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CLIMATE AND SOILS

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CLIMATE

The whole range of tropical climates is found in Sudan, from true desert with no rainy month, to the wet tropical type of the southern frontier with a dry season of only three or four months. Generally the climate is of the continental type in which the diurnal variation of temperature often exceeds 15°C. In the south of the country the highest temperatures occur in March and April: at the higher latitudes to the north the highest temperatures are delayed to May to July. Outside the southern provinces maximum temperatures often exceed 40°C (Figure 1). North of the 16th parallel and in the mountainous areas the winter nights are cool.

Rainfall is highly seasonal and is governed by the northward advance of the monsoonal Intertropical Convergence Zone. The rainfall pattern is unimodal, the peak reaching a maximum in July and August. Several natural, and traditionally described, climatic zones can be distinguished, from north to south:

- **the *desert* proper**, covering 24% of the country's area, where average annual rainfall is less than 50 mm but where it may not actually rain for several years (this zone may very occasionally be subject to Mediterranean influence and have rain in the winter);

- **the semi-desert,** which also covers 24% of the country, and which receives 75-300 mm of rain per year falling in one or two months only, following the hottest period, and where no rainfed cultivation is possible;

- **the arid zone,** covering 10% of the country, with annual rainfall between 300 and 500 mm, which allows rainfed cultivation of some specialized short-season crops, although this area is principally of importance (as is the previous one) in its support of the nomadic and semi-nomadic livestock production systems;

- **the semi-arid** and subhumid regions, which together cover 26% of the country, and where rainfall is between 500 and 1 000 mm per year;

- **the remainder of the country**, which has a humid climate or is covered by swamps.

Such a general classification is obviously subject to several local modifications. The Red Sea, for example, governs a special climatic regime along a narrow strip, inland to the coastal mountain ranges, where temperature variations are less extreme and where the rain, while still being small in amount, is more regularly distributed. In the south-east of the country a small arid area is less subject to the influence of the ITCZ and there is here a bimodal tendency in the rainfall pattern. The mountainous areas are both cooler and wetter than their immediate surroundings: Jebel Marra has heavier rains than the rest of Darfur, even though they fall in a relatively short period; the Nuba Mountains cause the general isohyets to inflect towards the north; and the southern highlands and the foothills of the Ethiopian massif also have heavier rains than would otherwise be the case in those general areas.

Aridity in Sudan

The isohyets as drawn provide little more than an indication of the climatic conditions. The potential evapo-transpiration is everywhere very high (from 1 600 to 3 000 mm per year) on account of the high temperatures, leading to a humidity index which is negative over most of the country. An index of - 66.6 is generally considered to be the boundary between the arid and semi-arid regions. In Sudan this index is found at about the 600 mm isohyet outside the areas that are at higher altitudes, and generally follows the 11th parallel of latitude. Except, however, where irrigation allows a good vegetation cover, actual evapo-transpiration falls far short of the potential, even during the growing season. Reduced vegetative cover and reduced physiological activity of the vegetation are common.

A further factor contributing to the aridity is that only a small proportion of the rain that falls is available to plants. Light rain falling during the hottest hours of the day evaporates immediately and adds nothing to the soil water bank. Heavy rains usually exceed the infiltration rate in to the soil and run-off results in considerable water loss, even in the arid zones. At eight stations receiving between 75 mm and 820 mm per year **(Table 1)** only 20 to 30% of rain days provide water useful for plant growth. In these areas, rain from a single violent storm may exceed the annual average in the semi-desert regions and can account for a quarter of annual rainfall in the arid zones. The total time during which rain falls in the very arid and arid areas does not usually exceed 100 hours.

Table 1 - Rainfall frequency and intensity for selected stations in Sudan in period 1931-1960

Location	Days with rain	Falls over 1 mm	Falls over 10 mm	Heaviest one day fall (mm)
Atbara	10.6	9.0	2.0	98.1
Khartoum	21.3	19.7	5.3	79.9
El Fasher	34.3	31.8	9.1	93.0
Kassala	33.5	30.4	11.0	95.5
El Obeid	41.6	36.7	13.8	96.7
Sennar	42.4	41.7	16.0	105.0
Gedaref	49.6	47.9	20.5	126.5
Malakal	78.0	69.8	23.4	176.1

Source: Oliver, 1968

Rainfall is not only limited in total amount, but also very irregular in time and space. An example (Oliver, 1968) is of two falls on 2 September 1962 in the cotton-growing area of the Gezira, only 6 km apart, one of which provided 20 mm and the other 250 mm of precipitation. Isohyets based on 30 years'observations can, therefore, be considered to be only approximations of what they might be in the very long term. Similarly, figures for average rainfall should also be considered merely indicative of the true figures, especially as they are often established from various sources which themselves differ considerably. Errors of tens of millimetres of the averages quoted are possible, especially in view of the fact that the meteorological stations are widely scattered over the greater part of the country and have little overlap. These problems are reflected in the lines adopted for the isohyets, which often result at least in part from little more than logical deduction.

Climatic trends

Subsequent to indications of a continuing reduction in crop yields under mechanized agriculture, attention has been directed to long-term variations in rainfall. Rainfall data for Gedaref for 1950-1979, for example, show means and standard deviations of 584 $\pm$ 72 mm, 582 $\pm$ 87 mm and 615 $\pm$ 81 mm for the successive decades in the overall period (IES, 1985). Within each decade, annual maximum and minimum totals were 714 and 470 mm, 743 and 439 mm and 775 and 474 mm. This study showed no major changes over the period covered in terms of total rainfall, nor were there any anomalies in its distribution, and it concluded that the fall in yields was due to soil exhaustion consequent on continuous cropping of sorghum without the application of mineral fertilizers. It has, however, since been shown that application of the amounts of nitrogen and phosphorus that are effective in maintaining yields in the subhumid zone do not restore initial production levels on clay soils in the arid zone. This is most likely because "degradation" of these black cracking clay soils (vertisols) includes changes in structure that render them less permeable to infiltration, and also susceptible to both sheet and gully erosion.

In spite of the foregoing, there have been some very dry years during the 1980s **(Table 2)**. As early as 1982 poor rains were noted over much of the country. These continued in subsequent years when precipitation at least 25% below normal was recorded at many places. In 1984, the worst year ever, rainfall was more than 50% below average. The effects of lack of rain in 1984 were disastrous on primary production, resulted in large scale divergences in nomadic migratory patterns and caused enormous losses of livestock. The shortfall over several successive years, coupled with overgrazing by a livestock population that had greatly increased prior to the drought, has resulted in long-term changes in the natural vegetation. There are various reports of increasing desertification, of the desert advancing southwards by as much as 100 km, and of widespread degradation of the natural resource base.

The majority of the most recent studies, however, are in general agreement that the precipitation deficit of the exceptional drought of the 1980s is more in the nature of a normal periodic fluctuation than a definitive tendency in the direction of increased aridity. It is not even possible to speak with any certainty of a constant trend towards dryness over the last three milennia, following the humid period which is known to have existed between 7,000 and 4,500 years before the present. Large rainfall oscillations do appear to be normal around the limits of the Sahara. Rainfall in Sudan in the period 1910-1940 was, for example, about 25% less than during the preceding 30 year period. It was in similar deficit in relation to the succeeding 30 years of 1940-1970, a period which is now often taken as the one of reference. The recent drought has, however, been accompanied by a 16% reduction in the discharge of the Nile, from which it can be taken that climatic variations have enormous repercussions on the total potential production of Sudan. The exaggerated and increasingly disastrous effects of recent droughts can largely be attributed to the pressure exerted by the human population which has shown a constant increase in recent times.

Table 2- Long-term and annual rainfall data for some selected Sudanese stations

Long-term data (1951-1980)			Annual data						
Location	Mean	Range	1980	1981	1982	1983	1984	1985	1986
Port Sudan	23	0 - 101	u	u	1	t	43	45	66
Abu Hamad	13	0 - 139	u	u	t	3	t	t	9
Dongola	19	0 - 79	u	u	7	1	t	t	t
Karima	30	0 - 137	u	u	5	t	t	t	21
Atbara	72	0 - 242	46	27	18	15	1	33	39
Khartoum	169	5 - 382	96	u	103	85	5	39	54
El Fasher	297	71 - 717	191	u	110	73	71	172	259
Kassala	324	96 - 488	193	u	182	250	98	146	305
Wad Medani	344	147 - 707	u	320	200	230	164	339	247
El Obeid	371	160 - 715	330	315	192	352	160	219	376
Kosti	396	96 - 559	373	u	314	267	96	360	280
Nyala	445	188 - 840	470	339	271	237	188	u	u
Sennar	479	175 - 685	365	u	227	346	209	413	435
Abu Naama	576	304 - 774	304	u	403	353	380	531	447
Gedaref	580	332 - 1035	571	646	710	473	326	729	574
Kadugli	687	256 - 1041	256	u	532	627	401	606	613
Ed Damazin	708	497 - 883	510	631	599	685	594	497	567
Juba	907	558 - 1251	1078	814	1032	890	832	1003	926

Notes: u = unknown; t = trace.

SOILS

General studies on Sudanese soils usually describe them in relation to their actual or potential use. The great clay plains resulting from ancient alluvial deposition and the soils of volcanic origin in the Nile basin, of which only 10% are cultivated intensively and 15% traditionally, are thus contrasted with the remainder of the country. This basic distinction between the clay plains and the sandy or rocky soils of the rest of the country provides a very simplified classification. It ignores, however, the areas of good cultivatable soils outside the central basin and the pockets of very diverse soils found in the general area of the dark cracking clays and where there are several areas of montmorillonite clays.

Among recent studies which cover the whole of Sudan, one (Purnell and Venema, 1976) identifies 16 soil regions. Each is described by particular topographical features or by soil associations (Table 3). The main areas of soil distribution are also marked on the climatic map as this allows an analysis of soil formation in relation to climate. Some soil regions have, in fact, been delimited in relation to climatic factors and it can be seen that the desert soils approximate to the 75 mm isohyet at about 17°N, from the frontier with Chad in the west to Atbara on the Nile in the east. Semi-desert soils and those of the Red Sea correspond, in a similar manner, to the area between the 75 mm and 200 mm isohyets. The semi-desert and Red Sea soils differ in respect of the particular topography found at the extreme east of the zone: the shallow Red Sea soils on steep slopes are calcareous and sandy fluvisols and are found in the numerous steep valleys descending from the hills towards the eastern run-off areas.

In areas of higher rainfall a first approximation of soil type can be related to altitude. In the Nuba mountains or uplands it is possible to distinguish the fertile soils of the plateau and the higher slopes, the often poorly drained variable clay plains and the eastern highlands of diverse geological provenance which result in soils ranging from fragile and acid lithosols to accumulations of saline and sodic clays. Jebel Marra in Darfur is characterized by the volcanic nature of the substrate: the soils here become deeper on descending from the summits to the piedmont zone; there are large expanses of volcanic ash and valleys that are partially in-filled by alluvial deposits. Jebel Marra is surrounded by another zone, the Darfur erosive plain, at relatively high altitude, generally undulating and dissected by water courses, where the soils are formed on Precambrian rocks.

The qoz region is typically an extensive peneplained plateau of ancient, once mobile but now fixed, dunes. Qoz soils are poor but free draining, deep and of loamy sand, even along the drainage lines. The qoz is limited to the south by the 10th parallel of latitude north, beyond which is a vast area of laterite, known as the ironstone country, which is continuously capped or has gravel outcrops. The lateritic soils are brown-red in colour, with better structure than the qoz soils, although this is largely determined by their position along the slopes. To the east of the White Nile the latitudes occupied by the qoz in the west comprise the central clay plain with soils that are dark in colour, that are usually alkaline and calcareous, and often reworked due to erosion. Micro-studies have enabled zones of exportation and of deposition to be identified; the river banks here are subject to strong erosive pressure. The transition to the clays of the south occurs at about 10 °N, as for the qoz, but can perhaps be considered to be a little artificial in view of the descriptions that have been made of the two regions. The boundary between the central and southern clays is perhaps better considered to be related to the length of waterlogging under the combined influence of the rainfall and the annual flood. the southern clays are then seen to comprise vast areas of permanent swamp with gley soils and peat underlying them.

The other soil regions are mainly alluvial and differ mainly in relation to their geographical location. The Gash delta is an enormous run on area of loamy clay which is flooded each year for only a short period, due to the flashy nature of the river. Central Kordofan is a gently sloping loamy plain formed from the combined effects of aeolian sediments and colluvium from the Nuba mountains. The plains and meander channels of Southern Darfur and Southern Kordofan are ancient extensions of the southern clay plains which are now partially submerged under imported sand. Southern Darfur and Southern Kordofan include two typical landscape types: the Baqqara comprises alternating low dunes with cracking clays at the contact zone with the qoz; the Raqaba has the dunes replaced by loamy sands or by non-cracking clays. The Baqqara and the Raqaba form an enormous transition zone between the Nile basin and the higher formations to the west and are witness to a more humid geological era in the past. The repetitive nature of the landscape, and the resulting soils, are very typical: an analogous transition zone from the qoz to the central clay plains occurs to the south-west of Kosti.

Table 3 - Soil regions of Sudan

Region	Area (km2)	Rainfall (mm)	Soil characteristics
Y = Desert	668 000	0 - 75	Hills, rock, sandsheets, dunes, gravelly plains; calcareous loamy and clayey plains
X = Semi-desert	387 000	75-300	Basement complex and Nubian sandstone plains; deep dark sandy clay and loam; both with sandsheets: deep yellowish brown soils with loamy topsoil over sandy clay or sandy clay loam
R = Red Sea	67 000	25-100	Steep rocky and stony; shallow soils: valleys; sandy and loamy
Q = Qoz	240 000	200-900	Deep soils slightly acid to neutral, low organic matter and nutrient contents, rapidly drained: brown sand, loamy sand, sandy loam; deep, well-drained, non calcareous, acid to neutral alluvions: yellowish red loamy sand
C = Central clay plain	212 000	200-900	Arid; alkaline and calcareous, sodic, sometimes saline: semi-arid; alkaline and calcareous: dry monsoon; slightly acid to slightly calcareous dark, grey-brown cracking clay, heavy very dark grey-brown clay, dark cracking clay
G = Gash delta	10 000	100-500	Dark brown to dark greyish brown silty clay
K = Central Kordofan basin	20 000	500-800	Flat gently sloping plain, aeolian, alluvial and colluvial sediments; dark reddish brown coarse loamy topsoil, dark red fine loamy subsoil with clay accumulation; associated acid yellowish red soils
J = Jebel Marra	30 000	600-1000	Volcanic area; shallow, stony: piedmont; deep well-drained: ash; loam: flood plains; coarse-texture with eutric and calcaric fluvisols
D = Darfur erosive plain	92 000	300-800	Undulating, weakly dissected plains surrounding Jebel Marra Basement complex; rocks: arid, semi-arid; freely drained reddish brown sandy clays, dark grey non-cracking clay, deep clay loam, clay with cover of quartz: strongly dissected plains; gravel, imperfectly drained dark grey to dark brown soils
N = Nuba uplands	65 000	500-800	Shallow fertile plateau; deep dark red soil: clay plains; dark greyish: eastern plains; brown cracking clay: central plains; imperfectly drained soils: western plains; very dark grey nearly black pellic vertisols, dark reddish brown clay
B = Alluvial plains	60 000	500-900	Old alluvial plains, Baqqara repeating pattern; alternating non-cracking clay and stabilized sand dunes: Raqaba overflow plain; dark grey cracking clay, non cracking clay loam, sandy clay loam
S = Southern clay plains	247 000	700-900	Highlands, non-flooded; yellowish sands and loamy sands: intermediate land; dark grey cracking clays: Toich; dark grey cracking clay, high organic matter, hydromorphic gleysols, non-cracking
M = Swamps	40 000	900-1000	Peaty surface layer of organic matter mixed with clay overlaying gleyed, clayey subsoils; dystric or eutric histosols, humic gleysols and eutric gleysols
I = Ironstone country	237 000	900-1300	Catenary toposequence on reddish brown soils with solid or fragmented iron pan: plateau; sandy loam: dissected plateau and jebels; sandy clay loam; transition zone; colluvial sandy loam to sandy clay, skeletal, hydromorphic
E = Eastern uplands and plains	105 000	1000-1600	Variable Basement complex; rocks and lava: mountain area; medium and fine, red or brown, acid clay and loam: piedmont; variable lithosols and nitosols: plains; grey cracking sodic and saline clay
F = Green belt	25 000	± 1400	Deep red, variable clay; shallow skeletal hydromorphic

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