TRENDS AND VARIATIONS OF SOME CLIMATIC ELEMENTS AT THREE STATIONS IN ADDIS ABABA

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ABSTRACT

The paper is organized into six chapters. The first and the second chapters deal with introductory discussions like specific objectives, justification and rationale, data sources and methodology and review of related literature. The third, fourth and fifth chapters are analysis of surface wind speed and direction, temperature and rainfall patterns whereas the sixth chapter is a summary of the findings and recommendations.

The paper discusses the three climatic elements of winds, temperature and rainfall at three stations in Addis Ababa. The decadal, monthly and seasonal variations of these elements at the three stations are examined. Some techniques of time series analysis have been employed to see some identifiable trends of the three climatic elements over time.

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CHAPTER I

INTRODUCTION

1. THE PROBLEM

A number of authors, as will be discussed in the next chapter, have written on rainfall, winds and temperature at Addis Ababa. Some of them, such as Wood (1979) and Gizaw Attlee (1965) have used long-term climatic data of 74 and 37 years respectively. The core of their study, however, probably with the exception of Gizaw Attlee, was not to analyse the climate of Addis Ababa. In most cases, the writers included Addis Ababa in their studies when in the main their intention was to describe the climate of Ethipia since Addis Ababa is one of the climatic stations with adequate climatic data.

Inspite of the use of long term records however, these authors had rarely dealt with more than one climatic element. Moreover, none of the authors had tried to examine the variations of these climatic elements over time. With the exception of Suzuki (1967), who examined the daily rainfall patterns at Addis Ababa, the scale of categorization by most authors has been on monthly or seasonal basis. This scale of categorization is obviously not useful for agricultural purposes where, in the case of rainfall, even five to ten days of "dry" period can impair the growth of crops, especially at an early stage.[1]

Therefore, such questions as which decades of each month are relatively dry or rainy and at what decade of the first month of a rainy period rain commences have to be answered. Also the relative variability of rainfall at the onset, advnce, retreat and end of the rainy period, the possible d rection of change which rainfall, temperature and winds could assume over time at Addis Ababa have not yet been studied. This study is an attempt to fill this gap by analysing and explaining the general pattern and variation of rainfall, temperature and winds at three stations in Addis Ababa.

2. OBJECTIVES OF THE STUDY

The specific objectives of this study are as follows.

1. To find out if there is any identif rainfall, temperature and surfac wind speed trends at the three stations in Addis Ababa over the years for which reliable data are available by examining the daily records for the three elements at the three climatic stations of Bole, Arat Kilo (Geophysical abservatory) and national Meteorological services Agency(A.A. Observatory).
2. To find out the time of the onset, advance, retreat and cessation of rainfall at the three stations and the similarities or differences among them. This analysis will inturn lead to the identification of the time of the arrival, persistence and retreat of seasonal winds over the three stations in Addis Ababa.

3. To find out the decadal, monthly and seasnal rainfall variability at the three climatic stations in Addis Ababa and their similarities or differences.

4. To find out the diurnal surface wind patterns in each month and seasonal variation of surface wind speed and direction at Bole and at A.A. observatory, the two stations for which wind speed data are available and the similarities or differences between them.

5. To find out the decadal, monthly and seasonal temperature patterns at the three stations and the similarities or differences among them.

3. JUSTIFICATION AND RATIONALE

Since rainfed agricultural activities are highly affected by climatic conditions and Ethiopia depends heavily on the agricultural sector of the economy, especially on rainfed agriculture, a knowledge of the degree of vulnerability of rainfed agriculture to the effects of "climatic" fluctuations" is obviously essential to plan agricultural development.

The need for the preparation of fields in the rural areas just before the onset of the rains, for example, requires some prior knowledge about the start of the rains. Farmers have to be sure that the rainy period has started before they sow their seeds. The problem often encountered in other East African countries is the fact that rainfall variability is in general high and becomes even more higher at the time of the onset or cessation of the rains.[2] Thus an occurrence of rainfall may be followed by dry spells but the farmer may be misled in believing that the rainy season has started. In other words, the farmer, assuming that the rains have started, may sow his seeds while in reality the rains have not yet started, at least in adequate amounts to start sowing. A high rainfall variability at the time of the cessation of the rains can also result in crop damage by disturbing the period of harvest.

An understanding of the rainfall, temperature and wind variations and their trends is necessary to plan and make the necessary adjustments not only in agricultural activities but also in various spheres of life. These include such simple domestic activities as the washing and the spreading of clothes and the more sophisticated industrial activities like cement production.

This study will, therefore, contribute towards the planning of agricultural activities around Addis Ababa as well as other weather-dependent economic activities within the city.

4. DATA SOURCES

For the purpose of this study, daily rainfall and temperature(maximum and minimum) data for as many years of complete recored as available were obtained from the three climatic stations in Addis Ababa. These are the Geophysical Observatory at the Arat Kilo Science Faculty, the Addis Ababa Observatory of the National Meteorological Services Agency near the Black Lion Hospital and the Addis Ababa Bole Airport. Monthly data at 0600, 1200 and 1800 hrs on windspeed and direction could only be obtained from the Addis Ababa Observatory and Addis Ababa Bole Airport. The number of years of record for each element and at each station on the data gathered for this study is shown in Table I

Table I Number of Years of Record For Each Element At EAch Esation

Station	Rainfall (mm)		Temperature(^{0}C)		Sur. Win.(at2m)	
	Time Coverage	Total No. of yrs.	Time Coverage	Total No. of yrs.	Time Coverage	Total No. of yrs.
Geophysical Observatory	1957-1980	24	1959-1980	22	-	-
A.A Obser-atory	1952-1980	29	1958-1980	23	1951-1980	30
A.A. Bole	1964-1080	17	1964-1980	17	1964-1980	17

The wind speed data for Bole was recorded at the control tower of the airport which is 10 meters above the ground. The wind speed data at Addis Ababa Observatory is at 2 meters. The Bole wind speed data was reduced to speeds at 2 meters by using a correction factor of 0.78 as suggested by J.S.G. McCulloch.[3]

As can be seen in the table (Table I), the total number of years of record at the three stations is not the same. This affects the comparability of the three stations; and it is with this understanding that the stations must be compared.

Data from other sources have not been used in this study. For example, the temperature data(from 1901-11+1924+1929-30+ 1937-40), wind data(from 1937-38-39-40) and rainfall data (from 1900-1940) recorded at $9^{0}02'00''$ N and $38^{0}45'00''$ E at a height of 2450 m. above sea level(The writer suspects this station to be at the Italian Embassy) summarized by Fantoli (1965) were not used mainly because (a) the rainfall data given only on monthly basis doesn't allow treatment of the data on decadal basis. (b) the temporal gap(1940-1952) when there has not been any data at the same station will still remain unknown and still give incomplete picture. (c) there has not been any information as to how(i.e. recording interval,heights of instruments etc.) these climatic elements were recorded. (d) the National Meteorological Services Agency does not give these data as data of one of the stations in Addis Ababa perhaps due to reliability problems.

There are temperature and rainfall records of different periods and different duration, mostly not exceeding ten years in Addis Ababa at some schools such as Teferi Makonnen, General Wingate, St. Joseph and Medhanealem documented at the National Meteorological Services Agancy. These have not been used in this study because, among other things, data for several months(4 to 6 months) are often missing and there are no records for a number of years. The climatic reocrds at these stations are in general incomplete, discontinuous and are of short periods.

5. METHODOLOGY

The daily rainfall amounts and the daily maximum,minimum and mean temperatures for the three climatic stations gathered for the purpose of this study were summarized by decade for each month. Further analysis of the data were then made based on these decadal values.* Wind speed and direction data made available at Addis Ababa Observatory and at Bole were only monthly recordings at 0600,1200 and 1800 hours.

The wind speed data at 0600,1200 and 1800 hours were averaged to get the monthly speed of surgace winds.

Data gathered on surface wind frequencies from different directions were tallied, tabulated and the frequency percentage contribution of each direction in a given month was calculated to draw the wind flow diagram which shows the relative prevalence of surface winds coming from each direction at the different times of the year.

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* The first decade of a month refers to days 1 to 10, the second to 11 to 20, and the third decade to 21 to the last day of the month.

A wind flow diagram is an isopleth diagram drawn on a table of percentage frequency of winds from each direction and for each month at a particular station. Gehrke (1944) studied the pattern of wind flow at Washington D.C. and found out that this method is preferable to other methods of studying wind flow like wind roses.[4] As Gehrke did in the case of Washington D.C., the prevailing directions were written horizontally and the months vertically. The percentage frequencies were written in their respective directions and months during which they occurred. Isolines were then drawn over the numbers at intervals convenient for drawing. Where a single direction prevails by a high frequency, a wider interval(10% in the case of this study) should be used to prevent the crowding of lines. The diagram is finalized by shading various intensities according to a scale of density to emphasize the gradiation values.

In an attempt at showing possible identifiable trend variation over time of the three elements of temperature, wind speed and rainfall, some of the various techniques of time series analyses like semi-average methods, running mean methods and the least squares method[5] have been adopted.

The semi-average method is a method where the available data is split into equal parts and where the figures in each half are averaged. The averages thus obtained are plotted at the center of their respective periods and a straight line is drawn through the two points. The running mean(moving averages) method is a series of successive averages secured from a series of figures by grouping a number of figures and obtaining the group average. The first figure in each group is dropped and the next figure in the series of figures is included to get the next average. The least squares method may be stated as

$$y = a + bx$$

where y represents the variable in question

a represents the average intercept on the vertical axis

*b represents the rate of change (increase or decrease) per x

x represents the time expressed in years.

The rainfall coefficient approach and the ogive curve model have been employed when examining the seasonality of rainfall at Addis Ababa and each one of these methods has revealed some patterns of rainfall seasonality at varying levels of accuracy.

The rainfall coefficient approach (R.C.) is an approach where the yaar is divided into dry periods and rainy periods by using rainfall coefficient values obtained by dividing the

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* The statistical significance of the rate of change was tested by the use of the student t distribution test. To do this the variance(r^2), the correlation of the variable with time (R), the standard error of b(the rate of change) and t were calculated.

mean monthly rainfall by one-twelfth of the annual mean.[6] Once the rainfall coefficients are obtained the classification is made on the following.

Designation	Rainfall coefficient
Dry month	less than 0.6
Rainy month	0.6 and over
Small rains	0.6 to 0.9
Big rains	1.0 and over
Moderate concentration	1.0 to 1.9
High concentration	2.0 to 2.9
Very high concentration	3.0 and above

The ogive curve approach which is supposed to indicate the onset, advance, retreat and cessation of rainfall,is constructed in the following procedure. a) Ten day means of rainfall were computed b) The percentage of the mean annual rainfall that occurred at each ten-day interval for every station was dervied c) The computed percentages at ten-day interval were accumulated d) The cumulative percentages at ten-day intervals were plotted through the year e) The time of onset of rainfall is identified at the first point of maximum curvature on the plotted graph. f)Advance of rainfall is established by the subsequent spells of heavy rainfall g) The retreat of rainfall is derived from the slope of the cumulative percentage graph of ten-day rainfall, The period of rainfall retreat coincides with the point on the graph at which the rate of increase of cumulated annual rainfall decelerates.[7]

Inorder to see the relative variability of rainfall, simple percentages and coefficient of variations have been used. Coefficient of variations are formulated as

$$C.V.(\%) = \frac{\sigma}{\bar{x}} \times 100$$

Where C.V.(%) = coefficient of variation expressed in percent.

σ = standard deviation

$\bar{x}$ = mean

Since the variation of temperatures is not as great as rainfall, the use of simple arithmetic mean is employed to reflect the reality.

CHAPTER II

Review of Related Literature

1. GENERAL INTRODUCTION

Addis Ababa is located on the Shewan Plateau which is a physiographic region in the centre of Ethiopia. The plateau is the least dissected physiographic region of the country. The Abay(Blue Nile) River system, the Omo and the Awash river systems cut deep gorges on the northern, western and southern sides of the plateau. The flat central table land of the plateau where Addis Ababa is located can be assumed to have a relatively more homogenous climatic condition than the rest of the highly dissececed parts of its edges.

The part of the Shewan Plateau where Addis Ababa is located ranges in height from about 2,333 m. at Addis Ababa Bole Airport, the southern part of the city, to approximately 2979m.[8] on Entoto Mountains which form the northern boundary of the city.[9] To the west of the city, Mt. Wachacha rises approximately to a height of 3,353 m; to the south are found a number of hills of smaller heights than Wachacha; and on the southeast Mt. Yerer rises to the height of Entoto.[10]

According to the information obtained from the two stations, Addis Ababa Observatory (2408 m. above sea level) is located almost at the center of the city, at $09^{\circ}\ 01'$N and $38^{\circ}44'$ E while the Geophysical Observatory (2442.5m) situated on the northeastern part of the city is found roughly at $09^{o}02'$N latitude and $38^{o}45'$ E longitude.

Most writers on the climate of Ethiopia have included Addis Ababa in their studies not only because of its central, and therefore representative location but also mainly because Addis Ababa is one of the few stations with adequate climatic data in the country. However, no author, as far as is known to this writer, has studied the climate of Addis Ababa as such. What follows, therefore, is a summary of available literature on the climate of Addis Ababa which also deal with other climatic stations in the other parts of the country. The review is limited to asmospheric circulation and winds in general and to what is written on the rainfall and temperature conditions which are relevant to this study.

2. ATMOSPHERIC CIRCULATION AND SEASONAL WINDS

Seasonalities in the climate of Addis Ababa is mainly due to the influence of the dry tropical air masses coming from the northeast in the dry season and the moist equatorial air streams from the southwest during the wet season. The Sudan and Arabian anti-cyclones in the north and the cyclonic center in Central Africa in the south determine the pattern of air circulation over Addis Ababa Region in the period between October to May.[10] In addition to the influence of the surface tropical air masses both from the south and north at alternate seasons the cold temperate westerlies joining the warm easterlies form

ADDIS ABABA

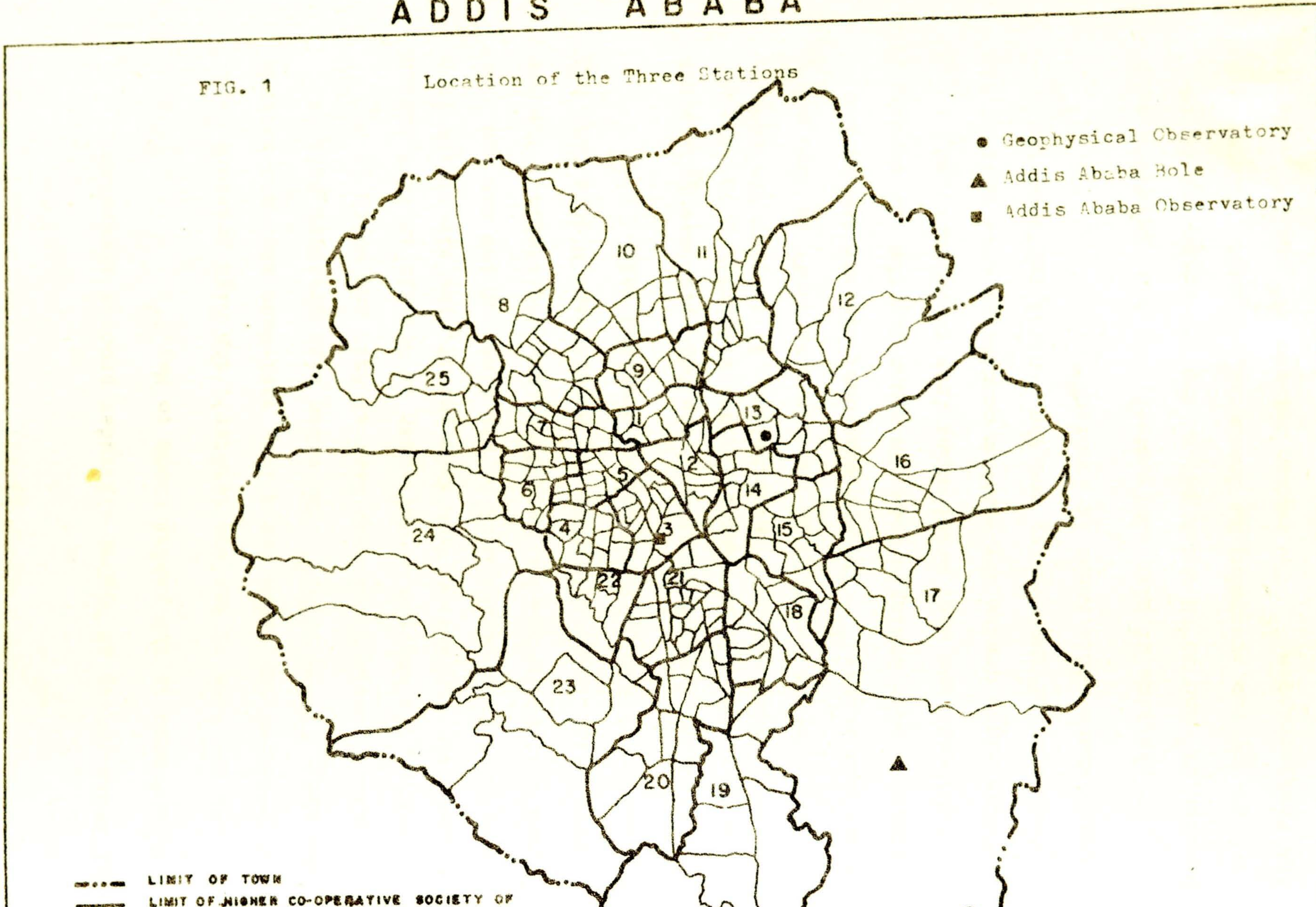


FIG. 1 Location of the Three Stations

the Indian Ocean at higher altitudes produce irregular thunderstorms in the period March to May.[12]

At the time of low sun (winter), the high pressure cell that overlies the Sudan has a long east-west axis and extends form about 27° to 30°N.[13] The other high pressure cell is the Arabian anticyclons over Central Asia and which is N-S oriented and elongated as far south as Somalia in East Africa. As Trewartja amd Kebede Tato have put it, the air stream from the Sudan high pressure cell at the time of low sun has had a land trajectory and is, therefore, dry and stable. The air current which originates from the Arabian and Middle East high pressure cell has again mainly an overland path.

Because of the extension of the high pressure cell southwards up to Somalia in winter, it has evidently a sea trajectory of a short lenght. Nevertheless, it is only the surface air which can be moist while the air mass aloft is dry, subsident and stable.[14] The dry subsident air streams moving southwards over Ethiopia from the Sudan and the air streams from the northeast and east originating from theArabian and Siberian Highs create dry weather conditions over most of the western half of the country and the central parts of the country where Addis Ababa is located.

At the time of high sun(summer), the high pressure cell between 27° and 30° N which had a long E-W extension at the time of low sun according to Trewartha, retreats polewords the Mediterranean.[15] The region between 20° and 22° develops an extensive E-W oriented low pressure cell over the Sahara and the Sudan.[16] The latitudinal location of the low pressure center, according to Gizaw Attlee(1965) approaches Addis Ababa(9^{o}N). Consequently air currents north of these low pressure cells flow in anticyclonic direction characterized by subsidence and dry weather. The air streams that come from the south are warm and moist. These air streams according to Trewartha, originate from the South Atlantic Ocean to produce the maximum amount of rainfall over the region. In addition to the convergence and convective instability, the intensive heating of the high plateauland where Addis Ababa is found is another cause of a significant proportion of the rainfall.[17]

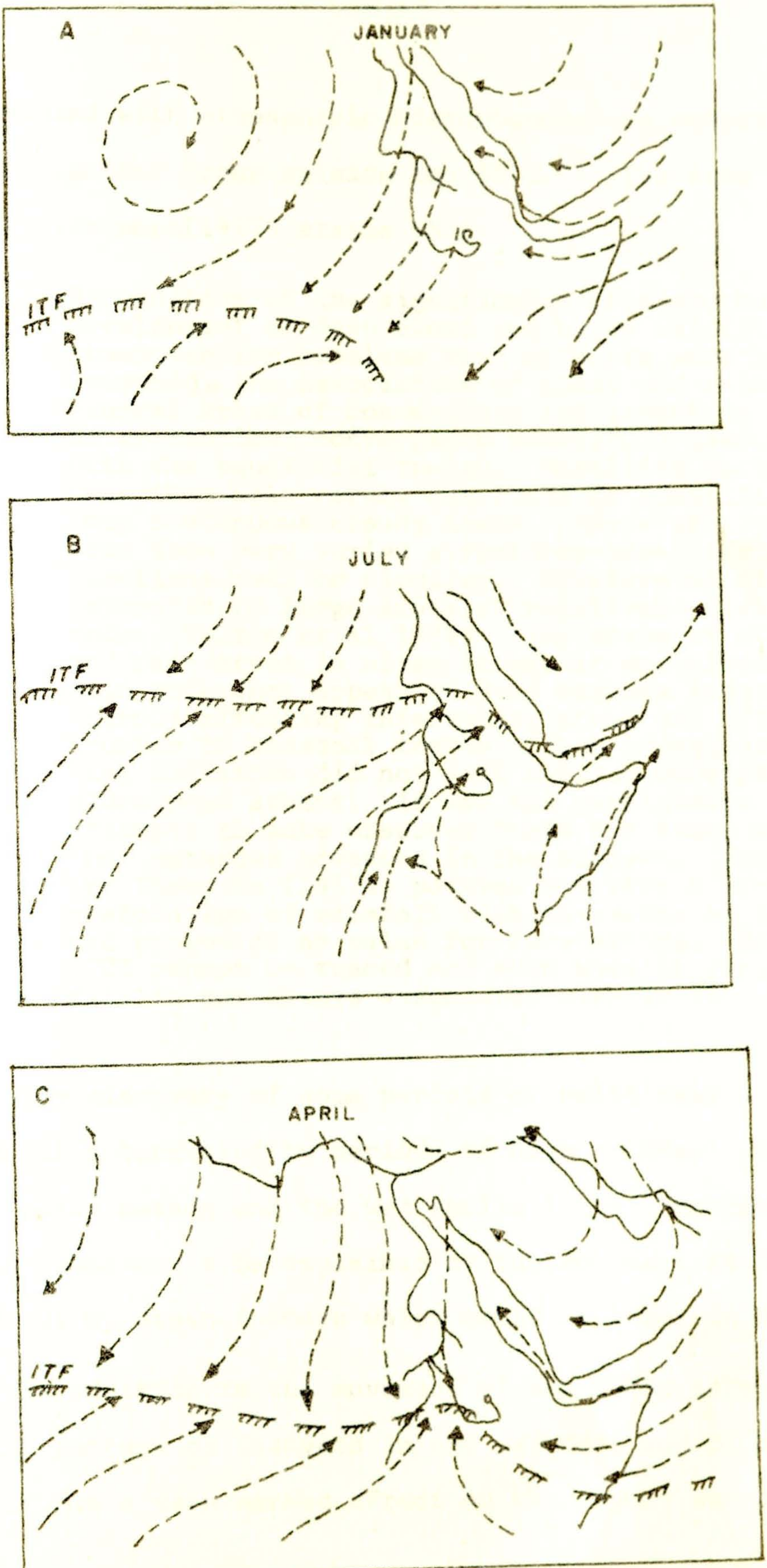
Interrupted by the periods of high sun and low sun are two transitional periods (Spring & Autumn) which are created by either the development of cyclonic cells over the Sudan and Arabia or by the progressive disintegration of these low pressure cells.

In Autumn, the low pressure centere gradually weaken with the southward movement of the sun and a high pressure cell which according to Gizaw Attlee extends a tongue towards the Ethiopian high ground develops in the period October to February.[18] At this same transitional period occasional cold burst from north temperate latitudes penetrate south and pass over the sub-tropical high pressure belts and the upper parts are usually carried away to the east by the upper westerlies before reaching the low latitudes.[19] Whenever this front cucceeds in reaching the Ethiopian Highlands, according to Kebede Tato, it produces a moderate temperate region climate and becomes a cold front aloft although its effects on the surface are not clearly marked.[20] The southeast air stream that originates from the Arabian anti-cyclones, being warm and moist due to its short sea trajectory yields usually scattered and showery type of precipitation over Addis Ababa but mainly over the Eastern Highlands.

The small rainy period (spring) (March to May) coincides according to Griffiths, with a dimunition of the Arabian high as it moves towards the Indian Ocean.[21] This then causes warm and moist air with a southerly component to flow over the southern half of the country without very much affecting the rainfall at Addis Ababa.

Generally, the prevailing air streams over Ethiopia in general and over Addis Ababa in particular advance and retreat seasonally following the seasonal shift of the ITCZ; and the wet and dry periods are closely linked to this shift of the ITCZ. But all rainfall occurrences can't be explained only by the ITCZ. There are many other factors that affect the 'wet' and 'dry' periods of a region. Jackson (1968) states that on a daily basis, even when it is possible to detect the ITCZ, on many occassions rainfall is not found there, but a longway away. Other more local areas of convergence,perhaps

Fig. 2. APPROXIMATE DIRECTIONS OF SURFACE WINDS AND THE POSITION OF ITF AT DIFFERENT TIME OF THE YEAR



A.A 1965 pp 4—7

associated with atmospheric disturbances are responsible for rainfalls that occur outside the ITCZ.[22] The same author in his latter work(1977) states that

> Recognition of the significance of disturbances in the development of deep cloud and heavy rainfall overcomes earlier problems when attempts were made to reconcile the association of cloud and rain with general areas of convergence and ascent in an inter-tropical convergence zone(ITCZ) associated with the equatorial trough. Satellite photographs show that only rarely can ITCZs be identified as long continuous cloudy areas. Areas of cloud and rain show very varied structures-sometimes linear, sometimes oval or circular. Clusters of clouds separated by large areas of relatively clear skies occur (Holton et al 1971). The movement of cloud and rain areas is often irregualr and clouds and rain sometimes appear to jump between locations without affecting intervening areas and often run counter to seasonal trends. Such irregular space-time variation did not suit earlier concepts of widespread ascent. It was the persistence with attempts to make observed facts fit these concepts that retarded advances in the subject. Many years ago Thompson (1957a) pointed out that a simple association of rainfall with movements of the ITCZ had proved of no value for forecasting. Often the ITCZ cannot be traced and even when it can,rainfall is not always associated with it.[23]

Suzuki's discovery of some periods of relatively low amount of rainfall interrupted by periods of high rainfall within the main rainy season and the wet spells in the dry season at Addis Ababa can't be explained by the movement of the ITCZ only but by other factors which could be local in nature.

In addition to the movement of the ITCZ, as ca in the pattern of isohyets in any rainfall map of Et relief has a very marked effect on the amount and dis of rainfall. Moreover, the highlands around Addis Ababa are aligned to the air flow to trigger of instability in the air mass and to contribute to the increase of rainfall over the area.

3. WIND SPEEDS OVER ADDIS ABABA

The wind patterns at the Airport according to their speed and direction were briefly examined by Gizaw Attlee(1965). He tried to see the patterns at four different levels; at the surface i.e. at 10m.above the ground: at 3048 m. (10,000ft) above mean sea level; at 4267 m.(14000ft.) and at 5486 m. (18000ft.) above mean sea level.

In the period December to February, the surface winds (at 10m. above the ground) were found to blow mainly from the SE direction at a speed of less than 2.6 m/sec. At 3048 m. above sea level, the prevailing winds are easterly winds at a speed of 7.7 m/sec. to 10.3 m/sec. Those winds blowing at 4267 m. above sea level are mainly NE or E winds at a velocity ranging from 5.2 m/sec. to 10.3m/sec; whereas the easterly winds blowing at a speed of 7.7. m/sec to 10.3m/sec.prevail at a height of 5486 m. above mean sea level. In spring (March to May), the southeast and south winds at a speed of less than 2.6m/sec. are common at the surface (at 10m. above the ground).

4. SEASONALITY OF RAINFALL AND TEMPERATURE CONDITIONS

According to Kebede Tato(1964) the rainy season in the "Central Highlands" of Ethiopia, Shewa, Wello, Gojjam, Gonder and Northern Wellega, extends from June to September, a period when 70 to 85% of the total annual rainfall occurs. He states that in these regions the "dry" period is from October to March and the "small rainy season" of spring is from April to May.

Gizaw Attlee(1965) has attempted to analyse the weather and climatic conditions of Addis Ababa in more detail. Although the basis of his demarcation is not clear, he classifies the period March to May as a period of the "small rains" of spring; and with an exception of a short dry spell in early June, the rainy season extends from June to September. Based on 37 years of rainfall data at Addis Ababa he wrote that November is the driest month with an average monthly rainfall of 1.9mm. while July and August are the rainiest months with monthly averages of 258 and 260 mm. respectively. The daily rainfall of the small rainy period is usually between 0.2 and 0.9 mm. whereas daily rainfall amounts ranging from 1.0 to 9.9 mm. are common in the main rainy season.

Suzuki(1967), using daily rainfall data from 1959 to 1965, found the following pattern of seasonal rainfall distribution in Addis Ababa.

Rain Period I - 2^{nd} decade of March to the 2^{nd} decade of May.

" " II - 3^{rd} decade of May to the 2^{nd} decade of October.

" " III - 2^{nd} decade of November to the 1^{st} decade of December.

The above show the lack of uniformity among the three authors in their scheme of classification of rainfall periods and in the delimitation of the beginning and the end of each period. The differences may be summarized as follows.

Table II Classification of the Year Different Authors

Author	Main Rainy Season	Small Rainy Season	Dry Season
Kebede Tato	June - September	April & May	October- March
Gizaw Atllee	June - September	March - May	October-February
*Hideo-Suzuki	June - October	March - May Nov. & Dec.	January & February

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* The table shows a generalized form of suzuki's findings. He has identified a lot of short dry spells in the rainy periods and wet spells in the dry periods.

The disagrement among the studies of the three authors might have originated either from the use of data collected at different times with varying accuracy or from the use of different methods of treating or processing the data.

Gizaw Attlee(1965) has also attempted to analyse temperature conditions at Addis Ababa. He states that the average annual temperature of the city varies between 16°C and 18°C. The average annual temperature of the city as reported in the works of Daniel Gamachu(1977) and Mesfin W/Mariam(1972) is 16.3°C. When talking about the seasonal patterns of temperature, Gizaw Attlee says that the period before the onset of the main rainy season(the months of April and May in particular) is the warmest period of the year while the period November to December experiences the lowest temperatures of the year. The average monthly maximum temperatures are 24°C to 26°C whereas the average minimum monthly temperatures are 8 to 10°C. The author goes on to mention the occurrence of cold nights in December and in January with temperatures 0°C to 2°C below zero.

CHAPTER III

SURFACE WINDS AT ADDIS ABABA

1. GENERAL

The understanding of the most prevalent surface winds is important in that it gives a basis for the selection of settlement sites, for windbreak and runway constructions, for orienting buildings and for deciding the location of windows, etc.[24] The speed component of the surface winds together with frequency lead, to a better understanding and to a relatively more reliable decision-making in many practical aspects of life. A general increase in the morning and evening wind speed means, an increased dynamic convection which mixes up the various layers of air. The mixing process in turn minimizes ground temperature inversion and the risk of frost. As Geiger states states "the farmer is not afraid of frost when there is wind, but he is if the wind descends with the sun"[25]

This chapter is the analysis of the daily and seasonal variation in the direction and speed of the surface air flow at 2 meters elevation at Bole and at Addis Ababa Observatory in Addis Ababa. The speed of the surface winds given in knots in the original data has been converted into meters per second (m/sec.)*

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* 1 Knot = 0.515 m/sec.

The surface wind speed observations were then ecatagorized into the following speed groupings.

Speed (Knots)	Speed (m/sec)
< 1	< 0.5
1.0 - 3.9	0.5 - 2.0
4.0 - 6.9	2.1 - 3.5
7.0 -10.9	3.6 - 5.6
11.0 -15.9	5.7 - 8.1
16.0 -20.9	5.7 - 8.1

Surface winds flowing at a speed of less than 0.5 m/sec. have been considered as calms.

2. VARIATIONS IN SURFACE WIND DIRECTIONS

2.1. Monthly Sirface Wind Directions at 0600,1200 and 1800 Hours, Table III shows the monthly prevailing surface wind directions at Addis Ababa Observatory and at Addis Ababa Bole. If no data was missing the total records of the prevailing directions at the Addis Ababa Observatory (from 1951-1980) would be 1080 while that of A.A. Bole (from 1964-1980) would add up to 612. But the available data indicates that in the period 1951-1980 a total of 967 surface wind observations were recorded while at Bole the total surface wind observations from 1964-1980 add up to 585.

The calms all occurred in the morning hours (at 0600hrs) at both stations. These calm conditions account for 12.5% of the total recorded absevations at Addis Ababa Observatory, whereas at Bole they constitute only 2% of the 585 recorded observations. The remaining 87.5% (846) of the surface wind o observations recorded at Addis Ababa Observatory and 98% of the recorded observations at Bole indicated an air flow at a speed of 0.5 m/sec. and above.

Table III Monthly Prevailing Surface Wind Directions at Addis Ababa Observatory & Bole at 0600, 1200 & 1800 hrs.

Station	Time	N	NE	E	SE	S	SW	W	NW	Total	%
A. A. Observa-tory	0600 hrs	22	6	57	0	11	1	8	30	135	16.0
	%	16.3	4.4	42.2	-	8.1	0.7	5.9	22.2	100.0	
	1200 hrs	16	16	170	36	84	16	9	1	348	41.1
	%	4.6	4.6	48.9	10.3	24.1	4.6	2.6	0.3	100.0	
	1800 hrs	22	52	182	28	22	8	11	38	363	42.9
	%	6.1	14.3	50.1	7.7	6.1	2.2	3.0	10.5	100.0	
	Total	60	74	409	64	117	25	28	69	846	99.9
	%	7.1	8.7	48.3	7.6	13.8	3.0	3.3	8.2	100.0	
A. A Bole	0600 hrs	22	13	71	2	1	1	17	47	184	32.1
	%	12.0	7.1	38.6	1.1	0.5	0.5	14.7	25.5	100	
	1200 hrs	0	0	88	36	37	25	8	0	194	33.8
	%	-	-	45.4	18.6	19.1	12.9	4.1	-	100.1	
	1800hrs	1	0	117	34	5	3	16	20	196	34.1
	%	0.5	-	59.7	17.3	2.6	1.5	8.2	10.2	100	
	Total	23	13	276	72	43	29	51	67	574	100.0
	%	4.0	2.3	48.1	12.5	7.5	5.1	8.9	11.7	100.1	

As can be seen from the table (Table III) the eastern northeastern and the western surface winds show a progressive increase in their frequency towards the evening at Addis Ababa Observatory whereas at Bole the increasingly occurring surface wind towards the evening are the easterlies only.

In the morning hours(at 0600 hrs) the northwesterlies, next to the easterlies are important at both stations while at midday (1200 hrs) the southeast and south winds begin to gain importance at the two stations. In the evenings, however, the two stations seem to differ from each other significantly. Other than the easterlies, the northeast, the northwest, the southeast, the south and north surface winds account for a reasonable proportion of the total surface wind occurrences in the evening at Addis Ababa Observatory. In the case of Bole, however, next to the easterlies, the southeast, the northwest and the west are the most prevailing directions in the evening hours.

The same table (Table III) shows that certain prevailing directions like the north, the northeast and northwest do not occur especially at midday at Bole. The prevalence of surface air flow from limited directions over Bole than over Addis Ababa Observatory found in the middle of the city, may indicate the diverting effects of the urban physical structures on the prevailing surface wind directions. Nonetheless, the easterly surface winds are the most prominent winds at both stations throughout the day inspite of the various structures (buildings, pillars etc.) that could affect the direction of winds at Addis Ababa Observatory.

2.2. Seasonal Surface Wind Directions. The seasonal surface wind variations as shown in Figs. 3 & 4 prepared on the basis of Tables IV and V indicate high similarities between the two stations.

Station A. A. Observatory

Table IV Monthly Surface Wind Frequencies & Percentages Of Frequencies of the Main Directions

Month	N	NE	E	SE	S	SW	W	NW	CALM	Total
JANUARY										
Frequency	4	5	46	11	4	1	0	2	11	84
%	5	6	55	13	5	1	0	2	13	100
FEBRUARY										
Frequency	3	4	49	8	2	1	0	4	12	83
%	4	5	59	10	2	1	0	5	14	100
MARCH										
Frequency	1	6	56	3	1	0	0	2	11	80
%	1	8	70	4	1	0	0	3	14	101
APRIL										
Frequency	4	7	52	6	1	0	0	2	10	82
%	5	9	63	7	1	0	0	2	12	99
MAY										
Frequency	5	5	50	3	5	1	0	4	9	82
%	6	6	61	4	6	1	0	5	11	100

Table IV Continued

Month	N	NE	E	SE	S	SW	W	NW	CALM	Total
JUNE										
Frequency	3	6	26	2	25	3	5	2	10	82
%	4	7	32	2	30	4	6	2	12	99
JULY										
Frequency	6	1	1	0	22	6	13	20	10	79
%	8	1	1	0	28	8	16	25	13	100
AUGUST										
Frequency	10	0	1	0	34	12	5	6	11	79
%	13	0	1	0	43	15	6	8	14	100
SEPTEMBER										
Frequency	10	3	25	11	18	0	0	5	7	79
%	13	4	32	14	23	0	0	6	9	101
OCTOBER										
Frequency	3	7	50	5	2	0	0	3	11	81
%	4	9	62	6	2	0	0	4	14	101
NOVEMBER										
Frequency	1	4	56	2	0	0	1	1	12	77
%	1	5	73	3	0	0	1	1	16	100
DECEMBER										
Frequency	2	5	53	5	0	0	0	4	10	79
%	3	6	67	6	0	0	0	5	13	100
Total										
Frequency	52	53	465	56	114	24	24	55	121	967
%	5.4	5.5	48.1	5.8	11.8	2.5	2.5	5.7	12.8	100.1

STATION: A.A. OBSERVATORY

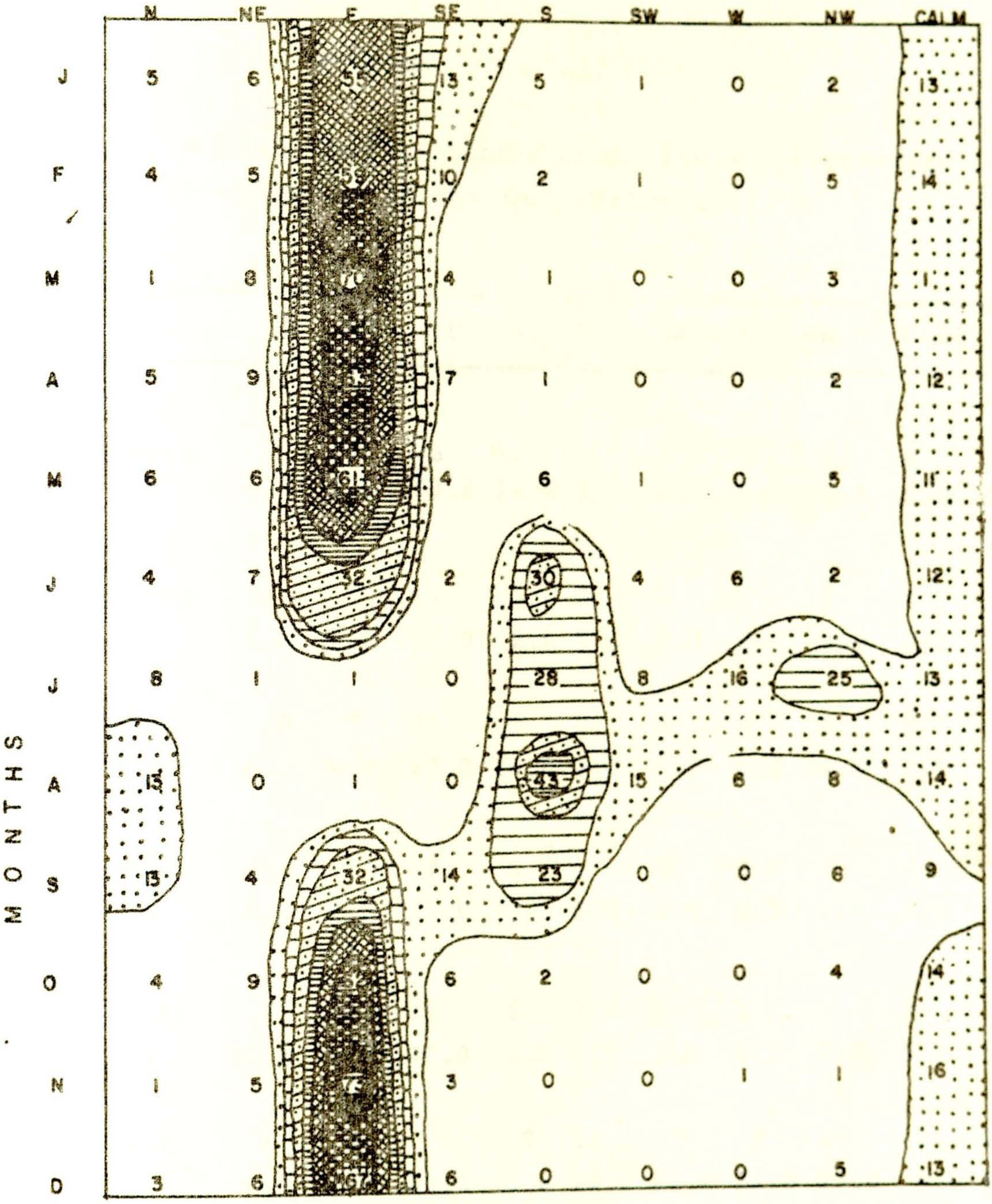


Fig. 3. WIND FLOW DIAGRAM

N.B: The Figures inside indicate percentage distributions of each prevailing surface wind in each month

Station: A.A. Bole

Table V Monthly Surface Wind Frequencies and Percentage Frequencies of the Main Directions

Month	N	NE	E	SE	S	SW	W	NW	Calm	Total
JANUARY										
Frequency	1	1	35	12	1	0	0	1	0	51
%	2.0	2.0	69.0	24.0	2.0	0.0	0.0	2.0	0.0	101.0
FEBRUARY										
Frequency	2	1	34	11	2	0	0	1	0	51
%	4.0	2.0	67.0	22.0	4.0	0.0	0.0	2.0	0.0	101.0
MARCH										
Frequency	0	2	34	12	1	0	0	2	0	51
%	0.0	4.0	67.0	24.0	2.0	0.0	0.0	4.0	0.0	101.0
APRIL										
Frequency	4	1	37	5	1	0	0	1	0	48
%	8.0	2.0	75.0	10.0	2.0	0.0	0.0	2.0	0.0	99.0
MAY										
Frequency	7	2	21	5	2	1	1	3	3	45
%	16.0	4.0	47.0	11.0	4.2	2.0	2.0	7.0	7.0	100.0
JUNE										
Frequency	2	0	5	0	12	7	8	14	0	100.0
%	4.0	0.0	10.0	0.0	25.0	15.0	17.0	29.0	0.0	100.0
JULY										
Frequency	0	0	0	0	3	9	21	12	0	45
%	0.0	0.0	0.0	0.0	7.0	20.0	47.0	27.0	0.0	101.0

Table V Continued

Month	NN	NE	E	SE	S	SW	W	NW	Calm	Total
AUGUST										
Frequency	0	1	0	1	7	9	19	14	0	50
%	0.0	2.0	0.0	2.0.	14.0	18.0	38.0	28.0	0.0	102.0
SEPTEMBER										
Frequency	2	1	14	6	14	2	2	8	2	51
%	4.0	2.0	27.0	12.0	27.0	4.0	4.0	16.0	4.0	100.0
OCTOBER										
Frequency	1	4	32	6	0	1	0	3	2	49
%	2.0	8.0	65.0	13.0	0.0	2.0	0.0	6.0	4.0	100.0
NOVEMBER										
Frequency	3	0	33	8	0	0	0	3	2	49
%	6.0	0.0	67.0	17.0	0.0	0.0	0.0	6.0	4.0	100.0
DECEMBER										
Frequency	3	0	33	6	0	0	0	4	2	48
%	6.0	0.0	69.0	13.0	0.0	0.0	0.0	8.0	4.0	100.0
Total										
Frequency	24	13	275	72	42	29	51	65	11	585
%	4.0	2.0	47.0	12.0	7.0	5.0	9.0	11.0	2.0	99.0

The easterlies are the most prevalent surface winds at both stations for most of the year. These surface winds prevail for ten months(September to June) at Addis Ababa Observatory while at Bole their prevalence is limited to eight months (October - May) of the year. These winds assume the highest monthly percentage contribution in November (73%) and in

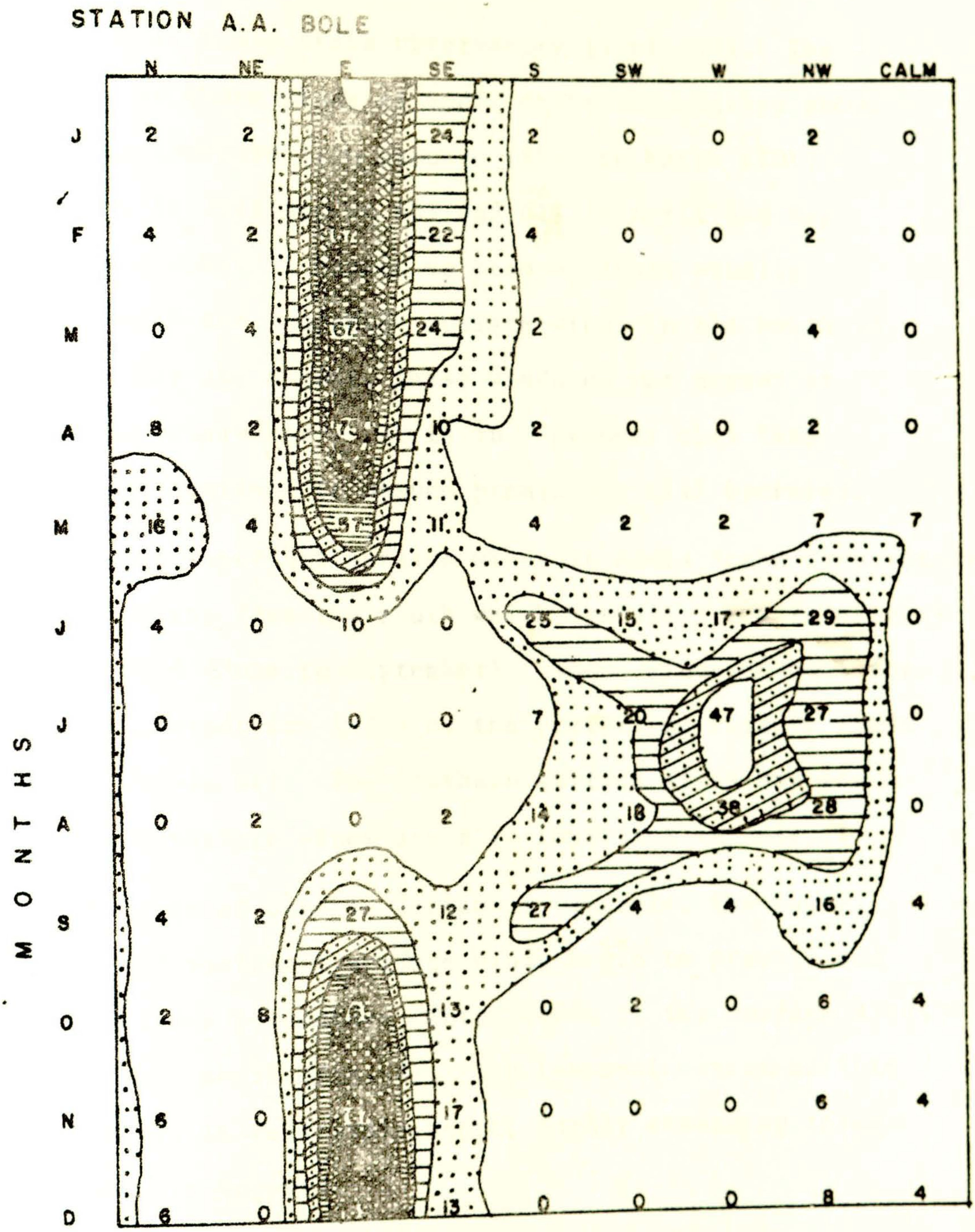


Fig.4. WIND FLOW DIAGRAM

N.B: The Figures inside indicate percentage distributions of each prevailing surface wind in each month.

March (70%) at Addis Ababa Observatory (Table IV). The occurrence of these winds at Addis Ababa Observatory shows a progressive increase from January (55%) to March (70%). Thereafter, it declines to 63% and 61% in April and May respectively until it begins to become almost equally important with the southerly surface winds in the month of June. In July and August, these winds do not appear at Addis Ababa Observatory. It is in September that they reappear and continue to assume prominence till December.

The next important surface winds at Addis Ababa Observatory are those coming from the south which prevail for a relatively shorter period (June to September). These winds account for the highest proportion (43%) of the prevailing surface winds in August (Table IV). The southern surface winds and the northwestern surface winds are also important in July.

In the period June to September, at Bole, the south, southwest and northwest surface winds begin to prevail and acquire a higher percentage contribution of the surface winds occurring each month (Fig. 4). The temporal extent of this group of winds is relatively short, hardly exceeding three months (June to August).

As can be seen from the table (Tables IV and V) at the time of seasonal shift (June and September in the case of Addis Ababa Observatory; and May and September at Bole), the prevalence of one single direction is reduced and each direction contributes a reasonable percentage share.

3. VARIATIONS IN SURFACE WIND SPEEDS

3.1. **Monthly Variation of Surface Wind Speeds at 0600, 1200 and 1800 Hours.** As already stated in the previous pages, a total of 967 recorded surface wind observations at Addis Ababa Observatory and 585 at Bole were analysed. Out of the 967 observations at Addis Ababa Observatory, 121 observations or 12.5% were calms while at Bole the calms account only for 11 observations or 1.9% of the 585 observations.

Table VI Total Recorded Surface Wind Speed Observations at Addis Ababa Observatory and at A. A. Bole

Station	Time		Calm (<0.5 m/sec.)	Speeds of 0.5.m/sec. or above	Total Observations
A.A Observatory	0600 hrs	N	121	135	256
		%	47.3	57.7	100
	1200 hrs	N	-	348	348
		%	-	100	100
	1800 hrs	N	-	363	363
		%		100	100
Total		N	121	846	967
		%	12.5	87.5	100
A. A. Bole	0600 hrs	N	11	184	195
		%	5.6	94.4	100
	1200 hrs	N	-	194	194
		%	-	100	100
	1800 hrs	N	-	196	196
		%	-	100	100
Total		N	11	574	585
		%	1.9	98.1	100

As shown in Table VI, all the calms occurred in the morning hours at both stations. The calms at Addis Ababa Observatory constitute a reasonably high proportion (47.3%) of the morning recorded surface wind observations than at Bole (5.6%); indicating a lower surface wind speed in the morning hours at Addis Ababa Observatory. The midday and evening records, however, reveal an absence of calm conditions at both stations.

As indicated in Table VII, which shows the variation in the monthly wind speeds above 0.5 m/sec. at different times of the day othere is no incidence of surface wind flowing at or greater than 5.7 m/sec in the morning hours at Addis Ababa Observatory while at Bole 8.1% of the morning winds flow at speeds of 5.7 m/sec or higher. Although the calms (0.5 m/sec) all occurred in the morning hours at both stations, the proportion of the calm observation at Bole is much smaller than at Addis Ababa Observatory (Table VI). The morning hours are, therefore, more windy at Bole than at Addis Ababa Observatory.

Table VII Diurnal Distribution of Surface Wind Speeds (excluding calms)

Station	Time	S P E E D S (M/Sec.)					Total
		0.5-2.0	2.1-3.5	3.6-5.6	5.7-8.1	8.2-10.7	
A. A.							
Observatory	0600 hrs	80	15	40	0	0	135
	%	59.3	11.1	29.6	-	-	100
	1200 hrs	147	114	82	5	0	348
	%	42.2	32.8	23.6	1.4	-	100
	1800 hrs	158	115	85	5	0	363
	%	43.5	31.7	23.4	1.4	-	100
Total		385	244	207	10	0	846
	%	45.5	28.8	24.5	1.2	-	100
A. A. Bole	0600 hrs	9	137	23	12	3	184
	%	4.9	74.5	12.5	6.5	1.6	100
	1200 hrs	1	19	96	36	42	194
	%	0.5	9.8	49.5	18.6	21.6	100
	1800 hrs	1	24	101	43	27	196
	%	0.5	12.2	51.5	21.9	13.8	100
Total		11	180	220	91	72	574
	%	1.9	31.4	38.3	15.9	12.5	100

Table VII also shows that not only is it more windy but also winds blow at higher speeds at Bole than at Addis Ababa Observatory at midday and in the evening. At Bole 28.4% of the surface winds above 0.5 m/sec blow at speeds of 5.7 m/sec. and above while at Addis Ababa Observatory, this proportion is only 1.2%.

In other words, about 98.8% of the daily surface wind occurrences of 0.5 m/sec. or above blow at speeds below 5.7 m/sec. at Addis Ababa Observatory whereas at Bole this proportion is 71.6%.

Table VIII shows the diurnal variation in wind speed, including calms at the two stations.

Table VIII Surface Wind Speeds at A.A. Observatory and A. A. Bole (including calms)

Station	SURFACE WIND SPEED (m/sec) Calm <0.5	0.5-2.0	2.1-3.5	3.6-5.6	5.7-8.1	8.2-10.7	Total
A. A. Observatory	121	385	244	207	10	-	967
%	12.5	39.8	25.2	21.4	1.0	-	100
A.A Bole	11	11	180	220	91	72	585
%	1.9	1.9	30.8	37.6	15.6	12.3	100

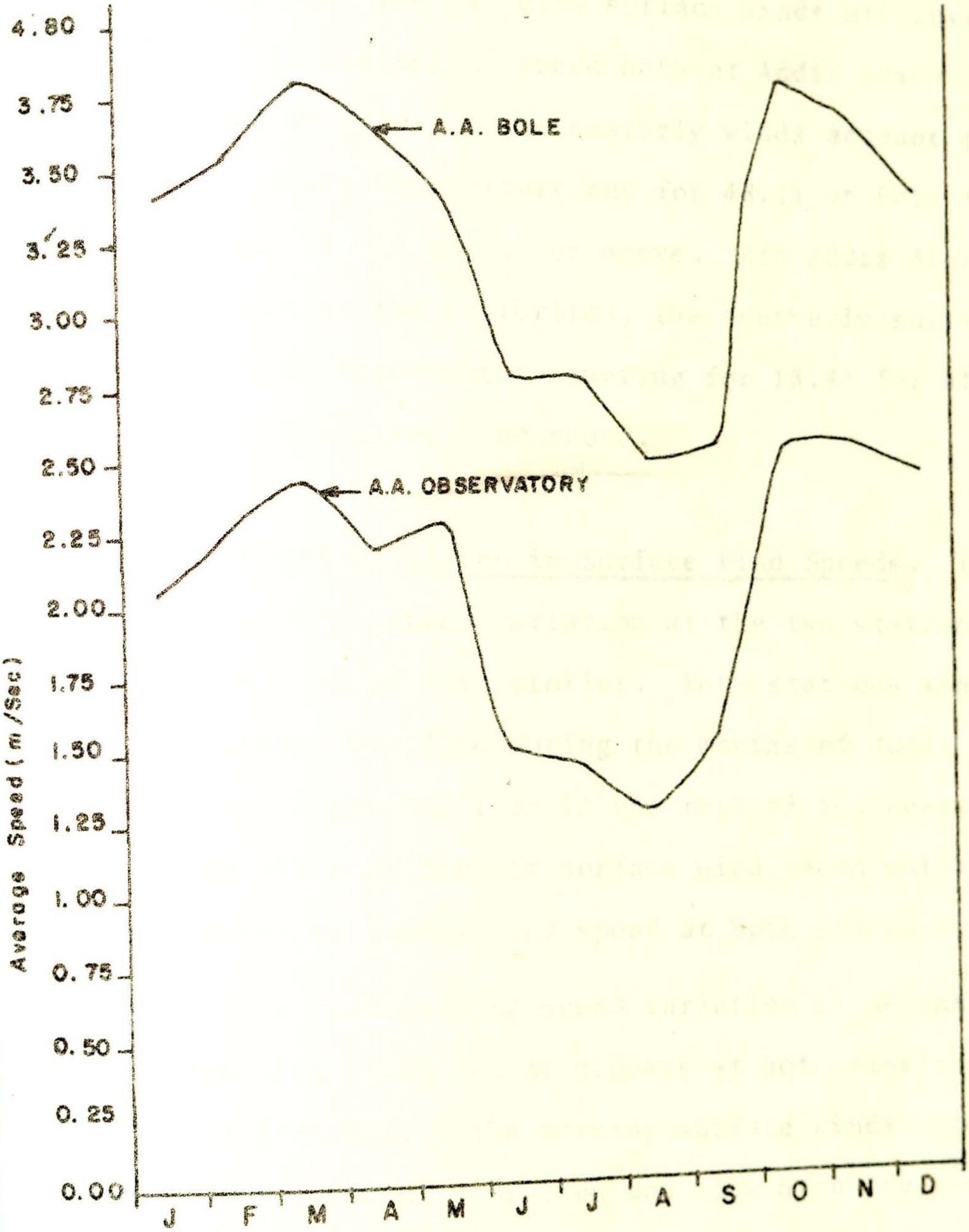
It may be observed from the table that only 1.0% of the surface winds at Addis Ababa Observatory flow at 5.7 m/sec. and above while at Bole this proportion is 27.9%. The lower wind speeds at Addis Ababa Observatory is perhaps due to the braking effects of the built-up area in which Addis Ababa Observatory is located. The tall buildings and the relatively densely constructed houses act as barriers to reduce wind speed to change wind direction and even to alter the pattern of air flow.

Table IX is constructed to identify the prevailing daily surface winds for the various classes of wind speed at the two stations.

Table IX Prevailing Wind Directions At Addis Ababa Observatory and A. A. Bole at Various Speeds (excluding calms).

Sation	Speed (m/sec)	N	NE	E	SE	S	SW	W	NW	Total
	0.5-2.0	31	5	180	29	80	9	16	35	385
Addis	%	8.1	1.3	46.8	7.5	20.8	2.3	4.2	9.1	100
	2.1-3.5	16	37	109	20	28	10	9	15	244
Ababa	%	6.6	15.2	44.7	8.2	11.5	4.1	3.7	6.1	100.0
Observatory	3.6-5.6	11	32	120	15	9	1	3	16	207
	%	5.3	15.5	58.0	7.2	4.3	0.5	1.4	7.7	100.0
	5.7-8.1	2	0	0	0	0	5	0	3	10
	%	20.0	-	-	-	-	50.0	-	30.0	100.0
	8.2-10.7	0	0	0	0	0	0	0	0	0
	%	-	-	-	-	-	-	-	-	-
	Total	60	74	409	64	117	25	28	69	846
	%	7.1	8.7	48.3	7.6	13.8	3.0	3.3	8.2	100.0
	0.5-2.0	0	1	5	1	0	0	1	3	11
	%	-	9.1	45.5	9.1	-	-	9.1	27.3	100.0
Addis	2.1-3.5	14	10	58	9	9	6	29	45	180
Ababa	%	7.8	5.6	32.2	5.0	5.0	3.3	16.1	25.0	100.0
Bole	3.6-5.6	2	1	149	30	11	6	13	8	220
	%	0.9	0.5	67.7	13.6	5.0	2.7	5.9	3.6	100.0
	5.7-8.1	7	1	44	15	14	3	4	3	91
	%	7.7	1.1	48.4	16.5	15.4	3.3	4.4	3.3	100.0
	8.2-10.7	0	0	20	17	9	15	4	7	72
	%	-	-	27.8	23.6	12.5	20.6	5.6	9.7	100.0
	Total	23	13	276	72	43	29	51	67	574
	%	4.0	2.3	48.1	12.5	7.5	5.1	8.9	11.7	100.0

Fig. 5 AVERAGE SURFACE WIND SPEED AT ADDIS ABABA OBSERVATORY AND BOLE



The table shows that the easterly surface winds are invariably prevalent for all classes of speed both at Addis Ababa Observatory and at Bole. These easterly winds account for 48.3% at Addis Ababa Observatory and for 48.1% at Bole for all observations of 0.5 m/sec. or above. Ato Addis Ababa Observatory, next to the easterlies, the southerly surface winds are the most important accounting for 13.8% for all observations of 0.5 m/sec. and above.

3.2. <u>Seasonal Variation in Surface Wind Speeds</u>. The seasonal surface wind speed variation at the two stations (as shown in fig. 5) is very similar. Both stations show a more steady surface air flow during the months of June, July, August and September than in the rest of the year. October is the month of highest surface wind speed while August is a month of lowest wind speed at both stations.

The seasonal surface wind speed variation is accentuated more in the evening hours and at middays at both stations. As can be seen from fig. 6 the morning surface winds show a relatively lower seasonal variation and blow at a low speed throughout the year.

Table X Mean Monthly Wind Speed (m/sec.) at 2m. at Addis Ababa Observatory and Bole.

Station	J	F	M	A	M	J	J	A	S	O	N	D
A. A. Observatory	2.1	2.3	2.4	2.2	2.3	1.5	1.4	1.3	1.6	2.6	2.6	2.4
A. A. Bole	3.4	3.6	3.8	3.7	3.4	2.8	2.8	2.5	2.6	3.8	3.7	3.4

Source: National Meteorolgical Services Agency; unpublished data.

Table XI Monthly Average Surface Wind Speed (m/sec.) at 2m at 0600, 1200 and 1800 hours at Addis Ababa Observatory.

Time of Day	J	F	M	A	M	J	J	A	S	O	N	D
Morning (0600 hrs)	0.67	0.69	0.59	0.63	0.68	0.71	0.64	0.54	0.71	0.56	0.52	0.85
Midday (1200 hrs)	2.68	2.89	2.79	2.53	2.58	2.13	2.14	2.02	2.27	3.21	3.31	2.51
Evening (1800 hrs)	3.04	2.97	3.19	2.84	3.00	2.12	1.98	1.71	2.22	3.14	3.11	3.12
Total	3.39	6.55	6.57	6.0	6.26	4.96	4.76	4.27	5.2	6.91	6.94	6.48
Average	2.1	2.2	2.2	2.0	2.1	1.7	1.6	1.4	1.7	2.3	2.3	2.2

N. B. The average in this table and the average in Table X differ from each other since the figures in this table are averages of mid-points of surface wind speed given in ranges.

FIG.6 MEAN MONTHLY SURFACE WIND SPEED

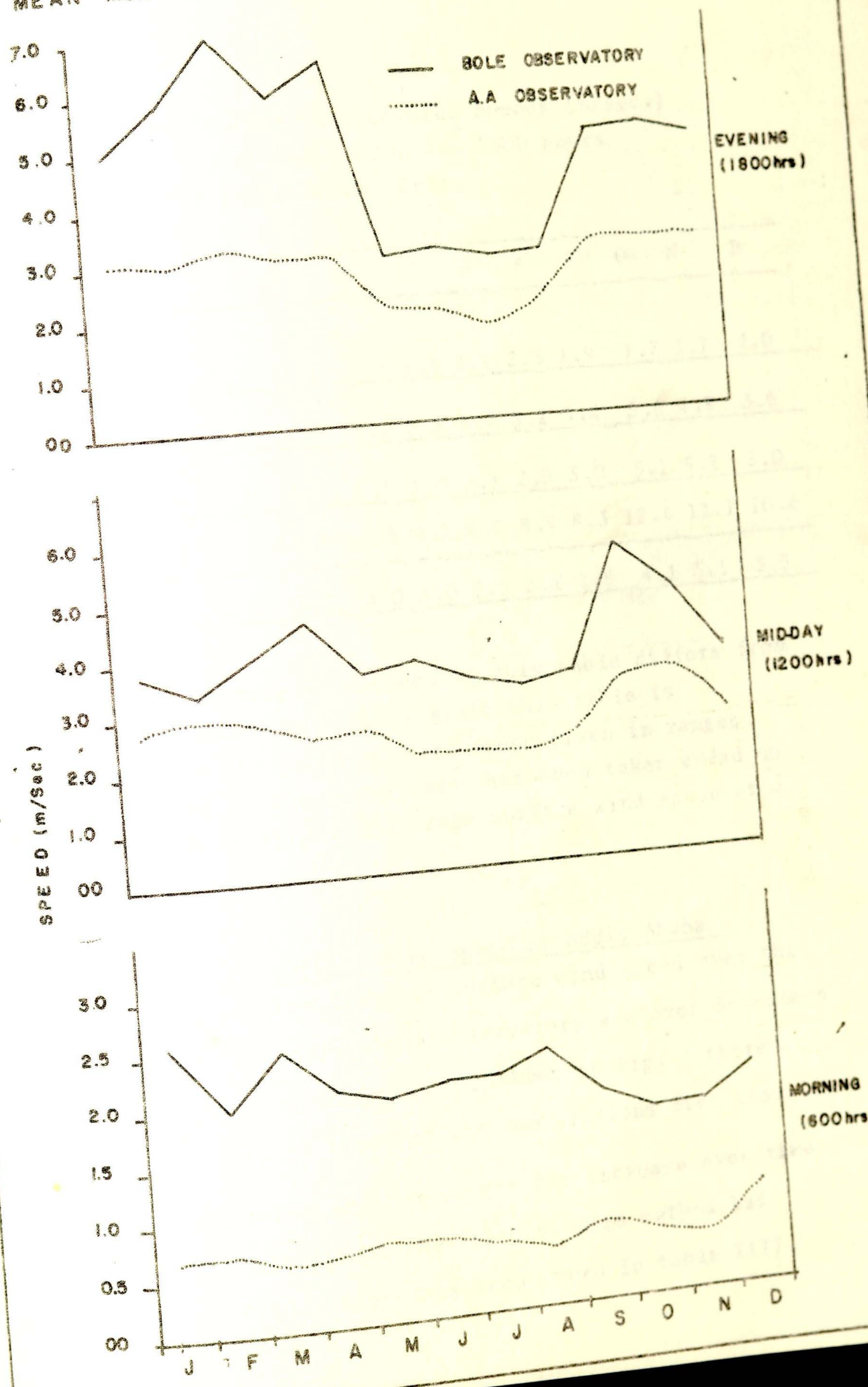


Table XII Monthly Average Surface Wind Speeds (m/sec.) At 2m. at 0600; 1200 and 1800 hours at Addis Ababa Bole.

Time	J	F	M	A	M	J	J	A	S	O	N	D
0600 hours	2.6	2.0	2.5	2.1	2.0	2.1	2.1	2.3	1.9	1.7	1.7	2.0
1200 hours	3.8	3.4	4.0	4.6	3.6	3.8	3.4	3.2	3.4	5.6	4.8	3.6
1800 hours	5.0	5.8	7.0	5.9	6.5	3.0	3.1	2.9	3.0	5.1	5.2	5.0
Total	11.4	11.2	13.5	12.6	12.1	8.9	8.6	8.4	8.3	12.4	11.7	10.6
Average	3.8	3.7	4.5	4.2	4.0	3.0	2.9	2.8	2.8	4.1	3.1	3.5

N.B The average surface wind speed in this table differs from the average shown in Table X since this table is summarized on the basis of wind speed given in ranges. The mid-point in the given range has been taken added up and averaged to give the average surface wind speed at a given time.

3.3. Trends in Surface Wind Speed at Addis Ababa Observatory & Bole. The trend of surface wind speed over the last thirty years at Addis Ababa Observatory and over Seventeen years at Bole has been examined. As shown in Fig. 7 there is a general increasing trend at the two stations over time.

Inorder to understand whether or not the increase over time is statistically significant the least squares method has been employed and the outcome has been shown in table XIII.

Fig. 7 MEAN ANNUAL SURFACE WIND SPEED VARIATION (m/s)

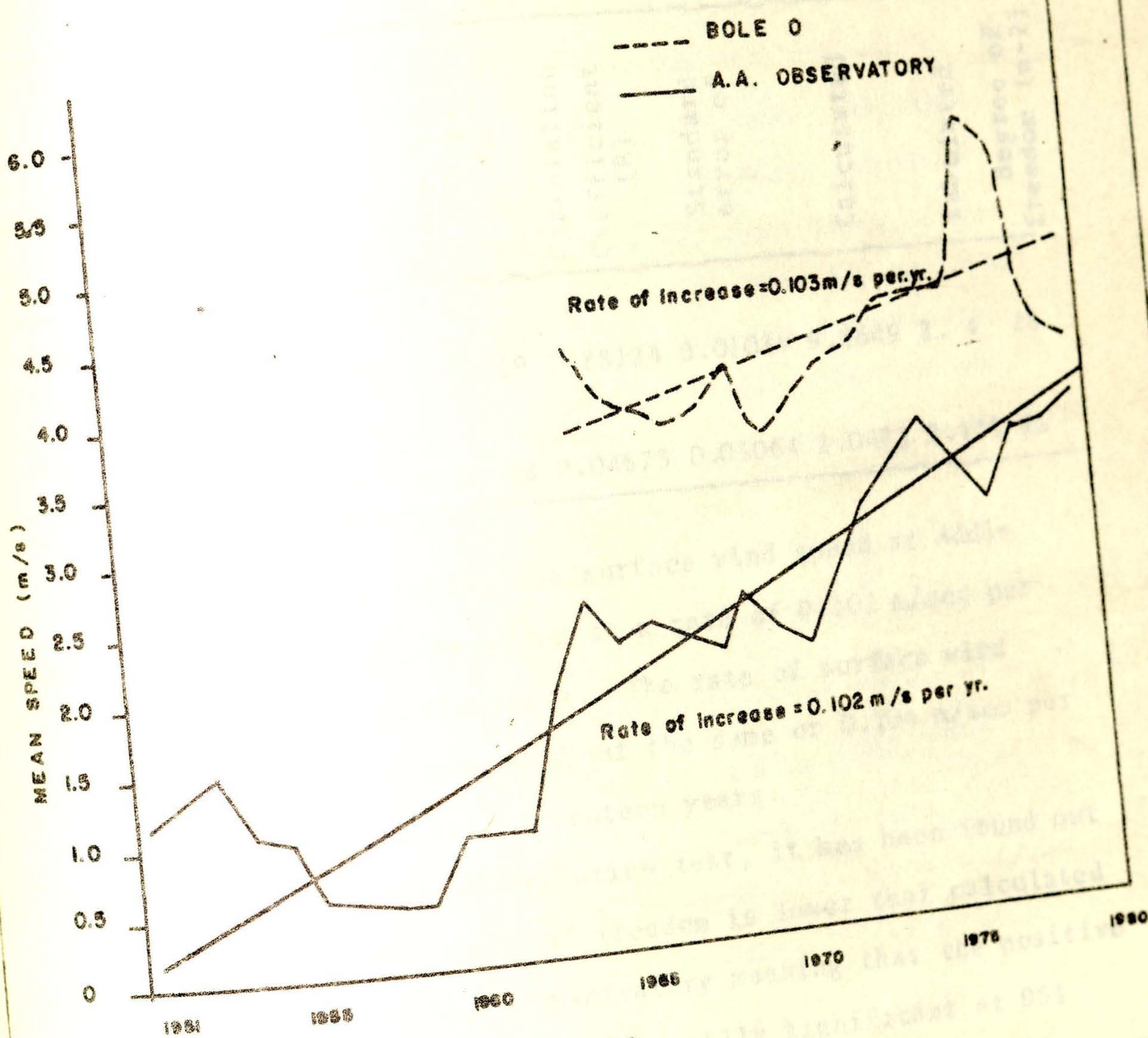


Table XIII Rate of Change of Surface Wind Speed Per Year at Addis Ababa Observatory & Bole

	Intercept (a)	Rate of change (b)	Correlation Coefficient (R)	Standard error of b	Calculated	tabulated	degree of freedom (n-2)
Addis Ababa Observatory	0.598223	0.10219	0.88124	0.01036	9.8649	2. 4	28
Addis Ababa Bole	2.3706	0.10368	0.04673	0.05064	2.0473	2.131	15

As shown in the table, the surface wind speed at Addis Ababa Observatory has increased at a rate of 0.102 m/sec per year over the last thirty years. The rate of surface wind speed increase has also been about the same or 0.104 m/sec per year at Bole over the last seventeen years.

Using the student distribution test, it has been found out that tabulated at 28 degree of freedom is lower that calculated in the case of Addis Ababa Observatory meaning that the positive chate of speed over time is statistically significant at 95% level of confidence. In the case of Bole, however, the application of the same test suggests that the change of surface wind speed is not statistically significant.

CHAPTER IV

TEMPERATURE VARIATIONS IN ADDIS ABABA

1. VARIATIONS IN MEAN TEMPERATURES

Unlike the data on surface winds which were available for two stations only, temperature data have been available at the three stations (A.A. Observatory, A.A. Bole and the Geophysical Observatory). It has therefore been possible to discuss decadal and seasonal temperature patterns at the three stations. The following table compares the mean temperatures of the three stations over the last 17 years at Bole, 23 years at A.A. Observatory and over the last 22 years at the Geophysical Observatory.

Table XIV Temperatures (C^{o}) At The Three Stations

Station	Height (m)	Min. Temp Yrs of record	Min. Temp Annu. mean	Mean Yrs. of reco	Mean Annu. mean	Temp Yrs. of rec	Temp Annu mean	Mean Annual Range of Temp.
A.A.Bole	2333	17	22.8	17	8.4	17	15.[illegible]	14.4
A.A. Observatory	2408	23	22.2	23	9.6	23	15.9	12.6
Geophysical Observatory	2442.5	22	21.6	22	8.5	22	15.1	13.1

As shown in the table, Addis Ababa Observatory has a mean annual temperature of 15.9°C; the Geophysical Observatory 15.1°C; and Bole 15.6°C. The highest mean annual maximum temperature is observed at Bole (22.8°C) and the lowest at the Geophysical Observatory(21.6°C). The lowest mean annual minimum temperature is observed at A.A. Bole Addis Ababa Observatory which is found in the middle of the city where a higher temperature than the surrounding more natural regions is expected has the highest mean annual temp(15.9°C) of the three stations.

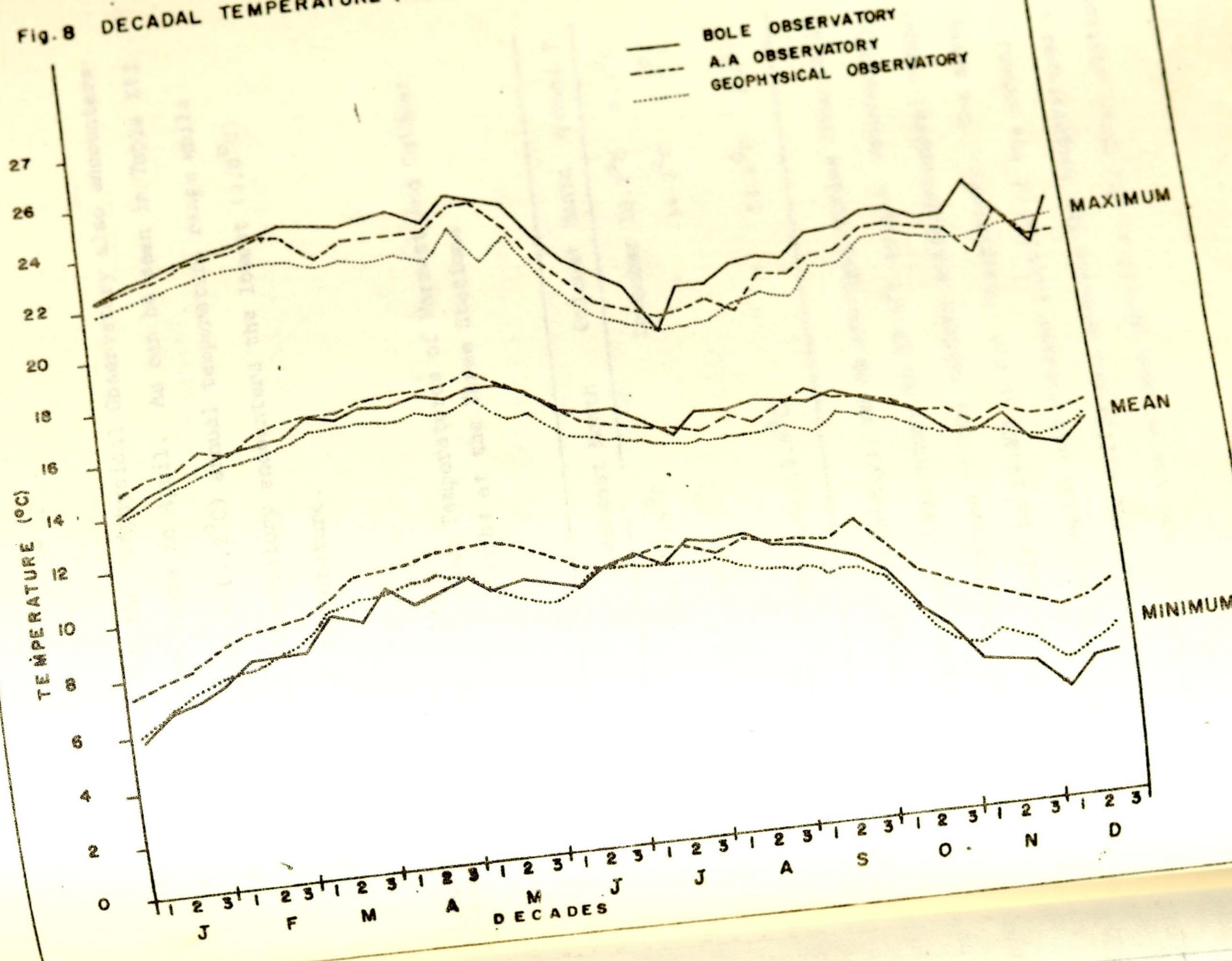
If we see the mean annual range of temperature (the difference between the mean annual maximum and mean annual minimum temperatures) in Table XIV, Addis Ababa Observatory has the least mean annual temperature range(12.6°C) perhaps attributable to the degree of urbanization of the area in which the station is found. The number of buildings near and around the station reduce wind speed and change both the direction and pattern of air flow. Turbulent air motion probably increases the rate of maxing and, therefore, enhancing heat exchange which in trun avoids the occurrence of extreme temperature conditions at Addis Ababa Observatory.

The coldest temperature is experienced in December at the three stations while May is the warmest month(Table XV).

Table XV Mean Decadal and Monthly Temperature (^oC) at the three Stations

Stations	Decades	J	F	M	A	M	J	J	A	S	O	N	D	Annual
A. A. Bole	1	14.0	15.5	16.4	17.3	17.2	17.1	16.0	15.6	15.8	15.5	13.8	13.1	
	2	14.7	16.0	17.1	17.1	17.5	16.3	15.5	15.6	15.5	15.1	13.7	12.8	
A. A.	3	15.1	16.2	16.9	17.4	17.5	16.1	14.8	15.8	15.8	14.7	14.2	13.7	
Observatory	Average	14.6	15.9	16.8	17.3	17.4	16.5	15.4	15.7	15.7	15.1	13.9	13.2	15.6
	1	14.9	16.1	16.9	17.4	17.7	17.2	15.4	14.9	15.5	15.6	14.8	14.5	
	2	15.3	15.9	17.1	17.5	18.1	16.3	15.3	15.3	15.4	15.4	14.7	14.1	
	3	15.5	16.6	17.1	17.6	17.6	15.7	15.1	14.9	16.0	15.2	14.0	14.4	
	Average	15.2	16.2	17.0	17.5	17.8	16.4	15.3	15.0	15.6	15.4	14.5	14.3	15.9
Giophysical	1	13.9	15.2	16.0	16.6	16.8	16.3	14.9	14.5	14.7	14.8	13.7	13.3	
Observatory	2	14.4	15.5	16.6	16.5	17.1	15.4	14.7	14.4	14.4	14.5	13.8	13.5	
	3	14.9	15.7	16.5	16.7	16.2	15.1	14.5	14.6	15.0	14.0	13.6	13.9	
	Average	14.4	15.5	16.3	16.6	16.6	15.6	14.7	14.5	14.7	14.4	13.7	13.6	15.1

Fig. 8 DECADAL TEMPERATURE (°C) PATTERNS AT THE THREE STATIONS

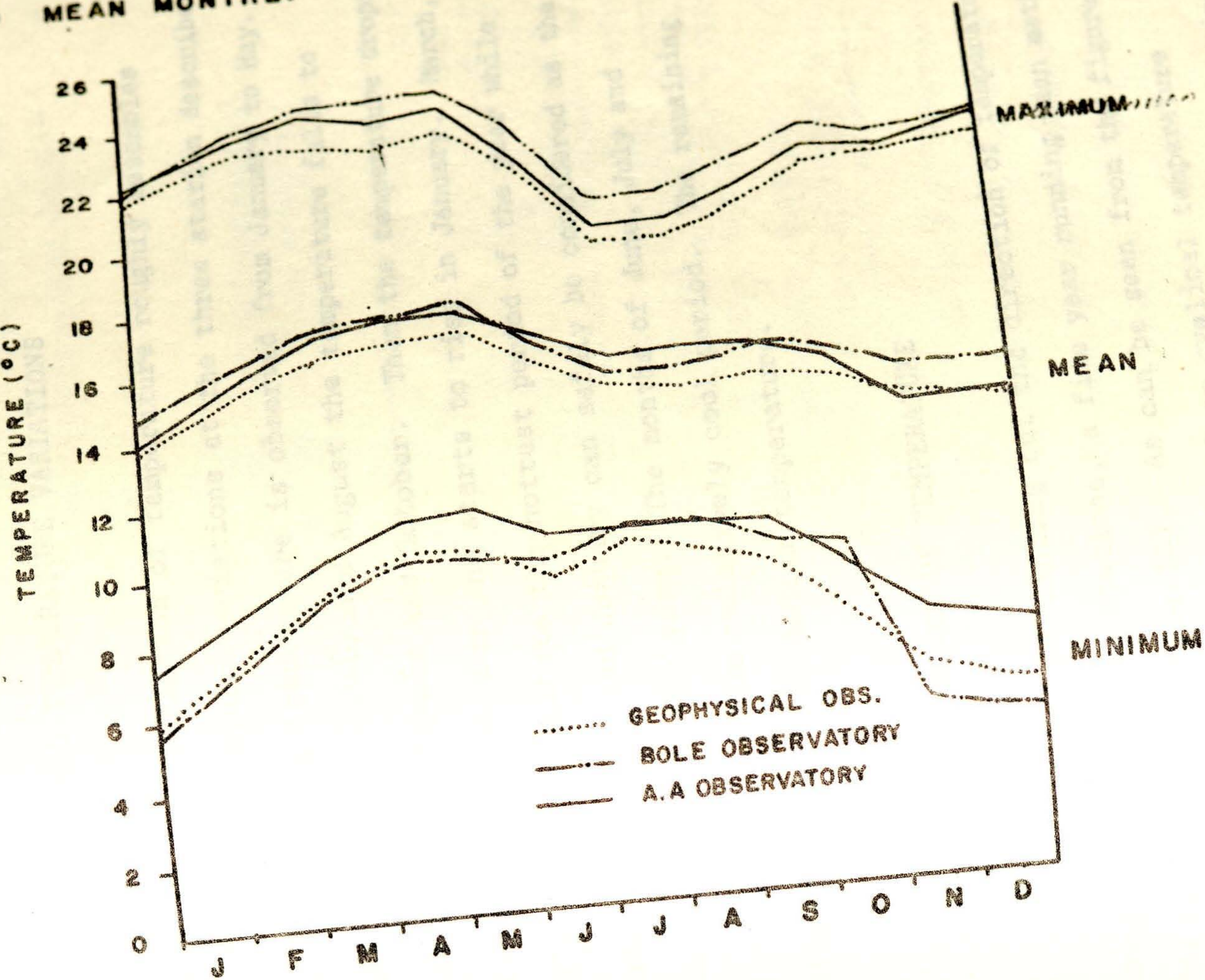


2. DECADAL TEMPERATURE VARIATION

As can be seen from Fig. 8, the mean temperature of the Geophysical Observatory is the lowest of the three stations at all decades for ten to eleven months of the year. At Addis Ababa Observatory, on the other hand, the temperature at all decades is the highest for nine to ten months of the year while the decadal temperature of Bole varies between the temperatures of Addis Ababa Observatory and Geophysical Observatory.

The decadal temperature graph (Fig.8) shows a general temperature increase towards the third decades starting from the third decade of December to the second decade of May. Thereafter, temperature decreases towards the third decade till the end of July and the beginning of August when the temperature again rises till the second decade and third decades of September. The summer as shown in Fig. 8 & 9, is a period of low temperature due to the relatively high cloud cover which results in a reduction of solar receipt.

Fig. 9 MEAN MONTHLY TEMPERATURE OF THE THREE STATIONS



3. SEASONAL TEMPERATURE VARIATIONS

The seasonal variation of temperature roughly resembles the decadal temperature variations at the three station described earlier. A rising temperature is observed from January to May. In the period June, July and August the temperature falls to rise again in September and October. Then the temperature drops in November and December and starts to rise in January. March, April and May constitute the hottest period of the year while November, December and January can safely be considered as the coldest period of the year. The months of June, July and August consist of the relatively cool period. The remaining months are months of medium temperature.

4. TRENDS OF TEMPERATURE

In an attempt of finding out the direction of temperature changes at the three stations, a five year running mean method has been employed (Fig.10). As can be seen from the figure there are no important seasonal or cyclical temperature changes. Instead, the changes seem to be secular occurring once in ten or more years, an impression obtainable from the five year running mean graphs which give a rough idea of temperature increase.

The direction of temperature change has further been elaborated by the use of the least squares method which resulted in the following outcome.

Table XVII Rate of Maximum and Minimum Temperature Changes (Per yr) at the Three Stations

Station	Temperature	Rate of increase or decrease °C /yr (b)	Intercept (a)	Correlation (R)	Standard error of (b)
A.A. Bole	Max	-0.018069	22.9563317	-0.000033	0.0203629
	Min	0.027451	8.2627451	0.1585836	0.0019474
A.A. Observatory	Max	-0.0412059	22.709787	-0.3664374	0.022832
	Min	0.111166	8.451087	0.2629795	0.0889976
Geophysical Obs.	Max	0.0476002	21.122925	0.044527	0.2393073
	Min	0.0213439	8.2577073	0.3721496	0.0119034

The maximum temperatures at Bole and at A.A. Observatory decrease at an average rate of 0.0188C and 0.041°C per year respectively. The maximum temperature at the Geophysical Observatory, however, increase at an average rate of 0.047°C per year.

The minimum temperature, on the other hand, increases at the three stations. The minimum temperature at A.A. Observatory showes the highest rate of annual increase (0.111°C/yr.)

Fig. 10. ADDIS ABABA OBSERVATORY, TEMPERATURE PATTERNS FROM 1958–1980

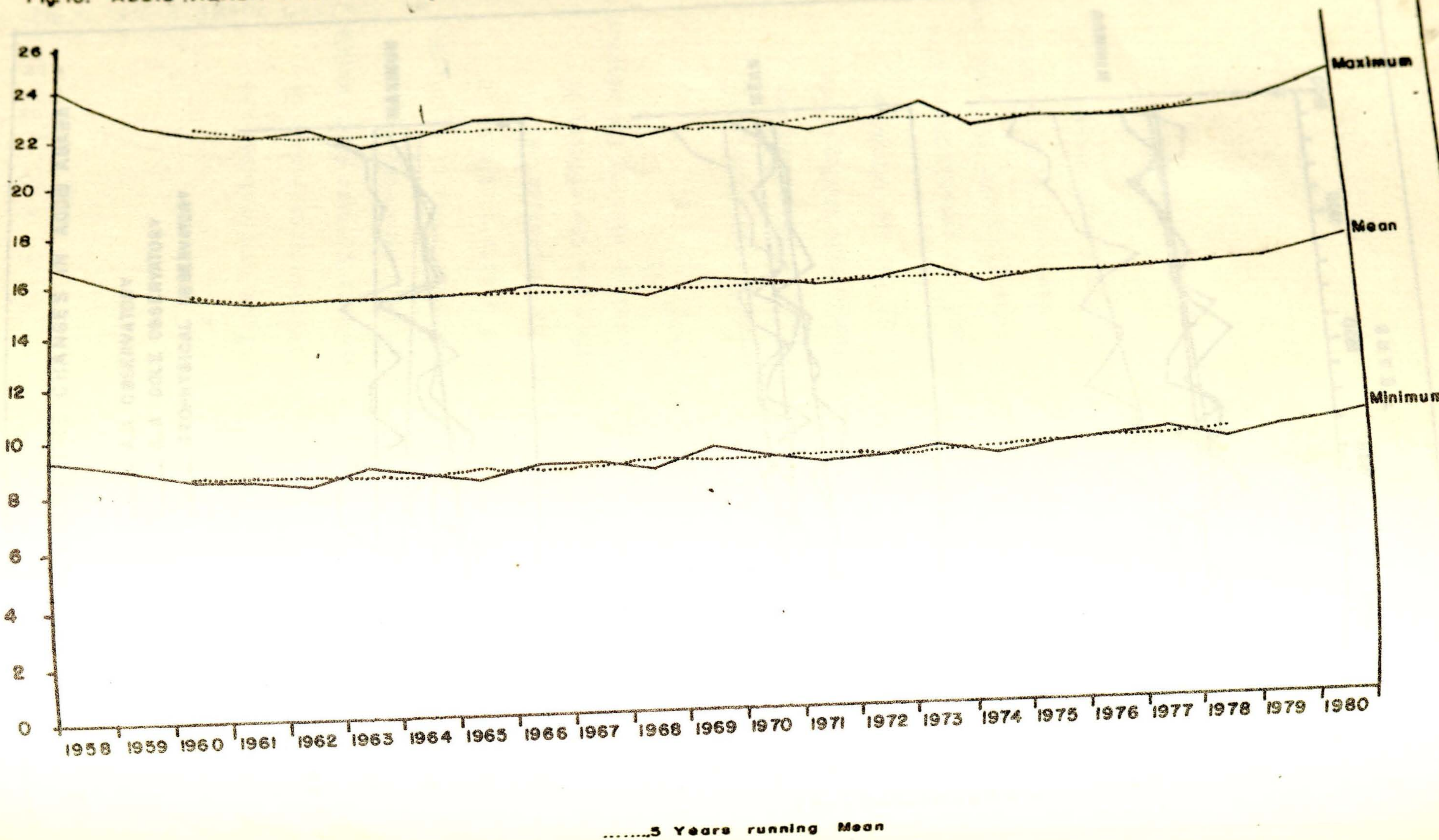
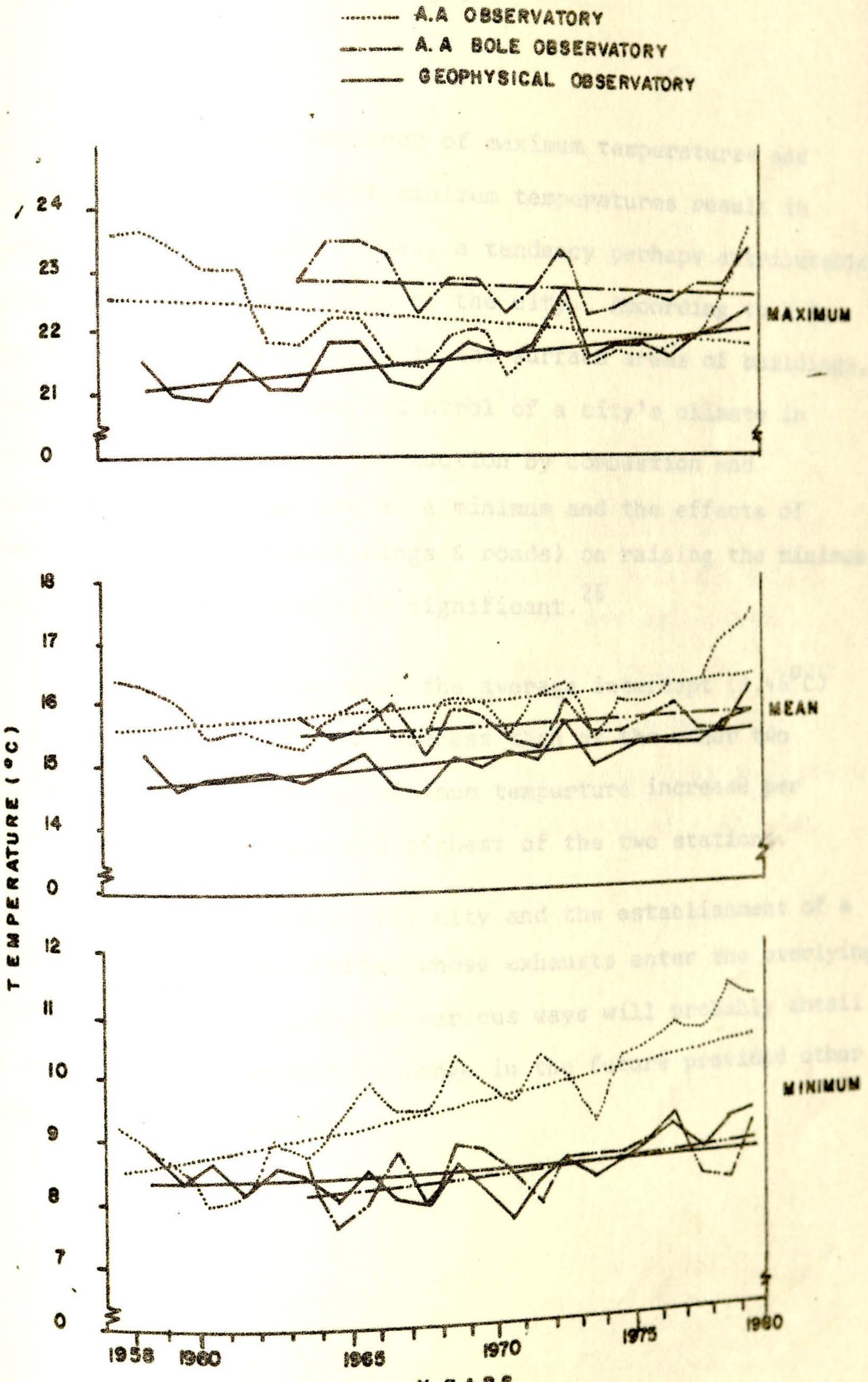


FIG. II TEMPORAL TEMPERATURE CHANGES IN ADDIS ABABA



The decreasing tendency of maximum temperatures and the increasing tendency of minimum temperatures result in decreasing temperature ranges, a tendency perhaps attributable to the growing urbanization of the city. According to R.G. Barry and R.J. chorley (1968), the surface areas of buildings, roads etc. are the primary control of a city's climate in periods when direct heat production by combustion and atmospheric pollution are at a minimum and the effects of these urban surfaces(buildings & roads) on raising the minimum temperatures are especially significant.[25]

Table XVII shows that the average intercept (8.45°C) at A.A. Observatory is the highest than at the other two stations, and the rate of minimum temperture increase per year (0.111°C) is again the highest of the two stations.

A further growth of the city and the establishment of a greater number of industries whose exhausts enter the overlying atmosphere of Addis Ababa in various ways will probably entail an even smaller temperature range in the future provided other factors are kept constant.

CHAPTER V

RAINFALL PATTERNS IN ADDIS ABABA

1. GENERAL

As mentioned earlied (CHAPTER IV) rainfall data of 17 years has been available at Bole while the rainfall data obtained at the Geophysical Observatory and Addis Ababa Observatory is for 24 and 29 years respectively. As shown in the following table, the annual rainfall varies from 1061.3 mm. at Bole to 1346.6mm. at the Geophysical Observatory. The A.A. Observatory with an annual rainfall of 1150.2 mm. falls between the two stations.

Table XVIII Mean Monthly Rainfall (mm) at the Three Stations in Addis Ababa

Station	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Addis Ababa Bole	17.9	40.4	63.1	74.6	76.8	114.2	244.2	233.3	144.1	39.1	9.1	4.0	1061.3
Addis Ababa Observatory	20.0	32.7	62.6	90.3	68.2	116.0	251.3	273.1	174.4	40.0	9.9	11.7	1150.2
Geophysical Observatory	28.0	47.1	75.5	92.7	79.1	132.1	297.0	330.9	197.6	39.8	11.5	11.5	1345.6

Although the three stations differ from each other in their monthly and annual amounts of rainfall, they are essentially similar in the annual march of rainfall(Fig.12).

2. SEASONAL RAINFALL PATTERNS IN ADDIS ABABA

The mean monthly rainfall generally increases from January on wards until a peak is reached in July and August at the three stations (Fig.12). Thereafter, the rainfall decreases until it reaches its minimum in November in the case of A.A. Observatory and in December in the case of the other two stations.

Bole differs from the other two stations not only in its low amount of rainfall but also in that a)its May average rainfall is greater than the average rainfall in April. b) The rainfall peak is reached in July while the other two stations have their highest monthly rainfall in August. c) December is the driest month at A.A. Bole and at the Geophysical Observatory while at A.A. Observatory November is the driest month (Fig.12).

In an attempt to divide the year into dry and rainy periods at the three stations, the rainfall coefficients of each month have been tabulated as follows.

Fig. 12 MEAN MONTHLY RAINFALL (mm.)

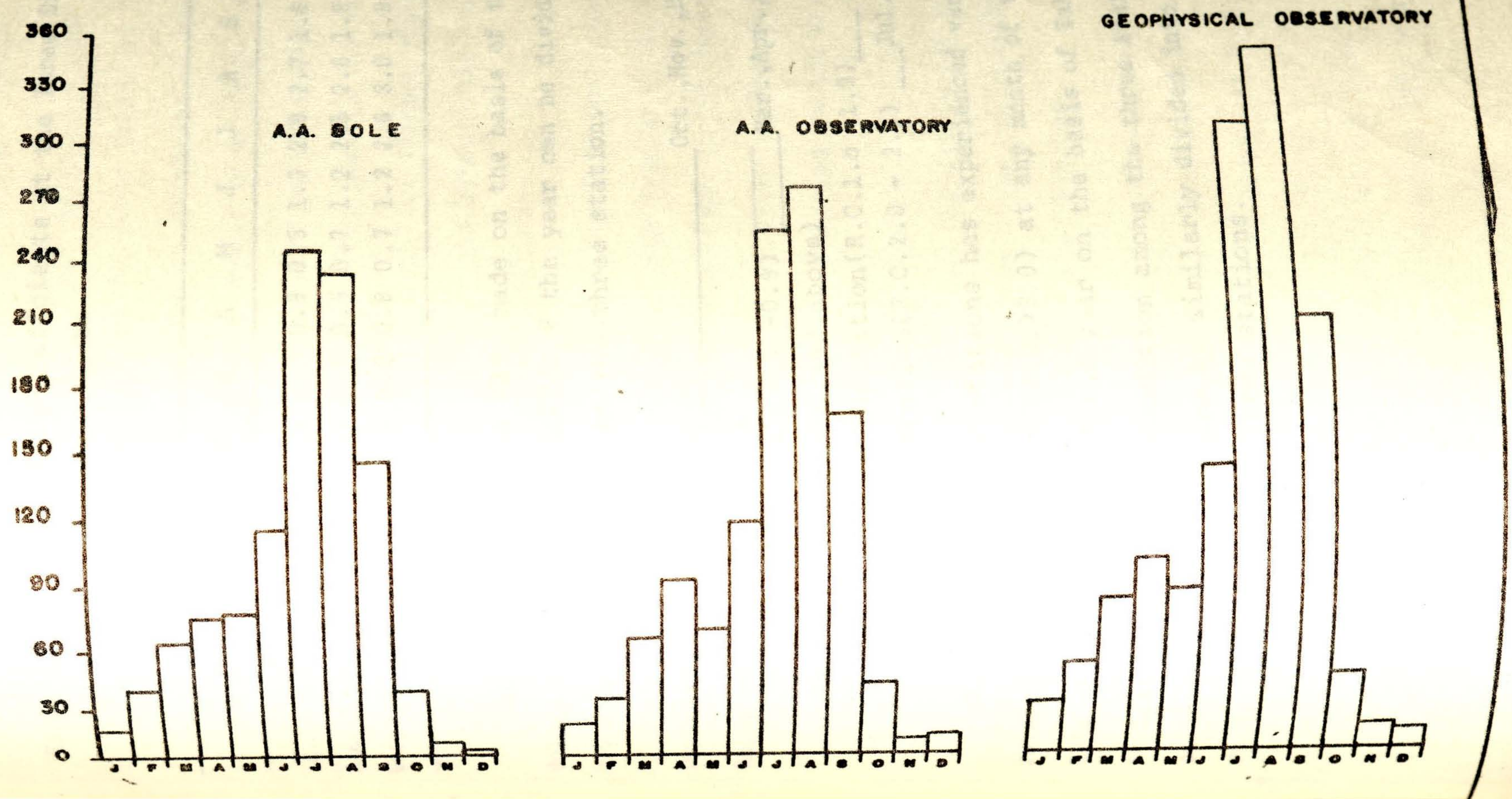


Table XIX Rainfall Coeffcients at the Three Stations in Addis Ababa

Station	J	F	M	A	M	J	J	A	S	O	N	D
A.A. Bole	0.2	0.5	0.7	0.8	0.9	1.3	2.8	2.7	1.6	0.4	0.1	0.1
A.A. Observatory	0.2	0.3	0.6	0.9	0.7	1.2	2.5	2.8	1.8	0.4	0.1	0.1
Geophysical Obs	0.2	0.4	0.6	0.8	0.7	1.2	2.6	3.0	1.8	0.4	0.1	0.1

According to Table XIX, made on the basis of the methodology mentioned in CHAPTER V the year can be divided into dry and rainy periods at the three station.

Dry period (B.C.<0.6) ______________ Oct.,Nov.,Dec.,Jan.,Feb.,

Rainy period (B.C.> 0.6
 Small rains (R.C. 0.6 -0.9) ______ Mar.,Apr.,May.
 Big rains (R.C.1.0 and above)
 Moderate concentration(R.C.1.o -1.9)____ Jun.,Sept.,
 High concentration(R.C.2.0 - 2.9) ___Jul., Aug.

None of the three stations has experienced very high rainfall concentration (R.C.>3.0) at any month of the year. This classification of the year on the basis of Table XIX, indicates a similar condition among the three stations. In otherwords, the year can be similarly divided into dry and rainy periods at the three stations.

3. DECADAL RAINFALL PATTERNS IN ADDIS ABABA

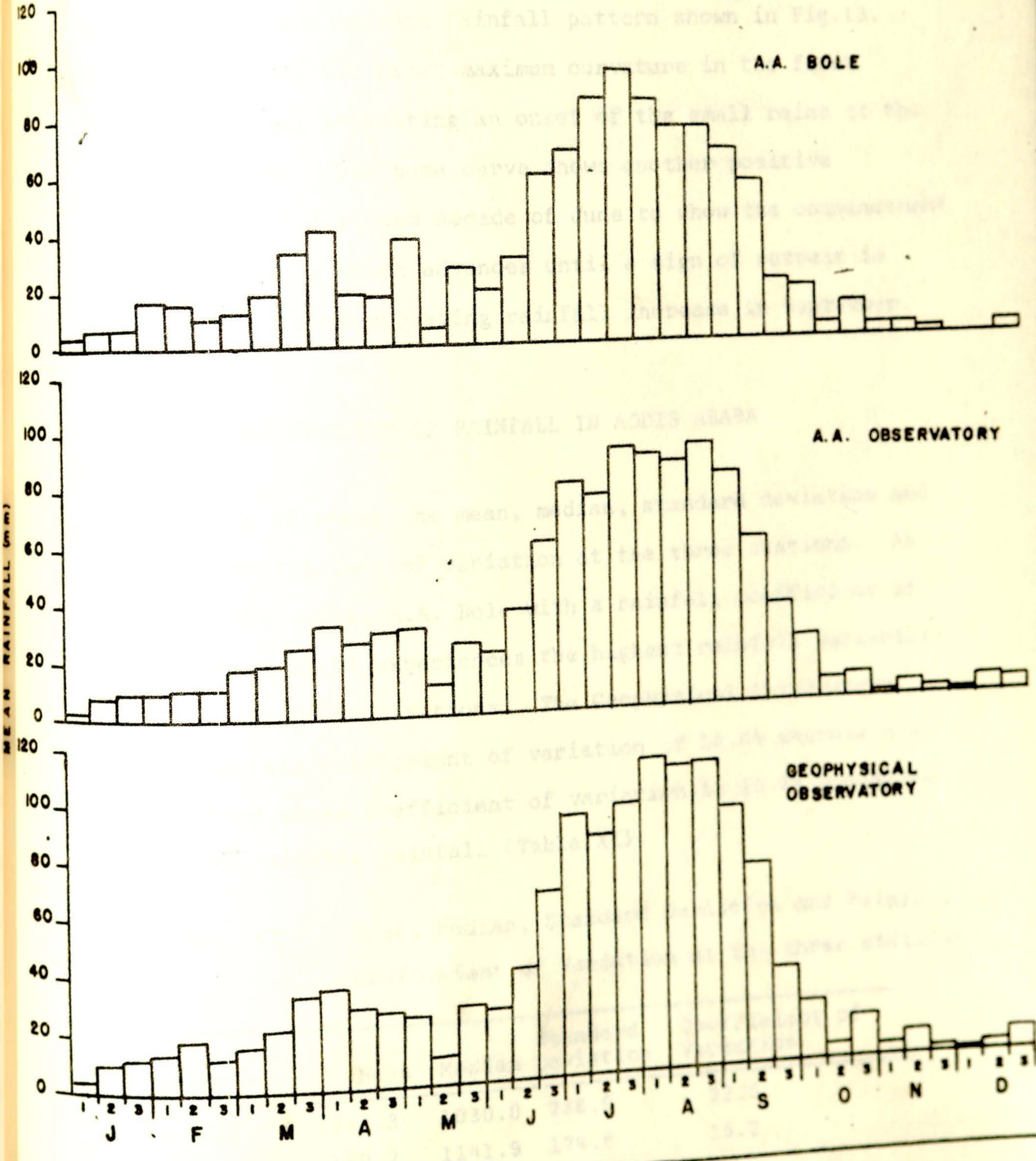
The decadal rainfall graphs (fig. 13.) show a consistently low amount of rainfall from the first decade of October to the third decade of February with an exception of Bole where this low rainfall seems to persist to the first decade of March (Fig. 13). The small rainy period commences in the first decade or March, reaches its peak in the first decade of April and gradually recedes until it reaches its minimum in the middle of May, the driest gap between the small rains and the big rains at the three stations.

The big rainy period starting from early June persists until it reaches its peak in late July at A. A. Bole; in late August at A. A. Observatory and in the first decade of August at the Geophysical Observatory. After August, the big rains slowly retreat and end sometime in the first decade of October at the three stations.

As the decadal graphs show the dry period starts in the first decade of October and with short, relatively wet spells persists until the last decade of February.

The "dry" period (October to February) accounts for about 10% of the annual rainfall that occurs at each station. Of the total annual rainfall that occurs at each station 17% comes during March, April and the first half of May, (period of small rains). The raining 73% of the annual rainfall come during June, July, August and September (the big rainy period).

Fig. 13 MEAN DECADAL RAINFALL (mm)



The Ogive curve (fig.14) which has been constructed to indicate the onset, advance and retreat of rainfall confirms roughly with the decadal rainfall pattern shown in Fig.13. The curve shows its first maximum curvature in the first decade of March indicating an onset of the small rains at the three stations. The same curve shows another positive curvature in the second decade of June to show the commencement of the big rains which advances until a sign of retreat is detected by the decelerating rainfall increase in September.

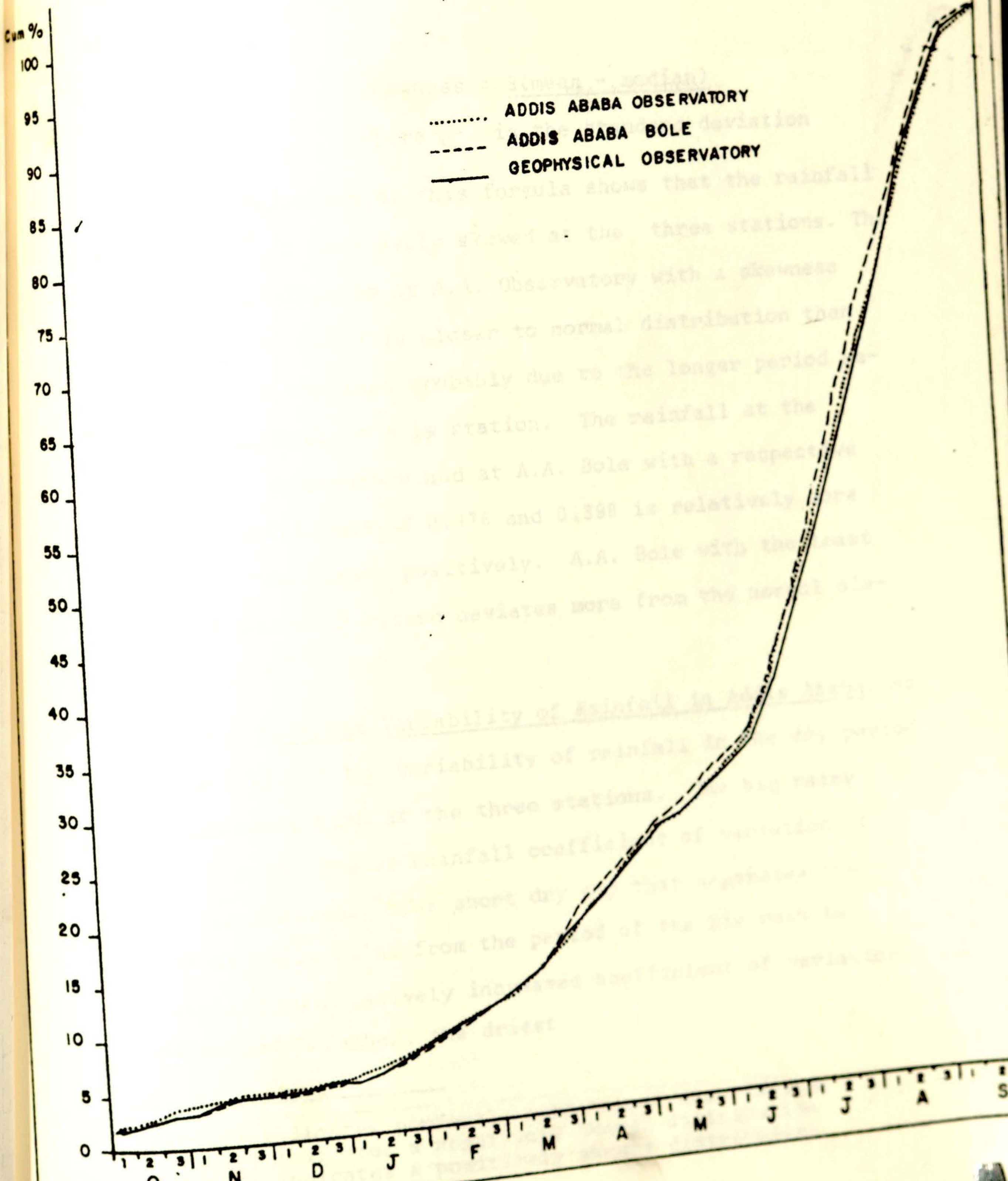
4. VARIABILITY OF RAINFALL IN ADDIS ABABA

Table XX shows the mean, median, standard deviation and rainfall coefficient of variation at the three stations. As shown in the table, A.A. Bole with a rainfall coefficient of variation of 22.0% experiences the highest rainfall variability of the other two stations. The Geophysical Observatory has a rainfall coefficient of variation of 18.0% whereas A.A. Observatory whose coefficient of variation is 15.2% ecounters the least variable rainfall (Table XX).

Table XX Mean, Median, Standard Deviation and Rainfall Coefficient of Variation at the three stations

Station	Mean	Median	Standard Deviation	Coefficient of Variation
A.A. Bole	1061.3	1030.0	236.0	22.0
A.A. Obser-vatory	1150.2	1141.9	174.8	15.2
Geogphysical Obse.	1345.6	1315.2	242.78	18.0

Fig. 14 OGIVE CURVE OF MEAN DECADAL RAINFALL



The pattern of annuao rainfall distribution at the three stations can also be compared with the following formula of skewness.

$$^{*}\text{Skewness} = \frac{3(\text{mean} - \text{median})}{\sigma}$$

Where σ is the standard deviation

The application of this formula shows that the rainfall distribution is positively skewed at the three stations. The rainfall distribution at A.A. Observatory with a skewness coefficient of 0.142 is closer to normal distribution than the other two stations probably due to the longer period records of rainfall at this station. The rainfall at the Geophysical Observatory and at A.A. Bole with a respective skewness Coefficient of 0.376 and 0.398 is relatively more skewed (to the right) positively. A.A. Bole with the least number of years of record deviates more from the normal distribution.

4.1. Seasonal Variability of Rainfall in Addis Ababa: As shown in Fig. 15 the variability of rainfall in the dry period are relatively high at the three stations. The big rainy period has the lowest rainfall coefficient of variation at the three stations. The short dry gap that separates the period of small rains from the period of the big rain is represented by relatively increased coefficient of variation. November and December, the driest

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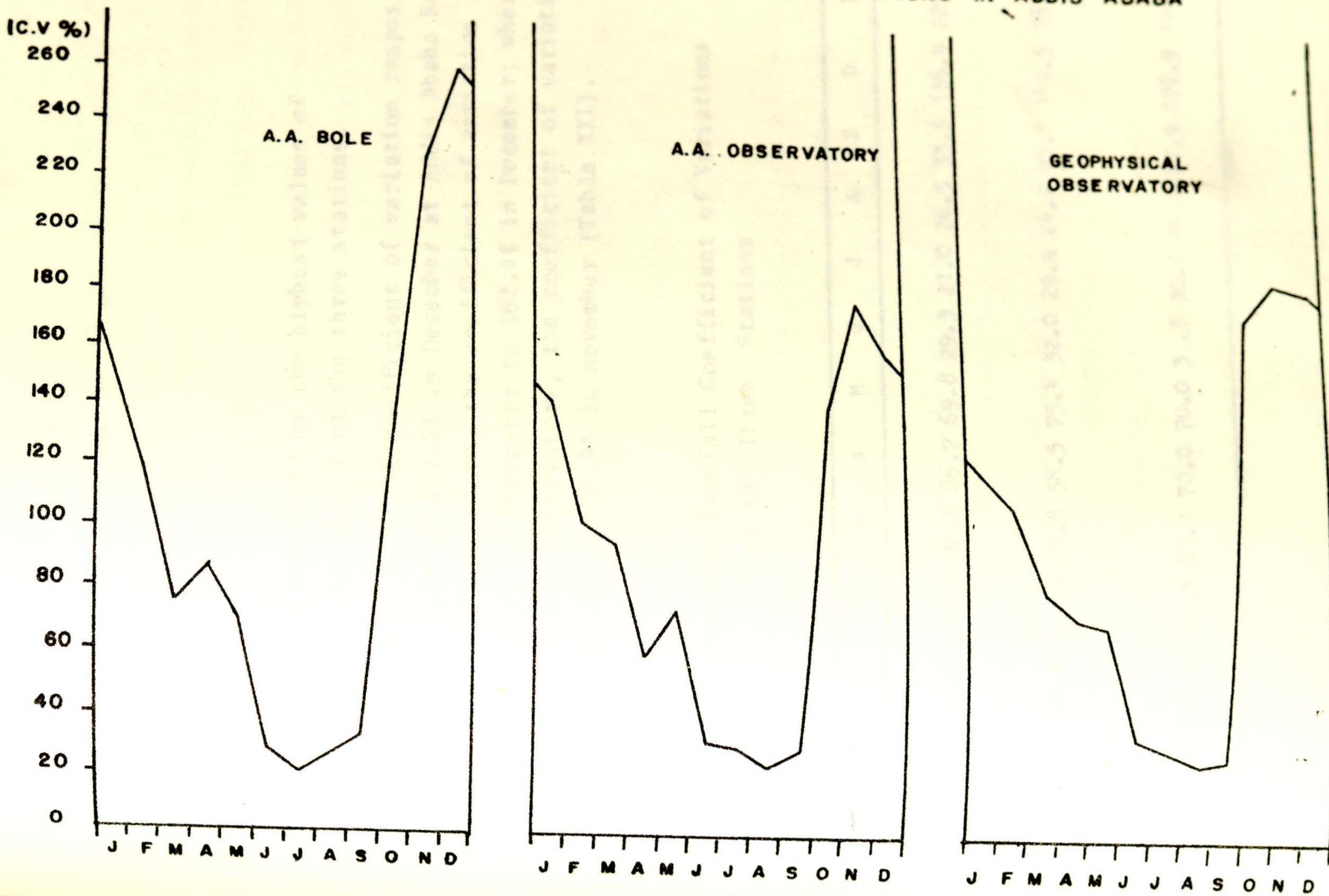
* Zero(0) indicates perfectly symmetrical distribution
neg. value(-) indicates a negatively skewed distribution
pos. value(+) indicates a positively skewed distribution.

Fig. 15 MONTHLY RAINFALL VARIABILITY AT THE THREE STATIONS IN ADDIS ABABA



Months, are characterized by the highest values of coefficient of variations at the three stations.

The monthly rainfall coefficient of variation ranges from 21.0% in July to 262.5% in December at Addis Ababa Bole. At Addis Ababa Observatory, the coefficient of variation ranges from 28.7% in September to 162.4% in December; whereas, at the Geophysical Observatory, the coefficient of variation varies from 26.4% to 190.9% in November (Table XXI).

Table XXI Monthly Rainfall Coefficient of Variations at the Three Stations

Station	J	F	M	A	M	J	J	A	S	O	N	D
A. A. Bole	154.7	119.1	76.4	86.7	69.8	29.3	21.0	26.5	33.5	136.9	227.5	262.5
A. A. Observatory	144.4	102.4	95.8	58.5	75.4	32.0	29.9	24.2	28.7	142.5	181.0	162.4
Geophysical Observatory	120.7	110.6	81.2	70.0	70.0	3 .8	30.1	26.4	27.9	178.9	190.9	187.8

4.2. <u>Decadal Rainfall Variability in Addis Ababa</u>: Fig.16 illustrates that the first and second decades of the"dry" months generally have higher coefficient of variation values than the last decades of the same months. This high first and second decade rainfall variability persists throughout the small rains and even to the first part of the big rains. Beginning from July and August, however, the third decades are associated with more variable rainfall. Tha last decade of October (whose coefficient of variation at Bole is 393%; at A.A. Observatory 478% and at the Geophysical Observatory 453%) is characterized by the highest rainfall variability in the year at the three stations(Appendix 3b)

Generally the decadal rainfalls are characterized by higher variability than the monthly rainfalls. This probably indicates uneven and highly skewed daily rainfall distributions. Whether a particular month recieves a high or low amount of rainfall, it is the destribution of that amount over the month that affects the decadal rainfall coefficient of variation. If the monthly rainfall has occurred only on a limited number of days of that month, a higher decadal rainfall variability will result than a rainfall variability of a decade where the rainfallis fairly distributed over the whole month.

The decadal rainfall coefficient of variations(Appendix3b) suggest a fair distribution of the rains over the whole month in the rainy periods than in the "dry" period at the three stations.

Fig.16 DECADAL RAINFALL VARIABILTY AT THREE STATIONS IN ADDIS ABABA

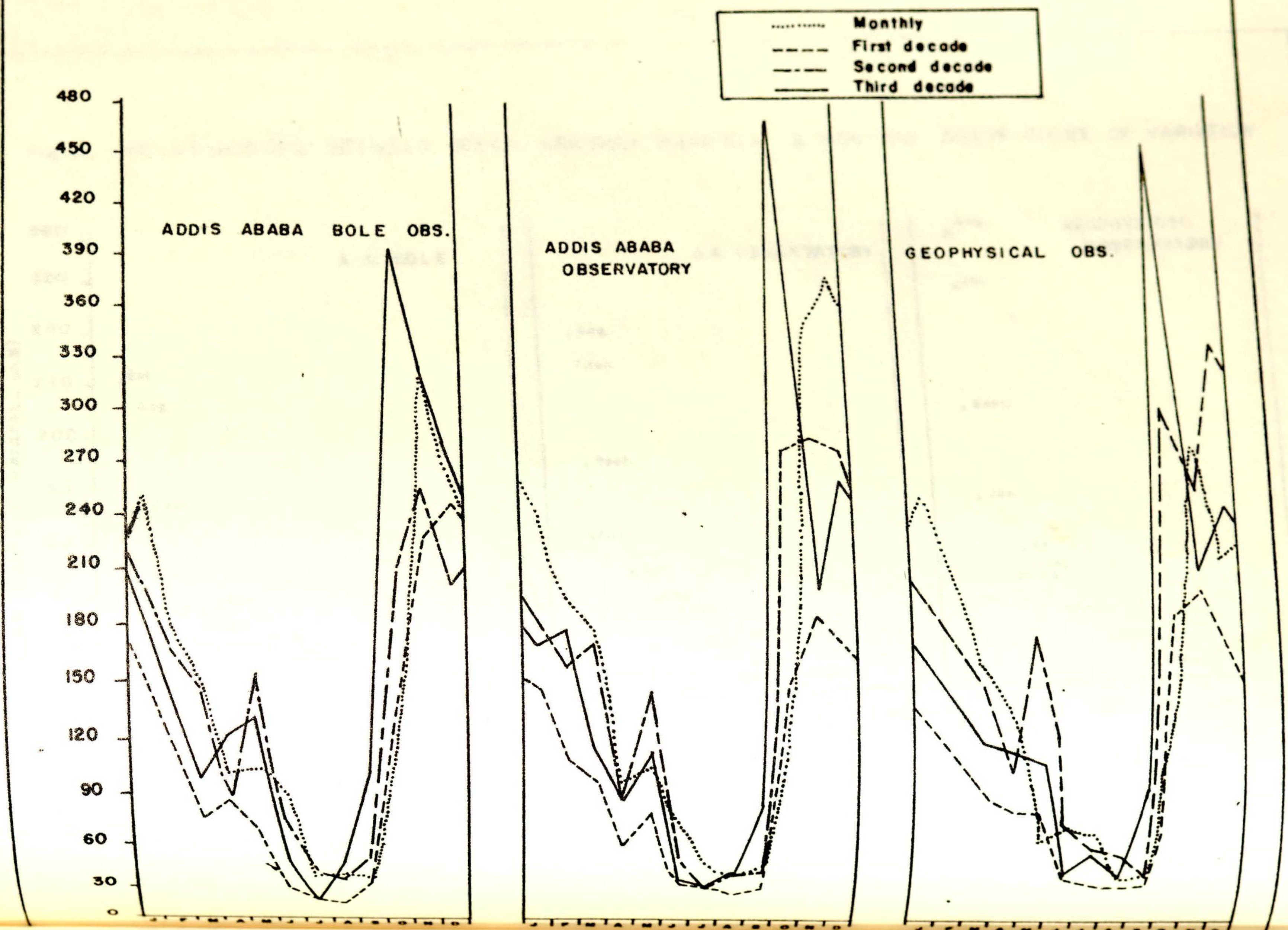
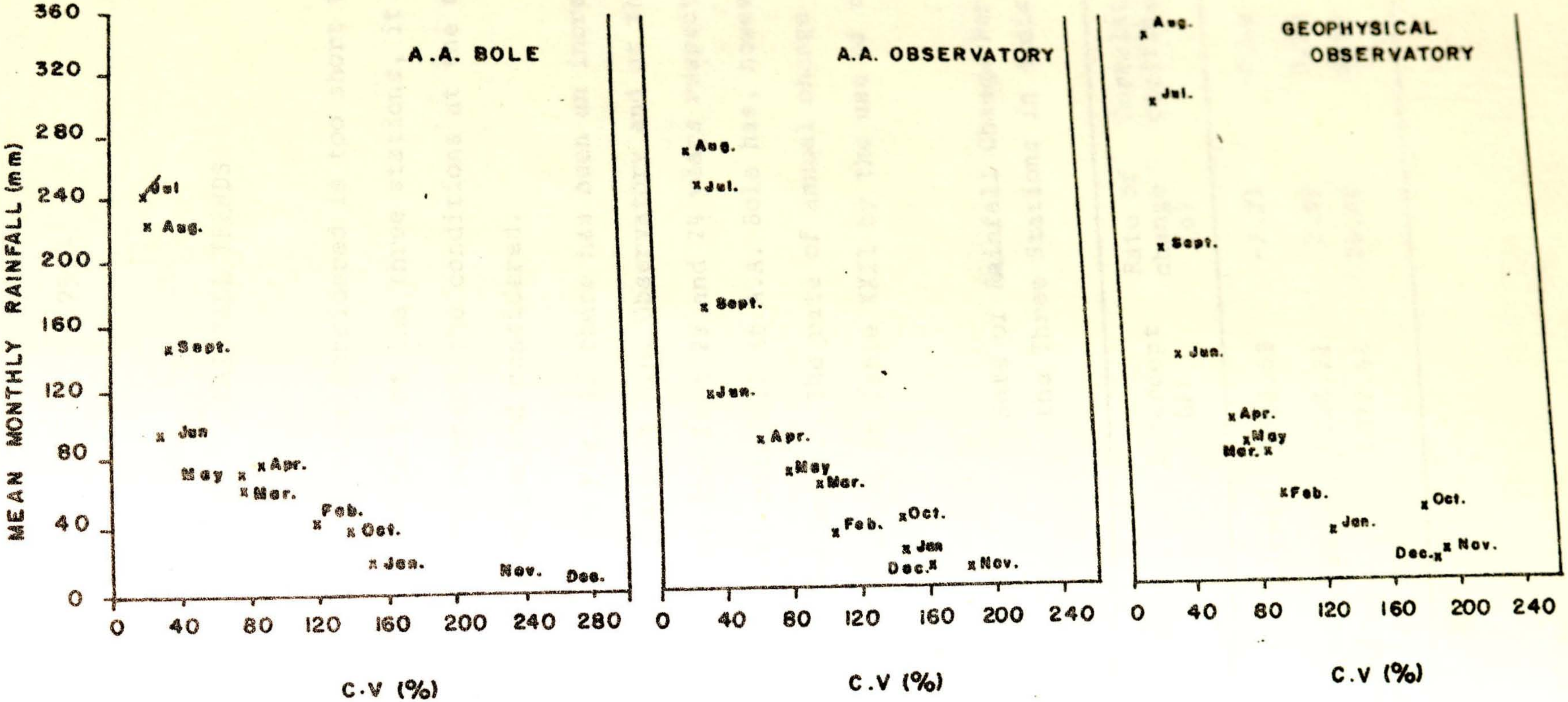


Fig.17, RELATIONSHIPS BETWEEN MEAN MONTHLY RAINFALL & MONTHLY COEFFICIENT OF VARIATION



5. RAINFALL TRENDS

Although the time considered is too short to speak of the trend of rainfall at the three stations, it has been included here to compare the conditions at the three stations only during the period considered.

As shown in Fig. 18 there has been an increasing tendency of annual rainfall at A.A. Observatory and at the Geophysical Observatory for the last 29 and 24 years respectively. The trend of annual rainfall at A.A. Bole has, however showed a decreasing tendency. The rate of annual change has been obtained and shown in Table XXII by the use of the least squares method.

Table XXII   Rate of Rainfall Change Per Year at the Three Stations in Addis Ababa

Station	Intercept (d)	Rate of change (b)	Correlation coefficient	standard error of b
A.A. Bole (17yrs)	1023.53	-2.21	-0.05	12.44
A.A. Obser.(29yrs)	1106.21	2.02	0.10	111.95
Geophysical Obser. (24 yrs)	1077.48	26.00	0.59	7.56

Fig. 18a. ANNUAL RAINFALL FLUCTUATIONS AND TRENDS AT THE THREE STATIONS IN ADDIS ABABA

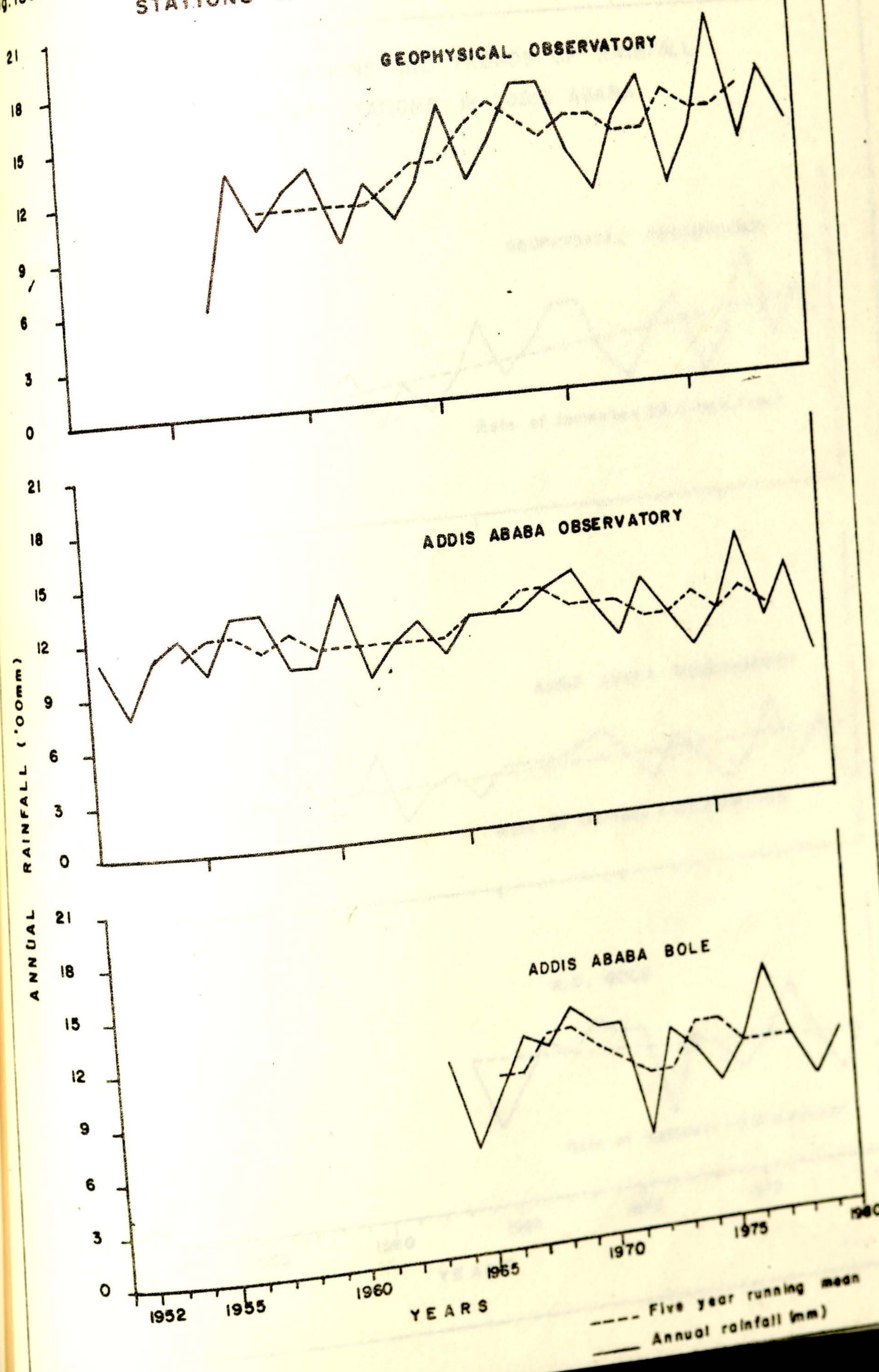
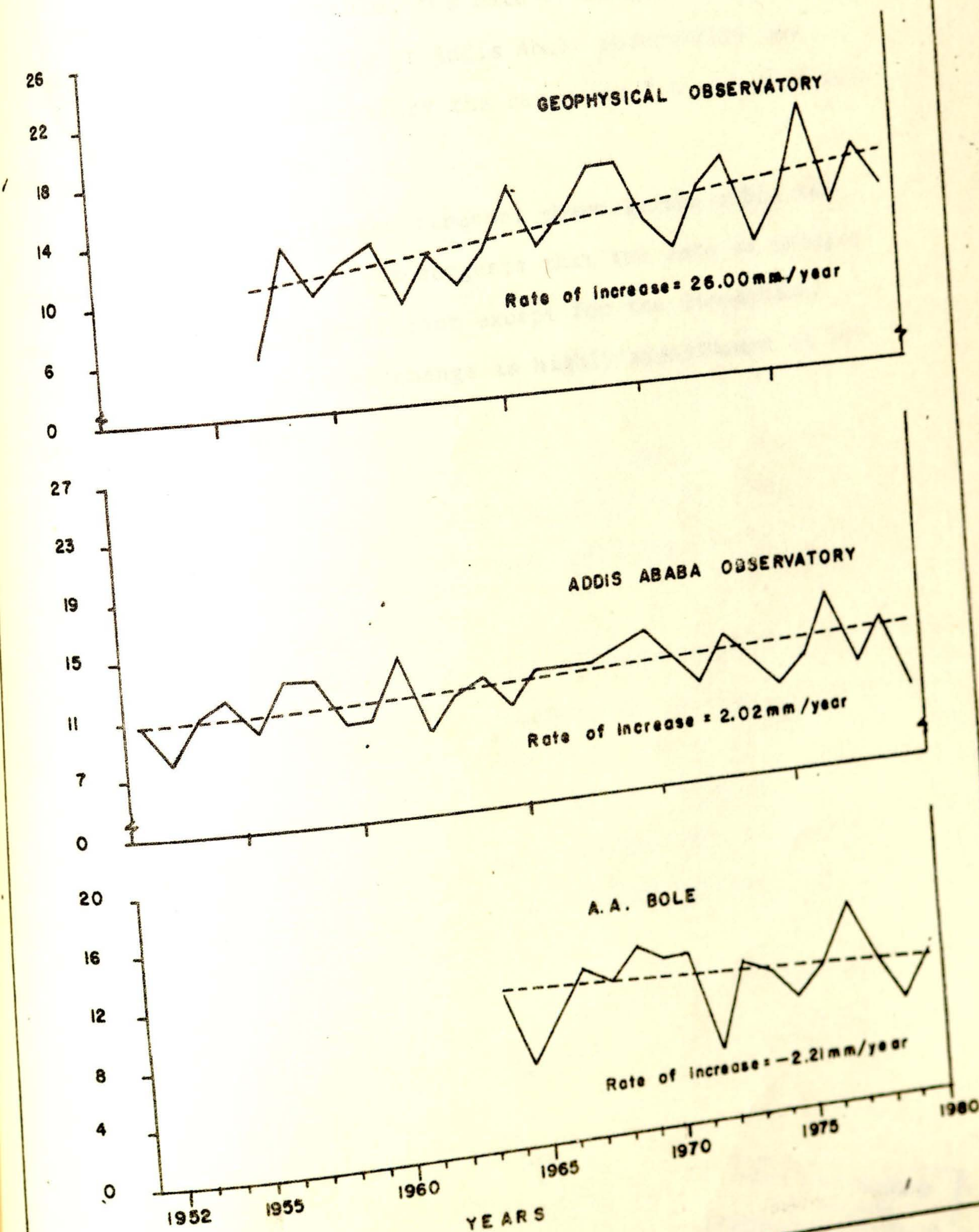


Fig. 18b ANNUAL FLUCTUATIONS AND TRENDS OF RAINFALL AT THE THREE STATIONS IN ADDIS ABABA



As shown in the table, the rate of change at A.A. Bole is -2.2 mm. per year while at Addis Ababa Observatory and at the Geophysical Observatory the rates are 2.0 and 26.0 mms. per year respectively.

Inspite of the changes (trends) shown in the table the student t distribution test suggests that the rate of chnages are statistically insignificant except for the Geophysical Observatory whose rate of change is highly significant at 95% level of confidence.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

1. SUMMARY

The details of the paper can be summarized as follows.

1.1. Surface Winds

1.1.1. The easterly surface winds are the most frequent winds at any time of the day and for eight to ten months of the year. The southeast surface winds, next to the easterlies prevail for most of the year but they disappear together with the easterlies in July and August at both A.A. Observatory and A.A. Bole.

1.1.2. In June, July, August and sSeptember, the S,SW,W and NW surfac winds are the most prevalent at both stations. The southerly surfac winds prevail from June to September to Addis Ababa Observatory whereas at Bole the occurrence of these winds is limited to the months of June and September. In the period June to August, the SW,W, and NW surface winds are the most prominent winds at Bole.

1.1.3. The periods of seasonal shift at the two stations as indicated by the wind flow diagrams of both stations are early June and September.

1.1.4. The morning hours(0600 hrs) at both stations are characterized by low surface wind speeds and calms. At Addis Ababa Observatory, a high proportion of surface winds occur at 3.5 m/sec. or below almost over the whole day while most of the surface winds at Bole flow at speeds of 3.6 m/sec.and above. In general, surface wind speeds are higher at Bole than at Addis Ababa Obsérvtory.

1.1.5. The evening winds (at 1800 hrs) in the "dry" period are faster than the midday winds of the same period at both stations. In the big rainy period(june,July, August, Sept.) however, the evening surface winds flow at lower speeds than the midday winds of the same period. The relatively higher surface winds speeds in the evening hours of the "dry" period (when the green house effect of the atmosphere is limited due to the absence of clouds) are useful to minimize the occurrences of radiation frost.

1.1.6. The months of June, July August and September are genrrally characterized by a slower surface air fllow than the rest of the year. The maximum average annual surface wind speed at A.A. Observatory occurs in October in October and November while at Bole, the maximum surface wind speed is encountered in October and March. August is a month when the surface winds flow at their minimum speed at both stations.

1.1.7. The midday and evening surface wind speeds have a marked seasonal variation while the morning surface wind speeds hardly show any clear pattern of seasonal change.

1.1.8. As described in the trend analysis, there has been a statistically significant positive change in the speed of the surface wind at Addis Ababa Obsevatory. This is not true of Bole probably due to the openness of the area and the resulting absence of turbulent air flow; whereas in the case of A.A. Observatory, the increasing temperature contrasts between the station and the surrounding regions might have led to an increasing surface wind speed.

1.2 Temperature

1.2.1. Addis Ababa Observatory with a mean temperature of 15.9°C is the hottest of the three climatic stations in the city. Addis Ababa Bole and the Geophysical Observatory have mean temperatures of 15.6°C and 15.1°C respectively.

1.2.2. The highest annual range of temperature (4.2°C) is encountered at A.A. Bole while A.A. Observatory and the Geophysical Observatory experience annnual temperature ranges of 3.5°C and 3.0°C respectively.

1.2.3. May is the hottest month while December is the coldest month at the three stations. March, April and May constitute the hottest period of the year while October, November and December constitute the coldest period of the year at the three stations.

1.2.4. The big rainy period (with the exception of September when the temperature at the three stations shows an increase) is characterized by ralatively lower temperatures probably due to the increased cloudiness that reduces incoming short wave radiation.

1.2.5. The maximum temperatures at Bole and at A.A.Observatory showed a decreasing tendency while the minimum temperatures of the three stations showed an increasing tendency over the years considered.

1.3. Rainfall

1.3.1. The three climatic stations vary in the magnitude of their rainfall. The lowest amount of annual rainfall (1061.3mm) occurs at A.A. Bole while A.A. Obsevatory and the Geophysical Observatory get 1150.2mm. and 1345.6.mm. of annual rainfall respectively.

1.3.2. The months comprising the periods designated as dry period, amall rains and big rains are similar at the three stations. The time of rainfall onset, advance and retrear as shown by the Ogive curve made(cumulative percentage curve) are essentially similar at the three stations.

1.3.3. July is the wettest month at A.A. Bole while August in the wettest month at the other two climatic station. November is the driest month at A.A. Observatory; whereas, for the Geo- physical Observatory and Bole, the driest month is December.

1.3.4. The pattern of annual rainfall distribution is more dispersed and more skewed to the right at A.A. Bole than at the other two stations. The annual rainfall distribution at A.A. Observatory is the closest to normal distribution. Inspite of the differences among the three stations in the degree of skewness, the distribution is skewed to the right at the three stations.

1.3.5. The higher degree of positive skewness of the annual rainfall distribution at A.A. Bole indicates a relatively lower amounts of rainfall at that station. The relatively low amount of rainfall at Bole, is more variable than the rain at the other two stations.

1.3.6. Rainfall variability deacreases towards the rainy periods at the three stations. The decadal rains at the three stations are characterized by very high rainfall variability.

1.3.7. The rainfall at Addis Ababa Observatory and at the Geophysical Observatory has shown an increasing tendency while the rain at A.A. Bole showed a decreasing tendency over the years considered. The changes, however have not been found to be statistically significant except for the Geophysical Observatory whose rainfall rate of increase has been statistically significant at 95% level of confidence.

2. RECOMMENDATIONS

The treatment of the three climatic elements of temperature, rainfall and winds at the three climatic stations gives a better picture of the climatic conditions of Addis Ababa than a study made on data gathered at one station would give.

Using the data collected at the three stations, it has been possible to discover some differences among the three stations in temperature, in wind speed and in rainfall amounts. A study based on data collected at greater number of stations would be expected to disclose more realistic and diversified climatic features of Addis Ababa. Additional number of climatic stations in different parts of the city should, therefore, be established.

Inorder to appreciate the influence of urbanization on the climatic conditions at Addis Ababa, data gathered at the different climatic stations within the city must be compared to data collected around the city. Such a comparison would help understand as to whether or not the climatic condition at Addis Ababa resembles that of the surrounding rural areas. It also helps to understand whether or not a recommendation made on the basis of a climatic study at Addis Ababa would hold true to the surrounding areas. The writer again suggests that climatic stations be installed in the outskirts of the city.

APPENDIX 1a

A.A. Observatory:

Mean Wind Speed (m/sec.) at 2m

Years	J	F	M	A	M	J	J	A	S	O	N	D	Mean of the year
1951	1.4	1.6	1.2	-	1.9	0.8	0.9	0.5	1.2	1.8	1.9	1.4	1.2
52	1.5	1.8	1.7	1.0	1.5	0.9	0.6	0.7	1.0	1.5	2.8	2.3	1.3
53	1.8	2,0	2.6	1.3	2.2	0.7	0.6	0.6	0.9	1.7	2.0	1.8	1.5
54	1.3	1.9	1.0	1.2	1.2	0.5	0.5	0.4	0.5	1.6	2.2	1.2	1.1
55	1.0	0.9	1.6	1.5	1.4	0.5	0.5	0.4	0.7	1.5	1.7	1.3	1.0
56	0.6	0.7	1.1	0.6	0.5	0.4	0.3	0.3	0.3	0.8	0.9	0.7	0.6
57	0.5	0.6	0.6	0.4	0.4	0.3	0.3	0.6	0.6	1.0	0.8	0.8	0.6
58	0.5	0.8	0.6	0.7	0.9	0.4	0.3	0.3	0.3	0.6	0.7	0.6	0.5
59	0.4	0.6	0.6	0.6	0.4	0.4	0.3	0.2	0.2	0.7	0.7	1.0	0.5
1960	1.1	1.5	1.0	1.0	0.6	0.7	0.5	0.6	0.6	1.3	1.3	1.2	0.9
61	1.1	1.5	1.2	0.7	0.8	0.5	0.6	0.6	0.6	1.1	1.1	1.2	0.9
62	1.1	1.1	0.9	0.7	1.0	0.6	0.6	0.7	0.8	1.2	1.4	1.0	0.9
63	1.0	1.4	2.5	1.8	2.1	1.4	1.3	1.6	1.6	2.5	2.6	2.2	1.8
64	2.7	2.2	2.4	3.9	3.3	2.2	1.6	1.8	2.1	3.7	2.8	2.2	2.5
65	2.4	2.2	2.6	1.5	3.7	1.2	1.2	1.3	2.0	2.8	3.6	2.6	2.2
66	3.0	1.8	2.5	2.5	3.5	1.2	1.5	1.9	2.6	2.8	2.7	2.0	2.3
67	3.2	3.3	2.6	2.3	2.3	2.1	1.4	1.2	1.2	3.1	2.4	2.3	2.2
68	2.3	1.4	2.4	2.1	2.6	1.8	2.0	1.5	1.9	3.1	2.7	2.4	2.1
69	2.5	2.5	2.8	2.7	2.2	1.6	1.5	1.4	1.8	3.1	4.0	2.8	2.4
1970	1.8	2.5	2.3	2.4	2.5	1.5	2.0	1.4	1.5	3.1	3.3	2.7	2.2
71	2.2	3.3	3.5	2.2	1.8	1.8	1.3	1.4	1.3	2.2	2.8	2.0	2.1
72	2.3	2.0	2.5	1.4	2.6	2.4	1.8	2.2	2.7	4.0	3.6	3.5	2.5
73	3.4	3.6	3.7	4.0	3.5	2.5	2.1	1.6	2.2	2.6	4.0	3.5	3.0
74	3.8	4.4	3.3	3.8	3.3	2.5	2.1	1.7	2.1	4.3	4.4	4.3	3.3
75	4.0	4.4	3.8	3.3	3.5	2.5	2.5	2.3	2.5	4.8	5.3	4.3	3.6
76	1.8	4.1	3.8	3.6	3.5	2.7	2.7	2.2	3.2	4.9	3.1	4.0	3.3
77	2.8	3.1	3.8	2.1	2.6	2.4	2.3	2.6	2.4	2.9	3.9	4.1	2.9
78	-	3.3	3.5	4.4	3.3	2.7	2.9	2.7	3.6	3.9	-	3.7	3.4
79	3.3	3.9	3.6	3.9	4.3	3.0	3.0	2.7	2.5	4.6	-	3.8	3.5
80	3.1	4.1	4.2	3.8	3.6	2.2	-	-	2.8	4.1	4.9	4.2	3.7
mean	2.0	2.3	2.3	2.1	2.2	1.5	1.3	1.3	1.6	2.6	2.6	2.4	2.0

- missing data

APPENDIX 1b

A.A. Bole

Mean Wind Speed (m/sec) at 10 m.

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean of the yr. m/sec.
1964	5.1	6.8	4.3	5.4	4.5	3.2	4.8	2.8	2.4	3.8	3.9	4.2	4.3
1965	4.1	4.6	5.2	4.1	4.5	3.2	3.0	2.9	2.9	3.9	4.4	3.7	3.9
1966	3.9	3.0	4.8	4.1	5.0	2.8	2.6	2.6	4.0	4.6	4.5	3.9	3.8
67	4.7	4.9	4.7	3.5	3.0	3.0	3.4	2.7	2.4	4.3	3.8	3.2	3.7
68	3.7	2.5	4.0	3.2	4.1	3.3	3.3	2.6	3.2	5.5	5.7	4.6	3.8
69	4.1	3.7	5.1	4.8	4.1	3.1	2.8	2.8	3.6	5.3	5.2	4.6	4.1
1970	2.9	3.6	3.6	3.7	4.1	2.8	3.1	2.3	2.9	5.0	4.6	4.0	3.6
71	4.1	4.8	5.2	4.1	3.0	2.6	2.8	3.0	2.5	4.3	5.0	3.9	3.8
72	4.1	3.7	4.6	-	-	-	-	2.9	3.2	5.2	4.7	4.0	4.1
73	4.0	4.7	5.6	6.0	4.4	3.4	3.0	2.3	2.4	4.9	4.9	4.2	4.2
74	4.6	5.6	4.0	5.6	4.6	3.9	3.6	3.8	3.2	-	5.4	-	4.4
75	4.9	5.2	5.2	4.7	5.2	4.0	4.0	3.6	3.5	4.5	5.2	4.5	4.5
76	4.8	5.4	4.9	4.9	3.9	3.2	3.2	3.5	4.4	6.0	3.7	5.8	4.5
77	5.5	6.0	7.1	5.9	5.6	5.4	5.0	4.0	5.3	5.9	5.7	6.1	5.7
78	6.4	5.3	6.3	7.0	5.7	5.6	5.5	5.2	4.0	5.0	5.0	4.6	5.5
79	4.1	4.1	4.3	4.8	4.8	4.2	3.3	3.5	3.5	5.0	4.5	4.1	4.2
1980	4.0	4.5	4.8	4.6	-	3.8	-	3.5	3.5	4.4	-	3.9	4.1
mean	4.4	4.6	4.9	4.8	4.4	3.6	3.6	3.2	3.3	4.9	4.8	4.3	4.2

- missing data

APPENDIX 2a

Mean Monthly Maximum Temprature at the Three Stations

Stations	Decade	J	F	M	A	M	J	J	A	S	O	N	D	Annual
A.A. Bole	1	22.3	23.5	24.4	24.3	24.1	24.5	21.4	20.5	21.4	22.1	22.2	22.3	
	2	22.8	23.8	24.6	24.5	25.1	23.1	20.9	20.5	21.2	22.7	22.2	20.8	
	3	23.1	24.0	24.5	24.8	24.9	22.0	10.9	21.2	22.1	22.7	23.5	22.4	
	Average	22.7	23.8	24.5	24.5	24.7	23.2	20.4	20.7	21.6	22.5	22.6	21.8	22.8
A.A. Obs.	1	22.3	23.3	24.2	23.7	23.8	23.6	20.3	19.6	20.6	21.3	21.8	22.1	
	2	22.7	23.6	24.1	23.8	24.6	22.2	19.9	19.9	20.5	22.0	21.7	21.1	
	3	22.9	23.8	23.2	23.8	23.8	21.3	19.5	19.4	21.1	22.1	20.6	21.1	
	Average	22.6	23.5	23.8	23.8	24.1	22.4	19.9	19.6	20.7	21.8	21.4	22.4	22.2
Geophysical Obs.	1	21.8	22.7	23.2	23.0	22.6	23.3	19.7	19.0	20.0	20.8	21.5	21.6	
	2	22.1	23.0	23.2	22.8	23.8	21.8	19.4	19.1	19.7	21.6	21.3	21.6	
	3	22.4	23.1	22.9	23.0	22.4	20.5	18.9	19.7	20.8	21.8	21.3	21.8	
	Average	22.1	22.9	23.1	22.9	22.9	21.9	19.3	19.3	20.2	21.4	21.4	21.7	21.6

APPENDIX 2b

Mean Minimum Temprature (^oC) at the Three Stations

Stations	Decades	J	F	M	A	M	J	J	A	S	O	N	D
A. A. Bole	1	5.7	7.4	8.3	10.3	10.3	9.7	10.5	10.6	10.2	8.9	5.3	3.8
	2	6.6	8.2	9.5	9.6	9.8	9.5	10.0	10.7	9.8	7.5	5.2	4.8
	3	1.0	8.3	9.2	10.0	10.0	10.2	10.7	10.3	9.5	6.6	4.9	5.0
	Average	6.4	8.0	9.0	10.0	10.0	9.8	10.4	10.5	9.8	7.7	5.1	4.5
A. A. Observatory	1	7.5	8.8	9.6	11.0	11.5	10.7	10.4	10.2	10.4	9.9	7.8	6.9
	2	7.9	9.2	10.1	11.1	11.6	10.3	10.7	10.6	10.3	8.7	7.6	7.1
	3	8.1	9.4	10.9	11.4	11.3	10.1	10.6	10.4	10.9	8.3	7.3	7.6
	Average	7.8	9.1	10.1	11.2	11.5	10.4	10.6	10.4	10.5	9.0	7.6	7.2
Geophysical Observatory	1	6.0	7.7	8.7	10.2	10.5	9.3	10.1	10.0	9.4	8.7	5.9	5.0
	2	6.6	7.9	9.7	10.1	10.3	9.0	10.0	9.6	9.0	7.3	6.3	5.4
	3	7.4	8.2	10.0	10.4	9.9	9.6	10.1	9.4	9.1	6.2	5.9	6.0
	Average	6.7	7.9	9.5	10.2	10.2	9.3	10.1	9.7	9.2	7.4	6.0	5.5

APPENDIX 3a

Monthly Rainfall Mean, Median, Standard Deviation and Coefficient of Variation at the Three Stations

Station		J	F	M	A	M	J	J	O	S	O	N	D	Annueal
A.A.Bole	X̄	17.9	40.4	63.1	74.6	76.8	114.8	244.2	233.3	144.1	39.3	9.1	4.0	1061.3
	med	5.7	15.7	52.4	65.9	86.6	124.8	256.5	228.4	128.8	24.8	0.0	0.0	1030.0
		27.7	48.1	48.2	64.7	53.6	33.6	51.4	61.8	48.3	53.8	20.7	10.5	236.0
	C,V(%)	154.7	119.1	76.4	86.7	69.8	29.3	21.0	26.5	33.5	136.9	227.5	262.5	22.2
A.A. Observatory	X̄	20.0	32.7	62.6	90.3	68.2	116.0	251.3	273.1	174.4	40.0	9.9	11.7	1150.2
	med	11.4	24.0	43.2	83.8	53.5	123.5	240.5	277.9	179.0	12.5	1.4	0.0	1141.9
		27.0	34.7	59.4	52.8	51.4	37.1	72.6	66.2	50.1	57.0	18.1	19.0	174.8
	C.V(%)	144.4	102.4	95.8	58.5	75.4	32.0	29.9	24.2	28.7	142.5	181.0	162.4	15.2
Geogphy. Observatory	X̄	28.0	47.1	75.5	92.7	79.1	132.1	297.0	330.9	197.6	39.8	14.3	11.5	1345.6
	med	17.4	25.6	71.0	75.2	57.2	130.9	284.0	329.5	197.0	12.2	1.8	2.2	1315.2
		33.8	52.1	61.3	64.9	55.4	44.7	89.4	87.2	55.1	71.2	27.3	21.6	242.78
	C.V(%)	120.7	110.6	81.2	70.0	70.0	33.8	30.1	26.4	27.9	178.9	190.9	187.8	18.0

APPENDIX 3b

Decalal Rainfall Mean, Median, Standard Deviation and Coefficient of Variation at the three Stations

STATIONS		J DECADE 1	J DECADE 2	J DECADE 3	F DECADE 1	F DECADE 2	F DECADE 3	M DECADE 1	M DECADE 2	M DECADE 3
A.A. Bole	$\bar{X}$	4.0	6.6	6.9	15.7	14.8	10.1	12.1	18.3	32.5
	med	0.0	0.0	1.0	0.2	5.8	0.0	7.0	2.8	26.0
		10.0	13.5	12.7	28.6	24.8	14.5	18.3	27.3	31.8
	C.V	250.0	204.5	184.1	182.2	167.6	143.6	152.2	149.2	97.8
A.A. Observatory	$\bar{X}$	2.6	8.1	9.5	9.5	10.7	10.9	18.0	19.4	26.1
	med	0.0	0.0	0.1	0.6	1.8	0.2	1.6	1.5	13.5
		6.2	14.6	15.8	18.2	16.6	19.2	31.2	32.2	28.3
	C.V	238.5	180.2	166.3	191.6	155.1	176.1	173.3	166.0	108.4
Geophysical Observatory	$\bar{X}$	3.5	10.1	12.4	13.8	18.7	12.4	15.9	22.3	34.2
	med	0.0	0.4	2.7	4.1	3.1	2.2	0.4	6.9	21.3
	-	8.6	19.0	19.0	28.2	30.5	16.4	24.0	31.1	37.4
	C.V	245.7	188.7	153.2	204.3	163.1	132.3	150.9	139.5	109.4

APPENDIX 3b Continued

STATIONS		A			M			J		
		DECADE			DECADE			DECADE		
		1	2	3	1	2	3	1	2	3
A.A. Bole	$\bar{X}$	37.3	17.3	16.1	37.4	5.7	26.7	19.8	2.9	58.8
	med	28.5	11.5	8.7	24.9	0.4	7.3	10.8	25.8	64.3
		40.0	16.6	26.4	40.5	48.8	34.7	16.5	22.3	28.4
	C.V	107.2	96.0	164.0	108.3	154.4	130.0	83.3	74.6	48.3
A.A. Observatory	$\bar{X}$	33.0	27.3	29.6	29.5	11.6	26.3	22.1	31.5	60.3
	med	31.0	22.6	27.2	18.9	1.1	22.0	17.0	36.5	58.4
		30.8	23.5	38.6	31.9	16.5	28.5	15.6	18.0	20.6
	C.V	93.3	86.1	130.4	108.1	142.2	168.4	70.6	49.3	34.2
Geophysical Observatory	$\bar{X}$	33.0	28.6	27.1	40.7	10.1	28.2	25.9	39.5	66.8
	med	27.2	24.6	17.0	27.0	1.2	20.0	25.6	38.9	61.9
		43.1	27.5	39.4	40.4	16.8	27.3	15.9	15.4	24.3
	C.V	130.6	96.2	145.4	99.3	166.3	96.8	61.4	64.3	36.4

APPENDIX 3b Continued

Stations		J			A			S		
		DECADE			DECADE			DECADE		
		1	2	3	1	2	3	1	2	3
A.A. Bole	$\bar{X}$	67.3	85.1	94.8	84.2	74.9	74.6	67.0	55.0	21.4
	med	68.6	87.5	98.5	76.2	67.9	71.6	74.1	50.6	17.1
		25.8	32.2	18.6	33.1	27.0	79.9	24.3	27.5	21.5
	C.V	38.3	37.8	19.6	39.3	36.0	107.1	36.3	50.0	100.5
A.A. Observatory	$\bar{X}$	81.1	76.6	93.2	89.9	87.5	94.9	81.6	59.3	35.1
	med	78.9	72.8	96.4	83.2	82.5	89.1	81.7	57.3	34.8
		35.8	21.1	27.2	34.2	32.4	100.6	34.3	24.6	27.8
	C.V	44.1	27.5	29.2	38.0	37.0	106.0	42.0	41.5	79.2
Geophysical Observatory	$\bar{X}$	93.4	95.1	108.5	112.4	108.9	108.9	93.1	72.1	31.7
	med	87.0	84.8	100.5	112.6	111.5	98.0	88.9	72.3	30.3
		55.4	42.3	76.6	34.7	49.4	114.9	30.5	24.8	27.7
	C.V	59.3	49.7	70.6	30.9	45.4	105.5	32.8	34.4	87.4

APPENDIX 3b Continued

Station		O			N			D		
		DECADE			DECADE			DECADE		
		1	2	3	1	2	3	1	2	3
A.A. Bole	$\bar{X}$	18.0	5.2	11.5	3.8	4.2	0.6	0.0	0.2	3.6
	med	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		20.9	10.8	45.2	12.0	10.6	1.9	0.0	0.4	10.1
	C.V	115.5	207.7	393.0	315.8	252.4	316.7	0.0	200.0	280.6
A.A. Observatory	$\bar{X}$	23.4	7.3	9.2	2.2	4.8	2.7	0.4	6.2	4.8
	med	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		28.1	20.0	44.0	7.6	13.5	5.2	1.5	17.0	12.3
	C.V	120.1	274.0	478.3	445.5	281.2	192.6	375.0	274.2	256.3
Geophysical Observatory	$\bar{X}$	20.8	4.6	14.5	4.2	8.0	2.1	1.0	2.6	7.8
	med	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		25.5	13.7	65.7	11.5	19.9	4.3	2.1	8.7	18.7
	C.V	122.6	297.8	453.1	273.8	248.8	204.8	210.0	334.6	239.7

APPENDIX 3c

Percentage Contributions of each Decade from the Annual Rainfall and Cumulative Percentages

Month	Decade	A.A. Bole Rainfall mm	%	cum %	A.A. Observatory Rainfall mm.	%	cum %	Geophysical Observatory Rainfall mm.	%	cum %
	1	18.1	1.738	1.738	23.4	2.032	2.032	20.8	1.572	1.572
October	2	5.2	0.499	2.237	7.3	0.634	2.666	4.6	0.348	1.920
	3	11.3	1.104	3.341	9.2	0.799	3.465	14.5	1.096	3.016
	1	3.8	0.365	3.706	2.2	0.191	3.656	4.2	0.317	3.333
November	2	4.2	0.403	4.109	4.8	0.417	4.073	8.0	0.605	3.938
	3	0.6	0.058	4.167	2.7	0.235	4.308	2.1	0.159	4.097
	1	0.0	0.000	4.167	0.4	0.035	4.343	1.0	0.075	4.172
December	2	0.2	0.019	4.186	6.2	0.539	4.882	2.6	0.197	4.369
	3	3.6	0.346	4.532	4.8	0.417	5.299	7.8	0.590	4.959
	1	4.0	0.384	4.916	2.6	0.226	5.525	3.5	0.265	5.224
January	2	6.6	0.634	5.550	8.1	0.704	6.229	10.1	0.763	5.987
	3	6.9	0.663	6.213	9.5	0.825	7.054	12.4	0.937	6.924

APPENDIX 3c Continued

Month	Decade	A.A Bole Rainfall mm	%	cum %	A.A. Observatory Rainfall mm.	%	cum %	Geophysical Observatory Rainfall mm.	%	cum %
February	1	15.7	1.507	7.720	9.5	0.825	7.879	13.8	1.043	7.967
	2	14.8	1.421	9.141	10.7	0.929	8.808	18.7	1.414	9.381
	3	10.1	0.970	10.111	10.9	0.947	9.755	12.4	0.937	10.318
March	1	12.1	1.162	11.273	18.0	1.563	11.318	15.9	1.202	11.520
	2	18.3	1.757	13.030	19.4	1.685	13.003	22.3	1.686	13.206
	3	32.5	3.120	16.150	26.1	2.267	15.270	34.2	2.585	15.791
April	1	37.3	3.581	19.731	33.0	2.866	18.136	33.0	2.495	18.286
	2	17.3	1.661	21.392	27.3	2.371	20.507	28.6	2.162	20.448
	3	16.1	1.564	22.938	29.6	2.571	23.078	27.1	2.049	22.497
May	1	37.4	3.591	26.529	29.5	2.562	25.640	40.7	3.077	25.574
	2	5.7	0.547	27.076	11.6	1.008	26.648	10.1	0.763	26.337
	3	26.7	2.564	29.640	26.3	2.284	28.932	28.2	2.132	28.469

APPENDIX 3c Continued

Month	Decade	A.A. Bole			A.A. Observatory			Geophysical Observatory		
		Rainfall mm	%	cum %	Rainfall mm	%	cum %	Rainfall mm.	%	cum %
June	1	19.8	1.901	31.541	22.1	1.920	30.852	25.9	1.958	30.427
	2	29.9	2.871	34.412	36.5	3.170	34.022	39.5	2.986	33.413
	3	58.8	5.646	40.058	60.3	5.238	39.260	66.8	5.050	38.463
July	1	67.3	6.462	46.520	81.1	7.044	46.304	93.4	7.060	45.523
	2	85.1	8.171	54.691	76.6	6.653	52.957	85.1	6.433	51.956
	3	94.8	9.102	63.793	93.2	8.095	61.052	108.5	8.202	60.158
August	1	84.2	8.084	71.877	89.9	7.809	68.861	112.4	8.469	68.654
	2	74.9	7.192	79.069	87.5	7.600	76.461	108.9	8.232	76.886
	3	74.6	7.163	86.232	94.9	8.243	84.704	108.9	8.232	85.118
Sepember	1	67.0	6.433	92.665	81.6	7.088	91.792	93.1	7.038	92.156
	2	55.0	5.282	97.946	59.3	5.151	96.943	72.1	5.450	97.606
	3	21.4	2.055	100.001	35.1	3.049	99.992	31.7	2.396	100.002
Total		1061.3			1150.9			1345.6		

FOOT NOTES

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DECLARATION

I the undersigned declare that this thesis is my work and that all sources of materials used for the thesis have been fully acknowledged.

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