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The effect of deforestation in equatorial Africa on rainfall in central Sudan

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सार — विश्व के अनेक भागों में इस बात को गंभीरता से नहीं लिया गया कि वन वर्षा की कुल मात्रा को प्रभावित करते हैं। उष्ण-कटिबंधीय अफ्रीका में संभवत: ऐसा न हो। भूमध्य रेखा के उत्तर की ओर अफ्रीका उष्णकटिबंधीय क्षेत्रों में एक विशालतम भूमि क्षेत्र है। जहां पर संवेदी ऊष्मा स्त्रोत प्रचुर मात्रा में हैं। वाष्पोत्सर्जन विभव काफी ऊंचा है। वायुराशि कम आर्द्र तथा वर्षा बहुत कम अवधि तक होती है।

केन्द्रीय सूडान के आठ स्टेशनों के अप्रैल से अक्तूबर महीनों के 1953 से 1983 तक की वर्षा ऋतु के आंकड़ों की तुलना की गई जिन तत्वों की तुलना की गई है वे इस प्रकार हैं :–

1200 बजे ग्री० मा० स० पर माह का औसत तापमान तथा औसत ओसांक के प्रेक्षण, मासिक वर्षा तथा विद्यमान वायु की दिशा।

इस अध्ययन से पता चलता है कि भूमध्यवर्ती अफ्रीका में वनों की सघनता में परिवर्तन से वायुराशि के अभिलक्षणों में किस प्रकार परिवर्तन होते हैं। जिसके फलस्वरूप, केन्द्रीय सूडान पहुंचने वाली वायु परिवर्तित हो गई है।

मासिक मानों की तुलना करने पर वर्ष 1953 की अपेक्षा वर्ष 1983 में केन्द्रीय सूडान में प्रभुरवत: वायु के सतही ताप का कुछ डिग्री से० बढ़ना तथा औसांक का घटना पाया गया है।

दक्षिण-पश्चिम मानसून की हवाएं दुर्बल हुई तथा यही बात ऊपरी पूर्वी हवाओं में पाई गई जो कि केन्द्रीय सूडान में वर्षा ऋतु के दौरान 700 मि० बार से ऊपर की ओर प्रमुख होती है।

ABSTRACT. Forests in most parts of the world were not taken seriously as to effect total amounts of rainfall. In tropical Africa this may not be so. Africa, north of the equator, is the largest land mass in the tropics. Sensible heat source is abundant, potential evaporation is high, air mass is less humid and rain is of short duration.

Data from central Sudan for the rainy seasons of 1953 and 1983 were compared for eight stations from April to October. The elements compared are : average temperature for the month and average monthly dew point observation at 1200 GMT monthly rainfall and prevailing wind direction.

The study explains how a change in the forest density in equatorial Africa caused a change in the air mass characteristics. As a result the air reaching central Sudan has changed. The changes were mainly that the surface temperature of the air in central Sudan increased by a few degrees celsius and the dew point decreased in 1983 as compared to those monthly values of 1953.

The southwesterlies monsoonal air weakened and so did the upper easterlies which are dominant during rainy season over central Sudan from 700 mb upward.

1. Introduction

Climatic changes are usually very slow to be observed during a life time of one generation. In Africa records of weather elements started in this century. During this period most records at least in Sudan indicate a gradual decrease in the rainfall amounts. Most of the nomads in north Sudan vacated their traditional areas to move towards the Nile valley or southward. During the first half of this century the immigration continued unnoticed. In recent years a rush was noticed especially from western Sudan towards the east to the Nile valley and southward. Since 1973 successive crop failures increased the flux. In 1984 a tragedy took place. New records in the lowest rainfall were established in most observing station north of Lat. 10° N in Sudan.

It is believed that this decrease is not new to Africa. It is an old story dating as far as 2000 B.C. Five thousands years ago the dominant kingdoms were around Cairo in Memphis. By 1500 B.C. the influence of these kingdoms was extended southward upto Semna around Lat. 22° N. This could be in search of more natural resources. Even the recent history of northern Sudan indicates such a southward handing of power from Dongola, Berber, Soba and Sennar from christian era upto the Turkish domination in the nineteenth century.

These kingdoms flourished where natural resources were abundant. In four thousands years the power traversed about 20° of latitude. If rain creeped with the same pace then the retreat is about 500 metre a year. Recent estimates of desert creep given are between 5 & 7 km, *i.e.*, ten to twenty folds.

Since 1980's the situation worsened. If we examine the annual rain for station El Geneina in western Sudan we find gradual decrease in rainfall amount from 528 mm in 1980 to 124 mm in 1984.

2. Drought

Drought is taken to mean dry weather or scanty rainfall. It also depend on temperature, places enjoying cold climate need less rain to turn green. In warm climate much rain is required by plants. Therefore, a place will get dry if (a) the rain is decreasing and (b) if temperature is increasing, or both effects are taking place.

If an area is getting both effects we can say that it is desertifying. This is at least in the tropical region. Koppen & Geiger gave a relation applicable in places with rainfall in hot season which states that $R=2t+28$ where R is rainfall in cm and t=mean annual temperature in degree celsius. This relation is used to define desert and semi-desert places. If annual rainfall is $P \leqslant R/2$ then the place is desert. If $P \leqslant R$ it is semi-desert. This relation when used in central Sudan gave results which were not in conformity with what has been accepted by many: in central Sudan desert place are those which receive twenty centimetres of rainfall or less. More over it designates places having annual rainfall more than 70 cm as semi-desert while, in fact, these are places of savanah regions (*see* Table 1).

In England an absolute drought was defined as a period of at least fifteen consecutive days' none of which credited 0.2 mm or more of rainfall (Simons 1887).

It seems very difficult to formulate an applicable definition that can be used in central Sudan. However, work is going on to get to a working formula that meets conditions in Sudan.

3. Forests and forests interception of rain

Forests intercept rain. The process first starts in the upper parts of foliage, once these parts were saturated droplets drip downward, until the whole tree is saturated. Some water flows down the stem. If the rain lasted long enough then water drips to the ground below.

Interception is known to regulate the downflow of the rain to the ground in such a way to prevent floods. This, in addition to other forest influences like soil erosion was realized long times ago and strict laws that conserve forest were passed by many countries. During colonial periods most colonial authorities imposed such laws in Africa.

Unfortunately in many parts of Africa these laws seem to have been relaxed. The situation in Sudan is a very clear example. Trees felling for charcoal, mechanized farming and timber in addition to uncontrolled forest fires reduced our forest stands.

African region, north of the equator, gets its moisture from the south Atlantic Ocean and from the Indian Ocean. This maritime tropical airmass pushes its way slowly into Africa behind the intense surface warming during summer. In Sudan the process starts in March-April in the south and move slowly northward to reach as far as Lat. 20° N by August. The rainy season first starts in the south between March and April.

TABLE 1

R values calculated from normal annual temperature 1941-70 and P=annual normal rainfall in cm for the same period

Stations	P=normal rain	R (cm)	Climate according
El Fasher	28.3	79.4	Desert
El Obeid	38.6	81.8	,,
Edduеim	27.2	84.4	,,
Khartoum	16.5	85.2	,,
Medani	36.2	84.6	,,
Geneina	55.9	79.4	Semi--desert
Gedaref	57.9	85.0	,, ,,
Sennar	47.3	84.8	,, ,,
Kadugli	73.1	83.8	,, ,,
Malakal	78.7	83.8	,, ,,
Damazine	73.6	80.2	,, ,,

The first rain in the season usually falls over hot relatively dry, air. Occasionally rain evaporates into the air before reaching the ground.

In some trees the total leaves area may be as large as eight times the projected area under the tree. A small pine tree of even dry weight of 58.8 gm of which 41.6 gm were leaves intercepted 61 gm of water to get to saturation, *i.e.*, 147% of the even dry weight of its leaves (Grah & Wilson 1944).

Mitchel and Horton (1915) and Mitchel (1930) estimated that different trees can intercept 40-100% of rain less than 0.1 inch and between 10 & 40% rain more than 0.4 of an inch. Using these estimates to calculate interception of rain in station Wau in southern Sudan which was situated in forested area, the annual rain for the station is 1130 mm, it is estimated that 155.2 mm of rain is intercepted.

Since most rain in Africa is from convectional clouds it is usually intermittent in nature. The rainfall duration rarely exceed sixty minutes. The rain intercepted is efficiently evaporated back to lower atmosphere boundary layers.

This evaporation is especially efficient in early days of the rainy season where the air is drier and temperatures are high.

The airmass after crossing into mainland, moisture source is cut off. As it flows northward the moisture is depleted.

The evaporation from forests saturated with intercepted rain is assumed to be more efficient than from saturated ground surface. Therefore, forests in the path of air help the air to retain some of the moisture of the air

TABLE 2

Annual yield of the *White Nile* measured at Melut in Milliard cubic (m³)

Year	Yield	Year	Yield	Year	Yield
1950	29.7	1962	34.2	1974	32.7
1951	24.6	1963	38.2	1975	32.9
1952	24.4	1964	46.1	1976	33.5
1953	25.0	1965	48.6	1977	31.3
1954	26.9	1966	38.8	1978	32.7
1955	27.6	1967	36.3	1979	32.1
1956	29.8	1968	35.1	1980	31.5
1957	28.8	1969	34.2	1981	30.8
1958	25.5	1970	33.9	1982	28.2
1959	25.6	1971	35.5	1983	28.7
1960	25.4	1972	32.5		
1961	26.5	1973	30.0		

lost in rain to the surface, that is on top on other influences of forest. In this way forests not only enrich boundary layer moisture but also degrade sensible heat by the evaporation in the boundary layer too and this is very important.

This means that if an airmass is passing into inland Africa over forest stands it gets inland with more water vapour and less temperatures.

It is unfortunate that no records of how much forests stands were removed, are available. Moreover no work of which the author knows, has been done to estimate the interception capacities of different trees of the region. To get round these difficulties two sets of data were used. The meteorological data which is used to investigate any characteristics differences of the air mass as observed in Sudan. The other data set is the yield of the *White Nile* river which constitutes the main drainage for south Sudan and parts of equatorial Africa measured at station Melut (Table 2).

The most interesting observation from this table is the sudden increase in the yield of the *White Nile* from 1962 onwards. This increase shows a miximum record in 1965 of 48.6 milliard cubic metres and slowly decreased to a value of 28.7 milliard cubic metres in 1983. Only three stations at Juba, Malakal and Wau were continuously active in weather records during the period and for the purpose of the *White Nile* yield at Melut only two data sets of Juba and Wau are of concern.

One way to think of the yield increment could be the decrease in intercepted portion of rain that usually find its way back to atmosphere. However, it is felt more work need to be done in this field, the idea of forest influence seem to be a reasonable approach or at least one of the reasonable approaches. If a river yield is increased the rain in the catchment area is expected to be higher than usual.

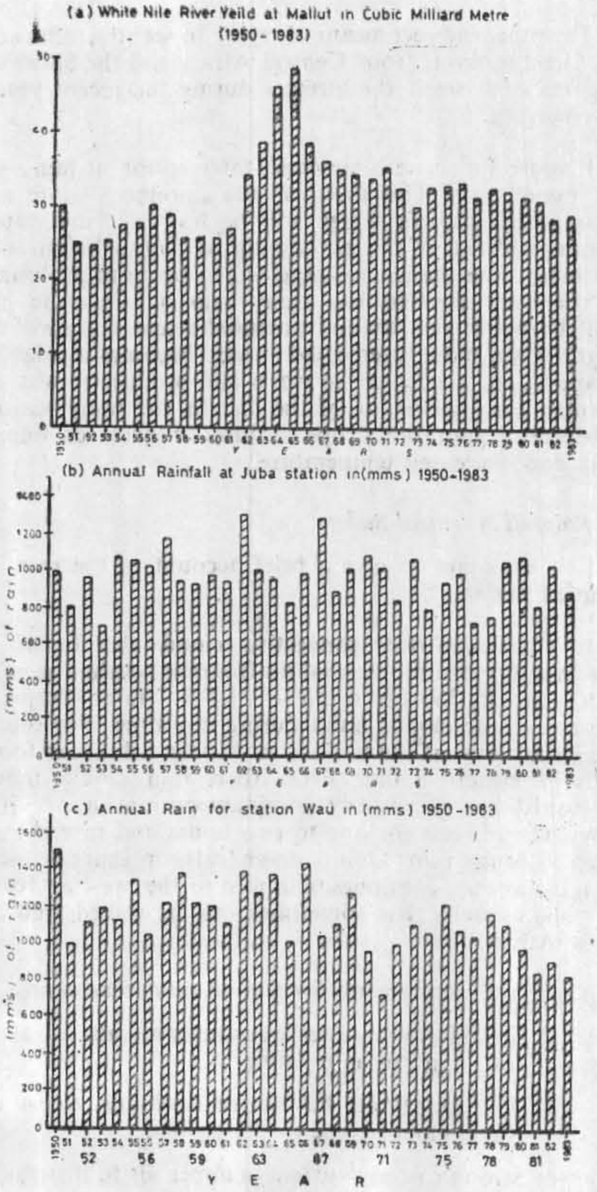

Fig. 1

However, if we look at the annual rain recorded at Juba and Wau for the year 1965 (Fig. 1) both stations recorded minimum rainfall. The relation of flood to total rain is certainly not a direct one it depends on so many factors mainly how rain was distributed and the rain intensities. However, if a high yield of the river coincides with minimum rainfall at two stations widely separated this may support the idea that this yield is related to forest clearance somewhere in the region.

If one looks carefully at the records of the *White Nile* yield at station Melut prior to 1962 fluctuations follow more or less fluctuations in rainfall records of stations Juba and Wau. From 1970 onwards rainfall records at both stations indicated some decrease yet the yield of the *White Nile* maintained relatively high levels.

Change in airmass characteristics in central Sudan

The other indirect means of trying to see the influence of forest removal from Central Africa and the Savanah regions is to see if the airmass during the recent years is changing.

If more forest were removed, interception of rain will be less efficient. This shows in the amounts of rain re-evaporated into air which will be less, *i.e.,* the water vapour contents of the air coming to central Sudan will decrease. The change are expected to be more profound in the early days of the rainy season, since the air will be warm and dry and potential evaporation will be high. When more intercepted water becomes available, evaporation is efficient to work and produce results of cooling and moistening of the air. As the rainy season advances evaporation drops because of increased humidity and decreased temperature.

Rainfall in central Sudan

It is impotant to give a brief account of the rain in central Sudan.

It is basically from convective clouds that forms in the humid moist monsoonal air from the south. The rain belt is usually 300 km south of I.T.F. (Inter Tropical Front). These clouds build during day time. For topographical reasons the build is more near Ethiopean foothills in eastern Sudan. From there rain clouds move westward by an easterly dominant current above 700 mb. Clouds last for one to two hours and in wake of each strong rain cloud downdrafts regenerate new rain cloud that continues with rain to the west in form of line squalls that sometimes can be traced well in west Africa.

The main requirements for a good rainy season are:

(a) Strong southwesterlies monsoons that advance as far north as possible.

(b) Monsoonal air has to be cool and moist to form clouds close to the ground.

(c) Strong easterly current in upper air to distribute rain, westward.

Intertropical front—This is the convergence zone where monsoonal westerlies meet with dry air mass from north and northeast. In winter, it is pushed south, in summer it advances north up to Lat. 22°N. When it advances north monsoonal westerly air is shallow south of I.T.F. and the advance is more like a cold front cutting under a warm air.

For this reason cloud can form 300 km south of the I.T.F. where monsoonal air is deep enough.

When it is pushed south the monsoonal air is usually deep enough just south of the I.T.F. and it is customary to get rainfall in the vicinity of the I.T.F. and sometimes north of it later in the rainy season.

The north advance of the I.T.F. is controlled by synoptic situations of the region but it is always secured where monsoonal air is cold an stable during season and southerly winds are strong.

TABLE 3

Differences in condensation levels (m) calculated for the months of the rainy season April-October for 1983 and 1953

Station	Apr	May	Jun	Jul	Aug	Sep	Oct
Kadugli	1,224	692	652	519	213	173	1,357
Malakal	1,809	155	386	306	160	200	519
Geneina	—	—	1,277	958	798	—	—
EL Fasher	—	—	811	1,170	1,942	745	—
EL Nuhud	—	1,649	1,423	399	133	160	—
El Obeid	—	1,104	399	412	505	—	—
Kosti	—	—	305	625	612	495	426
Khartoum	—	—	296	878	1,543	1,623	1,144
Gedaref	—	—	518	599	176	27	40
Kassala	—	—	150	120	785	452	173

4. The rainy season of central Sudan

The rainy season starts in the southern provinces of Sudan around March and April. At that time the I.T.F. is around 10°N latitude.

Areas upto Lat. 20°N receive rain in August and September where the I.T.F. can advance as far as Lat. 22°N. By the beginning of November the I.T.F. is pushed out of the country. The I.T.F. advance takes about six months while in two months it is pushed south. While the rainy season in the northern parts lasts for less than two months, in the south it is more than eight months, lasting from mid-march to November.

5. Temperature and dew point changes in central Sudan

To prove any change in the air temperature and humidity of monsoonal air mass during the rainy season records of 1953 and 1983 were taken. 1953 is taken to represent the times when trees cover over central Africa was preserved, 1983 to represent recent years when drought grip over Africa is very noticeable.

The best time of observation where readings can be most representative is observations at 1200 GMT.

At this time of the day the air is well mixed and any influence of surface conditions will be minimum, the values of the dew point are usually in their minimum. The factor $(T—T_d)$ where T is the surface temperature and T_d is the surface dew point is a direct relation of the cloud base of cumulus and thunderstrom clouds. The cloud base is controlled by condensation level $h \alpha (T—T_d)$. The constant of proportionality is the lapse rate. If we assume that lapse rate for 1953 and 1983 are not significantly different, then a positive change in h in 1983 will mean a high cloud base.

In Table 3 changes in height of condensation level calculated from the relation $(T—T_d)$ are given for 10 stations in central Sudan across the country from Geneina in the west to Gedaref in the east and from Malakal at about latitude 10°N to Khartoum in the fringe of the desert region.

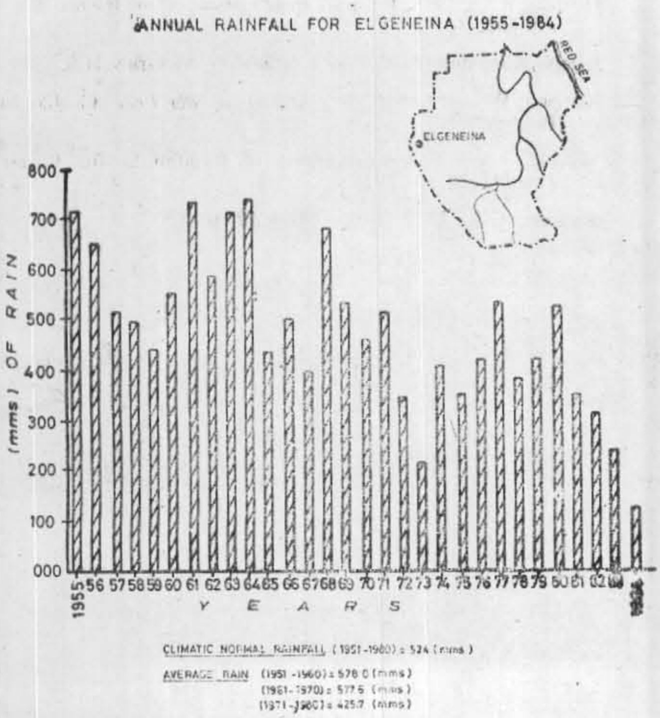

Fig. 2. Annual rainfall for Elgeneina (1955-1984)

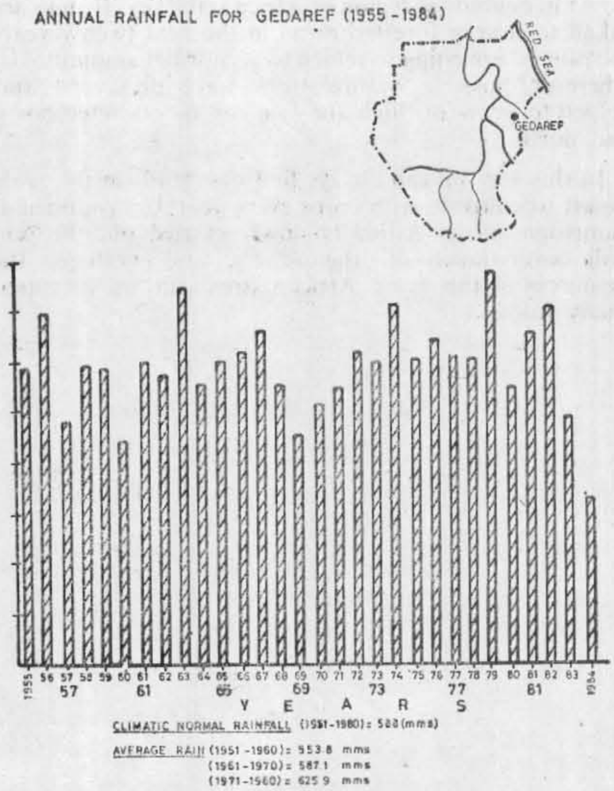

Fig. 3. Annual rainfall for Gedaref (1955-1984)

For the whole period of the rainy season from April to October differences in condensation level of 1983 and 1953 are given in Table 3. Positive values give high condensational level in 1983. Only those months for which in both years the flow of air is monsoonal were taken. A dash indicates that in one year or both years the prevailing wind is not predominently monsoonal.

From Table 3, the following can be deduced :

At all stations the condensation level in 1983 has lifted compared to 1953.

The lift is maximum in the first month of the rainy season and decreases after that.

These observations reveal where drought is rooted. The airmass coming year after year is getting drier. Cumulus clouds are not forming in regions used to enjoy rain, if they form they are too high to produce rain and if they rain only a small portion of that rain can reach to the ground.

However, there is another effect produced by the warming in the lower layer of the monsoonal airmass due to reduced evaporation because of forest clearing. This effect is two folds: firstly the air south of the I.T.F. in the monsoonal westerlies will be less stable and atmospheric pressure will be reduced due to this warming. This result in weak monsoon and I.T.F. can not advance north.

Secondly during the rainy season the Sahara desert of north Africa is very hot compared to the temperatures of the monsoonal air in the rainy areas. The horizontal temperature gradient that exist across Africa between the rain belt and the Sahara generates the upper easterlies in the troposphere above 700 mb level in an effect similar to the thermal wind of the westerlies in temperate latitudes. When more warming in the rain belt exist this reduce the horizontal temperature gradient at the surface and thus the upper easterly flow.

When the easterly flow is slowed rain clouds that generate in the east at Ethiopian hills stay there most of the time. This will have effect on the western regions of the Sudan which are the first deprived region of its rain, while eastern region enjoys usual rain and even more than usual rain. This is clearly seen from records of stations Geneina in the west (Fig. 2) where during the last twenty years the rain is decreasing steadily while at Gedaref the annual rainfall shows an increment in the same period (Fig. 3).

However, this additional yield in rain is not lasting and will be dry with the south movement of the rain belt. The same effect can be noticed in annual rainfall records of El Fasher and Wad Medani but less marked.

6. Conclusions

The continuous drought of African Sahel is caused primarily by felling of tropical trees to the south of it in the path of the humid rainy airmass.

To check further drought incidents preservation of forest in equatorial region of Africa is the key. If steps are taken to restore forested areas in the next twenty years the rain is sure going to return to its normal amounts. If, wherever, possible natural trees were preserved and helped to grow up high the rain can be attracted north and north.

In this way we can always find new lands in the wide desert to cultivate with crops every year. If a continental campaign across Africa is slowly carried out the rain will cover much of the Sahara and perhaps the resources of the poor African area can be increased many folds.

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