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THE CLIMATE OF THE SUDAN
ACCORDING
TO THREE CLIMATIC CLASSIFICATIONS

BY

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INTRODUCTION

This study compares the performance of three climatic classifications in the Sudan. Koppen (1936), Thornthwaite (1948-1955), and Bailey (1958-1960) (1). Climatic summaries published by the Meteorological Department of the Sudan were analyzed for all the stations included in the Sudan. Maps were prepared for the comparable elements of the classifications. The patterns of the classifications were then compared with each others, with the maps of rainfall, temperature and vegetation distributions.

LOCATION AND TERRAIN

Sudan covers a large area of 967,500 square miles. It extends between latitudes 3° oo N, and 23° oo N, and between longitudes 21° oo E and 39° oo E, thus the country lies within the tropics. However, the great expanse of the Sudan along 20° of latitude and over 18° of longitude

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(1) Koppen, W., and R. Geiger, *Handbuch der Klimatologie,* Band II, Berlin, 1936.

Bailey, Harry P., A Simple Moisture Index Based upon a Primary Law of Evaporation, *Geografiska Annaler,* Hafte 3-4 (1958), pp. 196-215.

——, A Method of Determining the Warmth and Temperateness of Climate, *Geog. Annaler,* Nr. 1 (1960), pp. 1-16.

Thornthwaite, C.W., An Approach toward a Rational Classification of Climate, *Geographical Review,* vol. 38 (1948), pp. 55-94.

gives rise to a wide variety of climatic conditions. The longitudinal expansion is effective in relation to the oceanic influences from the west and the east; or in other words from the Atlantic and the Indian Oceans.

The Sudan in general has a monotonous surface, only about 2% of the area of the country lies over 1,000 feet above sea level. This type of terrain has its climatic consequences. Very small parts of the country are high enough to be climatically different from their surroundings [1].

The high mountains of the Sudan are like inselbergs, isolated in different parts of the country and without continuity (Fig. 1). Their influences are limited to their locations and immediate surroundings; and they do not stand as climatic barriers.

The Imatong Mountains lie east of the line Juba-Nimule and south of the line Juba-Kapoeta, they are very close to the border between Sudan and Uganda [2]. The highest parts of the Imatongs rise to 11,000 feet above sea level.

The Red Sea Hills in the eastern part of the Sudan extend about 15 to 20 miles from the shore inland and they run almost parallel to the coast. These hills constitute the western horst of the Eastern African Rift Valley. The altitude here ranges between 3,000 and 4,000 feet.

The Marra Mountains in Darfur Province in western Sudan extend over 125 miles long and between 20 and 25 miles wide. They are a group of volcanic cones, the peaks of which rise to about 10,000 feet above sea level.

The Nuba Mountains in Kordofan Province in western Sudan are a group of isolated hills mounted over a high plain, the local relief is about 3,000 feet above the plain which is 2,000 feet above sea level.

One of the topographic features that affect the local climate of the southern part of the Sudan is the existence of a vast swampy area between latitudes 5° N and 10° N, resulting from the blocking of the (Sudds) in the course of the Nile, and the overspilling of its waters.

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(1) Y.P.R., Bhalotra, *Meteorology of Sudan*, Sudan Meteo. Service, Memoir No. 6. Printed by P and T Department, 1963.

(2) H.M. Barbour, *The Republic of the Sudan*, Univ. of London Press Ltd. London, 1961, pp. 26-37.

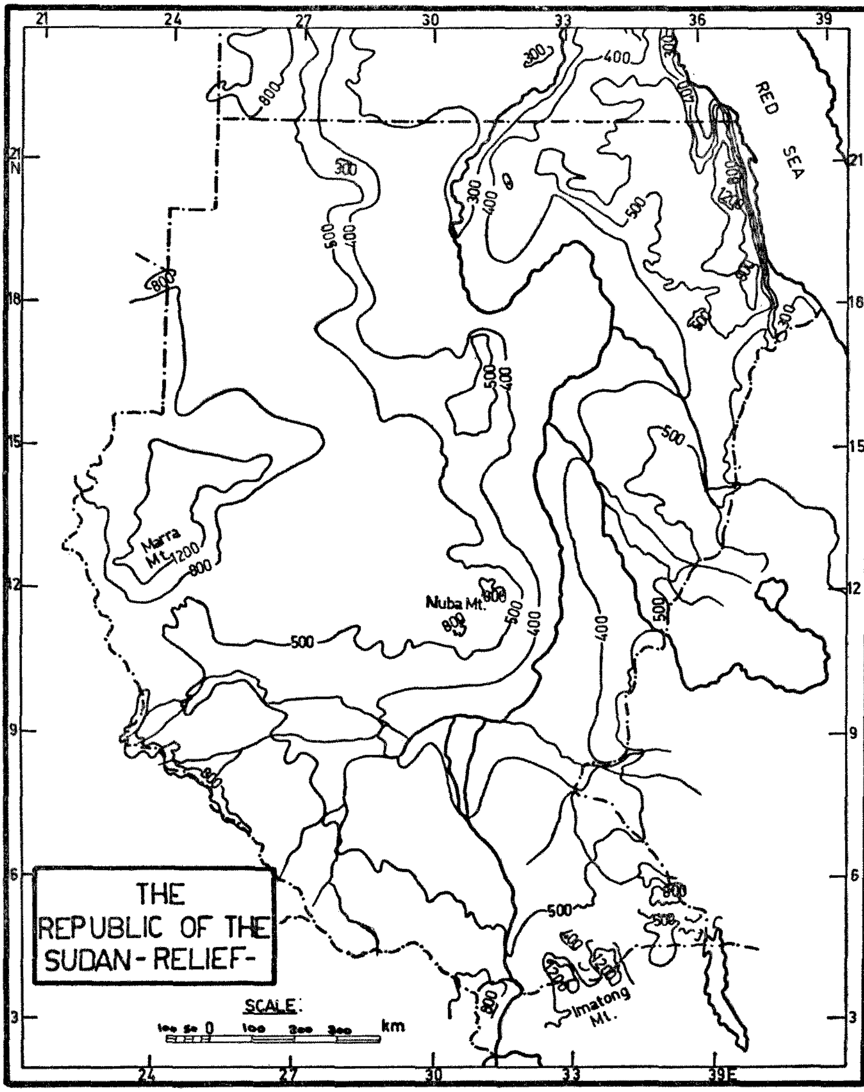
THE
REPUBLIC OF THE
SUDAN - RELIEF -
SCALE
km
RED SEA
Marra Mt.
Nuba Mt.
Imatong Mt.

Fig. 1.

The influence of the Red Sea as a water body on the climate of the Sudan is very slight and it is not felt in places lying few miles from the coast.

VEGETATION

The vegetation of the Sudan varies generally from north to south with the change in the amounts of rainfall. As rainfall decreases from 80 inches in a few high parts in southern Sudan to almost nil in the extreme north, the vegetation changes from the Tropical Rainforest in the south to the true desert in the north.

Desert : Desert vegetation covers about 280,000 S.M. It excludes a part of the Red Sea coast where a scrubby vegetation grows, especially along the stream beds. In the desert region plants are confined to the Nile and to the wadis flowing to it or ending in the desert such as Wadi El Melik and Wadi Hawar in western Sudan. In some parts of northern Darfur and Kordofan a certain type of grasses called « Gizzu» — which is very useful for grazing because of its high water content — grows after the first rains.

Semi-desert : It lies between the Desert and the Low Rainfall Savannah (Fig. 2). In western Sudan its southern boundary is at 14° N, but in eastern Sudan the southern limit is farther north because of the presence of clay soils in Kassala Province [1].

The main species are (*Acacia tortilis*), (*A. melifera*), and (*A. etbaica*). Where the soils are deeper grasses grow and trees are less such as the area between Khartoum and Kassala.

Low Rainfall Woodland Savannah : The trees in this region are higher than in the Semi-desert ranging between 10 and 15 feet. Their branches sometimes touch. The main species are (*Acacia melifera*), and on the wetter margins (*Acacia seyal*), and (*Balanites aegyptiaca*). There are some broad-leafed species especially the (*Combretaceae*). In some parts grasses are

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[1] F.W. Andrews, The Vegetation of the Sudan; in *Agriculture in the Sudan* by Tothill, J.D., pp. 35-38.

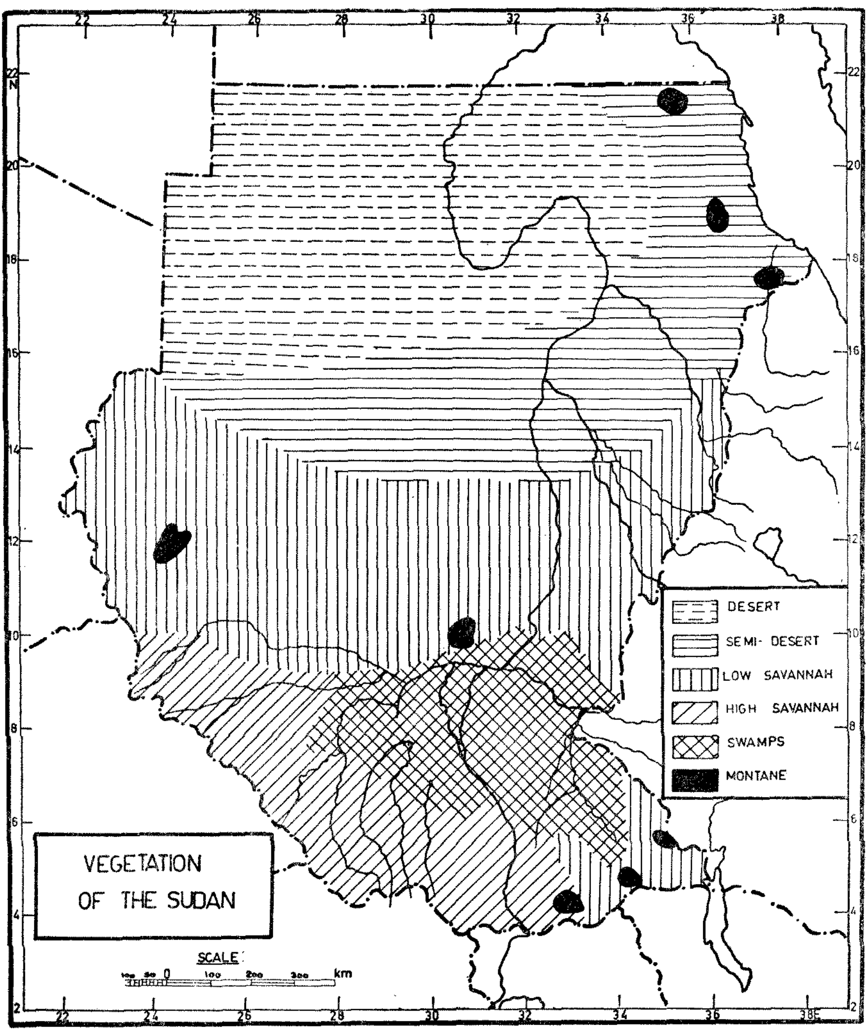
VEGETATION
OF THE SUDAN
DESERT
SEMI- DESERT
LOW SAVANNAH
HIGH SAVANNAH
SWAMPS
MONTANE
SCALE
km

Fig. 2.

dominant and trees are sparse. Acacia trees become established in this region after successive fires that would destroy the grass cover. On the other hand, grasses invade the region when the trees become old and decay. The main grass species are ; (*Cymbopogon neruatus*), (*Sorghum purpuro*), and (*Hyparrhenia pseudocymbaria*) [1].

High Rainfall Woodland Savannah : Sometimes this region is known as the Anogeissus-Khaya-Isoberlinia association. Harrison and Jackson mapped this vegetation type in the Bahr El Ghazal and western Equatoria provinces covering an area of about 120,000 S.M. This large area does not, of course, include one kind of vegetation but there is a variety of species depending on the amount and length of the rainy season. The most spread species of trees in the region are (*Khaya senegalensis*) or Sudan mahogany. Other species are (*Isoberlinia doka*), and (*Anogeissus schimperi*). These latter species usually have shrubby undergrowth and little grass. The chief grasses of the drier sections of the region are of the (*Hyparrhenia*) species [2].

Rain Forest : It occurs within the High Rainfall Woodland Savannah in small patches on both sides of the Nile and on higher land to the west of the river. The dominant species are ; (*Celtis zenkeri*), and (*Chrysophyllum albidum*). There are also some forests similar to the type known as « Galleria Forest», where (*Khaya grandifoliola*) and other trees appear.

Montane vegetation : Since each mountain section has its individual soil and climatic conditions which are reflected vividly by its vegetation, a separate discussion of each mountain area is more valid.

1. The lower slopes of the Imatong Mountains below 5,000 feet have a woodland with species of (*Boswellia papyrifera*), and (*Terminalia brownii*). From 5,000 to 10,000 feet the species are (*Olea hochstetteri*) and (*Podocarpus*). Above 10,000 feet the species are (*Erica arborea*) and (*Myrica salicifolia*) with many grasses and herbs occurring.

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(1) J. Smith, The Distribution of Tree Species in the Sudan, *Ministry of Agriculture, Bull. No. 4*, Khartoum, 1950, p. 11.

(2) *Ibid.*, pp. 12-13.

2. The low slopes of Jebel Marra (below 6,000 feet) have trees like (*Cordia abyssinica*) which appear in the cultivated fields among the growing crops [1]. The dominant grasses are (*Cymbopogon and Hyparrhenia spp.*). Between 6,000 and 8,000 feet there are (*Olea laperrini*) and (*Acacia albida*). Above 8,000 feet the area is covered with grasses mainly (*Hyparrhenia multiplex*) [1].

CLIMATIC DISTRIBUTIONS

In order to get a clear idea about the climatic patterns in the Sudan according to the classifications, we should present a picture of the distribution of climatic elements mainly temperature and rainfall. The choice of these two elements is justified by several reasons; firstly temperature and rainfall are the most important climatic elements in relation to vegetation distribution and other geographic aspects in the landscape. Secondly, all three classifications used in this study depend on temperature and precipitation in the computations of their values and it is relevant to find out the correlations between the patterns of the classifications and those of the climatic elements.

Rainfall : From the map of mean annual rainfall it is noticed that values increase with latitude, hence the pattern of isohyets is generally subparallel over the plains of the Sudan, while it is concentric in the highlands (Fig. 3).

The amount of rainfall reaches 55 inches in the extreme south especially on the highlands and from there they keep dropping untill the desert areas of the north are reached. Areas close to the highlands mainly in eastern Sudan where they are in contact with the Ethiopian Plateau get relatively high amounts of rainfall. Kassala for example gets 13.5 in. which is more than twice the amount at Khartoum (6.5 in.), and both stations are located on the same latitude. The highlands of Jebel Marra and the Nuba Mountains get higher amounts of rainfall in comparison

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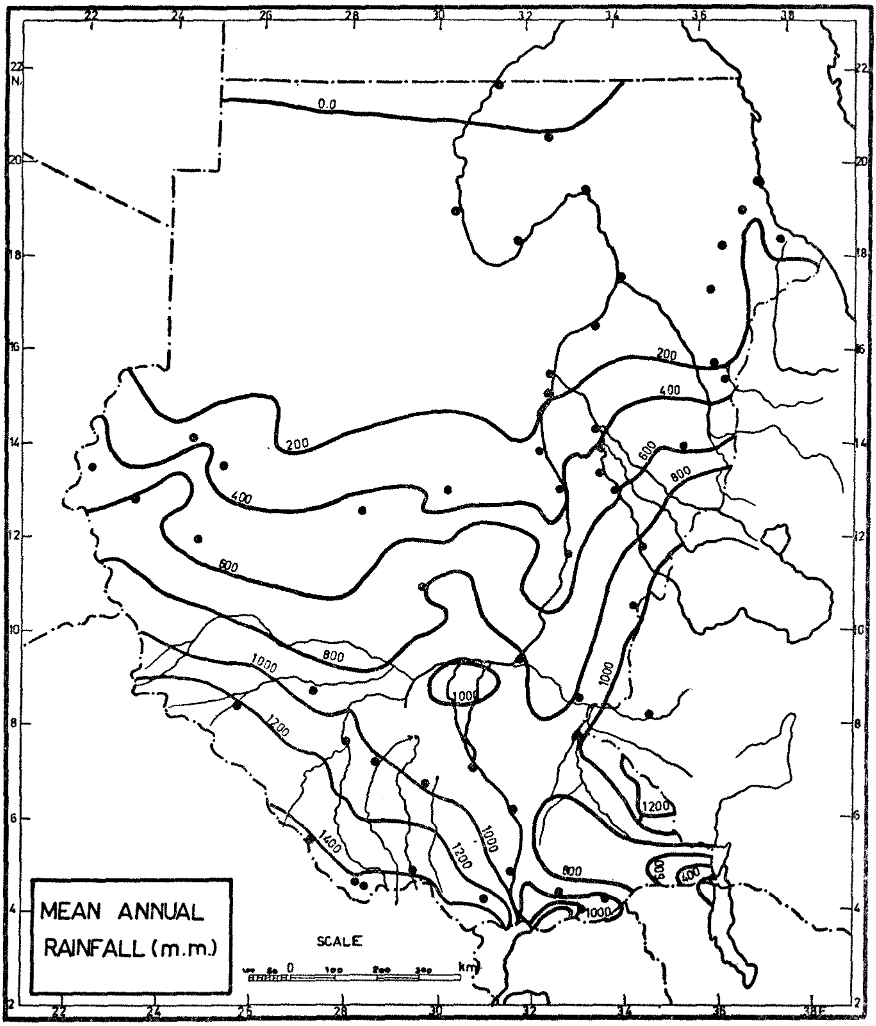
[1] Barbour, *op. cit.,* pp. 71-72.



MEAN ANNUAL
RAINFALL (m.m.)
SCALE
km
0.0
200
400
600
800
1000
1200
1400

Fig. 3.

with the surrounding areas. The mountains in southeastern Sudan get still greater amounts of rainfall and the values reach in certain limited localities 80 inches.

Temperature : In dealing with temperature it is customary to consider the values for the months of January and July as representatives of winter and summer respectively (in the Northern Hemisphere). However, dealing with the Sudan it was found that January and July do not stand as seasonal averages. The months of mean temperature minimum and maximum are different, from one place to another in the country. Therefore, it is more accurate to study the maps of the mean annual temperature minimum and the mean annual temperature maximum irrespective of the months they fall in.

Mean annual temperature minimum : In the map of mean annual temperature minimum the isotherms are mostly subparallel. Few isotherms are closed around the high mountains especially Jebel Marra and the Imatong Mountains where isotherms are adjusted to terrain (Fig. 4). The high mountains mentioned above include the coldest parts of the Sudan where the mean minima reach 53° F. Minima are the highest in the center of the country where there is a closed isotherm of 72° F covering the area along the Nile valley from Khartoum to Atbara. From this center of warmth, values decrease both northward and southward to reach 64° F in both directions.

It is peculiar to notice that the Red Sea Hills do not have a cooling effect. The values of mean annual temperature minimum increase along the eastern foothills to 75° F which is the highest value for the whole country.

Mean annual temperature maximum : In relation to the mean annual maximum (Fig. 5), the patterns of isotherms are similar to those of the mean annual temperature minimum with a general subparallel pattern over most of the country and few closed isotherms in the mountains sections. The hottest part of the Sudan is the north central portion starting from the latitude of Kosti northward to about the latitude of Dongola.

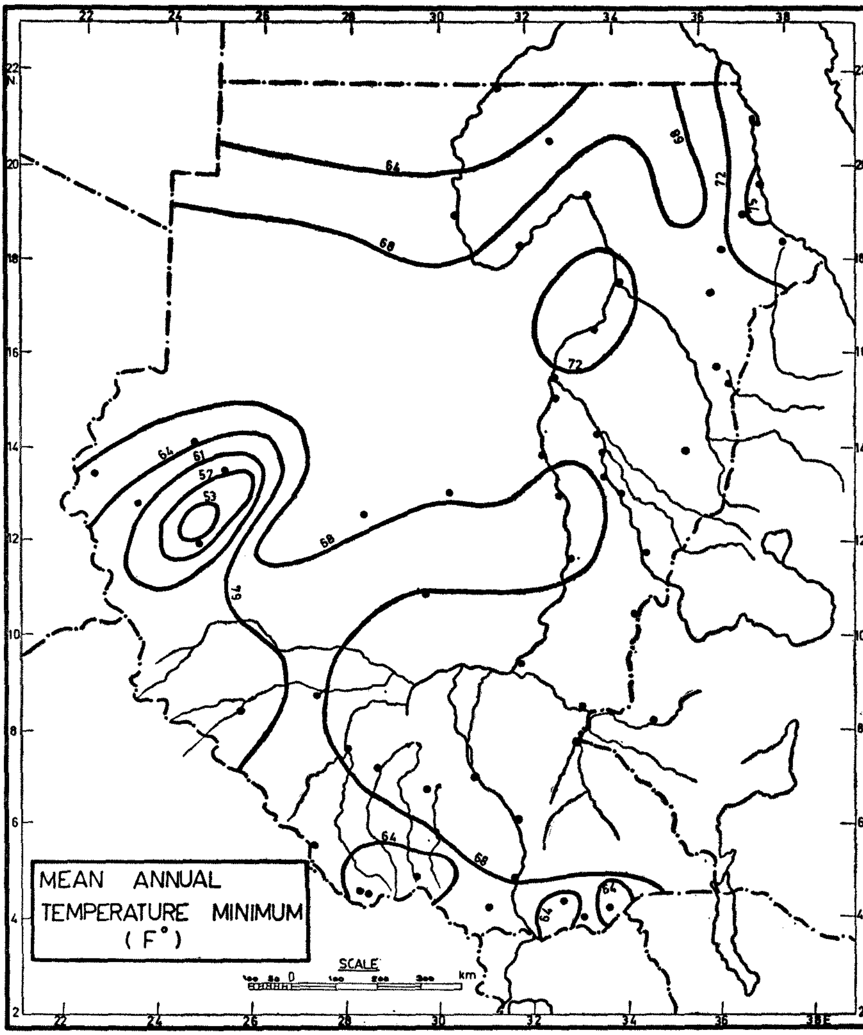


Fig. 4.

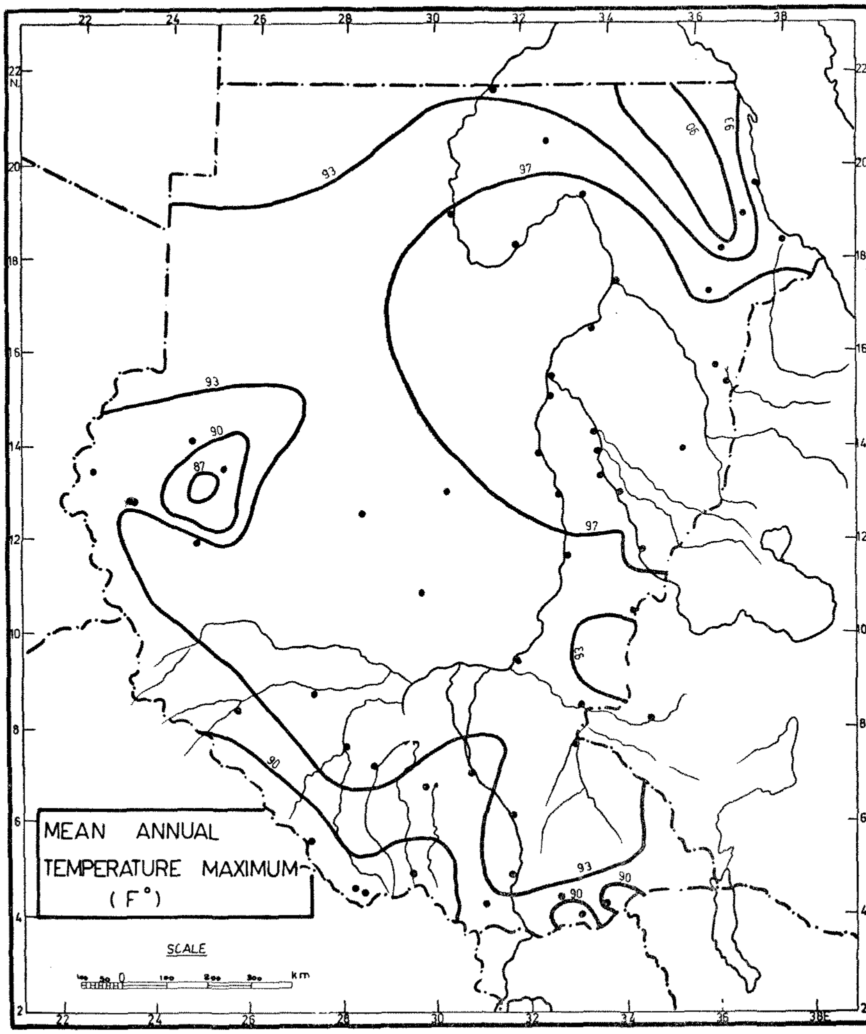

MEAN ANNUAL
TEMPERATURE MAXIMUM
(F°)
SCALE
km
93
97
90
87
22
24
26
28
30
32
34
36
38
38E
20
18
16
14
12
10
8
6
4
2
N.

Fig. 5.

It is to be noticed that this same area has also the highest mean temperature minima. Temperature maxima decrease from this center of heat toward the north and the south reaching 93° F in the extreme northern part of the Sudan and 90° F in southern Sudan.

The high mountains of western and southern Sudan show a cooling effect and maxima drop to 90° F or less. The Red Sea Hills have a slight cooling influence. On the other hand along the coast the maximum rises up to 93° F.

THE PERFORMANCE OF THE THREE CLASSIFICATIONS IN THE SUDAN

Considering the maps of temperature, rainfall and vegetation distributions in the Sudan it is noticed that in all these geographic patterns there is a general gradient from north to south with the change in latitude. There are few exceptions in the highland sections in the east along the Red Sea; in the west in the Nuba mountains and Jebel Marra and in the south in the Imatong mountains. These highlands portray a different setting because of their altitude. In the highlands temperatures are lower, rainfall amounts are higher and vegetation is usually richer and of a more temperate type.

Moisture conditions according to the classifications : According to *Koppen,* about two thirds of the Sudan are dry, desert or steppe. The (B) climate extends far southward along the Nile valley to include places like Shambe (latitude 7° 7' N). However, the boundary between the Steppe (BS) and the humid climate (A) swings northward in eastern and western Sudan where places like Kurmuk (latitude 10° 33' N) in the east has an (A) climate and Kadugli (latitude 11° oo N) in the west is also included within the humid region (Fig. 6).

The highlands probably have (C) climate differentiated on the basis of temperature conditions in winter, yet consequently considered humid.

The boundary between the desert region (BW) and the steppe region (BS) runs almost with latitude 14° North with few bends to the south in the Nile valley and northward in the eastern and western margins

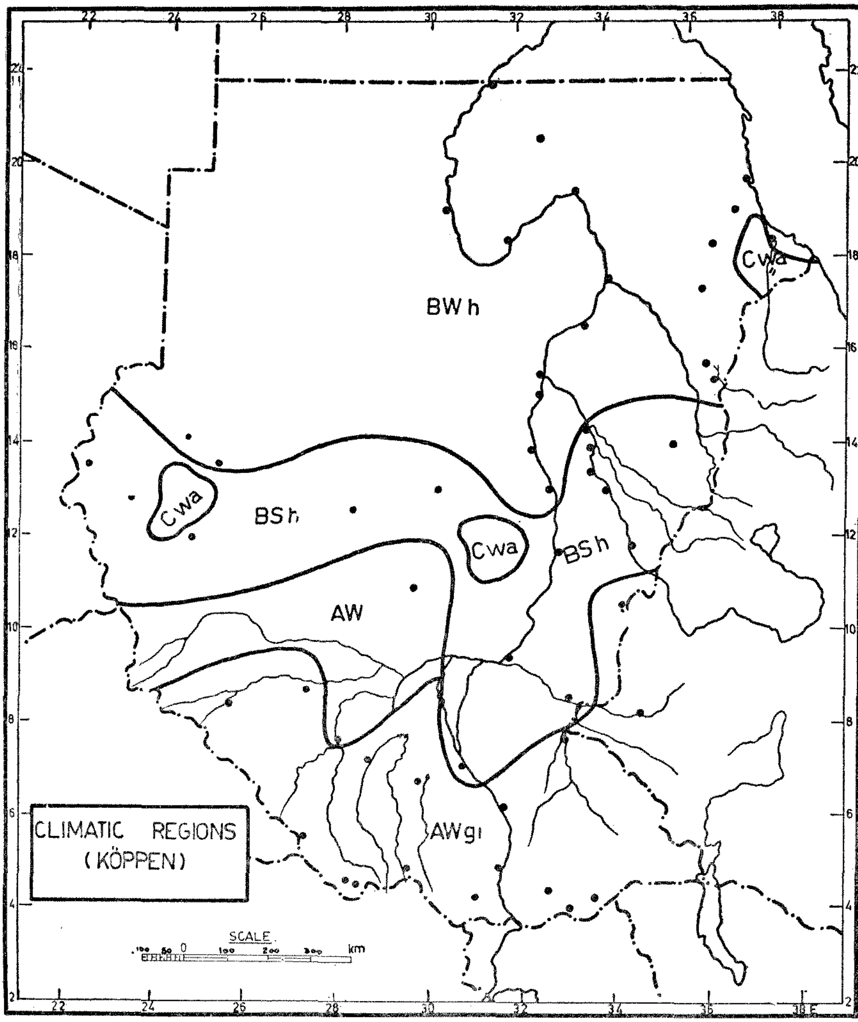

BWh
BSh
Cwa
Cwa
BSh
Cwa
AW
AWgi
CLIMATIC REGIONS
(KÖPPEN)
SCALE
km

Fig. 6.

where it is close to latitude 18° North. This condition is obviously a result of the higher altitudes in those marginal portions of the country and their proximity to the oceanic influences from the east and the west.

According to *Thornthwaite's* moisture index, most of the Sudan is arid. Juba (latitude 4° 52' N) for example is considered arid with an index of -42.9. The same is Aweil (latitude 8° 46' N) with a moisture index of -42.8. South of the arid region there are small strips classified as semi-arid, dry sub-humid and moist sub-humid respectively. A small highland section in the southeast is classified humid according to Thornthwaite (Fig. 7). Nagishot and Katrie have moisture indices of 35.5 and 26.2 respectively.

In the map of *Bailey's* Moistness of Climate, the arid climate includes the northern half of the Sudan up to the latitude of Renk (11° 45' N) along the valley with a bend northward in the east and the west where places like Wad Medani (latitude 14° 23' N), and Gedaref (latitude 14° 02' N) in eastern Sudan are not included in the arid category and also Zalengi (latitude 12° 54' N), and Geneina (latitude 13° 29' N) in western Sudan are considered semi-arid. The semi-arid climate extends southward to include most of Bahr El Gabal basin with a swing northward in eastern and western Sudan (Fig. 8). Thus while the boundary between the semi-arid and the sub-humid regions reaches to latitude 5° North in the Nile valley, it is located at latitude 10° North in the western part of the country and at latitude 12° North in eastern Sudan.

Narrow strips of the dry-humid, the wet sub-humid and the humid categories follow in a steep gradient toward the southern highlands.

It is clear from the above description of the patterns of the moisture regions in the Sudan according to the three classifications under consideration that all of them agree on the general gradient of increasing moisture toward the south. The increase in moisture is more apparent in eastern and western Sudan than in central Sudan, an effect of the high altitude. However, there are differences among the three classifications. Thornthwaite's classification shows the northern three quarters of the Sudan as arid. In the maps of Koppen and Bailey, the location of the arid boundary is father north. Koppen's and Bailey's

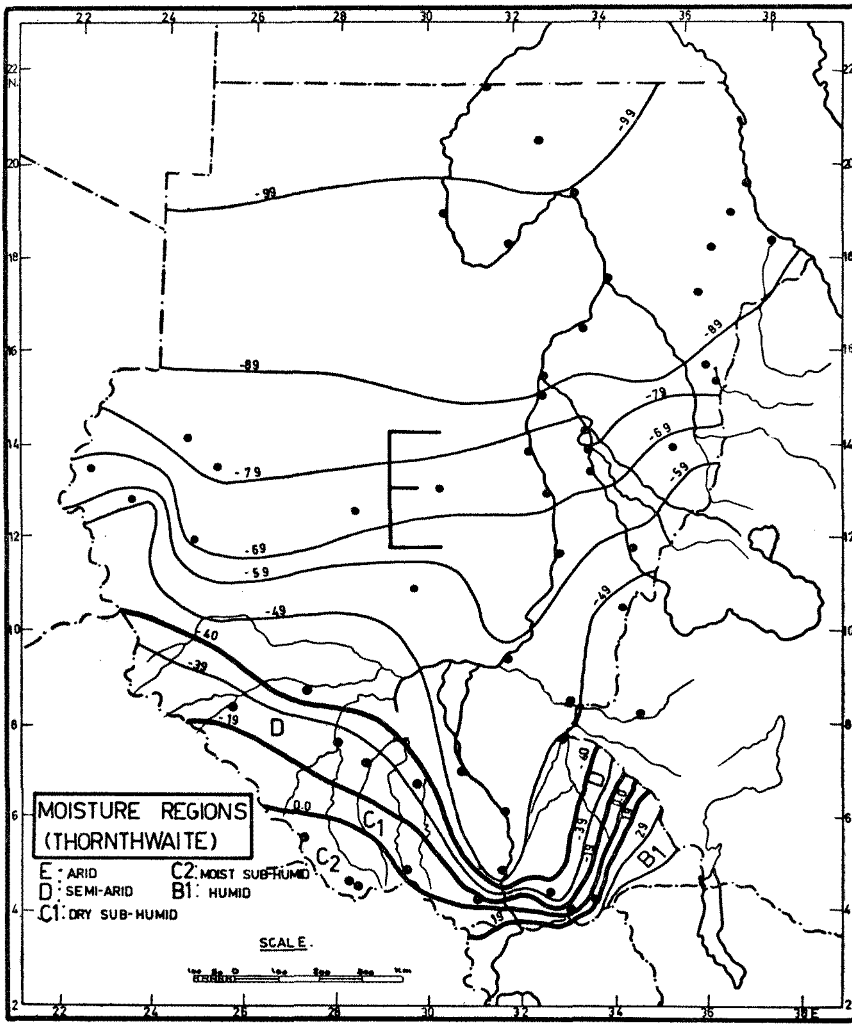

MOISTURE REGIONS
(THORNTHWAITE)
E: ARID
D: SEMI-ARID
C1: DRY SUB-HUMID
C2: MOIST SUB-HUMID
B1: HUMID
SCALE.

Fig. 7.

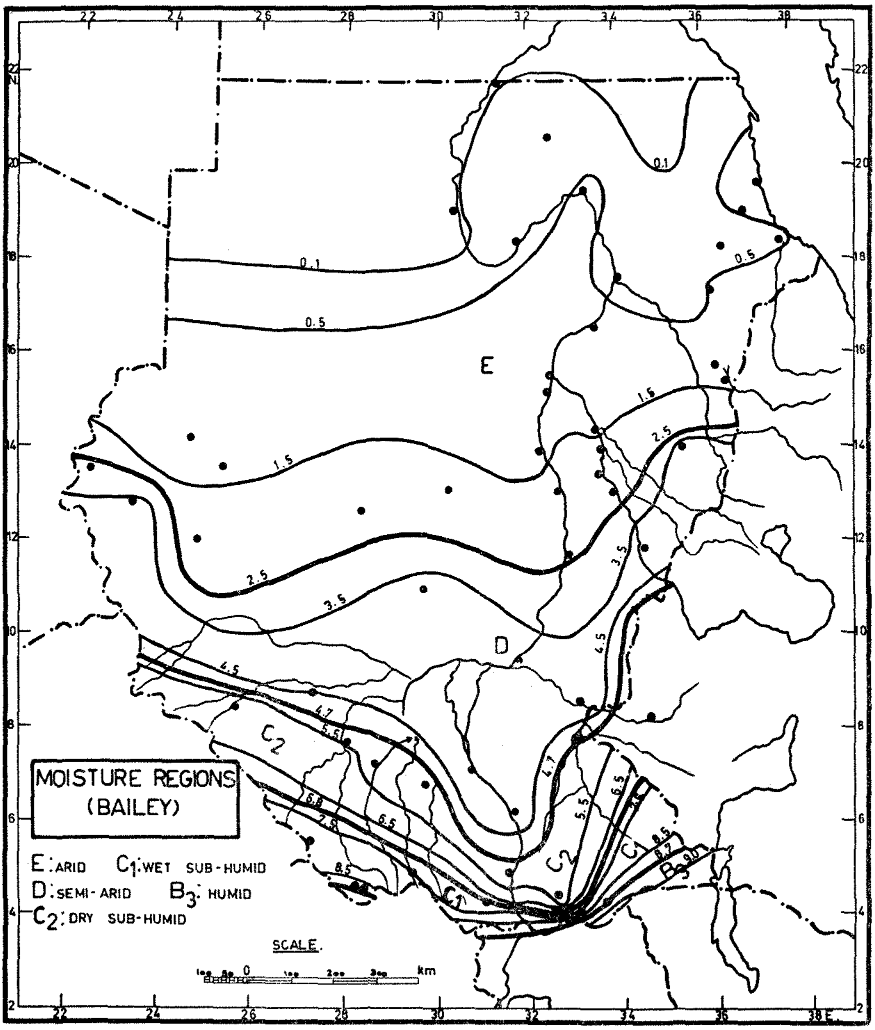

MOISTURE REGIONS (BAILEY)
E: ARID
C1: WET SUB-HUMID
D: SEMI-ARID
B3: HUMID
C2: DRY SUB-HUMID
SCALE.
km
E
D
C2
C1
B3
0.1
0.5
1.5
2.5
3.5
4.5
4.7
5.5
6.5
8.5
9.0

Fig. 8.

arid/semi-arid boundary is in good correlation with the boundary between the semi-desert and the low rainfall woodland savannah in the vegetation map. There is no master boundary between the desert and semi-desert in the map of Bailey's moistness of climate, yet the *0.5* isoline shows a good correlation with the southern boundary of the desert region.

The southern boundary of the semi-arid category in the maps of Koppen and Bailey are almost the same, both have a good correlation with the vegetation boundary between the low rainfall woodland savannah and the high rainfall woodland savannah. Thornthwaite's boundary between the semi-arid and the sub-humid categories is far to the south. The extreme dryness shown by Thornthwaite's scheme in the Sudan — as compared with the other two schemes and with the vegetation types-results from the influence of the high values of potential evapotranspiration for this part of the world. It is obvious that the values of potential evapotranspiration are very high when summer temperatures are high. High summer temperatures are characteristic of most parts of the Sudan. The amounts of rainfall are always lower than the values of potential evapotranspiration and the result is — of course — high values for the water deficit or in other words a rather dry climate. The broad area of the arid climate in the Sudan according to Thornthwaite's scheme cannot be justified. Juba for example is considered arid, while in the vegetation map it is included in the high rainfall woodland savannah.

Koppen's and Bailey's schemes show better correlations with vegetation distributions. The lack of a moisture boundary between the desert and the semi-desert can be compensated for in the map of Bailey by one of the field lines since the scheme supplies a continuous field of values over the surface. On the other hand, Koppen's classification is handicapped in this respect for supplying master boundaries only. The high value for the boundary between the desert and the semi-desert in Bailey's map could be attributed to Bailey's concept of the desert which might be different from its concept in the minds of the authors of the vegetation map of the Sudan. Travelling in western Sudan, the author of this paper thinks that the boundary between the desert and the semi-desert in the vegetation map is put far northward. Kutum for example which is included in the low rainfall woodland savannah has an annual amount of rainfall of about 9 inches and rainfall effectiveness is expected to be low because of the high temperatures of the area. The landscape in the area is one of scattered low grasses that can be designated as semi-desert at most.

Thermal conditions according to the three classifications : According to *Koppen,* the only major differentiation in thermal conditions in the Sudan is between the 'C' climate and the other climates. This divisioning is a mere interpolation since there are no weather stations on the high mountains. The areas included in the 'C' region are very limited to altitudes over 6,000 feet above sea level where mean monthly temperatures in winter are expected to drop below 64.4° F. The areas having 'C' climate are designated in the vegetation map as (Montane vegetation) where species like (*Boswellia papyrifera*) and (*Terminalia brownii*) are found.

A slight or a secondary divisioning based on differences in temperature ranges is shown in the southern part of western Sudan where the small letter (i) does not apply. The temperature ranges in that part of the Sudan are thought to be greater than 9° F because of the pronounced seasonality in rainfall and insolation.

Southern Sudan according to Koppen has a tropical climate with a small mean annual range of temperature and a temperature maximum occurring before the date of the summer solstice. This — of course — is different from the central and northern parts of the country where temperature ranges are much greater. Mean annual temperature ranges reach 25.0° F at Abu Hamad in northern Sudan (latitude 19° 32' N), while they drop to 6.0° F at Maridi in southern Sudan (latitude 4° 49' N).

In *Thornthwaite's* thermal efficiency map only one category exists. The whole country is classified as Megathermal (Fig. 9). The field lines drawn in the map show an increase in the values of potential evapotranspiration from the northern part of the Sudan to the center, then a decrease from there southward. Values are low in the mountain areas such as in the south and the west (Nagishot in the south has a value of 32.4 inches and Zalingi in the west 48.1 inches).

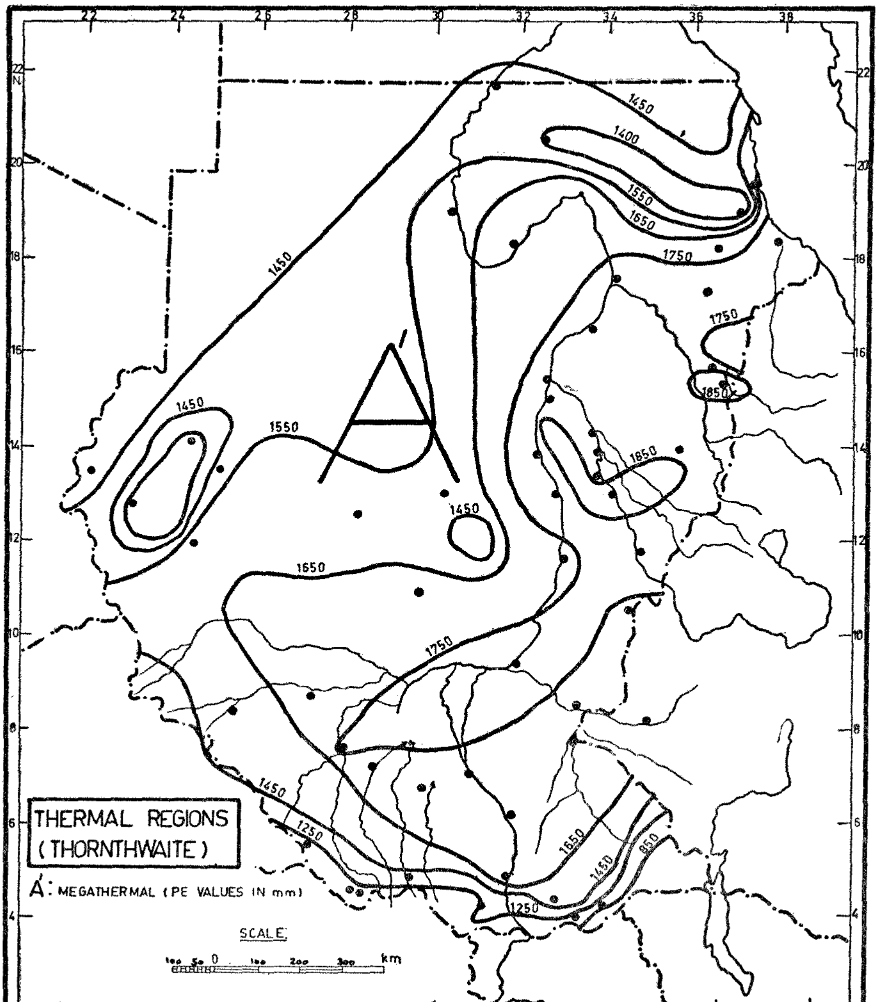

THERMAL REGIONS
(THORNTHWAITE)
A': MEGATHERMAL (PE VALUES IN mm)
SCALE
km
A'
1450
1400
1550
1650
1750
1850
1250
850

Fig. 9.

The high values of potential evapotranspiration result from the high summer temperatures in the Sudan in general and in northern and central Sudan in particular. It is known that Thornthwaite's scheme is very much affected by the high summer temperatures. Winter temperatures are not very low to counter balance for the high summer temperatures. The result is high annual values for potential evapotranspiration. It was mentioned previously that the great aridity of the Sudan according to Thornthwaite's scheme results from the high values of potential evapotranspiration when compared with the amounts of rainfall.

The failure of Thornthwaite's classification in a tropical region was discovered by others. Fuson applied the system to Panama and found that it does not work there (Professional Geographer, May, 1963).

According to *Bailey's* warmth of climate, the Sudan is divided into three thermal categories; the central part of the country is hot with values over 70. Thermal values decrease from this hot center toward the north where the very warm and the warm categories occur (Fig. 10). The same sequence of change is noticed toward the south and south-east but the gradient is steeper in this direction especially upon approaching the highlands. It is clear that the *ET* values in the map of Bailey show a close correlation with the temperature maps. The patterns in Bailey's system are reasonable and they agree with the general idea about thermal conditions in the Sudan. No clear correlation exists between thermal patterns and vegetation distribution in the Sudan.

CONCLUSION

From the preceding discussion on the climate of the Sudan according to the classifications of Koppen, Thornthwaite and Bailey we can conclude that the three classifications agree on the general trend of moisture and thermal conditions. Vegetation distributions are correlated with moisture conditions and not with thermal conditions.

Koppen's and Bailey's moisture boundaries proved to be better than Thornthwaite's boundaries. In relation to thermal and moisture regions Thornthwaite's values are too high in the former and too dry in the latter as compared with vegetation types and with the categories in the other two classifications.

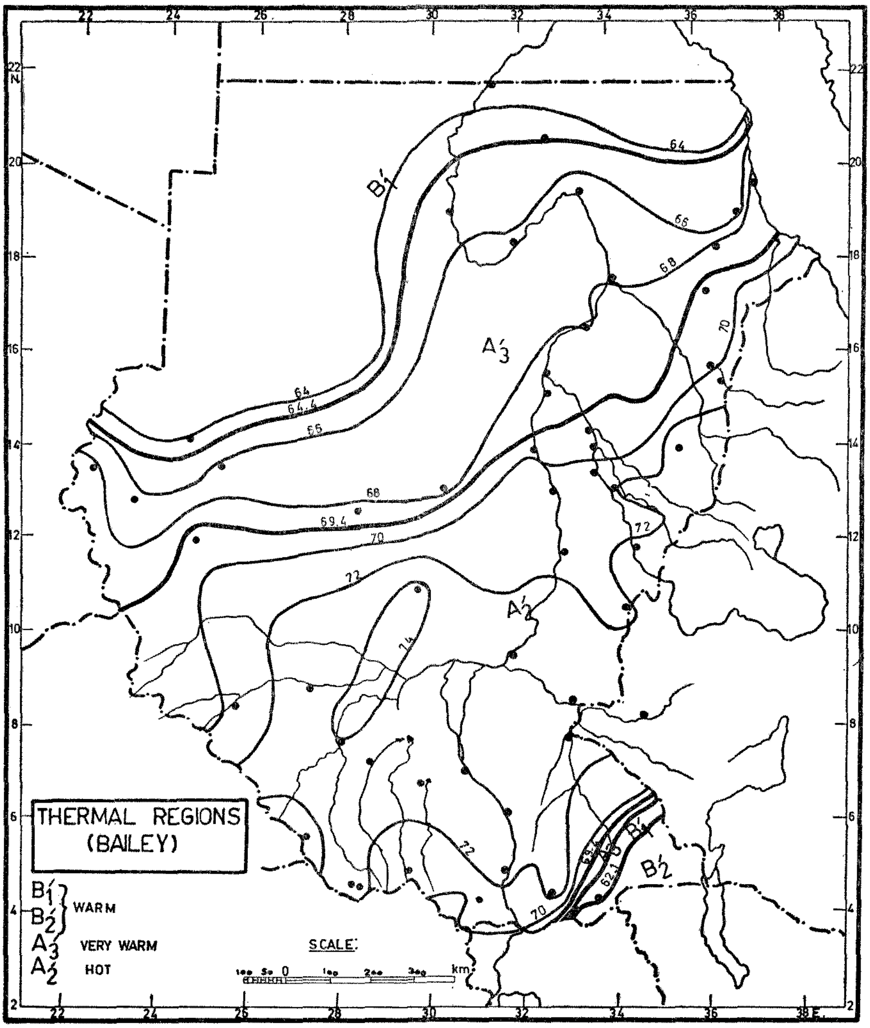

THERMAL REGIONS
(BAILEY)
B'1
B'2 WARM
A'3 VERY WARM
A'2 HOT
SCALE:
km
A'3
A'2
B'1
B'2
64
64.4
66
68
69.4
70
72
74
62.1

Fig. 10.

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