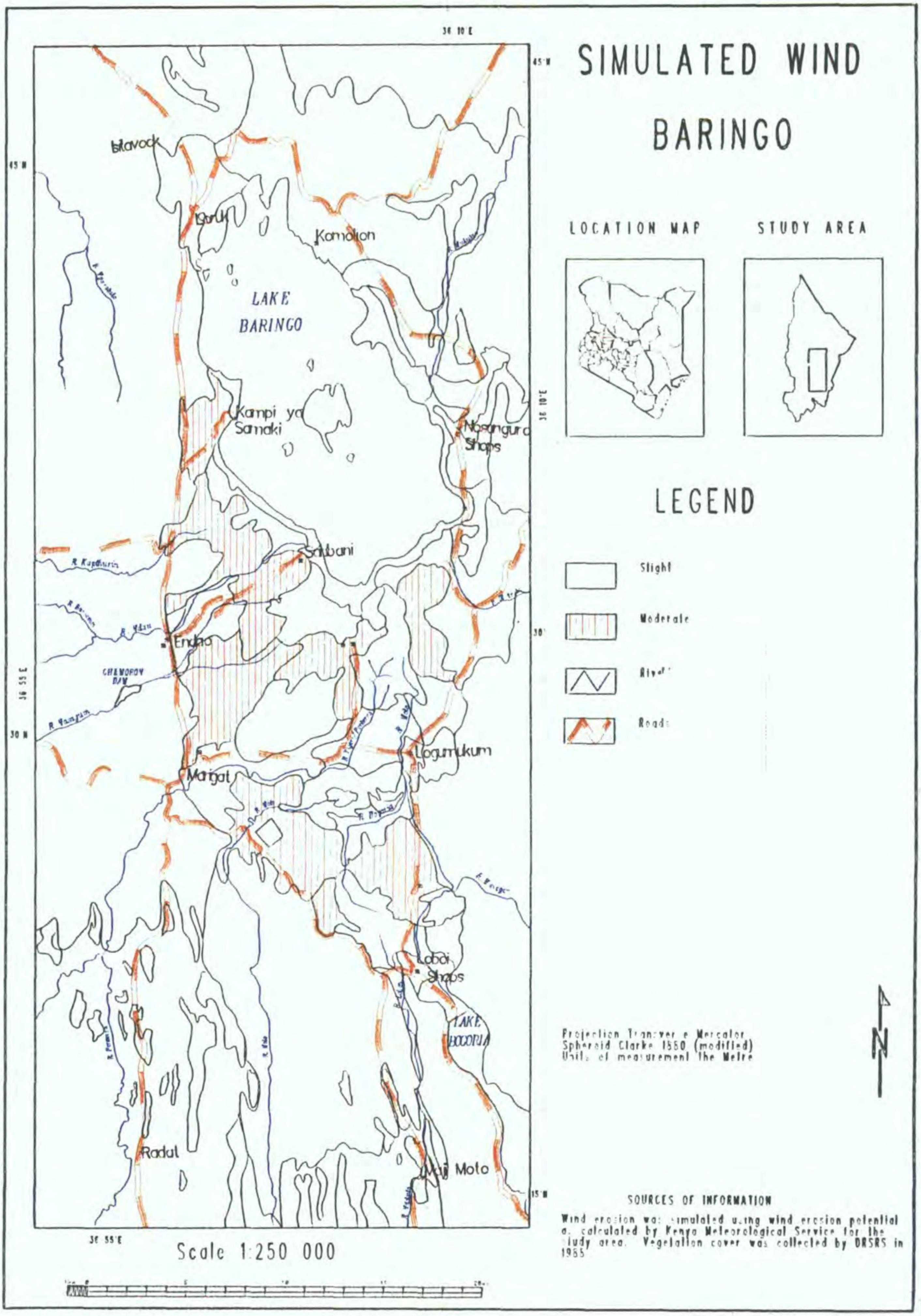

SIMULATED WATER
EROSION, BARINGO
LOCATION MAP
STUDY AREA
LEGEND
Type of Water Erosion
Dominant Less Dominant
Slight Splash Sheet
Moderate Sheet Rills
Severe Rills Gullies
Rivers
Roads
Projection Transverse Mercator
Spheroid Clarke 1880 (modified)
Units of measurement the Metre
N
SOURCES OF INFORMATION
Soil water erosion was simulated using a modified USLE approach. Terrain was digitized from 1:250,000 topographic sheets while vegetation, soil, and surface rockiness data were collected by DRSRS surveys in 1988. Rainfall data was taken from Farm Management Handbook, (Jaetzold and Schmidt,1983).
LAKE
BARINGO
Kampi ya Samaki
Salabani
Kamalion
Marigat
Loruk
Radat
Moto
Scale 1 250 000

Figure 4a




>BARI>#WIA4 87 10:47

Figure 4b




>BARI>MAP>#SWI
87 10:52

Figure 5

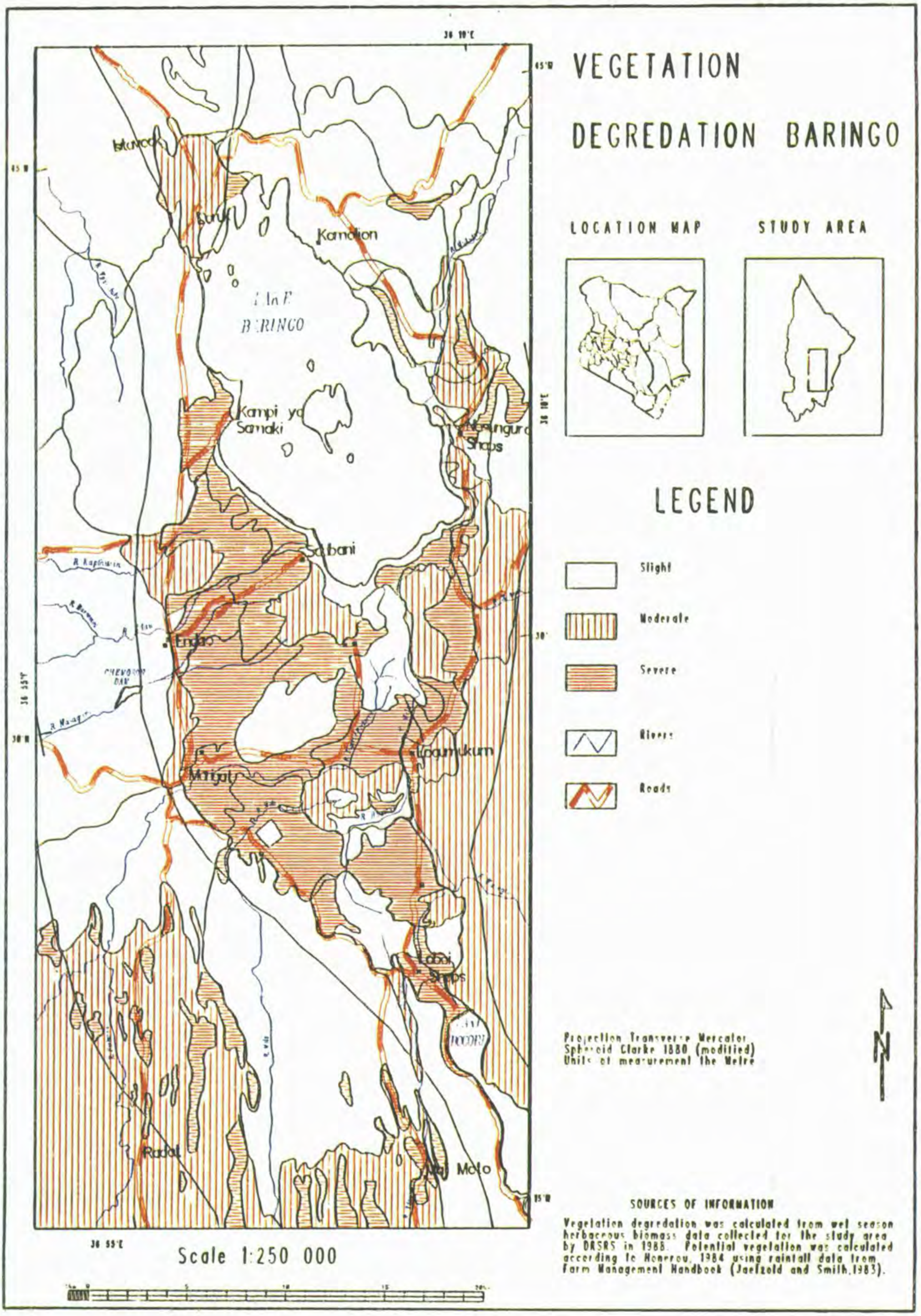

VEGETATION
DEGREDATION BARINGO
LOCATION MAP
STUDY AREA
LEGEND
Slight
Moderate
Severe
Rivers
Roads
Projection Transverse Mercator
Spheroid Clarke 1880 (modified)
Units of measurement the Metre
N
SOURCES OF INFORMATION
Vegetation degradation was calculated from wet season herbaceous biomass data collected for the study area by DRSRS in 1988. Potential vegetation was calculated according to Le Houerou, 1984 using rainfall data from Farm Management Handbook (Jaetzold and Smith,1983).
Scale 1:250 000
LAKE BARINGO
Kampi ya Samaki
Kamalion
Salabani
Endao
Marigat
Loruk
Radat
Mogotio
CHEMERON DAM
R. Kapthurin
36 55'E
36 10'E

Figure 6

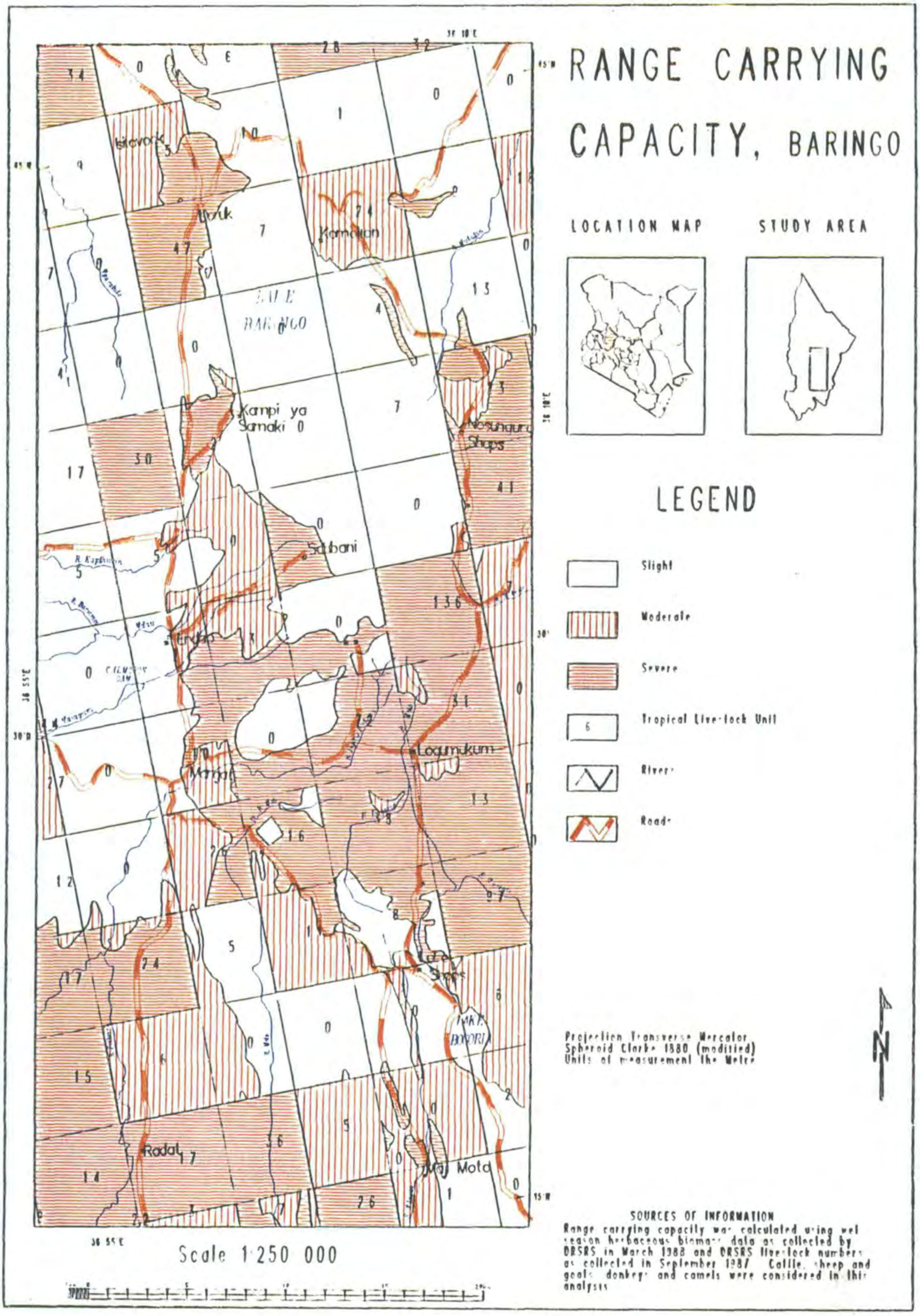

RANGE CARRYING CAPACITY, BARINGO
LOCATION MAP
STUDY AREA
LEGEND
Slight
Moderate
Severe
Tropical Livestock Unit
Rivers
Roads
Projection Transverse Mercator
Spheroid Clarke 1880 (modified)
Units of measurement the Metre
SOURCES OF INFORMATION
Range carrying capacity was calculated using wet season herbaceous biomass data as collected by DRSRS in March 1988 and DRSRS livestock numbers as collected in September 1987. Cattle, sheep and goats, donkeys and camels were considered in this analysis.
Scale 1:250 000
Loruk
Kamolion
LAKE BARINGO
Kampi ya Samaki
Nosunguru Shops
Salbani
Marigat
Logumukum
Radat
Mogotio
LAKE BOGORIA
36°55'E

Figure 7

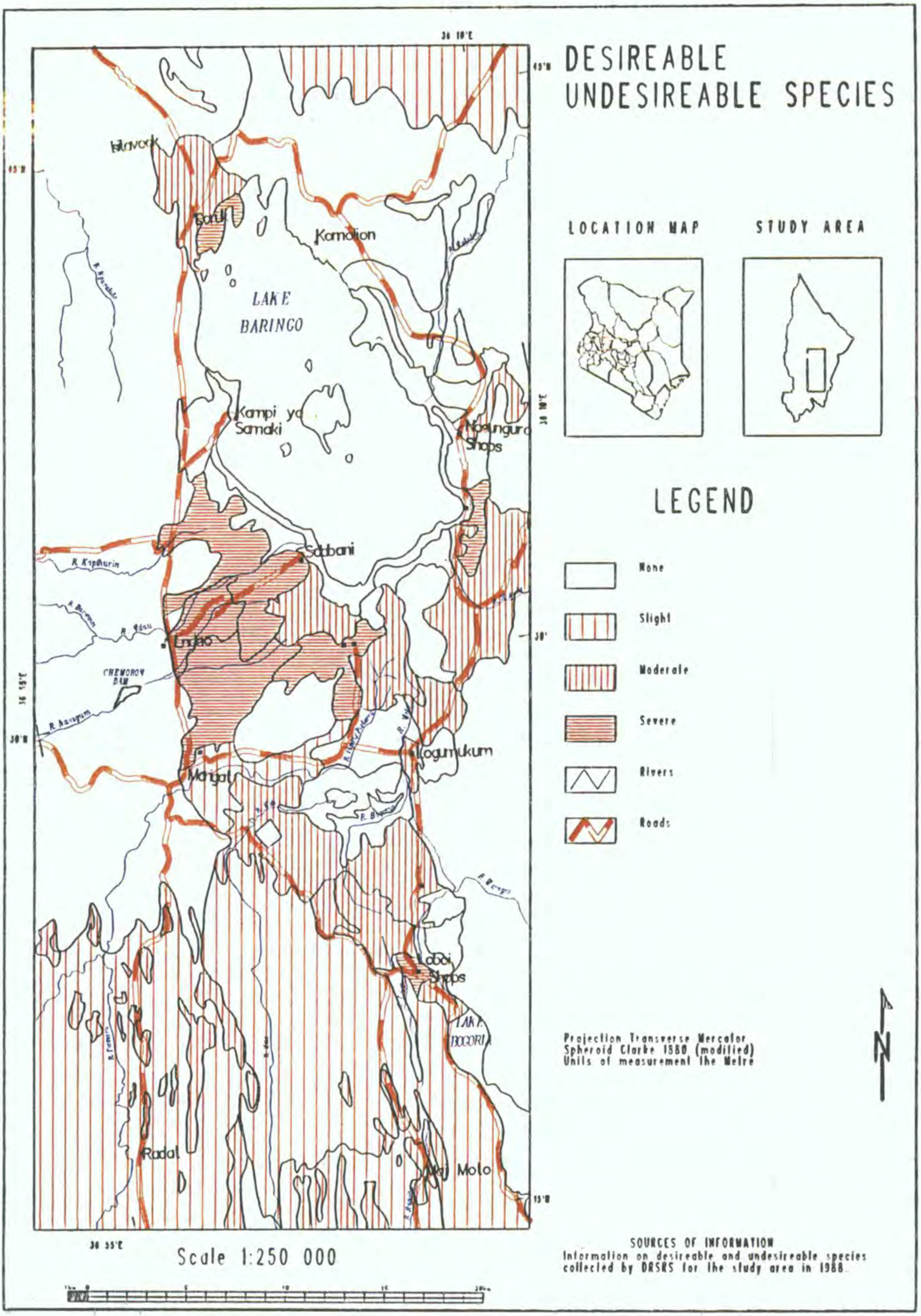

DESIREABLE
UNDESIREABLE SPECIES
LOCATION MAP
STUDY AREA
LEGEND
None
Slight
Moderate
Severe
Rivers
Roads
Projection Transverse Mercator
Spheroid Clarke 1880 (modified)
Units of measurement the Metre
SOURCES OF INFORMATION
Information on desireable and undesireable species collected by DRSRS for the study area in 1988.
Scale 1:250 000
LAKE
BARINGO
Kampi ya
Samaki
Kamolion
Loruk
Marigat
Loboi
Shops
Mogotio
Radat
Logumukum
CHEMORON
DAM
R. Kapthurin
LAKE
BOGORIA
Endao
Sabbani
Kabarnet
N

Figure 8

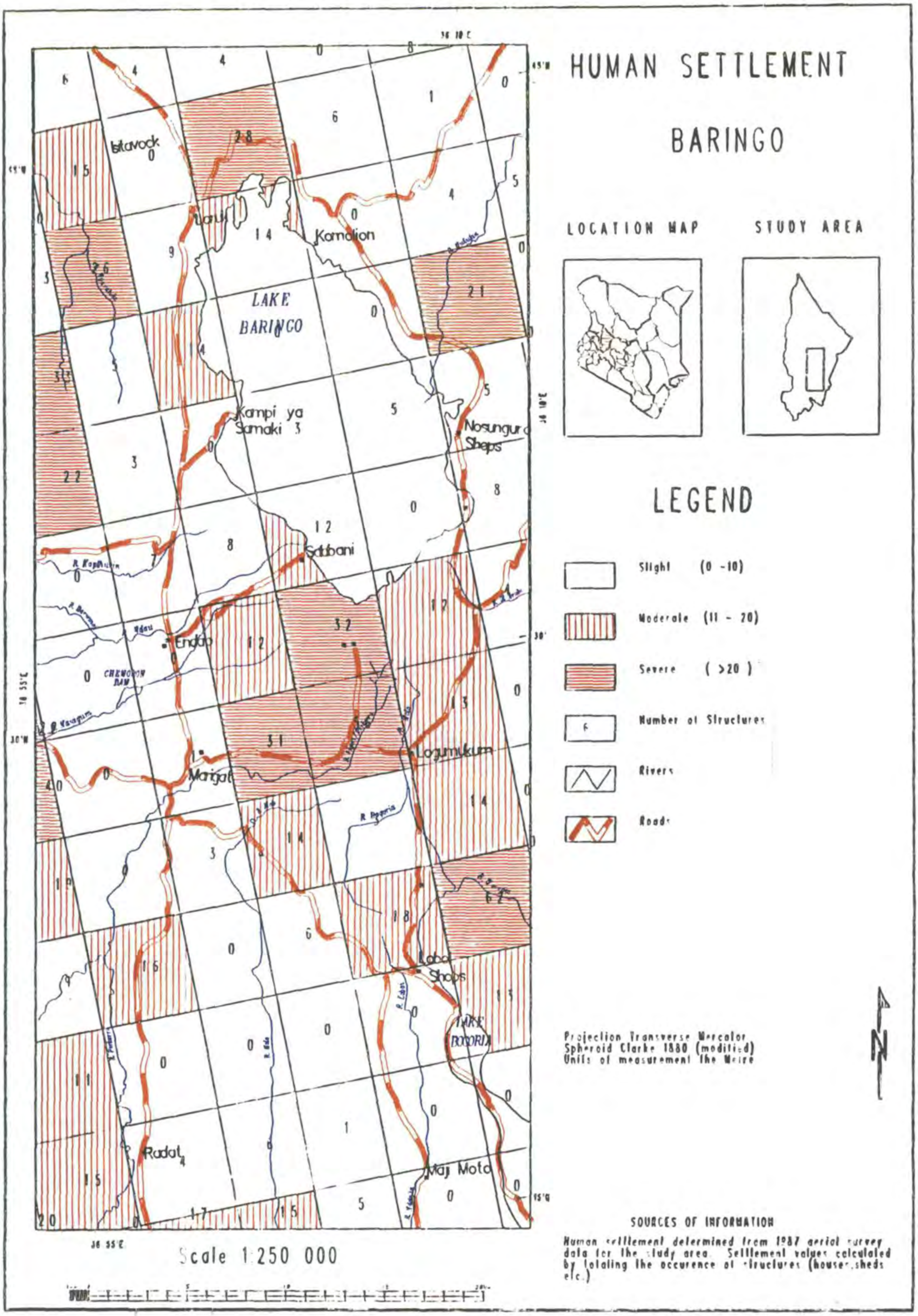
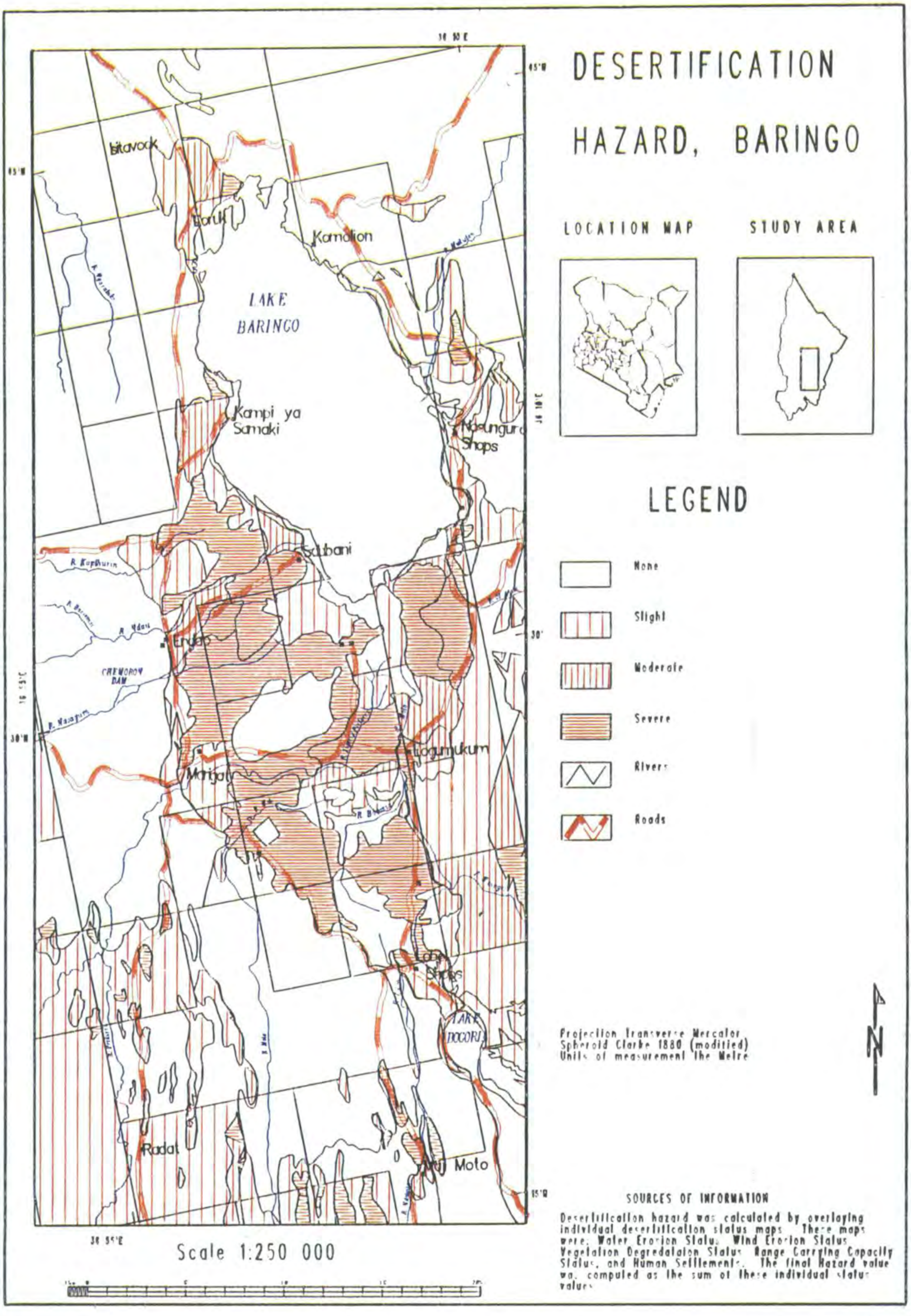

HUMAN SETTLEMENT
BARINGO
LOCATION MAP
STUDY AREA
LEGEND
Slight (0 - 10)
Moderate (11 - 20)
Severe ( >20 )
Number of Structures
Rivers
Roads
Projection Transverse Mercator
Spheroid Clarke 1880 (modified)
Units of measurement the Metre
SOURCES OF INFORMATION
Human settlement determined from 1987 aerial survey data for the study area. Settlement values calculated by totaling the occurence of structures (houses, sheds etc.)
Scale 1:250 000
LAKE BARINGO
Kampi ya Samaki
Kamalion
Nosunguro Shops
Salabani
Endao
CHEMORON DAM
Marigat
Logumukum
Loboi Shops
LAKE BOGORIA
Radat
Maji Moto

Figure 9




'90 15:17 >BARI>MAP>#DESE