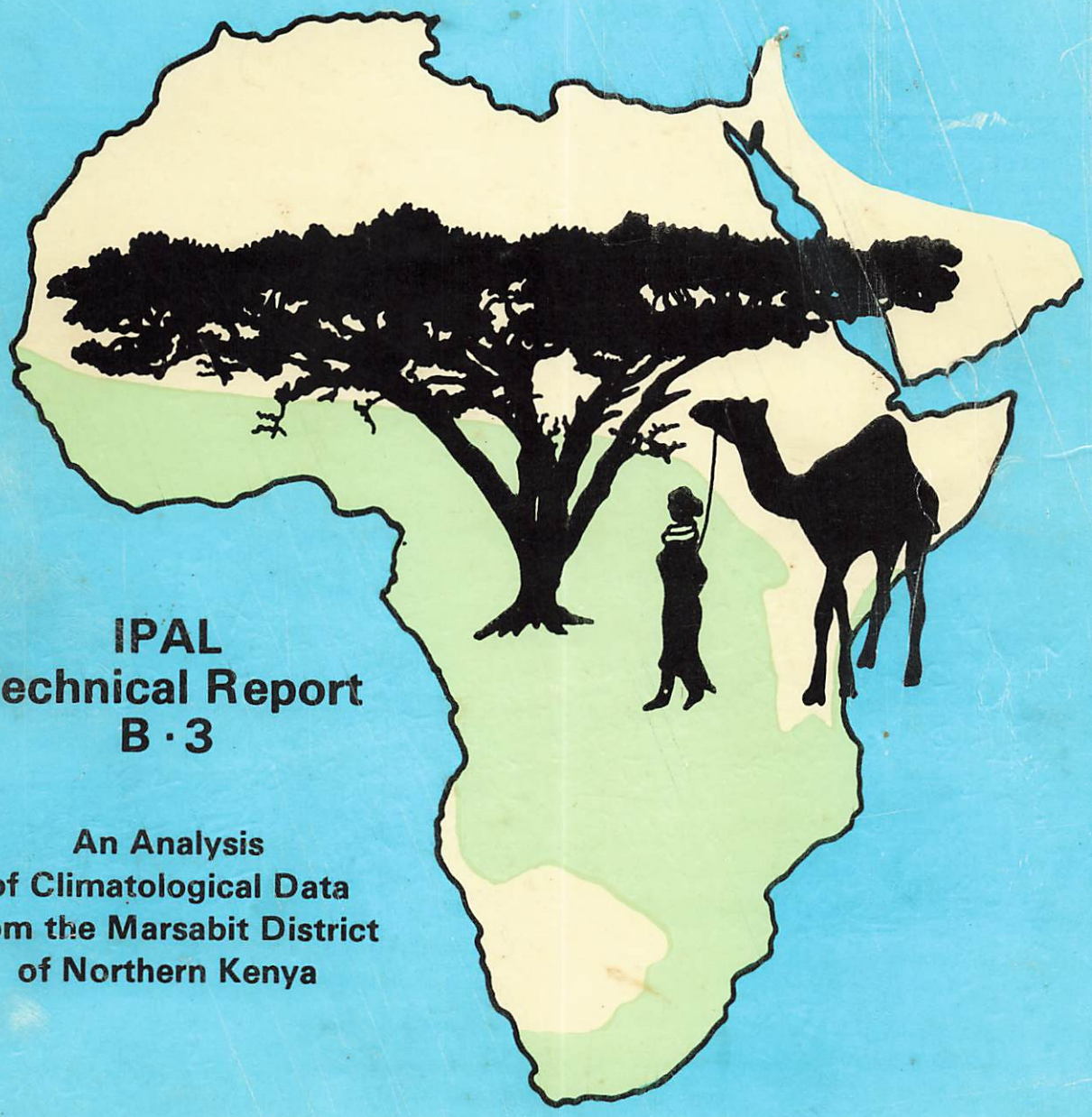
Federal Republic of Germany

UNESCO MAB

Unesco Programme on Man and the Biosphere (MAB)

Republic of Kenya

Integrated Project in Arid Lands (IPAL)



IPAL Technical Report B·3

An Analysis of Climatological Data from the Marsabit District of Northern Kenya

MAN AND THE BIOSPHERE PROGRAMME

Project 3: Impact of Human Activities and Land Use Practices on Grazing Lands

Published in 1983 by the United Nations
Educational, Scientific and Cultural Organization. Nairobi.

© Unesco 1983

IPAL Technical Report No. B-3

AN ANALYSIS OF CLIMATOLOGICAL DATA FROM THE MARSABIT DISTRICT OF NORTHERN KENYA

by
GERNOT BAKE (IPAL Consultant)

April 1983

UNESCO-MAB Integrated Project in Arid Lands

SUMMARY INTRODUCTION TO IPAL AND THE TECHNICAL REPORT SERIES

The Integrated Project in Arid Lands (IPAL) was established by UNESCO with financial support from UNEP in 1976 with the aim of finding direct solutions to the most urgent environmental problems associated with desert encroachment and ecological degradation of arid lands. It forms part of the international UNESCO Programme, Man and the Biosphere (MAB) which has links not only with UNEP's Desertification Unit but also with FAO, in response to the Plan of Action adopted by the 1977 United Nations Conference on Desertification. It is an example of the type of pilot activity that UNESCO and UNEP, together with other organizations and a number of government, are trying to promote to provide the scientific basis for the rehabilitation and rational management of arid and semi-arid zone ecosystems, through integrated programmes of research (including survey, observation and experimentation), training and demonstration. Phase III of the project, 1980-1983, is supported by funds-in-trust to UNESCO provided by the Federal Republic of Germany.

During the first phases of IPAL, a co-ordination unit was established in Nairobi and the initial field word started in the arid zone of northern Kenya in a working area of 23,000 km^2 situated between Lake Turkana and Marsabit Mountain. The project now operates five field stations, at Mount Kulal, Olturot, Kargi, Korr and Ngurunit, with the project headquarters in Marsabit, which is the administrative centre of the District. Since its establishment the project has researched several aspects of experimental management of the region, concentrating upon the 'human ecology' of the nomadic pastoralists in dynamic interrelationship with the animals, plants and other resources of a drought-prone uncertain environment.

During the following three years (1980-1983), the investigations in progress have been extended and intensified to develop resource management plan or models for the area, taking into account the increasing human population, the trend towards sedentarization, the degradation of the primary productivity, and the increasing incidence of soil erosion, all of which are factors resulting in the necessity for constant famine-relief measures in the region. Results obtained in the project are the subject of a number of training workshops and seminars in which Kenyan and regional scientists from the Sudano-Sahelian region participate.

This report is one of a series published by IPAL describing technical findings of the project and, where appropriate, giving management recommendations relating to the central problems of ecological degradation in the arid zone. The reports are divided into the following categories, distinguished by the base colours of their covers:

A general, introductory and historical: white

B climate and hydrology: blue

C geology, geomorphology and soils: brown

D vegetation: green

E livestock and other animal life: red

F social and anthropological: yellow

CONTENTS

		Page
Summary Introduction to IPAL and the Technical Report Series		
Acknowledgements		
List of Tables		
List of Figures		
1	Introduction	11
2	Livestock husbandry in arid and semi-arid climates	12
3	Data monitoring	13
4	General climatology of East Africa with special reference to the Marsabit District	17
5	Rainfall	18
5.1	Data collection	18
5.2	Annual rainfall and spatial variation	20
5.3	Variation in time of annual rainfall	22
5.4	Monthly rainfall patterns	30
	5.4.1 The variability of monthly rainfall	32
	5.4.2 Spatial distribution of seasonal rainfall	33
5.5	Duration and intensity of rainfall	45
5.6	Probability of rainfall	47
5.7	Rainfall at Marsabit	51
	5.7.1 Introduction	51
	5.7.2 The annual rainfall	54
	5.7.3 The monthly rainfall	54
	5.7.4 Aridity and humidity	55
	5.7.5 The seasons	58
6	The temperature regime	60
7	Aridity and humidity	62
7.1	General	62
7.2	Methods of determination of aridity and humidity	62
7.3	Results	64
8	Evaporation	65
9	The relative humidity	71
10	Wind direction and speed	78
11	Other climatic factors	86
12	Conclustion	87
	References	88

Figure 1. Location of IPAL study area

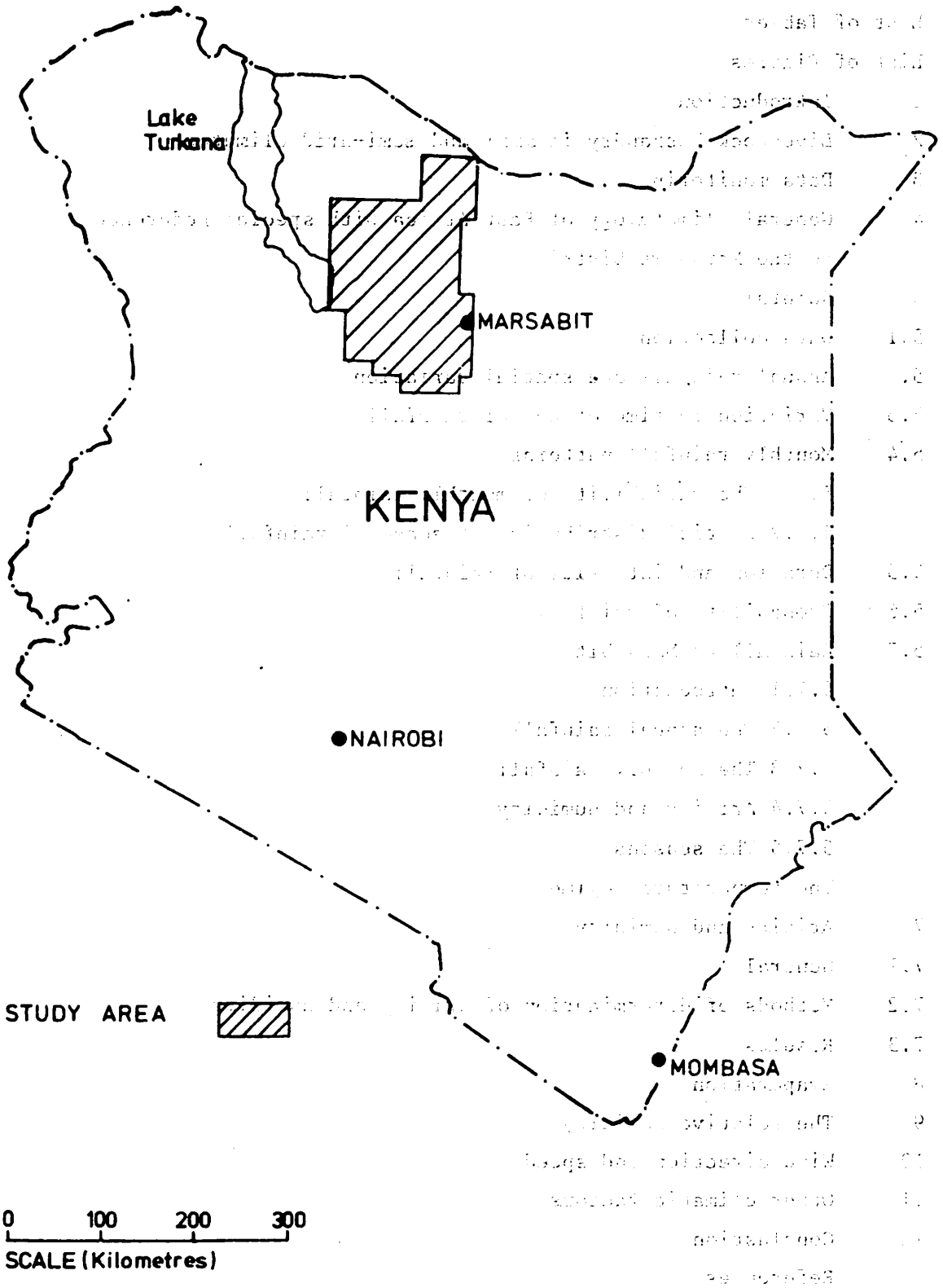
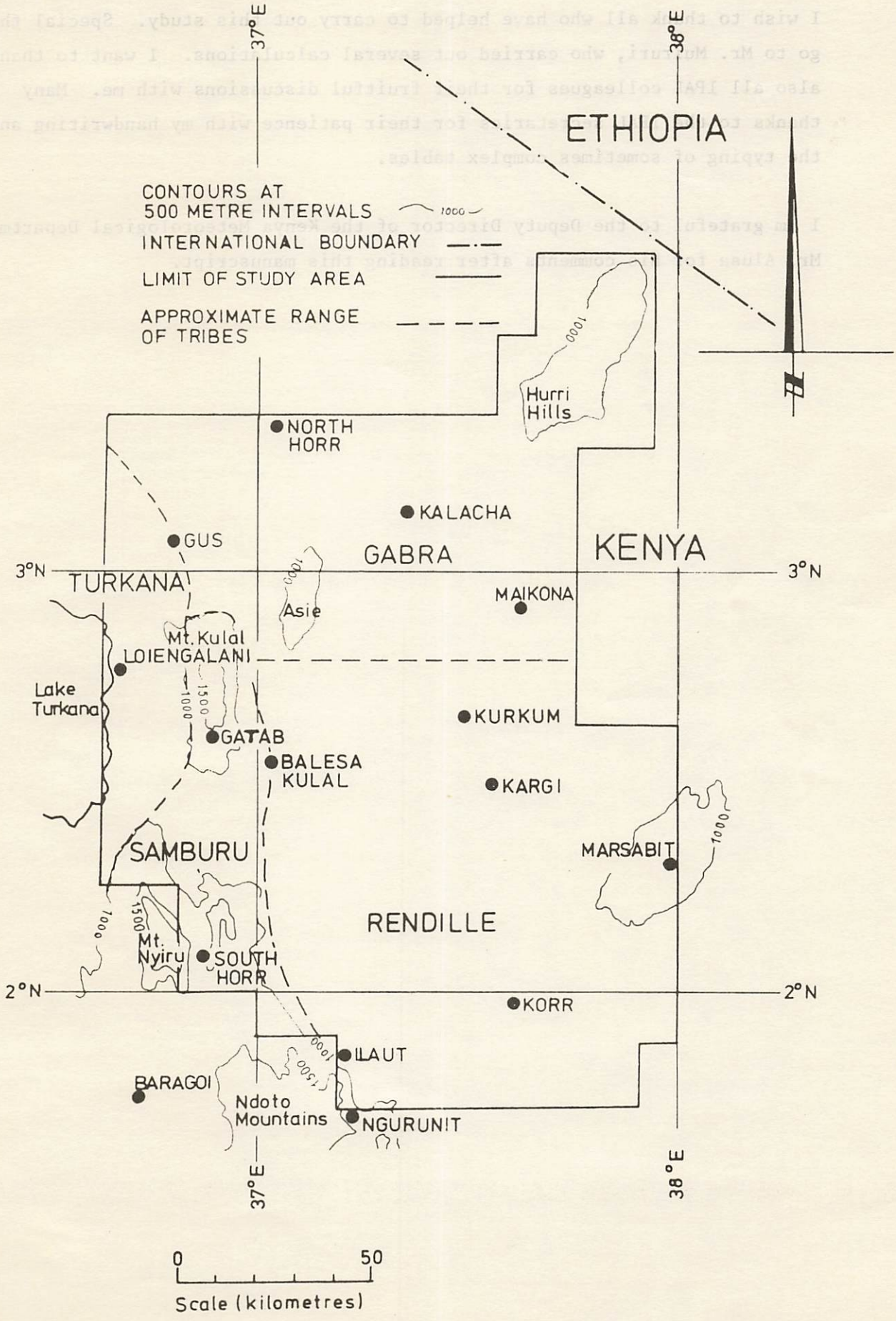


Figure 2. The study area



Acknowledgements

I wish to thank all who have helped to carry out this study. Special thanks go to Mr. Muiruri, who carried out several calculations. I want to thank also all IPAL colleagues for their fruitful discussions with me. Many thanks to the IPAL secretaries for their patience with my handwriting and for the typing of sometimes complex tables.

I am grateful to the Deputy Director of the Kenya Meteorological Department, Mr. Alusa for his comments after reading this manuscript.

List of Tables

		Page
Table 1	Meteorological variables recorded by automatic weather stations	16
Table 2a	Absolute variation of annual rainfall	28
Table 2b	Mean variabilities of annual rainfall	28
Table 3	Absolute monthly variation of rainfall at various station	31
Table 4	Percentage amount of rainfall for each month (1976-1981)	31
Table 5	Monthly variabilities at various stations	33
Table 6	Percentage of rainfall in November 1980 from the mean of second wet seasons (1976-1981)	34
Table 7	Highest intensities and highest rainfall at Gatab	46
Table 8a/b	Monthly rainfall probabilities	48/49
Table 9	Rainfall characteristics of the wet seasons	50
Table 10	Probabilities of annual rainfall and their return periods	52
Table 11	Classification of years at Marsabit	54
Table 12	Monthly rainfall and monthly threshold values	55
Table 13	Probability of arid months and their return period	55
Table 14	Probability of arid months in % and their return period	58
Table 15	Return periods of the duration and beginning of the wet seasons	60
Table 16a	Cumulative frequency of length of dry spells	60
Table 16b	Dry spells at Marsabit	60
Table 17	Mean monthly temperatures	61
Table 18	Monthly rates of evaporation (potential) rainfall and water balance at Lodwar	66
Table 19	Actual evaporation rates for selected months at Marsabit and Lodwar compared with rainfall	70
Table 20a	Diural variation of wind direction at Olturot (21/1-8/2/1982)	79
Table 20b	Diurnal variation of wind direction at Olturot (1/3-15/4/1982)	80
Table 21	Diurnal variation of wind direction at Korr (3/12-30/12/1982)	83
Table 22	Variation of wind direction at Olturot	84

List of Figures

		Page
Figure 1	Location of the IPAL study area	
Figure 2	The study area	
Figure 3	Distribution of raingauges	15
Figure 4	Mean annual rainfall in the IPAL area	21
Figure 5	Deviation of annual rainfall from the mean - Lodwar	23
Figure 6	Deviation of annual rainfall from the mean - Moyale	24
Figure 7	Deviation of annual rainfall from the mean - North Horr	25
Figure 8	Deviation of annual rainfall from the mean - Gatab	26
Figure 9	Variability of annual rainfall - Marsabit	27
Figure 10	Isohyets for March - May 1977	35
Figure 11	Isohyets for October - December 1977	36
Figure 12	Isohyets for February - April 1978	37
Figure 13	Isohyets for September - December 1978	38
Figure 14	Isohyets for January - April 1979	39
Figure 15	Isohyets for November - December 1979	40
Figure 16	Isohyets for April - May 1980	41
Figure 17	Isohyets for November 1980	42
Figure 18	Isohyets for March - May 1981	43
Figure 19	Isohyets for October - December 1982	44
Figure 20	Probabilities of annual rainfal at Marsabit and Marsabit/3	53
Figure 21	Probabilities of arid north of Marsabit	56
Figure 22	Variation of starts and duration of rainy seasons at Marsabit	59
Figure 23	Rainfall and threshold values	63
Figure 24	Potential evaporation and rainfall at Marsabit	68
Figure 25	Changes of relative humidity at Olturot	73
Figure 26 (a-l)	Diurnal changes of relative humidity at Olturot	74
Figure 27 (a-x)	Changes of relative humidity of specific times during the year	75/76
Figure 28	Mean monthly relative humidity at Olturot	77

AN ANALYSIS OF CLIMATOLOGICAL DATA FROM THE MARSABIT DISTRICT OF NORTHERN KENYA

1. Introduction

The Integrated Project in Arid Lands (IPAL) was initiated in 1976 in the Marsabit District of northern Kenya to study the arid and semi-arid grazing lands ecosystems and to develop range resource management plans.

Climate is one of the most important steering factors in the ecosystem. It steers surface runoff, groundwater, soil moisture, soil development, vegetation in type, species, density and production rate, actual geomorphological processes, etc. Human livestock husbandry is thus highly dependent on climatic conditions, because there is a direct correlation between actual rainfall and optimal stock numbers.

Climate is not a constant factor. Especially in an arid or semi-arid region, variabilities, fluctuations and perhaps also changes are common features. In the present state of science we cannot determine whether or not the world or some parts of it are in a phase of general climatic change, but there are some indications that this may be so.

The spread of desert-like conditions (desertification) drew the attention of the world in the early seventies, at the time of the great drought over all the Sahelian zone and East Africa, which caused high mortality of people and livestock throughout the area. Parts of northern Kenya were affected. This problem was discussed as a world-wide phenomenon at the World Conference on Desertification held in Nairobi in 1977.

Desertification is a man-induced process. It can only occur under semi-arid conditions where the ecosystems can shift to a desert-like state under the impact of human activities. This process can be reinforced by severe droughts. Desertification is thus not a natural process. We know indeed that all over the world climates have changed in the geological past, including the emergence of desert climates, but this is not what we call desertification.

2. Livestock Husbandry in Arid and Semi-Arid Climates

There are a number of climatic features which determine the conditions of livestock husbandry in an arid or semi-arid area, most of them directly related to the rainfall regime of the specific region.

First of all, there is the relationship between climate and primary production of the vegetation cover. The vegetation of an area is largely determined by the amount and the time distribution of rainfall. Species composition, density etc. are directly connected with rainfall. It is of course clear that there are other factors operating to determine the vegetation of an area, but climate is usually the most important. Normally the vegetation should be in equilibrium with the climate, which means that the vegetation can survive in periods of drought or of extremes of rainfall. (We are not here discussing a situation where the climate is changing to a different general pattern; in such a case the vegetation will change too.) A good summary of plants, pasture and drought conditions and related phenomena can be found in WMO (1975), Technical Note 138, Chapter 6.

The primary production of plants is directly related to rainfall. This means that within certain limits production will increase with an increase in the amount of rainfall. The limits are also given by the rainfall characteristics (e.g. in time; rainfall with lower intensity but longer duration well distributed in time will lead to an increase of primary production, whereas short, intensive rainfalls have only a short and unimportant effect).

Grazing and browsing are spatially organized land-use forms, which require a rainfall well distributed also in spatial variance. Otherwise there would be no possibility of grazing all the year round.
Nomadism is an adaption to spatial distribution of rainfall in northern Kenya.. If there is a clear division, as in a mountain-plain area with seasonal transitions in grazing, we speak of a transhumance system.

There is another important relationship involving climate: that between rainfall and livestock. In most of the pastoral areas all over the world, rainfall determines also the supply of drinking water for people and animals. The vegetation in a grazing area may be in excellent condition, but if there is no water for watering the animals it is useless. Today, such areas can often be made useable by digging wells, drilling boreholes or constructing water storage systems, but a considerable technical and financial input is necessary.

The IPAL study area includes two general climatic types for grazing systems. Both have a bimodal regime of rainfall, which is better for pastoralism than a single rainy season because the amount of rainfall is distributed in two periods over the year.

Another favourable feature is the presence of several high mountain areas: Mt. Kulal, the Huri Hills, Mt. Marsabit and the Ndoto and Njiru mountains. The benefit lies in two factors. First, there is a prolongation of the duration of the rainy season in these higher areas and also an increase in the amount of rainfall with altitude. This gives the pastoralists the possibility of shifting quickly from an arid and a subhumid grazing area. For example, the distance by road from Kargi (arid) to Marsabit (semi-arid) is only 70 km. Second, these mountains play an enormous role in the steering of the water supply for the whole study area. The long duration of the rains in the high areas continues to send water down to the lowlands when there has been no local rain for a long time. The different vegetation type (.e.g tropical rain forests) slows down the runoff and retains water. It is certain that most of the subsurface water of the lowlands comes from the surrounding mountains.

3. Data Monitoring

One of the major problems in all arid and semi-arid countries is the collection of climatological and meteorological data. Due to the high variabilities (e.g. of rainfall), data collection over a long period is required. In most areas there are only a few stations which have been recording climatological data over a long period.

For the IPAL study area there is only Marsabit, which started keeping records in 1918. For comparison we use also the records of Moyale and Lodwar, which are not too far from the study area.
The periods of record keeping are:

- Marsabit: 1918 - the present
- Moyale : 1915 - the present
- Lodwar : 1919 - the present

Stations with a relatively long period of record keeping also include Gatab and North Horr, which started in 1971 and 1959 repectively. But it has to be considered that Gatab is a mountain station while North Horr lies at the edge of the Chalbi Desert. This means that there is no weather station with a relatively long period of recording which represents climatic conditions in the middle of the study area (e.g. the area of the Hedad).

In 1976, IPAL initiated a climatology network programme. The base consists of one climatological enclosure in Gatab containing a Stevensons screen, recording anemometer, Litronic solarimeter and standard and recording rain gauges. Twice a day (9 a.m. E.A.S.T) temperature measurements are taken. From June 1976 to November 1977 an Epsylon Automatic Weather Station was working in Gatab, but was then shifted to North Horr to monitor the drier parts of the study area. Meanwhile, this station is working in Korr. A Didcot Automatic Weather Station was installed in June 1977 near the Balesa Kulal river, but was moved for security reasons to the IPAL station at Olturot, a few kilometres away.

These two automatic stations are recording different variables (listed in Table 1) every five minutes on a magnetic tape. The Epyslon station works with a computer tape (6 mm) which lasts up to 3 months when there is power supply available. The Didcot uses normal C-60 cassettes, which give an operating time of 21 days. Every 14 days the casettes are changed to avoid data loss.

Figure 3· Distribution of raingauges

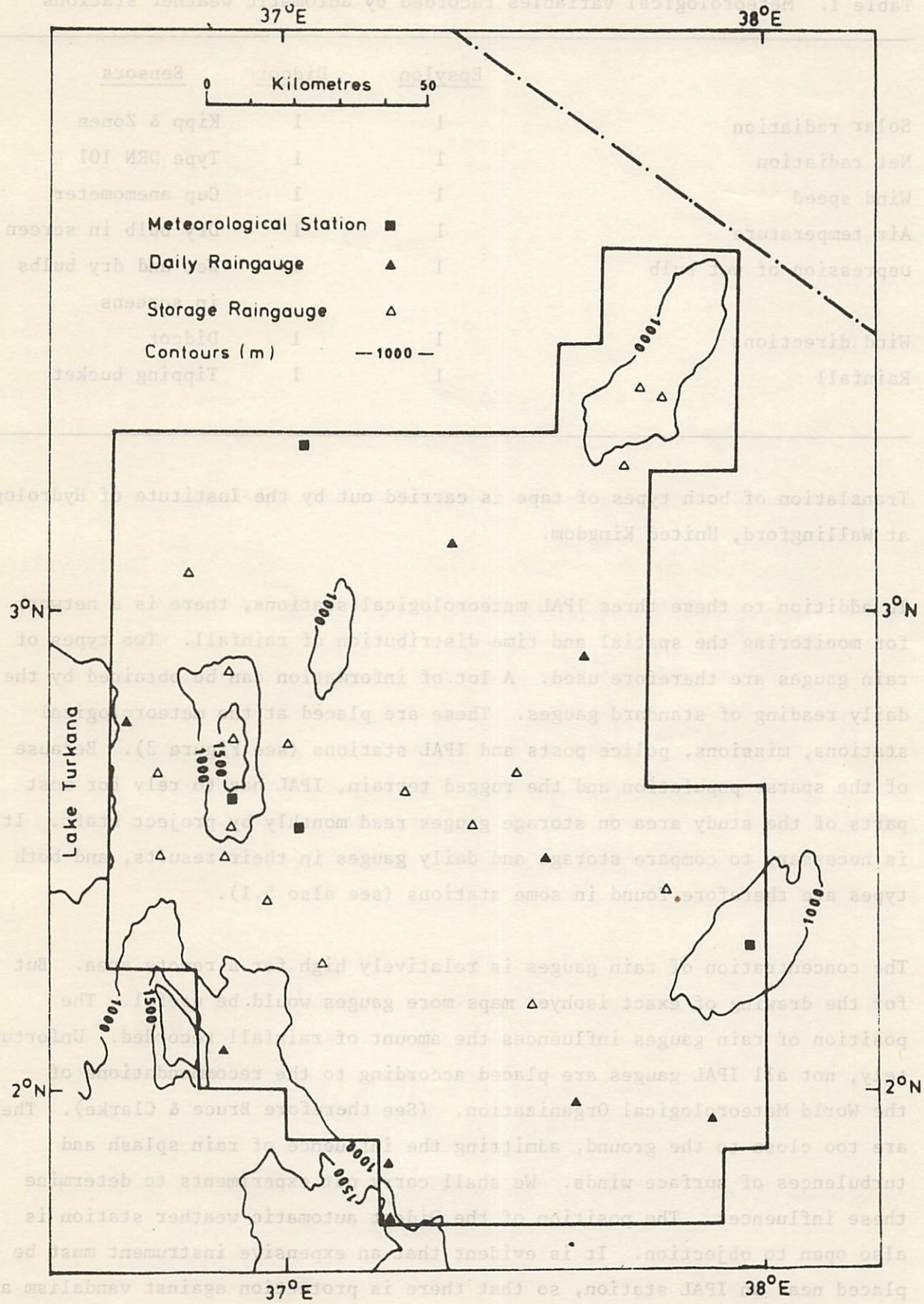


Table 1. Meteorological variables recorded by automatic weather stations

	Epsylon	Didcot	Sensors
Solar radiation	1	1	Kipp & Zonen
Net radiation	1	1	Type DRN 101
Wind speed	1	1	Cup anemometer
Air temperature	1	1	Dry bulb in screen
Depression of wet bulb	1	1	Wet and dry bulbs in screens
Wind directions	1	1	Didcot
Rainfall	1	1	Tipping bucket

Translation of both types of tape is carried out by the Institute of Hydrology at Wallingford, United Kingdom.

In addition to these three IPAL meteorological stations, there is a network for monitoring the spatial and time distribution of rainfall. Two types of rain gauges are therefore used. A lot of information can be obtained by the daily reading of standard gauges. These are placed at the meteorological stations, missions, police posts and IPAL stations (see Figure 3). Because of the sparse population and the rugged terrain, IPAL has to rely for most parts of the study area on storage gauges read monthly by project staff. It is necessary to compare storage and daily gauges in their results, and both types are therefore found in some stations (see also 5.1).

The concentration of rain gauges is relatively high for a remote area. But for the drawing of exact isohyet maps more gauges would be useful. The position of rain gauges influences the amount of rainfall recorded. Unfortunately, not all IPAL gauges are placed according to the recommendations of the World Meteorological Organization. (See therefore Bruce & Clarke). They are too close to the ground, admitting the influence of rain splash and turbulences of surface winds. We shall carry out experiments to determine these influences. The position of the Didcot automatic weather station is also open to objection. It is evident that an expensive instrument must be placed near an IPAL station, so that there is protection against vandalism and staff are available for maintenance.

But the chosen site should also lie within a common and representative climatic feature of the study area. From this point of view, Korr is a very well chosen place for monitoring climatological data in the southern part of the study area. This area is also threatened by desertification, which can be related to the actual climatology.

Olturot, on the other hand, is not a good site. As pointed out already by Edwards et al (1979) this site lies under the influence of the local wind system of the Mt. Kulal slopes (see also chapter 9 in this report). The area is too small and its importance too low for an expensive instrument like the weather station to be used here when others are not available. Places like Kargi or Kalacha would give more valuable data for wider parts of the study area.

From a specific point of view, this also applies to the meteorological enclosure at Gatab. The importance of the subhumid regions of Mt. Kulal should not be under estimated, and it is very important to analyse the climate of these areas, but we have also to consider that a similar region is monitored at Marsabit by a government weather station and that there is a lack of climatological stations for more climate parameters in the lowlands of the study area. These areas in fact represent more than 90% of the IPAL area.

4. General climatology of East Africa with special reference to Marsabit District

The climate of East Africa is often described in terms of a simplified model of circulation. There is a broad equatorial low-pressure trough created by the convergence of the trade-wind systems of both hemispheres. In the modern literature this trough is called the Intertropical Convergence (ITCZ). This zone of low-pressure is not stable but moves within the year northwards or southwards in accordance with the movement of the thermal equator, say the sun.

The main convergence zone can be displaced and distorted, giving rise to areas of enhanced convergence and divergence. One of these areas is the Marsabit region, where there is enhanced divergence, and there is a corridor of low land between the Ethiopian and Kenya highlands which both

rise to more than 3,000 m. These barriers force the winds from the Indian ocean to prevail throughout the year in an easterly direction. It can also be assumed that there is an increase of wind speed in this area compared with other regions of the same altitude, caused by the so-called delta effect.

The monthly changes in the flow over East Africa and its relation to rainfall are shown in Figures 4.3 and 4.8 in Ojany and Ogendo (1982).

As an addition, some observations made by the author at Marsabit should not be forgotten. During the "short" rainy season of 1982, it was observed that there was quite often a change in wind speed and direction occurring with the appearance of rainfall.

Clouds were appearing over Marsabit mountain, mostly of convective origin. They could be classified as cumulostratus, partly cumulonimbus; base approximately 1,500 - 2, 000 m/ml. With the formation of these clouds the wind calmed down and also changed its direction from easterly through south to a westerly direction. Quite often a very dense fog drifted up from the western slopes of Mt. Marsabit. A short time after that the rain started. After the rain the wind shifted over some time back to its normal direction from the east.

As an explanation it is proposed that we have to deal here with a cell drifted to this area from the ITCZ. (In the modern literature the ITCZ is not looked upon as a belt but as a collection of cells.)

It is interesting that the same occurs at Gatab but at different times, which means that the dimension of these cells is small.

Also their vertical diameter is not very big. It has been observed that the upper clouds continue to move in their normal direction.

5. Rainfall

5.1 *Data collection*

The analysis of rainfall is based on the recording of 36 rain gauges and the automatic weather stations. The use of two different types of gauges brings many problems.

In the first place, there is the problem of placing the gauge. All sites in the IPAL area are well chosen but the placement of the gauges affects their reliability. Situated just a few centimetres above ground, all of them are subject to the influence of the splash effect. This leads to an accumulation of soil particles in the gauge and there is also an interference in the amount of recorded rainfall by splashed rain-drops. We must consequently assume that the amount of rainfall recorded is too high. Researchers (see Bruce and Clarke 1975) show that the effect of gauge height is fairly strong. Placing gauges the way it is done in Kenya might be possible in humid climates with their dense grass cover and sometimes lower intensities of rainfall. Our investigations show that here in northern Kenya the splash effect reaches up to 1 m and more. Compared with the standard gauge at 1.5 m the Kenya gauge recorded 3% too much rainfall over one rain period under calm wind conditions.

There is also the influence of wind speed. A speed at 4 m/sec decreases the recorded rainfall by 10%. For 9 m/sec it is already 35%. But this problem affects the climatological network throughout the world. Shelter belts around the gauges may be a solution.

The biggest problem for IPAL is the use of storage gauges. Read only once a month, it is necessary to determine the reliability of this type. This is done by comparing them with a daily gauge at the same site. In this ideal case both types show exactly the same result, which can be expressed by the equation:

$$y = x$$

(where y = storage gauge and
x = daily gauge).

But this case does not appear even approximately. Calculations show that the amount of rainfall in the storage gauge compared with the daily gauge varies between 50% and 92%, which is too inaccurate for the purpose of planning a scheme of grazing and water supply.

So far the data obtained from storage gauges and daily gauges at the same site give us an approximate impression. A linear regression with data from 4 different sites gave a correction factor of 1.2.

This means that the monthly data of the storage gauges should be multiplied by 1.2, to include also the loss by evaporation over the whole month. (The coefficient of regression is 0.92). Expressed in other terms, in a storage gauge 20% of the recorded rainfall is evaporated in one month.

Remark: The Isohyetical maps included here have not been corrected so that they are comparable with others all over Kenya.

5.2 *Annual rainfall and spatial variation*

An area can be divided into several regions by the spatial distribution of the annual rainfall. There is a general division of the IPAL study area into two parts: dry lowlands with rainfall less than 300 - 500 mm/a and wetter highlands (Basement complex in the south, Mt. Kulal in the west, Mt. Marsabit in the east and the Huri Hills in the north) with rainfall higher than 700 mm/a. Edwards et al. found a good relationship between rainfall and altitude on the southern slope of Mt. Kulal.

$$R = 0.089\ A - 283.8$$

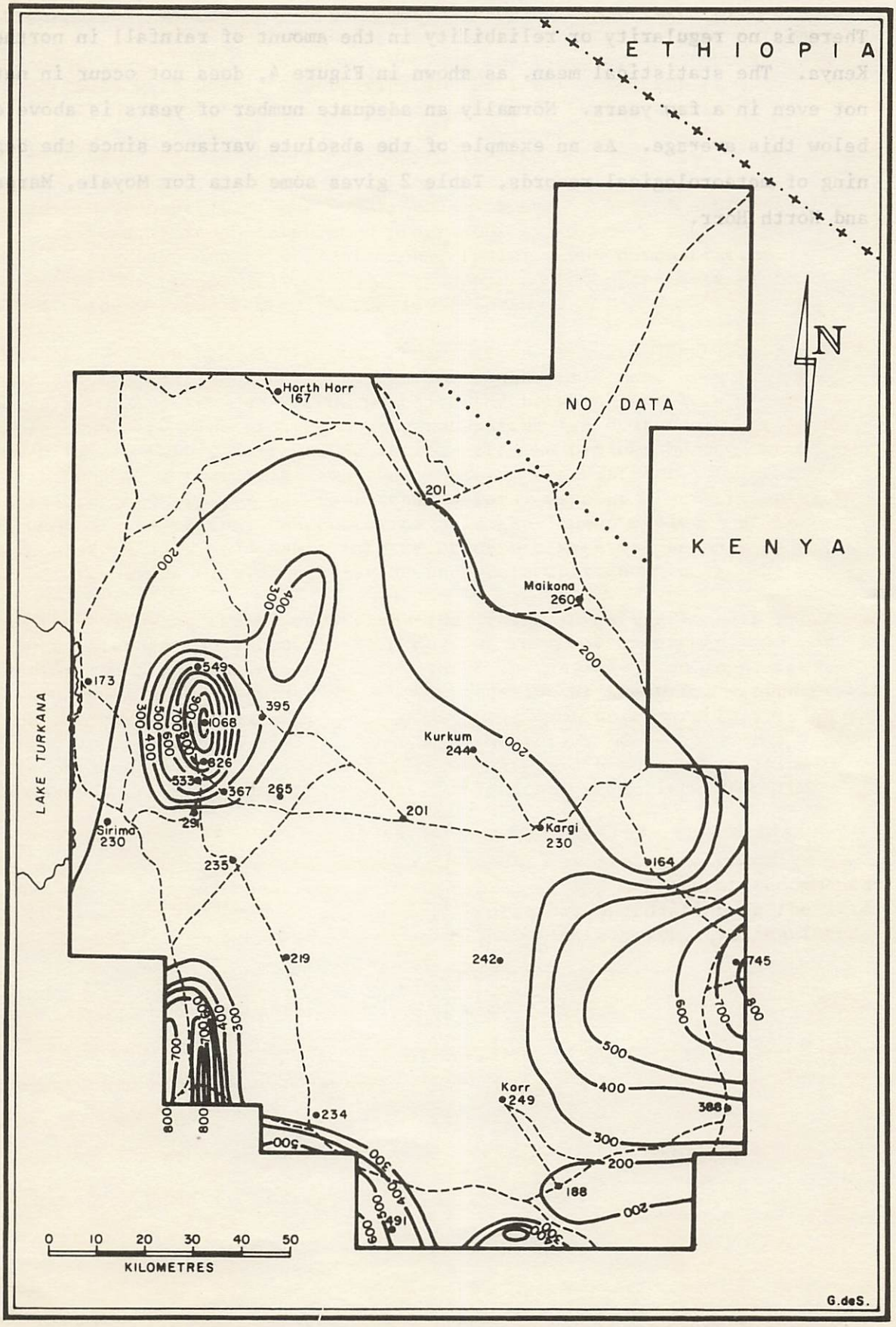
(R = rain, A = altitude). with a regression coefficient of 0.98

They mention also that this has to be divided into leeward and windward sides, but we can assume that similar correlations will be valid for other parts of the study area too.

The estimated distribution of annual rainfall in this part of northern Kenya is shown in Figure 4. The isohyets are based on five years of rainfall recording, which is a very short period, but as mentioned above there are only a few stations in northern Kenya with longer records. This will be analysed in the next chapter.

As the climatology monitoring programme of IPAL continues in the coming years there will be a change in the isohyets. We do not know exactly if we "caught" in these five years of records a normal or an abnormal period. The data obtained from Marsabit and North Horr allows us to assume that the recording period 1976 - 1981 was drier than the long-term mean, but we cannot be sure if this statement is valid for the whole study area.

Figure 4. Mean annual rainfall in the IPAL Area



5.3 *Variation in time of annual rainfall*

There is no regularity or reliability in the amount of rainfall in northern Kenya. The statistical mean, as shown in Figure 4, does not occur in nature, not even in a few years. Normally an adequate number of years is above or below this average. As an example of the absolute variance since the beginning of meteorological records, Table 2 gives some data for Moyale, Marsabit and North Horr.

Figure 5.

DEVIATION OF ANNUAL RAINFALL FROM THE MEAN - LODWAR

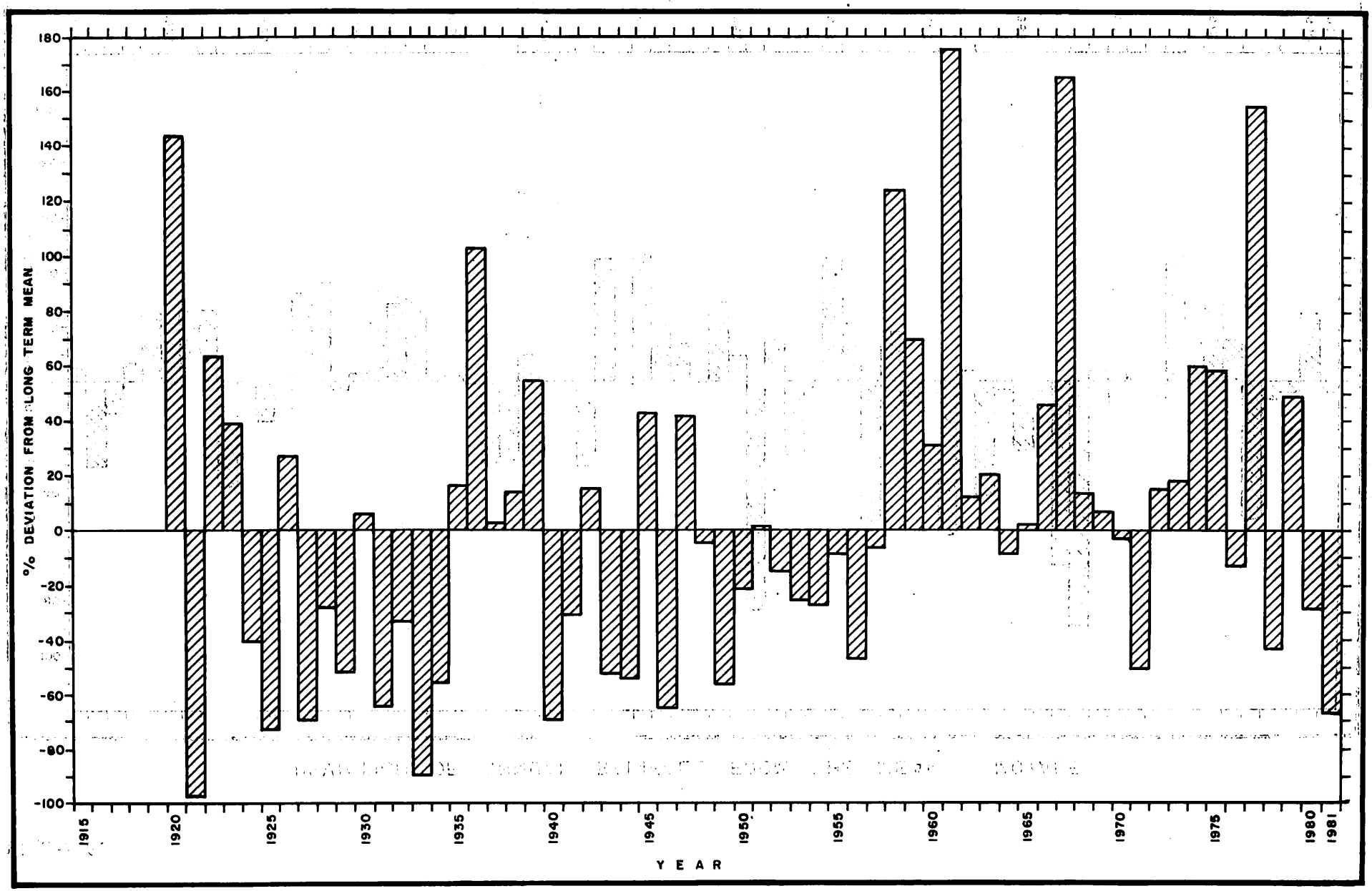


Figure 6.

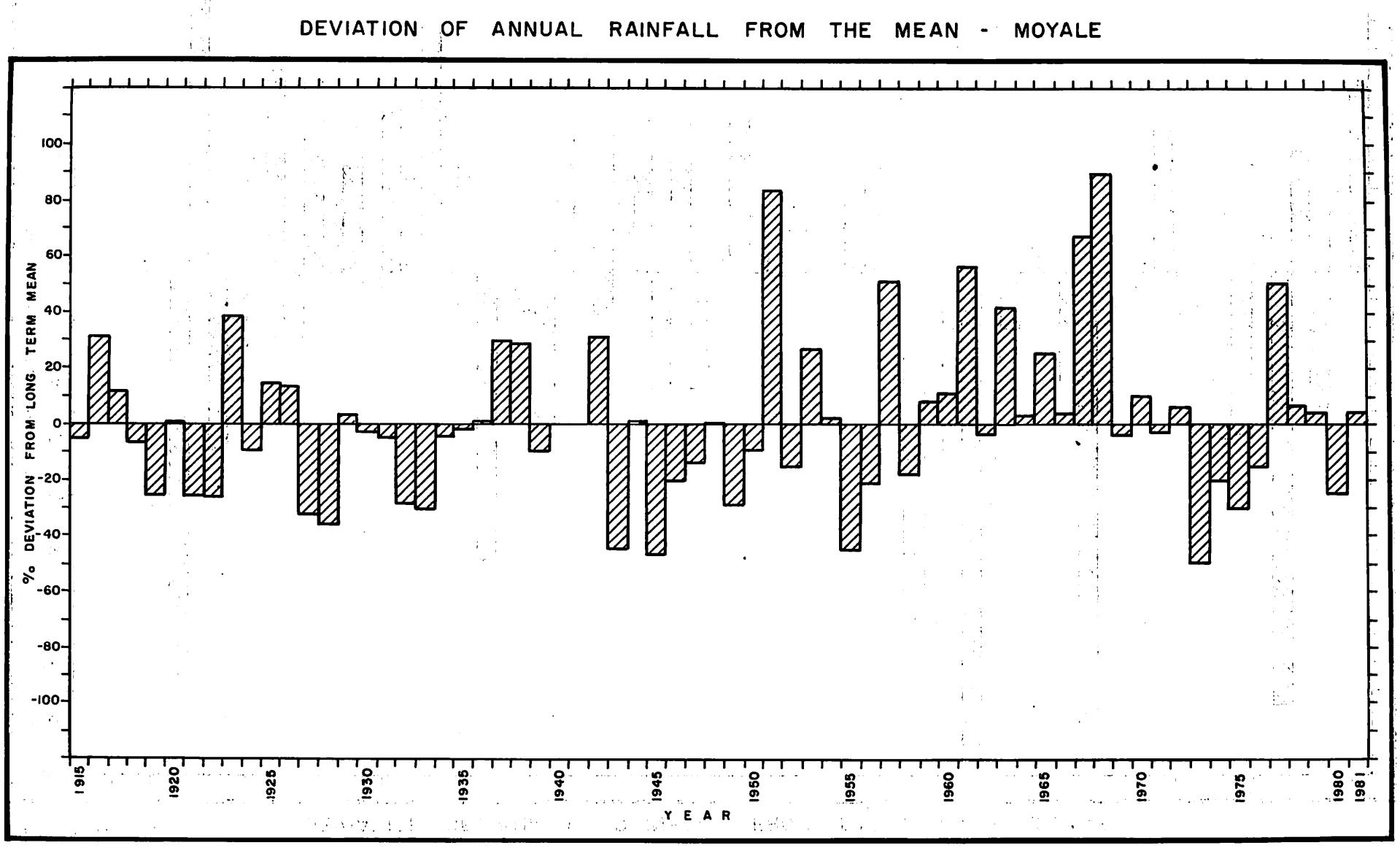

DEVIATION OF ANNUAL RAINFALL FROM THE MEAN - MOYALE
% DEVIATION FROM LONG TERM MEAN
100
80
60
40
20
0
-20
-40
-60
-80
-100
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1981
YEAR

Figure 7.

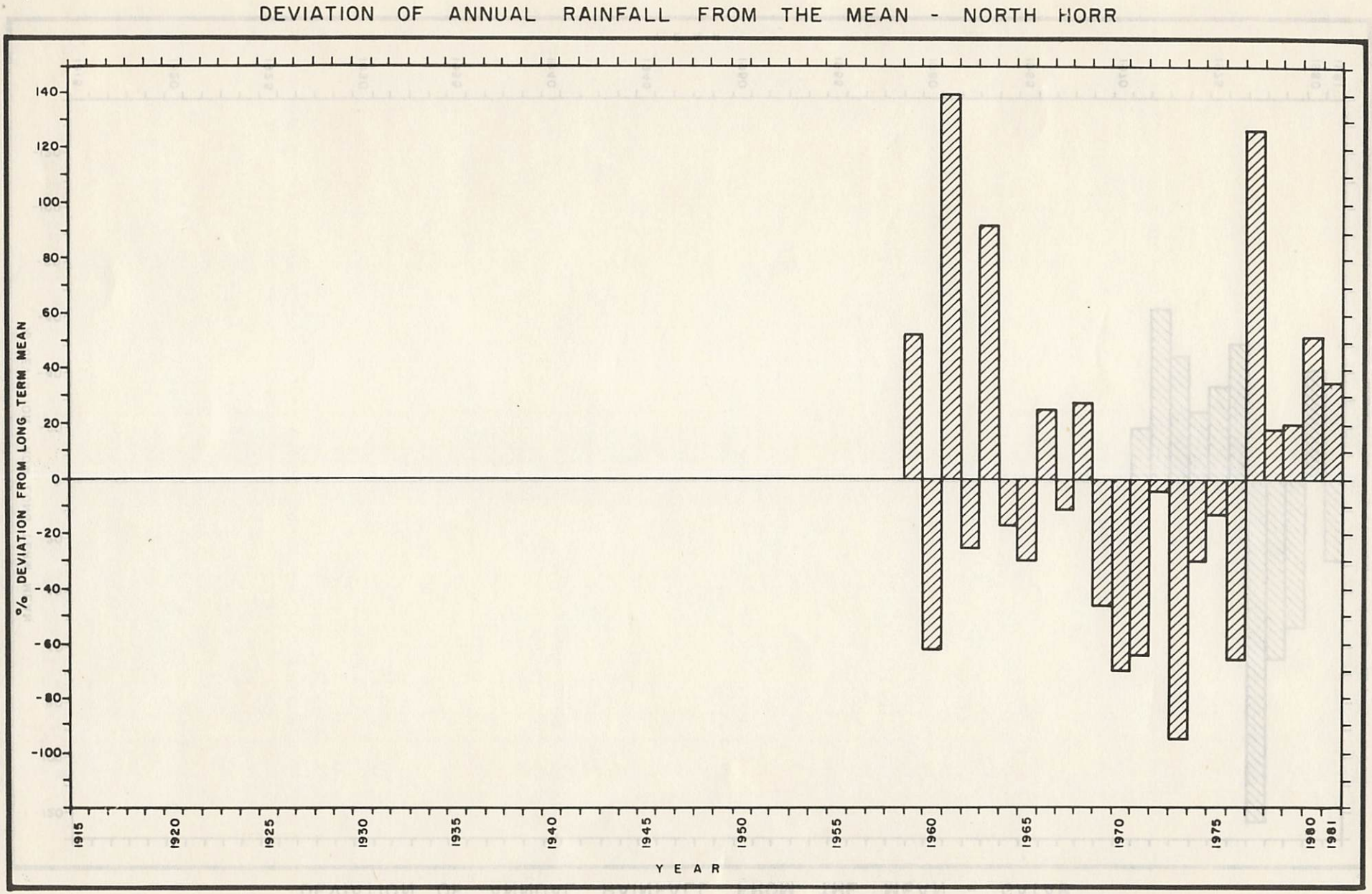

DEVIATION OF ANNUAL RAINFALL FROM THE MEAN - NORTH HORR
% DEVIATION FROM LONG TERM MEAN
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1981
YEAR

Figure 8.

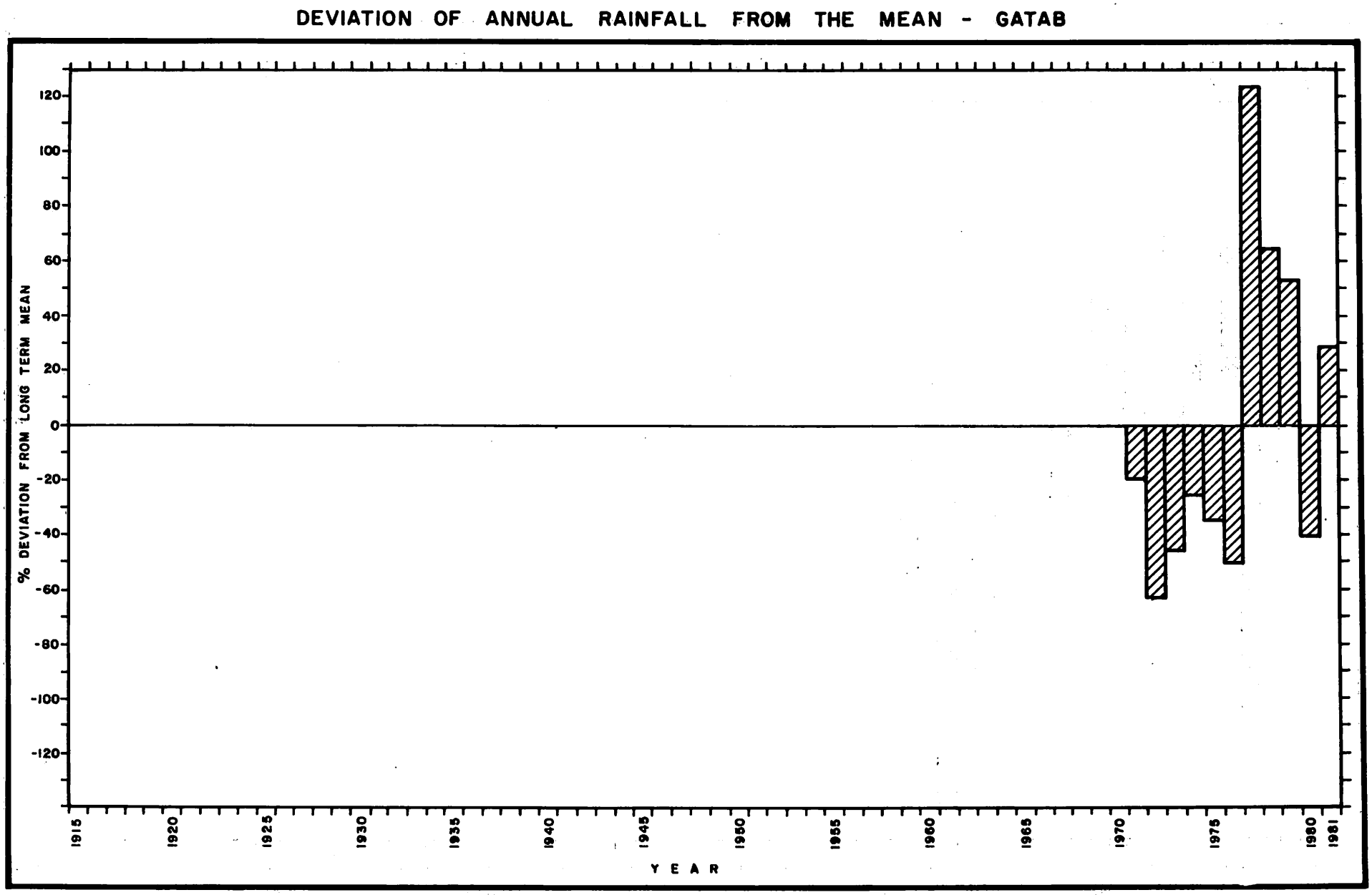

DEVIATION OF ANNUAL RAINFALL FROM THE MEAN - GATAB
% DEVIATION FROM LONG TERM MEAN
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1981
YEAR

Figure 9. Variability of annual rainfall

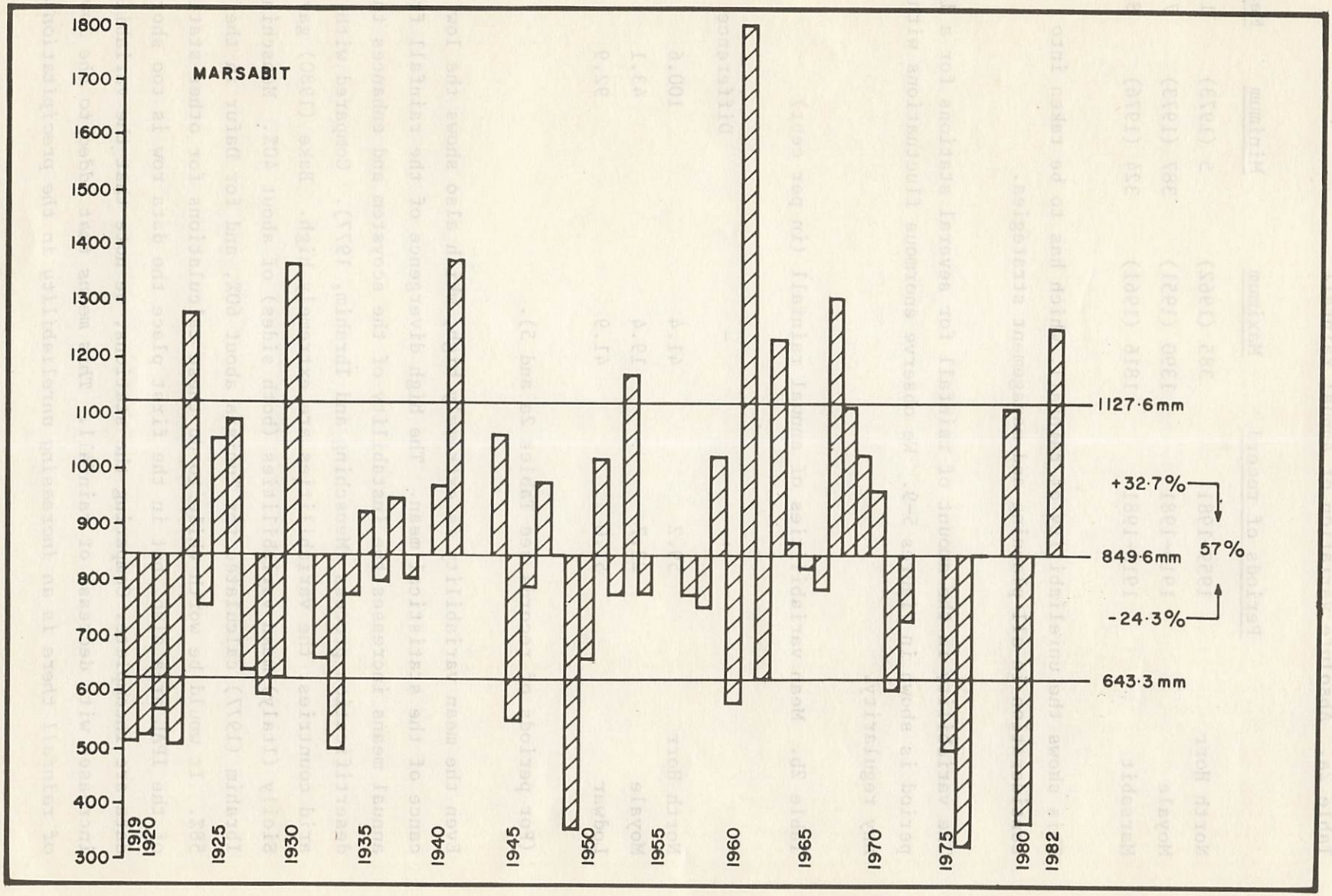


Table 2a. Absolute variation of annual rainfall

	Periods of record	Maximum	Minimum	Mean
North Horr	1959-1981	385 (1962)	5 (1973)	157
Moyale	1915-1981	1390 (1951)	387 (1973)	713
Marsabit	1918-1981	1816 (1961)	324 (1976)	859

This shows the unreliability of rainfall, which has to be taken into consideration in all planning and management strategies.

The variability in the amount of rainfall for several stations for a longer period is shown in Figures 5-9. We observe enormous fluctuations without any regularity.

Table 2b. Mean variabilities of annual rainfall (in per cent)

	+	-	Difference
North Horr	59.2	41.4	100.6
Moyale	23.7	19.4	43.1
Lodwar	51.0	41.9	92.9

(For periods of records see Tables 2a and 5).

Even the mean variability is extremely high, which also shows the low significance of the statistical mean. The high divergence of the rainfall from the annual means increases the instability of the ecoystem and enhances the desertification process (Mensching and Ibrahim, 1977). Compared with other arid countries, the variabilities are extremely high. Bake (1980) gave for Sicily (Italy) mean variabilities (both sides) of about 40%. Mensching and Ibrahim (1977) calculated for Tunisia about 60%, and for Dafur in the Sudan, 58%. It would be worth while to do these calculations for other stations of the IPAL area also, but in the first place the data row is too short or the data are incomplete. Comparing the stations, we note that the variability increases with decrease of rainfall. *This means that added to the lower amount of rainfall there is an increasing unreliability in the precipitation as well.*

One of the major questions for climatology is whether there is any significant trend in the amount of annual rainfall which will allow us to give a forecast for coming years. At the moment the answer is "we don't know". It is certain that there are periods of lower rainfall, drought periods, as listed by Sobania (1979) and periods of higher rainfall. But so far we can show no periodicity. Even whether there has been a general decrease in rainfall since the beginning of meteorological record keeping cannot be stated clearly. Some linear regression analyses show an increase for one station and a decrease for another in the amount of annual rainfall. Also the trends are not significant.

This high variability has to be considered in the determination of the primary production rate of fodder plants. We do not know what amount of rain will fall in the next year. That is why stocking rates should not be based on the mean but *on the average of the years below* the long-term average. This calculation gives enough security for drought years and even for a longer period of drought. They should be based on the average lower variability figure.

The occurrence of a run of dry years after several wet years is a general characteristic of arid environments. The hydrology of the area becomes very episodic, which can also include the supply of subsurface water for the watering of animals. The traditional adaption to this climatic feature is pastoralist nomadism, which allows the people to shift in dry years to wetter areas. Unfortunately, tribalism, politics and the increase of sedentarization tend to arrest this well adapted system. This leads to a definite degradation of the natural environment in some sites, which is actually visible in the IPAL area around places like Korr and Kargi.

In some years, correlation of rainfall is possible over the whole study area (see also Edwards et al. 1979), but not in every year; 1977, for example, was a wet year all over northern Kenya, while 1973 was exceptionally dry. Other years do not show this clear correlation; often the variance is not very high. This is different from other areas in the arid zones. Probably one reason is that we have to deal in northern Kenya with a bimodal rainfall regime,

whereas in the Sahel and Mediterranean region there is only one wet season. Also, much of the year's rainfall can fall within one month, while the others are quite normal or even drier than the average.

This shows the limited value of the annual rainfall patterns, but their analysis is nevertheless the first step in the investigation of the climatic environment, especially for the comparison of different areas within a bigger zone or all over the world.

5.4 *Monthly rainfall patterns*

This section is based for the most part on five-year records in the IPAL study area. That is why there are sometimes differences in the amount of rainfall at various stations. The reason is that we had sometimes to use a longer or shorter period of records. Rainfall in northern Kenya follows a bimodal pattern with peaks in April and November. Even in the subhumid regions of the different mountains the monthly amount is highly variable.

Table 3. Absolute monthly variation of rainfall at various stations

	Marsabit			Moyale			Lodwar		
Month	Mean	Highest	Lowest	Mean	Highest	Lowest	Mean	Highest	Lowest
January	38	185	0	15	160	0	9	111	0
February	19	222	0	19	125	0	7	42	0
March	78	299	0	58	175	0	21	149	0
April	225	690	37	189	395	25	48	186	0
May	98	270	0	120	397	8	25	114	0
June	7	44	0	28	92	0	7	116	0
July	16	137	0	17	89	0	14	132	0
August	18	183	0	17	94	0	10	63	0
September	13	66	0	25	135	0	3	57	0
October	123	390	0	104	388	9	8	89	0
November	154	623	25	89	267	5	13	107	0
December	70	232	0	42	161	0	13	198	0
Year	859	1816	361	713	1290	387	178	498	19

Source: E.A.M.D. 1975

Table 4. Percentage amount of rainfall for each month (1976-1981)

	J	F	M	A	M	J	J	A	S	O	N	D
North Horr	4.9	4.4	10.0	27.5	16.9	1.5	0.2	0	2.8	12.5	18.2	1.1
Ngurunit	12.6	1.8	22.9	25.6	6.2	0.2	0.7	0.3	0.9	5.0	17.7	6.1

The bimodal rainfall pattern is shown quite clearly by these figures. It is worth while to discuss why there should be a considerable difference in some months between the north and the south of the study area. First of all, Ngurunit is located in a mountainous area with higher rainfall. Situated in the Ndoto mountains, it receives earlier and longer falls than the desert station of North Horr. Also, a strong influence is exerted on the calculation of the short period covered by the records. It is possible to divide the year into different seasons.

The first long rainy season "generally" starts in March and reaches its maximum in April. In May the amount of rainfall is already less and tends towards zero in June. June to September are nearly without rainfall (the figures in Table 4 are influenced by local showers). October is the beginning of the short rainy season, with the peak in November. December can be dry again, and also January and February. Showers are possible in the dry seasons but their effect on vegetation, surface runoff and water storage is almost nil. It should be mentioned that this model is based on the statistical means. Because of the high variabilities it is almost impossible to say exactly when the rainy season will start. Even a short period of rain in March is not a sign that the rainy season is beginning. But unlike the situation in agricultural systems the pastoralist is able to react to these high variabilities by movement to wetter areas.

5.4.1 *The variability of monthly rainfall*

To obtain more information about the character of monthly rainfall, an analysis of the variability was carried out. Using the formula:

$$\frac{S}{\bar{x}} \times 100 = v$$

S = standard deviation
$\bar{x}$ = stat. mean
v = variability

further information can be obtained. Note that this method is only intended to indicate the magnitude of variabilities in each of the months. It is also intended to compare the variabilities of various stations. In dealing only with one station this method cannot be used. If the result obtained by the formula is higher than 60, this station and month is classified as highly variable.

Table 5. Monthly variabilities at various stations

Station	Period of records	J	F	M	A	M	J	J	A	S	O	N	D
Moyale	1915-81	180	130	79	52	58	87	97	89	146	229	182	261
Lodwar	1919-81	231	143	137	97	121	220	169	248	288	230	181	253
North Horr	1959-81	170	174	119	92	146	358	228	315	367	229	139	191
Marsabit	1959-81	165	182	190	73	70	158	92	105	92	90	70	68
Gatab	1971-81	164	108	106	95	67	140	145	230	264	133	100	94
Kargi	1976-81	131	123	101	103	122	*	*	*	200	49	74	50

* indicates no rainfall recorded since the start of observation

These figures show the high uncertainty of rainfall in every month of the year. The wetter months, like April and March, show high variabilities in all stations, even in the mountainous areas. It is interesting that the minimum variability is found in the wettest month, in April, for almost all stations. The reason must be sought in the slow building up of the atmospheric conditions for rainfall in northern Kenya. Often the synoptic situation is much delayed or too early according to the mean. Also there is an influence from the method used. When there is rainfall in all years the standard deviation is not as high. The variabilities show the general problem of arid lands all over the world: 'The water supply by rainfall is only well spread out in a few years; the regularity consists in a shifting between extremes; there is a deficit of water for a long time but there is also an enormous surplus of water in a very short time'.

5.4.2 *Spatial distribution of seasonal rainfall*

The variability of rainfall applies to its spatial distribution also. This means that in every rainy season the isohyets are different from those of the previous one. But the IPAL study area is too small to show a general difference, such as a drought in the south and exceptional rainfall in the north or vice versa. We can say that when there is a drought or a period of higher rainfall, this will be true of the whole area.

Also there is the effect of the character of the rainfall. Thunderstorms and rain showers occur only in very limited areas.

Figures 10-19 show the varying distribution in the rainy seasons since the inception of IPAL in northern Kenya. Some of them have already been published by Edwards et al. (1979), but for the sake of completeness they are reprinted here. There are examples for normal, dry and wet rainy seasons, all possibilities that range management has to deal with. Special attention is drawn to the second (short) rainy season of 1980, when only a fraction of the average rainfall was recorded.

Table 6. Percentage of rainfall in November 1980 from the mean of second wet seasons (1976-1981)

North Horr	Loiengalani	Marsabit	Gatab	Kargi	Korr	Ngurunit
+25.4	-17.0	-62.7	-75.3	-26.0	-33.2	-22.8

The rainy season in 1980 was extremely dry, with little rain even in December. Even the mountains did not receive much rain. The data for Gatab and Marsabit show that they received (as a percentage) much less rain than the stations in the lowlands. It is strange that this drought did not occur in the north, where North Horr, with 38 mm, received over 25% more than the statistical mean. Due to the lack of detailed flow maps at the 500 mb level we cannot determine the atmospheric situation at this time.

On the other hand, the second wet season in 1982 was extremely wet. Due to incomplete data we cannot present an isohyetic map from the whole study area. Most of the stations received in these "short" rains more than the statistical average for the whole year.

So far no synoptic analysis of pressure distribution in this area of the African continent has been done. Comparing various synoptic situations with the occurrence and amount of rainfall would help to predict rainfall. Therefore computers with big storage capacities are absolutely necessary.

Figure 10.

ISOYHETS FOR MARCH-MAY 1977

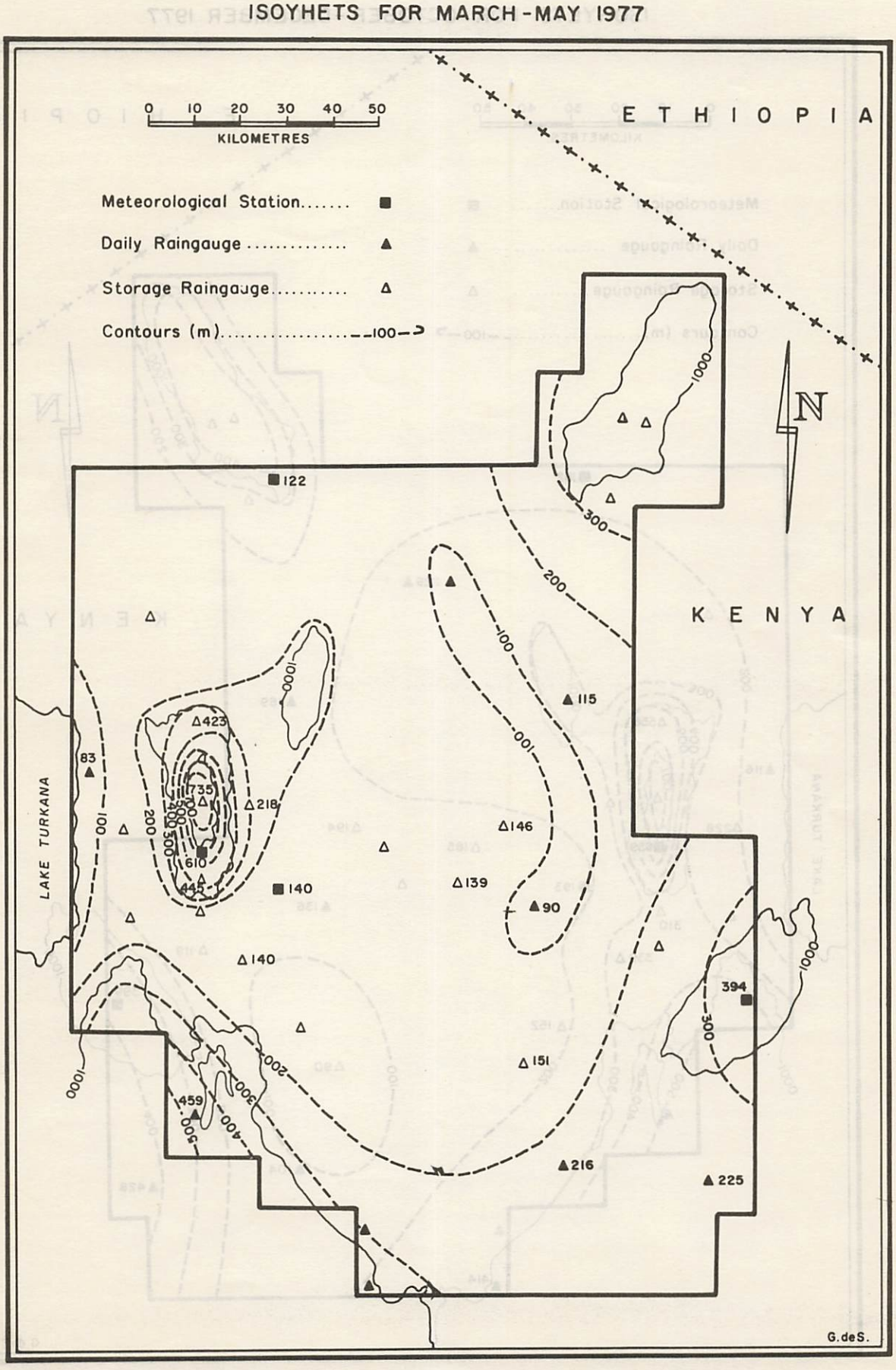


Figure 11.

ISOHYETS FOR OCTOBER-DECEMBER 1977

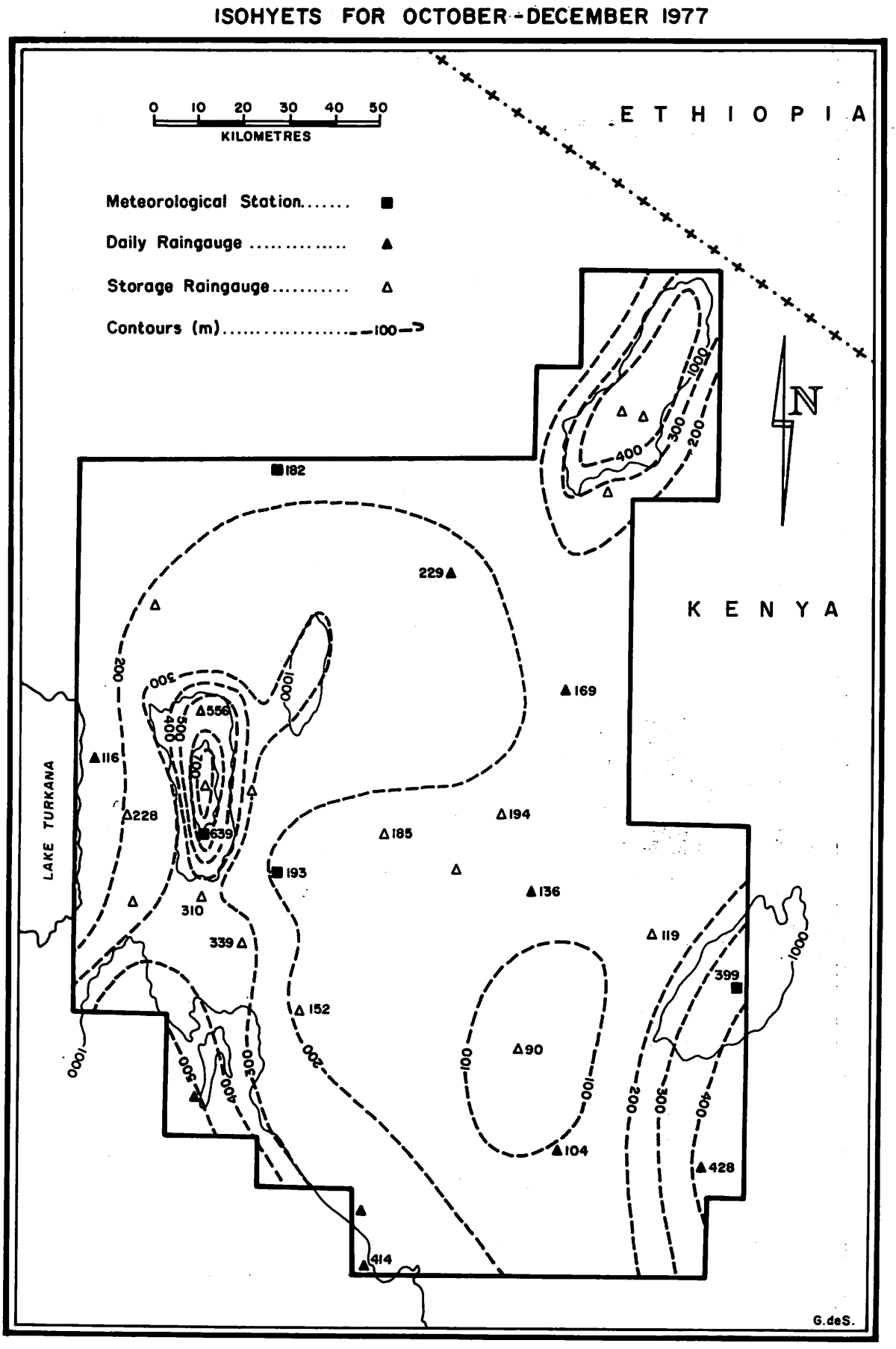


Figure 12.

ISOHYETS FOR FEBRUARY - APRIL 1978

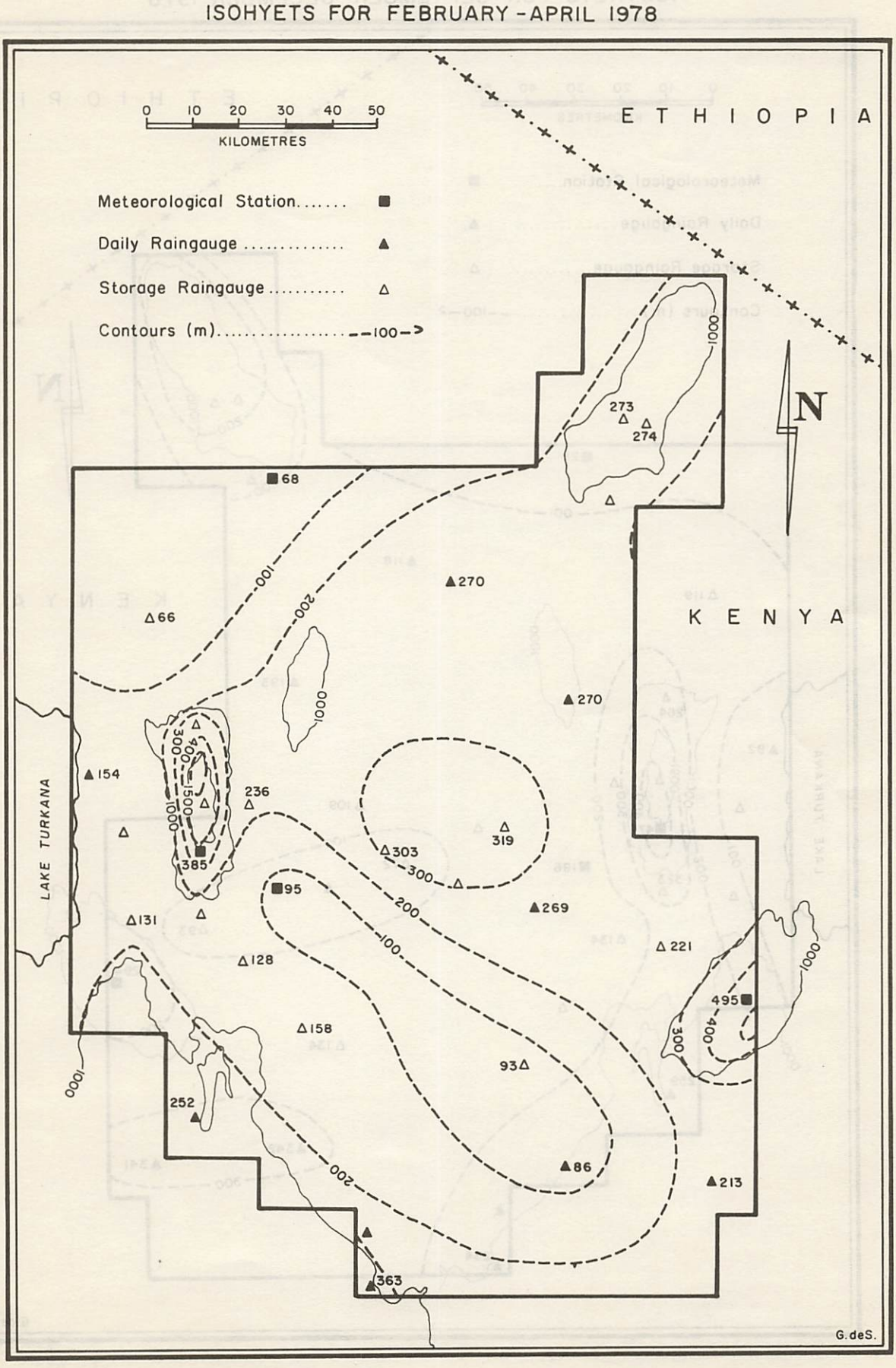


Figure 13.

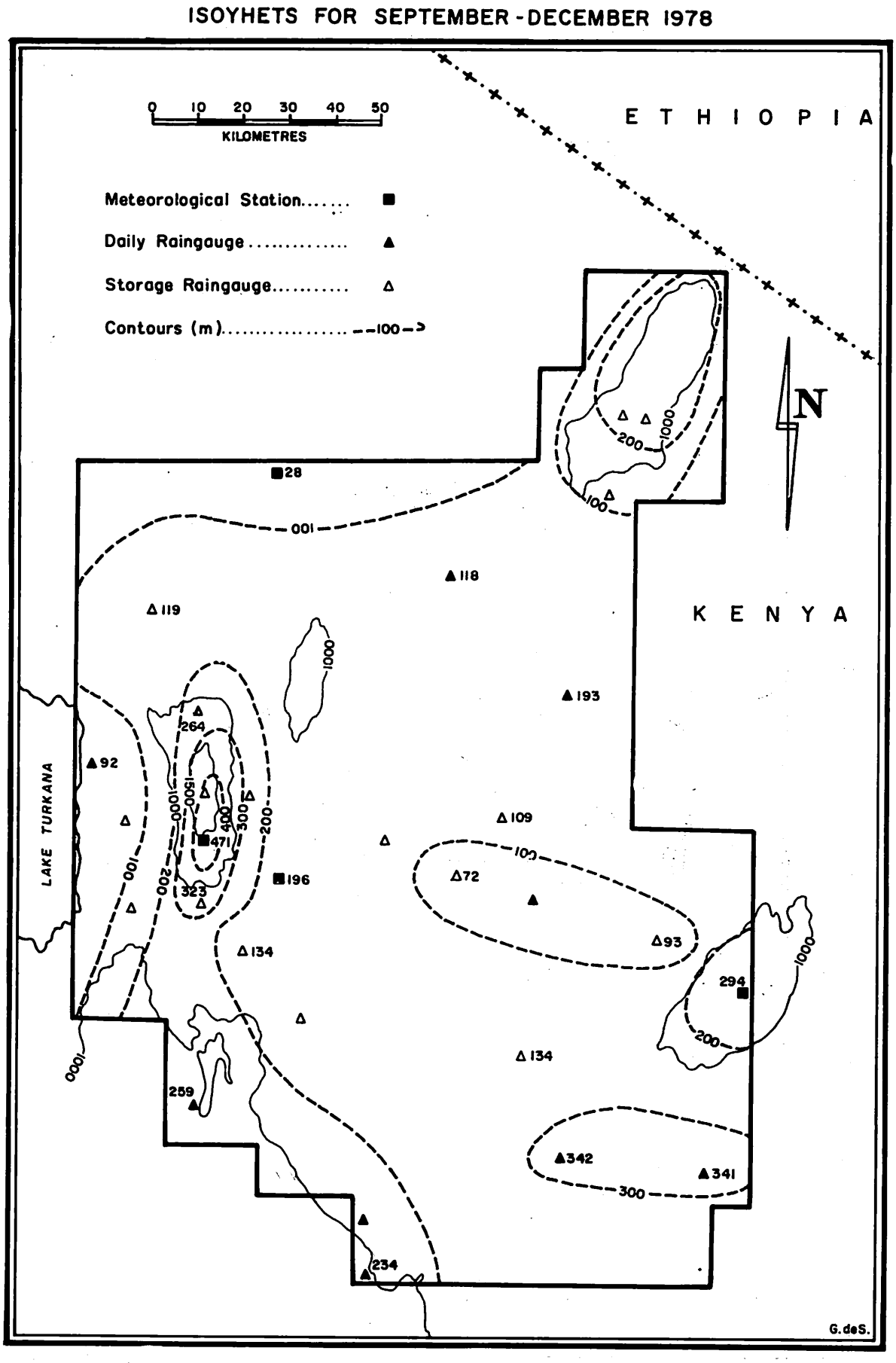

ISOYHETS FOR SEPTEMBER-DECEMBER 1978
0 10 20 30 40 50
KILOMETRES
Meteorological Station.....
Daily Raingauge.....
Storage Raingauge.....
Contours (m).....100
ETHIOPIA
KENYA
LAKE TURKANA
N
28
118
119
193
92
264
471
196
323
109
72
93
294
134
259
342
341
234
G.deS.

Figure 14.

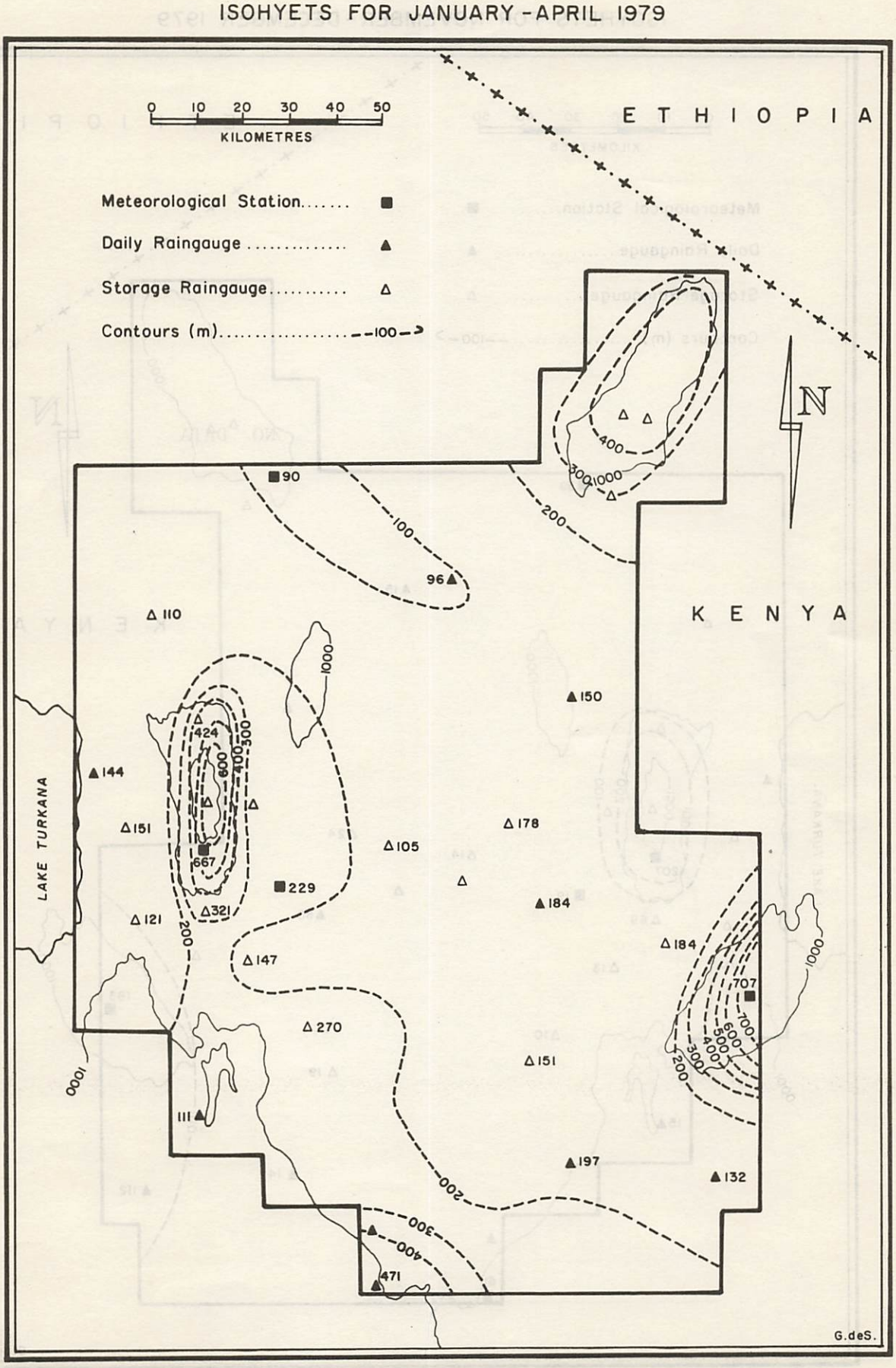

ISOHYETS FOR JANUARY - APRIL 1979
0 10 20 30 40 50
KILOMETRES
Meteorological Station.....
Daily Raingauge.....
Storage Raingauge.....
Contours (m).....100
ETHIOPIA
KENYA
LAKE TURKANA
N
G.deS.

Figure 15.

ISOYHETS FOR NOVEMBER-DECEMBER 1979

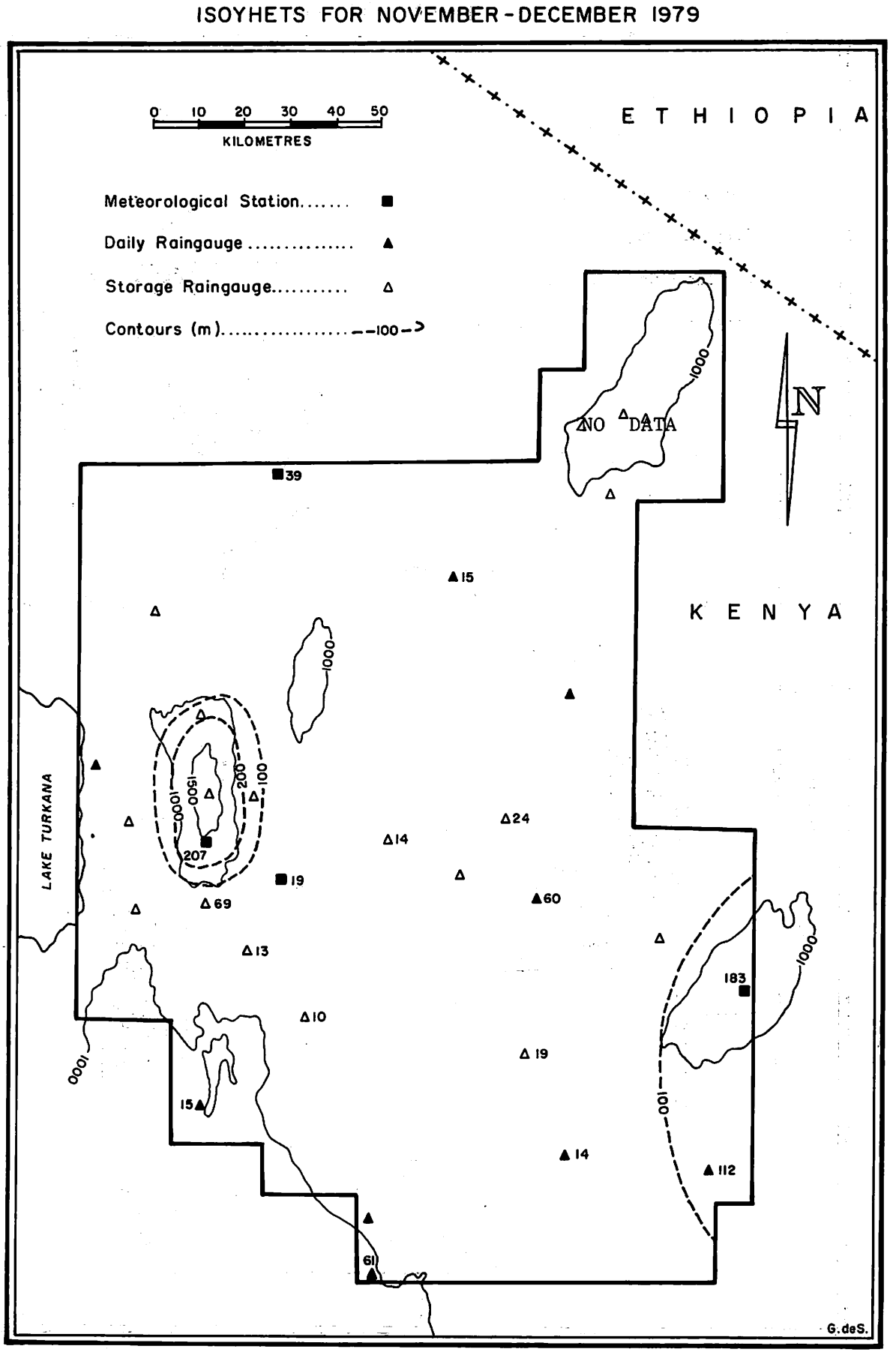


Figure 16.

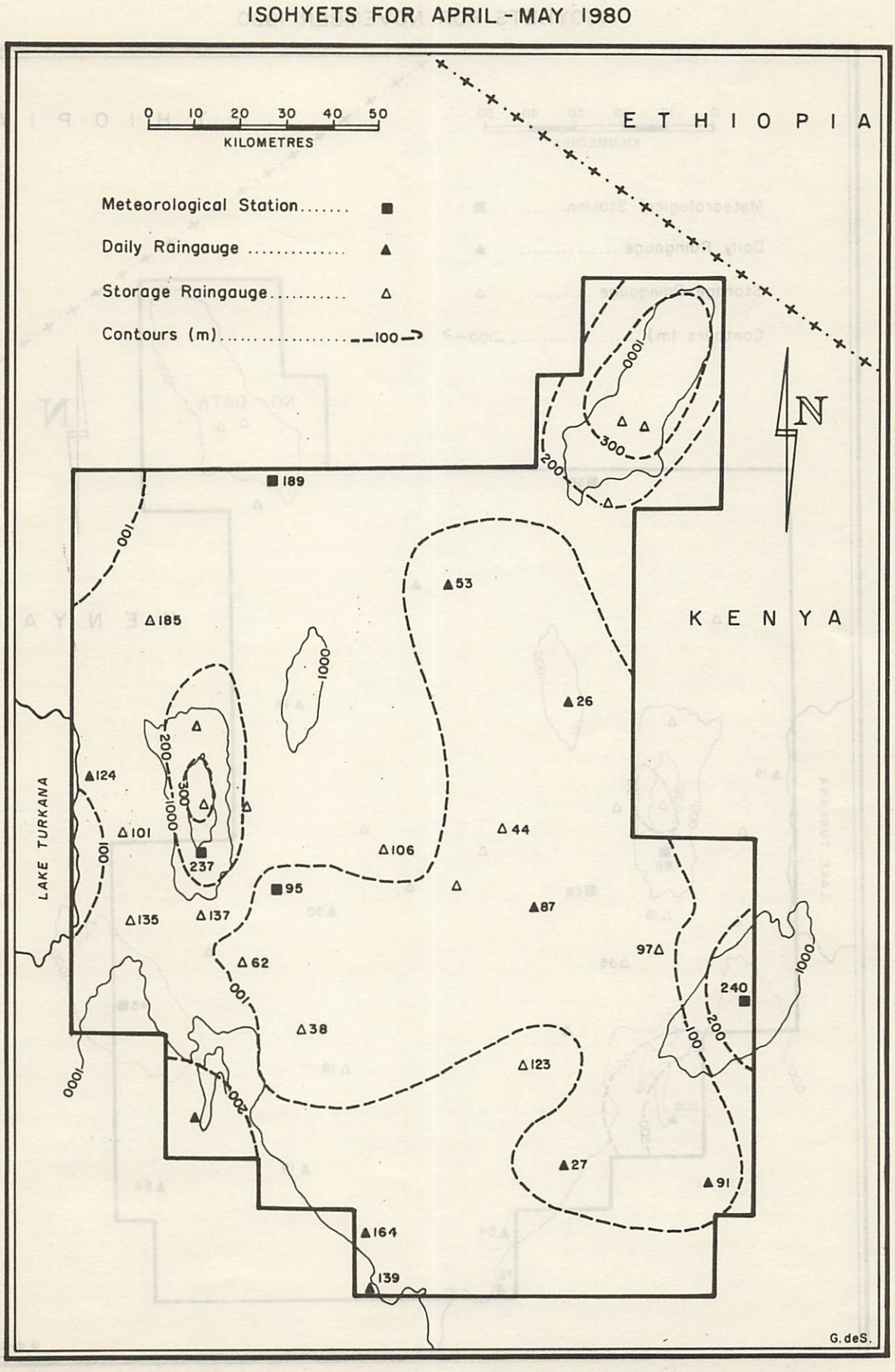

ISOHYETS FOR APRIL - MAY 1980
0 10 20 30 40 50
KILOMETRES
Meteorological Station.....
Daily Raingauge .....
Storage Raingauge.....
Contours (m).....100
ETHIOPIA
KENYA
N
LAKE TURKANA
189
185
53
26
124
101
237
95
106
44
87
135
137
62
38
123
27
91
164
139
97
240
G.deS.

Figure 17.

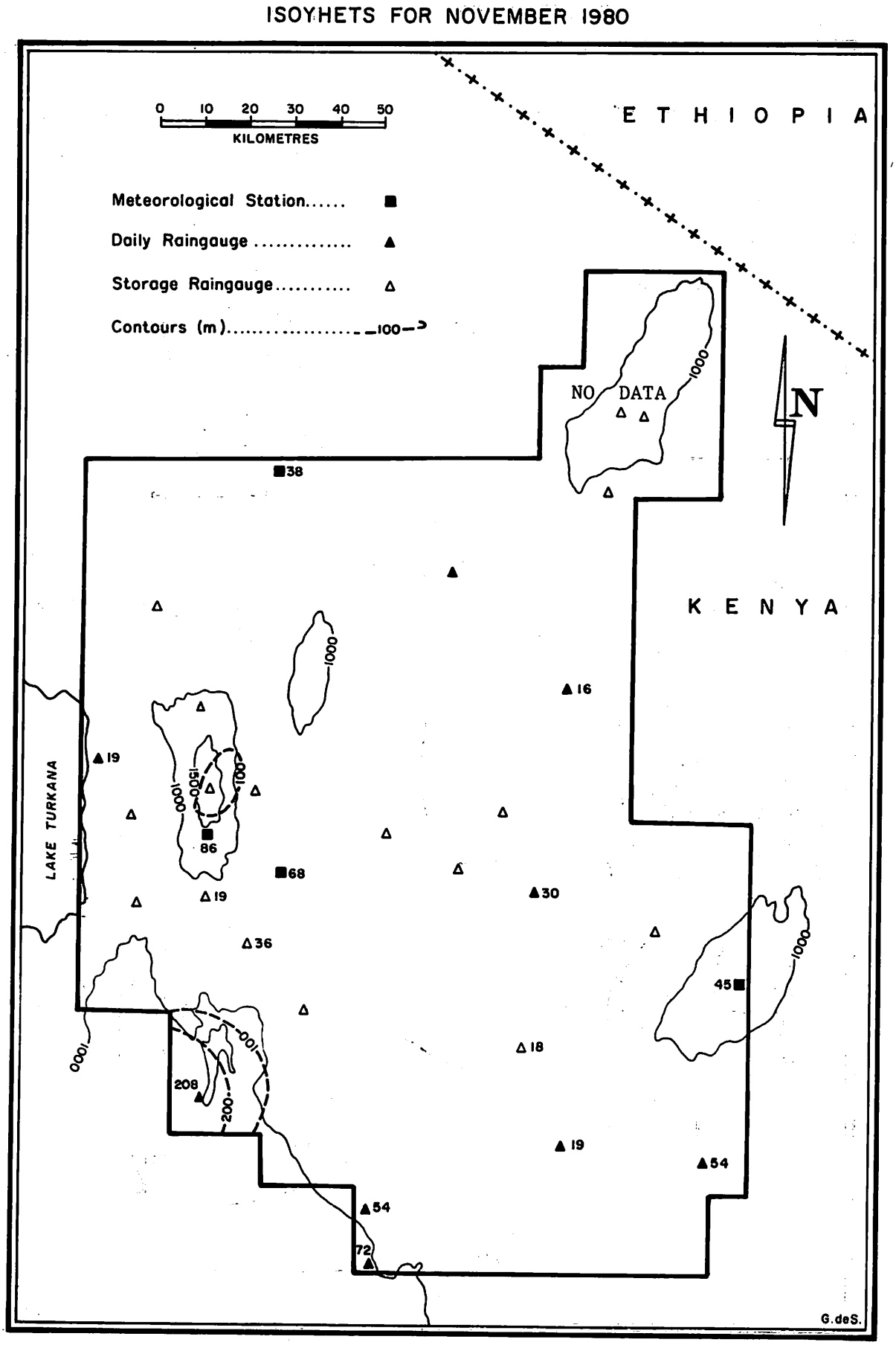

ISOYHETS FOR NOVEMBER 1980
0 10 20 30 40 50
KILOMETRES
Meteorological Station.....
Daily Raingauge .....
Storage Raingauge.....
Contours (m).....100
ETHIOPIA
KENYA
NO DATA
N
LAKE TURKANA
38
16
19
86
68
19
30
36
45
18
208
19
54
54
72
1000
1500
100
200
G.deS.

Figure 18.

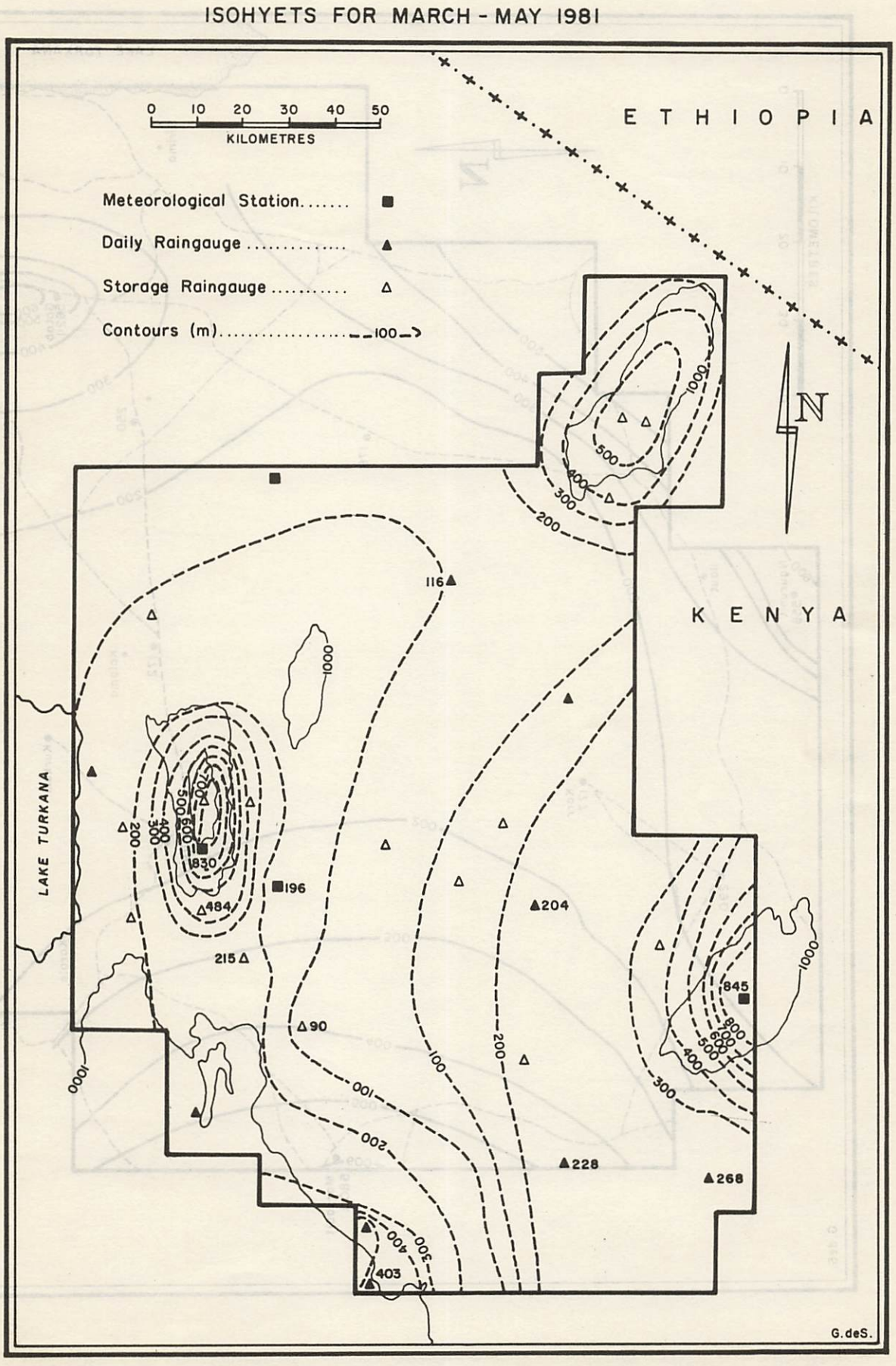
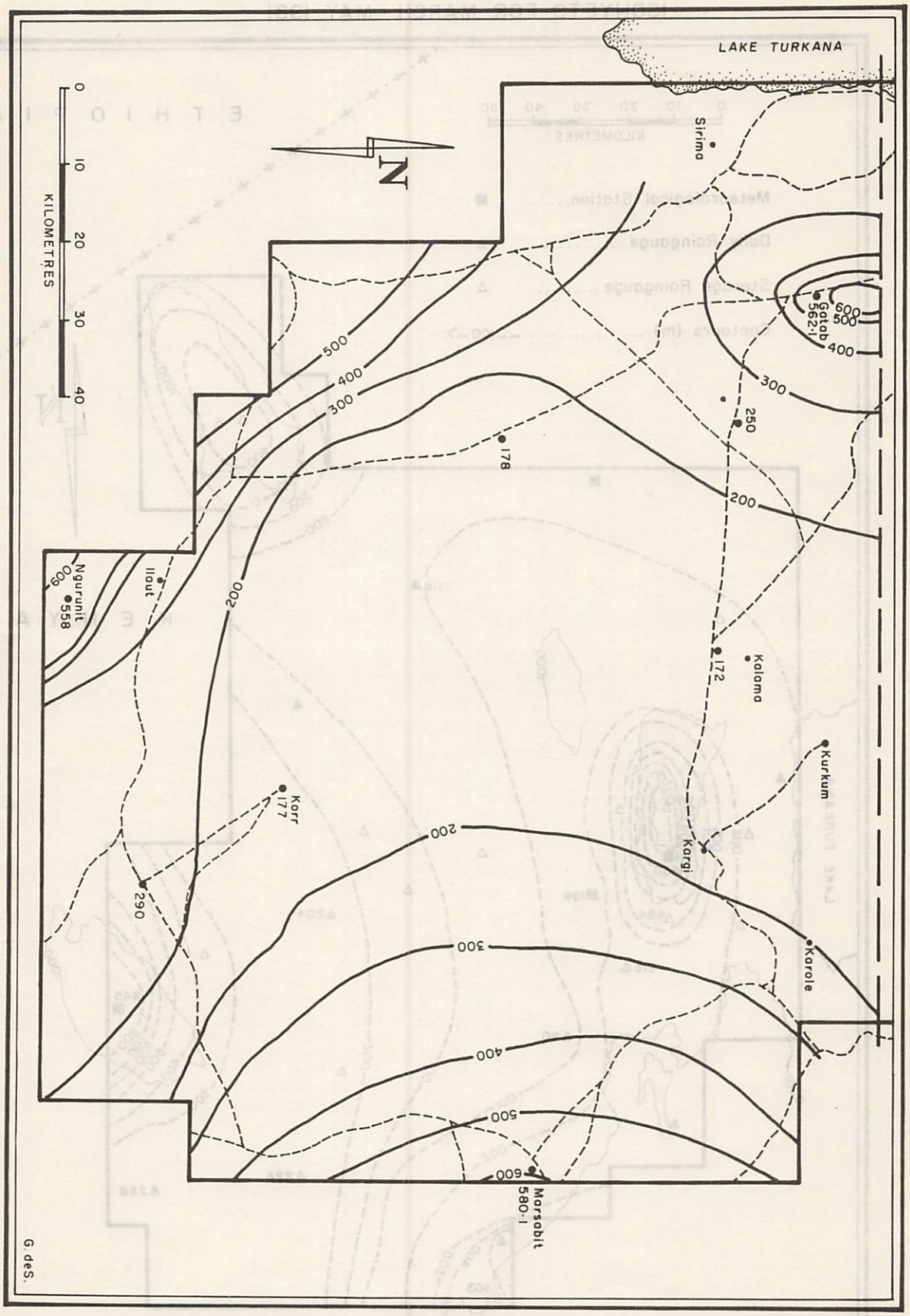

ISOHYETS FOR MARCH - MAY 1981
0 10 20 30 40 50
KILOMETRES
Meteorological Station.....
Daily Raingauge .....
Storage Raingauge .....
Contours (m).....100
ETHIOPIA
KENYA
LAKE TURKANA
N
116
1830
196
484
215
204
90
845
228
268
403
G.deS.

Figure 19. ISOHYETS FOR OCTOBER-DECEMBER 1982 (SOUTHERN AREA ONLY)



5.5. *Duration and intensity of rainfall*

Duration and intensity of rainfall are not only of academic interest. The intensity of rainfall is the major steering factor for the actual geomorphological processes. Duration and intensity also influence the amount of water which can run off the surface and which can infiltrate the soil to become finally available for the growth of plants.

Rainfall of a high intensity and short duration is of only restricted value for the vegetation cover. Much of the water cannot enter the soil and reach the roots of the plants. It is difficult to give a quantitative definition of "useful" and "useless" rains. But we can say that a long rain of lower intensity provides more water for plant growth than a short heavy fall of the same amount.

There are only a few stations from which data on rainfall intensity are available. It seems that rains of high intensity (torrential rains) are not as common as in the arid and semi-arid parts of northern Africa and the Mediterranean region.

There are few data available to carry out a comprehensive analysis of the structure of rainfall intensity in the IPAL area, but it must be noted that this is necessary for work in geomorphology..

It seems that intensive rainfall occurs at any time of the year. This raises the assumption that high rainfall intensities are highly correlated with the convective genesis of the rainshower. Another indication of this is the limited area of occurrence. We have also to consider that a large number of intensive falls in the wet season are reduced by the general atmospheric conditions. Table 7 gives an estimate of the rainfall intensities and highest rainfall at the mountain station of Gatab. For the lowland stations these data are not yet available.

Table 7. Highest rainfall intensities and highest rainfall at Gatab

Month	Year	Highest rainfall intensity per hour	Duration in minutes	Highest rainfall	Duration in minutes
November	1977	34.44 (mm)	27	113.40	453
December		21.67	90	32.50	90
January	1978	23.83 (mm)	104	66.10	305
February		16.12	16	35.00	466
March		24.52	104	55.60	450
April		48.28	21	16.90	21
May					
June					
July		27.00		23.40	109
August					
September		9.79	291	54.30	747
October		52.89	270	238.00	270
November		27.27	33	29.10	284
December		11.88	49	22.20	158
January	1979	9.34 (mm)	687	106.90	687
February		176.40	5	31.60	35
March		43.38	16	75.00	356
April		55.64	33	31.80	125
May		23.63	16	11.30	93
June		12.54	33	16.60	240
July					
August					
September					
October					
November		18.37	49	21.70	136
December		16.67	27	28.40	106.50
January	1980				
February					
March					
April		18.88 (mm)	49	27.8	425
May		7.67	54	53.7	878
June					
July					
August					
September					
October		7.50 (mm)	60	7.50	60
November		100.91	11	18.50	11
December					
January	1981				
February					
March		54.9	180	36.00	49
April		53.09	182	160.90	182
May		4.88	534	43.40	534

5.6 *Probability of rainfall*

Not enough data are available to draw probability maps of the amount of rainfall, even on a yearly basis, for the entire study area.
Five years of records mean that every year has a value of 20%. As has been said, we do not know in which way we are to understand these data: Has it been a normal, a dry or a wet period?

The ILCA prepared in 1979 a study of the probability of rainfall in Kenya. We extract from that study three representative stations for northern Kenya: Lodwar, representing the arid north, Moyale the wetter parts, and Marsabit the wet mountain areas.

Table 8 gives also the data for the medians of these stations, which is a good addition to our results. To include wider parts of the study area, data for one-third of the amount of rainfall at Marsabit and one-half for Moyale are given as well. A first approach to how an analysis should look is shown in section 5.7 where there is also a discussion on the probability of rainfall at Marsabit.

Table 8a. Monthly rainfall probabilities

Lodwar n = 52 med. = 174 mm/a

	J	F	M	A	M	J	J	A	S	O	N	D
Median	0	1	9	39	10	1	6	1	0	0	2	2
Probabilities												
<25 mm	.89	.89	.72	.91	.64	.91	.77	.83	.95	.91	.80	.87
>50 mm	.60	0	.10	.34	.19	.02	.12	.09	.02	.07	.11	.04
>100 mm	.02	0	.05	.20	.05	.02	.04	.02	0	0	.05	.02
>200 mm	0	0	0	0	0	0	0	0	0	0	0	0

Moyale n = 56 med. = 676 mm/a

Median	8	10	39	157	144	16	13	13	9	95	77	28
Probabilities												
<25 mm	.87	.74	.34	0	.02	.78	.79	.85	.68	.12	.10	.47
>50 mm	.07	.11	.46	.97	.87	.05	.02	.03	.17	.72	.71	.28
>100 mm	.02	.02	.21	.84	.61	0	0	0	.02	.47	.36	.09
>200 mm	0	0	0	.03	.11	0	0	0	0	.13	.02	0

Marsabit n = 50 med. = 777 mm/a

Median	17	4	43	209	30	3	7	7	7	103	116	47
Probabilities												
<25 mm	.61	.77	.28	0	.28	.93	.83	.80	.82	.16	.04	.30
>50 mm	.25	.14	.44	.91	.60	0	.03	.06	.04	.68	.80	.44
>100 mm	.13	.05	.21	.78	.41	0	.02	.02	0	.50	.54	.26
>200 mm	0	.02	.04	.44	.14	0	0	0	0	.23	.20	.07

Table 8b. Monthly rainfall probabilities

1/3 Marsabit n = 50 med. = 259 mm/a

	J	F	M	A	M	JU	JL	A	S	O	N	D
Median	6	1	14	70	23	1	2	2	2	34	39	16
Probabilities												
<25 mm	.86	.93	.63	.14	.52	1	.98	.96	1	.38	.36	.65
<50 mm	.05	.02	.12	.66	.28	0	0	.02	0	.29	.38	.13
<100 mm	0	0	0	.26	0	0	0	0	0	.04	.09	0
<200 mm	0	0	0	.02	0	0	0	0	0	0	.01	0

1/2 Moyale n = 56 med. = 338 mm/a

Median	4	5	20	79	56	8	7	7	5	48	39	14
Probabilities												
<25 mm	.93	.89	.54	.03	.13	.95	.98	.97	.83	.29	.29	.72
<50 mm	.02	.02	.21	.84	.61	0	0	0	.02	.46	.36	.09
<100 mm	0	0	0	.30	.11	0	0	0	0	.13	.02	0
>200 mm	0	0	0	0	0	0	0	0	0	0	0	0

Source: ILCA, 1979

The two rainy seasons have the following characteristics:

Table 9. Rainfall characteristics of the wet seasons

Moyale	February - July	August - January
Median	195 mm	130 mm
Lower quartile	155 mm	85 mm
Upper quartile	260 mm	180 mm
Marsabit		
Median	145 mm	120 mm
Lower quartile	90 mm	85 mm
Upper quartile	190 mm	170 mm

Source: ILCA, 1979

The ILCA also carried out an analysis of the combination of both rainy seasons. There is a probability of two-thirds that a bad wet season will be followed by a second bad wet season. Similarly, a good wet season will be followed in two-thirds of the cases by a second good wet season.

The value of these probabilities for range management is very great. This effects especially the beginning of the wet season. The probability of rainfall of more than 50 mm per month is of great interest, as this amount is below the minimum required for plant growth. Even in the wettest month, April, there is only a probability of 70% in all years. In the other months the situation is even worse. In the second wet season, more than 50 mm per month was received in only half the years. The probabilities are higher in the mountains but these areas are of very limited extent.

Nevertheless, the figures show the real importance of these wetter areas in supplying the lowlands with subsurface and even, partly, with surface water. There is a need for conservation of the environment in the mountains, since any degeneration there will also affect the desertification-threatened areas in the lowland plains of Marsabit District.

5.7 *Rainfall at Marsabit*

An example for the statistical analysis of rainfall data

5.7.1 *Introduction*

Marsabit is the only station in the IPAL study area with a long-term record of rainfall. These records started in 1918 and have continued with various interruptions till today. Presumably the site of the meteorological station had been moved several times but there are not enough data to compute a consistency analysis to get correction data. Unfortunately, the present site of the meteorological station is not chosen very well. Lying between two mountains and open to the east and west, we have to deal with very high wind speeds which affect measurements of all meteorological parameters.

5.7.2 *The annual rainfall and its variability*

The long-term mean of Marsabit has been determined as 796 mm. ILCA (1979) gives for a shorter period 843 mm and as median 777 mm per year. The variability as shown in the absolute figures (Table 2a) is extremely high. Also the mean variabilities have to be seen in this way. The mean positive one is +32.7%, with -24.3% for the negative one.

Table 10 shows the probabilities in percentage and return periods and various amounts of annual rainfall. It must be mentioned that the probability in this case has been calculated from events in the past and does not give any prediction of the amount of rainfall for the coming years. Therefore, other methods have to be applied which take into account the physics of atmospheric movements all over Africa. This is something that, so far, nobody has successfully achieved.

Table 10. Probabilities of annual rainfall and their return periods

Rainfall in mm	Probability in %	Return period in years*
300-400	5.6	17
401-500	1.9	50
501-600	16.7	6
601-700	9.3	11
701-800	18.5	5
801-900	9.3	11
901-1,000	9.3	11
1,001-1,100	13.0	8
1,101-1,200	3.7	25
1,201-1,300	3.7	25
Over 1,301	9.3	11

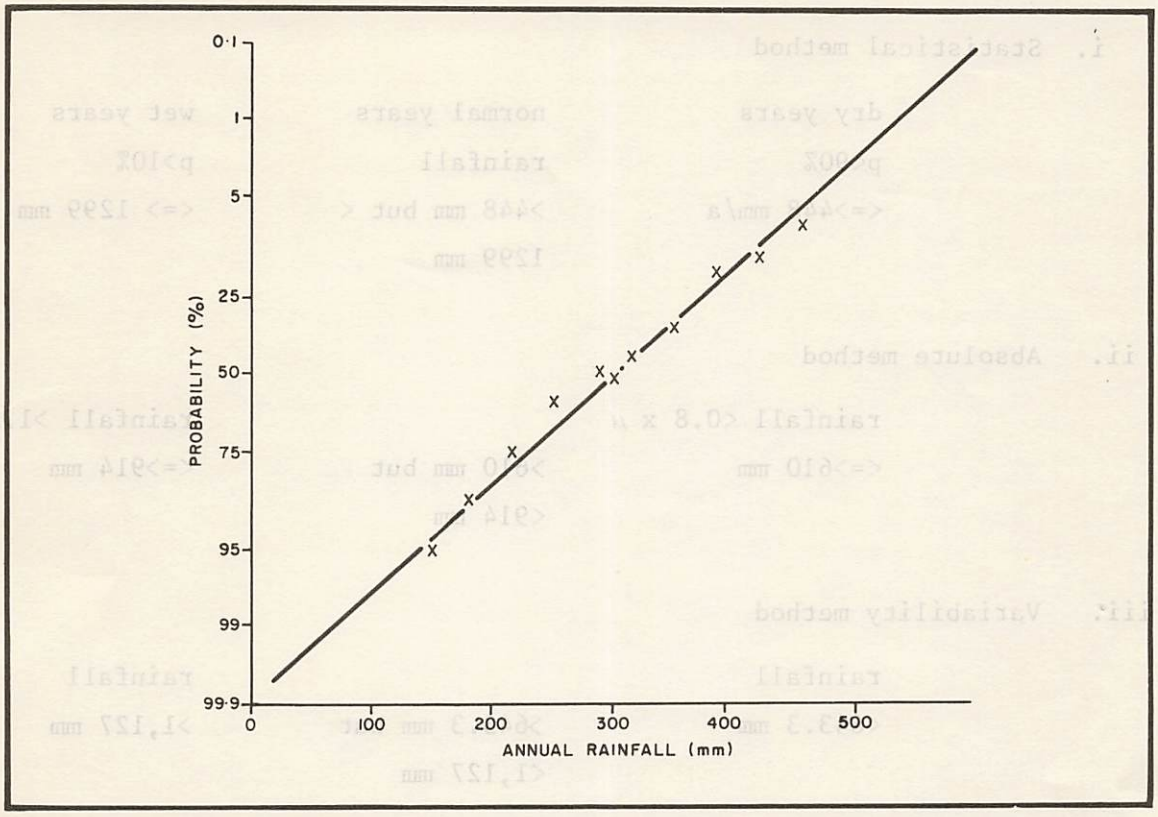
* Data have been rounded up to full years

It is interesting to note that the mean lies in the same region as the highest probability, but have also to consider that the probability is fairly low (<20%).

More information is obtained from Figure 20, also showing the rainfall probability but in a different form. From this the value of
has been calculated which means the amount of rainfall with the accumulative probability of 50%. Also, the values for 90% and 10% have been calculated. This leads to a classification of dry and wet years, and in addition the values obtained by the analysis of variability are also given.

Figure 20a/b. Probabilities of annual rainfall at Marsabit and Marsabit/3

a. Marsabit



b. Marsabit/3

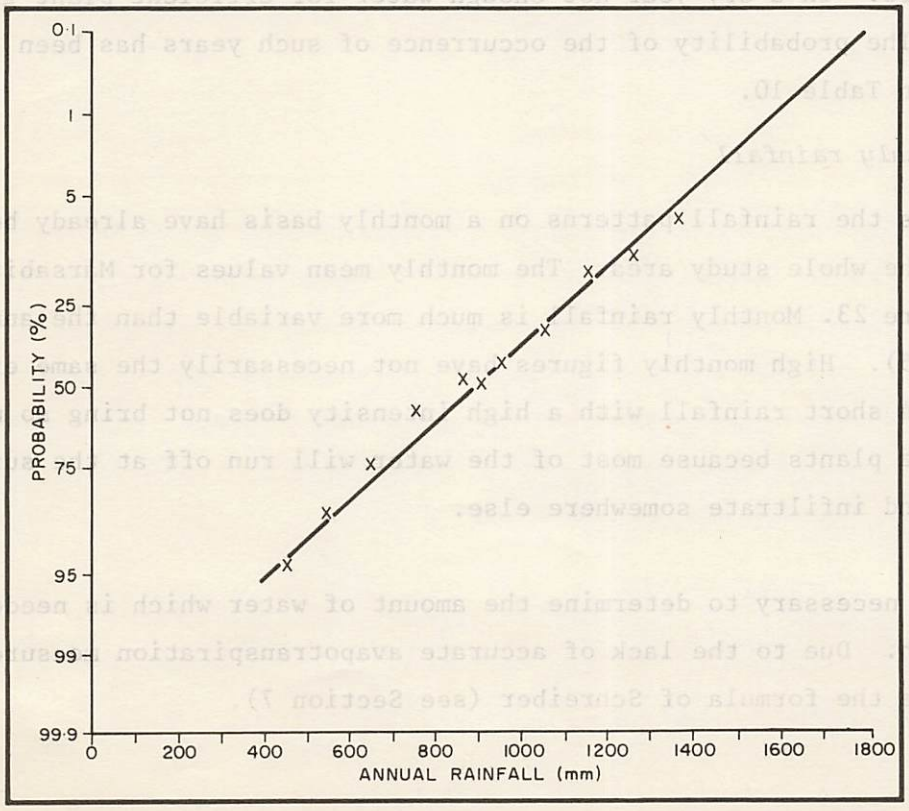


Table 11. Classification of years at Marsabit

i. Statistical method

dry years	normal years	wet years
p<90%	rainfall	p>10%
<=>448 mm/a	>448 mm but < 1299 mm	<=> 1299 mm

ii. Absolute method

rainfall <0.8 x μ		rainfall >1.2 x μ
<=>610 mm	>610 mm but <914 mm	<=>914 mm

iii. Variability method

rainfall		rainfall
<643.3 mm	>643.3 mm but <1,127 mm	>1,127 mm

This statistical approach shows in which value the means have to be seen. Also it already gives a first view of the conditions of vegetation during the various years. In a dry year not enough water for efficient plant growth is available. The probability of the occurrence of such years has been shown already in Table 10.

5.7.3 *The monthly rainfall*

In general terms the rainfall patterns on a monthly basis have already been described for the whole study area. The monthly mean values for Marsabit can be seen in Figure 23. Monthly rainfall is much more variable than the annual one (see Table 5). High monthly figures have not necessarily the same effects in two years. A short rainfall with a high intensity does not bring so much moisture for the plants because most of the water will run off at the surface and evaporate and infiltrate somewhere else.

It is therefore necessary to determine the amount of water which is needed for plant growth. Due to the lack of accurate avapotranspiration measurements we use for these the formula of Schreiber (see Section 7).

Table 12. Monthly rainfall and monthly threshold values

	J	F	M	A	M	J	J	A	S	O	N	D
Mean	33.9	18.9	70.3	190.9	190.9	16.5	14.3	14.2	13.0	177.6	136.5	74.2
Threshold	66.3	66.3	66.7	64.6	63.6	60.5	57.9	57.2	59.9	62.2	61.5	60.9
Classification	A	A	H	H	H	A	A	A	A	H	H	H

A = arid; H = humid

All figures in mm.

If the mean of the rainfall of a month is higher than threshold value this month has been classified as humid. Therefore in the average we have 6 humid months at Marsabit.

As usual, this amount is variable. The probabilities of the number of arid months are given in Table 13.

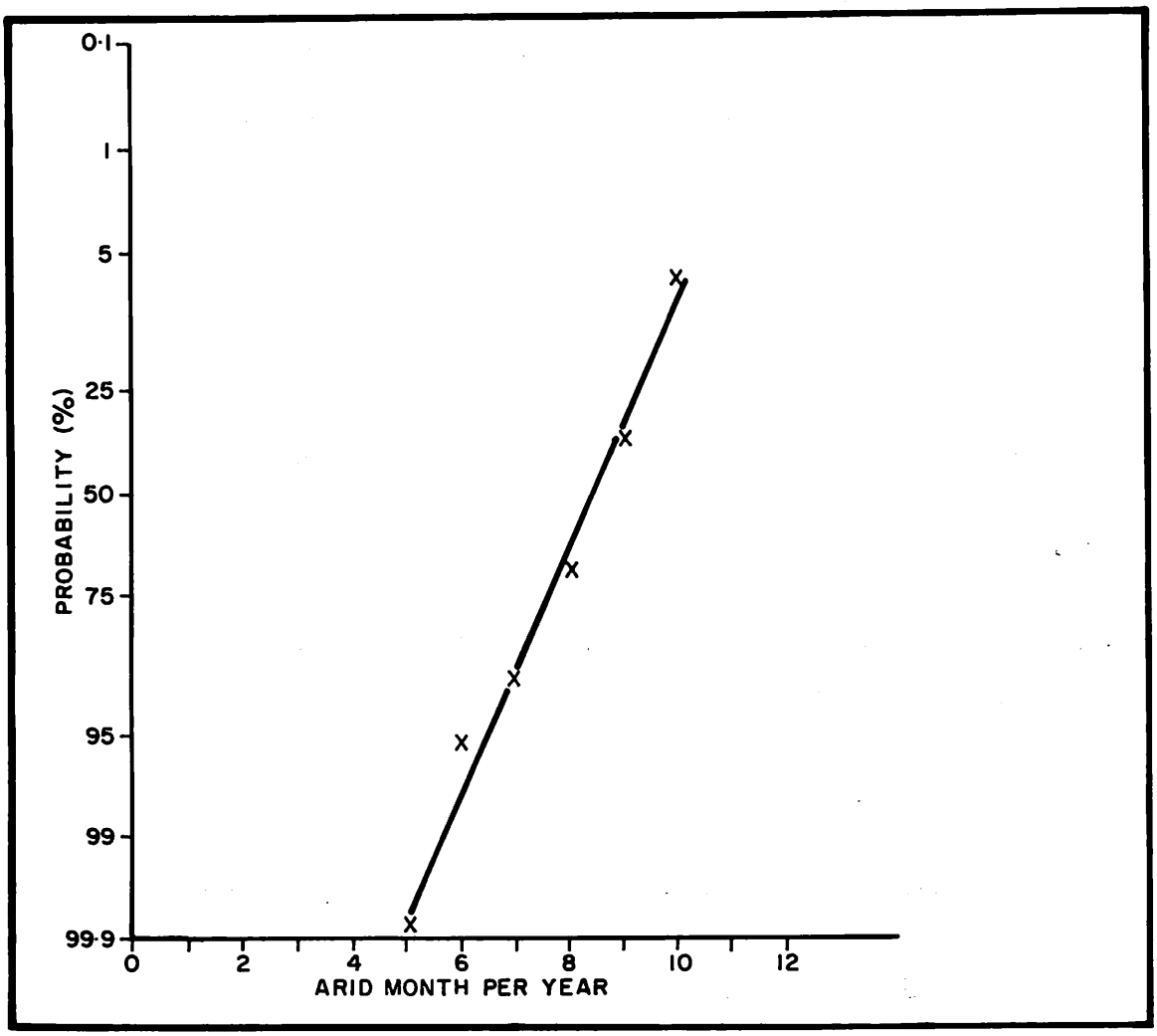
5.7.4 *Aridity and humidity*

Table 13. Probability of arid months per year (in %) and their return period

Number of arid months per year	Probability	Return period
5	3.5	29
6	10.5	10
7	15.8	6
8	36.8	3
9	24.6	4
10	8.7	11

A further interpretation shows that μ is much higher than the mean of 6 arid months per year. It lies over 8. That this value is more reliable than the mean is also shown in the direct analysis of arid months where the mean is 7.9 with a standard deviation of 1.23. This means that in the majority of years one has to expect more than 6 arid months. It is only in 14% of all years or every seventh year that there are fewer arid months. Marsabit (Meteorological station) has therefore to be classified as semi-arid and not as humid or subhumid, as by Gwynne and Pratt. It has to be

Figure 21. Probabilities of arid months at Marsabit



acknowledged that this is especially valid for the upper western slopes of Mt. Marsabit. The eastern side is wetter (luv effect) as there is also an outcombing of fog and clouds by the vegetation.

Not only the number of arid months per year is important but also their distribution over the year. The statistical mean distribution is shown in Figure 23. It follows the general rainfall pattern. Nevertheless, as in other months there is a probability that this month has to be classified as arid.

Table 14. Probability of arid months in % and return period

	J	F	M	A	M	J	J	A	S	O	N	D
Probability	77	85	61	20	47	98	97	95	98	36	24	57
Return period	1	1	2	5	1	1	1	1	1	3	4	2

(return periods rounded)

Even for the "traditional" wet months like April and November the probabilities that these months are arid are still $\geq$ 20%, which is fairly high. The insecurity of plant growth is shown quite obviously. There is no certainty that in the "wet season" enogh water is available.

One thing should be clearly noted at this point. This statistical analysis is carried out for Marsabit, lying on a mountain where there is much higher precipitation. We have to consider that for the lowlands there is less than one-third of the Marsabit rainfall. Therefore the situation is much worse. Unfortunately, Marsabit is the only long-term station in the study area. The other recording periods are not long enough to carry out an analysis like this.

5.7.5 *The seasons*

According to the mean the wet season starts in March and lasts till the end of May, while the short rains are from October to December. The actual conditions in the past are shown by Figure 22 where the rainy seasons have been drawn in. Also the duration and the beginning of the wet seasons have been analysed and can be found in this figure. We also give the return period here.

Figure 22. Variation of starts and duration of rainy seasons at Marsabit

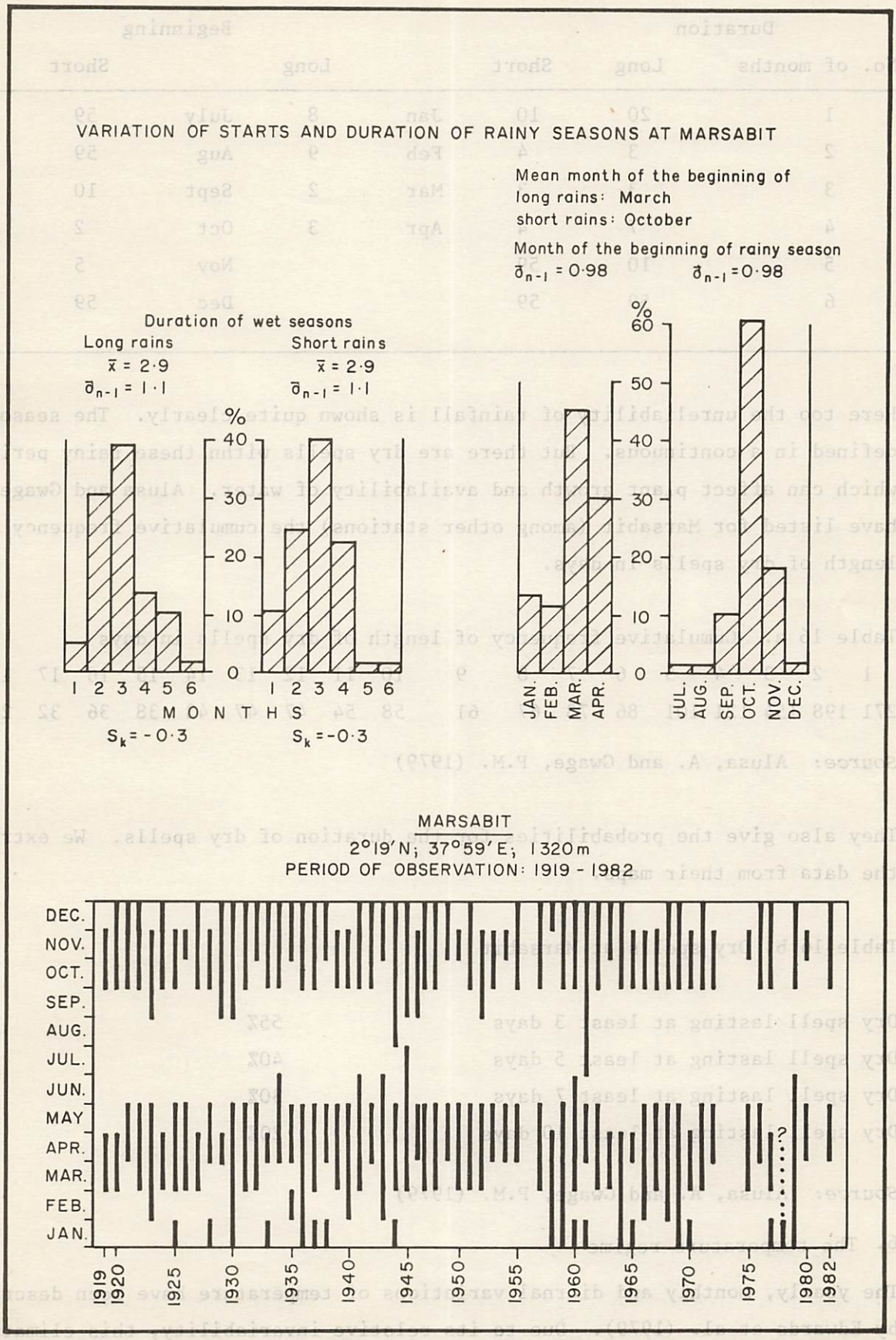


Table 15. Return periods of the duration and beginning of the wet seasons (in years)

Duration			Beginning			
No. of months	Long	Short		Long		Short
1	20	10	Jan	8	July	59
2	3	4	Feb	9	Aug	59
3	3	3	Mar	2	Sept	10
4	7	4	Apr	3	Oct	2
5	10	59			Nov	5
6	59	59			Dec	59

Here too the unreliability of rainfall is shown quite clearly. The seasons are defined in a continuous. But there are dry spells withn these rainy periods which can affect plant growth and availability of water. Alusa and Gwage (1979) have listed for Marsabit (among other stations) the cumulative frequency of length of dry spells in days.

Table 16 a. Cumulative frequency of length of dry spells in days

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
271	198	154	121	101	86	73	67	61	58	54	47	47	43	38	36	32	29	24	21

Source: Alusa, A. and Gwage, P.M. (1979)

They also give the probabilities for the duration of dry spells. We extrapolate the data from their maps.

Table 16 b. Dry spells at Marsabit

Dry spell lasting at least 3 days	55%
Dry spell lasting at least 5 days	40%
Dry spell lasting at least 7 days	30%
Dry spell lasting at least 10 days	20%

Source: Alusa, A. and Gwage, P.M. (1979)

6. The temperature regime

The yearly, monthly and diurnal variations of temperature have been described by Edwards et al. (1979). Due to its relative invariability, this climatological factor is unlikely to show much change over a longer recording period.

Temperature as a climatic factor varies only within a small range, much less than 10%, and for that reason only a few additional remarks are made here. The basic information can be obtained from IPAL Technical Report B1 (1979).

The temperature measurement network (daily maxima and minima) is restricted. More stations have been included in 1982, but the period of observation is still less than 12 months, and these data are not included here.

One aspect that should not be ignored concerns the decrease of temperature with altitude. This can be seen by comparing the stations of Olturot and Gatab, which are less than 20 m apart. Gatab lies at an altitude of approximately 1,670 m, while Olturot lies at 550 m, influenced by katabatic winds from Mt. Kulal.

Table 17. Mean monthly temperature (^{o}C)

	J	F	M	A	M	J	J	A	S	O	N	D	Y
Olturot	28.2	28.5	28.1	27.4	27.5	27.3	26.8	27.4	28.1	28.9	27.3	27.9	27.9
Gatab	19.0	19.8	19.7	19.0	19.3	18.8	17.6	17.9	19.0	19.1	18.7	18.8	18.9
Difference	9.2	8.2	8.4	8.4	8.2	8.5	9.2	9.5	9.1	9.8	8.6	9.1	8.9

Over the whole year we have a temperature difference of 8.9^{o}C, which is equivalent to a gradient of 0.8^{o}C/100 m. Within the year there is a variation caused by differences in humidity and rainfall. Thus, the mean gradient in March, April, May and November is somewhat lower than during the other months. The minimum for May is difficult to explain, but is probably influenced by higher rainfall in the short period of observation. The higher temperatures in the lowlands impose a shorter period for watering animals, but there is in general no large change throughout the lower parts of the study area.

Temperature in areas with a lava cover are higher than in those areas with sandy soils, since the dark lava absorbs incoming radiation energy and heats the air near the surface. Thus at Kargi a temperature of 45°C in the shade was measured at 14 h in July. This effect will have to be considered when we are able to draw temperature maps of Marsabit District.

7. Aridity and humidity

7.1 *General*

In the investigation of the problem of desertification aridity takes a central place. The relation of humidity and aridity, and the duration and degree of aridity have to be seen in the environmental balance of an arid area as the most important climatic factors. There is also a special relation of aridity to actual morphodynamics, where it is one of the major steering factors. By this approach to a hydro balance we can draw conclusions for the land-use potential of a land unit. In the case of northern Kenya this is mostly a matter of range condition.

7.2 *Method of determination of aridity and humidity*

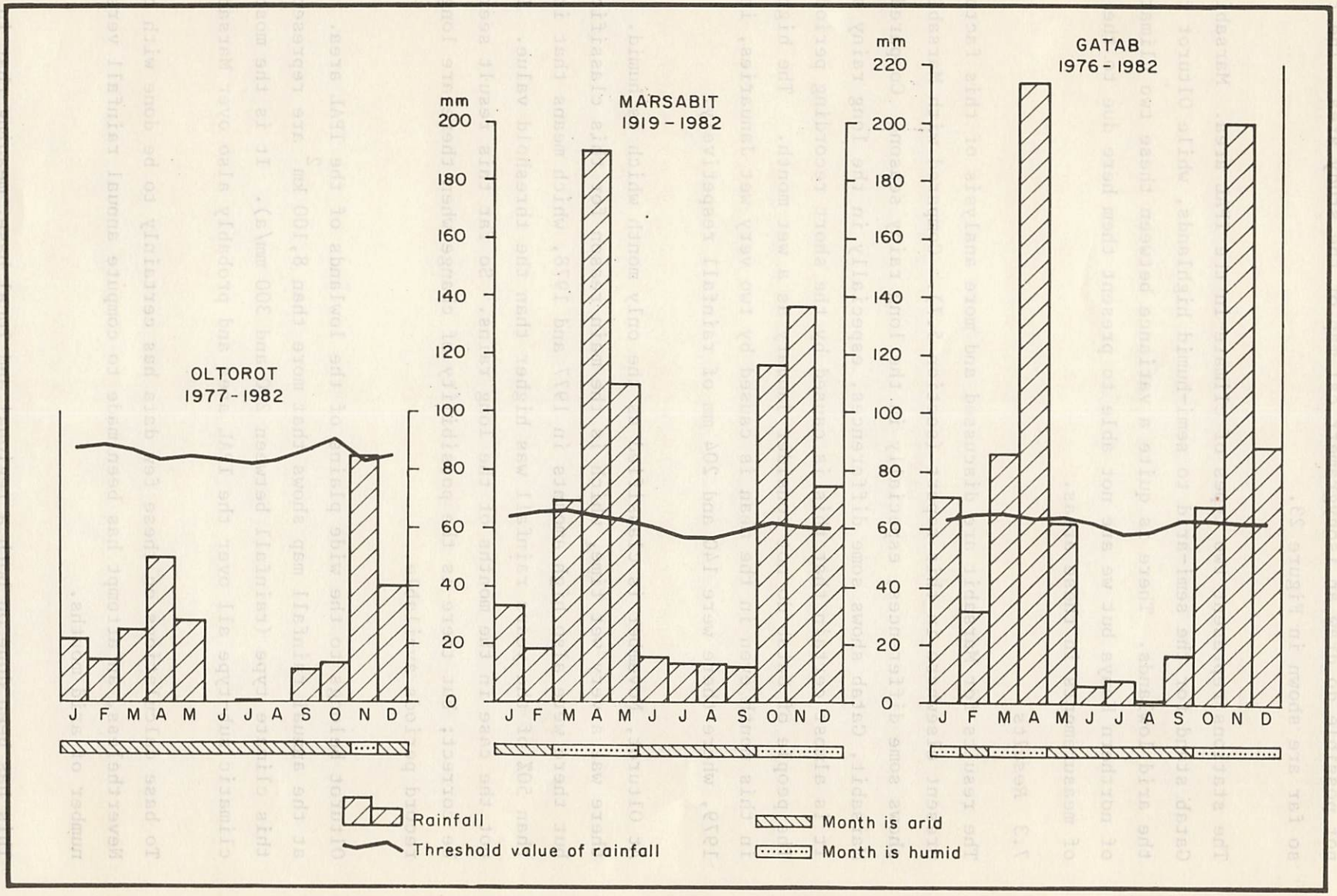
The ideal would be to have data on evapotranspiration and rainfall. In northern Kenya there are only (and in some cases only potential) evaporation data. Therefore we have to use other data more easily available.
Several formulas have been developed to get out of this dilemma, most of them applicable only to particular climates. The most suitable for northern Kenya is that of Schreiber, which uses temperature, air pressure and length of day light to determine the threshold value of rainfall for the different months.

The formula is: $r = (2t + 0.03\ t) \cdot \frac{Po}{P} \cdot \frac{\zeta}{12}$

where r = monthly precipitation limit in terms of mm of rainfall
t = mean monthly temperature in ^{o}C
Po = air pressure under normal conditions (1,013 mb) at sea level
P = mean air pressure as a function of altitude (in mb)
ζ = mean monthly daylight in hours

For three stations in the IPAL area, r has been computed and plotted over the year versus the mean rainfall. When rainfall is higher in a specific month than the threshold value that month has been classified as humid.
It was not possible to take more stations into account because the measurement of temperature has not been going on long enough.

Figure 23. Rainfall and threshold values of rainfall



(Remark: It is possible to calculate the factors P and ζ). Therefore it is not possible do draw an isohygrametrical map of the study area. The results so far are shown in Figure 23.

The stations represent two types of climate in the IPAL area. Marsabit and Gatab stand for the semi-arid to semi-humid highlands, while Olturot represents the arid lowlands. There is quite a variance between these two climatic types of northern Kenya but we are not able to present them here due to the lack of measurements in these areas.

7.3 *Results*

The results for Marsabit are discussed and more analysis of this factor present elsewhere in this report (section 5.7). Compared with Marsabit, Gatab shows some differences, especially in the long rainy season. Compared with Marsabit, Gatab shows some differences, especially in the long rainy season. It is almost certain that this is caused by the short recording period. The people of Gatab do not consider January as a wet month. The high rainfall in this month even in the mean is caused by two very wet Januaries, in 1978 and 1979, where there were 140 and 204 mm of rainfall respetively.

At Olturot, November is classified as the only month which is humid. In 1982 there was a very wet time, which is the main reason for this classification, but there were also high amounts in 1977 and 1978, which means that in more than 50% of the years rainfall was higher than the threshold value. This is not the case in the months of the long rains. So far this result seems to be correct; but there is the possibility of change when there are longer record periods available.

Olturot belongs to the wide plains of the lowlands of the IPAL area. A look at the annual rainfall map shows that more than 8,100 km^2 are represented by this climate type (rainfall between 200 and 300 mm/a). It is the most common climatic sub-type all over the IPAL area and probably also over Marsabit District.

To base calculations on these few data has certainly to be done with caution. Nevertheless, an attempt has been made to compute annual rainfall versus the number of arid months.

This has been done on both a regional and local base, meaning that in the first case the annual rainfall of different stations is computed against the mean number of arid month, in the second case the annual amount of rainfall

is computed against the annual number of arid months for one station (Marsabit) only. The results are as follows: (in all cases exponential regression).

(i) $A = 15.3 \times 0.99877^{R}$

A = number of arid month (mean)

R = annual rainfall (mean)

r = 0.99

(ii) $A = 10.2 \times 0.99685^{R}$

A = arid months per year

R = annual rainfall

r = 0.56

The second formula has been improved by using the average amount of rainfall versus the number of arid months. Two regression types (linear and exponential) give the same regression coefficient of r = 0.95.
The formulas are:

(iii) a) $A = -0.008\ R + 15$

and

b) $A = 20.2 \times 0.99887^{R}$

Formula (iiia) can be more easily used.

8. Evaporation

For range management, drinking water supply and other purposes it is essential to know the rates of evaporation and evapotranspiration. Compared with data on the amount of rainfall this will give an idea of the real amount of water available for plant growth, subsurface storage, surface water, etc. Apart from rainfall, evaporation/evapotranspiration is the most important climatic factor in arid and semi-arid areas.

Unlike rainfall, it is not easy to measure the rate of evaporation/evapotranspiration. Potential evaporation can be gauged by using an open water surface and determining the loss of water over time. Actual evapotranspiration can only be measured by the lysimeter, a rather expensive instrument. There are also several formulas using different climatological parameters to determine actual or potential evaporation or evapotranspiration. But none give more than a rough approximation, since there are too many influences which cannot be measured. Also, especially in arid regions, many of the necessary parameters are not measured by the normal climatological network.

For the Mediterranean area there are some good adapted formula, but these cannot be used in the tropics. Here we do not have a generally applicable determination for this feature. Most authors use instead the well known formulas of Thornswaite or Penman. Data on evaporation for the IPAL study area are hard to obtain. The best results have been discussed by Edwards et al. (1979), and here we simply reproduce their histogram.

It is necessary to remark that Marsabit itself lies in the semi-arid regions of Mt. Marsabit area; the rainfall is much higher than in the lowlands, while the evaporation rate is less.

In addition we use the data from Lodwar, especially for the drier lowlands. As with Marsabit, rainfall and evaporation data are not available for the same period, so that there is a small error in the calculation of the water balance, but this error should be less than 10% and the data are still very valuable.

Table 18. Monthly rates of evaporation (potential), rainfall and water balance at Lodwar

(Periods of records: rainfall 1919 -1970; evaporation 1961 - 1970)

	Evaporation (pot.)			Rainfall	Water balance
	Highest	Lowest	Mean	Mean	Mean
January	392	22	311	9	-302
February	361	221	292	7	-285
March	405	231	324	21	-303
April	339	209	275	48	-227
May	385	183	285	25	-260
June	349	233	287	7	-280
July	333	213	283	14	-269
August	243	233	292	10	-282
September	363	281	326	3	-323
October	381	291	343	8	-335
November	345	195	284	13	-273
December	339	194	276	13	-263
Year	-	-	3,578	178	-3,400

Remarks:

Evaporation has been measured by counting the water loss in a pan with a depth of 25 cm according to the standards of the World Meteorological Organization (EAMD 1975).

The results obtained are not the actual evaporation, but they show the amount of water which could evaporate if surface water was available: potential evaporation (but not potential evapotranspiration!).

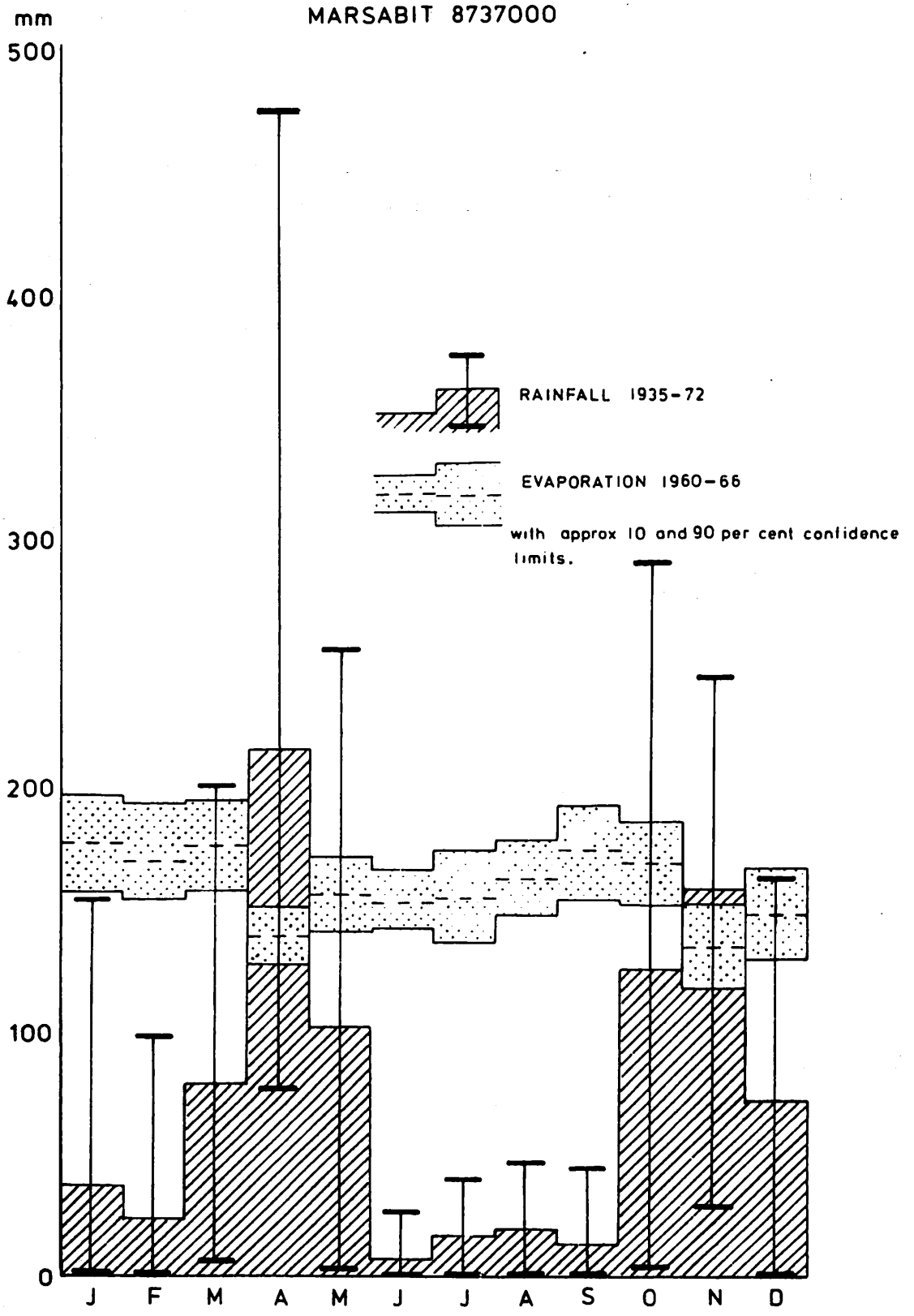
In the rainfall regime of northern Kenya, potential evaporation reaches its maximum in September and October, with a secondary maximum in January and March. In the wetter months the rate is much lower due to increased humidity of the air, rainfall, and lower radiation and temperatures. The same variation over the years is shown in the data for Marsabit (Figure 24).

It could be concluded from these figures that there is no water storage in the soil, no infiltration, and no water available for plant growth. But we have to consider that these measurements have been taken from an open water surface. After each rainfall a specific amount of water will infiltrate the soil and cannot be evaporated as easily as from an open water surface. The infiltration rate is very hard to determine. An applicable solution can only be found by using good lysimeters and measuring the soil moisture over quite a long period and several times a day. Experiments therefore have been initiated at Marsabit during the rainy seasons of 1982, but results are still preliminary. They will be published later in another report.

Seen over the whole year, the water balance is extremely negative in Lodwar, and also in the arid lowlands of the IPAL study area. In Marsabit too the balance is negative in most months. For the lowlands this can be proved by the data obtained from the automatic weather stations, calculated using the formula of Penman, at Olturot. We shall concentrate here on the month of March, which is one of the wettest in this area. The mean potential evaporation rate is 5.96 mm/day. The evaporation rate is normally higher than 6 mm/day, but when there is rain or a cloud cover greater than six octa the amount decreases.

Figure 24. Potential evaporation and rainfall at Marsabit

Source: Edwards et al. (1979).



On 1 April 1982 at Olturot there was a fall of 25 mm, while the evaporation rate was calculated at 2.2 mm, giving a water surplus of 22.8 mm able to infiltrate the soil and/or run off the surface. The next day the evaporation rate increased to 7 mm/day. This shows that in the lowlands the potential evaporation rate is fairly high, even in the wettest months. In these areas we have to deal with a yearly potential evaporation rate of 2,500 mm/a. In the north (North Horr) and probably in the lowlands in the east and south-east of Olturot the amount of potential and (it can be assumed) actual evaporation also increases due to higher radiation and higher temperature. This daily mean for North Horr is about 6.5 mm/day. In August, September and October this can increase to 7 mm/day.

Due to interruptions in the data collection it is not possible to give a complete histogram for variations throughout the year at North Horr.

Actual evaporation and evapotranspiration rates were estimated for several East African stations and mapped, using the Morton model, by Nyenzi (1980). This also provides some additional information for the IPAL study area. In comparing these data with others, we have to consider that here the *actual* rates are determined by calculation, whereas before we looked at data obtained from an open water surface or by calculation as the *potential* evaporation. In particular, the effect of plant transpiration, which can be quite high, is not included here since it is not evaporation. That is why the Morton formula gives the highest rates for Mt. Marsabit and the other mountains, where rainfall is higher and the transpiration by vegetation is greater. The rates decrease on the slopes towards the drier lowlands with their special vegetation types adapted to the increasing aridity. Rates in the lowlands are less than 25 mm/month.

Table 19. Actual evaporation rates for selected months at Marsabit and Lodwar compared with rainfall

Marsabit	January	April	July	October	Year
Actual evap.	113	109	87	108	1322
Rainfall	38	225	16	123	859
Difference	-75	+116	-71	+15	-463
Lodwar					
Actual evap.	5	49	27	28	329
Rainfall	9	48	14	8	178
Difference	+4	-1	-13	-20	-151

Source: Actual evaporation rate from Nyenzi (1980)

Nyenzi remarks that there is a general deficit of water in the arid and semi-arid areas of north Kenya. It is not known where the actual moisture is coming from since the rainfall patterns are much too low. Perhaps this may indicate a gap in the model, but we can also assume that this water is coming from the plants, using stored water or shallow underground water layers for transpiration. It is certain that this must be the case with the riverine vegetation near luggas, where we have a ground-water table quite close to the surface. The consequences of these evaporation and evapotranspiration rates, compared with the rainfall patterns, are quite important, since there is a general water deficit over the whole year, probably even in the wetter months of the rainy seasons. The mountainous areas are excluded from this observation; here we can find a water surplus during the rainy seasons.

The land-use system can therefore only be nomadic grazing with a fairly low stocking rate. Desertification hazards from this point of view are fairly high. Agriculture is possible in the higher parts of Mt. Marsabit, Mt. Kulal, and possibly in the southern mountains, but we must repeat that this can itself result in damage to the environment, which it is essential to conserve because of its importance for the water supply of the lowlands.

9. The relative humidity

The temperature of the air is directly correlated with the amount of water vapour the air can contain. It is quite difficult to measure the absolute amount of moisture in the air, so we normally obtain data on relative humidity instead. Measurements for this have been done at Olturot using the dry and wet bulb method. Data were recorded automatically by the weather station. From the printouts the hourly data have been extracted and averaged for five years.

The Figure (26a-1) shows the average diurnal changes for all months of the year. The diurnal amplitude is much higher than the annual, according to the tropical temperature regime. With the beginning of the rainy seasons the moisture content also increases, reaching its maximum in April and November. The maximum relative humidity during the day is reached in the early hours of the morning, just before sunrise. This happens in every month of the year. The minima are recorded in the late hours of the afternoon. This can also correlate with daily temperature changes.

Regarding the records over the five years since the installation of the station, even in the months of the rainy season the relative humidity has never been higher than 90%. Therefore no additional water is available from dew. Due to the high temperatures even at night the dew point is not reached in the lowlands of the IPAL area. On the other hand, in the mountains we can find condensation even in the dry seasons, normally shown by fog or very low clouds. As already mentioned they give a large amount of additional moisture.

The minima in the lowlands are just about 40% relative humidity, which means that there is a highly unsaturated air, indicating high figures of potential evaporation.

As additional information, Figure 27 shows the yearly variation in the monthly means of relative humidity. The maximum is recorded in April, traditionally the wettest month (mean) for northern Kenya. This is not correlated with the threshold values of rainfall and the actual mean rainfall. The reason for this is that while there is moisture in the air in April, the atmospheric conditions do not permit the maximum of rainfall, while in November there is more rainfall due to the higher liability of the air. This confirms the

observation that in the short rains the character of the rainfall is more convective than in the long ones.

The average yearly amplitude is less than the daily one, which emphasizes the tropical nature of climatic conditions of this area in northern Kenya. The same is true for the amplitudes and the changes throughout the different months for the various times of day. This is shown by Figure 27a-x.

Figure 25. Changes of relative humidity at Olturot

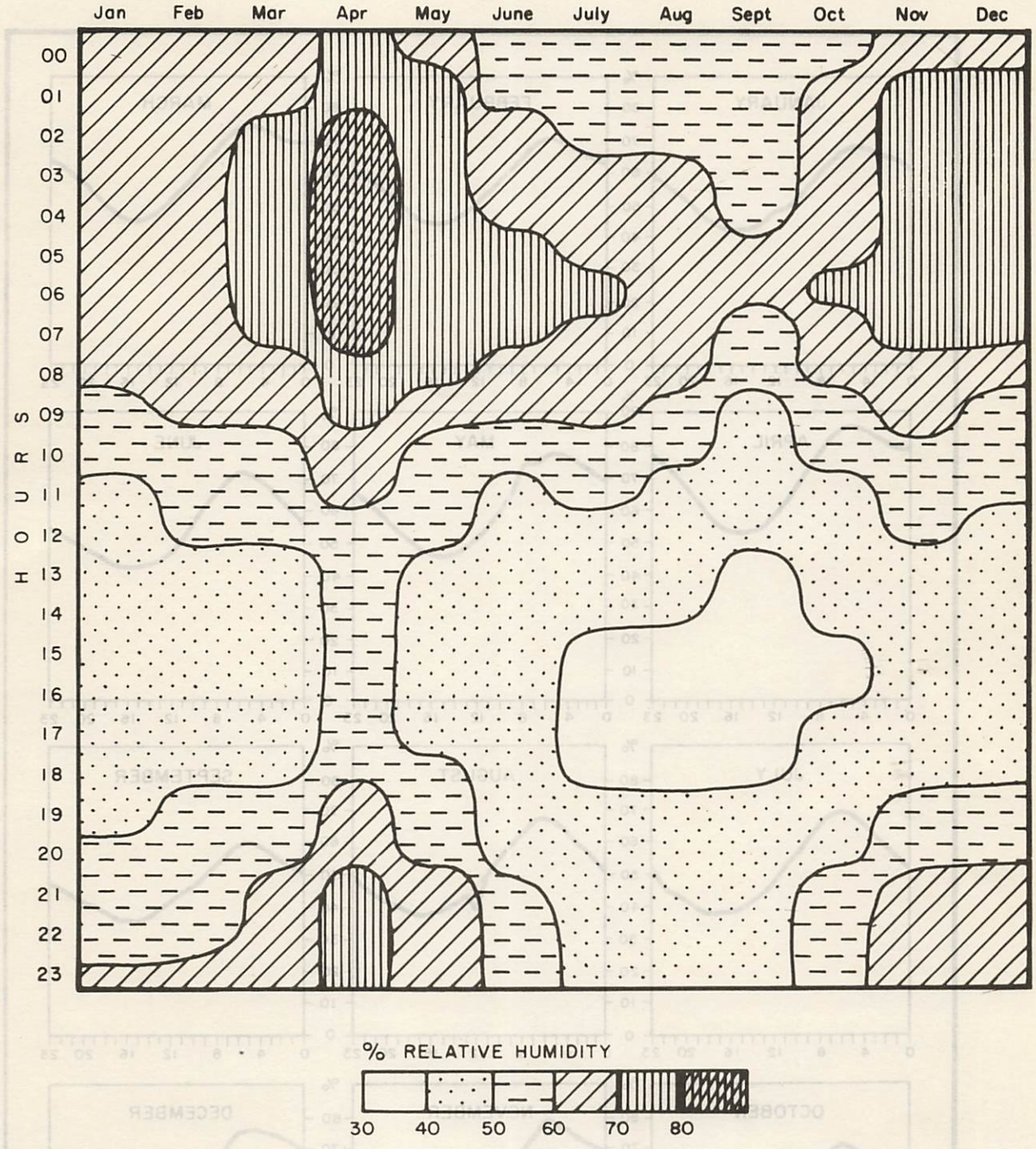


Figure 26 (a-1). Diurnal changes of relative humidity at Olturot

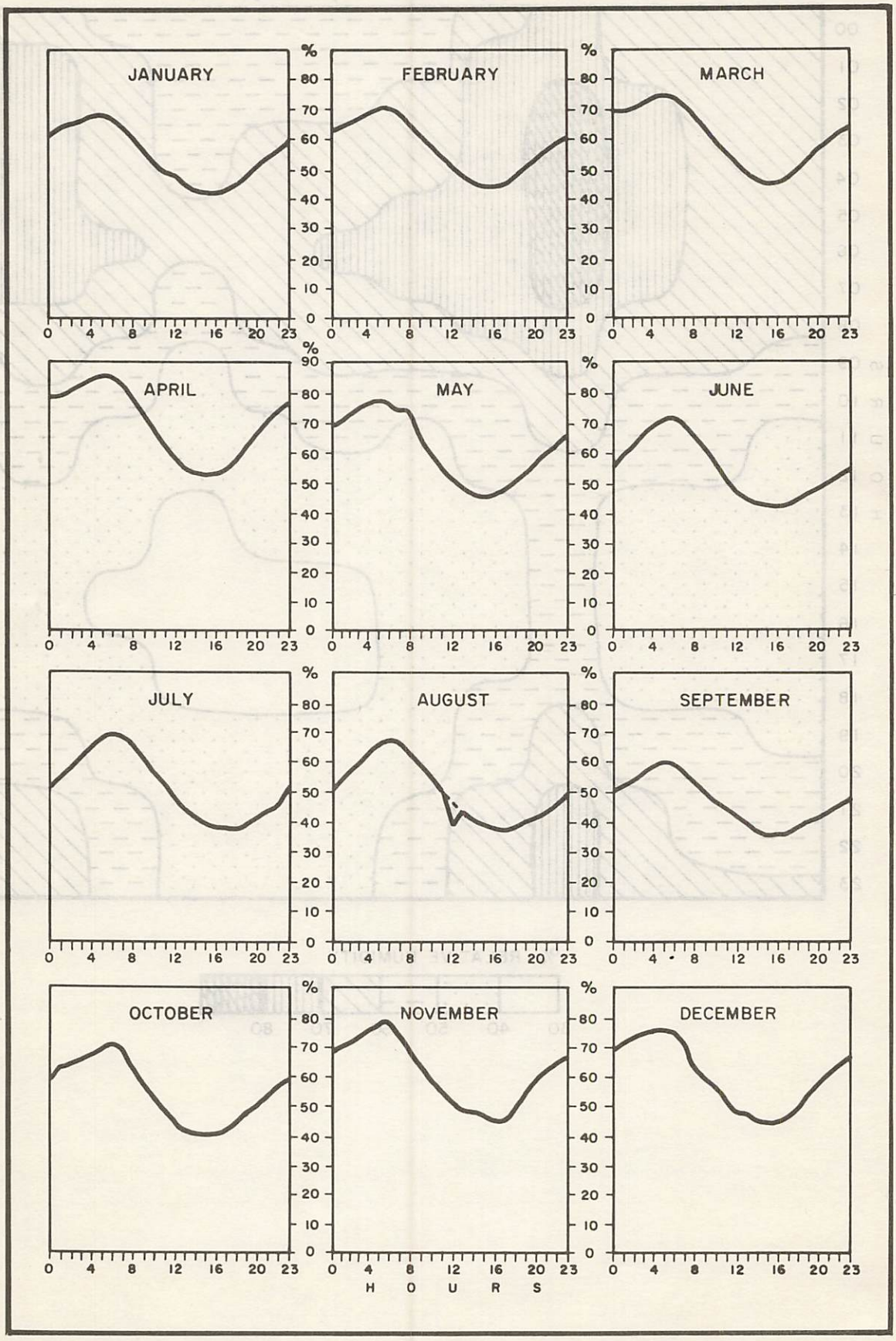
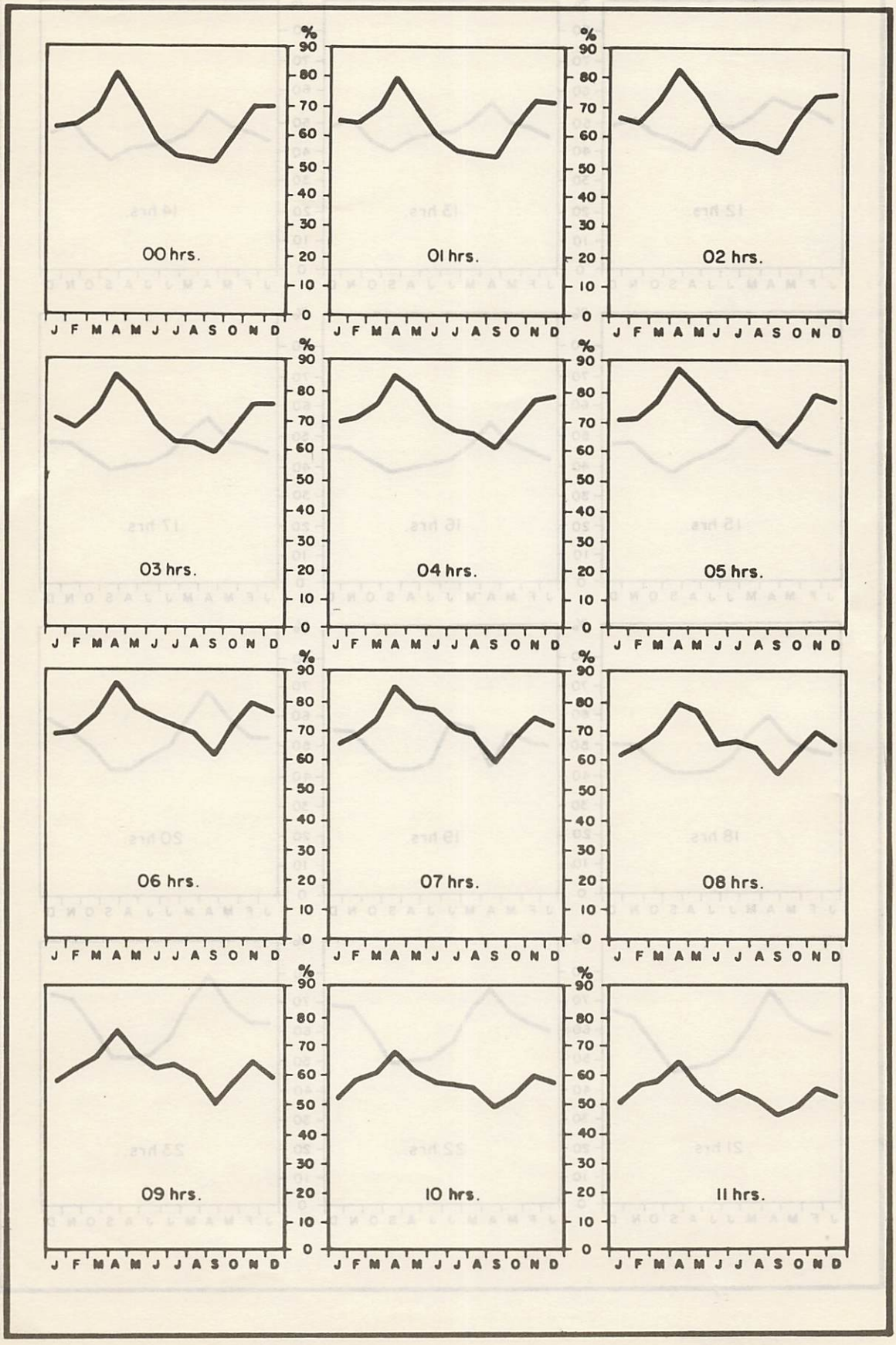


Figure 27 (a-x). Changes of relative humidity at Olturot at specific times during the year



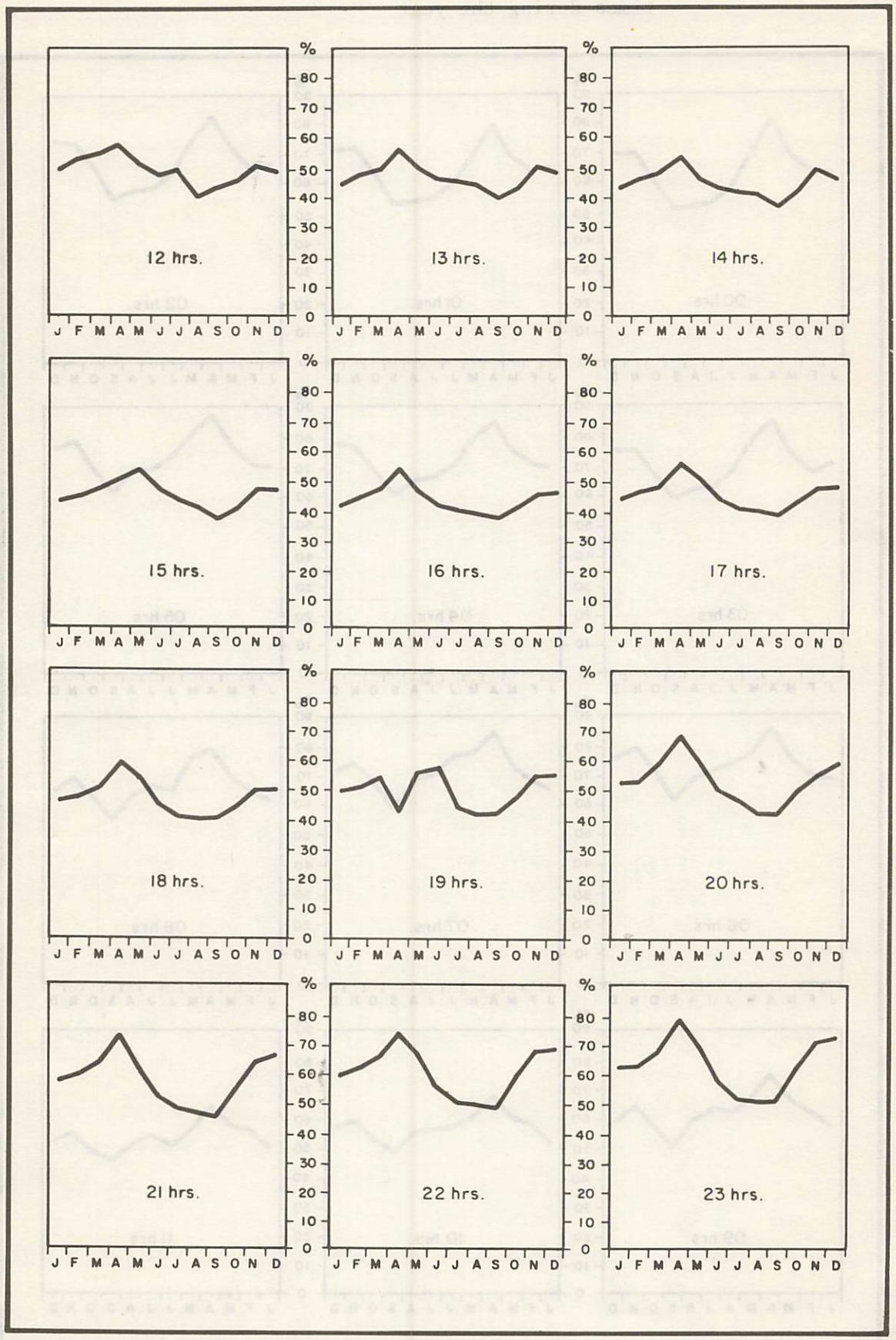
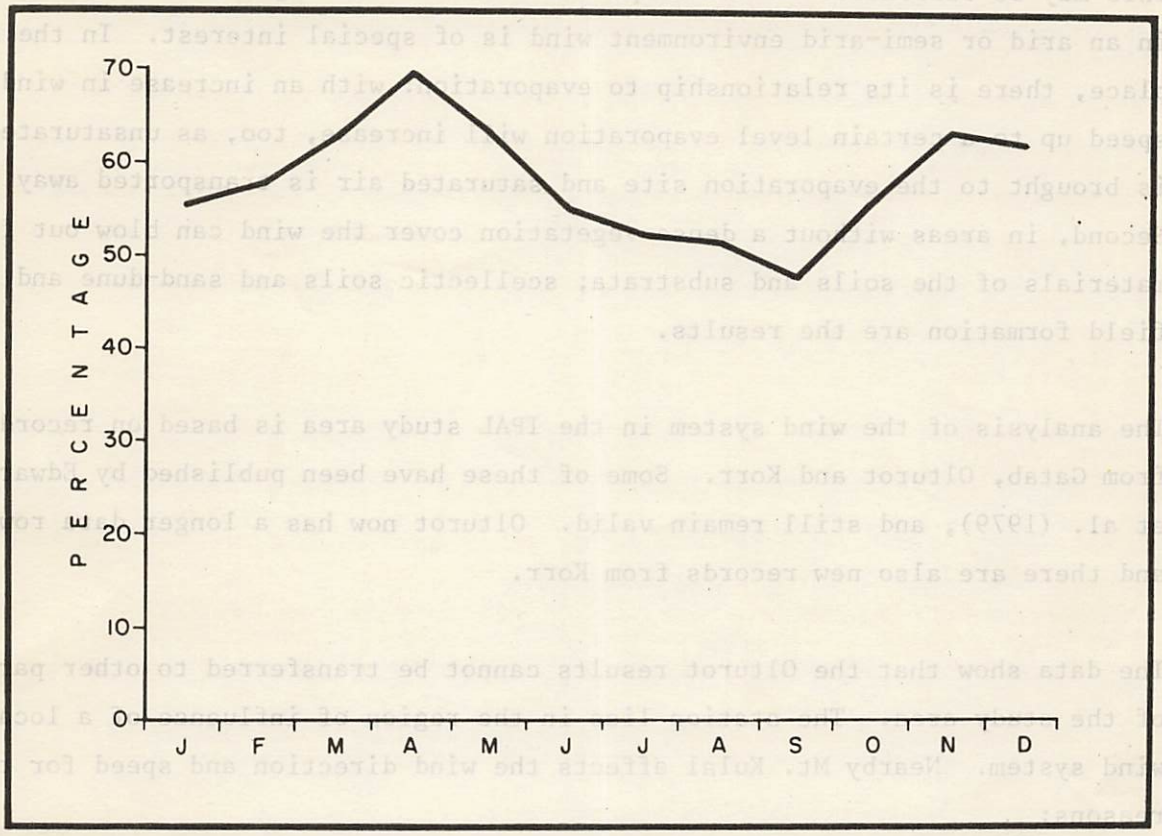

%
80
70
60
50
40
30
20
10
0
J F M A M J J A S O N D
12 hrs.
13 hrs.
14 hrs.
15 hrs.
16 hrs.
17 hrs.
18 hrs.
19 hrs.
20 hrs.
21 hrs.
22 hrs.
23 hrs.

Figure 28. Mean variability at Olturot



10. Wind: direction and speed

Wind is one factor which is not often taken into account in range management. This may be reasonable in the temperate zones of the higher latitudes, but in an arid or semi-arid environment wind is of special interest. In the first place, there is its relationship to evaporation: with an increase in wind speed up to a certain level evaporation will increase, too, as unsaturated air is brought to the evaporation site and saturated air is transported away. Second, in areas without a dense vegetation cover the wind can blow out finer materials of the soils and substrata; scellectic soils and sand-dune and sand-field formation are the results.

The analysis of the wind system in the IPAL study area is based on records from Gatab, Olturot and Korr. Some of these have been published by Edwards et al. (1979), and still remain valid. Olturot now has a longer data row and there are also new records from Korr.

The data show that the Olturot results cannot be transferred to other parts of the study area. The station lies in the region of influence of a local wind system. Nearby Mt. Kulal affects the wind direction and speed for two reasons:

- the mountain forms a barrier against the air masses coming from the east, changing their direction and decreasing their speed;
- it influences by its altitude a local wind system which differs by day and by night, when colder air dropping down during the hours of darkness from the upper slopes of the mountain produces a so-called katabatic wind; during the day there is an uplift by convection.

This case is illustrated in Table 20 for a period at the beginning of 1982.

Regarding the mean wind direction, it seems that this wind system is not as well developed in the middle of the year as in the earlier months, but further investigations are necessary.

The region affected by this wind system is limited to the eastern slopes of Mt. Kulal and the border of the plains in the east, up to about 10 km east of the slopes. The conditions of the western side of the mountain are quite different, since there the influence of the enormous water surface of Lake Turkana operates too. Here we find wind direction influenced by both mountain and lake.

Table 20a. Diurnal variation of wind direction at Olturot (21/1-18/2 1982) (in percent o/h)

o/h	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	
90					5.3	5.3	5.9	8.3	8.6	3.0	5.9												2.9		90
100				2.1	5.3	10.5	2.9	8.3	8.6	6.1	8.8	2.3			2.6						2.6				100
110	2.3	2.6	5.1	8.3	15.8	28.9	17.6	16.7	11.4	6.1		2.3									2.6	2.8	5.7	5.3	110
120	11.4	7.9	12.8	18.8	23.7	21.1	17.6	27.8	22.9	3.0	2.9	4.9	2.7	2.6	2.6					2.9		2.8	11.4	13.2	120
130	22.7	34.2	25.6	31.3	34.2	28.9	29.4	11.1	17.9	15.2	11.8	2.3	2.7								5.3	2.8	8.6	15.8	130
140	36.4	42.1	33.3	35.4	5.3	2.6	23.5	19.4	28.6	48.5	25.3	11.6	18.9	5.2	2.6	2.2					2.6	5.6	8.6	31.6	140
150	25.0	10.5	20.5	2.1	10.5	2.6	2.9	5.6	2.9	12.1	11.1	11.8	5.4	2.6		2.2		2.8			2.6	19.4	5.7	7.9	150
160	2.3	2.6	2.6	2.1				2.8		3.0	14.9	20.9	24.3	18.4	10.3	8.9	2.2	2.8		5.7	2.6	5.6	17.1	15.8	160
170											2.9	14.0	16.2	10.5	10.3	8.9	2.2				10.5	5.6	2.9		170
180												2.3	13.5	5.3	12.8	8.9		5.6			2.6	5.6	5.7		180
190												2.3	2.7	21.1	5.7	4.4	2.2			5.7	10.5	2.8	2.9	2.6	190
200													5.4	5.2	7.7	6.7	4.4	2.8	9.1	2.9	2.6	8.3	5.7	2.6	200
210												2.3	2.7	13.2	25.6	13.3	6.7	2.8	4.5	5.7	7.4	5.6	5.7		210
220													2.7	2.6	10.6	17.8	13.7	2.8	4.5	14.3	5.3	8.3	2.9		220
230														5.2	5.1	51.6	13.7	2.8	18.2	8.6	13.2		8.6		230
240											2.9			7.9	5.1	8.9	24.2	11.1	18.2	14.3	15.8	5.6		2.6	240
250																2.2	17.8	13.9	9.1	20.0	2.6	8.3	2.9		250
260													2.7				2.2	19.4	13.6	5.7	2.6	5.6	2.9		260
270																	4.4	11.1	4.5	5.7			2.9		270
280																	4.4	11.1	9.1	2.9		2.8			280
290											2.9						2.1	5.6	4.5						290
300																		2.8	4.5	5.7			2.9		300
310																		2.8			5.3	2.8	2.9	2.6	310
320																					2.6				320
330																									330
340																									340
350																									350

Table 20b. Diurnal variation of wind direction at Olturot (1/3-15/4, 1982)(in percent/h)

0/h	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	
90	2.2			2.3	8.9	5.7	2.6	12.2	17.1	12.2	7.0				2.2							4.7		2.4	90
100	4.3			2.3	6.9	20.0	15.8	22.0	17.1	9.8	2.3		2.4							2.2	4.3			4.9	100
110	6.5	5.0	2.3	13.6	4.4	14.3	26.3	17.1	12.2	12.2	7.0	7.0	11.9	4.9						2.2	2.2		2.4	4.9	110
120	15.2	30.0	25.6	29.5	28.9	17.1	26.3	19.5	22.0	17.1	4.7	7.0	9.5	4.9	2.2			4.2	4.5	6.9			4.8		120
130	30.4	32.5	41.9	27.3	24.4	45.7	21.1	19.5	14.6	12.8	25.6	23.3	4.8	2.4		2.2				4.4	6.5	16.7	14.3	29.3	130
140	30.4	17.5	23.3	20.5	22.2	20.0	2.6	4.9	7.3	17.1	16.3	18.6	16.7	4.9	6.7		2.3		4.5	6.9	10.9	11.6	14.3	36.6	140
150	6.5	10.0	2.3	2.3	2.2	2.9			2.4	4.8	18.6	7.0	11.9	19.5	6.7	2.2				2.2	6.9	20.9	14.3	9.8	150
160	2.2		2.3							2.4	4.7	14.0	11.9	2.4	4.4	2.2		2.1		4.4		4.7	9.5	4.9	160
170		2.5		2.3						4.8	2.3	7.0	2.4	14.6	2.2		4.5	6.3	2.3	2.2	6.9		11.9	4.9	170
180					2.2						4.7	2.3	7.1	7.3	8.9	4.3	6.8	2.1	2.3	6.9	4.3	2.3	2.4		180
190								2.4				2.3	4.8	4.9	4.4	4.3	2.3			4.4	6.9	4.7	4.8		190
200			2.3						2.4	2.4	2.3		2.4	4.9		4.3	2.3	2.1	6.8	2.2	10.9		2.4		200
210						2.9					2.3		2.4	7.3	8.9	19.6	11.4	14.6	18.2	2.2		1.0			210
220	2.2	2.5									2.3	7.0		7.3	13.3	19.6	9.1	8.3	4.5	6.9	8.7	7.0	4.8		220
230													4.8	7.3	11.1	23.4	15.9	22.9	13.6	6.9	2.2		2.4		230
240												2.3	2.4	4.9	13.3	4.3	18.2	14.6	13.6	13.3	4.3	4.7	4.8		240
250							5.2	2.4	4.8	2.4					4.4	8.7	9.1	8.3	15.9	13.3	4.3	2.3			250
260																2.2	9.1	8.3	4.5	6.9	6.9	4.7			260
270													2.4	2.4	2.2	2.2	2.3	4.2	4.5	4.9	6.9	2.3			270
280										2.4					2.2		4.5		2.3	2.2		2.3			280
290															2.2		2.3				2.2		2.4		290
300												2.3										2.3			300
310																									310
320													2.4					2.1			4.3				320
330															4.4						2.2				330
340																							2.4		340
350																						2.3			350
360																									360

(Table 20b Contd.)

16	17	18	19	20	21	22	23	24	25	26	27	28	1/3	2	3	4	5	6	7	8	9	10	11	12	13	14	15
210	151	139	148	139	134	118	140	161	142	140	146	136	143	120	146	156	141	135	134	143	129	136	127	119	144	146	130
153	145	131	152	130	143	135	134	137	127	156	137	135	130	129	150	151	146	122	129	126	132	149	126	124	119	137	141
128	156	138	130	133	141	136	140	152	143	152	116	121	147	146	120	134	133	146	136	124	140	137	132	151	138	137	141
118	128	129	134	137	131	128	133	143	139	139	137	120	126	149	103	139	119	120	137	149	138	117	119	128	117	133	147
125	134	123	118	139	137	128	134	136	156	144	138	136	128	148	81	135	131	95	140	148	125	128	119	107	105	142	134
116	102	116	119	134	133	126	119	98	108	117	118	123	135	137	136	150	119	106	145	137	138	126	131	125	132	106	141
128	112	131	191	124	138	108	128	93	45	130	119	133	120	122	109	141	-	87	133	133	121	106	114	103	86	112	130
111	129	112	142	140	153	105	140	125	96	121	110	124	130	124	102	118	126	57	133	112	123	40	104	94	90	115	137
141	128	112	-	139	142	116	144	111	113	144	100	133	119	137	100	139	104	95	142	92	123	289	88	95	88	115	140
118	120	135	149	145	152	131	147	119	82	142	141	132	115	174	103	143	105	90	157	109	128	284	97	119	97	117	141
138	130	136	162	167	172	157	155	145	128	137	142	118	139	178	137	130	142	130	167	138	138	218	134	124	143	142	154
162	163	155	175	178	178	171	158	154	124	130	144	143	121	222	142	136	142	164	175	157	132	178	143	188	137	138	160
187	168	160	212	184	181	176	184	162	206	127	147	145	122	149	144	113	165	169	189	159	140	216	143	178	122	149	167
234	187	169	223	194	183	189	186	197	235	133	149	159	115	189	176	122	228	205	191	155	215	224	151	173	158	171	180
187	235	210	218	210	214	194	215	211	212	141	184	177	126	233	244	144	233	221	220	222	219	224	158	166	180	222	229
172	195	248	229	255	249	232	227	249	189	154	201	228	236	259	218	196	223	227	180	230	216	243	166	228	233	212	238
237	177	243	235	237	252	243	234	226	275	160	224	246	210	235	216	219	184	265	179	255	231	244	209	227	282	243	260
277	184	260	194	255	265	242	248	234	247	170	271	231	237	214	248	210	262	240	249	224	231	250	320	214	211	243	274
213	65	178	204	273	271	294	273	255	240	182	265	188	251	229	246	216	257	232	257	248	240	246	165	218	260	264	274
168	2	259	233	195	204	246	302	302	256	197	274	268	251	252	240	217	231	185	289	257	154	129	130	224	264	246	276
164	241	205	251	144	146	250	186	12	191	180	217	250	234	242	178	60	223	196	150	203	197	147	143	226	275	172	224
172	151	153	175	142	149	269	155	152	39	115	184	250	249	223	218	303	216	189	142	139	131	145	139	267	151	143	151
115	149	146	161	149	126	138	164	165	122	127	115	91	238	184	224	170	169	188	157	161	123	133	144	122	190	138	146
144	147	143	123	145	132	142	162	130	162	125	138	121	32	155	137	134	149	136	143	146	130	132	138	139	160	153	130

(Table 20b Contd.)

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1/4	2	3	4	5	6	7	8	9	10	11	12	13/4	14	14	15
143	114	124	136	122	134	145	152	137	137	142	129	144	147	133	142	224	117	142	139	103	107	137	165	139	137	129	143	139	152	152	83
137	122	121	151	128	140	176	136	132	149	148	154	131	146	130	146	244	71	141	134	124	97	117	138	124	131	127	147	133	135		56
125	139	121	146	139	120	136	134	131	128	138	141	128	160	138	136	105	77	126	138	130	126	143	110	128	149	126	130	126	144		53
128	128	126	146	138	137	145	142	134	129	127	133	153	133	143	127	172	77	142	134	121	144	138	128	128	130	90	125	101	114		62
122	135	130	143	121	144	125	144	134	120	151	125	127	131	136	144	180	121	141	146	121	94	120	133	121	135	90	112	93	50		114
106	147	123	134	133	134	116	126	131	130	136	130	136	116	138	112	90	126	141	108	101	141	98	141	98	137	85	108	112	28		140
123	118	120	141	123	119	115	136	130	138	123	114	118	117	86	86	255	86	84	134	121	128	89	124	3	119	92	92	111	118	345	161
109	107	119	136	101	119	141	122	131	127	120	109	88	114	76	1	98	118	130	120	122	95	47	101	134	95	105	110	265	192		192
92	94	124	101	131	119	108	126	128	133	126	120	125	58	107	85	332	102	200	119	123	124	91	157	144	120	94	114	106	227		190
137	113	124	124	126	133	114	141	150	123	132	144	98	68	121	84	169	145	111	121	130	127	66	147	148	80	92	83	132	252		202
165	150	147	96	155	154	135	140	156	140	118	151	137	63	115	50	202	144	188	114	138	132	90	159	155	90	89	123	019	221		181
184	175	139	128	134	149	157	138	161	136	148	141	169	149	56	117	44	149	221	115	130	166	23	168	148	304	120	136	112	247		196
198	161	151	128	149	180	156	159	157	120	207	136	164	19	111	190	196	123	114	234	59	118	148	104	89	273	135	135	113	324		12
249	198	155	154	159	203	165	170	75	111	243	237	4	24	123	183	220	143	212	4	233	150	172	215	130	273	151	146	236	39		36
237	247	178	154	181	241	168	192	246	158	240	270	145	98	216	198	188	341	249	216	214	251	140	238	224	347	180	238	224	347		294
230	252	226	250	205	215	225	222	262	188	219	230	214	194	217	217	225	228	250	333	238	206	215	229	135	253	238	225	210	279		234
226	281	245	241	239	247	231	232	218	230	252	251	239	170	143	184	183	274	226	19	252	211	193	262	299	244	231	220	268	246		82
233	258	244	231	234	243	262	252	256	232	234	220	210	172	125	172	263	206	124	354	219	260	172	278	227	239	248	273	223	249		217
66	236	222	245	206	229	134	273	196	244	244	178	118	163	147	126	190	140	257	106	266	230	148	11	132	261	257	185	188	248		253
201	200	148	250	254	262	292	222	205	266	203	109	151	132	132	158	197	141	34	12	174	131	191	107	38	241	191	143	156	275		177
157	223	140	246	169	355	136	33	218	262	283	161	153	135	148	156	199	150	95	24	273	131	90	152	4	152	194	139	154	227		251
143	106	137	114	120	138	169	113	298	126	341	143	169	150	145	160	218	135	137	17	316	120	129	210	39	153	233	143	150	21		51
148	133	145	112	142	140	146	141	145	103	115	140	148	139	141	176	160	139	153	353	90	134	172	145	107	145	137	148	153	81		6

Table 21. Diurnal variation of wind direction at Korr (3/12-30/12 1982) (in percent/h)

o/h	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8
90	3.6								3.6	3.6	3.6							7.1	3.6					
100			3.6		3.6	7.1			3.6	7.1										3.6		3.6	3.6	3.6
110	17.9	21.4	17.9	21.4	50.0	21.4	50.0	35.7	25	35.7	17.9					3.6	3.6		7.1	3.6	14.9	17.9	39.3	32.1
120	60.9	67.9	57.1	39.3	46.4	42.9	14.9	39.3	25	2.5	28.6	17.9			7.1	3.6		3.6	3.6	17.9	17.9	42.9	17.9	25
130	17.9	10.7	14.9	35.7	35.7	28.6	35.7	25	42.9	28.6	46.4	78.3	96.4	92.9	89.3	89.3	82.1	78.3	75	57.1	46.4	21.4	32.1	39.3
140			3.6	3.6								3.6		3.6				3.6	3.6	10.7	3.6		3.6	
150													3.6								7.1	3.6	3.6	
160													3.6	3.6	3.6				3.6		7.1			
170											3.6						3.6			7.1		7.1		
180															3.6			3.6						
190															3.6	3.6	3.6	3.6			3.6	3.6		

Table 22. Variation of the wind direction at Olturot (in degree)

h/day	21/1	22	23	24	25	26	27	28	28	30	31	1/2	2	3	4	5	6	7	8	9	10	11	12	13	14	15
9		150	143	142	152	145	135	156	35	143	91	145	151	137	150	132	156	152	143	139	142	139	148	148	147	133
10		139	145	136	141	154	144	147	146	143	113	141	148	144	142	136	143	147	137	142	123	133	144	160	145	126
11		134	141	141	149	148	132	141	156	151	130	152	129	148	158	114	121	143	139	123	144	140	139	165	140	135
12		131	142	137	151	140	113	146	140	144	128	118	136	134	149	125	126	132	139	119	124	130	136	134	163	108
13		133	122	124	134	150	96	139	129	146	93	105	110	120	136	145	121	126	136	118	105	113	116	130	118	133
14		126	136	127	126	131	90	112	126	125	67	145	131	131	114	134	124	132	137	127	68	115	130	158	103	121
15		124	141	118	130	147	91	154	140	144	61	68	138	144	117	144	138	147	137	124	47	149	132	68	111	116
16	165	121	149	116	123	140	92	138	147	129	103	79	137	123	94	131	136	119	151	89	56	131	111	143	131	101
17	156	141	142	120	142	129	96	136	148	135	53	100	97	107	144	129	136	122	145	84	72	131	121	120	45	101
18	152	141	160	140	152	130	91	148	142	142	81	84	104	133	257	140	148	147	149	85	104	140	150	147	89	27
19	154	153	145	144	147	142	100	169	157	142	60	96	107	147	241	148	155	165	161	57	91	158	156	149	105	299
20	169	165	160	152	157	155	143	175	161	156	118	147	147	162	213	176	166	180	162	107	195	151	152	158	123	38
21	172	166	182	147	159	166	163	203	141	140	51	161	154	173	223	199	177	175	170	142	266	160	167	146	135	18
22	176	175	184	153	159	162	160	202	157	139	159	157	152	206	232	221	205	187	218	186	204	145	187	209	171	17
23	241	176	165	169	183	161	177	184	191	221	209	168	187	207	248	215	225	236	214	223	224	179	202	220	218	103
0	224	215	175	163	226	173	233	221	233	231	229	187	243	231	240	220	185	282	234	226	207	239	235	216	200	141
1	213	286	219	261	242	261	238	231	232	227	226	218	238	206	240	236	200	275	227	248	222	239	243	243	230	194
2	140	159	215	287	247	10	263	221	253	239	231	256	295	126	313	29	248	268	228	246	235	249	222	258	229	246
3	271	225	267	268	283	298	259	248	218	238	206	230	92	262	258	312	281	233	249	238	207	242	249	307	173	344
4	225	225	211	232	16	218	349	273	261	254	78	250	241	125	249	284	228	255	256	224	223	239	258	242	164	358
5	188	230	339	108	118	241	183	326	322	222	202	260	240	179	279	259	218	221	258	246	159	255	204	204	207	328
6	158	209	61	215	252	217	285	164	317	206	269	152	211	241	243	222	205	181	262	211	160	138	128	25	199	14
7	162	154	152	186	219	215	239	241	271	251	196	163	194	167	220	184	172	139	237	206	139	124	300	235	163	78
8	163	145	136	168	151	166	196	317	162	72	200	114	156	136	146	156	145	146	129	113	138	144	147	146	129	244

That is why more attention is given to the data from the weather station at Korr. At first it was thought that the results from Korr should be regarded with suspicion, since the wind speed seemed to be too high. Checks of the anemometer did not support this idea, and it was then discovered that wind speeds in this area really are fairly high. This is brought about by a so-called delta effect, caused by Mt. Marsabit and the mountains of Marti ya Ampara in the south. The air masses are channelled through the deep depression between these mountains, leading to an increase in their speed. Mean wind speeds have been determined as 6 m/s for Korr. Analysis has not yet been completed.

Mean wind directions in these areas are also shown in Table 21 from them we can find the orientation of smaller sand dunes in the region.

Diurnal variation in wind direction is noticeable only in the Mt. Kulal area. We only have data for this from the station at Olturot. This is shown quite clearly in Table 20. At 9 a.m. the wind has a strong eastern component, which prevails till sunset. The eastern component is the result of the general wind direction in the area and the uplift of air masses on the slopes of Mt. Kulal by convection. This also affects the wind speed, which increases during the day.

After sunset the wind begins to shift towards the south and finally the east. Table 20 shows that in the month of April there is a less well defined distribution; directions are more spread.

At around 4 a.m. wind direction begins to move back again, until at around 8 a.m. it reaches a mainly easterly direction. Over the whole day (9 a.m. to 9 a.m.) the shift follows a sinus curve. Variations over the year are determined by general changes in the upper atmosphere induced by the movement of the sun.

Unlike the situation at Olturot, wind directions at Korr are more persistent. Easterly winds (120-130°) from the absolute majority throughout the year. After sunset there is a light tendency to shift towards the south, but this is not very marked. The prevailing wind direction in the Korr area is clearly shown by the sand dunes and sand deposits.

11. Other climatic factors

The automatic weather stations also record radiation and wet bulb depression. These results have already been analysed in *IPAL Technical Report B-1*, by Edwards et al. (1979).

There will be a need to analyse air humidity, but these data must be compared with rainfall and, for example, with soil moisture and there is a great deal of work to be done in the wet seasons. The result will probably be published in another technical report in 1983 concerning the physical geography of the IPAL study area. There is also a need to carry out experiments to improve the reliability of the readings of storage gauges. Of further interest is the amount of precipitation caught by trees and shrubs in both lowland and mountainous areas. This has importance, not only for the amount of rainfall in the mountains but for an understanding of other areas as well. Compared with the recorded rainfall in, for example, Marsabit and Gatab, the vegetation is much too dense. For an annual rainfall of 700-800 mm or more, the typical vegetation type is not such a dense tropical rain-forest. There must be a great deal of water being caught and filtered by trees and their parasites from fog and clouds. Edwards et al. mention in this connection the results of investigations at Macloth and Nagel in South Africa. Research in Teneriffe (Canary Islands) in the trade-wide zone, shows that there most of the water supply for plants and even the soil moisture is filtered from fogs and clouds. IPAL will therefore carry out some new experiments, since the importance of the mountains, with their dense forests and their capacity to store water, extends to the lowlands. Water runs down mostly below the surface (sometimes on the surface) and reappears in the lowlands as springs or waterholes, or can be recovered by drilling boreholes.

12. Conclusion

Like the first analysis of the climate of Marsabit District by Edwards et al.,the present paper still has a preliminary character. The period of record keeping, now five years only, is not long enough in a climatic zone where the only constant factor is change. It should be made clear that IPAL has done a great deal of pioneer work in this remote district of northern Kenya. Due to the relief of the area we have several different climatic features with all the interferences that arise from them. Rising from the arid and semi-arid areas there are the sub-humid regions of Mt. Marsabit, Mt. Kulal and the southern mountains, with their enormous importance for the steering of the water flow in the area.

There is also the question of climatic change. Regarding the long-term records, we do not at present know if these show only the normal variability of arid areas, or if there is a real climatic change taking place, as has often been postulated since the drought disasters of the early 1970s in the Sahel and in East Africa.

We do not know what will happen to this sensitive ecosystem as the carbon dioxide content of the atmosphere continues to increase, as in the past decades. We can try to find a theoretical answer by modelling and different calculations, but the true answer will be given to us by Mother Nature in the near future.

There still remains a lot to do in monitoring climate in northern Kenya. It has not been possible to include here chapters on such topics as bioclimatology, due to shortness of time. However, the work in climatology by IPAL will continue, and must with time yield fruitful results.

References

Alusa, A.L. and Mushi, M.T. *A Study of the Onset, Duration and Cessation of the Rains in East Africa*. E.A. Meteorological Department.

Asnani, G.C. and Kinuthia, J.H. (1979). *Diurnal Variation of Precipitation in East Africa*. East African Institute for Meteorological Training and Research, Research Report 8-79.

Atkinson, G.D. (1971). *Forecaster's Guide to Tropical Meteorology*. Air Weather Service (MAC), USAF, Technical Report 240.

Bake, G.F.W. (1980). *Physisch-geographische Grundlagen und Dynamik von Desertifikationserscheinungen in Suedwest-Sizilien (Italien)*. Hamburg.

Barry, R.C. and Chorley, R.J. (1976). *Atmosphere, Weather and Climate* (3rd ed.). London.

Bruce, P. and Clark, R.H. (1975). *Introduction to Hydrometeorology*. Oxford.

Chorley, R.J. and Kennedy, B.A. (1971). *Physical Geography: A System Approach*. London.

Edwards, K.A., Field, C.R. and Hogg, I.G.G. (1979). *A Preliminary Analysis of Climatological Data from the Marsabit District of Northern Kenya*. IPAL Technical Report B-1.

Gwage, P.M. (1979). The occurrence of dry spells during the East African long rains. In: *Role of Water Resources in Development*.

Herlocker, D.H. (1979). *The Vegetation of South-Western Marsabit District, Kenya*. IPAL Technical Report D-1.

International Livestock Centre for Africa (ILCA) (1978). *Development of a Methodology for the Ecological Monitoring of Range Trends in Kenya*. Working Document 3.

_____ (1979). *An Illustrated Introduction to the Rainfall Patterns of Kenya*. Working Document 12.

Lusigi, W.J. (1981). *Combating Desertification and Rehabilitating Degraded Production Systems in Northern Kenya*. IPAL Technical Report A-4.

Mensching, H. and Ibrahim, F. (1979). The problem of desertification in and around arid lands. *Applied Science and Development*, Vol. 10, pp. 8-43.

Nieuwolts, S. (1980). *The Interpolation of Rainfall in the Nairobi Area*. East African Institute for Meteorological Training and Research, Research Report 8/80.

_____ (1981). *The Nature of Homogeneity in Rainfall Records over East Africa*. East African Institute for Meteorological Training and Research, Research Report 5/81.

Nyenzi, B.S. (1980). *The Distribution of Actual Evaporation/Evapotranspiration over East Africa*. East African Institute for Meteorological Training and Research,. Research Report 7/80.

Ogallo, L. (1978). *Rainfall in Africa*. East African Institute for Meteorological Training and Research,. Research Report 5/78.

Ojany, F.F.R. and Ogendo, R.B. (1982). *Kenya, a Study in Physical and Human Geography*. Nairobi.

Okoola, E.A. (1982). *Solar Power Potential in Kenya*. East African Institute for Meteorological Training and Research,. Research Report 1/82.

Oteng'i, S.B.B. (1981). *Use of Weibull Distribution in Modelling Pental Rainfall*. East African Institute for Meteorological Training and Research,. Research Report 1/81.

Patnaik, J.K., Kiargi, F.M.R. and Ng'ang'a, J.K. (1979). *Some Aspects of the Seasonal Features of the Southern Hemisphere Subtropical Jet Stream*. East African Institute for Meteorological Training and Research,. Research Report 1/79.

Pratt, D.J. and Gwynne, M.D. (eds.)(1977). *Rangeland Management and Ecology in East Africa*. London.

Schreiber, D. (1979). A comparative examination of threshold values for dry months, taking the situation in Kenya as an example. In: *Applied Science and Development*.

Sobania, N.W. (1979). *Background History of the Mt. Kulal Region of Kenya*. IPAL Technical Report A-2.

UNESCO (1965). *Agroclimatological Methods*. Paris.
____ (1980). *Case Studies on Desertification*. Natural Resource Research 18.

World Meteorological Organization (1975). *Drought and Agriculture*. Technical Note 138. Geneva.

A LIST OF IPAL PUBLICATIONS

Adu Bobie, G.J. (1983). The Role of Rendille Women. *IPAL Technical Report F—2,* Unesco, Nairobi.

Allen, I.A. (1983). Report of a Consultancy in Education and Training. *IPAL Technical Report F—1,* Unesco, Nairobi.

Ayiemba, E.H.O. (1983). Human Ecology: A Study of Environmental Perception and Modes of Survival among the Samburu in Kenya. *IPAL Technical Report F—2,* Unesco, Nairobi.

Baur, P.J. (1983). Report on a Short Term Consultancy on Water Development in some part of Marsabit District, Northern Kenya. *IPAL Technical Report B—2,* Unesco, Nairobi.

Borgeson, R.H. (1983). A Preliminary Analysis of Ground-Water Data from the Marsabit District of Northern Kenya. *IPAL Technical Report B—2,* Unesco, Nairobi.

Edwards, K.A., C.R. Field and I.G.G. Hogg (1979). A Preliminary Analysis of Climatological Data from the Marsabit District of Northern Kenya. *IPAL Technical Report B—1,* Unesco, Kenya.

Field, A.C. (1978). ODM — IPAL Sheep and Goats Project Preliminary Report on the Impact of Sheep and Goats on the Vegetation in the Arid Zone of Northern Kenya. *IPAL Technical Report E—2,* Unesco, Nairobi.

Field, C.R. (1979). Preliminary Report on Ecology and Management of Camels, Sheep and Goats in Northern Kenya. *IPAL Technical Report E—1a,* Unesco, Nairobi.

Hepper, F.N., P.M.L. Jaeger, J.B. Gillett and M.G. Gilbert (1981). Annotated Check-list of the Plants of Mount Kulal, Kenya. *IPAL Technical Report D—3,* Unesco, Nairobi.

Herlocker, D.J. (1979). Vegetation of Southwestern Marsabit District, Kenya. *IPAL Technical Report D—1,* Unesco, Nairobi.

Kokwaro, J.O. and D.J. Herlocker (1982). A Check-list of Botanical, Samburu and Rendille Names of Plants of the "IPAL" Study Area, Marsabit District, Kenya. *IPAL Technical Report D—4,* Unesco, Nairobi.

Kruuk, H. (1980). The Effects of Large Carnivores on Livestock and Animal Husbandry in Marsabit District, Kenya. *IPAL Technical Report E—4,* Unesco, Nairobi.

Lewis, J.G. (1977). Report of a Short-term Consultancy on the Grazing Ecosystem in the Mt. Kulal Region, Northern Kenya. *IPAL Technical Report E—3,* Unesco, Nairobi.

Lusigi, W.J. (1980). ED. Proceedings of a Scientific Seminar Nairobi 24—27 November 1980. *IPAL Technical Report A—3,* Unesco, Nairobi.

Lusigi, W.J. (1981). Combatting Desertification and Rehabilitation Degraded Production Systems in Northern Kenya. *IPAL Technical Report A—4,* Unesco, Nairobi.

Lusigi, W.J. (1983). ED. Proceedings of the IPAL Scientific Seminar Nairobi, 1—2 December 1981. *IPAL Technical Report A—5,* Unesco, Nairobi.

Martin, G.H.G., J.J. Opiyo and P. Simpkin (1981). Small Mammals of the Arid Savanna and Two Montane Sites in Northern Kenya. *IPAL Technical Report E—5,* Unesco, Nairobi.

Mburugu, E.K. (1983). Factors Related to Stock Ownership and Population Movements; and Perception of Land Pressure and Other Environmental Changes among the Rendille in Marsabit District. *IPAL Technical Report F—2,* Unesco, Nairobi.

Ndombi, J.M. (1983). Report of Feasibility Studies for Ground-Water Development in the UNESCO/IPAL Study Area, Marsabit, Northern Kenya. *IPAL Technical Report B—2,* Unesco, Nairobi.

Okelo, R.O. (1981). Some acridids of Arid and Semi-Arid Southwestern Marsabit District, Northern Kenya. *IPAL Technical Report E—5,* Unesco, Nairobi.

Ongweny, S.G. (1983). A Preliminary Account of Erosion, Sediment Transport and Surface-Water Resources of Parts of Marsabit District. *IPAL Technical Report B—2,* Unesco, Nairobi.

Sobania, N.W. (1979). Background History of the Mt. Kulal Region of Kenya. *IPAL Technical Report A—2,* Unesco, Nairobi.

Synott, T.J. (1979). A Report on the Status, Importance and Protection of the Montane Forests. *IPAL Technical Report D—2a,* Unesco, Nairobi.

Wilson, A.J., Rosemary Dolan and W. Mukani Olahu (1981). Important Camel Diseases in Selected Areas in Kenya. *IPAL Technical Report E—6,* Unesco, Nairobi.