A contribution to the climatic studies on Saudi Arabia

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ABSTRACT

The climate of Saudi Arabia has not been studied in any detail and this thesis is an attempt to analyse the general climatic conditions of the country.

Chapter I comments on the difficulties that are manifest in climatic studies of the area and also refers to work that has been carried out on some parts of the country. Specifically, the chapter is concerned with the needs for more detailed and comprehensive climatic research on Saudi Arabia.

A number of geographical factors are considered, in chapter II, to affect the distribution of the climatic elements:-

the latitude, the geographical location relative to the land masses, the position relative to the waterbodies and the altitude.

Chapter III is a brief description of the topography of the study area. Subdivision into topographic units of Saudi Arabia is made on the basis of variations in elevations and type of landscape.

Air masses and fronts and the pressure systems that dominate the country in winter and summer, are discussed in some detail in chapter IV. Some references to the winter and summer depressions are also made in this chapter.

In chapter V an attempt is made to describe the velocity and direction of winds. According to their directions, they are classified into three types - the north-west, the south-east monsoon and the south-west monsoon. Special consideration is placed on the phenomenon of sand and dust storms as a climatic factor affecting visibility.

In chapters VI and VII air temperatures and precipitation have been considered in some detail but, unfortunately a full treatment is

not possible due to lack of data. However, while inter-seasonal variations in temperature were found to be large, intra-seasonal conditions seem to be comparatively uniform. Most of rainfall, although low, occurs in the winter season. It is very variable from one year to another and also varies in incidence spatially. The only area which receives relatively high constant precipitation is the high land of the south-west region of Saudi Arabia.

The study concludes in chapter VIII by classifying Saudi Arabia into climatic regions on the basis of Koppen's system. While a major part of the country is classified as an extremely arid region, limited areas in the mountainous south-west exhibit considerable climatic variations.

A CONTRIBUTION TO THE CLIMATIC STUDIES
ON SAUDI ARABIA

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CHAPTER I

INTRODUCTION

Saudi Arabia is mainly an arid country, though it is affected in the south by the south west monsoon during the period June to August, and by the Mediterranean depressions from the north during the period October to May which bring some rain. While there are areas which experience rainfall each year, there are many areas which do not record rainfall for several consecutive years. Climatic stations in the north of the country generally do not experience rainfall during the period June to September, while others in the south west have the main rainy season during the period April to August.

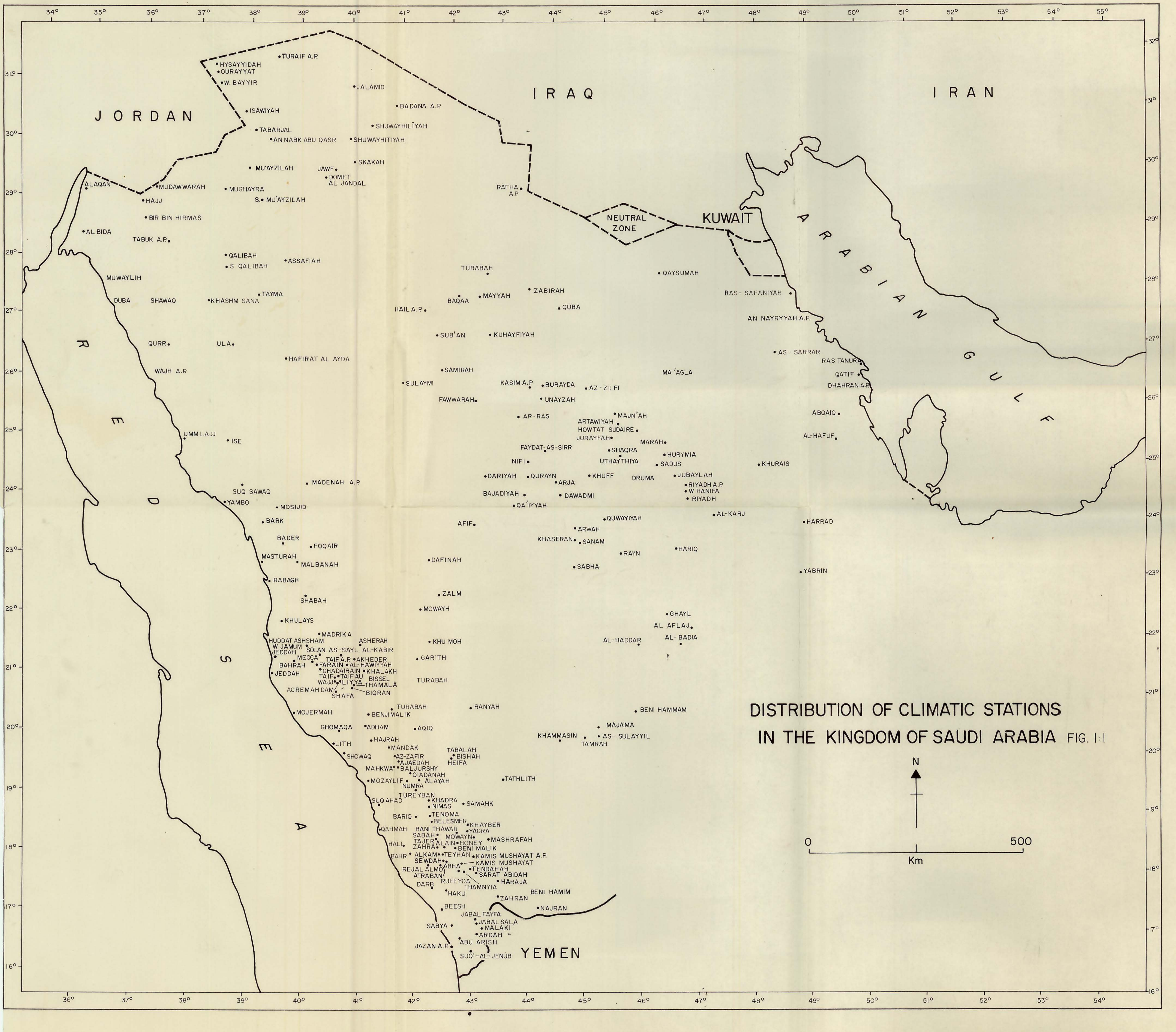
Though the country can be taken generally as an arid zone, there are the high mountains of Asir which exhibit a range of climatic types; the mountainous climate on the high peaks, the steppe regions on the lower peaks of the escarpment, and the arid conditions which cover the low slopes. However, the arid climate which composes the major part of the country can be classified as a hot desert type.

The climate of Saudi Arabia is, in fact, more complex than this simplification would suggest, for parts may be affected by polar air masses which may be dry or humid, while others may be affected by dry or humid tropical air masses. These air masses vie for supremacy, either over the country or over the surrounding regions, and thus give very variable weather conditions from year to year. Because of this complexity and the lack of long term climatic records one cannot, at present, study the climate of this country without encountering some difficulties.

The climate of Saudi Arabia has not yet been studied in any detail. Indeed, in a report (Baumer, 1964) it is emphasised that a knowledge of climate is essential to "smooth overall development, especially to that of agriculture and satisfactory hygiene; it does not merely consist in recording rain, wind and temperature measurements, but also in interpreting them as well as a whole series of phenomena such as intensity of evaporation, duration and rhythm of insolation, evapotranspiration, frosts, sand storms, length of potential growth period for each plant species, rate of growth of plant, etc....."

However, the climatic conditions which exist and the factors which control or affect them have not been expounded clearly or properly. The present study represents the first attempt to summarise the climatic conditions of the country. It discusses the regional differences and the geographical distribution of the climatic elements and describes the factors which control the climate.

A study of this type brings to light major difficulties: the available data are not of a long term nature and rarely commence at the same time. Different distinct short term periods may also be represented. Some stations have records for fifteen or twenty years while others only cover three to five years. Hence, they may fail to show abnormalities and cannot be relied upon as an accurate indication of long term features. The stations are not of sufficient number to cover such a wide country as Saudi Arabia and their records do not give good results for climatic study due to their poor geographical distribution (Figure 1(I)). They are mostly concentrated in the central and south-western regions, are fewer in the northern and eastern regions, and are absent in the Empty Quarter. Furthermore, a large proportion of the climatic stations have solely recorded rainfall



DISTRIBUTION OF CLIMATIC STATIONS IN THE KINGDOM OF SAUDI ARABIA FIG. 1:1

while others omit measurement of other important climatic elements such as wind velocities or evaporation. The locations of the stations are not selected for national climatic studies but for aviation, defence and agricultural projects. A full list of meteorological stations is found in Appendix I.

There are three institutions which operate and run the climatic stations, the General Directorate of Meteorology, Ministry of Defence, the Department of Water Resources Development, Hydrology Division, Ministry of Agriculture and Water, and Aramco. Neither of the first two organisations have provided any climatic analyses but have only issued monthly and annual publications which include climatic data. Aramco installed climatic stations in the eastern and northern regions along the oil pipe line, but again have not issued any climatic reports.

The location of the stations of the Ministry of Defence are related to the distribution of airports and therefore are not found except in well populated areas, which exist on the low ground rather than in the mountainous areas. The stations of the Ministry of Agriculture are located in particular areas where there is some agricultural potential or where hydrological data are required, such as the large valleys and the oases. Considerable emphasis is placed on the highland areas which receive the greatest amounts of rainfall.

The officials who serve and examine the stations and record the climatic data are not well trained. Most of them can only read and write, so the data are not always accurate and there may be periods when there are gaps in the climatic data. In fact, comments such as "data are not available" or "data are missing" are common in the tables of the reports of these agencies.

The instrumentation from one station to another and from one agency to another varies, so that the units of the climatic data are not strictly comparable. For example, the wind speeds in the Ministry of Defence data are measured in units of knots while the Ministry of Agriculture use the units of metres and kilometres.

In addition to the stations installed by these agencies there are other stations which are established by consultant companies. The data recorded by these stations are only for very short periods because they are only installed temporarily for carrying out agricultural projects in particular places; some of them are even installed in vehicles and move from locality to locality.

The installation and maintenance of an effective nation-wide network of climatic stations encounters local and logistical problems. Vast regions of the country are composed of expanses of sand or rugged rocky areas where the road communications are poor or insufficient. Furthermore, the numbers of trained staff necessary for servicing the climatic stations are not at present available. The nomadic peoples are unaware of scientific development, and automatic stations installed in the remote and unpopulated areas will most probably be destroyed by these nomads. There has been a lack of appreciation of the physical environment and this has caused problems: the consultant companies, during the course of their investigation, found some of their climatic stations buried under a metre of drifting sand. The installation of effective stations to record evaporation in a dry country requires the transportation of water for refilling the pans recording evaporation.

Before 1952 the only stations installed were at Dhahran and Ras Tanura which were established by the American Army in 1948. After 1958 Dhahran station became the property of the Saudi Arabian Ministry of Defence. Averages of some of the climatic data from 1948 to 1957 have not yet been worked out. Since 1952 the Ministry of Defence has installed two stations in Jeddah and Riyadh. Another two stations have also been installed since 1960 in Madenah and Taif. These five stations are the only ones which have relatively reliable averages of recordings.

In 1955 the Ministry of Agriculture and Water installed a small number of rainfall stations in some places of agricultural importance. During 1966 the Ministry instituted the Hydrology Division which has since installed a wide network of climatic stations. Most of these stations do not record all the climatic elements but record only rainfall. A list of operating stations, numbering over 150, are listed in Appendix I, along with the date of their establishment and the type of data recorded.

It should not be inferred from the foregoing description that there is a complete lack of climatic information on Saudi Arabia. There is available a considerable amount of material on the country, collected and prepared by various authorities. During the past ten years the Ministry of Agriculture and Water has divided the country into hydrological areas (Figure 1 (II)). Most of these areas have now been studied by consultant companies and climatic studies have formed an important part of the investigations. These investigations had the objective of assessing the natural resources of the areas and consequently the climatic studies have formed a useful stop gap until more detailed analyses can be made. Every observation, or set of observations, can have its value as long as the existing limitations

HYDROLOGICAL AREAS IN SAUDI ARABIA

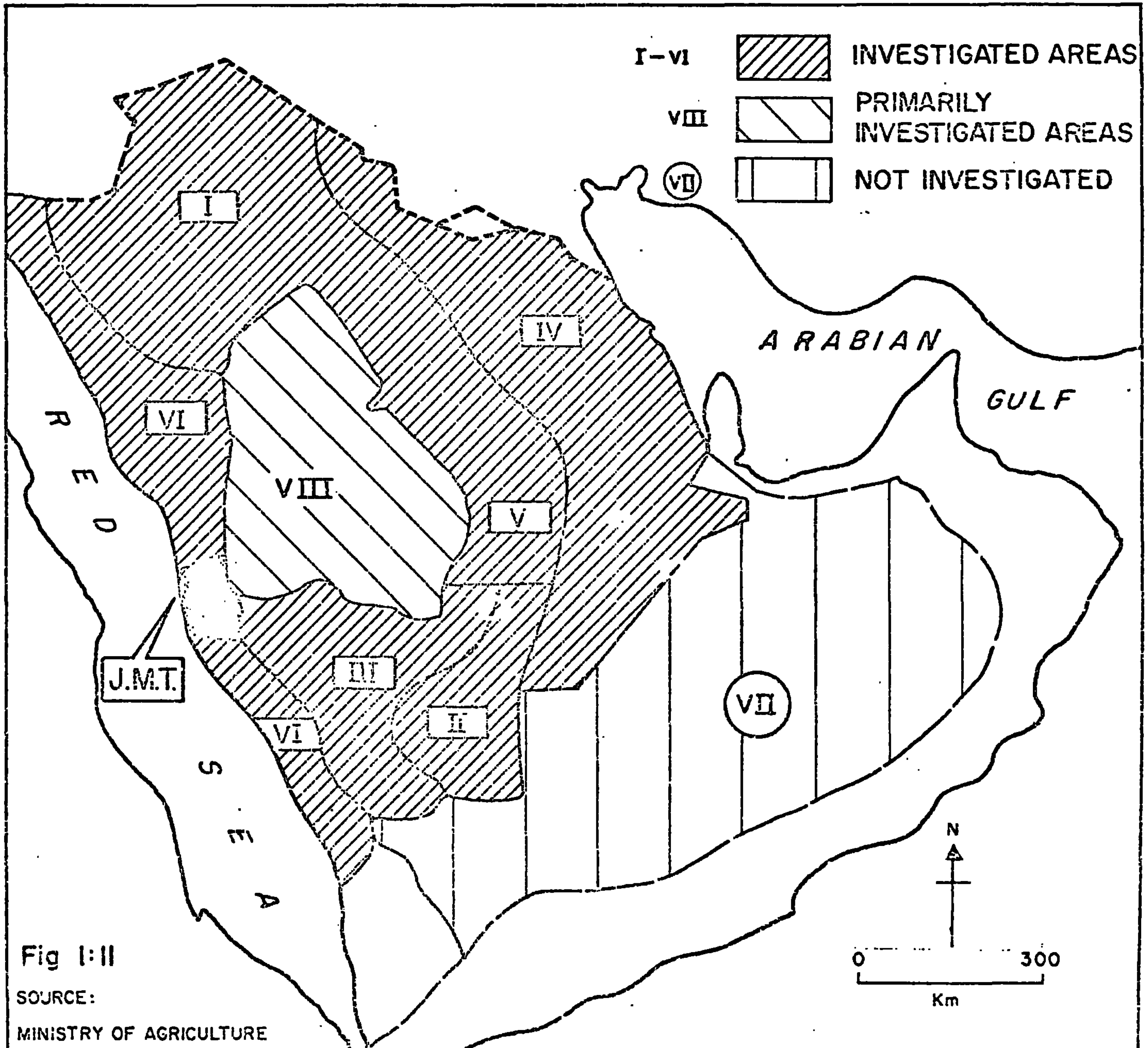


Fig 1:11

SOURCE:

MINISTRY OF AGRICULTURE

are understood. Every study, however incomplete, is a step forward towards completion and unless the existing irregular data are not coordinated and brought together in a systematic way, no progress can be made in a scientific investigation even when more information becomes available.

The aim of the present study is threefold:

1. To make an attempt to fill the gap that at present exists in the climatology of the Middle East as far as Saudi Arabia is concerned.
2. To provide a clearer picture of the general climatic conditions over Saudi Arabia with respect to the main climatic elements.
3. An attempt to analyse some of the data which, up to now, have never been presented except in "raw" form.

The data on which the present study is based were obtained from the Ministry of Agriculture and Water, Department of Water Resources Development, Hydrology Division and the Ministry of Defence, General Directorate of Meteorology. They fall into nine categories as follows:

1. Monthly and annual average temperature.
2. Monthly and annual average absolute maximum and minimum air temperature.
3. Monthly absolute maximum and minimum air temperature.

4. Monthly and annual average rainfall.

5. Monthly and annual average relative humidity.

6. Monthly and annual average absolute maximum and minimum relative humidity.

7. Monthly absolute maximum and minimum relative humidity.

8. Monthly wind speeds and directions.

9. Monthly and annual averages sand and dust storms.

Despite the large number of climatic stations operated and run by these two agencies, records were, in a number of cases, incomplete or of short duration. When the data for all the stations had been tabulated it was found that data from less than half the stations were suitable, even for a broad study such as this.

CHAPTER II

FACTORS AFFECTING THE CLIMATE OF SAUDI ARABIA

Saudi Arabia is a vast country, some 2.2 million sq km in extent, bounded by extensive land masses, namely North Africa to the west and Southern Asia to the east. They are usually favourable for the development of specific air masses which are normally dry due to their continental nature. Since the water bodies which separate the country from these land masses are very narrow, little modification can occur when the air blows from the Sahara across the Red Sea or from Southern Asia across the Arabian Gulf. The nearest large water bodies are the Mediterranean Sea in the north and the Arabian Sea to the south, and both do cause some maritime influence. The country, on the other hand, has a considerable range of elevation, particularly in the western part where the high lands of Asir and Hejaz occur. The modest plateau of Najd and the low plains of the Red Sea and the Arabian Gulf, on the other hand, provide a distinct contrast. Furthermore, the country is located in the tropical and the subtropical zone and, hence, the continental climate, which is characterised by seasonal extremes of temperature, with low rainfall and humidity, dominates most of Saudi Arabia.

Three main factors affect the climate of Saudi Arabia and may be summarised as follows:

1. The latitudinal location.
2. The geographical position relative to: the land masses and water bodies.
3. The altitude.

These factors are shown on Figure 3(I).

1. The Latitudinal Location

By and large, the country lies in the tropical and subtropical zone, lying between latitude 32°N and latitude 16°N. As a result of this location the number of hours of daylight during the summer months is considerable. The length of the day time on the 21st of June ranges from 14 hours in the north of the country to 13 hours in the south, but during winter the length of the day is considerably less. In January it ranges from 10 hours 24 minutes in the north to 11 hours 14 minutes in the south. Because of the long periods of daylight during the summer months and a marked lack of cloud cover, the solar radiation during the day and the ground radiation during the night are very intense. Consequently the summer months are very hot and a large range of air temperatures occurs between day and night, particularly in the regions which are not affected by maritime influences.

During the winter months the length of night is longer although the length of day is still sufficient to supply enough solar radiation to keep the air temperatures relatively high. As a result of the clear skies and the dry air, temperatures at night often fall below zero centigrade in the regions away from the coastal lowlands and may drop to -10°C in the northern territories. In spite of the tropical and subtropical location, frost is not unknown during the winter months.

2. (a) The Geographical Position Relative to the Surrounding Land Masses

Saudi Arabia is located between, and close to, vast expanses of land masses, namely South Asia and Saharan Africa. These two extensive land masses affect the country with their prevailing weather conditions. During winter the Asian land mass becomes colder and dry air blows out over surrounding areas. This cold, dry air affects Saudi Arabia and is little modified en route due to the short distance it travels. It causes low air temperatures and the occurrence of frost particularly during the nights. The modest vegetation and the small areas of cultivation may be severely affected, people suffer from chest complaints, colds etc., and some of them may die, particularly those who have little shelter. Furthermore, the high pressure system that develops in winter over the continental regions may expand and extend over the country and cause the development of a high pressure cell. This situation normally prevents the maritime air from the Mediterranean moving southwards over Saudi Arabia.

A similar but less intense climatic process obtains with the build up of cool and dry air over the Saharan Africa which also affects Saudi Arabia during the cool months. This air always blows eastward but usually only affects the western regions. Because of the presence of the Red Sea, the blowing air may recharge with moisture in the lower layers and cause light showers in the western highlands. However, the common effect of the Saharan air is that the blowing air usually causes sand and dust storms in the north west regions of Saudi Arabia, especially during the passage of the Mediterranean depressions over, or to the north of, the country.

During the summer months the adjacent regions develop into areas of hot and dry air. This air usually moves to cover most of the country, causing hot, dry and stable weather conditions. Consequently, most of the country becomes favourable for the development of low pressure. In summer the whole area of north west India, southern Iran and Arabia comes under the influence of this low pressure. It has been suggested that this area contains the lowest known low pressures (Banerji, 1931). The low pressure region draws in the trade winds south of the equator to the southern areas of the Arabian Peninsula as strong and steady south-westerly winds. The south west air stream appears to advance regularly during the period of June to August over the south west of the country as far north as Taif and as far east as Bishah every year, though there are unusual advances of the disturbances associated with the south west monsoon winds up to a latitude of about 25^{o}N. The advances of these disturbances occasionally result in light showers preceded by dust storms.

2. (b) The Geographical Position Relative to the Water Bodies

Saudi Arabia is bounded to the west by the Red Sea and to the east by the Arabian Gulf. Both are very narrow and, hence, have only weak effects on the climate except within a short distance from the coastline. Furthermore, the prevailing winds do not appear to transfer the maritime influences far into the country. In the Arabian Gulf area the prevailing winds are the north-westerly winds which blow off the land towards the Gulf. In the Red Sea the prevailing winds to the north of latitude 20^{o}N are the north-north-westerly winds, while to the south of latitude $20^{\circ}N$ the prevailing winds are the south-south-westerly winds with a westerly component. When these types of winds blow onto the coastal plain, they do not appear to penetrate far into the country since the high scarp of the western mountains prevents the damp air from escaping toward the interior.

The importance of the two water bodies is that, during the cool months, they may create two low troughs through which the moist air, either from the Mediterranean or from the Arabian Sea, sweeps towards the Arabian Peninsula, causing development of disturbances and a build up of clouds and the occurrence of rain.

The other water bodies which affect the climate of Saudi Arabia are: the Mediterranean and the Arabian Seas. The Mediterranean Sea is of particular climatic importance to the weather conditions during the period October to May. Atlantic depressions move eastwards over the Mediterranean while others may develop over this sea. They track eastwards or southeastwards due to the high pressure that exists over the Asian continent and affect Saudi Arabia, causing variable weather conditions, dust or sand storms, mild and cool winds, or sometimes thunderstorms and rain. Cold polar air flowing from Eurasia during the cool season also passes over the Mediterranean Sea, becomes warmer, gains moisture, and occasionally sweeps southwards along the Red Sea trench, or trends to the southeast towards the country, and yields rain. Development of disturbances as a result of the invasion of this air is not uncommon over Saudi Arabia, particularly during the mid-winter (Banerji, 1931).

The Arabian Sea is also of climatic importance to Saudi Arabia. From this water body two types of monsoon winds normally blow over the country. The first type is the southeast monsoon, which blows from October until May, though more steady and persistent during the period of November to April. The south-easterly monsoon winds originate from the Asian anti-cyclone. When the north east monsoon enters the Arabian Sea it recurves in a clockwise path and blows toward Arabia as south-easterly winds (Kreeton, 1928). The south-easterly winds cause tropical disturbances to invade major parts of southern Saudi Arabia during the cool season, but these disturbances rarely approach the northern regions of the country (Flohn, 1965).

The second type is the south west monsoon of the summer months which dominates the Asir highlands and southern Hejaz. This type of wind originates in the Indian Ocean and blows into the Arabian Sea during the period of June to August. During the period of the maximum effect of the south west monsoon during July and August, tropical depressions normally form in the Arabian Sea, and a number of them track towards the north west via the Red Sea, and cause thunderstorms, rain and hail (Pedgley, 1969).

The tropical cyclones, an intense form of the depressions, form over the south eastern quadrant of the Arabian Sea and move west-north-west toward Arabia, then they recurve to the north or north east toward north west India and Pakistan. About one in three moves into the western Arabian Sea, approaching the coast of Arabia. They approach, or occasionally cross, the coast of Arabia once in three years on average. Rarely do they enter the Gulf of Aden or the Gulf of Oman (Pedgley, 1969). From the available data concerning Saudi Arabia, these cyclones rarely move into the country, though they are not unknown in the south-eastern and eastern regions during the summer months where they may cause dust or sand storms, rather than giving rainfall.

3. The Altitude

Over a large part of Saudi Arabia the absence of high mountains causes little modification to the climatic conditions. Over the eastern half of the country the only hill areas which seem to have slight effects on rainfall distribution are the parallel escarpments of Tuwayq and Aruma. The increase in rainfall amounts is proportionate to the height of the escarpment, even though the elevations of the two chains rarely exceed 200 metres over the surrounding areas. Toward the western highlands the elevation increases gradually, but from the available data it does not appear that there is a considerable increase in rainfall. For instance, the annual average rainfall at Riyadh, for the period 1966-70, was 109.2 mm. Toward the west at Dawadmi, the annual average rainfall decreases. At Afif, which is located to the west of Dawadmi, and at the same altitude (940 m), the annual average rainfall, for the same period, was in the order of 84 mm. At Dafinah, which lies to the east of Harrat Kashab, and at an elevation of 1000 metres, the annual average rainfall, for the period of 1966-70, is 56.6 mm (Figure 2(I)). There thus appears to be a distinct rain shadow to the east of the western uplands.

The major changes in climatic conditions appear to take place in the western highlands. There are no installed stations on the high peaks of the Madian and the northern section of the

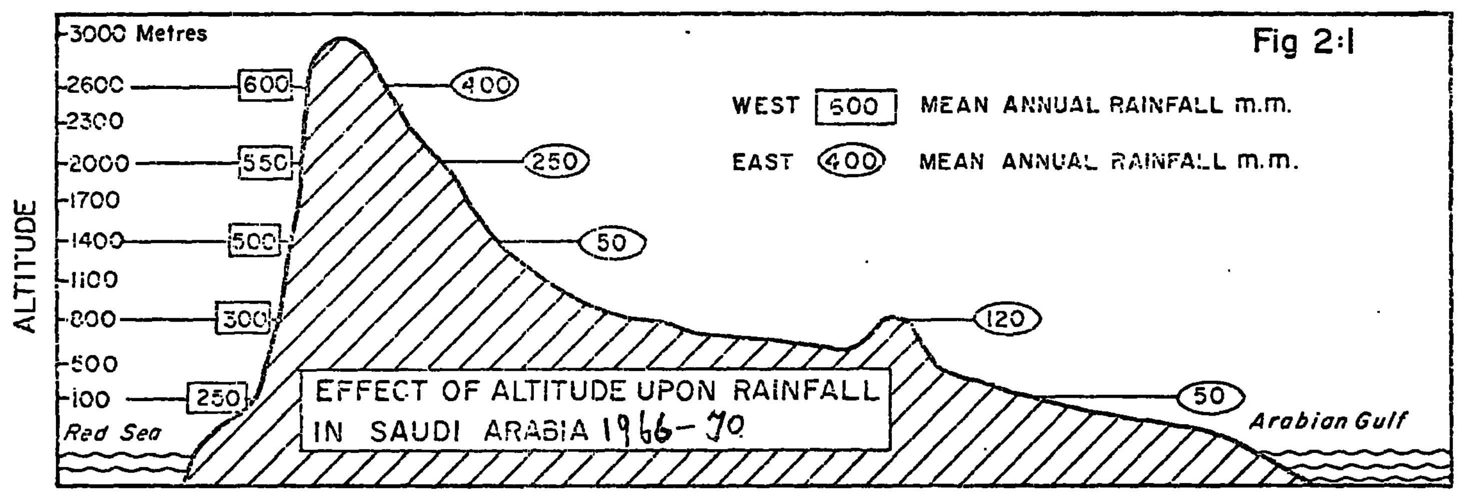


Fig 2:1

EFFECT OF ALTITUDE UPON RAINFALL IN SAUDI ARABIA 1966-70

Hejaz mountains to show the climatic changes. From the scanty available data on the area it seems that the western mountains north of latitude 22^{O}N cause slight increases in the amount of rainfall, but are probably not sufficient to cause significant changes in the climatic conditions. Arid conditions prevail here just as in the desert areas of the interior regions.

It appears that the main changes in the climatic conditions occur in the Asir highlands and the southern Hejaz mountains. The region has a unique climate among the surrounding areas. In fact, this is not only because of its height, but also as a result of its location. In the western highlands north of latitude 22^{O}N, the elevation is about 2000 metres, while the annual rainfall is rarely more than 100 mm. In Asir, while some minor mountain ranges have elevations of less than 1000 metres, others exceed 3000 metres, and the annual rainfall usually exceeds 500 mm. The mountains to the north of latitude 22^{O}N are, during the cool season, under the influences of the attenuated Mediterranean depressions, while during the hot season they are under the effects of extremely hot, dry air. In the highlands, to the south of latitude 22^{O}N, the atmosphere throughout the year is usually moist, due to the Mediterranean air in the winter months which accumulates moisture during its movement southwards along the Red Sea trench. The south west monsoon affects the mountains of Asir in the late summer also, causing moist conditions to develop and providing the major component of rainfall.

Altitude has also considerable effects on the temperature distribution over the western parts of Saudi Arabia. The Asir and southern Hejaz highlands, with elevations of 3000 metres and even more, introduce remarkable decreases in air temperature and appear to obscure the effects of the decreases of latitude toward the southern parts of the country. They also create temperature gradients from the high ranges toward the inland, and from the western slopes of the escarpment toward the Red Sea coastal plain. In general, because of the increases of altitude of these regions, the air temperature conditions are temperate throughout the year and even during the summer months when the air temperature at some stations located in the low areas reaches or exceeds 50°C. Outside these highlands the effect of altitude is not found to create local temperature conditions and the factor which controls the temperature distribution is mostly the latitude.

CHAPTER III

TOPOGRAPHY OF SAUDI ARABIA

Arabia is generally a vast quadrangular peninsula, 2.2 million sq km in extent, lying between the Arabian Gulf and the Gulf of Oman to the east, the Red Sea to the west, and the Arabian Sea to the south. In the north it is bounded by Kuwait, Iraq and Jordan. It has a longitudinal extent of about 2400 km and a width of about 8800 km.

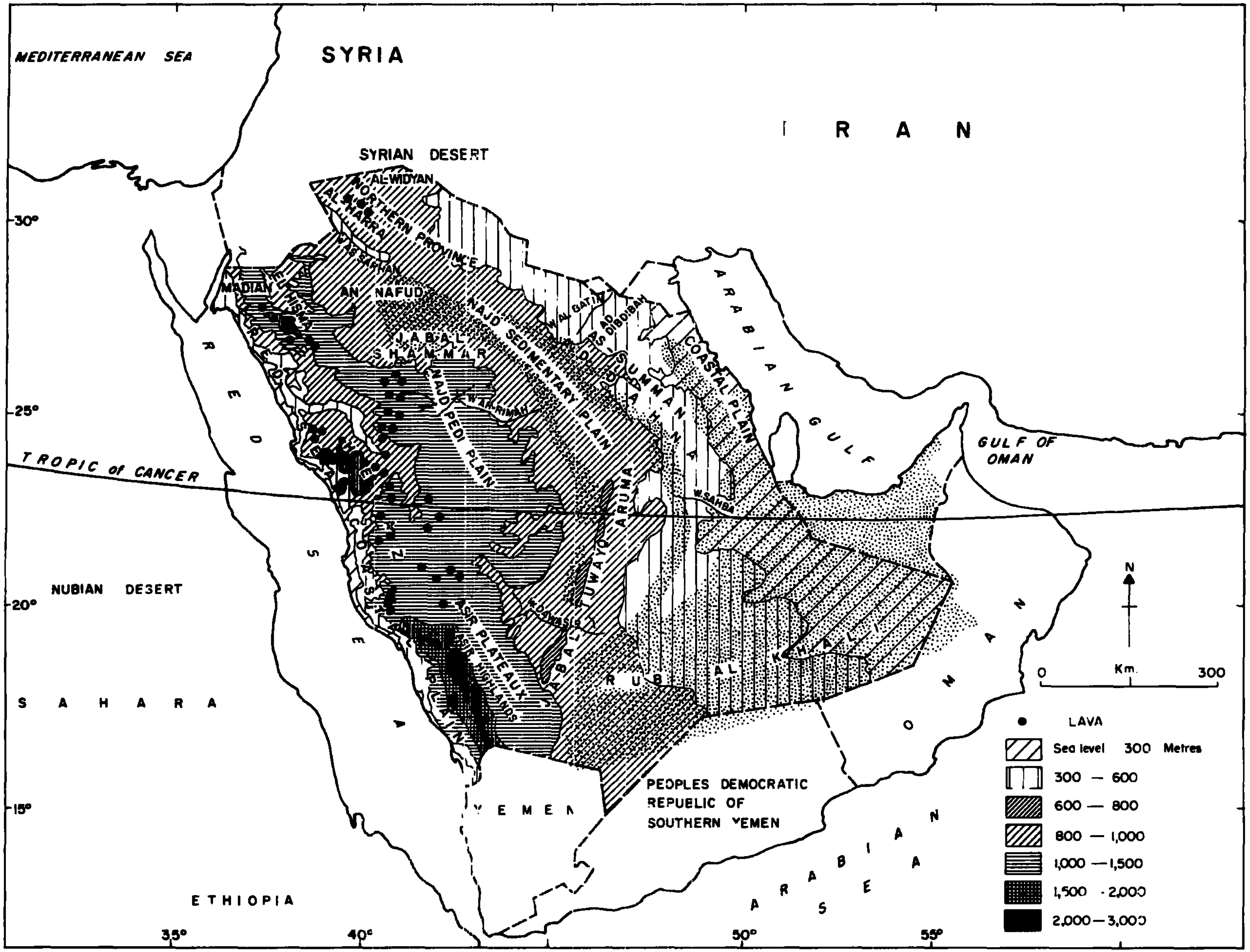
The country can be divided into eight topographical units (Holm, 1953; Brown, 1960) as follows:

a. The Red Sea Coastal Plain
b. The Western Highlands
c. Najd Pediplain
d. The Sedimentary Najd Province
e. The Sand Dune Zones
f. As-Summan and Ad-Dibdibah Plateaux
g. The Arabian Gulf Coastal Plain
h. The Northern Province

These topographical units are shown on Figure 3(I).

a. The Red Sea Coastal Plain (Tihama)

The flat strip of low land bordering the Red Sea from Aqaba to the Yemen borders is a well defined topographical unit



TOPOGRAPHY AND GEOGRAPHICAL LOCATION OF SAUDI ARABIA. Fig 3:1

known as Tihama. [1] The width of this plain varies from almost nil, as in the Duba area, to 40 km, as in the Jazan district. The width of this coastal strip generally increases from north to south. From the Red Sea shore toward the mountains in the east it rises from sea level up to 60 metres, though in some areas it rises to about 150 metres.

In the northern section of this strip, particularly to the north of Jeddah, spurs from the mountains terminate in bluffs and promontories. The plain close to the sea consists mainly of recent coralline and evaporite deposits affected by sand, while further eastwards it rises gradually and forms a pediment of Tertiary sedimentary beds or crystalline rocks. Raised beaches are prominent. The heavy occasional rainstorms coupled with the steepness of the slopes of the highlands cause violent floods in the valleys and erosion of the slopes, the sediments being deposited on the coastal plain. These deposits in some parts occur as alluvial cones, while in other parts they form alluvial terraces.

b. The Western Highlands

These highlands extend north-northwest to south-southeast from Aqaba to the Yemen borders, running parallel to the Red Sea coastal plain for about 2020 km. They are known as a whole as As-Sarat, but have different names in different places. In the

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1 Tihama is an Arabic word meaning a region whose weather is hot and damp.

northern section, from Al Aqaba to Al Wajh, they are known as Jebal Madian, between Al Wajh and Taif, they are known as Jebal Al-Hejaz, while in the southern region between Taif and the Yemen borders they are known as Jebal Asir.

The width of these highlands varies from 220 to 240 km; the widest section lies between latitudes 24 and 26°N. These highlands are not, in fact, a distinct single range and are very heterogeneous, dissected by valleys and plains of various widths and depths. The elevation of these uplands ranges from 1000 to 2300 metres with few summits reaching or exceeding 3000 metres in the Asir region, such as As-Sawdah near Abha. Some depressions, typified by the area around Mecca, are of low elevation and rarely exceed 300 metres.

Most of this geomorphological unit consists mainly of Precambrian basement complex rocks, covered in some places by basalt flows of varying ages, particularly in the northern section. From Taif southwards, where the ranges tend to be higher and closer together, basalt flows are smaller and less frequent. From west to east, these uplands can be subdivided into: the escarpment, the highlands, and the western plateaux.

The Escarpment:

The escarpment is particularly marked to the south of Taif, flanking the highlands of Asir. The belt varies in width from 40 to 60 km, with an elevation of 650 to 850 metres. The mountains have been split up here into fault blocks, associated with the formation of the Red Sea Rift. The sedimentary beds within the escarpment which form the lower blocks have gradually been eroded and have given rise to some plains of reasonably extensive areas now covered by alluvial deposits. Typical examples of these plains are Khulays-Usfan and Shumaysi plains in the Jeddah, Mecca and Taif area. Basalt flows cover some parts of the escarpment, such as Harrat Ar-Rahah, north-north-east of Jeddah, and the area around Harrat An-near, east of Umm Lajj.

The drainage of this belt runs mostly toward the Red Sea coastal plain, but wadi flows rarely reach the sea. The drainage pattern is clearly affected by a series of faults, since some major valleys lie along the most marked structural lines. Examples of this type can be seen in the course of Wadi Asugah in Usfan, the course of Wadi Fatimah, and the course of Wadi Al Yamaniyyah (Italconsultant, 1969A).

The Highlands:

This subprovince lies between the escarpment and the western plateaux. The escarpment is not well defined to the north of Taif, and the topography consists of small ranges, though of no considerable elevation. The width of the highlands ranges from 20 km in Jebal Asir, to over 50 km in Jebal Hejaz. The elevation varies considerably - in Jebal Madian it does not often exceed 2000 metres, while in Jebal Asir it exceeds 3000 metres in some places. Moreover, the highlands have much more gradual slopes in the north, while they slope abruptly in the south. Like the escarpment, the highlands have been affected by orientated faults now occupied by upper courses of the valleys, and form in some places gaps which give rise to easier accessibility from one place to another in the highlands themselves, and from the interior to the Red Sea coastal plain. They also provide suitable areas for human settlements. Taken as a whole, this region includes numerous wadis running along the broken ranges to the Red Sea. However, the drainage of some wadis does not reach the sea, particularly when rainfall is insufficient for a large run-off.

These imposing highlands represent the main watershed in Saudi Arabia from which wadis flow both eastward and westward. Many of the cultivated, and cultivable lands are found within these wadis. Elsewhere, human ingenuity has overcome physical difficulties as in Jebal Asir where there are intensely cultivated man-made terraces. The function of these terraces is to reduce the run-off, thus facilitating infiltration of the rain water in order to prevent erosion of the slopes and to give more area for utilisation.

The highlands consist mainly of igneous and metamorphic rocks, granite or schists, which belong to the Precambrian basement complex, though there are extensive outcrops of basalts of different ages. Recent formation of sand stones and accumulations of aeolian deposits are found in the depressions and on the lower slopes within the ranges. The aeolian deposits are less in the southern section than in the northern part. In fact, south of Taif, the mountains are in the shape of close, continuous ranges of considerable elevation and this part experiences a remarkably humid climate during most of the year.

The Western Plateaux:

This subprovince includes the land situated to the east of the highlands and parallel to them from Najran to the Jordan borders. It can be subdivided into the Asir plateau and Al-Hisma plateau, though the former contains two distinct plateau areas.

The Asir plateau extends south of Harrat Al-Bugum to the Yemeni borders, running parallel to the Asir mountains. The Asir mountains, which are composed of an uplifted block, decrease in elevation inland along a series of faults on the eastern edge. This plateau was, in fact, the lower eastern slopes of this block, but it was eroded and cut off by the Bishah and Tathlith valleys so that it now appears as two separated plateaux regions.

The two plateaux appear to contain two subprovinces having somewhat different morphological features defined according to differences in the drainage system. In the northern part, the principal drainage system drains towards the north-north-east, whilst in the south the direction is due east. Moreover, the southern section has an extremely rough outline, so it is difficult to draw a clear cut distinction between the highlands and the plateau. This can only be done on the basis of elevation. In the northern section the valleys are broader, with more alluvial deposits. At times their slopes are more gentle and the ridges do not rise above the valley bottoms by more than 200 to 300 metres.

To the north of these two plateaux, the Harrats extend northwards. They are located between Al Hisma plateau in the north, Asir plateau in the south, and the highlands in the west, while the Najd pediplain bounds them on the east. Numerous basalt flows cover many places in this area. These basalt flows cover vast areas separated from each other by gaps often occupied by oases.

Almost all of these Harrats feature a flattish surface with scattered and small volcanic cones. They consist of masses of blocks formed by extensive faulting. Most of the edges of these masses form small scarps with heights varying from a few metres to more than a hundred metres.

Each Harrat slopes gently in all directions from a central dome so that the drainage pattern tends to be radial. The contemporary valleys are not generally entrenched in the basalt flows since this type of rock is fairly resistant to erosion. It is only at the edges of the Harrats that the valleys manage to cut into the thickness of the lava, down to the underlying rocks of the Basement complex. Numerous tongues of basalt extend from the Harrats and follow old drainage lines for many kilometres and have sides standing above the old valley bottoms where the present valleys do not completely fill these old valleys. Typical examples of the latter type can be seen east-north-east of Turabah where the basalt flow, at least 2 km wide, runs northwards for 40 km following what was once the valley of Wadi Karah. An example of the former type can be seen at Kashim Shayil, 25 km southwest of Ranyah where Wadi Ranyah runs along the basalt flow, but does not cut completely through it. The elevation of these Harrats is not the same, but they generally range from 1000 to 1500 metres.

Al-Hisma is the northernmost plateau, bounded on the west by Jebal Madian and on the north by Tubeg hills, while to the south it is bounded by Harrat Rahah. It dips gently eastward and forms a featureless plateau, due to the effects of erosion, in the form of a pediplain rising to an elevation of about 800 to 1000 metres.

The Tubeg hills and Al Hisma have been affected by the northwesterly winds which have removed debris from the erosion of sandstone formations and deposited them as unstable sand dunes in a wide depression which lies to the south and east and is known as An-Nafud Al-Kabir.

c. The Najd Pediplain

The area which extends from the western plateau and the Harrats eastward as far as the first outcrop of the sedimentary series, northward to the southern limits of An-Nafud Al Kabir and southwards to the western limits of Nafud Ad Dohi, forms the Nadj pediplain. It is generally flat and featureless, with a predominantly eastward slope from slightly over 1000 metres in the west to an elevation ranging between 600 and 800 metres in the east. The main topographical features are small ranges and inselbergs which rise to about 300 metres above the surrounding country. The major ranges in this area are Jabal Aja and the slightly smaller Jabal Salma, which are together called Jebal Shammer. Both are granitic. However, the ranges and the hills occur as scattered groups, separated from each other by vast plains, some being covered by alluvial or aeolian deposits.

Practically the whole area is underlain by igneous and metamorphic rocks of the Precambrian crystalline basement overlain in the extreme east by large areas of Tertiary and Quaternary formations.

The pediplain is crossed by the largest five valleys in the country. Wadi Turabah, Wadi Bishah and Wadi Tathlith eventually unite to form one waid - Wadi Ad-Dawasir - in the south, while Wadi Ar-Remmah is the northernmost wadi. Wadi Ar-Remmah originates on the western Highlands in the basalts of Harrat Khayber at an altitude of about 1100 metres before crossing Najd sedimentary province. Around Unayzah it is found at an altitude of about 600 metres. Probably an ancient north-eastward extension, before its course was affected and cut off by the Quaternary aeolian sands of Nafud Ad-Dahna and Nafud Athuwayrat, it may be traced toward the Arabian Gulf as Wadi Al-Batin.

d. The Sedimentary Najd Province

This province lies immediately to the east of the Najd pediplain and extends eastward to the western limits of Ad Dahna sand dunes. The remarkable geomorphological features here are the large arcuate cuestas which consist of limestone in the form of escarpments with their west-facing fronts paralleling the crescentic shape of the Arabian shield.

The geomorphological province is composed of a number of topographical units:

1. The Wajid plateau is found in the south and is bordered in the west by Asir plateau and in the northwest by Najd pediplain. The landscape here is in the form of frequent masses and hills of considerable height along the western edge, but these diminish toward the north and east. Alluvial plains and deposits are infrequent because the drainage system of the western highlands runs to the north and to the south of this plateau.

2. Trans-Tuwayq is an irregular plain whose elevation ranges between 600 and 700 metres lying to the west of the Tuwayq mountain escarpment. It is a very persistent morphological unit, characterised by mature erosion surfaces. The relief is further smoothed by the presence of alluvial deposits which are in the form of thin layers of gravel with only rare outcrops of bedrock. Some accumulations of recent aeolian sands cover the surface and have modified the landscape. The drainage is not well developed except in the strip along the Tuwayq mountain escarpment. This strip ranges in width from 2 to 4 km. Well-developed active wadis run from north to south in the southern part and from south to north in the northern section.

3. The Tuwayq mountains form a multiple arcuate cuesta trending north-north-west in the northern section and south-south-west in the southern part. This escarpment is the most imposing feature interrupting the eastward dip of this province. The Tuwayq mountains are a typical escarpment landscape formed probably by tectonic movements during the Tertiary period. They can be followed for 1200 km and it is possible that they extended farther northwards and southwards in the past, but because of erosion and accumulations of extensive sands they appear now to have less extent than formerly. The valleys have dissected the mountains, forming deep gorges typified in the Ad Dawasir valley in As-Sulayyil area and in Wadi Nesah to the southwest of Riyadh. These features may have been caused by a greater volume of run-off and floods in the past, probably during a pluvial period. Along the margins of the Tuwayq mountains, where the upper Jurassic anhydrite and gypsums outcrop, karst landscapes have been formed by the dissolution of the sulphate layers and the collapse of the overlying Lower Cretaceous limestone.

Because of the eastward slope of the mountain, most of the wadis flow from west to east and then they run into the piedmont valleys, collecting their water and trenching towards the north or towards the south, according to the gradient directions of the land. Numerous villages have utilised the alluvial water tables of these valleys.

While the general elevation of Jebal Tuwayq varies between 750 and 850 metres, the higher points on the western side rise to about 1100 metres where the escarpment lies about 300 to 500 metres above the western low land.

The hills are composed of Jurassic sand stone, capped by harder Jurassic and Cretaceous limestones. The topographic gradient eastwards varies between 4 and 7.5 metres per kilometre (Italconsultant, 1969A).

4. Eastwards of Tuwayq there are other escarpments of lesser height and smaller in extent, known as Aruma and Bayad. They are separated from Tuwayq by low land which represents the drainage area of the valleys which flow towards the east from Tuwayq. Aruma consists of upper Cretaceous limestones dipping gently eastwards and affected by locally entrenched wadis. The elevations of these escarpments range from 700 metres on the western side to 550 metres at the base of the dip slope. The Bayad is less well developed and forms a broad plain with gentle relief and a poorly developed drainage system. While quartz gravel derived from the Lower and Upper Cretaceous sandstones covers this plain, some resistant intercalations of dolomite and quartzite form rare benches and low escarpments. Alluvial deposits are rare, occurring only at the outlet of major drainage systems of the Tuwayq mountains. The elevation of Bayad is between 650 to 600 metres. All these escarpments are known, as a whole, by the name of Jebal-al-Arid.

e. <u>The Sand Dune Zones</u>

These extensive areas include all the large accumulations of aeolian sands in the country. The different areas are known as follows: Ar-Rub' Al-Khali (the Empty Quarter), An-Nafud Al-Kabir (the Great Sand Dunes), and the narrow belt of sand linking the two: Ad-Dahna. Ar-Rub' Al-Khali is a vast area of sand dunes occupying the southern part of the country from the coast of the Arabian Gulf in the east to the northern and eastern slopes of Hadramaut, Dhafar and Yemen in the west. It has an area of about 400,000 sq km, with a length of about 1200 km, and a width of about 640 km. It consists of large accumulations of drifting aeolian sands, much of which is mobile today. These deposits of sand form enormous wandering dunes lying parallel ENE-WSW lines almost masking the features of some earlier land forms. The shapes of the sand dunes are mainly dictated by the predominant northwest and southeast winds. Between the elongated dunes there are usually long, gravel floored flats about 2-3 km wide. The general elevations of the area decrease from 800 metres in the west, to less than 100 metres in the east. In the eastern part there are groups of craters possibly formed by the impact of meteorites on the desert sand. The craters lie at Al-Hadid (50° 40'E 21°29'N), and the diameter of some reaches 90 metres.

The southern part of the Arabian Peninsula was probably a wide depression surrounded on three sides by ramparts of mountains. The Asir and Yemen highlands in the west, the Hadramaut and Dhafar mountains in the south, and the Oman mountains in the east, while the changing size and shape of the Arabian Gulf also contributed considerable material. This depression has been filled with aeolian sands as well as some alluvial origin.

An-Nafud Al-Kabir: To the north of Jebal Shammar large accumulations of sand dunes cover an area of about 32,200 sq km in the form of a large triangle. These sand dunes have probably been deposited by the prevailing NNW and NNE winds in a depression bounded by higher land which gave this area its shape as a triangle. Since the directions of the prevailing winds are generally from the northern quarter, the sand dunes in the southern part tend to have formed on a surface at a higher elevation, about 1000 metres, compared to about 600 metres in the north.

Ad-Dahna: Ar-Rub' Al-Khali is separated from An-Nafud Al-Kabir by a long band of sand dunes called Ad-Dahna. It runs for about 1280km, forming an arcuate crescent parallel to the Aruma-Bayad escarpments in the west and to the As-Summan plateau in the east. This sand dune belt is widest in its middle portion, about 80 km wide, and it is probable that it has been formed by northwesterly winds along the marked escarpment facing the west. The width of Ad-Dahna ranges from 32 to 80 km and the area consists of a series of crescent-shaped sand dunes of high elevation, pink in colour, mostly because of a higher percentage of iron oxide stain in its composition. The elevation of Ad-Dahna varies considerably from one part to another. In the northern section, the height may reach 500 metres, while in the southern part it rarely exceeds 200 metres. In the intermediate section the height ranges between 350 and 400 metres.

f. <u>As-Summan and Ad-Dibdibah Plateaux</u>

Taken as a single unit these plateaux are smooth areas sloping gradually eastwards and north eastwards. While As-Summan consists of more rolling relief, Ad-Dibdibah is in the form of a flat pediplain covered with gravels and sloping eastward to the Arabian Gulf and north-eastward towards Mesopotamia. It is dissected by a large, wide valley, Wadi Al-Batin, formed by either one or two actions: tectonic movements or, more likely, rainfall and run-off during a pluvial period.

The morphology of As-Summan is characterised by slightly rolling landforms and by karst phenomena. In the eastern margins Karst phenomena occur and appear to have been formed at various periods by the termination of drainage networks where the water accumulated in slight depressions similar to dolines, and then infiltrated. Hence the solution of gypsum layers and circular collapse of the structures occur.

The drainage network is characterised by short lengths of very random pattern that tend to follow the trend of the solid outcrops though they get lost in the superficial gravels. The largest wadi which runs in this area is Wadi As-Sahba which runs to the south of the railroad for some distance and then trends to the south east, to be later masked by the sand dunes of Al-Jafurah. The valley-beds of As-Sahba and Al-Batin are flat and gravelly, and probably were the source of the alluvial deposits which now form the surface of the plateaux.

g. The Coastal Plain of the Arabian Gulf

This plain is a strip of low land extending along the coast from Ras Mish'ab in the north to the southern point of Dohat-Salwa in the south. The topography is relatively flat with land-form rarely exceeding a height of 60 metres, but despite this, there are some points which have altitudes of more than 100 metres. Close to the Gulf there are widespread areas of coarse detritus and sand cover, the latter, in some areas, due to northern extensions of the Rub'al Kahli, but elsewhere due to raised shorelines of the Gulf.

Along the Arabian Gulf, and for some kilometres inland, there are wide areas of Sabkah. These are shallow, flat depressions, covered by salt crust. They are located along the Gulf, but they are also found inland on a large scale just to the east of the Ghawar anticline. The rain water and the run-off accumulate in these depressions and, due to the high rate of evaporation, salt accumulates on the surface, forming a crust a few centimetres thick. In the majority of cases they represent former shore-lines of the Gulf for lagoons along the Arabian Gulf are currently being infilled and forming Sabkhah. The largest of the Sabkhah is the Sabkhah Matei on the borders of Saudi Arabia and the United Arab Emirates.

h. The Northern Province

This province comprises the area lying to the north of An-Nafud Al-Kabir. It extends to the Jordan-Iraq borders. This province consists of a variety of geological formations which cause heterogeneity in the landscape. The topography mainly consists of small hills standing on a wide plateau which is dissected by innumerable valleys which trend east-north-east. In the extreme northwest of this province there is a depression, possibly formed by tectonic movements, now occupied by Wadi As-Sarhan. Eastward from this depression there is an extensive basalt flow of recent age extending into Jordan, known as Al-Harrah. Al-Harrah has an elevation of 300 metres above the bottom of Wadi As-Sarhan. The wide plateau, which is known as Al-Hammad, lies mainly to the east of Al-Harrah and has a gravel cover. The elevations of this province vary from 1000 metres in Al-Harrah to about 400 metres in the extreme eastern section of the plateau.

From the foregoing description of the physiographic regions in Saudi Arabia it can be found that these regions have distinguishable weather conditions which in one physiographic region may differ from the others, especially the differences in the weather conditions between Najd sedimentary plain and Najd pediplain and between those areas and the Asir highlands, as will be described in the next chapters. It can also be seen in the next chapters that there are considerable differences in the weather conditions between the coastal plains of the Red Sea and the Arabian Gulf.

The topographic variations between one region and another naturally have considerable effects on both rainfall and temperature. The Najd plateau, with an elevation of only 800 metres, shows a low mean annual rainfall and high air temperature, while the Asir and southern Hejaz highlands, with elevations exceeding 3000 metres, show moderate temperature conditions and high mean annual rainfall.

The vast expanses of the lava fields in the western part of Saudi Arabia may have effects on both temperature and rainfall. The dark coloured lava create local cells of high temperature which, during winter, cause convectional activities and may lead to marginal increases in the amounts of rainfall. Furthermore, the advected warm air, which originates over these dark lava, may transfer the heat from over these areas to other surrounding regions.

The distribution of the sand dunes also affects the weather conditions in areas where they prevail.

CHAPTER IV

AIR MASSES, FRONTS AND PRESSURE SYSTEMS

1. Air Masses

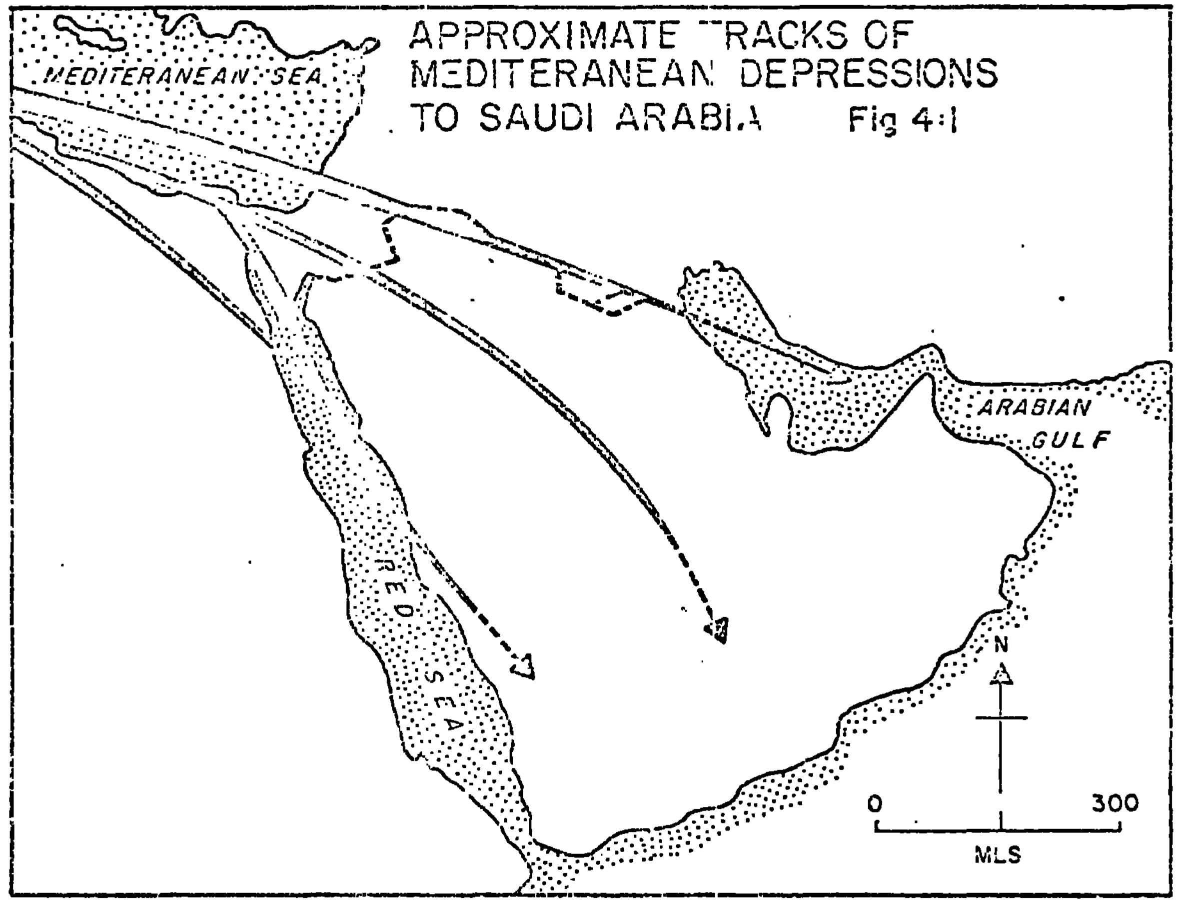
The predominant weather of Saudi Arabia can be explained by the action of air masses. During the period October to May the prevalent air masses are the Continental polar air mass which develops over Central Asia and the Iranian-Baluchistan plateau, the Maritime polar air mass which develops over the Atlantic Ocean and extends eastwards over Europe and south-eastwards where it becomes modified during its passage across the Mediterranean Basin, and the Continental tropical air mass which builds up over the Sahara. During the period June to September the prevalent air masses are the Tropical air masses of thermal low pressure which cover an area extending from northwest India to north Africa through Arabia, and the Maritime tropical air mass which originally develops over the Indian Ocean and the Arabian Sea.

a. Winter Air Masses (December - February): Dry, cold air, since it is continental and polar in origin, sweeps from the Iranian-Baluchistan plateau in winter into Saudi Arabia and normally forms a ridge over the eastern half of the country. This ridge often breaks up and forms a high pressure cell over the heart of Arabia. While these cold, dry air conditions prevail, the atmospheric conditions result in clear skies and relatively cold and stable air conditions. At this time, night air temperatures may drop considerably below $0^{\circ}C$, though daily air temperatures tend to be around 10°C and the prevalent weather conditions are usually pleasant. However, air temperatures rarely drop below 0°C for prolonged periods due to modification imposed on the air by latitudinal and adiabatic heating, since the air descends southward from the Zagros mountains via the low lying areas of Mesopotamia and the Arabian Gulf before reaching Saudi Arabia.

During temporary recessions of the Asian Anticyclone this high pressure ridge does not develop over the country. Consequently, occasional invasions of the maritime air from the Mediterranean, and the associated depressions, may penetrate the country, introducing maritime and modified polar air behind the frontal passage of these depressions. The invasion of these depressions depends mostly on large scale pressure patterns over the European continent. When the northerly cold maritime or continental air meets the warmer southerly air over the Mediterranean area instability and convergence occur and there is increased cyclonic activity. Consequently, the depressions may retain sufficient energy to travel southwards or south-eastwards. No attempt has been made to determine the tracks of these depressions toward the country. According to the scanty reports and data available concerning the depressions, it appears that these disturbances often travel along the following tracks:

1. Palestine, Jordan and North Arabia to the Arabian Gulf.
2. Palestine or North Africa, Sinai to Northern and Central Saudi Arabia.
3. North Africa or Palestine via the Red Sea to Southern Saudi Arabia.

These tracks are shown on Figure 4(1).


APPROXIMATE TRACKS OF
MEDITERANEAN DEPRESSIONS
TO SAUDI ARABIA Fig 4:1
MEDITERANEAN SEA
RED SEA
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N
0
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The western depressions usually originate in the Mediterranean Basin, but there are very rare depressions which sometimes develop in the interior of Arabia (Banerji, 1931). These tend to occur during mid-winter when the anticyclone over Iran intensifies considerably and causes an outflow of cold air over the Arabian Gulf to Saudi Arabia which meets the air coming into the country from the Mediterranean (The Meteorological Office, Great Britain, 1951). However, such disturbances tend to be very weak.

Mediterranean type depressions in late autumn and early winter tend to follow the first track to the northern and eastern regions of the country. The second track appears to be followed by depressions which develop over the southern coast of the Mediterranean Sea. The effects of these disturbances appear to occur throughout the cool season, though they are most frequent during the period November - April. The third track is that used by depressions which develop in the eastern and southern Mediterranean. The effects of the depressions following this track appear to be largely confined to the western regions of the country.

In the cool season the country generally comes under the effects of the activity of these depressions. They are vigorous from November to April, though they may occasionally affect the country as early as October or as late as May. This is particularly confined to the north of the country, though they rarely affect regions further south or east before November. In spring they are often frequent, but in May they rarely occur, due to the intense heat. Rainfall during this month is caused by sharp thunderstorms due to convectional activities. Normally the western depressions move along their most southerly tracks in mid-April and then gradually recede northwards.

When a depression approaches, the normally prevailing NNW winds change to between ESE and SSW. Gradually the air becomes warmer and more humid, clouds increase and become lower, temperature rises and light drizzle may occur. Rain may be relatively heavy with the approach of the warm front and the cloud and rain often persists for a more prolonged period over the hills. Small secondary depressions may appear in the warm air in advance of the main cold front, giving rise to rapid falls of air pressure, strong SE or SW winds, and some showers. When the depression passes there is a return to fairer weather, winds are replaced by cool winds from the NW with a fall in temperature and humidity, some occurrences of squalls of gale force, sharp and isolated thunderstorms, and sometimes dust or sand storms.

A fairly cool, dry air mass normally develops over the Sahara during the winter months. The air may blow over northwest Saudi Arabia from time to time, particularly during the passage of western depression down the west of Saudi Arabia, causing sand or dust storms over the north west of the country. Because of the limited width of the Red Sea, the Saharan air rarely recharges with sufficient quantities of moisture and, hence, it does not usually give rain over the Red Sea coastal plain, but it may produce increases in relative humidity and may, though rarely, give light showers on the western mountains.

b. Spring Air Masses (March to early May): With the onset of the spring season the insolation becomes more intense and, hence, the Asian anticyclone starts to become less active. The ridge of high pressure over Saudi Arabia begins to diminish and becomes replaced by a low pressure cell over the head of the

Arabian Gulf and lower Iraq. The Sudan monsoonal low is, during this season, advancing from Central Africa towards the north-eastern Sudan and Western Arabia across the Red Sea. During some years the Sudan monsoonal low may extend north-eastward across Saudi Arabia and cause the development of a trough towards the head of the Arabian Gulf and lower Iraq. A high pressure area normally develops over the Arabian Sea. In these circumstances tropical maritime air masses may advance from the Arabian Sea and from the Mediterranean.

The most important phenomenon during this season is the occurrence of sharp and isolated convectional thunderstorms accompanied by very heavy showers. The south-eastern maritime air, which blows from late October or early November, reaches its maximum flow in March and April. At the same time, the north-west maritime air over Europe reaches its maximum flow towards the Mediterranean and the cyclonic disturbances over the Mediterranean reach their highest frequency during March and April (Trewartha, 1962).

c. Summer Air Masses (late May to the end of September): In summer the air masses tend to be more static than in other seasons with no significant day-to-day changes in weather conditions taking place over the major part of Saudi Arabia. During this season, south-west Asia is affected by a continental tropical air mass. The cyclonic air flow, part of the Indian monsoon system, dominates this region. This air is humid when it blows as a southwesterly air stream over India. Because of the low pressure region existing over north-west India and southern Iran, part of this air-stream is deflected in an anti-clockwise direction as a south-easterly or even easterly flow and affects Saudi Arabia as an easterly or even north-easterly air-stream. Because of the distance travelled over land, it is extremely dry. When this air stream flows over the southern regions of the country during the hot season (late May - end of September) it prevents the tropical maritime air of the south-west monsoon from penetrating further north or east of Asir and southern Hejaz mountains (Parsons Basil-Consultant, 1968).

In the south-west region of the country the situation is a result of a combination of three factors: the proximity to the Red Sea, the orographic effects, and the oscillatory Inter-Tropical Convergence Zone.

The Red Sea is a trench through which the maritime air of the south-west monsoon and the associated depressions normally flow and affect the Asir and southern Hejaz. When this type of air flows over the southern section of the Red Sea coastal plain, the Tihama, it becomes forced to ascend rapidly over the mountains to the east of this region towards the low pressure area over Arabia. It becomes cooler, saturated adiabatically, and condensation of this air normally results in rain and hail, particularly over the ranges of the Asir highlands.

The Inter-Tropical Convergence Zone (I.T.C.Z.) often becomes convex towards the Red Sea in the form of tongue within which the west to south-west monsoon reaches the south-west of Saudi Arabia (El-Fandy, 1949). The region which is normally affected by the south-west monsoon has not yet been defined accurately because of the lack of sufficient data. According to the available data concerning rainfall, the area which is often influenced by the south-west monsoon extends northwards to Al-Lith in the Red Sea coastal plain and Taif in the western highlands. However, it appears that there may be unusual penetrations of the tropical disturbances during July or August which can cause light showers in the western highlands north of the Taif area, Jabal Shammer and Tuwayq mountains. The tropical disturbances which give rain in summer come from the west, probably from the Sudan, and give rain in the Madenah area and Jabal Shammer, while those which give rain in Tuwayq and the eastern regions come from the south-east; probably from the Arabian Sea via the Gulf of Oman and the Arabian Gulf.

The origin of the south-west monsoon air is of a controversial nature. Some geographers (Aziz, 1971) suggest that the humid air of the monsoon originates over the Gulf of Guinea from which the maritime air flows across Central Africa and Ethiopia to the south-west of Arabia. Other geographers (Fisher, 1971) suggest that the air stream of the monsoon originally comes from the Indian Ocean where it blows across the Arabian Sea to the southern areas of Arabia and the southern section of the Red Sea.

During the summer months two high pressures develop over the Indian and South Atlantic Oceans and extend into Central Africa in the form of regions of high pressure. At this time the Sudan low pressure is at its northernmost location and effectively forms a continuation of the main Asiatic thermal low. From the ridges of high pressure over Central Africa, maritime air advances from the south-west while continental tropical air advances from the south-west of Asia as a north-easterly air stream. The two air currents converge in a zone that oscillates over the Red Sea and southern Arabia.

Part of the south-west monsoon air blows from the high pressure ridges over Central Africa as south-easterly winds, south of the Equator, as the south-east trade, and then bends to the south-west after crossing the Equator due to the deviating coriolis force.

Then it veers over the Ethiopian plateau in a west-north-west to north-west direction between latitude 8 and 15^{o}N before it joins the general south-west stream over the south-east of the plateau (El-Fandy, 1949). However, it has been suggested (Sogreah, 1970) that the maritime air mass of the monsoon comes solidly from the Indian Ocean,pushed by the south-east trade winds via the Arabian Sea and the Red Sea. The air, when it enters the Red Sea, becomes deflected to the south-west of Arabia by the Ethiopian plateau. Furthermore, it is suggested (Italconsultant, 1969A) that a part of the moist monsoon blows from the Arabian Sea as a south-easterly air stream, but the high relief of the Yemen has a blocking effect. The air stream arrives in the south-west region modified by subsequent orographic effects. Part of the south-west monsoon, on the other hand, is channelled along the Red Sea trench from which it is deviated either towards Sudan or Saudi Arabia due to differential heating of the land masses - again orographic influences are important.

However, it appears from the available data on wind direction in Jazan, Taif and Kamis-Mushait that the south-west monsoon winds are coming from the Arabian Sea through the Red Sea trench. They flow over the south-west region as westerly, south-westerly or southerly air streams, as can be seen from Figure 5(II) which shows the wind directions during the summer months in Saudi Arabia.

d. Autumn Air Masses (October - November): During the start of this season the country is still under the effects of the hot and dry air masses of the summer months, but in late October or early November the intense hot and dry air masses appear to be replaced by slightly moister and more temperate air as solar insolation declines. In November, bursts of maritime air appear to advance from the Mediterranean to cover substantial portions of Saudi Arabia, particularly the northern regions of the country. In late November this air may become prevalent over much of Saudi Arabia and usually the rainfall of this period comes from these air masses. The Mediterranean-type depressions often start to invade the country as early as late October, but their rainfall is normally restricted to the northern regions and the western highlands, while the major part of the country is still under the influence of dry air. The Mediterranean disturbances often draw dry, tropical air into the warm sector of the cyclonic system. The dry air is usually drawn from North-east Africa, or from Arabia itself. Development of troughs may occur during November, but this is not as frequent nor as deep as in the spring season. The development of troughs during autumn appears to be restricted to late November. For example, in November 1967, a trough developed across Saudi Arabia from Ethiopia to the Arabian Gulf, causing the outburst of moist tropical air to converge with the cooler, moist air which had advanced from the Mediterranean Sea. Large amounts of rainfall occurred over a period of two to three days in the middle of the month. This situation appeared to be centred over a belt extending from Jeddah to Dhahran and from the southern Tuwayq to Hail (Italconsultant, 1969A). Table 4(I) shows the amount of rain which fell in November 1967 within the area affected by this trough. However, during the major part of this season the air over Saudi Arabia is warm and considerably dry and often laden with dust or at least haze, due to rather strong winds and convection activities within dry air.

TABLE 4(I)

Amounts of rainfall in November 1967

Station	Total November rainfall (mm)
Jeddah	33.0
As-Sulayyil	11.5
Unayzah	88.0
Riyadh	16.0
Dhahran	6.1
Ras Tanura	35.8

2. <u>Fronts</u>

From time to time Saudi Arabia becomes influenced by relatively active fronts. They usually develop due to the convergence of two air masses different from each other in characteristics, and accentuated by local effects. These fronts can be classified as follows:

a. The Inter-Tropical Convergence Zone which affects Saudi Arabia during the summer season when it is active over the south-west region and accentuated by the presence of Asir highlands and the Red Sea.

b. The Transition Seasons' fronts which usually develop in mid-spring and late autumn. These fronts may be the reason why November and April have the maximum rainfall at the majority of the stations in Saudi Arabia.

c. The Winter Season Front over the Arabian Gulf. This front appears to develop over the eastern regions during mid-winter.

d. The Red Sea Convergence Zone which develops during the period of October to May over the Red Sea.

A. The Inter-Tropical Convergence Zone (I.T.C.Z.)

During the summer season the south-west region of Saudi Arabia is under the influence of the Inter-Tropical Convergence Zone. It develops as a result of the convergence of the north-east and south east trade winds. It oscillates over the southern regions of the country during the hot season between latitudes 20 and 16^{o}N. It becomes convex toward the land in the form of a tongue within which the WSW monsoon winds reach the south-western region of the country. This zone of convergence suffers diurnal oscillations in both north and south directions. These oscillations of the convergence zone are very variable (El-Fandy, 1950B). During some years it may affect the central regions of the country up to 25^{o}N, while during other years it does not advance far to the north at all and, consequently, its effects are restricted mostly to the south-western region. Its effects in the interior areas are rarely in the form of rainfall, but usually in the form of increases in relative humidity and the formation of high clouds. *

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*The inhabitants of Najd area call these climatic phenomena of high relative humidities and formation of clouds "Tabbakh At-Tamir" which is an Arabic term meaning "the palm date cooker".

Table 4(2) represents the amounts of rainfall and the relative humidity at Riyadh station - 24° 39'N 46° 43'E - in the interior of Saudi Arabia during the northern oscillation of the I.T.C.Z. in late July 1973.

TABLE 4(2)

Rainfall and relative humidity at Riyadh station in late July 1973

Day	21	22	23	24	25	26	27	28	29	30	31
Rainfall (mm)	nil	nil	0.7	3.2	nil	nil	nil	nil	nil	nil	nil
Relative Humidity (%)	27	25	47	48	49	33	33	28	28	36	36

The I.T.C.Z. is normally associated with rainfall of relatively large amounts over the highlands of Asir and southern Hejaz. This area extends from Taif southwards. Disturbances leading to rainfall due to rapid oscillation of the zone during the months of July and August tend to be frequent in the south-western region. Obviously, the rapid northern movement leads to large-scale flows of the moist monsoon winds over the country. In general, these conditions are superimposed by the orographic effect of the high escarpment and shield area. Even the relatively low relief of Tuwayq escarpment appears to be significant (Italconsultant, 1969A).

b. The Transition Seasons' Front

During the transition seasons the country is sometimes under the effects of an active front. This front usually develops as a result of the convergence of two air masses; the maritime polar air mass which advances from the north, and the warmer, moist air mass from the tropics. In some years this front is relatively intensive, and during others it is shallow. This depends on the local conditions and the scale of the flows of the two air masses, and consequently on the intensity of the convergence and the resultant disturbances. During some years a deep trough extends from the Sudan low across Saudi Arabia to the Arabian Gulf, or possibly to lower Iraq. The front usually inclines over Saudi Arabia from NNE to SSW. It does not often affect the northern regions of the country - north of latitude 29°N - or regions to the south of the Bayadh escarpment towards the Empty Quarter. This front often causes the development of groups of sharp and isolated thunderstorms, characterised by their effect on limited areas. These thunderstorms can cause torrential rainfall over a limited area and violent flash floods. The amounts of rainfall are usually affected by relief, even hills of modest elevations. Thunderbolts and hail usually accompany these thunderstorms, killing people and animals, and sometimes damaging buildings.

c. The Winter Season Front Over the Arabian Gulf

This front develops in the eastern region of the country during mid-winter due to the convergence of two air masses; the north-east air mass which is cold and dry and which reaches the country from Iran, and the north-west air mass which is cool, relatively moist and which accumulates more moisture from the Arabian Gulf. This air is polar in origin, but as it travels southwards via the Mediterranean it becomes warmer (Meteorological Office, Great Britain, 1951). Disturbances as a result of the flow and convergence of the two air masses develop and give the largest amounts of rainfall in the year. The area affected by this front is usually restricted to the eastern province, but sometimes it affects areas as far west as Riyadh and causes large amounts of winter rain in the interior regions.

In general, the two frontal systems in the winter and transitional seasons may be deep and intense, causing large amounts of rainfall during some successive year, while during other years they may be shallow, or may not develop at all. This is what leads to the suggestion of the occurrence of climatic periods, some being humid while others are dry. Moreover, the regions which are under the effects of these fronts are not usually affected by them. They may affect regions further northwards or southwards, eastwards or westwards.

d. The Red Sea Convergence Zone (R.S.C.Z.)

D. E. Pedgley (1966) has shown that during the period of October to May there is a convergence zone in the Red Sea between a northern air mass arriving from the Mediterranean via the northern part of the Red Sea, while there is a tropical moist air mass coming from the south-east through Bab Al-Mandeb in the southern part of the sea. The two air masses converge in an area which oscillates from the Jeddah-Port Sudan latitude in the north to the Massawa latitude in the south. Disturbances leading to the formation of clouds and rainfall occur frequently over the Red Sea and the escarpments bordering the sea within this zone. Pedgley has mentioned that there is little chance for the moist tropical air and the disturbances to rise over the escarpments towards the interior of the mainland because of the stable vertical temperature structure of both airstreams. This can explain the remarkable decrease of rainfall towards the interior of the country beyond the Asir mountains.

3. Atmospheric Pressure

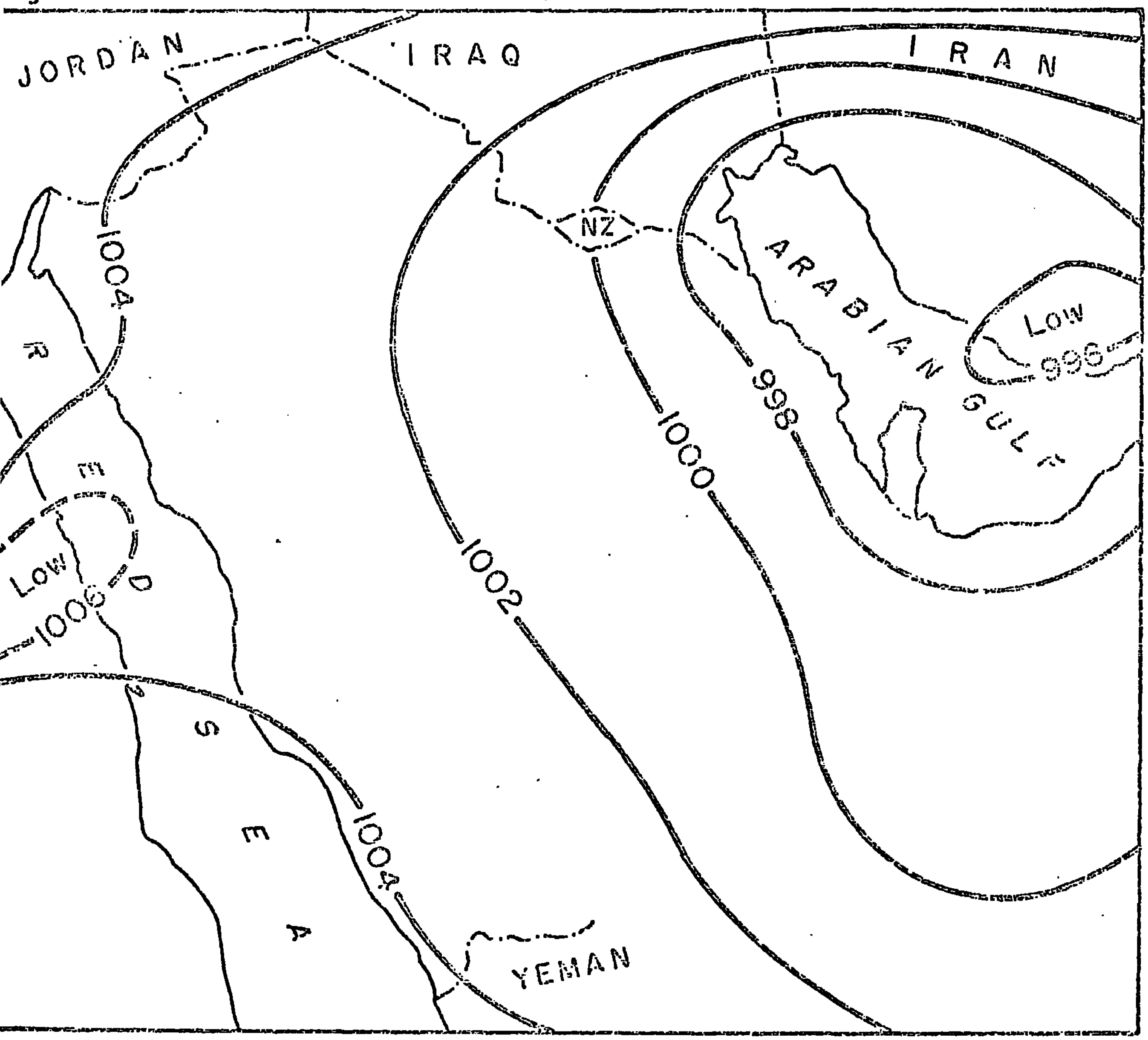
Information about the atmospheric pressure over Saudi Arabia is available from a small number of climatic stations. Most of the stations which record atmospheric pressure have been installed recently. The other stations, which installed equipment a number of years ago, normally have interrupted data of the atmospheric pressure. In fact, there is not any single station which has a complete record of the atmospheric pressure for consecutive years. In the present study of the atmospheric pressure over Saudi Arabia, the scanty data recorded at a small number of stations in 1964 were utilised in an attempt to give a general indication of the distribution of the atmospheric pressure over the country.

During the summer months a thermal low pressure region develops over an area extending from Northwest India to North Africa. In this season the Sudan low, at its northernmost extension, forms part of the Asiatic thermal low region. The low pressure region is caused mainly by the low air density due to intense heat over the land masses. The low pressure region is replaced at upper levels by high pressure due to the global subsident air of the general air circulation in the Horse Latitudes within the subtropical belts. The height of the cyclonic circulations around the lows varies according to the excess difference in air temperature relative to the surrounding air. In India it is up to 3 km in height, while over North Africa the cyclonic circulation is replaced by high pressure at 4 km (Soliman, 1949). During the hot season the conditions over most of the country are cloudless skies and intense insolation resulting in remarkable convectional activity within a very dry air. In July 1964 the isobaric mean of 998 millibars passed westward over the Euphrates delta and bent back southwards over the eastern region of the country around Dhahran and over the Gulf of Oman. In the interior regions the isobaric mean of 1000 millibars in July 1964 crossed from north to south, while in the western regions the July mean (1964) of 1004 millibars extended across the Jazan area, bent westwards to include the Sudan low, and then bent back to cross the north-west region of the country.

Over the whole country the atmospheric pressure reached its lowest value during July when the mean value for 1964 was about 998 mb. It rose to its highest value during January 1964, when the mean of this month approached 1019 to 1020 mb. Thereafter it gradually fell. The most rapid rise took place between September and October (1964), and the most rapid fall occurred between May and June (1964). During the periods September to November and March to May, the pressure distribution was changing from one type to another. In winter, December to February (1964), a region of high pressure was developing over Central Asia and the Baluchistan-Iran plateau, with a high ridge extending into Arabia which broke off and formed a cell of high pressure over the country. The semi-permanent Sudan low was near the Lake Plateau of Central Africa during this season, with a trough extending to the Red Sea.

In the cool season pressure conditions are normally more variable due to the oscillations of the Asiatic Anticyclone and the

Fig.4·II ATMOSPHERIC PRESSURE (Mb) JULY 1964



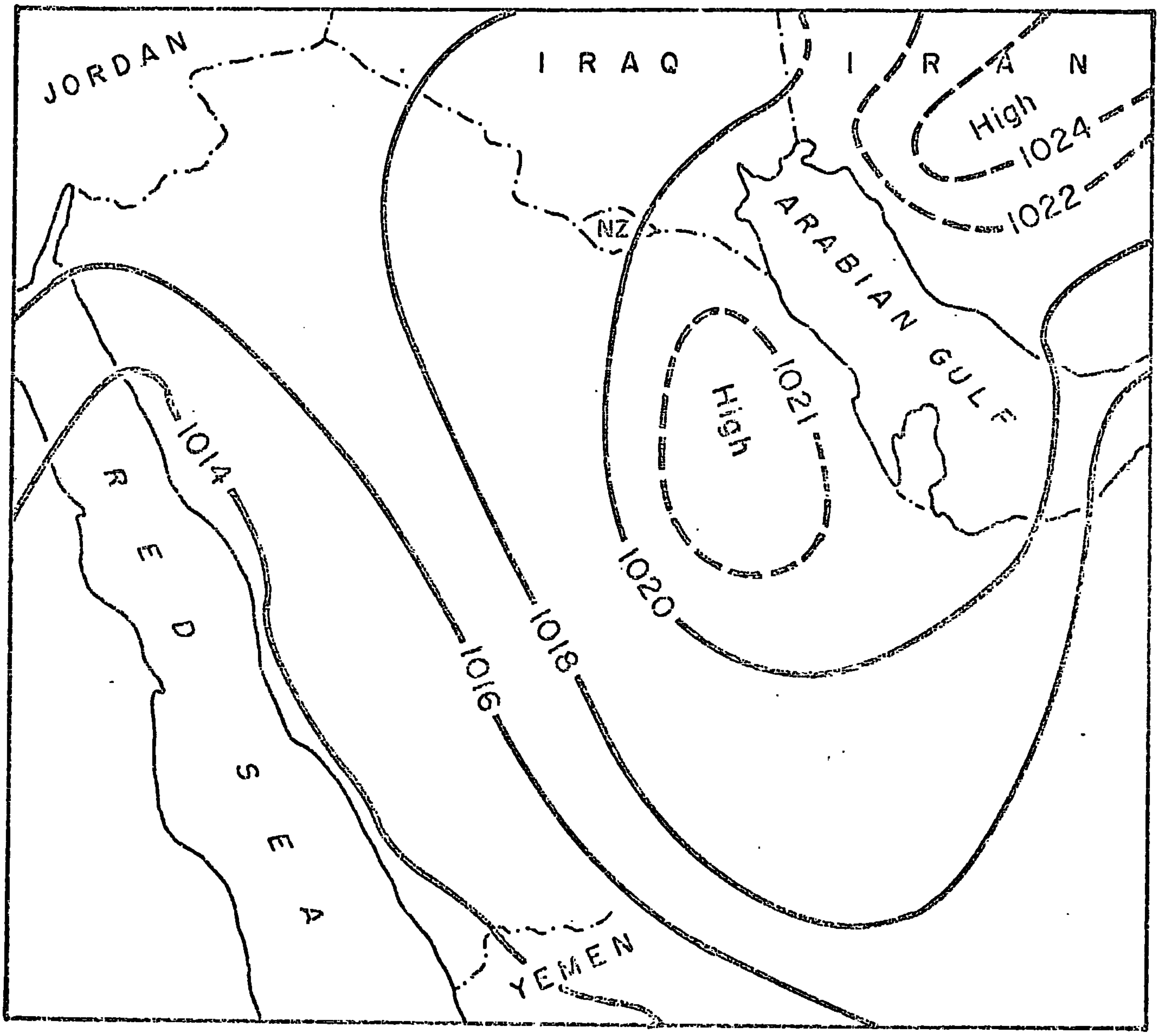
invasions of the Mediterranean depressions, or as a result of the development of local disturbances. In January, a high pressure normally exists over most of Saudi Arabia. The January (1964) isobaric mean of 1018 millibars intersected the country from north to south, while a high cell of 1021 millibars developed over the eastern half of Arabia. The January (1964) isobaric mean of 1016 millibars crossed the western regions.

The atmospheric pressure in the western regions is affected by the high altitudes of the Western mountains. At Taif, (1395 metres) in the southern section of the escarpment of the Hejaz, the January and July (1964) isobaric means were 850 millibars and 847 millibars respectively. In Kamis Mushait (1950 metres) in the southern section of the highlands of Asir, the January and July (1964) isobaric means were 800 and 790 millibars.

During the spring season, which is essentially a short period, the high pressure of Asia weakened. At the same time the ridge of high pressure over the country was displaced by low pressure though there appeared to be an area of high pressure still over the Arabian Sea. Troughs may develop and extend across Arabia from the Sudan low during this season and, while of a localised nature, they do bring the last appreciable cloudiness and rainfall (Huo, W.S., 1965).

Autumn, like spring, is also a short period, and is characterised by similar atmospheric pressure conditions, though the trends are reversed. The significant characters of the pressure distribution during the transitional seasons over the area are the existence of relatively low pressure over southern Iran which extends eastward to cover the Arabian Gulf and lower Iraq. The Sudan monsoon low is normally centred over northern Ethiopia and extends eastward to cover the Red Sea.

Fig. 4·III ATMOSPHERIC PRESSURE (Mb) JANUARY 1964



CHAPTER V

SURFACE WINDS AND RELATED PHENOMENA

Surface Winds

Information on wind directions and velocity is not available for the great majority of climatic stations of Saudi Arabia. Most of the stations run by the Ministry of Agriculture did not record wind directions until recently and, therefore, the wind data used in the present study were recorded by the stations run by the Ministry of Defence. The available data on winds show that there are three types of winds which can be classified as follows:

1. The north-west winds (The Shamal)
2. The south-east monsoon
3. The south-west monsoon

1. The North-west Winds (The Shamal)

The north-west winds are called, locally, the Shamal (Figure 5(I)). They prevail over the whole country, with the exception of the Asir mountains and the southern section of the Red Sea coastal plain, during the period June to September. During the summer season a high pressure of the Azores normally extends eastward to cover most of the Mediterranean area. Over north-west India, on the other hand, a low pressure develops and

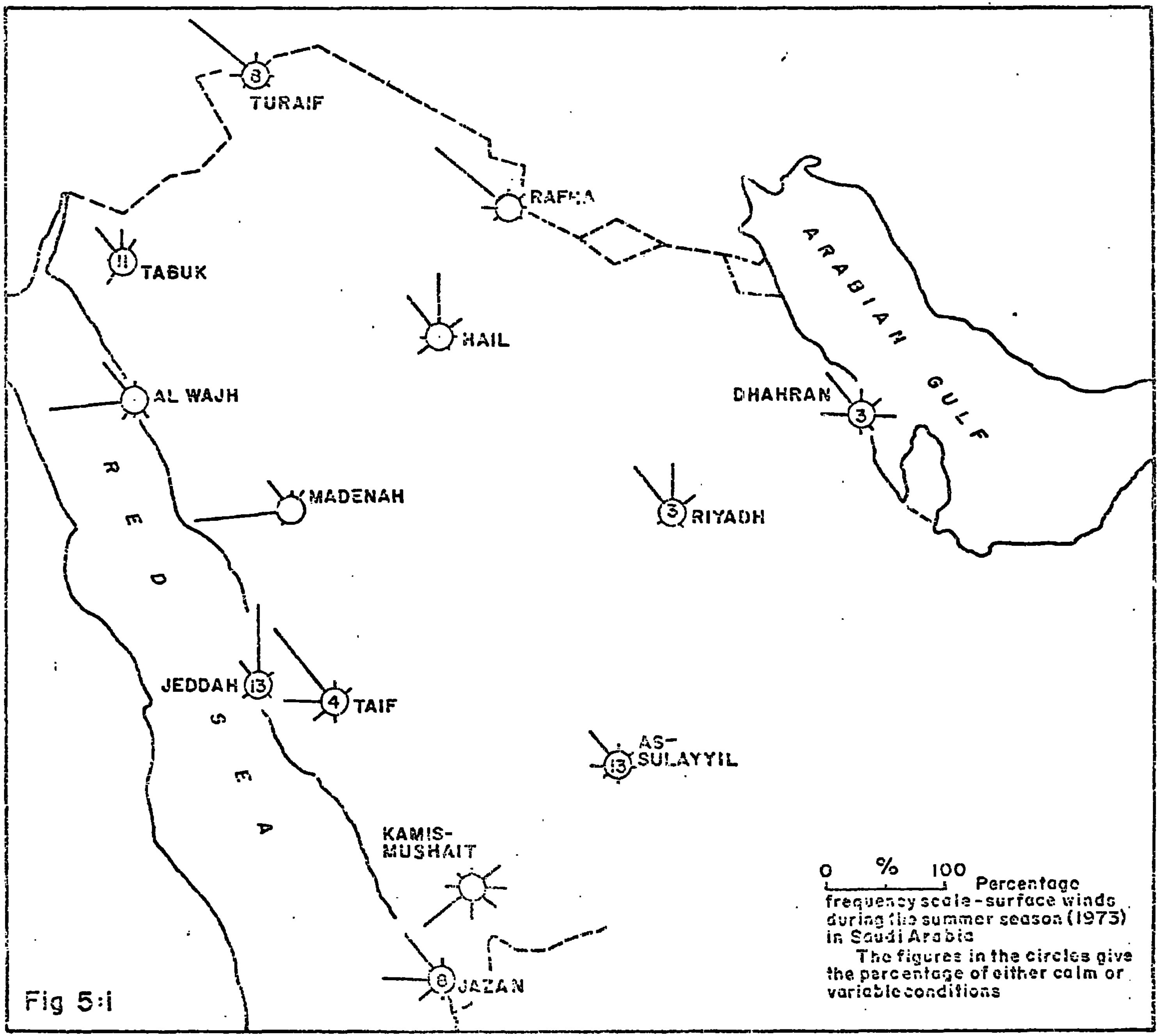


Fig 5:i

Percentage frequency scale - surface winds during the summer season (1973) in Saudi Arabia

The figures in the circles give the percentage of either calm or variable conditions extends westward over southern Iran and the Arabian Gulf. This pressure pattern causes persistent north-west winds to blow from the Mediterranean and North Africa high pressure area in a south-easterly direction towards the low pressure area.

The direction and speed of the winds are affected by the local topography. In the west of the country the winds sweep from the subtropical anticyclone of the Azores and enter the Red Sea trench as northerly winds. They blow parallel to its shores and regularly blow as northerly to north-westerly winds in the Jeddah area and as westerly or west-north-westerly winds in the Al-Wajh and Jazan areas. Along the escarpment of the western highlands the direction is more westerly, while the winds on the eastern slopes are north-westerly. Wind speeds on the coastal plain during the summer months are low, the average being about 8 knots. Over the escarpment the wind speed is still low as the wind ascends the mountains, the average at Taif being 9 knots. On the leeward side of the mountains the wind speed increases slightly with the summer average for Madenah being 10 knots. Generally, the western highlands stand as a shelter to the Red Sea coastal plain from the north-easterly and the south-easterly winds which have a significant component on the eastern slopes of the mountains.

In the eastern regions of the country the north-west winds are rarely interrupted during the summer months. They are continuous and persistent and vary in force. It is suggested (Meteorological Office, Great Britain, 1951) that the remarkably high, though variable, speed is a result of fluctuations in the intensity of the seasonal low pressure area over north-west India. When the low pressure deepens, the north-west winds (the Shamal) may become strong and may blow with an average speed of 20 knots, though at times reaching gale force. However, the wind force usually decreases gradually when the low pressure area returns to normal, a striking contrast with the squally Shamal of winter. The mean of the wind speeds at Dhahran in summer ranges between 9 and 13 knots.

During the periods of summer when the Shamal is strong it is often gusty and laden with dust or sand which reduces visibility, but it is not associated with thunderstorms or sudden squalls, the air being dry and hot, and the sky often cloudless.

It is suggested (Siraj, 1971) that the wind direction in the eastern regions is affected by the topography of western Iran. The Zagros mountains which trend northwest south-east, roughly parallel to the eastern shores of the Arabian Gulf, deflect the westerly winds which blow from the extended Azores anticyclone to a south-easterly direction.

In the northern region of the country the wind direction is affected by the proximity of the area to the Mediterranean Basin. The wind direction throughout the summer months is variable between west and west-north-west. Sufficient data to show the wind velocities are not available for the region, but from the available scanty data the wind speed is comparatively high, rarely decreasing to less than 11 knots. Further south, the west-northwest winds change direction slightly to north-north-west in the interior regions and the mean wind velocity in the summer season decreases to 8 knots.

During the cool season - October to May - the wind direction is affected by the high pressure region over the Iran-Baluchistan plateau and the high pressure area over the Atlantic Ocean which in mid-winter extends over North Africa almost to the Red Sea. Owing to the comparatively high temperature of the water bodies bounding

Saudi Arabia, low pressure areas often develop over the Red Sea, the Arabian Gulf and the Arabian Sea. In these circumstances the wind's direction is either north-easterly or north-westerly over the major part of the country. If the Asian anticyclone is not very intense, the wind direction will be west-north-westerly over most of Saudi Arabia. These types of wind, either blowing from north-east or from north-west, are known locally as the Shamal.

Comparing the wind velocity of the Shamal during the cool season to the Shamal of the summer months, it can be found that the Shamal of the cool season is less in speed, despite the fact that they may blow very strongly during the periods of the passage of the Mediterranean depressions. During the periods of undisturbed weather, the velocity of the Shamal of the cool season ranges between 7 and 8 knots, while during the periods of the passage of the Mediterranean depressions the speed may increase by more than 20 knots. When the Shamal winds blow strongly, they are normally laden with dust or sand particles.

2. The South-east Monsoon

This type of wind prevails during the period of November-April though it may start to make its appearance as early as October and as late as May. It is a persistent wind, blowing from the southerly quadrant over the southern regions of the country. Unfortunately, there are no installed climatic stations in the Rub-al-Khali to show its velocity and directions, but according to the available data on wind speed and directions recorded by stations installed in the northern flanks of the Rub-al-Khali, this type of wind blows from either an easterly or a south-easterly direction. These winds are in origin the north-east monsoon which blows toward the Arabian Sea from the Asian anticyclone during the cool season. When the north-east monsoon winds blow over the Arabian Sea they recurve toward the west and north-west and enter the southern regions of the country as easterly and south-easterly winds. This type of wind normally enters the Red Sea and flows towards the north-west, causing persistent southerly to south-westerly winds over the southern part of the Red Sea (Pedgley, 1969 and 1966).

The northern and western extent of the south-east monsoon has not yet been determined because of the lack of sufficient data on wind directions. However, it would appear that the south-east monsoon may penetrate into the interior regions of the country and flow over areas as far north as Ha'il and as far east as As-Sulayyil, as can be seen from Figure 5(II) which shows the wind direction from November to April in Saudi Arabia.

The velocity of the south-east monsoon normally ranges between 8 and 10 knots, though they may blow strongly during the period of the passage of the western depressions. When they are associated with the passage of the Mediterranean depressions, they are often laden with sand or dust particles. The south-east monsoon winds, when they have these characteristics of high velocity and sand or dust particles, are called by the natives in the Arabian Gulf coastal plain as Al-Kaus.

Tables 5(1) and 5(2) show the number of days on which the wind directions were from the north (the Shamal) or from the S-ESE (the SE Monsoon).

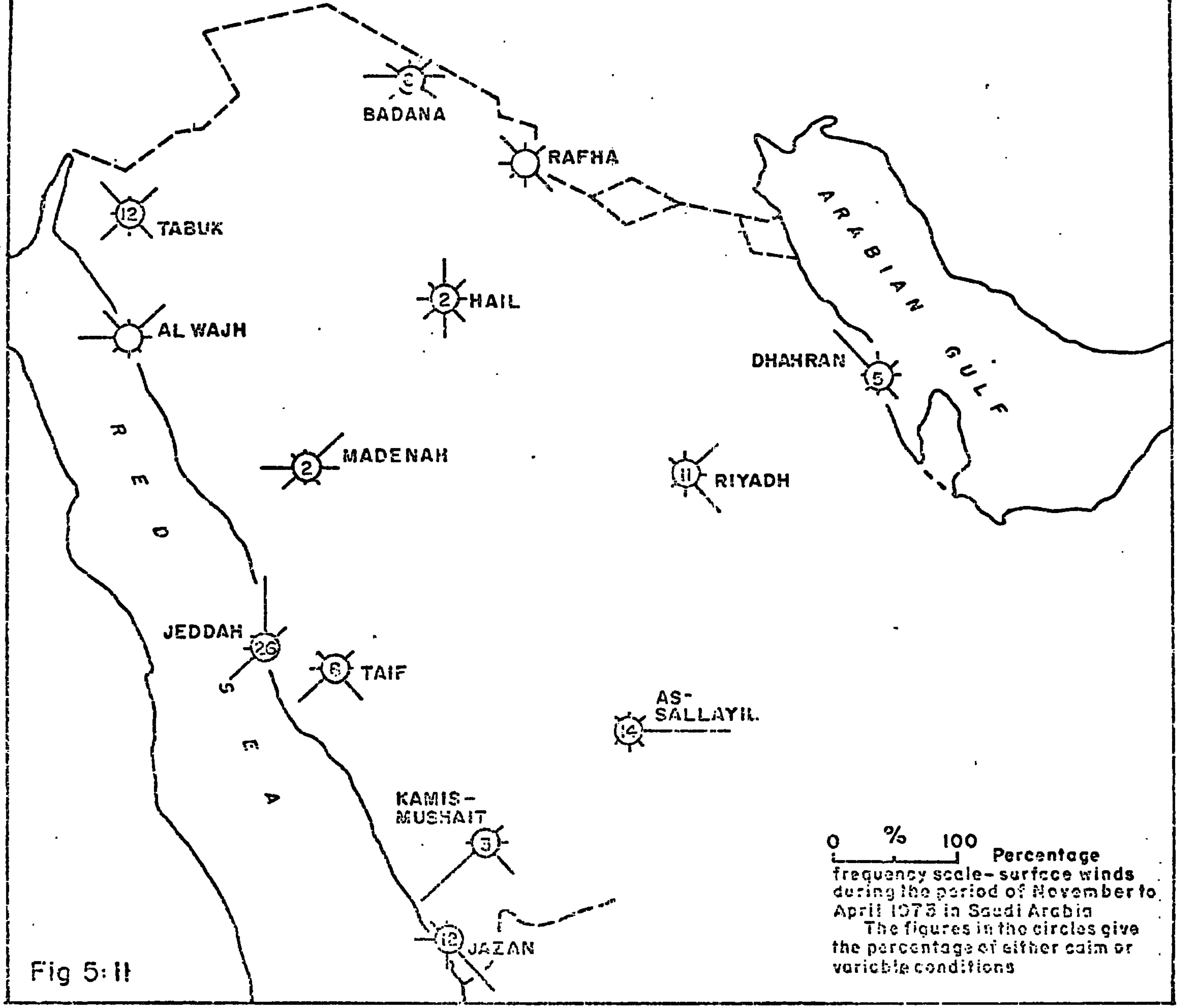


Fig 5: 11

Percentage frequency scale– surface winds during the period of November to April 1973 in Saudi Arabia

The figures in the circles give the percentage of either calm or variable conditions

TABLE 5(1)

NUMBER OF DAYS ON WHICH THE PREVAILING WINDS WERE FROM THE NORTH IN 1971 AT SELECTED STATIONS*

Station	J	F	M	A	M	J	J	A	S	O	N	D
Al-Wajh	6	21	20	21	10	12	17	27	20	11	19	15
Dhahran	23	15	16	18	22	25	28	20	14	20	16	21
Hail	12	11	11	12	12	28	27	23	22	15	9	14
Jazan	4	7	2	15	21	29	9	4	1	0	0	4
Jeddah	11	13	10	12	11	17	22	22	16	18	15	13
Qassim A.R.	9	6	7	8	6	x	22	9	14	12	11	12
Riyadh	16	11	9	11	10	28	27	23	22	14	10	17
Tabuk	22	4	9	10	13	15	x	8	7	16	14	18

TABLE 5(2)

NUMBER OF DAYS ON WHICH THE PREVAILING WINDS WERE FROM THE S,ESE AT SELECTED STATIONS IN 1973

Station	J	F	M	A	M	J	J	A	S	O	N	D
Dhahran	4	7	10	10	0	3	0	4	5	5	5	8
Hail	10	12	10	12	8	0	0	6	2	4	12	5
Madenah	18	4	13	7	5	0	0	1	14	16	19	9
Qassim A.R.	10	15	14	8	4	x	1	18	11	10	9	10
Riyadh	7	11	10	11	1	1	1	2	2	8	10	11
Tabuk	6	2	4	1	0	0	x	0	1	4	6	5
Taif	15	4	6	6	7	9	5	1	13	9	11	9

* Two different years were used as data from some of the stations in Table 5(1) were unavailable.

x Data are unavailable

It should be realised that the winds, when blowing from the south-east during summer, are not the south-east monsoon, but, in fact, they are the south-west monsoon of summer which enter Arabia as south-westerly winds and then recurve to south-easterly inland of Saudi Arabia.

3. The South-West Monsoon

This type of wind prevails during the period of June-August over an area covering the Asir highlands and southern Hejaz mountains and the southern section of the Red Sea coastal plain as far north as Al-Gonfideh (Sogreah, 1970) (Figure 5(I).

The only climatic stations which record data on wind direction in the area are three: Jazan and Kamis-Mushait in the southern part, and Taif in the northern section. The lack of climatic stations recording wind speeds and direction make it impossible, at present, to define how far this type of wind penetrates into the sub-continent beyond the region.

During the summer months two high pressure areas develop over the Indian and Atlantic oceans and extend into Central Africa and the Arabian Sea. At the same time a thermal low pressure develops over North-west India and extends westwards over the Arabian Gulf and Arabia (El Fandy, 1949). In these circumstances the wind will blow over the area from a west to south-west direction. The available data on wind direction have shown that this is the case, though it appears that the north-west winds show a significant component in Jazan and Taif stations. Taif station is located at the northern extremity of the area and hence it is in a position to be affected by the Shamal winds. Jazan station is located in the southern part of the Red Sea coastal plain and appears to be affected considerably by the south-west monsoon, but since the Shamal winds may extend from time to time during the summer season to cover the Red Sea (Pedgely, 1966), they have a significant component at Jazan. Kamis-Mushait, which is located in the eastern slopes of the Asir mountains, shows persistent south-westerly winds blowing in July and August, though an easterly component is in evidence during early autumn. Table 5(3) shows the number of days on which the wind directions were from W,SW during the period of March - August of 1971 at stations located in this area.

TABLE 5(3)

NUMBER OF DAYS ON WHICH THE WIND BLOWS FROM W,SW DURING MARCH-AUGUST 1971

Station	M	A	M	J	J	A
Jazan	28	15	10	1	21	27
Kamis-Mushait	6	14	13	8	13	x
Taif	19	6	24	20	25	24

The wind speeds over Jazan area are normally gentle to moderate, with the velocity ranging between 9 and 13 knots, though they may become strong during the advance or the passage of depressions. During periods of depressions the winds blow from the north or the north-west and normally produce dust storms in Jazan area. The local inhabitants call this type of wind "Al-Gobreh".

The local people are optimistic when the dust storms are strong, since they predict that the rain will be heavy (Al-Akeeli, 1969).

The wind speeds along the escarpment are consistent throughout the year. In the summer season the mean monthly wind speed is between 12 and 18 knots, but this decreases eastward away from the escarpment and mountain regions to a value of between 60-70% of the speed recorded in the former regions. In the escarpment and mountain regions the average wind speeds are sometimes sufficient to operate wind-mill type pumps (Italconsultant, 1969A).

Sand and Dust Storms

These phenomena, which often cause restricted visibility, prevail over most of the country throughout the year. The maximum occurrence of these storms is in the eastern regions of the country rather than any other area. They are often caused by the strong winds, normally coming from the north (the Shamal). During the summer months the Shamal winds, transporting sand and dust, generally occur between the hours of 1100 and 1700 local time. The onset usually occurs when the surface inversion is broken up by insolation and when the strong northerly gradient winds start to gust at a speed of about 30 to 35 knots. Blowing sand is rarely lifted to more than 1000 metres, but dust may be lifted to 3000-5000 metres, and forms the characteristic dust haze of the summer months. The summer dust haze has the effect of reducing the radiation transmission constancy, and a reduction in the amount of incoming radiation during the peak of occurrence of severe storms is often apparent. During these periods it has been observed that a net radiometer will record zero radiation at approximately 1½ hours before the sunset (Italconsultant, 1969B).

The causes of the high frequency of occurrence of dust and sand storms in the Eastern Province have not been fully investigated. It is suggested (Siraj, 1971) that the topography and the prevalent climate have an important influence. The Arabian Gulf extends from NW to SE from the mouth of the Euphrates-Tigris rivers to the tip of Oman. This extension is about 750 km long. Along and near the west coast of the Gulf, sand dunes stretch inland for more than 200 km. The topography is comparatively featureless for a long distance in the area and into the Euphrates-Tigris plain of lower Iraq. To the west, the surface comprises a terrain of low rocky hills dissected by shallow valleys. The average altitude of these hills is between 200 and 300 metres. The Euphrates-Tigris plain forms a low, flat depression composed of fine alluvial deposits. This plain, and the desert in the west - Badiat Ash-sham, or the Syrian desert - represent a good source of fine dust which is easily transported in a southerly direction by the Shamal winds. In the east, the Zagros mountains bound the eastern coast of the Arabian Gulf and Mesopotamia and extend north, north-westward towards Turkey. They are precipitous and high and appear to cause a cyclonic bending of the surface isobars which tends to augment the pre-existing strong pressure gradients of North Africa-Arabia and is believed to be one of the main causes for the strong persistent summer Shamals (Siraj, 1966).

Generally, the sand and dust storms over much of Saudi Arabia appear to be caused by the following reasons:

a. The steep pressure gradients from the north-west towards the south-east.

b. The unconsolidated, dry soils.

c. The dry climate.

d. The existence of widespread sand dunes.

e. The intense heating in summer months.

f. The passages of depressions and troughs in the cool season.

The visibility in the south-western region of the country is normally between 500 and 1000 metres, improving to about 1000 metres in the afternoon. However, this region may experience dust and sand storms, particularly during the periods of the advances of the I.T.C.Z. (Siraj, 1966), which cause the development of a deepening trough and associated frontal activities across southern Arabia. Unless there has been rain, a windspeed of over 20 knots normally raises dust aloft,and deterioration of visibility may prevail with wind speeds of 30 knots or more. The dust storm in the Jazan area is called locally "Al-Gobreh". It blows from the north during the summer months at the time of the approach of a depression associated with the SW monsoon winds. It precedes the occurrence of heavy rain in the plain and the adjacent hills and mountains of Asir. It normally prevails in the forenoon and dies out in the afternoon (Al-Akeeli, 1969). Five to six day dust storms may occur during the period of June-September, though this can vary widely from year to year. The following table represents the annual and monthly mean of days with sand storms in Jazan and Asir areas.

TABLE 5(4)

ANNUAL AND MONTHLY MEAN OF DAYS WITH SAND STORMS IN JAZAN AND ASIR AREAS (1967-1969)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
Jazan	0	0	0	0.7	1.7	1.4	3.8	0.8	0.2	1.0	0	0	8.0
Kamis-Mushait	1.0	0.5	1.0	1.7	1.0	1.7	2.0	1.0	0	0	0	1.3	7.0

In general, the sand and dust storms over the country are related to the passage of the western depressions during the cool season and to the invasion of the tropical disturbances associated with the SW monsoon in the south-western region during the summer months. During the cool season the dust and sand storms over the country are more intensive than those of summer due to the fast movement of the cyclones, but their duration is usually much shorter than those in the summer. In the eastern half of the country the summer season is the period of maximum occurrence of sand and dust storms. In this season the Shamal blows more persistently than in the cool season.

During the summer months the sand and dust storms are persistent in sufficient quantities and duration to reduce visibility over the eastern province of Saudi Arabia. At Dhahran, for example, the number of days with sand or dust storms in June 1968 was 22 out of 30, and in July 1961 there were 24 days out of 31 with sand or dust storms.

The factors which are responsible for the pulsation of the speeds of the Shamal winds during the summer months have not yet been known exactly. It is possible that the increases of the speeds of the Shamal winds during the summer season are as a result of the passage of the eastern cyclones (Meteorological Office, Great Britain, 1951). These cyclones travel at times in summer across India or Arabia on a northerly, north-westerly track, passing into southern Iran and the Arabian Gulf area. They normally do not give rain, but cause strong winds of the Shamal which raise sand or dust particles and cause a deterioration in visibility, especially in the eastern province.

The local effects are also suggested to be main factors for the increases in the speeds of the Shamal winds during the summer months (Kuo, 1965). During this season the surface of the Arabian Gulf is considerably cooler than the adjacent coastal plains, causing air temperatures below 3000 to 4000 feet over the water of the Gulf to be lower than those over the coastal plain. Consequently, there is a remarkable area of discontinuity along the coast of the Arabian Gulf. The strong Shamal winds of summer are, thus, set up in the zone of maximum discontinuity along the coast at the gradient level. Over a period of days the wind speeds wipe out the temperature discontinuity and remove the driving force behind the winds which become light again.

F. E. Coles (1938), in considering the dust and sand storms over Iraq, has suggested that the strong north-westerly winds and the increases in the frequency of the occurrence of the sand and dust storms during the summer season is caused by the north-west, south-east steep pressure gradients from the high pressure area of the Azores to the low pressure region of North-west India and southern Iran.

However, according to the available data, these phenomena prevail over the whole country with the minimum in the western parts of the country and the maximum in the eastern province. The strong Shamal winds which cause the high frequency of the occurrence of sand and dust storms may be attributed to four factors as follows:

a. The relatively steep pressure gradients during the summer months from the high pressure area over the Mediterranean Sea (the Azores High Pressure) towards the low pressure zone over North-west India and southern Iran.

b. The passages of the Mediterranean depressions during the period of October-May over, or to the north of, Saudi Arabia which, due to the fast movement of the pressure system, cause strong winds normally laden with sand or dust particles.

c. The passages of the tropical depressions which may enter the Red Sea and invade the south-western region of the country during the period of June-August and cause sand and dust storms in Jazan district.

d. The wide spread of sand dunes and fine particles within a vast area of dry climate in Saudi Arabia and the surrounding regions.

Table 5(5) represents the mean monthly and annual days with sand or dust storms at selected stations.

TABLE 5(5)

MEAN MONTHLY AND ANNUAL DAYS WITH SAND AND DUST STORMS

Station		J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
Badana	1961-64	2.2	4.2	7.0	4.2	7.5	5.0	3.3	1.5	1.2	2.0	0.8	2.5	40.5
Dhahran	1961-69	2.3	4.6	7.8	5.6	7.8	13.6	13.0	7.7	5.2	2.8	1.9	2.2	73.8
Jazan	1967-69	0.0	0.0	0.0	0.7	1.7	1.4	3.8	0.8	0.2	1.0	0.0	0.0	8.0
Jeddah	1961-69	4.5	2.8	3.8	3.6	3.5	3.2	4.3	2.3	7.1	0.3	1.9	2.8	34.0
Qassim A.R.	1967-69	6.0	2.5	6.0	4.3	7.3	2.0	2.0	1.0	0.6	1.3	0.6	0.8	30.0
Qaysumah	1961-64	0.8	2.0	2.2	4.0	3.0	4.0	2.2	0.5	1.0	0.2	1.0	0.8	21.2
Riyadh	1961-69	5.2	5.2	6.6	10.0	8.3	9.8	7.7	5.8	2.6	1.8	2.6	3.6	68.6

This table provides examples of the characteristics of these phenomena and it can be seen that the maximum frequency of the occurrence of sand or dust storms is found to be recorded at all stations located in the eastern parts of the country, such as Riyadh, Dhahran and Badana. It can be also noticed that the minimum number of days with sand or dust storms is recorded during the autumn, while the maximum number of days with sand or dust storms is recorded in spring and summer. From March to August visibility normally becomes deteriorated over a considerably large number of days in a major part of Saudi Arabia.

CHAPTER VI

AIR TEMPERATURE

Introduction

The primary climatic control of temperature in any part of the world is latitude, for latitude determines the amount of heat received directly from the sun in the form of radiant energy. It is therefore necessary to remember the latitudinal position of Saudi Arabia on the earth's surface. This country is situated wholly within the tropical and subtropical belt. The Tropic of Cancer intersects Arabia. Toward the south, the country extends almost to 17°N latitude, while the northernmost portion of Saudi Arabia territory extends into the Syrian desert at 32°N.

Next to latitude, elevation is probably the most important control in the distribution of temperature. Air temperature decreases as elevation increases. It has already been indicated that Saudi Arabia is almost a plateau country of modest elevation in which the total area of the land below 800 metres of altitude constitutes the major proportion of the total land surface of the country. It can be said that the high elevation is almost limited to very narrow mountain chains in Asir and southern Hejaz. Of the total surface area of Saudi Arabia, only about 3% has an elevation exceeding 2000 metres.

Water bodies are also considered important in controlling the temperature conditions of their surrounding areas. In the case of Saudi Arabia, because of the narrowness of the water bodies relative to the extensive land mass of Arabia, the prevailing wind directions and the peculiar layout of the mountains along the Red

Sea coastal plain, the influences of the seas are somewhat limited to their immediate vicinity, and it is seldom that they play an important part in the control of temperature of the country beyond the narrow coastal strips.

There is one more fact that deserves special attention in this brief survey of general temperature control in Saudi Arabia. The country is exposed to the movement of air masses that have their origin in distant places and therefore of totally different temperatures than those prevailing in the country. Such air masses are likely to exert great influence on the pattern of temperature distribution over the country, especially during the winter season when the local control by insolation is weak. Imported temperature is therefore greatly responsible for producing a somewhat peculiar distribution of temperature, particularly when the country is invaded by cold air from Eurasia.

Characteristics of Air Temperatures

In studying the conditions of air temperature over Saudi Arabia, the data concerning this climatic parameter covers the period 1966-1972. All mean monthly, mean annual, and the mean maxima and minima temperature mentioned in this chapter are related to this period, unless otherwise stated.

During the winter months the air temperatures all over the country are moderate, with maximum air temperature in the coastal strips and minimum air temperature in the northern regions. The mean air temperature during the three months is normally over 10°C, though it may drop to less than this value in the northernmost areas and in the Asir mountains. The maritime influences of the Red Sea and the Arabian Gulf do not appear to penetrate far inland since, in the case of the Arabian Gulf, the wind direction is predominantly the persistent north-west winds which blow off the land. In the case of the Red Sea, the western highlands prevent the modification by concentrating the maritime effects in the coastal strips. However, the two water bodies are narrow and the air, when it blows across them to Saudi Arabia, does not have long to recharge with sufficient moisture to modify air temperature, since the moisture diminishes beyond the coastal plain toward the inland rapidly.

During the hot season, air temperature all over Saudi Arabia is very high, with the maximum temperatures being recorded by inland stations and the minimum in the Asir highlands and the northern regions. In the summer months, mean temperature is normally over 30°C and the absolute maximum inland may exceed 50°C, though at night the absolute minimum may drop to less than 25°C. Thus, it is expected that diurnal and annual range is wide, though in coastal areas both diurnal and annual ranges are smaller.

Increasing altitude generally modifies these characteristics and may obscure the latitudinal influence. In the western highlands south of Taif the skies are cloudy throughout much of the year, and the amounts of rainfall are relatively large. These characteristics accentuate relative humidity and attenuate solar insolation and air temperature.

In the mountain regions, north of Taif, the effects of the altitude, though they exist, do not obscure the latitudinal influence. This region, for the greater part of the year, is dominated by hot and dry air, and continental characteristics are apparent. Air temperature recorded in this area is high, as those recorded in the inland and diurnal and annual ranges are also high.

However, the continental characteristics of air temperature dominate all the country, the only exceptions being the Asir and southern Hejaz mountains and the narrow coastal strips.

Mean Annual Temperature

Mean annual temperature has, in fact, little significance and, indeed, may be misleading in a study of temperature in this type of climate. For example, Riyadh, which lies in the interior of the country, shows a similar mean annual temperature to that of Ras Tanura (25°C), which lies in the coastal strip of the Arabian Gulf, while the annual march of air temperature at the two stations is different.

However, there are four factors which seem to control the distribution of the mean annual temperature. The most important factor is the latitude, where the mean annual temperature decreases over a major part of the country from south toward the north. In the southern region at As-Sulayyil - 20° 28'N - the mean annual temperature is 26°C. Further to the north, the mean annual temperature decreases at Al-Karj - 24° 10'N - to 24°C. The decreases in temperature continue northwards where the mean annual temperature at Qurayyat - 31° 20'N - is only 19°C.

However, the northerly decreases of mean annual temperature are not the same throughout the country. It appears that the decreases are gradual in the southern part of the country and more rapid in the northern part. For instance, the difference between the mean annual temperature at As-Sulayyil and Skakah - 29° 58'N - is only 4°C over a latitudinal difference of 9° 30', while the difference in mean annual temperature between Skakah and Qurayyat, both located in the northern province, is 3°C over a latitudinal difference of 1° 62'. The elevations of these stations are substantially the same (As-Sulayyil - 510m, Skakah - 574m, Qurayyat - 549m). It seems that the only excuse is the different insolation between summer and winter. In the northern province the difference in insolation between the two seasons is large, while in the southern part of the country the difference of insolation between summer and winter is comparatively limited.

The water bodies are considered to have a major effect on air temperatures over the land in close proximity to them and most coastal areas remain hot throughout the year. The trend of the coastal plains of the Red Sea and the Arabian Gulf is from north-west to south-east. Consequently, there are constant south-east north-west gradients of mean annual air temperature as a result of the effect of the latitudinal factor. Over the Red Sea coastal plain, for example, the mean annual temperature at Jazan (17°N) is 30°C, at Jeddah (21° 30'N) is 28°C, and at Al-Wajh (26° 13'N) is 24°C. Similarly, in proximity to the Arabian Gulf, the mean annual temperature at Dhahran (26° 17'N) is 27°C, at Qatif*(26° 33'N) it is 25°C, and at Ras-Saffaniyyah* (28°N) it is 24°C.

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* 1967-72 mean of data

Altitude is also an important factor and has a considerable effect upon air temperature distribution. The elevation of the surface in Saudi Arabia increases from the east toward the western highlands, after which the ground dips down rapidly toward the coastal plain of the Red Sea. There are thus two directions of air temperature gradients. The major one, since it comprises most of the country, is from east to the west. A second minor one, occurring on the western slopes of the western highlands from the west to east. These gradients are shown on Figure 6(I). An attempt has been made to compare the mean annual temperature of stations located at approximately similar latitudes. The mean annual temperature at Al-Aflaj (539m) is 25^{o}C, while at Taif Airport (1395m) the mean annual temperature is 22^{o}C. At As-Sulayyil (510m) the mean annual temperature is 26^{o}C, while at Bishah (1040m) the mean annual temperature is 25^{o}C. Further westwards, the mean annual temperature at Baljurshi (2400m) in the Asir highlands is 17^{o}C only.

From east to west the temperature gradient is interrupted by the Tuwayq mountains. For example, the mean annual temperature for the period 1967-1968 at Riyadh (609m) is 25^{o}C and at Shaqra (730m) is 25^{o}C. Between Riyadh and Shaqra the Tuwayq escarpment, with an altitude of about 800 metres, has a slight effect upon air temperature, for the mean annual temperature, for the same period, at Dirab station, 25 km to the west of Riyadh, is 23^{o}C.

The west-east temperature gradient from the coastal plain of the Red Sea toward the western highlands can be seen by the difference in temperature between Jeddah in the coastal plain and Taif in the highlands of Hejaz. The mean annual temperature at Jeddah is 28^{o}C, while at Taif it decreases, as a result of the increase in elevation, to 22^{o}C.

In the north-west of Saudi Arabia there is high ground forming the northern section of the Hejaz and Madian mountains. In this area there are only four stations recording temperature, but they do not provide adequate data since they are located in depressions in the eastern part of the highlands. However, it is expected that the mean annual temperature ranges between 19 and 20°C over the mountains where the elevation reaches 2000 metres. At Tayma, to the east of the mountains, the elevation is 820 metres and the mean annual temperature is 22°C. At Tabuk* (900m), which is located in a depression between the western mountains and Al-Hisma plateau, the mean annual temperature is 21°C. To the south of Tabuk, Al-Ula station, located to the south-east of Harrat Al-Uwayrid, has an elevation of about 1000 metres. The low elevation, coupled with the effect of the dark coloured lava, results in relatively high air temperatures of 22°C.

Figure 6(I) shows the distribution of the mean annual temperature over Saudi Arabia. The data on which this map is constructed are considered sufficient to show most of the characteristics of the distribution of the mean annual air temperatures. It can be easily noticed the north-south temperature gradients as a result of the latitudinal factor, and the east-west, west-east temperature gradients as a result of the increases in elevation.

Annual Range of Temperature

The annual range of temperature is defined as the difference

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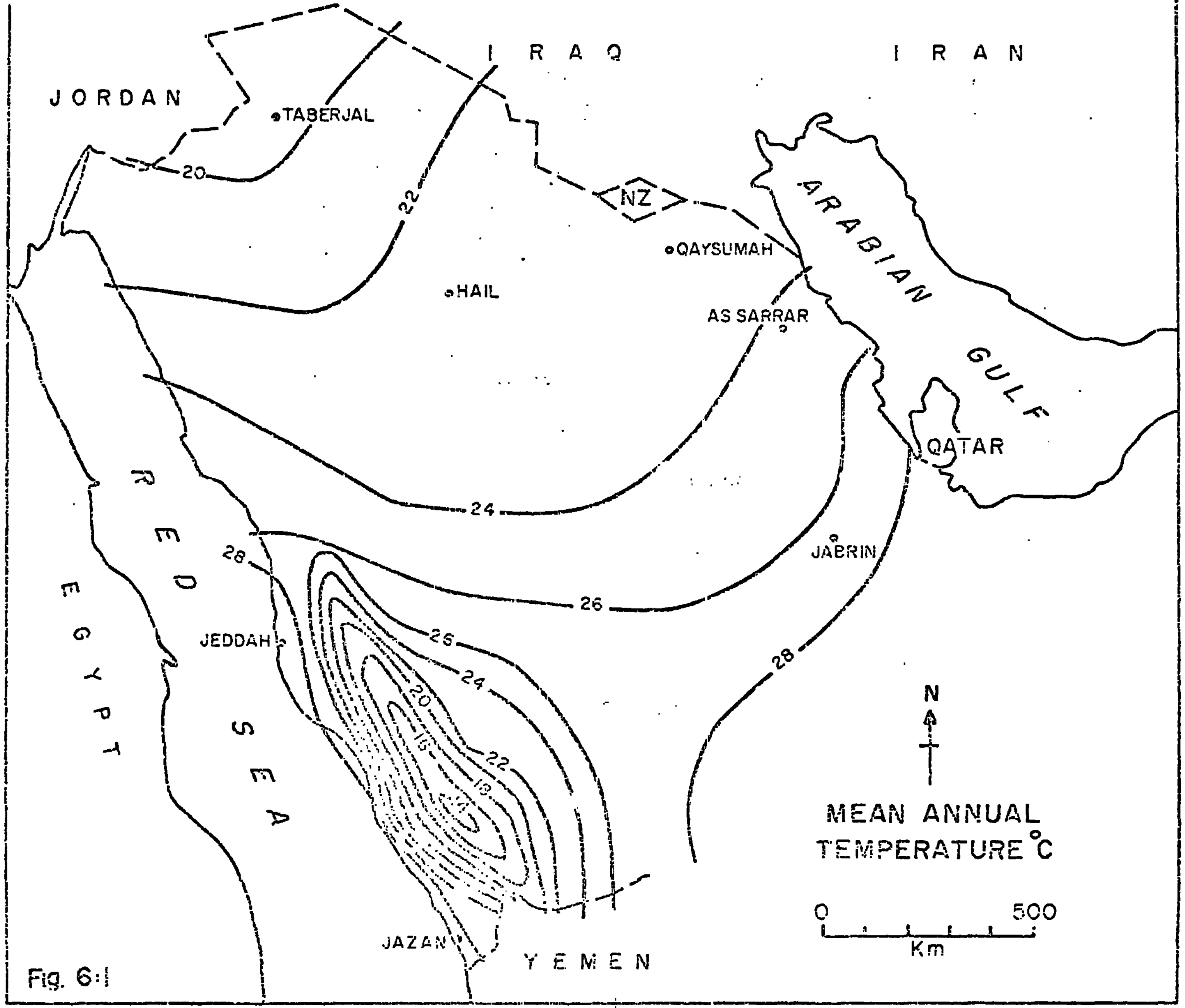
* 1967-72 mean of data

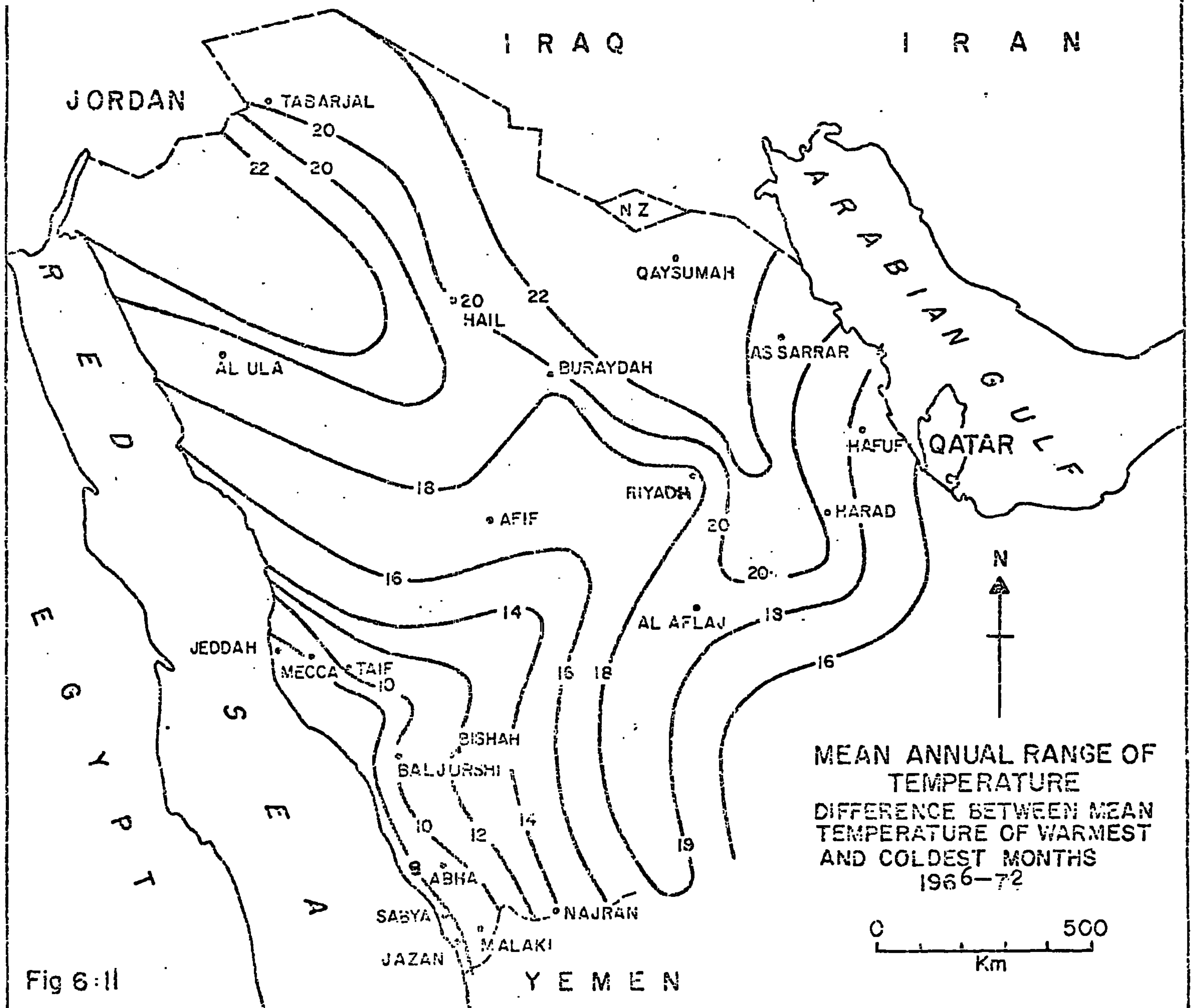


JORDAN
IRAQ
IRAN
TABERJAL
NZ
QAYSUMAH
HAIL
AS SARRAR
ARABIAN GULF
QATAR
RED SEA
EGYPT
JEDDAH
JABRIN
JAZAN
YEMEN
20
22
24
26
28
18
16
N
MEAN ANNUAL TEMPERATURE °C
0
500
Km

Fig. 6:1

between the mean temperature of the warmest month and that of the coldest month. The annual range of temperature increases with the increases of latitude because of the greater difference between winter and summer insolation as the distance from the equator becomes greater. The distance from the bodies of water is another factor that influences the annual range of temperature.

As far as Saudi Arabia is concerned, the effect of both the above-mentioned factors is clearly observed in Figure 6(II) which shows the distribution of the mean annual range of temperature. The lowest annual temperature range is found in the southern section of the coastal plain of the Red Sea. This area is situated by the sea and also has a southerly position in the country. Here the difference between the coldest (January) and the warmest (July) months ranges between 8.0°C in Jazan district to 9.0°C in Jeddah area. In easterly and northerly directions, the annual range increases either because the distance from the sea increases, or because the latitude becomes greater. At Abha, a mountainous station to the northeast of Jazan, the annual range increases to 10°C, while at Taif, another mountainous station to the east of Jeddah and to the north of Abha, the annual range increases to 11°C. Toward the north, the mean annual range of temperature increases as the latitude increases towards the northern part of the Red Sea coastal plain. At Yanbu (24° 07'N), the difference of temperature between January and July is 14°C, while at Al-Wajh, the most northerly station recording temperature in this coastal plain, the mean annual range is 18°C. The following figures show the mean annual range of temperature at climatic stations in the Red Sea coastal plain from north to south:


MEAN ANNUAL RANGE OF TEMPERATURE
DIFFERENCE BETWEEN MEAN TEMPERATURE OF WARMEST AND COLDEST MONTHS 1966–72
IRAQ
IRAN
JORDAN
TABARJAL
NZ
QAYSUMAH
HAIL
BURAYDAH
AS SARRAR
AL ULA
ARABIAN GULF
HAFUF
QATAR
RIYADH
AFIF
HARAD
RED SEA
EGYPT
AL AFLAJ
JEDDAH
MECCA
TAIF
BISHAH
BALJURSHI
ABHA
SABYA
NAJRAN
MALAKI
JAZAN
YEMEN
N
0
500
Km
20
22
18
16
14
12
10
8
19
Fig 6:11

Al-Wajh	18°C
Jeddah	9°C
Sabya	9°C
Malaki	9°C
Jazan	8°C

In the coastal plain of the Arabian Gulf the mean annual range again increases from south-east toward the north-west as the latitude becomes greater, and from the east, on the coast, to the west inland. Within the area, the annual range is between 16°C in the southern section and 21°C in the northern part. At Qatif, about two hundred and fifty kilometres to the north of Salwa and on the coast, the annual range is 17°C, while at Hafuf, about 30 kilometres inland and about a hundred kilometres to the north of Salwa, the mean annual range is 18°C. The south-east, north-west gradients of the annual range in the coastal plain of the Arabian Gulf reach maximum value at Ras-Saffaniyyah where the annual range is over 20°C. The following figures show the mean annual range in the coastal plain of the Arabian Gulf:

As-Sarrar	21°C
Dhahran	20°C
Hafuf	18°C
Qatif 1967-72	17°C
Yabrin 1967-72	18°C

Inland and in the northern province where the distance from the water bodies is at a maximum, and the latitude increases, the continental conditions become dominant. Here again there are south-north gradients. At As-Sulayyil, the most southerly station inland recording temperature, the annual range is 19°C, while at Al-Karj, to the south-east of the capital of the country (Riyadh), the annual range increases slightly to 20°C.

In the northern province, the highest annual ranges are recorded. In this area the annual range generally ranges between 20 and 22°C. At Linah, in the north-east of the country, and close to the political boundary of Saudi Arabia and Iraq, the annual range is 21°C. At Skakah, in the northern province, the annual range is 21°C. The following figures show the annual range recorded at selected stations in the north and north-west of Saudi Arabia.

Al-Ula	20°C
Hail	21°C
Tabarjal	21°C
Tabuk	22°C
Shakah	21°C

Monthly Variations

There are two main seasons during which air temperatures are very different; winter, which lasts from early December until late February; and summer, which covers the period from late May to the end of September. The winter season is normally moderate and the prevailing weather conditions are pleasant. The summer period is very hot over the major part of Saudi Arabia and the dominant weather conditions are oppressive inland during the day and throughout the summer months in the coastal plain of the Red Sea and the Arabian Gulf as a result of the increases in relative humidity. The night temperature conditions are bearable in the interior of the country, especially when the prevailing wind is the "Shamal".

Between the two main seasons there are two transitional periods, spring and autumn. Both are short seasons and the prevailing weather conditions have the characteristics of both the winter months, where nights are temperate, and summer months, where days are relatively warm.

Winter Conditions

The coldest month over all Saudi Arabia is January, though this country may experience during any month of the winter season cold waves from Eastern Europe or Central Asia during which the air temperature may drop to below freezing point for several nights on end and frost may occur, particularly in the northern province and in the western highlands. The people may suffer from these cold waves if the air is coming from Central Asia. The air flowing from this area to the country is dry and the winds are persistently northerly. If the cold air comes from Europe it is cold, but normally is accompanied by cloudiness and rainfall, so the air temperature may not drop for any prolonged period below freezing. Furthermore, the cool northerly winds do not persist since the winds normally change to southerly when the depressions associated with these maritime northerly winds pass.

Descriptions of such as these cold waves, and the reasons, have been summarised in the local newspapers in the country by the meteorologists of the General Directorate of Meteorology. It is desirable for some of these descriptions to be written down in the present discussion of temperature. During the winter season of 1972 Saudi Arabia experienced cold waves because of the invasion of cold air masses from Europe. The air temperature over several days dropped to below freezing and water in pipes froze. The official meteorolcgist (Nweelati) of the General Directorate of Meteorology wrote the following report:

> "As a result of the existence of extensive high pressure over the Middle and Eastern Europe, cold northerly winds blew from Europe to the eastern Mediterranean Sea and affected Saudi Arabia. These winds are in origin very cold, but since they blow in a southerly direction over the Mediterranean Sea, they become slightly warmer and more moist".

He added,

> "The daily mean of air temperatures was 5°C at Qassim Airport, 15°C at Dhahran, 8°C at Riyadh, and 2°C at Turaif".

Further examples came from reports written by the consultant companies during their investigations in Saudi Arabia in 1967-1968. In January 1967, Saudi Arabia also came under the influence of similar cold waves and the air temperature dropped below freezing in the northern province and snowfall was reported from Madian mountain areas to the west of Tabuk (Parsons, Basil-Consultant, 1968).

In 1968 frost and ice were observed during winter and as late as April over the Asir highlands (Italconsultant, 1969A).

The coldest areas all over the country during the winter months are the Asir highlands and the northern province. The mean monthly temperature of the winter months in these two cold areas normally ranges between 4 and 12°C in Asir, and between 6 and 11°C in the northern province. In both areas the minimum temperature is normally recorded in January. Away from these two regions the prevailing conditions are more temperate, though a low temperature of 0 or -2°C may be recorded in the interior of the country for three to five days during January or February. However, the altitude factor, which leads to low temperatures in Asir, is not operative.

Consequently, the main factors that control air temperature distribution are the latitude, the water bodies, and the invasion of cold air masses. At Qurayyat, in the northern province, the mean monthly temperature of the winter months ranges between 6°C in January and 8°C in December and February. To the south the mean temperature increases to 12°C in January and 14°C in both December and February at Az-Zilfi. The constant southerly increases in the temperature continue toward the southern part of the country where the mean temperature of the winter months at As-Sulayyil, just to the north of the Rub-Al-Kali, ranges between 16°C in January and 18°C in February.

Unfortunately, the available data on air temperature are insufficient to show the east-west temperature gradients toward the western highlands. However, the available scanty data show that there is a slight decrease in air temperature from Riyadh toward the Arabian shield area and further west toward the western highlands. Further southwards from Riyadh there is a remarkable decrease in temperature from As-Sulayyil in the Najd sedimentary plain to Bishah in the Arabian shield area and also further westwards at Baljurshi in the Asir mountains. Riyadh and Dawadmi are located at the same latitude, but at different altitudes. Riyadh is located in the Najd sedimentary plain, while Dawadmi is situated in the Arabian shield area. As-Sulayyil, Bishah and Baljurshi are all located in approximately the same latitude, but at different altitudes. The following figures may show the east-west gradient from the Najd sedimentary plain to the Arabian shield and the western highlands.

TABLE 6(1)

EAST-WEST TEMPERATURE GRADIENT FROM NAJD TO THE WESTERN HIGHLANDS (°C)

Station	Elevation (m)	Latitude (N)	Dec Mean	Jan Mean	Feb Mean	1966-72
Riyadh	609	24° 42'	15	14	16	
Dawadmi	940	24° 29'	14	13	15	
As-Sulayyil	510	20° 28'	18	18	20	
Bishah	1040	20° 20'	17	16	18	
Baljurshi	2400	19° 52'	13	12	12	

The warmest areas in Saudi Arabia during the winter are the littoral regions along the Red Sea in the west and the Arabian Gulf in the east. Since the littoral areas extend from the south-east toward north-west, air temperatures decrease in this direction. The mean temperature of the winter months is constantly over 15°C at all the climatic stations located in the coastal plains. At Jazan, in the southernmost region of the coastal plain of the Red Sea, the mean monthly air temperature during winter ranges between 23°C in January and 25°C in December. Toward the north-west, along the Red Sea coastal plain, the mean monthly temperature of winter decreases considerably as a result of the increases of latitude. Al-Wajh, about 750 kilometres to the north of Jeddah, has a mean monthly temperature in the winter months ranging between 19°C in January and 20°C in December.

In the coastal plain of the Arabian Gulf there are eight stations recording air temperature. Three of them are located close to each other on the coastal plain and other two stations are located in the hinterland and seem to be affected by the continental conditions that dominate the inland, rather than being influenced by the maritime effects of the Arabian Gulf. However, as the coastal plain of the Arabian Gulf extends from the south-east toward the north-west, there is a temperature gradient in this direction, though again data are very scanty.

The mean monthly temperature in winter over the Arabian Gulf coastal plain is normally over 15°C, though it may drop to less than this value in the northern part of the area. Along the coast the mean monthly temperature of winter at Qatif* ranges

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* 1967-72 mean of data

between 16°C in January and 17°C in February. At Ras-Suffaniyyah*, about 40 kilometres to the north of Qatif, the mean monthly temperature during winter decreases to 14°C in January and 15°C in February.

In the hinterland the mean monthly air temperature decreases since the distance from the Arabian Gulf increases. Furthermore, there is a north-south temperature gradient. From the north toward the south there are four well-distributed stations, Qaysumah, As-Sarrar, in the north, and Abqaiq, Al-Hafuf, in the south, as shown on Figure 6(III). At Al-Hafuf the mean monthly temperature of winter ranges between 16°C in January and 17°C in December. Toward the north the mean temperature of winter decreases to 15°C in January and 16°C in February. Further northwards the decrease in temperature can be seen from the mean monthly temperature at As-Sarrar and Qaysumah. At As-Sarrar the mean temperature ranges between 14°C in January and 15°C in December, while at Qaysumah the mean monthly temperature of winter ranges between 13°C in January and 15°C in December.

Figure 6(III) is a map showing the distribution of the mean monthly temperature in the winter season. From this map it is easy to recognise the temperature distribution and the north-south gradient, as well as the east-west temperature gradients toward the western highlands. It is also easy to notice the warmest and coldest areas in Saudi Arabia during the winter season. The temperate conditions which dominate the country during winter can also be seen, where the air temperature during this

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*1967–72 mean of data

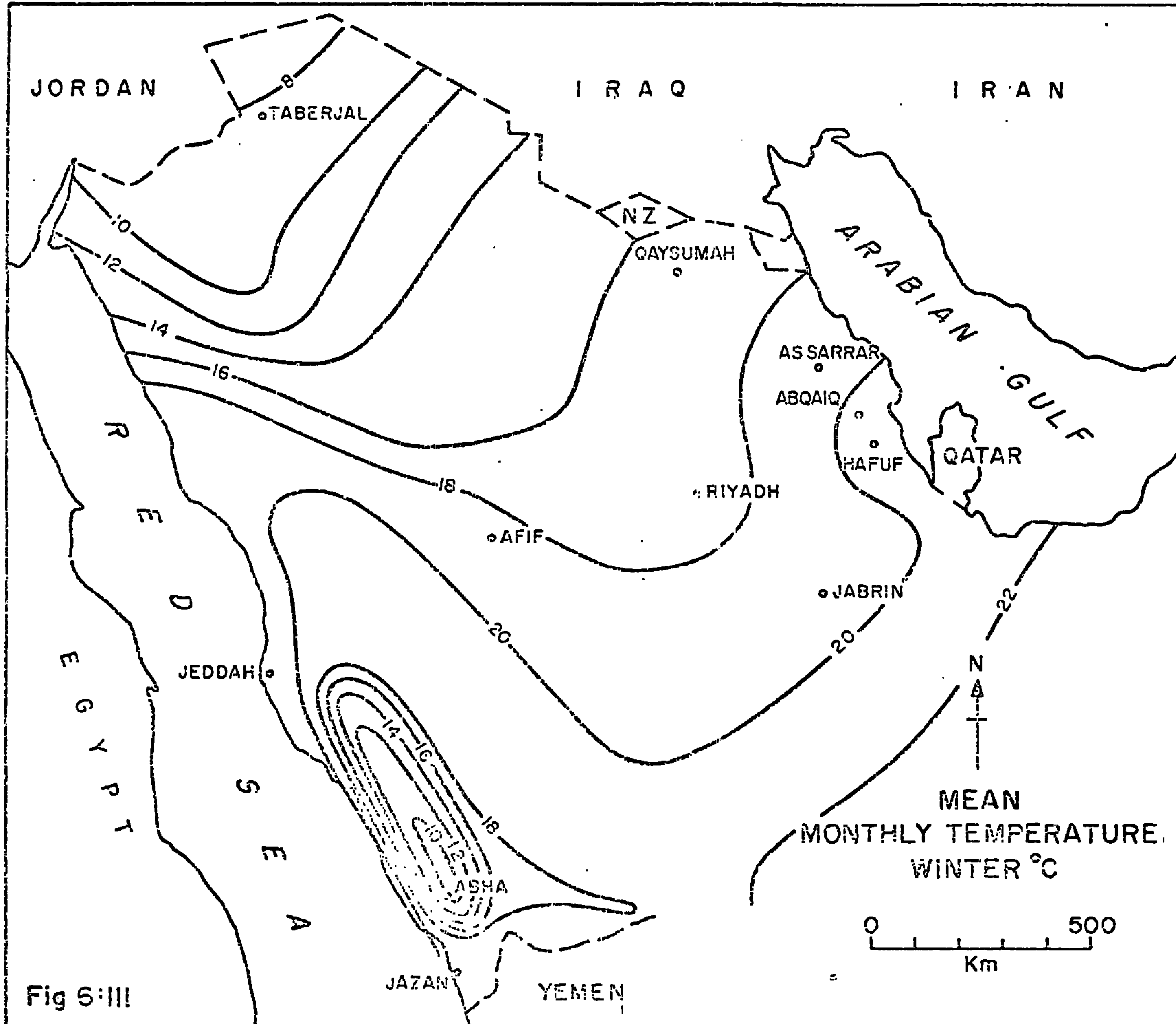

JORDAN
IRAQ
IRAN
TABERJAL
NZ
QAYSUMAH
ARABIAN GULF
AS SARRAR
ABQAIQ
HAFUF
QATAR
RIYADH
AFIF
JABRIN
RED SEA
EGYPT
JEDDAH
ASHA
JAZAN
YEMEN
8
10
12
14
16
18
20
22
N
MEAN
MONTHLY TEMPERATURE
WINTER °C
0
500
Km

Fig 6:III

season ranges between 14 and 20°C over the major part of Saudi Arabia.

Spring Conditions

During the spring season no appreciable heating appears to take place in the Asir highlands and the northern province before April, while in the interior regions the temperature remains at a low level throughout winter until the end of February, after which a relatively sharp increase in spring carries air temperature to that normally found in the hotter low regions. In the coastal plains, the variations from month to month, and from season to season, are small. There is a constant, but gradual, increase in air temperature from March. In general, the mean monthly air temperature in the littoral regions is normally over 20°C during March and may approach or exceed 25°C during April. However, this varies from part to part because of the difference in latitude. The following table (6(2)) shows the different conditions of air temperatures in the various regions in Saudi Arabia in spring.

The smallest variations in air temperature occur in Asir and southern Hejaz mountains. In these areas the effects of elevation on air temperature far outweigh those of decreasing latitude. Within these highlands the mean monthly air temperature of spring ranges at Abha - 18° 13'N - between 14°C in March and 18°C in May, while at As-Sulayyil - 20° 28'N - to the north-east of Abha and in the low desert areas, the mean monthly temperature of spring is normally over 20°C. The difference between the two stations reflects the influence of two factors: the altitude and

TABLE 6(2)

MEAN MONTHLY TEMPERATURE DURING SPRING IN VARIOUS REGIONS IN SAUDI ARABIA (°C)

	March Mean	April Mean	May Mean	1966-1972
Asir Type				
An-Nimas 1967-72	11	12	15	
Abha	14	15	18	
Baljurshi	15	17	20	
Northern Province Type				
Qurayyat (1967-72)	14	20	22	
Skakah	16	23	25	
Tabarjal	13	20	23	
Red Sea Coastal Plain Type				
Jazan	28	30	32	
Jeddah	25	28	29	
Al-Wajh	22	24	23	
Arabian Gulf Type				
Dhahran	22	25	31	
Qatif 1967-72	22	25	28	
Qaysumah (hinterland)	20	22	30	
Interior Type				
Riyadh	20	24	30	
Az-Zilfi	19	22	27	
Unayzah	19	23	28	

the difference in humidity. Abha is situated at a height of 2190 metres, while As-Sulayyil is located in a minor gorge of Wadi Dawasir within the Tuwayq escarpment and has an elevation of only 510 metres. Abha also is affected for the major part of the year by moist air, while As-Sulayyil is affected by dry air during most of the year. Within this region the main factor that controls the distribution of temperature is the elevation, rather than the latitude.

To the north of Abha, some stations of considerable elevation show low temperatures. At Belesmer (18° 47'N), which has a height of 2250 metres, the mean monthly temperature is only 11°C in March and 12°C in April. From this high mountainous area, air temperature increases in a west-east direction inland and an east-west direction towards the coastal plain of the Red Sea where the elevation decreases. Unfortunately, the intensive network of climatic stations in this area records rainfall only. The stations which record temperature are either located on the high peaks of the escarpment or in the low-lying areas to the east and west of the slopes. Consequently, it is impossible at this stage to investigate the lapse-rate of air temperature along the whole region until intensive and well-distributed stations with long-term records are available.
To the east from Abha, Kamis-Mushait Airport, at a height of 2060 metres and 25 km from Abha, has a mean monthly temperature during the spring season of between 17°C in March and 19°C in April. To the west of the Asir escarpment, Sabya station, located in the low-lying coastal plain of the Red Sea, is situated at an elevation of 40 metres. The mean monthly

temperature increases rapidly in short distance when one descends the Asir escarpment to the coastal plain of the Red Sea where the mean monthly temperature in spring at Sabya is 27°C in March and 31°C in April. As would be noticed, the increases of air temperature are gradual when one descends the highland to the low desert since the decreases of elevation are so gradual, but when one descends the escarpment toward the coastal plain of the Red Sea the increases in air temperature are very great because of the rapid decrease in elevation in this direction.

The other area which normally experiences relatively cool springs is the northern province, as can be noticed from Table 6(2). During spring, the southern parts of the country come under the influence of relatively high insolation as a result of the northern movement of the sun, but at this time the northern province is still under the effect of comparatively low solar insolation as a result of the northern location. However, despite the fact that this province shows low air temperature in winter, spring is comparatively warm and there are sharp increases in March. During late April relatively intense heating may carry air temperature in this province to those levels found in the low hot deserts. For instance, the mean air temperature at Qurayyat is 8°C in February, while in March it increases to a value of 14°C, or almost double that of winter. However, this considerable increase in March is normally followed by remarkable increases in April. For example, the mean monthly temperature at Skakah in April is 7 degrees above that of March (23°C).

Toward the Rub-Al-Kali, air temperature increases rapidly as the distance from the equator decreases. In general, the mean monthly air temperature of the spring season is normally over 20°C in the northern and interior regions, though the March increase is not nearly so marked and the mean monthly temperature of March is normally less than this level. From north to south the air temperature increases and, thus, there is a temperature gradient in this direction, as can be seen from Table 6(3).

TABLE 6(3)

MEAN MONTHLY TEMPERATURE (1966-1972) OF SPRING AT STATIONS LOCATED FROM NORTH TO SOUTH (°C)

Station	Latitude (N)	March Mean	April Mean	May Mean
Rafha	29° 39'	19	20	27
Shaqra	25° 15'	19	22	28
Al-Aflaj	22° 17'	22	26	32
As-Sulayyil	20° 28'	23	27	32

In the littoral areas along the coastal plain of the Red Sea the increases in air temperature are very small. The difference between the mean temperature of late winter and early spring in the southern section of the Red Sea coastal strip is only 1°C. During spring, the temperature difference between March and April figures at both Jazan and Jeddah increases, but only to the extent of 2-3°C. Toward the north in this plain there is a gradual decrease in mean temperature of spring as a result of an increase of latitude, but there also is an increase in the difference of the mean monthly temperature between March and April. There are only two stations to the north of Jeddah which record temperature, located at the airports at Yanbu and Al-Wajh. However, there is a temperature gradient from south toward the north along this coastal plain where the difference in insolation between winter and summer increases in this direction. Table 6(4) shows the mean monthly temperature of spring at selected stations along the coastal plain of the Red Sea.

TABLE 6(4)

MEAN MONTHLY TEMPERATURE (1966-1972) OF SPRING IN THE COASTAL PLAIN OF THE RED SEA (^{o}C)

Station	Latitude (N)	March Mean	April Mean	May Mean
Al-Wajh	26° 13'	22	24	26
Jeddah	21° 30'	25	28	29
Jazan	17° 03'	28	30	32

As in the northern section of the Red Sea coastal plain, warm weather conditions prevail in the Arabian Gulf area during spring, and the variations from month to month are found to be low. Furthermore, there is a south-north temperature gradient where the temperature decreases in a northern direction. Dhahran - 26° 14'N - and Qatif - 26° 33'N - in the Arabian Gulf coastal plain are located approximately at the same latitude as Al-Wajh -

26^{o} 16'N - in the Red Sea coastal plain. Thus, it is expected that the temperature conditions in the two areas are similar, but because of a lack of sufficient data concerning temperature in the Red Sea coastal plain as a whole, and the southern section of the Arabian Gulf area, the conformity in air temperature conditions between the northern section of the coastal plain of the Red Sea and the Arabian Gulf coastal plain cannot be discussed until sufficient data from well-distributed stations are available. The fact which can be mentioned at present is that the mean monthly air temperature at Al-Wajh and Qatif is almost similar, though the Arabian Gulf stations tend to record slightly higher temperatures. The increases in air temperature at the stations in the Arabian Gulf coastal plain may be attributed to local factors, ecpecially the existence of vast areas of sand dunes. Table 6(5) shows the mean monthly temperature at selected stations in the coastal plain of the Arabian Gulf.

TABLE 6(5)

MEAN MONTHLY TEMPERATURE (1966-1972) OF SPRING IN THE COASTAL PLAIN OF THE ARABIAN GULF (^{o}C)

Station	Latitude (N)	March Mean	April Mean	May Mean
Ras-Saffaniyyah 1967-72	28^{o} 00'	22	23	26
Qatif 1967-72	26^{o} 33'	22	24	28
Dhahran	26^{o} 17'	22	25	31
Al-Hafuf (hinterland)	25^{o} 30'	19	24	28

From this table it can be easily deduced that there is a south-north gradient along the coast of the Arabian Gulf.

Al-Hafuf shows lower mean temperatures because it is located some 60 kilometres from the Arabian Gulf and, hence, it may experience continental conditions that prevail inland, rather than the maritime conditions that dominate the coast of the Arabian Gulf.

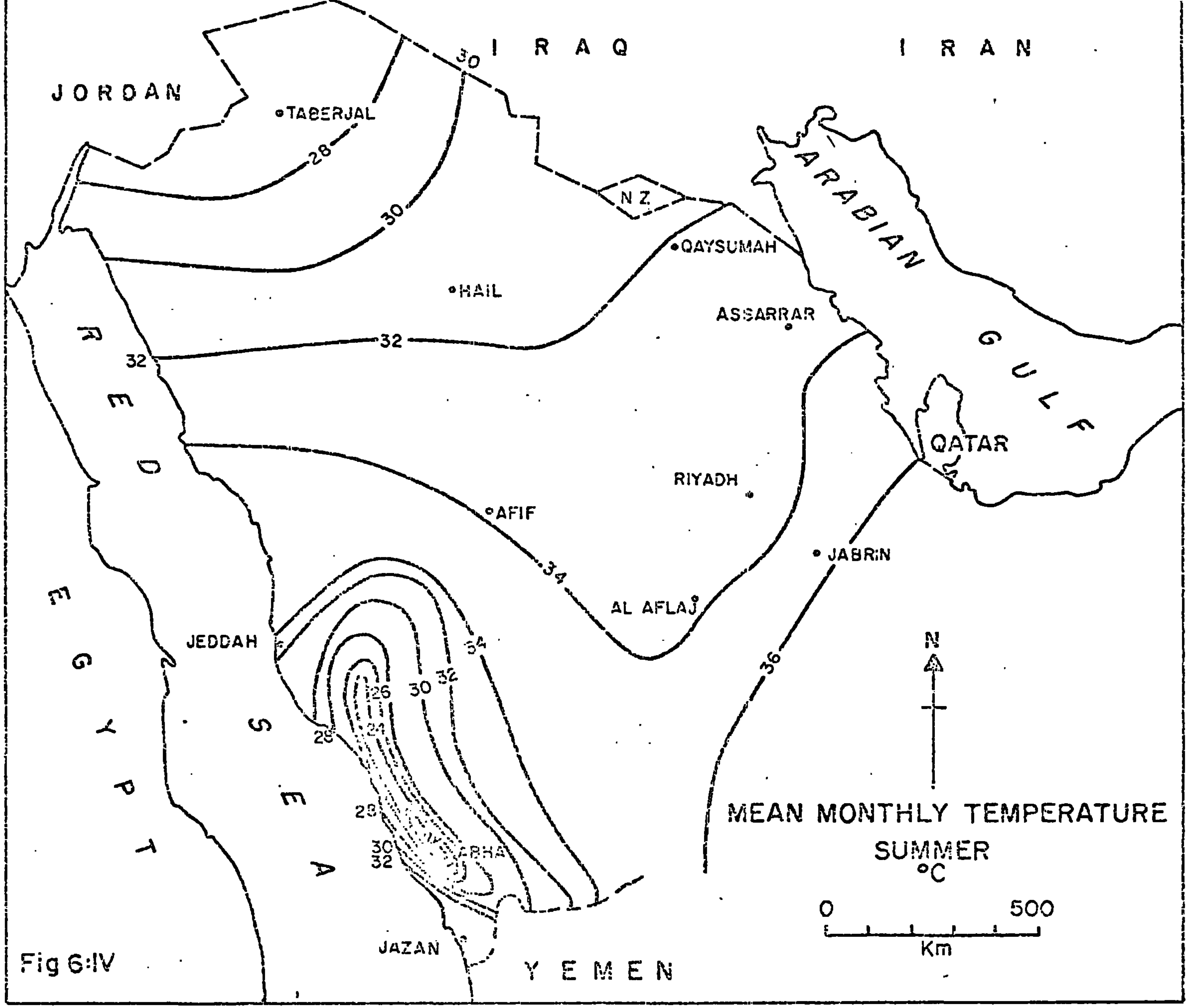
Summer Conditions

The hot season conditions start to dominate Saudi Arabia in early June. At the beginning of this month the country comes under the influence of hot and dry air. During the mid-period of June the sun is at its northernmost movement and the sun's mid-day rays are almost vertical over the whole country. The cloudless skies over most of Saudi Arabia, coupled with the dry air, the predominance of the continentality, and the high solar insolation, cause air temperature to be very high during the afternoon where the absolute maximum temperatures may exceed 50°C. Since the country is a vast land mass, and the maritime influences are limited to minor areas, the air temperature during the night may drop to 30°C or less.

During the summer season July is the hottest month over most of Saudi Arabia, though the highest absolute maximum may be recorded in June or August. During this season the differences in temperature between one area and another are smaller than those found during the cool season. In the littoral areas the weather is oppressive, due to high humidities, while only for short distances from these littoral areas the heat is intense during the day and the air temperature is high at night. The only area which does not normally experience the mentioned conditions is the Asir and southern Hejaz highlands.

In addition to the difference in the values of air temperature between the cool season and the hot season, there is a difference in the regime of temperature between the two seasons. During the cool season there are remarkable fluctuations of temperature. These considerable increases and decreases of temperature in the cool season are mainly caused by the sudden incursions of either cold polar air or hot, dry air. During the hot season, air temperature all over Saudi Arabia is persistently high, with maximum at day and minimum at night.

However, all over the whole country there is a significant temperature gradient from the south toward the north where air temperature again is lowest. Moreover, there is an east-west temperature gradient from Najd sedimentary plain toward the Asir and southern Hejaz mountains. A west-east temperature gradient is found to occur from the coastal plain of the Red Sea toward the escarpment of Asir and Hejaz. Sufficient data on air temperature to systematise all these three temperature gradients are not available. The only air temperature gradient that can be studied in detail is the south-north temperature gradient. Some indications to the east-west and west-east temperature gradient can be made. It has been found that there is a gradual south-north temperature gradient from As-Sulayyil, the southern station in the country, toward Qurayyat, the northern station in Saudi Arabia, as can be seen from Figure 6(IV) which shows the distribution of air temperature of summer. The difference in air temperature of summer between As-Sulayyil, just to the northwest from the Rub-Al-Kali, and Qurayyat, in the northern province and at the political boundary of Saudi Arabia and Jordan,


IRAQ
IRAN
JORDAN
TABERJAL
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QAYSUMAH
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AFIF
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28
30
32
34
36
26
24
MEAN MONTHLY TEMPERATURE
SUMMER
°C
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Fig 6:IV

is only $8^{o}C$. Table 6(6) shows the mean monthly temperature of the summer months at selected stations located from north to south.

TABLE 6(6)

NORTH-SOUTH TEMPERATURE GRADIENTS (1966-1972) IN THE INTERIOR OF SAUDI ARABIA IN SUMMER (^{o}C)

Station	Latitude (N)	June Mean	July Mean	August Mean	September Mean
Qurayyat	31° 20'	26	27	27	26
Hail	27° 31'	29	31	31	29
Unayzah	26° 04'	30	32	32	30
Shaqra	25° 15'	33	33	33	31
As-Sulayyil	20° 28'	34	35	35	32

The east-west temperature gradient which exists from Najd sedimentary plain to the western highlands can be seen from Table 6(7) which shows the mean monthly temperature at selected stations located from east to west at approximately the same latitude.

TABLE 6(7)

EAST-WEST TEMPERATURE GRADIENT IN SUMMER (1966-72) FROM NAJD TO THE WESTERN HIGHLANDS (^{o}C)

Station	Elevation(m)	June Mean	July Mean	August Mean	September Mean
Al-Aflaj	539	34	34	33	31
Taif	1395	28	28	28	27
As-Sulayyil	510	34	35	35	32
Bishah	1040	30	31	31	28
Baljurshi	2400	23	22	22	21

As one ascends the western highlands from the coastal plain of the Red Sea one finds relatively low temperature conditions where temperature decreases rapidly from the low coastal plain to the high escarpment of these highlands, as can be seen from the following figures:

TABLE 6(8)

WEST-EAST TEMPERATURE GRADIENT IN SUMMER (1966-72) FROM THE RED SEA COASTAL PLAIN TO THE WESTERN HIGHLANDS (^{o}C)

Station	Elevation(m)	June Mean	July Mean	August Mean	September Mean
Sabya	40	34	34	33	32
Jeddah	11	31	32	32	31
Abha	2190	20	21	21	20
Belesmer	2250	18	19	18	18

In the eastern province, where sand and dust storms prevail during the hot season and reach their maximum frequency in July and August, the air temperature at stations such as Dhahran, As-Sarrar and Qaysumah is very high and may be equal to, or exceed, those temperatures recorded at stations in the southern parts of the country. Table 6(9) shows the summer temperatures in the two areas.

TABLE 6(9)

COMPARISON OF TEMPERATURE IN THE EASTERN PROVINCE (1966-72) AND IN THE SOUTH OF SAUDI ARABIA (°C)

Station	Latitude (N)	June Mean	July Mean	August Mean	September Mean
Eastern Province Stations					
As-Sarrar	(approx) 27° 00'	35	36	35	30
Dhahran	26° 17'	35	36	35	32
Abqaiq	25° 56'	35	36	36	32
Stations in the southern parts					
Al-Karj	24° 10'	32	34	33	30
Al-Aflaj	22° 17'	34	34	33	31
As-Sulayyil	20° 28'	34	35	35	32

There is a gradual decrease in temperature from south to north in the coastal plains of the Red Sea and the Arabian Gulf, but when the summer temperature gradient is compared with that of winter, it can be seen that the hot season gradient is more slack since the whole country during summer is under a relatively similar intense heat and, thus, the difference in air temperature between one station and another is small. The hottest area during summer is the coastal plain of the Arabian Gulf and probably the Rub-Al-Kali.

As in the cool season, there is a decrease in air temperature from the south to the north in the coastal plains of the Arabian Gulf and the Red Sea, as can be seen from Table 6(10) which shows the mean temperature of the summer months at selected stations located from north to south in both plains.

TABLE 6(10)

COMPARISON OF AIR TEMPERATURE IN THE COASTAL PLAINS (1966-72) OF THE RED SEA AND THE ARABIAN GULF IN SUMMER (^{o}C)

Station	Latitude (N)		June Mean	July Mean	August Mean	September Mean
Ras-Saffaniyyah*	28° 00'	(Arabian (Gulf	32	33	33	31
Qatif*	26° 33'	(plain	33	34	33	31
Al-Wajh	26° 13'		28	29	29	28
Jeddah	21° 30'	(Red (Sea	31	32	32	31
Jazan	17° 03	(plain	35	34	33	32

1967-72 mean of data

Autumn Conditions

During October sharp decreases carry air temperature to those conditions normally experienced in the cool season. All the climatic stations throughout the country show a rapid drop in temperature in the first half of this month. Indeed, October and November represent a transition period between the hot temperature conditions that prevail in the summer months and the cool temperature that dominates Saudi Arabia in the winter season. The weather phenomenon which causes a sharp decrease in air temperature is the incursion of cold air masses that primarily develop either over Eurasia or over Iran. If the air mass originates in Iran, cold weather conditions dominate most of Saudi Arabia and a comparatively low air temperature may be recorded from a major portion of the stations in the country. This type of air mass arrives in the country very dry and little changes in the characteristics may take place, but because of the proximity between Saudi Arabia and Iran, very little change can occur.

If the air mass is in origin advancing from Eurasia, it is normally cold, but because it arrives in Saudi Arabia after crossing the Mediterranean Sea, it becomes warmer and moist and, consequently, air temperature is rarely low.

However, the littoral areas show a slight decrease in air temperature during October. The difference between the mean temperature of September and October in these areas is often 1 to 3^{o}C only. At Jazan and Jeddah stations in the southern section of the Red Sea coastal plain, the difference between the last month of summer and the first month of Autumn is only 1°C at Jazan and 2°C at Jeddah.

In the littoral area of the Arabian Gulf the decrease of air temperature in October is comparatively higher than the decrease of the temperature in the coastal plain of the Red Sea. To explain the reason for the difference in temperature between the two plains, the topography of the two areas has to be considered. The Arabian Gulf coastal plain is directly exposed to the effects of the cool air masses that develop either over the Iran plateau or over the interior of Arabia, while the Red Sea coastal plain is almost sheltered by the highlands of Hejaz and Asir from the effects of the cool air masses that normally develop over the interior of the country. Table 6(11) shows the mean temperature of October and November in the coastal plains of the Red Sea and the Arabian Gulf.

TABLE 6(11)

TEMPERATURE CONDITIONS IN AUTUMN (1966-72) IN THE COASTAL PLAINS OF THE RED SEA AND THE ARABIAN GULF (°C)

Station		October Mean	November Mean
Al-Wajh	Red Sea plain	26	24
Jeddah	Red Sea plain	29	27
Jazan	Red Sea plain	31	28
Ras-Saffaniyyah (1967-72)	Arabian Gulf plain	25	21
Qatif (1967-72)	Arabian Gulf plain	26	23
Dhahran	Arabian Gulf plain	28	23
Abqaiq (hinterland)	Arabian Gulf plain	27	21

Coming out of the littoral areas toward the interior regions of Saudi Arabia, the decreases of air temperature are considerably larger as the distance from the sea increases. Moreover, there is a sharp decrease in air temperature from south toward the north since the latitude increases. In general, the differences between air temperature conditions of summer and the autumnal temperature conditions increase as one comes out of the littoral areas and also as one goes from south to north. Table 6(12) may serve in showing the decreases in temperature in areas which do not experience considerable maritime influences in the autumn season.

TABLE 6(12)

NORTH-SOUTH TEMPERATURE GRADIENT (1966-72) IN THE INTERIOR OF SAUDI ARABIA (^{o}C)

Station	Latitude	October Mean	November Mean
Qurayyat (1967-72)	31° 20'	16	12
Hail	27° 31'	22	18
Riyadh	24° 42'	25	19
As-Sulayyil	20° 28'	26	22

The warmest area during autumn is the southern section of the coastal plain of the Red Sea in which the mean monthly temperature of autumn is usually over 25°C. The high temperature, coupled with high humidity, makes the weather conditions, which are relatively temperate over most of the country, oppressive even in the autumn season.

The coldest area, on the other hand, is the Asir and southern Hejaz highlands in which the mean temperature of the autumn season is normally between 18 and 11°C. High elevations in these mountainous areas may make the temperature conditions relatively cold, particularly during November when air temperature may drop to less than 5°C at night. In these areas the large differences which have been found in the interior regions do not exist, and the variations in air temperature between summer and autumn are normally small. At An-Nimas and Baljurshi the difference in air temperature between September and October is only 2 to 3°C. Table 6(13) shows the temperature conditions in the highlands of Asir.

TABLE 6(13)

TEMPERATURE CONDITIONS (1966-72) IN THE HIGHLANDS OF ASIR DURING AUTUMN (°C)

Station	Altitude (m)	October Mean	November Mean
Baljurshi	2400	16	13
Abha	2190	17	14
Belesmer	2250	16	13
An-Nimas (1967-72)	2600	14	11

The Maximum and Minimum Temperature

The study of the mean and absolute extremes of temperature is interesting from a climatological point of view because of the fact that they give an idea of the average thermal conditions by day and by night and, in addition, they furnish information in regard to the daily range of temperature.

Monthly mean and absolute values of maximum and minimum temperature were available for the present study in the case of a great number of stations with temperature records. In the course of computation of mean monthly and other averages, so far used in the present study, attention was paid to the maximum and minimum data, and some reference may be made here to the results obtained.

The highest value in the mean monthly maximum temperature naturally comes from the southern parts of the country. As-Sulayyil, the southern station in the inland of the country records temperature, and at a height of 510 metres has a mean monthly maximum temperature of 44°C in July and August. The lowest value in this respect comes from the Asir highlands where Abha, at an elevation of 2190 metres, shows a mean monthly maximum temperature of 16°C in January. In the mean monthly minimum temperature, the lowest value comes from the northern province. In the southern part of the Red Sea coastal plain, Jazan, which is influenced by the maritime influences and is at a height of 4 metres only, has recorded the highest mean monthly minimum temperature, namely, 30°C in the summer months. In the northern province of Saudi Arabia, the lowest figure for this value comes from Qurayyat which has a mean monthly minimum temperature of 6°C in the winter months.

More interesting than the mean extreme values of temperature are the absolute extremes, i.e., the highest and the lowest on record during the period of observation. They indicate the extreme temperature conditions to which an area can be subjected due to local conditions or under the influence of external factors. The available data concerning the absolute extremes cover a period of seven years only.

The stories associated with terrific heat or intense cold of the Middle East, often referred to in books written on this area, or even in the newspapers, arouse a great deal of curiosity regarding the extreme conditions that may occur in this part of the world. The foregoing description of the temperature conditions of Saudi Arabia would clearly indicate that the country, as a whole, can be subjected to abnormal hot or cold waves during the summer or winter, and on such occasions unusually high or low records may be made.

During the summer months of July and August, high temperatures occur almost in all parts of Saudi Arabia, and the intense heat pushes the mercury to high levels. The summer heat is so great that extreme maxima of 49°C have been recorded at such stations as Riyadh and As-Sulayyil on many occasions. Even at stations influenced by maritime influences, such as Jeddah in the coastal plain of the Red Sea, and Dhahran in the coastal plain of the Arabian Gulf, extreme maxima of 48°C are found to be recorded in many cases during the summer months. In the northern province of the country which shows the lowest minimum temperature in Saudi Arabia, such intense heat may carry the extreme maxima to a high level. At stations in this area, such as Qurayyat and Tabarjal, absolute maxima of 44°C have been recorded during the summer months and as late as September.

The highest recorded temperature during the period used for this study (1966-1972) comes from Riyadh and As-Sulayyil in the inland of the country, where the mercury rose to 49°C in June 1969 at Riyadh and in August 1969 at As-Sulayyil. At As-Sarrar, in the hinterland of the Arabian Gulf and to the north-west of Qatif, an absolute maximum temperature of 50.5°C was recorded on the 15th of July 1967 (Italconsultant, 1969B), which is 7.3°C less than the world maximum of 57.8°C recorded near Tripoli, and 6.2°C below the all-time high temperature of 56.7°C recorded for the United States in the Death Valley.

The lowest temperature recorded during the period 1966-1972 was in the northern province where in December 1972 a low absolute minimum temperature of -13.3°C was put on record at Tabarjal. During this month unusually low temperatures were recorded at almost all the stations in the province where the absolute minimum at Skakah was -8.5°C and at Qurayyat was -12.8°C. Next to the northern province is the interior region and the Asir highlands where the absolute minimum temperature may drop to -5°C. Stations such as Riyadh, As-Sulayyil and Unayzah normally show low temperature of sub-zero during the winter months. Because of the high elevation of the Asir mountains, low temperature of less than sub-zero may be recorded at stations such as Belesmer and An-Nimas. Even at stations located in the lowlying coastal plain of the Arabian Gulf, low temperatures of -2°C were recorded at stations such as As-Sarrar, Abqaiq and Al-Hafuf. During the winter months, sub-zero (centigrade) temperature may occur in almost every part of the country, and $-2^{o}C$ has been recorded on many occasions in the areas outside the littoral regions at nights.

CHAPTER VII

PRECIPITATION

Introduction

Rainfall over most of Saudi Arabia is confined to the cool months; the only exceptions are the mountains of Asir and southern Hejaz, the southern shores of the Red Sea and possibly the southern borders of the Rub-al-Kali which experience a monsoon rainfall regime. Arid conditions persist over much of the country with the mean annual rainfall being 85.5mm if the Asir and southern Hejaz are omitted. This figure has been obtained from rainfall data that have been recorded from 71 stations distributed over the arid regions of the country. In the mountain masses of Asir and southern Hejaz where the monsoon rainfall regime prevails in summer and where the orographic rainfall associated with W winds dominates during the cool season, the mean annual rainfall is 319.2mm. This figure was obtained from data recorded from 30 stations in the area.

During the winter months the eastern and north-eastern regions of Saudi Arabia may come under the influence of the Asiatic anticyclone. In this case it is likely that a tongue of high pressure dominates over the central deserts of Saudi Arabia. This local centre of high pressure may block easy penetration of the Mediterranean depressions into major parts of the country. However, during the breakdown of this anti-cyclone system, migrating depressions from the Atlantic Ocean may travel along the Mediterranean low pressure trough and may invade the country during the period of

October-May. The number of the western depressions which invade Saudi Arabia has not been investigated in detail, but over the south-west of Asia in general, the average is about 50 a year, mainly during the period of October-April. About 30 of them reach as far east as Afghanistan and India, while the remainder pass through Mesopotamia to the Arabian Gulf (U.S. Army Air Force, 1945). The rainfall which occurs during the winter months is obviously produced by the depressions which invade Saudi Arabia from the Mediterranean.

The Mediterranean type depressions normally follow a west to east path across the northern region of the country in early autumn, and the associated cold front may give rain in the northern province as early as October. In November, when the Asian anti-cyclone has not developed fully, and in early spring, as the anti-cyclone recedes, frontal activity accompanied by widespread rain reaches its maximum. However, the Mediterranean moist air loses much of its moisture over land prior to reaching Saudi Arabia while its relative humidity is lowered by latitudinal heating as the moist air moves southward.

During the summer season the belt of the depressions shifts northward with the sun, the Mediterranean low pressure trough disappears, and the rain-bearing winds from the Atlantic pass to the north of the country. During this season the only part of Saudi Arabia to receive appreciable amounts of moisture is the south-west region which covers the Asir and southern Hejaz and the southern section of the coastal plain of the Red Sea. This area, during the summer, is dominated by a moist air coming in origin from the Indian Ocean.

Despite the fact that the summer rain is confined to the southwest area of the country, light showers may occur in the interior of the country and as far north as Riyadh and Qassim districts. This summer rain no doubt comes from the Arabian Sea through the Gulf of Oman and the Arabian Gulf. The random storms which bring this rain during the summer months are not unknown in the southern and eastern flanks of the Rub-al-Kali (Stevens, 1970). The I.T.C.Z. and the associated summer monsoon may penetrate the country and bring light showers over the high ground of the Tuwayq and the surrounding hills, but it has little effect due to rapid evaporation.

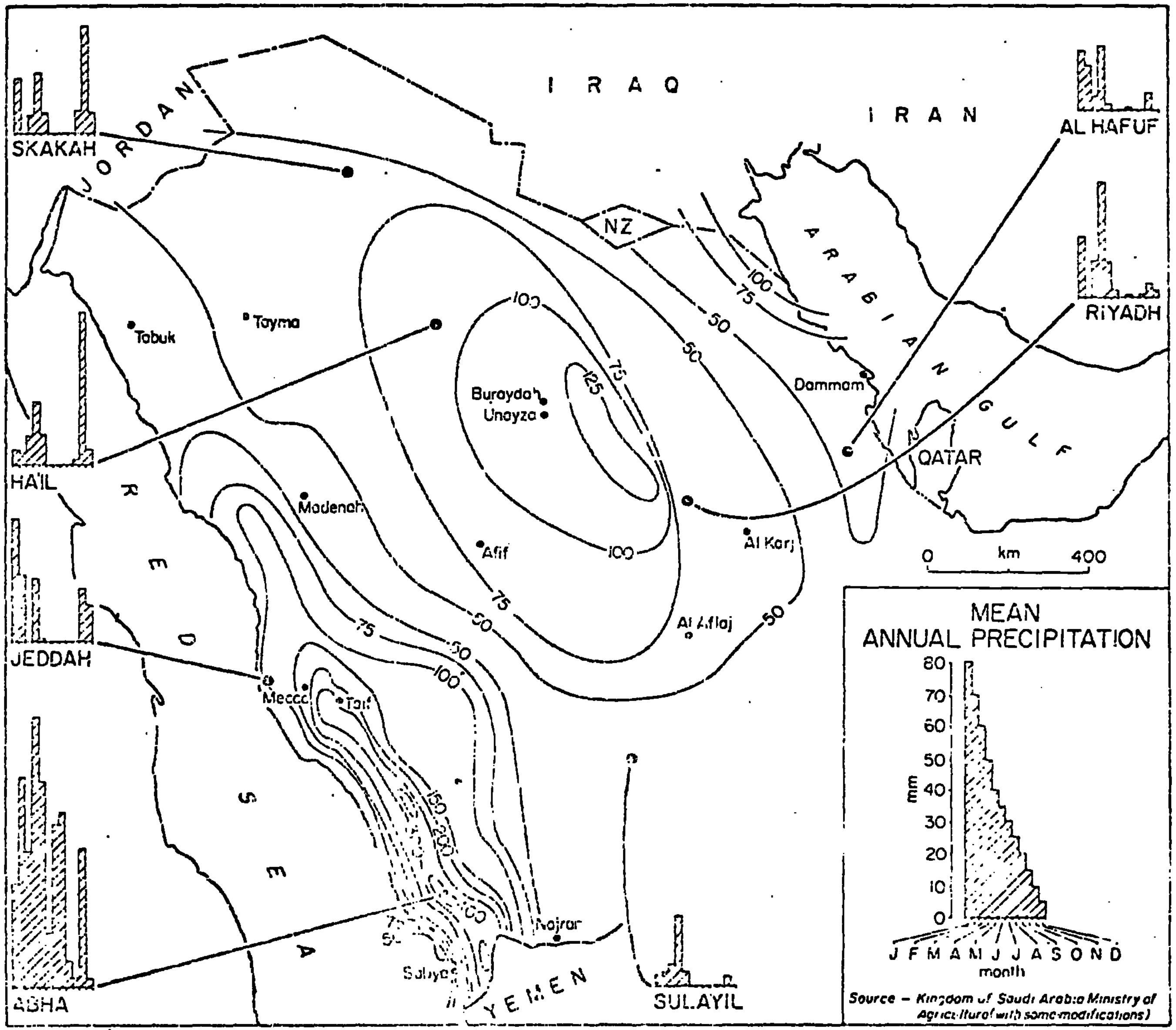
However, the main rainy season in the whole country is during the cool months, October to April, though rainfall may occur in September and May, but over most of Saudi Arabia again it evaporates in the atmosphere before reaching the ground as a result of the intense heat. The rain occurs during the cool season either as a result of the western depressions mentioned previously or from convectional activities within relatively moist air which can be classified as polar air coming from the Atlantic Ocean via the Mediterranean, and tropical air coming from the Indian Ocean via the Arabian Sea.

The Mediterranean depressions occasionally retain sufficient energy for their associated cold fronts of polar air to have an effect, albeit attenuated, on the country, but the major part of Saudi Arabia lies in a region of warm subsiding air as previously indicated. The possibility of widespread winter rain over a major part of the country is therefore greatly diminished because the upper air subsidence inhibits convection and causes a reduction in rainfall.

Mean Annual Precipitation

The map of mean annual precipitation in Saudi Arabia presented and discussed in this study is based upon one prepared by the Ministry of Agriculture, Hydrology Division (Figure 7(I). Some major modifications on this map were made to take account of more data. This map of mean annual precipitation was based upon data from about 90 stations distributed over the country with the exception of the Rub-al-Kali, about which no information is available. The length of the period of the records of rainfall ranges between twenty and three years. Unfortunately, the major proportion of the stations have a record term of five to six years. Consequently, the rainfall map, though showing the general distribution of the amounts of rainfall, is an initial map on rainfall of Saudi Arabia. Another fact to be added on the circumstances of construction of the map is the lack of rainfall stations on high ground in the north-west of Saudi Arabia and therefore the isohyets mainly show in this area the mean annual rainfall of the lower areas : Al-Bid'a and Tabuk are situated at low levels of less than 800 metres. Furthermore, they are located in depressions within the northern Hejaz and Madian mountains and are influenced by the rain shadow of the high ranges of the mountains.

For the purpose of analyzing the annual precipitation of the country it is advisable to divide Saudi Arabia into geographical regions, namely, the northern province which includes Skakah, Tabarjal, Turaif, and Badana stations, the eastern province which covers the Arabian Gulf coastal plain, and as far east as



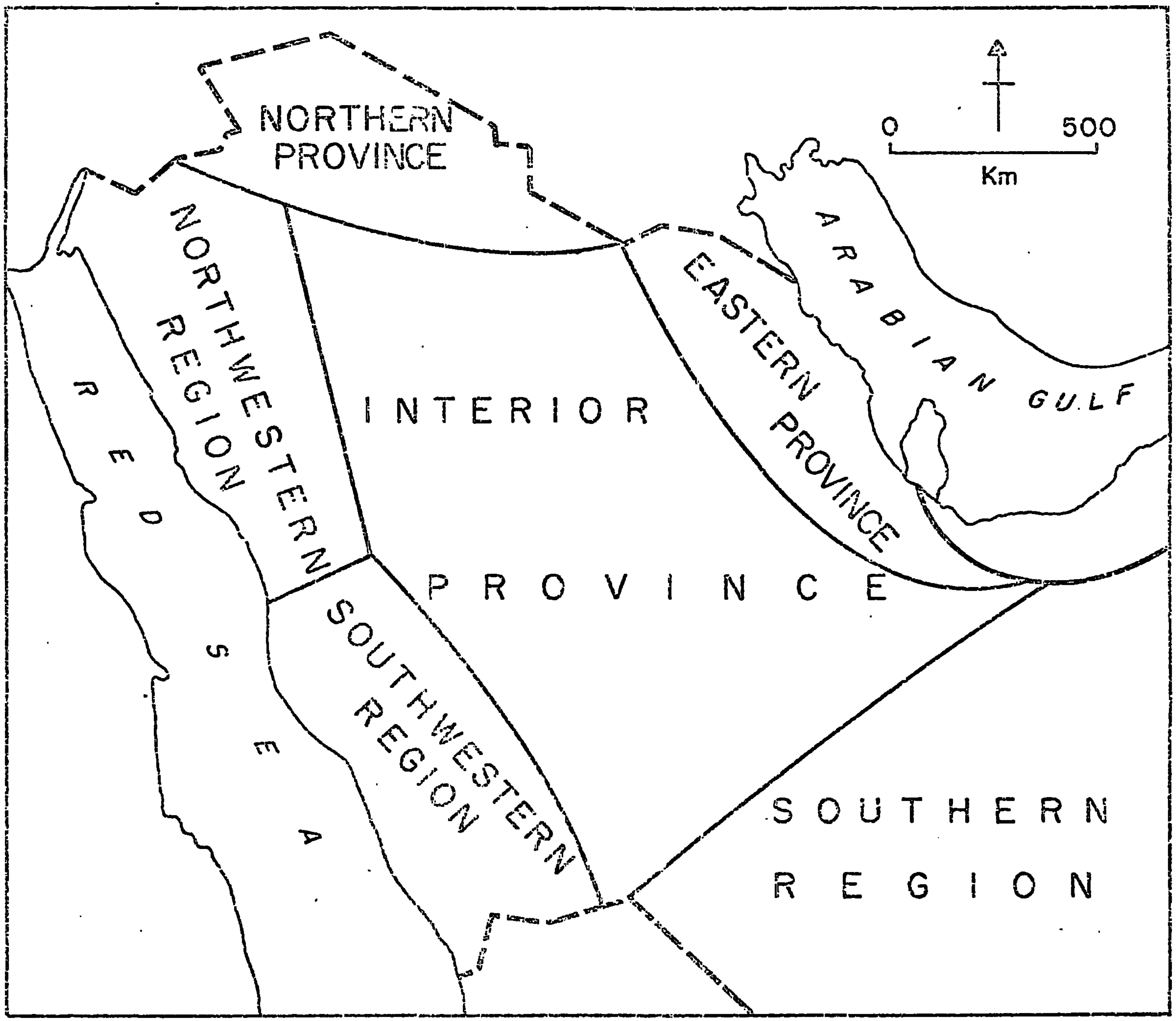
IRAQ
IRAN
JORDAN
NZ
ARABIAN GULF
RED SEA
QATAR
YEMEN
SKAKAH
HAIL
JEDDAH
ABHA
AL HAFUF
RIYADH
SULAYIL
Tabuk
Tayma
Buraydah
Unayza
Madenah
Afif
Al Karj
Al Aflaj
Dammam
Mecca
Taif
Najran
Sabya
0 km 400
MEAN
ANNUAL PRECIPITATION
mm
month
J F M A M J J A S O N D
Source – Kingdom of Saudi Arabia Ministry of Agriculture (with some modifications)

Fig 1.1

Qaysumah in the north and Yabrin in the south, the north-west region and the northern section of the Red Sea coastal plain and the southwestern region which covers the southern Hejaz mountains and the Asir highlands, and also the southern section of the Red Sea coastal plain (Figure 7(II).

The amount of the mean annual rainfall in the northern province of Saudi Arabia ranges between 69.7mm for the period 1955-1969 at Skakah and 29.2mm for the period 1961-69 at Badana, which is less than the mean annual rainfall of the desert regions of the country (85.5mm). The probable reason for the low amount of rainfall is that the depressions from the Mediterranean lose most of their moisture when they move across the Palestine and Jordan escarpment before arriving in the area. However, along the Jordan escarpment there is a decrease in precipitation from north to south. This is due almost entirely to the synoptic weather pattern associated with the Mediterranean depressions. The strongest contrast between the cold and warm air will be in the north. Further south the contrast will decrease because of the modification brought about by the warmer air and the longer southward track. The frontal activity tends to decrease as the depression moves southward and, consequently, the amount of the rainfall will decrease toward the south. It has been suggested (Flohn, 1965) that the low rainfall amount in the northern province of Saudi Arabia is that the tropical disturbances which invade the country from the south do not reach this area. However, within the surrounding areas there are a number of marked topographical features that, when considered in conjunction with the normal synoptic weather during the cool season, suggest a possible rainfall

GEOGRAPHICAL REGIONS OF SAUDI ARABIA Fig. 7:11



distribution. The south-western part of the northern province is in the immediate rainshadow of the Madian mountains that rise to a height of over 2000 metres and also in the rain shadow of the Sinai Peninsula which lies further westward. These barriers, combined with the general decrease from falling off of precipitation from the north-west to south-east, would suggest that precipitation is likely to be very low. The northern part of the province is possibly in a less marked rain shadow of the Jordan escarpment. Within the province there is some evidence to show that relatively insignificant topographical features appear to exert some orographic effects. Over the basalt area of the north-west, recorded data of rainfall indicate that precipitation over this slightly elevated region is greater than that experienced in the neighbouring lower area where the mean annual precipitation at Qurayyat in the eastern slopes of Al-Harrah is about double the mean annual rainfall at Al-Isawiyah to the south, namely, 52mm for the period 1967-69 at Qurayyat and 30.9mm for the period 1966-69 at Al-Isawiyah. As this area presents a large expanse of dark coloured rock, it is possible that localized differential heating may give rise to instability sufficient to set up convection currents in a relatively moist westerly air stream. On the other hand, it is possible that the province represents a lee wave region under the influence of the Jordan escarpment. The effect of the Jordan escarpment can be recognised from parallel lines of lenticularis cloud in the area (Parsons Basil - Consultant, 1968). Owing to an adverse combination of synoptic weather and topography, the area can rarely be invaded by air sufficiently cool and moist to respond to orographic influences, as these are nowhere very marked.

In the north-west of the country the Madian and northern Hejaz mountains have a height of over 2000 metres, but, as has already been indicated, the stations installed in the area are located on the low ground and consequently the amount of rainfall in the mountain areas is expected to be relatively higher than what is shown by the available data recorded at stations such as Tabuk and Al-Bid'a. However, the high mountains in the north-west of Saudi Arabia are limited to minor areas where most of the region is of moderate elevation. The mean annual rainfall in the whole region is normally 50mm and less. It is expected that the mean annual rainfall over the high ranges of the mountains is about 100mm.

Table 7(1) may serve for showing the amounts of the mean annual rainfall at selected stations in the northern province and in the north-west of the country.

TABLE 7(1)

Mean annual rainfall in the north and the north-west of Saudi Arabia

Station and period of utilised data		Elevation (metres)	Mean Annual Rainfall (mm)
Al-Bid'a	1966-69	247	12.9
Qurayyat	1967-69	549	54.4
Tabuk	1967-69	773	32.0
Turaif	1966-69	830	29.0

From this table it can be shown that the mean annual rainfall in the northern province and the north-west region of the country is normally less than 50mm. Despite the fact that the received rainfall in these two regions is of small amounts, it is necessary to emphasise that Al-Bid'a and Tabuk are located in the rain shadow of the Madian and Hejaz mountains. Al-Bid'a is located in the Afal Wadi in the rain shadow of Jabal Al-Loz.

From the northern province toward the Najd plateau the mean annual rainfall increases from 50mm in the northern province to 75 and 100mm in the Najd plateau where the 75 and 100mm isohyets take the form of two closed circles on the top of Najd plateau. Furthermore, it can be noticed from the map of the mean annual rainfall that the Tuwayq escarpment promotes local precipitation where the mean annual rainfall increases to 125mm on the Tuwayq mountains. In general, there is an island of higher rainfall in Najd plateau from Hail - 27° 31'N in the north, to Sabhah - 23° 15'N in the south, and from Afif - 23° 55'N, 42° 56'E - in the west to the eastern slopes of the Tuwayq escarpment. Table 7(2) shows the increases of rainfall in Najd plateau.

TABLE 7(2)

Mean annual rainfall on the Najd plateau

Station and period of utilised data		Elevation (metres)	Mean Annual Rainfall (mm)
Dawadmi	1966-69	940	111.8
Hail	1966-69	914	156.1
Qurayn	1967-69	910	96.9
Quwayiyah	1967-69	960	127.9
Nifi	1967-69	780	100.0
Sabhah	1967-69	820	100.0
Shaqra	1966-69	730	96.5
Unayzah	1966-69	650	118.2

It can be seen from this table that there is a considerable increase in rainfall amounts on the Najd plateau. The mean annual rainfall becomes remarkably higher when a station is located at a higher elevation as in the case of Quwayiyah which is located on As-Sirk escarpment to the east of Nafud As-Sir. The explanation for the considerable increases in the mean annual rainfall on the Najd plateau is the combined action of three factors : the first is the increase in elevation, the second is the invasion of the tropical disturbances from the Arabian Sea during the cool season which are associated with the south-east monsoon winds, and thirdly the influences of the Mediterranean depressions of the winter season. Again there is a decrease in the mean annual rainfall from Najd plateau toward the Rub-Al-Kali, the Arabian Gulf and toward the lower eastern slopes of the Asir and southern Hejaz uplands. The decrease in the amounts of rainfall toward the south is the result of the decrease of altitude towards the Rub-al-Kali. The decrease toward the eastern province is also as a result of the decrease in elevation toward the Arabian Gulf. Toward the western highlands from Najd plateau the amount of rainfall decreases to a mean annual value of 50mm only, despite the fact that the elevation increases. Indeed, there is an elongated trough of low rainfall extending from Tabuk in the north-west of Saudi Arabia to As-Sulayyil, including Madenah, Tathlith and Khammasin. The explanation for the decrease in the amounts of rainfall is that this area experiences the air stream of Fohn type where the moist wind precipitates most of its moisture on the Asir and Hejaz mountains and arrives in this region as warm, dry winds when they descend the eastern slopes. Table 7(3) shows the mean annual rainfall at selected stations within the trough of least rainfall.

It can be seen that although the elevation at the stations within the trough of low rainfall is more than 1000 metres in a number of cases, the mean annual rainfall, comparable with the mean annual rainfall of Najd plateau, is small. In fact, the nature of the configuration of the Najd plateau has an important role in increasing rainfall amounts. The configuration of the topography is in the form of many escarpments facing the west, north-west and south-west, i.e., the directions of the moist air; hence, when the relatively humid air stream ascends the modest escarpments, it becomes to some extent cooler, saturated, and precipitates some of its moisture.

TABLE 7(3)

Mean annual rainfall in the rain-shadow of the western highlands, 1966-69

Station	Elevation (metres)	Mean Annual Rainfall (mm)
As-Sulayyil	510	39.5
Beni Hammim	1200	20.2
Khammasin	523	23.9
Madenah	672	47.6
Najran	1150	68.8
Tathlith	975	44.6

In the south-western region of the country there is a small island of comparatively large amounts of rainfall. Here the mean annual rainfall ranges from 100 and 150mm on the Asir plateau and Harrat Nowasif and Al-Bugom, to 400mm at the top of the Asir and southern Hejaz mountains. In this area the amount of rainfall is superimposed by the orographic effects of the high escarpment and shield area and the mass of Wajid Jabals. In attempting a study of the rainfall amounts in this area one is immediately faced with a complex problem which is difficult to resolve without adequate long term records from well distributed stations over both slopes of the highlands. The area comes under the influence of two different air masses for the major part of the year, the cool season, either singly or in combination, or following each other, and these in turn are controlled by the variation of the high relief topography. During the winter months, December-February, rainfall is generally associated with weak influxes of moist-cool air of the Mediterranean origin which, combined with the localised effects of the Red Sea and the highlands, gives rise to rainfall along the main crest of the escarpment. During the spring season of March-May there is a strengthening of the monsoon type flow and its consequent convergence with the weakening Mediterranean air. This normally gives rise to rainfall amounts over wide areas of the country, particularly in the Asir and southern Hejaz mountains, and even the low relief of the Tuwayq escarpment, but rarely do the southerly monsoon winds and the associated tropical disturbances reach the northern areas of the country.

During the summer months the south-west monsoon flow predominates in the south-western region, giving rise to thunderstorms along the escarpment and as far north as the Taif area in the Hejaz mountains. In the plateaux the summer thunderstorms do not appear to develop to the east or north of Bishah area.

The mean annual rainfall in the Asir highlands may range at one station during two consecutive years between 700mm and 200mm. The map of the mean annual rainfall does not show some minor areas of high mean annual rainfall which are in the shape of "lobes" within the Asir mountains. At stations within these lobes the mean annual rainfall is normally over 500mm and may exceed 600mm. These minor areas in the south-west region of Saudi Arabia experience a humid climate. A fact has to be added about the rainfall in the south-western region. It appears from the available data that rainfall increases to a particular elevation after which rainfall begins to decline. As has already been indicated, there are no data of long duration recorded from stations on both slopes to enable investigations on the distribution of rainfall as a result of the increases in elevation. Climatologists generally agree that precipitation increases with altitude, although at various rates, up to the level of about 2000 metres, after which it shows signs of decline (Trewartha, 1954). In Asir and southern Hejaz, the mean annual rainfall at stations located at the first ranges of the mountains exceeds 500mm, though the elevation does not exceed 900 metres. At stations located on the high ranges of the escarpment, the mean annual rainfall is normally less than 500mm although the elevations of these stations are more than 2000 metres. It appears that the moist air precipitates the largest amounts of rainfall at the first mountainous chains after which the amounts of moisture decrease when the air stream penetrates further eastward in the Asir and Hejaz highlands. Table 7(4) shows the characteristics of the declination of rainfall in Taif, Gamid and Abha areas.

It can be shown from the table that the amount of the mean annual precipitation in the first lower ranges of the highlands of the south-west region is higher than the precipitation in the high ranges, since the mean annual rainfall at Jabal Fayfa and Jabal Salah, to the east of Sabya, is 704mm and 514.4mm respectively, despite the elevation of these stations being only 900 metres or less. At stations on the high ranges, the mean annual rainfall is about 400mm and at some of them it is even less than this value.

TABLE 7(4)

Mean annual rainfall in the highlands of Asir and southern Hejaz

Station and period of utilised data		Elevation (metres)	Mean Annual Precipitation (mm)
Abha	1966-69	2190	404.3
Al-Ain	1965-69	2300	212.0
Al-Amir	1966-69	2100	335.4
Al-Alayyah	1966-69	1840	485.7
Al-Gorrah	1967-69	2060	268.7
Al-Kam	1965-69	2200	451.6
Beni-Thawr	1966-69	2140	390.0
Baljurshi	1967-69	2400	452.5
Al-Abis)		2350	250.6
Al-Gadairin)		1900	238.5
Jabal Fayfa)		900	704.0
Jabal Salah)	1966-69	860	514.4
Liyyah)		1640	230.8
Taif Airport)		1395	135.9
Thurayban)		575	627.5

After a careful examination of the nature of the locations of the stations on the high ranges it has been found that they are located in minor rain shadows of higher ranges to the west of them. Data recorded at recently installed stations have shown that precipitation is expected to increase with the increase of elevation, though the increase is slight. As has already been indicated, the stations with records of more than five years, such as Abha, Baljurshi and Taif, are located in the rain shadow of the higher ranges of the Asir and southern Hejaz mountains. However, As-Sawdah station, which was installed recently, with an altitude of about 2820 metres, is located in a position exposed to the moist south-west monsoon of summer, as well as to the moist north-west winds of winter. When someone stands at this position he can see the clouds approaching from the Red Sea below his level. Vegetation of forest type covers the area and many perennial springs occur. An-Nimas, midway between Abha and Baljurshi, with an altitude of 2600 metres, is also exposed to the moist winds. The stations in Asir and southern Hejaz normally become exposed to the moist winds when either they are situated at a high elevation or when they are located looking over a major wadi or looking over the Red Sea coastal plain.

It has been found preferable to divide the stations located in the high ground of the south-west region of Saudi Arabia into three groups; the first is the group which is located in the foothills and the first ranges, the second group is that found in the rain shadow in the eastern slopes of the highlands, and the third is that which has locations on the high ranges and is exposed to the moist winds. Comparison between them can be made according to their total precipitation of 1972.

TABLE 7(5)

Rainfall in 1972 in the Asir and southern Hejaz highlands

Station	Elevation (metres)	Annual Total Precipitation 1972 (mm)
Group 1 : Stations located in the foothills and the first ranges		
Al-Barig	390	551.8
Jabal Salah	860	520.8
Horub	519	864.3
Az-Zandi	420	614.6
Malaki	178	405.4
Mikhwa	364	601.6
Group 2 : Stations located in a rain shadow in the eastern slopes		
Abha	2190	456.9
Al-Abis	2350	395.0
Beni-Thawr	2140	188.4
Sarat-Abidah	2400	308.4
Taif	1395	378.9
Group 3 : Stations located in exposed positions to the moist winds		
Al-Aja'edah	2330	641.3
Al-Yazid	2400	754.4
An.Nimas	2600	632.0
As-Sawdah	2820	688.4
Belesmer	2250	554.3
Shafa (Taif area)	-	462.0

It can be seen from the first group that the moist air which dominates the area throughout the year precipitates the largest amounts of rainfall on the first ranges, even on those of modest elevation. Horub station, which is located in the foothills at a height of 519 metres, received during the year of 1972 precipitation amounting to 864.3mm. This station is located in the foothills of Jabal Horub which has a height of 1292 metres and is exposed directly to the moist wind approaching from the Red Sea. If there was a station on the summit of this mountain, precipitation of 1000mm might be expected. Mikhwa station, which is located in the foothills of southern Hejaz mountains to the south-east of Jeddah and to the south-west of Taif, received during 1972 a large amount of rainfall - 601.6mm - although it is situated at a low elevation of 364 metres. This group generally represents the low western slope of the escarpment.

The second group represents the eastern slope of the Asir and southern Hejaz highlands. All these stations are located in a minor rain shadow and therefore the amounts of rainfall decrease by about 20-25% from the rainfall received at the high and exposed stations.

Group 3 represents the high or exposed ranges. The stations located in these areas record large amounts of precipitation. Within this area is Beni Malik (not mentioned in the table) which is located at a height of 1996 metres to the north of Baljurshi. The total rainfall received here during 1972 was 679.7mm, which is more than double the rainfall received at Taif station in the rain shadow. This station is exposed to the moist winds, especially the south-westerly ones which flow to this station through Tayyah Wadi. Again, Al-Yazid station, which is located at an elevation of 2400 metres to the south-east of Abha, is exposed to the moist winds. This station is located on a high range from which a steep funnel-like depression extends to the south-west through which the moist air of summer and spring flows persistently. The amount of precipitation received at this station during 1972 was 754.4mm. When the three groups are compared, the largest amount of precipitation was recorded, during 1972, at Horub station in the western slopes of the escarpment where 864.3mm was received. Moreover, when the first group is compared with the third group, it can be noticed that the stations of the latter group show consistently high amounts of precipitation, particularly those stations located to the west and south-west of Abha.

However, when there are well-distributed stations and relatively reliable records of longer duration, west-east and north-south rainfall gradients over the highlands of the south-west region of the country will be even more apparent.

From Najd plateau the mean annual rainfall decreases toward the eastern province. The isohyet of 50mm extends from the northern province to the eastern flanks of the Najd plateau toward the northern boundary of the Rub-al-Kali, showing an area of low rainfall of about 150 kilometres broad, between the Najd plateau and the coastal plain of the Arabian Gulf, then the mean annual rainfall increases as a result of the proximity to the Arabian Gulf.

In the eastern province of Saudi Arabia the distribution of rainfall is affected by the proximity to the Arabian Gulf. Over the Arabian Gulf shallow warm air sometimes covers the Gulf and Euphrates Delta region with an anti-clockwise circulation around a low at the heart of the Gulf, giving north-west winds over the area and a line of convergence or boundary front between this warm air and a cooler polar air in origin which advances during the cool season from Iran. Either cyclonic rain or sporadic shallow convectional rainfall along the boundary front may be expected to occur in the province. Rainfall distribution is normally linked with these conditions in the coastal plain of the Arabian Gulf. In the hinterland of the Gulf, rainfall is low because of a transition between extremely attenuated Mediterranean type cold fronts and the localised increase in rainfall due to the presence of the Arabian Gulf. The influence of the Gulf on rainfall appears to cause an increase northward along the coast between Dhahran and Kuwait. There are no marked topographical features in the area that would give rise to significant increases in rainfall. In only one area, the Ghawar ridge running between Ras-Saffaniyah and Harad, does there appear to be a slight marginal increase due to relief. In general, the rainfall decreases from north toward the south in the province. In the northern section of the coastal plain of the Arabian Gulf the isohyets of 100 and 75mm extend from the north-west to the south-east parallel to the coast of the Gulf. Toward the southern section of the plain, the rainfall decreases to a mean annual value ranging between 75 and 50mm. Table 7(6) represents the mean annual precipitation at selected stations in the eastern province.

TABLE 7(6)

Mean annual rainfall in the eastern province of Saudi Arabia

1966-1969

Station	Elevation (metres)	Mean Annual Precipitation (mm)
Abqaiq	155	59.2
An-Nariyah	50	50.1
Dhahran	22	53.3
Al-Hafuf	160	59.2
Qatif	4	78.6
Qaysumah	360	44.7
Ras-Saffaniyyah 1967-69	5	123.5
Ras-Tanura	5	56.5

SEASONAL DISTRIBUTION OF PRECIPITATION

The discussion of the seasonal distribution of precipitation is based on the percentage of the proportion of the annual precipitation occurring in each season of the year, and the aggregates of precipitation of every season. It is hoped to be helpful in explaining the seasonal distribution of the annual precipitation in Saudi Arabia.

WINTER PRECIPITATION

It can be said without any hesitation that winter is the main rainy season of Saudi Arabia for it is during this season that the whole country receives precipitation, though there are some stations which show maxima rainfall in other seasons. In other words, despite the fact that some stations receive their maxima in spring or autumn, it is during the winter months when precipitation occurs over the largest area of the surface of Saudi Arabia. The percentage value of winter rainfall may range from 70% to less than 8% of the annual. The area which shows the highest percentage value of winter rainfall in Saudi Arabia is the eastern and north-eastern regions in the coastal plain and the hinterland of the Arabian Gulf, as can be deduced from Table 7(7).

TABLE 7(7)

Winter rainfall in the eastern province of Saudi Arabia

1966-69

Station	Mean Annual Precipitation (mm)	Mean Winter Precipitation (mm)	% of annual
Abqaiq	59.2	35.0	59.0
An-Nariyah	50.1	36.6	73.0
Dhahran	53.3	28.3	53.1
Al-Hafuf	59.2	43.2	72.9
Qaysumah	44.7	29.6	66.0
Ras Tanura	58.3	28.6	50.6

In general, the percentage value of winter precipitation decreases from north to south in Saudi Arabia with the lowest percentage value of the winter precipitation being found in the Asir highlands, and probably in the Rub-al-Kali, while the highest percentage normally exists in the Arabian Gulf area and in the north and north-west of the country.

The lowest percentage value of winter precipitation is found in the Asir highlands and in the southern section of the Red Sea coastal plain. As will be discussed shortly in the present study, the winter precipitation of Saudi Arabia is mostly cyclonic in nature. Consequently, the stations that show a smaller percentage of winter rainfall are those that receive either a considerable amount of convectional rain in spring or a good deal of orographic rain in other seasons of the year. The stations in the Abha area in the southern section of Asir mountains, and the stations in Jazan district in the southern section of the coastal plain of the Red Sea, show the lowest percentage of the seasonal precipitation in the winter months, as shown in Table 7(8).

TABLE 7(8)

Winter rainfall in the Aʿsir and Jazan areas

Station and period of utilised data		Mean Annual Precipitation (mm)	Mean Winter Precipitation (mm)	% of Annual
Abha	1966-69	404.3	81.0	20.0
Al-Ain	1965-69	212.1	21.7	10.0
Al-Alayyah	1966-69	485.7	136.3	28.0
Al-Kam	1965-69	451.6	54.5	12.0
Bishah	1966-69	125.2	19.5	15.5
Jazan	1966-69	44.6	4.3	9.6
Kamis-Mushait	1966-69	247.1	47.1	19.0
Thurayban	1966-69	627.5	107.9	17.0

In the northern section of the Red Sea coastal plain winter provides a high percentage of the annual rainfall. The climatic stations in this section are situated at low elevations and thus they gain most of their rainfall during the winter season from the Mediterranean depressions. Table 7(9) shows the winter percentage rainfall at selected stations in the northern section of the Red Sea coastal plain.

TABLE 7(9)

Winter rainfall in the western highlands

Station and period of utilised data		Mean Annual Precipitation (mm)	Mean Winter Precipitation (mm)	% of Annual
Al-Muwaylih*	1967-69	136.5	65.6	48.0
Al-Wajh *	1966-69	31.5	13.3	42.0
Badr *	1966-69	57.8	33.0	57.0
Bahrah*	1966-69	92.9	34.2	37.0
Shawaqah	1967-69	62.6	12.0	19.0
Sug-Suwayq	1966-69	71.0	22.2	31.0
Yanbu *	1966-69	19.4	17.0	87.0

Table 7(10) shows that the stations of low elevation (*) in the northern section of the Red Sea coastal plain show high winter percentages since these stations gain their precipitation from the cyclones of the Mediterranean Sea. The stations, which are located at higher elevations such as Shawaqah, show relatively lower percentages of winter precipitation since these stations gain more convectional or orographic rainfall in other seasons. As a general rule, the percentage value of winter precipitation decreases in the western highlands and the coastal plain of the Red Sea from north to south as the distance from the Mediterranean Sea increases. In the northern province of Saudi Arabia, the percentage value of winter rainfall is relatively low since the stations in this province receive considerable amounts of their annual rain during spring or autumn. The depressions of the winter season which arrive in this area are very attenuated, in reverse situation to those which track through the Red Sea trench.

TABLE 7(10)

Winter rainfall in the northern province of Saudi Arabia.

Station	Mean Annual Precipitation (mm)	Mean Winter Precipitation (mm)	% of Annual
Badana(1966-69)	29.2	10.0	34.0
Qurayyat(1967-69)	52.4	14.5	27.6

In the interior province of the country a number of stations show low percentages of winter precipitation. In this province, as in the north of the country, the Mediterranean depressions precipitate most of their moisture before approaching this area, and thus stations such as Riyadh and Al-Karj show low percentages of winter rainfall. Furthermore, in this province the percentages of winter rainfall decrease from north to south as the distance from the Mediterranean increases. Table 7(11) shows the percentage of winter rainfall at stations located from north to south in the area.

TABLE 7(11)

Winter rainfall in the interior of Saudi Arabia, 1966-69

Station	Mean Annual Precipitation (mm)	Mean Winter Precipitation (mm)	% of Annual
Hail	156.1	86.0	55.0
Unayzah	118.2	42.9	36.9
Riyadh	127.6	66.3	51.9
Al-Karj	27.5	11.1	40.0
As-Sulayyil	39.5	6.2	16.0
Tathlith	44.6	10.1	22.6

The wettest part of Saudi Arabia during the winter months is the southern Hejaz and the Asir mountains, although, as has already been indicated, the stations in this area show low percentages of winter rainfall. The rest of the country is, in fact, dry, although the ranges of northern Hejaz, Madian, as well as Tuwayq and Shammar mountains may receive enough precipitation for these areas to be relatively wet in winter.

The driest part of Saudi Arabia during the three months of winter is probably the Rub-al-Kali. No information is available about this remote and vast part of the country, but since rainfall normally decreases toward this part from the surrounding areas, it is expected that the Rub-al-Kali is the driest area in the country.

SPRING PRECIPITATION

During the spring season, March-May, Saudi Arabia receives another important portion of the annual rainfall, particularly during March and April. The spring months are the period of retreating Mediterranean depressions that, during winter, invade the country from time to time. During spring, the cyclonic activity which is more frequent in Saudi Arabia during winter, is reduced considerably, as a result of the northern shift of the tracks of these depressions. The Mediterranean depressions, when moving toward the country during spring, are weaker and therefore less able to penetrate far into the interior of the country. On the other hand, with the advance of the spring season, temperatures all over the country rise rapidly and this rise in temperature produces a great deal of convectional rain and sharp thundershowers that become accentuated over the highlands, even those of moderate elevation. The combined result of the above factors is that the spring precipitation decreases considerably in the lowlands which are extensive in Saudi Arabia. Spring is the period during which the moist south-eastern monsoon reaches its maximum flow, and is also the period during which the maritime air advancing from the Atlantic Ocean or Europe via the Mediterranean flows from time to time, as has been discussed previously. The fact that needs to be emphasised is that the importance of spring precipitation decreases from south to the north, while the importance of autumn rainfall, as will be discussed shortly, decreases from north to south.

The area that receives an important portion of its annual precipitation in spring is the highlands of Asir and southern Hejaz. Two combined factors result in large amounts of precipitation within this area; the first is the high altitude where the maritime air that dominates the area is forced to rise in a short distance along the slopes of the mountains, and the second is the considerable flow of maritime air that advances from the Arabian Sea when a low pressure area begins to develop over Saudi Arabia in spring. The spring months are indeed a main rainy season in the highlands of the Asir and southern Hejaz mountains where a considerable amount of precipitation is normally received, especially in April and May. Table 7(12) may serve in showing the importance of spring precipitation to the annual rainfall.

In this elevated area the percentage of spring rainfall ranges between 53.2 and 19%. As has been indicated, the nature of the location of the stations has an important effect upon the seasonal distribution of rainfall. Those which are exposed to the north-west winds of winter and autumn show lower percentages of spring rainfall, while the stations which are exposed to the south-east monsoon winds of spring show higher percentages. Taif and Bissel stations are located in the northern section of the escarpment of the Asir-Hejaz highlands. The former is exposed to the north-west winds and thus has a percentage of 19% only; the latter is exposed to the south-east monsoon winds rather than to the north-west winds (the Shamal) and consequently has a percentage value of 41.2% Al-aja'edah and Baljurshi are both exposed either to the north-west winds of winter or the south-west winds of summer

TABLE 7(12)

Spring rainfall in the Asir and southern Hejaz highlands

Station and period of utilised data		Mean Annual Precipitation (mm)	Mean Spring Precipitation (mm)	% of Annual
Abha	1966-69	404.3	136.0	34.0
Al-Aja'edah	1967-69	539.4	155.6	29.0
Al-Ain	1965-69	212.1	77.8	36.6
Al-Alayyah	1966-69	485.7	204.8	42.0
Al-Hawiyah	1966-69	280.7	99.5	35.0
Al-Kam	1965-69	451.6	147.1	32.0
Baljurshi	1967-69	452.5	100.6	22.0
Bishah	1966-69	125.2	67.2	53.2
Bissel	1966-69	173.9	71.8	41.2
Kamis-Mushait	65-70	247.1	97.8	39.5
Taif	1966-69	135.9	26.3	19.3
Zahran-Al-Jenub	1966-69	215.0	53.8	25.0

and thus show a low spring percentage, while Abha, Al-Alayyah, Bishah and Kamis-Mushait as well as Zahran-Al-Jenub are all exposed to the south-east monsoon winds and consequently show high spring percentage values.

In the north-west of Saudi Arabia the percentage value of spring precipitation is low where there is a considerable decrease in the percentage value of spring precipitation as one goes in a northerly direction from the southern Hejaz mountains into the north-west region of the country. Precipitation here is mostly caused by the Mediterranean cyclones which normally make their appearance in this region as early as October. In spring these cyclones invade the country after they become very attenuated. When a cyclone arrives in the north-west region of the country in spring, the moisture it includes is of low amount and, thus, it gives a low amount of rainfall, as can be seen from Table 7(13).

TABLE 7(13)

Spring rainfall in the north-west of Saudi Arabia

Station and period of utilised data		Mean Annual Precipitation (mm)	Mean Spring Precipitation (mm)	% of Annual
Al-Ula	1966-69	50.1	12.3	24.5
Al-Wajh	1966-69	31.5	7.5	24.0
Tabuk	1967-69	32.0	8.7	27.0
Shawagah	1967-69	62.6	27.0	43.0

As a result of the increases of the elevation of some stations there is a considerable increase in the amount of spring precipitation and consequently there is a similar increase in the percentage of the spring precipitation. The only available example may come from Shawagah station which is located on the northern slopes of Jabal Al-Garah in northern Hejaz mountains at an elevation of about 1200 metres.

In the northern province of Saudi Arabia the spring precipitation forms an important portion of the annual rainfall. The percentage value of spring precipitation ranges in the province between 24% and 40.6%. There is a considerable decline in the spring precipitation from north-west to south and south-east, where the percentage of spring precipitation decreases in these directions. This decline is obviously as a result of the increases of winter precipitation percentages. Toward the Arabian Gulf the spring percentage is found to be low at Rafha in the south-eastern part of the northern province. Toward the south the spring percentage of the annual precipitation decreases toward Hail. The south and south-east decline of the percentages of spring precipitation can be noticed from Table 7(14) which represents stations located from north-west to south and south-east in the northern province of the country.

TABLE 7(14)

North-south and south-east decline of rainfall from the northern province (1966-1969)

Station	Mean Annual Precipitation (mm)	Mean Spring Precipitation (mm)	% of Annual
Qurayyat (1967-69)	50.4	21.0	40.6
Al-Isawiyah	30.9	7.5	24.0
Hail	156.1	37.7	24.0
Turaif	29.0	10.9	37.5
Rafha	17.8	2.5	14.0

To the south of Hail the percentage of spring precipitation increases at Unayzah station in Qassim district. Indeed, the spring precipitation represents an important portion of the annual rainfall in the interior of the country. At Riyadh on the eastern slope of the Tuwayq mountains, the percentage of spring precipitation is more than double the percentage of winter, namely, 66%. At Al-Karj and As-Sulayyil the percentage of spring precipitation is very high where more than half of the annual precipitation occurs in spring, as is shown in Table 7(15).

TABLE 7(15)

Increase of spring rainfall toward the south of the interior of Saudi Arabia, 1966-1969

Station	Mean Annual Precipitation (mm)	Mean Spring Precipitation (mm)	% of Annual
Al-Karj	27.8	15.2	55.2
As-Sulayyil	39.5	29.2	74.0

The logical explanation for the increase in the percentage of spring precipitation in the interior of the country in a southern direction is that the Mediterranean depressions lose most of their moisture before reaching the southern section of the interior at a station such as As-Sulayyil. Furthermore, this area is often dominated during the spring season by the south-east monsoon and associated tropical disturbances. These conditions, combined with the remarkable convectional activities, cause spring precipitation to be an important component of the annual rainfall. Toward the south from As-Sulayyil there is no information concerning the Rub-al-Kali.

As has been found to exist in the north-western region of Saudi Arabia, the percentage of spring rainfall in the coastal plain and the hinterland of the Arabian Gulf is low. The highest percentage in this region is for winter precipitation. Winter in the eastern province of the country represents the main rainy season. As has been indicated previously, rainfall in this province is mostly cyclonic, which occurs usually during the winter months. However, convectional rain normally occurs in this area during the spring months. The percentage of the spring precipitation comes next to the percentage of winter precipitation in this province where summer is rainless and autumn is almost dry. Table 7(15) represents the percentage of spring precipitation in the province at selected stations.

TABLE 7(16)

Spring rainfall in the eastern province of Saudi Arabia 1966-1969

Station	Mean Annual Precipitation (mm)	Mean Spring Precipitation (mm)	% of Annual
Abqaiq	59.2	18.6	31.4
An-Anariyah	50.1	12.3	24.5
Al-Hafuf	59.2	12.8	21.6
Dhahran	53.3	19.0	35.6
Qatif	78.6	20.9	26.5
Ras-Tanura	56.5	18.4	32.6
Qaysumah	44.7	10.1	22.5

SUMMER PRECIPITATION

The summer season is one of monotonous weather conditions where there is not any major change for at least a period of six months over most of Saudi Arabia. During this season the skies are cloudless, the heat is intense, and about 96% of the surface area of the country is dry. With the onset of the summer heat, which in many places makes itself felt as early as late April, the inhabitants begin to shift their living from winter to summer conditions. During the winter months the inhabitants make their living in the south-facing rooms that benefit more from the warm rays of the sun. Stoves and other heating devices are set up and heavy clothes and coverings are used. As soon as the hot season shows its signs, a sudden change takes place in the common domestic life of the inhabitants. The government and some of the officials move to the highlands of southern Hejaz where they make the Taif area a summer resort. All heavy, dark coloured clothing and coverings of winter are packed away and, instead, light and white clothing is used. In the villages, where electricity is not normally used, the wind catchers, either in the walls or in the roofs of the dwellings, that let air enter the rooms and produce some ventilation, are characteristic of the Saudian architecture. They are opened in all living quarters to allow the mitigatory Shamal winds to enter every part of the dwellings. Bedding is transferred outdoors for use throughout the summer, for in most of Saudi Arabia, there is no risk even of a shower. All through the long summer season nobody spends a night indoors. On the high ground, such as the hills, however, an occasional shower of very short duration may break the monotony. A few stations in the Najd plateau and the eastern province may record in the summer months some occasional rainfall for which the whole season amounts to 2-4mm or thereabouts. The summer showers, outside the south-western region of the country, are mostly unexpected, though some stations in Tuwayq massif or Jabal Shammer may receive as much as 1.0% of their annual precipitation occasionally, as can be seen in Table 7(17).

TABLE 7(17)

Summer rainfall in Saudi Arabia outside Asir and southern Hejaz areas

Station and period of utilised data		Mean Annual Precipitation (mm)	Mean Summer Precipitation (mm)	% of Annual
Hail	1955-70	80.3	0.7	0.9
Riyadh	1952-71	100.6	0.8	0.8

It is obvious that summer precipitation is more likely in the southern part of the country but, unfortunately, the available data concern the south-western region only, while there is no information concerning the Rub-al-Kali. As long as the moisture-bearing winds, namely the south-west monsoon of summer, blow from the south, it is expected that summer showers will occur in the Rub-al-Kali, particularly in July or August when the monsoon winds are at their maximum flow. The available data concerning the Najd and the eastern province show that light showers may occur occasionally on the hills in these areas. In the Rub-al-Kali these showers of summer may occur on the relatively high ground, such as the hills surrounding this vast area of sand dunes (Stevens, 1970).

In the Asir and southern Hejaz mountains, however, different conditions prevail and as soon as one rises over these mountainous barriers one finds a totally different world. In contrast to the desolate and barren scenery and absolute dryness of summer in these regions all over most of the country, one finds on the high ranges of Asir and southern Hejaz luxurious forests, green fields all over the man-made terraces and, above all, frequent precipitation which is sometimes in the form of exceptional hail of large size. The summer precipitation of the south-western region is mostly orographic in nature. It is mostly due to the moist south-western monsoon winds that bring a considerable amount of moisture from the extensive water surfaces of the Indian Ocean and the Arabian Sea via the Red Sea. They produce copious precipitation when forced to rise up to 3200 metres altitude in short horizontal distances. Summer precipitation in Asir, particularly on the southern part, is regular and almost a matter of daily occurrence at some stations along the western slopes. Some stations in the Asir mountains receive as much as 30% and more of their annual precipitation during the summer months. In fact, the amount of precipitation that some stations in Asir receive during the summer months, June-August, is higher than the total at many other stations over the whole country, as can be noticed from Table 7(18).

TABLE 7(18)

Comparison of summer rainfall in Asir highlands and the annual rainfall in the desert areas

1966-69

Station	Mean Summer Rain at Selected Stations in Asir (mm)	Mean Annual Rain at Stations in other Areas (mm)
Abha	137.1	
Al-Aja'edah	104.4	
Jabal Salah	304.1	
Thurayban	209.4	
Abqaiq		59.2
Dhahran		53.3
Hail		156.1
Jeddah Airport		117.3
Riyadh		127.6
Ras-Tanura		56.5

Within Asir and southern Hejaz, the wettest section in the summer season is the western slopes of the escarpment and the high peaks, as well as the foothills to the west. Thurayban in the foothills receives 209.4mm (33% of its annual amount), or more than double the mean annual for the arid zones, in the three summer months. No information is available regarding the precipitation received on the steep slopes between the foothills and the highest ranges. Horub station - 519 metres - in the foothills area receives 292.3mm (33.8% of its annual precipitation). Between Horub and As-Sawdah - 2820 metres - on the highest ranges, there is no available data. However, the amount of precipitation received on the western slopes of the escarpment must be more than what the foothill stations record. Beyond the western slopes and the highest ranges, rainfall decreases as one descends down to the eastern slopes of Asir and southern Hejaz where the summer moist monsoon winds precipitate most of their moisture on these highlands and where the winds descend the eastern slopes they become heated and there is no good chance for rainfall to occur.

To the west of the foothills of the Asir and southern Hejaz mountains, the summer precipitation in the lowlying coastal plain of the Red Sea occurs almost every year as far north as Al-Lith - 20° 09' N. Sporadic, light showers may occur during the summer months to the north of Al-Lith as a result of invasions of random storms northward, though they are not as regular as in the coastal plain to the south of latitude 20°N. Table 7(19) shows the summer precipitation percentages from the annual rainfall in the highlands of Asir and southern Hejaz as well as the coastal plain of the Red Sea.

It can be seen from Table 7(19) that the summer precipitation represents low percentages from the annual rainfall in the low coastal strip where the percentage of the summer precipitation is only 13% at Jazan and 4% at Al-Lith. For short distances from the shores of the Red Sea the elevation increases from 4 metres at Jazan to 40 metres at Sabya and Suq-al-Jenub. At the latter stations the summer precipitation forms a high percentage from the annual precipitation where it ranges between

TABLE 7(19)

Summer rainfall in Asir and southern Hejaz highlands and the coastal plain of the Red Sea

Station and period of utilised data		Latitude (N)	Longitude (E)	Elevation (metres)	Mean Annual Precipitation (mm)	Mean Summer Precipitation (mm)	% of Annual
Abha)		18° 13'	42° 30'	2190	404.3	137.1	33.9
Al-Bariq)	1966-69	18° 56'	41° 58'	390	966.6	277.5	38.7
Al-Kam)		18° 16'	42° 29'	2200	451.6	181.2	40.0
Al-Lith)		20° 09'	40° 17'	6	97.5	4.0	4.0
Baljurshi	1967-69	19° 51'	41° 34'	2400	452.5	64.0	14.0
Bishah)		20° 00'	42° 36'	1040	125.2	12.9	10.3
Haddah-Ash-Sham)		21° 47'	39° 41'	288	132.0	9.0	7.0
Jabal Fayfa)		17° 16'	48° 05'	860	704.0	286.1	40.6
Jazan)		17° 03'	42° 57'	4	44.6	5.9	13.0
Kamis-Mushait)		18° 18'	42° 44'	1950	247.1	67.6	27.0
Liyyah)		21° 13'	40° 28'	1640	230.8	53.5	23.0
Madrakah)	1966-	21° 59'	39° 59'	980	189.5	9.1	5.0
Mecca)	69	21° 26'	39° 49'	280	204.8	7.7	3.7
Muzaylif)		19° 32'	41° 03'	58	154.1	14.6	9.4
Sabya)		18° 56'	41° 58'	40	111.9	46.1	41.0
Suq-Al-Jenub)		16° 43'	41° 37'	40	207.7	108.1	52.0
Taif (A.R.))		21° 59'	40° 31'	1390	135.9	16.2	11.9
Tathlith)		19° 32'	48° 31'	975	44.6	1.8	4.0
Thurayban)		19° 27'	41° 50'	575	627.5	209.4	33.0
Umm-Lajj)		- -	- -	-	78.4	2.3	3.0

41% and 53%. The influence of the topography on the moist summer monsoon is remarkable where the percentage of the summer precipitation is still high at the foothills of the Asir highlands. Jabal Fayfa and Thurayban are all situated in the foothills at a height ranging between 575 metres and 900 metres. The percentage of the summer precipitation at these stations ranges between 33% at Thurayban and 40.6% at Jabal Salah.

In the high ranges of the Asir highlands the percentage of the summer precipitation is high wherever a station is exposed to the south-west monsoon winds. At Al-Kam, which is situated to the north-west of Abha at a height of 2200 metres, the percentage of the summer precipitation is 40%, which is the highest seasonal percentage of these stations. As one descends the high ranges down to the eastern slopes of the Asir and southern Hejaz highlands, the percentage of the summer precipitation decreases considerably. The highest seasonal percentage in the eastern slopes of these highlands is normally in spring. The eastern slopes of these highlands are exposed directly to the moist south-east monsoon winds of spring which blow from the Arabian Sea. These winds, when blowing over the low-lying Rub-al-Kali, do not precipitate appreciable amounts of rainfall before reaching the Asir and southern Hejaz highlands. When these types of winds ascend these highlands they precipitate large amounts of rainfall which exceed, at the majority of the stations in the area, the precipitation of the other seasons. When these winds descend the western slopes of the escarpment, they precipitate small amounts of rainfall. Adverse situations occur in summer where the south-west monsoon winds blow via the Red Sea and recurve toward the country where a low pressure exists in summer. When these winds rise over the first relatively high ground, they precipitate the largest amounts of the annual precipitation in these exposed areas, such as the foothills and the western slopes of the escarpment. When these winds descend the eastern slopes of the Asir and southern Hejaz, they precipitate smaller amounts of rainfall. Consequently, the percentage of the summer precipitation decreases from the west to east, as can be deduced from Table 7(19). At Abha, Kamis-Mushait, Baljurshi and Taif on the eastern slopes of the highlands, the percentage of summer precipitation ranges between 34% at Abha and 11.9% at Taif. In the low ground of the Asir plateaux in the east, the percentage of the summer precipitation reaches its minimum value. At Tathlith in the low ground of the Asir plateaux, the percentage of the summer precipitation is 3% only. At Turabah - 21° 13'N, 41° 39'E - which is situated at an elevation of 1100 metres to the north-west of Tathlith, the percentage of the summer precipitation is only 1%. In addition to the decrease in the percentage of the summer precipitation from west to east, there is another decrease from the south-west to north-west. In the low ground (less than 10m) of the Red Sea coastal plain, the decrease can be seen from the difference in summer percentage of precipitation between Jazan and Al-Lith. The former station has 13% while the latter has only 5%. On the higher ground of the coastal plain of the Red Sea, the decrease in summer precipitation toward the north is even more marked, as can be seen from the difference in the summer percentage between Sabya (40m) and Muzaylif (58m). At the former, the percentage is 41%, while at the latter, the summer percentage is only 9.4%.

In the foothills area, the south-west, north-west decrease in summer precipitation can be seen from the difference in the percentage between Jabal Fayfa to the east of Sabya and Thurayban. At Jabal Fayfa the percentage of the summer precipitation is 40.6, while at Thurayban the percentage of summer rainfall is 33%. In the escarpment, the decrease of the summer precipitation is again toward the north-west; at Al-Kam in the south the percentage of the summer rain is 40%, but at Liyyah in Taif area in the north the percentage of the summer rain is only 23%. Similarly, the summer rain decreases in the eastern slopes towards the north-west where the percentage of the summer rain at Abha in the south is 34.2%, while at Taif Airport in the north, the percentage of summer rain is only 11.9%. Between Abha and Taif, Baljurshi in the Gamid area has a low percentage of summer rain, namely 14%. A glance at the topographic map of the area will show that this station lies in a rain shadow created by the high mountainous ridges to the south-west. Taif itself is influenced by a severe rain shadow created by the highlands of Jabal Dakak and Jabal Qarnayt which have an elevation of 2565 metres to the south. To the west and south-west is Harthi and Al-Wuhayt areas which have a height of about 2386 metres and are exposed to the maritime winds from the south-west and north-west or west, but which create a remarkable rain shadow in the Taif area which is the only area about which rainfall data are available. Abha is also situated in a rain shadow created by the high ridge to the south-west and west, but it is not as severe as that found in the Gamid or Taif areas.

AUTUMN PRECIPITATION

The Mediterranean depressions to which Saudi Arabia owes most of its precipitation during autumn are least active during September, but as soon as the shift in the general pattern of the atmospheric pressure over the Middle East begins during October, the depressions begin to make themselves felt over the country and by late October or early November some of them get sufficient strength to penetrate the interior of the country and may reach as far south as Jazan in the coastal plain of the Red Sea and As-Sulayyil in the interior. As time goes on their frequency becomes greater and they are able to influence most of the country. The Red Sea coastal plain and the western highlands, as well as the northern province of the country, drew more benefit from the autumnal cyclonic activities than the coastal plain of the Arabian Gulf and the southern portion of the Najd plateau and the Rub-al-Kali. During autumn, adverse situations to those which exist in spring occur. The percentage of the autumn precipitation decreases generally from north to south where rainfall in this season reaches its minimum percentage at As-Sulayyil in the southern part of Najd plateau and Abha in the southern section of the Asir mountains. The moisture bearing winds in autumn come from the Mediterranean Sea and, consequently, they precipitate most of their moisture on the northern regions rather than the southern part. Furthermore, while precipitation is higher on the eastern slopes of the Asir and southern Hejaz mountains in spring, it is higher on the western slopes of these mountains and in the coastal plain of the Red Sea in autumn where the moisture bearing winds in this season blow from the Mediterranean along the Red Sea trench in a southern direction. The autumn season is dry all over most of Saudi Arabia, but November is comparatively moist where large amounts of precipitation are normally received where the country at the beginning of this month is under the influence of the moist Shamal winds of the cool season which blow from the Mediterranean and the south-east monsoon winds which come from the Arabian Sea. In fact, the largest portion of the percentage of the autumn precipitation represents the November rainfall. The wettest regions of the country during this season are the western highlands and the coastal plain of the Red Sea, as can be seen from Table 7(20).

TABLE 7(20)

Autumn rainfall in the western highlands and the Red Sea coastal plain

Station and period of utilised data		Mean Annual Precipitation (mm)	Mean Autumn Precipitation(mm)	Mean November Precipitation(mm)	% of Annual
Abha	1966-69	404.3	49.3	41.5	12.0
Al-Ain	1965-69	212.1	61.4	44.3	29.0
Al-Bid'a	1966-69	12.9	6.2	5.9	48.0
Al-Lith	1966-69	79.5	53.6	47.8	67.0
Al-Muwaylih	1967-69	136.5	65.3	65.3	48.0
Al-Ula	1966-69	50.1	26.0	24.0	51.8
Al-Wajh	1966-69	31.5	10.7	10.7	33.9
Baljurshi	1967-69	452.5	166.0	133.0	35.7
Bishah	1966-69	125.2	25.5	25.5	20.4
Jazan	1966-69	44.6	20.1	1.7	45.0
Jeddah Airport	1966-69	117.3	25.3	21.6	21.5
Sabya	1966-69	111.9	50.9	17.1	45.0
Taif Airport	1966-69	135.9	89.0	51.3	50.7
Umm-Lajj	1966-69	71.0	33.8	29.1	47.6

The autumn precipitation represents a considerable percentage in the northern province of the country where the Mediterranean depressions normally begin to invade the province as early as October, but to the south, toward the Najd plateau, and to the south-east, toward the Arabian Gulf coastal plain, the percentage of autumn precipitation decreases rapidly where it is rarely that the Mediterranean depressions reach the Najd plateau and the coastal plain of the Arabian Gulf before November. Table 7(21) represents stations located in the northern province - Qurayyat - and in the Najd plateau - Unayzah in the north, and Riyadh, As-Sulayyil in the south. Toward the Arabian Gulf from the northern province in a south-eastern direction there are a number of stations located from the north-east to south-east, namely Rafha, Qaysumah and Dhahran.

TABLE 7(21)

Autumn rainfall in the northern, eastern and central provinces

Station and period of utilised data		Mean Annual Precipitation (mm)	Mean Autumn Precipitation (mm)	Mean November Precipitation (mm)	% of Annual
Qurayyat	1967-69	52.4	16.9	8.5	32.0
Unayzah	1966-1969	118.2	38.5	35.1	32.5
Riyadh	1966-1969	127.6	6.8	6.8	5.4
As-Sulayyil	1966-1969	39.5	2.8	2.8	7.3
Rafha	1966-1969	17.8	4.3	4.0	24.0
Qaysumah	1966-1969	44.7	6.8	4.8	15.0
Dhahran	1966-1969	53.3	6.4	6.4	12.0

From this table it can be deduced that the percentage of autumn precipitation decreases rapidly toward the south and the south-east where the rainfall of this season is almost all concentrated in November. Riyadh station, which has a record term of 20 years, shows a dry period of September and October. In fact, the months of September and October, over most of Saudi Arabia, is a continuity of the dry period which covers the summer season.

FORMS OF PRECIPITATION

Three forms of precipitation are generally recognised by climatologists : convectional, cyclonic and orographic. It is important to notice the characteristic features as well as the circumstances that produce each of these forms. Convectional rain is caused by the heating of the surface layer of the atmosphere which expands and is forced to rise. If the rising of such heated air continues to higher levels of the atmosphere, reaching an altitude where temperatures below the dew point of the rising air prevail, condensation takes place, which results in clouds and, consequently, rain. As a class, convectional rains are of local nature and may cover only a small portion of the land. They are of short duration but occasionally can be very violent, in the form of disastrous thunder-showers and cloudbursts.

Cyclonic rain is usually associated with the passage of atmospheric low pressure centres or barometric lows, of which a good deal has been said in another section of the present study. In low pressure storms, air from various directions, and, consequently, of various temperatures and density, tend to converge toward a centre.

As a result of convergence and consequent lifting, plus the under-running of warmer, lighter air masses, generally from lower latitudes, by colder and denser air from higher latitudes, large volumes of air are forced to ascend. However, the rising of air does not involve vertical lifting as in the case of convectional ascents. The warm air in cyclones often tends to rise obliquely and slowly along slightly inclined surfaces of colder and denser air prevailing below. Cooling is therefore less rapid and precipitation in cyclones is characterised by less violence and more steadiness and duration.

Orographic rains are caused by the interference of higher land and mountain barriers in the path of moisture bearing winds and the forcing up of the moist air upon encountering the land barrier. Orographic rains are likely to occur with considerable range of density and persistence, depending mainly on the strength and duration of the prevailing moisture bearing winds.

The above mentioned three divisions of rainfall forms are by no means sharply separated one from the other. In fact, they often merge into each other to such an extent that one can hardly venture to assign a certain proportion of the annual rainfall of a station to one or another form of precipitation. Nevertheless, some general remarks may be made regarding the approximate pre-dominance of each form in Saudi Arabia.

It can be said that most of the winter rain which is more widespread than that of the other seasons has its origin in the western depressions and is therefore cyclonic in nature. 52 out of 91 stations with rainfall records show a winter maximum. This indicates that most of the rain received in Saudi Arabia is cyclonic. In fact, if a line is drawn from Salwa in the coastal plain of the Arabian Gulf to Jeddah in the coastal plain of the Red Sea, it will be seen that the areas north of this line receive 40 to 60% of its annual precipitation during the winter months (December to February). Furthermore, stations with a spring or autumn maxima benefit a great deal from the winter cyclonic rains as they receive a considerable proportion of their annual rainfall during this season.

There is no record concerning the duration of the cyclonic rain in Saudi Arabia, but it can be said that, generally, the passage of a depression varies from 6 to 8 hours, though this varies considerably from year to year. During some years Saudi Arabia may come under the influence of a depression for two to three days, while during other years the passage may last only for 6 to 8 hours. The duration of rainfall varies from place to place. In general, the duration of the winter rain is longer than that of the other seasons. Western stations with heavier annual precipitation, and the coastal stations with more local effect as a result of the proximity to the water bodies, have longer lasting rains. In the interior, cyclonic rains are of short duration. At Riyadh, Unayzah and Hail, the average period of rainfall on any one rainy day hardly exceeds 4 hours, though the cyclonic rains of winter can be persistent, and soft drizzly rain may continue to fall for one to two days when there is a depression centering over the country.

Convectional rains occur mostly in spring when longer days and bright sunshine produce considerable heat over the earth surface and result in expansion and rising of the adjoining air layer. Convection is greater in the western highlands where solar radiation is more intense than the lower areas, and where there is great emissivity of the basalt flows of dark colour and the other kinds of

Pre-cambrian rocks. On the other hand, in the upper layers of air, colder temperatures still prevail, with the result that when moist air from near the surface rises due to heating and expansion, condensation can take place at comparatively low altitudes above the ground. Thundershowers and hail are typical convectional precipitation and are common to most of Saudi Arabia in spring and summer, particularly in the western highlands as well as Tuwayq mountains and Shammer Jabals.

Convectional rainfall is of short duration, but it can be exceptionally violent and disastrous on occasions. It occurs mainly in the afternoons or early in the evenings on the days when the morning temperatures rise to higher levels than the average and when there are incursions of relatively moist air from either the Mediterranean Sea or from the Arabian Sea. It sometimes changes to hailstorms which are more dangerous to the human and plant lives. The hailstorms are sometimes accompanied by thunderbolts which in many cases kill people and animals.

Topography is a major factor in the distribution of precipitation in Saudi Arabia, and its influence can be seen on all rainfall maps and should be emphasised in any climatic study of the country. Relief of the land becomes an important factor in the climate of any region when highlands or mountain ranges lie in the paths of moist winds. The parallel ridges of the western highlands, with a general NW-SE trend, are in the way of the moist winds which blow from the Arabian Sea as the south-east monsoon of the cool season or as the south-west monsoon of the summer months. They are also in the way of the moist Shamal winds which blow from the Mediterranean via the Red Sea during the cool season. In some cases these ridges form continuous walls over which the moist winds have to climb and thus lose a great deal of their moisture. There are sections where the ranges of the mountains are extending from east to west and their influence becomes more predominant. The fact which is very easily recognised from the annual rainfall map of the country is that the amount of precipitation decreases from the Asir and southern Hejaz highlands to the Najd plateau in the same way that the ground tends to become lower in elevation. In the Western highlands of Saudi Arabia, orographic precipitation can be hardly separated from either the cyclonic or the convectional rains. It can be said that the three types of rains occur in the area and the orography is here an intensifying element.

The best examples of the orographic rains in Saudi Arabia are to be seen along the southern shores of the Red Sea. Here the mighty ranges that rise almost abruptly from sea level to heights of over 3000 metres produce great barriers in the way of the south-easterly and south-westerly monsoon winds which blow from the Arabian Sea and the north-westerly winds which blow from the Mediterranean Sea. The winds that blow from these two seas pick up some more moisture from the Red Sea when blowing toward the country and, therefore, on their ascent over the slopes of the highlands, they produce considerable precipitation that ranges annually between 1000mm and 300mm.

Tuwayq escarpment, with a west face and a height ranging between 600 and 800 metres, has also orographic effects where rainfall increases on the highest peaks to a mean annual rainfall of 125mm.

ANNUAL RAINFALL REGIME

Studying rainfall regime is considered of significant importance since it shows the distribution of rainfall through the months of the year and the seasonal fluctuations of rainfall in any given area. In Saudi Arabia, rainfall is experienced at some stations throughout the year, while at others it is restricted to the cool season. Furthermore, the importance of the rainfall of any season differs from one area to another according to its location relative to the source of the moist air.

Rainfall normally occurs in the northern province in mid-autumn until late spring, namely, from October to early May. Peak rainfall occurs in late autumn and early winter, November until January; then there is a remarkable attenuation of rainfall in February followed by a significant peak in March and April. Thereafter, rainfall diminishes during late May, after which the rainless period begins, from early June until early October. Table 7(22) may serve in showing the distribution of rainfall during the year at selected stations in the northern province.

In the north-west region of Saudi Arabia rainfall occurs in late October until early May. The main rainy season is the period of November-February, after which rainfall deteriorates in the spring season. Summer is rainless, though light showers of moderate amounts may occur when a random storm associated with the northern extension of the south-west monsoon winds invades this region. The following table 7(23) shows the distribution of rainfall throughout the year at selected stations in the north-west region of the country.

TABLE 7(22)

Mean monthly rainfall in the northern province (mm)

Station and period of utilised data		J	F	M	A	M	J	J	A	S	O	N	D
Badana	1966-69	4.3	0.5	5.2	5.6	2.9	0	0	0	0	0.5	5.0	5.2
Qurayyat	1967-69	10.9	1.4	16.6	10.8	4.9	0	0	0	0	8.4	8.5	2.2
Skakah	1956-69	7.4	3.2	4.4	12.9	0.1	0	0	0	0	5.4	27.6	4.2

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TABLE 7(23)

Mean monthly rainfall in the north-west region of Saudi Arabia (mm)

Station and period of utilised data		J	F	M	A	M	J	J	A	S	O	N	D
Al-Wajh	1966-69	3.3	4.5	0.3	2.5	4.7	0	0	0	0	0	10.7	5.5
Sug-Sawayq	1967-69	10.2	4.5	1.5	13.4	0	0.1	0	0	0	4.7	29.1	7.5
Tabuk	1967-69	7.1	3.6	1.9	4.0	2.8	0	0	0	0	1.7	10.9	6.0
Umm-Lajj	1966-69	10.6	5.6	5.5	5.3	3.8	0.6	0.5	1.2	0	2.5	37.4	5.4

In the southern section of the coastal plain of the Red Sea to the south of Al-Lith - 20° 09'N - rainfall is expected to occur in any month of the year, though the available data show dry periods, especially in the cool season. Abu-Arish, which has a record period of 10 years, shows a moist period from the second half of July until late December. In early January rainfall decreases rapidly where a dry period lasts until the first half of July. Rainfall is probable to occur, but in small amounts. At Sabya, which has a record term of 5 years only, the main rainy season is almost as at Abu-Arish, from the second half of July until the end of November. The dry period extends from December until the first half of July. Suq-al-Jenub, the southern station in Saudi Arabia at the border of the country with Yemen, shows a moist period from early May until late November. During the period of December-April rainfall rarely occurs, except of light showers as a result of random storms.

In the northern part of the southern section of the Red Sea coastal plain rainfall is almost concentrating in the cool season. Summer is almost dry, with light showers in July or August when the monsoon of summer is at its maximum advance toward the north.

It has to be emphasised that the available data are of short term and at this stage it is difficult to distinguish which are the most important rains; is it the summer rain or the autumn rain? The autumnal rain is of great importance in the whole area of the coastal plain of the Red Sea where it is of large amount and widespread in nature. Summer rain decreases rapidly as one goes toward the north and may represent only light showers at Al-Lith during July or August. Beyond Al-Lith area the summer rain disappears, though moderate showers may occur during some years beyond this area. However, this appears to be rare. In general, winter rainfall increases rapidly as one goes toward the north, while summer rainfall increases as one goes toward the south. Autumn rain is important all over the area. Spring rain is of least importance as long as the ground is low where the available data show that orography as a main factor promotes the spring rain. Table 7(24) shows the rainfall regime in the southern section of the coastal plain of the Red Sea.

In the foothills of the Asir and southern Hejaz rainfall throughout the year is of considerable large amounts and there are some months in which mean rainfall is more than the mean annual rainfall of the arid zone. There are four main stations in the area located at moderate heights ranging between 390 metres and 900 metres. Two stations are located in the northern section of the area and the other two stations are situated in the southern part. At Thurayban and Al-Bariq, which are located in the northern section, there are two main rainy seasons. The first extends from April until November, and the second is in the period of January-February. During the former long rainy period mean monthly rainfall ranges between 65.4mm in April and 145.7mm in September at Al-Bariq station. The maximum peak of the April-November rainy season is during the period of August-October where mean monthly rainfall is always over 100mm. In December and March, rainfall reaches its minimum amount.

TABLE 7(24)

Mean monthly rainfall in the southern section of the Red Sea coastal plain (mm)

Station and period of utilised data		Latitude	J	F	M	A	M	J	J	A	S	O	N	D
Al-Lith	1966-69	20° 09'	4.4	2.8	0	14.7	0	0	4.0	0	0	6.1	47.5	0
Muzayhif	1966-69	19° 32'	40.4	12.5	0.6	12.0	0	0	10.6	4.0	0	9.9	52.8	11.3
Sabya	1966-69	17° 10'	9.6	1.4	0	0.8	1.3	0	42.2	3.9	20.0	13.8	17.1	1.7
Abu-Arish	1955-69	16° 58'	9.2	2.1	4.7	1.5	12.3	1.6	50.3	62.8	23.0	10.0	11.8	24.3
Sug-al-Jenub	1966-69	16° 43'	0	15.0	0	11.0	25.5	15.0	67.7	12.5	17.5	18.0	25.5	0

In the southern section of the foothills there is a main rainy season extending from April until August. Rainfall during this period is constantly of high amounts, but in June there is a remarkably sharp decrease in rainfall. The explanation for this decrease is that this month represents the retreats of the moist south-east monsoon of spring which is replaced by the moist south-west monsoon in July and August. At the beginning of September rainfall decreases considerably and there is no constant remarkable increase before the beginning of April, after which falls of large amounts carry the mean monthly rainfall in this area to those found in the humid climate areas. Table 7(25) shows the rainfall regime at selected stations in the foothills of the Asir and southern Hejaz mountains.

It can be seen from Table 7(25) that the spring, summer and autumn rainfall is of large amounts at Al-Bariq, since this station benefits from three types of moist air masses; the south-east monsoon winds of the spring months, the south-west monsoon winds which prevail in the summer season, and the north-west winds which dominate the area as early as autumn. At Jabal-Salah, which is located further south, winter and autumn are comparatively dry where this station does not benefit from large amounts from the moist northerly winds. This type of winds does not usually penetrate far to the southern section of the coastal plain of the Red Sea.

The rainfall regime which exists in the foothills is found to dominate the escarpment. As one goes to the south, the winter and autumn rainfall decreases, while the spring and summer rainfall increases, and vice versa. Table 7(26) may serve for showing this type of rainfall regime.

TABLE 7(25)

Mean monthly rainfall in the foothills of Asir and the southern Hejaz highlands (mm)

Station and period of utilised data		Elevation	Latitude	J	F	M	A	M	J	J	A	S	O	N	D
Al-Bariq	1966-69	390	18° 56'	48.1	64.8	25.7	65.4	124.1	47.9	86.7	112.9	145.7	138.8	82.0	35.5
Jabal-Salah *	1955-70	900	17° 03'	32.6	10.6	7.8	28.3	34.2	23.3	100.6	120.4	47.2	43.0	46.8	68.1

* data are doubtful in 1968 and not reported

TABLE 7(26)

Mean monthly rainfall in Asir and southern Hejaz highlands (mm)

Station and period of utilised data		Elevation	Latitude	J	F	M	A	M	J	J	A	S	O	N	D
Az-Zafir	1957-69	2530	19° 58'	84.6	48.6	19.8	60.0	38.7	9.2	17.0	23.9	7.3	16.1	110.8	55.2
Al-Kam	1965-69	2200	18° 16'	12.9	41.6	18.8	65.6	62.7	24.0	80.2	77.0	15.5	4.4	48.9	0
Farain	1966-69	2100	21° 22'	61.4	25.0	9.4	53.9	24.2	14.1	1.2	39.9	14.8	57.6	53.9	3.5

In the northern part of Asir and the southern section of the Hejaz mountains there are two rainy periods. The first is the main one, from November until February; the second is the minor one in April. Between the two rainy seasons the area appears to be dry. In the southern part of the Asir highlands where there is a displacement of the south-east monsoon winds of spring and the south-west monsoon winds of summer, the moist rainy seasons are in March-April and in July-August, May-June and September-October are dry periods.

As one goes southward in the Asir highlands one finds a different rainfall regime. In the southern part of the Asir highlands autumn is almost dry and during the period of September-October rarely do the moist north-west winds penetrate in this part and give rain at stations such as Abha or Kamis-Mushait. In the northern part of the Asir highlands and the southern Hejaz mountains there is a main rainy season extending from October until February. The period of March-September is of least rainfall and can be considered as a dry season. Table 7(27) on the following page shows the rainfall regime at selected stations in the area.

In the interior of the country rainfall occurs during the period of October-May, but rainfall rarely occurs during October to the south of Shaqra - 25^{o} 15'N. In fact, the importance of autumn rainfall decreases from north to south. In the interior of the country the autumnal rain does not occur in October at stations located to the south of latitude 25^{o}N. Riyadh station, which has a record term of 20 years, does not show autumnal rain before November. At all stations to the south of latitude 25^{o}N rainfall is restricted to the period of November-May, as can be seen from Table 7(28) on the following page.

TABLE 7(27)

Mean monthly rainfall in Asir highlands (mm)

Station and period of utilised data		Elevation	Latitude	J	F	M	A	M	J	J	A	S	O	N	D
Abha *	1953-70	2190	18° 13'	43.1	20.4	43.4	77.4	32.3	13.5	50.9	46.6	2.0	2.5	39.4	15.4
Baljurshi **	1960-70	2400	19° 51'	52.7	36.7	13.6	45.7	22.9	6.7	15.4	17.6	6.6	19.6	76.9	31.9
Kamis-Mushait	1966-70	1950	18° 18'	9.0	36,6	34.9	32.7	30.2	8.3	34.1	25.2	10.4	0.1	24.1	1.5

* data are not available for 1961

** data for 1966 are broken in summer

TABLE 7(28)

Mean monthly rainfall in the central province of Saudi Arabia (mm)

Station and period of utilised data		Latitude	J	F	M	A	M	J	J	A	S	O	N	D
Unayzah	1965-69	26° 04'	27.5	9.6	22.2	9.9	12.2	0	0	0	0	2.0	21.4	6.3
Shaqra	1966-69	25° 15'	28.5	14.6	19.3	13.7	6.1	0	0	0	0	1.3	11.5	1.5
Riyadh	1952-70	24° 42'	23.5	11.3	11.7	20.4	11.4	0.7	0.1	0	0	0	10.2	11.3
Al-Haddar	1965-69	21° 59'	17.2	10.9	5.5	19.6	11.0	0	0	0	0	0	12.5	5.0
As-Sulayyil	1965-70	20° 28'	2.0	3.7	4.5	13.0	2.7	0	0	0	0	0	54.1	2.0

It can be noticed from this table that the main rainy season is from November until May. During this period there are three rainfall peaks. The first is in November, the second is in January, and the third is mainly in April. Summer is almost rainless, though light showers may be recorded at stations such as Riyadh, but this summer rain is of low effect due to the intense heat.

In the coastal plain of the Arabian Gulf, rainfall is restricted to the period of November-May. During the rainy period there are two rainfall peaks. The first is the main one, from December to February, and the second one is the minor one, in April. The following table shows the rainfall regime at selected stations in the coastal plain of the Arabian Gulf.

NUMBER OF RAINY DAYS

The relation of the total rainfall to the number of days with rain is a climatic factor of some importance, indicative of the type of rainfall and the general impression of dampness or dryness given by climate. The term "rainy day" in climatic studies is generally regarded as a day on which an appreciable amount of rain (about 0.25mm) falls.

As far as Saudi Arabia is concerned, information about the number of rainy days is very scanty and almost non-existent for a great number of stations. In fact, out of about 200 stations in the country, only 14 stations have records for the number of days on which appreciable rain has been received. It can be said with certainty that the number of rainy days is very small in Saudi Arabia, especially in the arid zone, i.e. out of the Asir and southern Hejaz highlands.

TABLE 7(29)

Mean monthly rainfall in the Arabian Gulf coastal plain (mm)

Station and period of utilised data		J	F	M	Ä	M	J	J	A	S	O	N	D
Abqaiq	1964-69	8.4	12.6	4.6	11.3	2.7	0	0	0	0	0	5.6	14.0
Al-Hafuf	1964-69	9.4	16.2	4.0	7.2	1.6	0	0	0	0	0	3.2	17.6
Ras-Tanura	1964-69	13.3	14.3	2.6	12.8	5.6	0	0	0	0	0	1.7	7.9
Qatif	1967-69	19.3	22.0	3.9	16.6	0.5	0	0	0	0	0	16.0	0.4

When the number of rainy days and the amount of rain received in the year is considered, two facts about the climate of this country can be recognised: the first is the dryness which dominates a major part of Saudi Arabia, and the second is the nature of the fall of rain which is normally of extravagant intensity. In the Asir and southern Hejaz area, where there is rain every month of the year, this number is, no doubt, far greater than in the other regions. It is therefore true to say that the number of rainy days decreases from the high ranges of these highlands to the surrounding low areas. Topography and the location relative to the water bodies are two important factors in the number of rainy days. As far as the two factors are available in a given area, the number of rainy days is relatively higher. Consequently, the number of rainy days at stations such as Jabal Salah and Thurayban in the foothills of the Asir highlands is probably of large number since these stations are of high grounds and located very close to the Red Sea. Jazan, on the other hand, is located in the coastal strip of the Red Sea, but situated at a height of 4 metres only. Hence the number of rainy days is very small. Even a moderate height may have a remarkable effect when a station is located close to a water body. Dhahran station, which is located in the coastal plain of the Arabian Gulf at a height of 23 metres, shows a larger number of rainy days than Riyadh, which is located in the interior at a height of 609 metres. Therefore it is probably true to say that the number of rainy days decreases from the coastal plain of the Arabian Gulf to the interior of the country.

In general, the number of rainy days outside the highlands of the Asir and southern Hejaz is of very small number.

It may range between 5 and 20 days outside the high areas. The following table represents the number of days on which appreciable falls of rain of 0.25mm and more were recorded.

TABLE 7(30)

Number of rainy days at stations outside Asir highlands

Station and period of utilised data		Number of Rainy Days	Years of Observation	Mean Annual Rainy Days
Al-Wajh	(1966-70)	22	5	4.4
As-Sulayyil	(1965-70)	30	6	5.0
Badana	(1961-64)	36	4	9.0
Dhahran	(1961-70)	222	10	22.2
Jazan	(1965-70)	45	6	7.5
Jeddah	(1961-70)	85	10	8.5
Madenah	(1961-70)	69	10	6.9
Qaysumah	(1961-64)	61	4	15.2
Riyadh	(1961-70)	191	10	19.1

As has been already indicated, the number of rainy days in a major part of Saudi Arabia is very small. When this table is converted in a percentage table of the rainy periods to the period of observation, the figures deduced will indicate an extreme aridity.

The available data for the number of rainy days in the Asir and southern Hejaz highlands are very scanty and are not indicative of the rainy period in the whole area. The data of the number of rainy days are available for Abha and Baljurshi which are almost dry, and for Taif which is located within the arid zone in the Hejaz mountains. It is possible that the number of rainy days in the high ridges and the western slopes, as well as the foothills of the escarpment, is more than 150. The following table shows the number of rainy days in the Asir and southern Hejaz highlands.

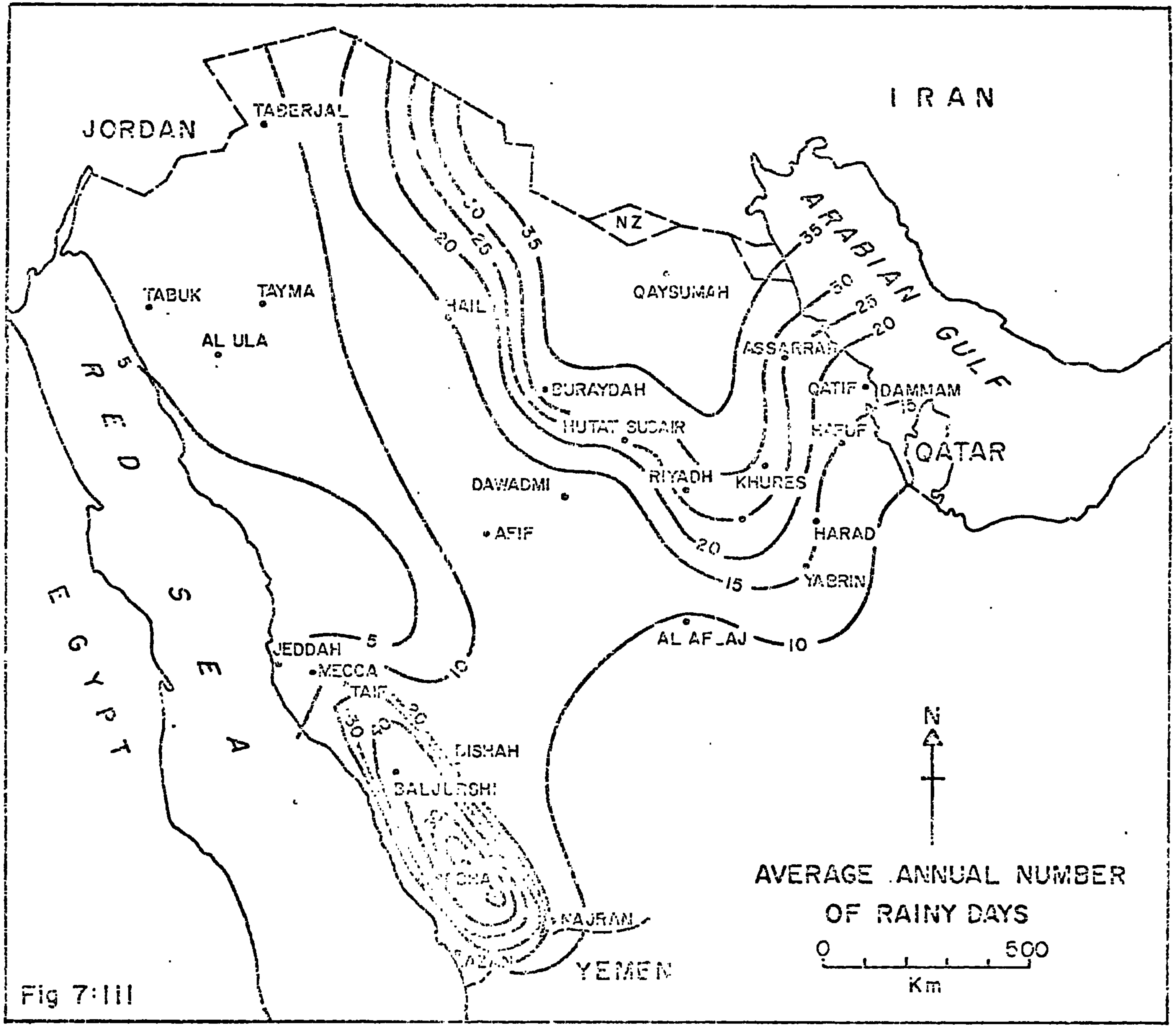
TABLE 7(31)

Number of rainy days in Asir and southern Hejaz highlands

Station and period of utilised data		Number of Rainy Days	Years of Observation	Mean Annual Rainy Days
Abha	(1966-70)	328	5	65.6
Baljurshi*	(1966-70)	226	5	45.2
Taif	(1961-70)	257	10	25.7

* data is broken in summer 1966

Figure 7(III) shows the distribution of the number of rainy days in Saudi Arabia. It can be noticed that the number of rainy days reaches its maximum in the Asir and southern Hejaz mountains where this area represents the wettest region in the country.

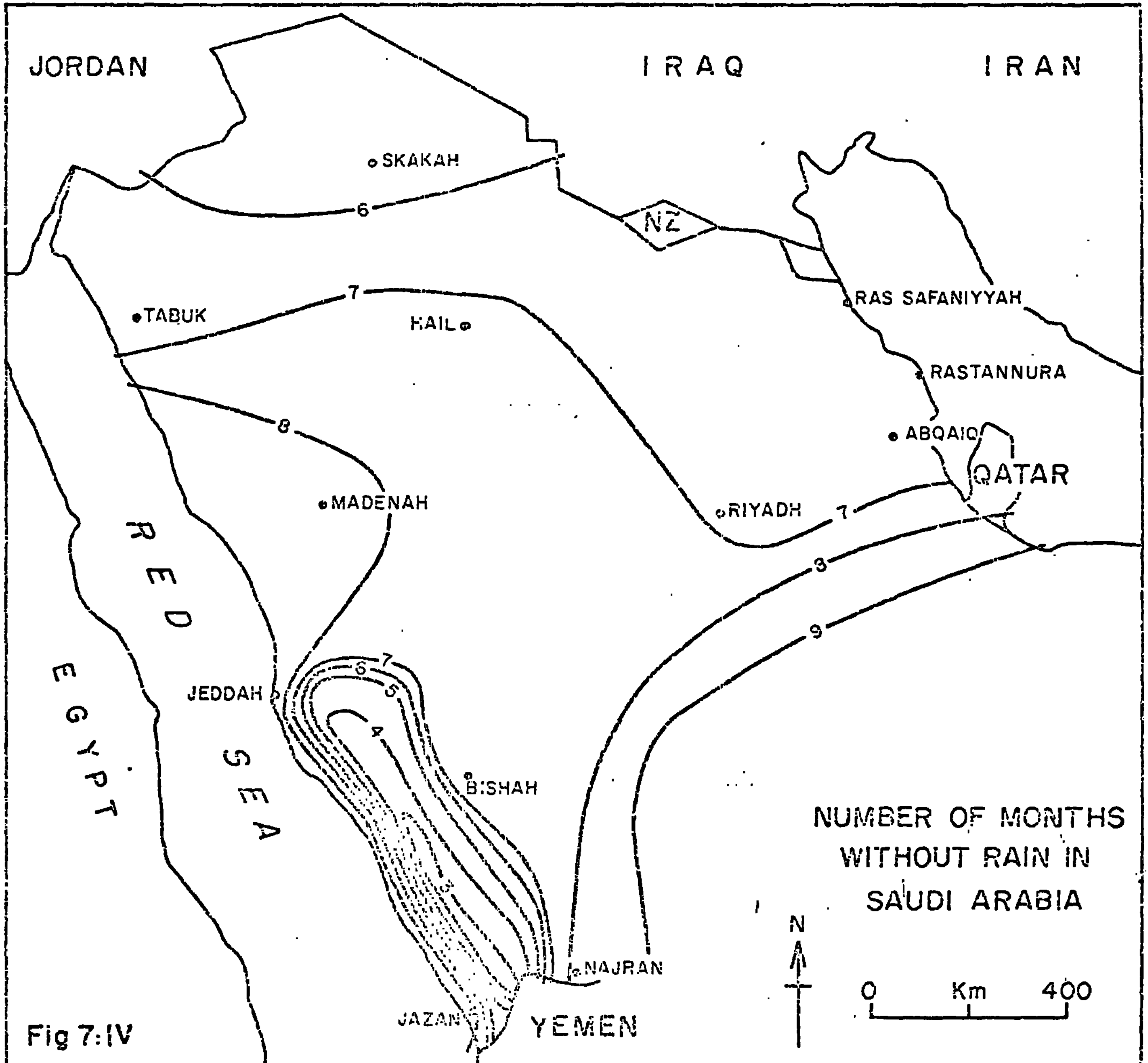


source: Ministry Of Agriculture and Water

From this region the number of rainy days decreases in every direction as a result of the decrease in elevation. Next to the highlands of Asir and southern Hejaz is the eastern half of the country where the number of days with rain ranges between 35 and 10 days. In this area there is a remarkable decrease from the north to south since the length of the rainy season decreases in this direction, as has been discussed previously. From the table it can be seen also that there is a vast area of a small number of rainy days extending from As-Sulayyil in the south to the north and north-west regions of Saudi Arabia. In fact, this area represents the trough of least rainfall which has been discussed in another section of the present study. Indeed, this vast area represents the poorish area with population, vegetation and underground water. To the south of As-Sulayyil there are no available data, but it is expected that the number of days on which rainfall occurs decreases toward the Rub-al-Kali where the winter and summer precipitation decreases toward this area.

NUMBER OF RAINLESS MONTHS

The extreme aridity which dominates most of Saudi Arabia becomes quite apparent when one considers the number of months without rain. The accompanying map (Figure 7(IV)) is an attempt to show the number of rainless months in the country. The data on which the construction of this map is made are of short record term, thus when longer periods of observation are available, different patterns may be introduced. It can be said that roughly about 97% of the surface area of the country receive no precipitation of any form during at least half of the year.



JORDAN
IRAQ
IRAN
SKAKAH
NZ
RAS SAFANIYYAH
TABUK
HAIL
RASTANNURA
ABQAIQ
QATAR
MADENAH
RIYADH
RED SEA
EGYPT
JEDDAH
BISHAH
NUMBER OF MONTHS WITHOUT RAIN IN SAUDI ARABIA
N
0 Km 400
NAJRAN
JAZAN
YEMEN
Fig 7:IV

In the Asir and southern Hejaz highlands, which form about 3% of the surface of the country, the rain is often expected to occur every month of the year, although there are times that rains may fail, even in this part of Saudi Arabia which is dominated almost throughout the year by moist air masses. The prevalent moist air masses, coupled with remarkable effects of relief, get the dry period of a small number of months. In these highlands the probability of rainlessness varies generally between two months and four. The western slopes of Asir, especially in its northern section, may be regarded as without rain for two months every year. In the rest of the area of the highlands the number of rainless months ranges between three and four.

In the southern section of the Asir highlands rainfall probably fails during the months of winter. During the months of autumn the moist bearing winds which come from the north-west do not normally reach the eastern slopes of the southern section of the Asir and, thus, the rain fails at stations such as Abha and Kamis-Mushait during these months. In the northern section of the Asir the rains normally do not fail throughout the year, as can be seen at stations such as Bal jurshi. The following table shows the number of rainless months in the area of the Asir and southern Hejaz highlands.

The number of months without rain increases rapidly as one descends the highlands of Asir and southern Hejaz toward the interior of the country and the coastal plain of the Red Sea. In the rest of Saudi Arabia the number of rainless months increases from north to south. In the desert regions of the country the rain may fail for six months in the northern province and nine in the southern part.

TABLE 7(32)

Number of rainless months in Asir and southern Hejaz highlands

Station and period of utilised data		Years of Observation	J	F	M	A	M	J	J	A	S	O	N	D
Abha *	1955-70	15	5	4	3	1	3	6	0	1	11	11	8	7
Baljurshi **	1960-71	11	3	4	2	0	1	3	1	2	3	1	0	2
Jabal-Salah ***	1957-70	14	6	7	6	3	2	4	1	0	2	4	5	5
Kamis-Mushait	1965-70	5	1	2	1	1	0	2	0	1	2	3	2	3
Taif	1960-70	11	4	7	3	0	0	4	6	1	3	5	0	5

* data for 1961 are not available

** data are broken in summer 1966

*** data for 1968 are not available

In the coastal plain of the Red Sea and the Arabian Gulf the number of rainless months ranges between seven and eight months.

The summer months are usually rainless in the desert zone of the country as a whole. The probability of rainlessness of the autumn months is found in the southern section where the moist bearing winds of autumn rarely reach stations such as As-Sulayyil and Tathlith. The following table represents the number of rainless months in the desert area of the country at selected stations.

From this table it can be deduced that the rain rarely fails in December and January during the winter season, and in spring - March and April - at stations of relatively long periods such as Riyadh in the interior of the country. In the coastal plain of the Arabian Gulf the rain rarely fails from December until April, as can be seen from comparatively long periods of record at stations such as Abqaiq, Dhahran and Ras-Tanura. In the coastal plain of the Red Sea there is only one station with a long period of record. Jeddah, with 20 years of observation, shows only one or two months, normally November and December, during which rainfall normally does not fail. In the southern section of the coastal plain of the Red Sea there is no record of long period. However, it can be said that the rain normally does not fail in the months of July to November. Indeed, it is during this period that the dry cultivation season starts in Jazan and Sabya plain.

TABLE 7(33)

Number of rainless months in the desert areas of Saudi Arabia

Station and period of utilised data		Period of Observation	J	F	M	A	M	J	J	A	S	O	N	D
Abqaiq	(1953-68)	16	6	4	3	7	11	16	16	16	16	15	7	8
Dhahran	(1951-68)	18	4	5	2	4	12	18	18	18	18	18	9	5
Hail	(1955-70)	16	7	8	12	8	10	15	16	16	16	13	8	7
Jazan	(1964-70)	7	5	3	5	6	6	5	2	3	3	4	3	5
Jeddah	(1952-70)	19	8	12	12	15	15	18	16	18	18	20	6	4
Ras-Tanura	(1950-68)	19	3	5	3	6	11	19	19	19	19	17	8	2
Riyadh	(1952-71)	20	5	9	4	3	9	20	19	19	20	20	10	6
Sabya	(1965-71)	7	4	3	5	4	4	7	3	3	3	1	1	4
As-Sulayyil	(1965-70)	6	3	2	2	2	5	6	6	6	6	6	4	6
Tabuk	(1964-70)	7	3	1	3	2	2	6	6	6	6	2	0	6

VARIABILITY AND DISPERSION OF RAINFALL

An important feature in studies of rainfall is the fluctuation in the amount of rainfall, both annually and monthly. An assured annual or seasonal precipitation means steady economic progress, whereas an uncertain rainfall implies the permanent risk of drought and crop failure with accompanying famines and diseases.

Variability in the total amount of annual or monthly rainfall is common to most climates and therefore occurs in the tropical rainy areas, but it is a major characteristic feature of the semi and arid climates. One expects to find great variations in the precipitation of an arid country like Saudi Arabia, in which the total annual and monthly rainfall is extremely variable. At one station in the arid areas of the country the total rainfall, either annual or monthly, may range between nil and more than 100mm.

The effects of the variability of rainfall are very serious in agriculture and in the pastoral areas where the lives of these communities depend directly on rainfall. A year of adequate rainfall may result in a relatively large production for the agricultural communities and a good pasture for the tribal populations that lead a pastoral way of life in the vast desert areas. A deficit in rainfall, on the other hand, results in crop failure, famine and diseases for the majority of the population and may be the cause of death for some of the people and the animals.

Analyses of rainfall variability or reliability can be worked out when long periods of unbroken data are available and hence one cannot, at present, study the fluctuation of rainfall in detail at stations in the various parts of the country, since the duration of rainfall records at the majority of the stations is too short to enable one to study this important aspect of precipitation. The period of climatic observations in the area under study is far too short to enable one to form a definite idea or make conclusive statements about the features of the variability of rainfall in the various parts of Saudi Arabia, but short as this period may be, it affords striking examples of extreme monthly and annual dryness and heavy rainfall.

The available data concerning rainfall do not go far enough back in the past to show the permanent fluctuations of rainfall, but when one studies the social historical books which were written by authors from Najd area one can find many significant statements which refer to extremes of dryness and tremendously heavy showers. An-Nus (1971) has mentioned that authors from Najd area, such as Bin-Bisher and Bin-Grannam, were interested in writing about the effects of dry years and wet periods on the social life in some parts of Saudi Arabia during the eighteenth and the nineteenth centuries. During the dry years some of the local population of Najd moved to Al-Hasa in the eastern province of the country, and to Az-Zabir, Al-Basrah in Iraq, and to Kuwait, while others died as a result of famine. In reverse to these statements about the effects of the dry years, they also wrote about the effects of the humid years. Bin-Bisher, for example, mentioned that during the winter of 1192 Hejri (1849 A.D.), heavy rainfall swept away some of the dwellings of Unayzah and some of the population had died, while others were left homeless and lived in tents. An-Nus has mentioned that these authors wrote about every dry and humid year over a space of 243 years. When the number of dry years was calculated, An-Nus (1971) found that there were 35 years during which the rain was probably below the average, between 1047 and 1290 Hejri (1704 - 1947 A.D.). Consequently it can be deduced that the dryness recurs about every seven years. Between one period of dryness and another there is a relatively humid period, probably lasting for between seven and nine years. The dry period usually lasted for two to four years, but Bin-Bisher mentioned a dry period that lasted for nine years in Najd. Furthermore, anatomical analyses of a trunk of a 100-years old Juniperus procera from the highlands of Hejaz has shown that the dry cycle tends to recur every seven to nine years (An-Nus, 1971).

In the present study an attempt has been made to work out the dispersion and the variability of rainfall at stations that had a longer period of unbroken records. Mean deviation of rainfall was calculated according to formula :

$$\text{Mean deviation} = \frac{\sum |x - \bar{x}|}{n}$$

However, the available data concerning rainfall are too short to give an accurate standard deviation and consequently relative variability of rainfall was calculated using the following formula :

$$\text{Relative variability} = \frac{\text{Mean deviation}}{\text{mean rainfall}} \times 100\%$$

In this section of the present study Jeddah, Dhahran and Riyadh stations were selected as they have the longest period of uninterrupted records. In Asir there is not a single station with unbroken rainfall data. However, an attempt was made to work out rainfall dispersion and relative variability at Jabal-Fayfa from 1960 to 1972 in this area as rainfall records over this period at this station are complete. Tables 7(34), 7(35), 7(36) and 7(37) show rainfall deviation and relative varibaility (%) at these stations.

The rainy period outside Asir and southern Hejaz highlands is confined almost entirely to the months from November to May. The period June-October is rainless, although a few mm may be recorded on one or two days during the summer months. Consequently, relative rainfall variability was studied outside the Asir and southern Hejaz highlands during the rainy period, November-May. When rainfall variations from the mean and relative variability were studied, it was found that none of the selected stations shows a reliable rainfall. For the desert stations, such as Jeddah and Riyadh, the relative variability for each month of the rainy season is very high and exceeds 100% in most months of the rainy period. During the period of utilised data (1952-1968) rainfall deviations from the mean can range for each month from between 100% below the mean to over 150% above the mean monthly rainfall. In other words, monthly rainfall totals can range for each month during this period from between zero to a value several times that of the mean rainfall for that month. However, during this period, Jeddah shows extremely variable rainfall from February until May, while relative variability is slightly lower during the period November-January. At Dhahran, the most reliable rainfall is during the period January-April and also in November; the months of May and December show the highest relative rainfall variability. In the interior of the country, Riyadh shows the most reliable rainfall in three months, namely, April, May and November.

TABLE 7(34)

Monthly rainfall variations from the mean (mm) and relative variability (%) at Jeddah Airport (1952-68)

	J	F	M	A	M	N	D
1952	-3.1	-2.5	+52.6	- 7.0	-1.7	-15.2	+3.7
1953	-4.1	-2.5	- 5.4	- 7.0	-1.7	+136.8	-17.3
1954	-4.1	-2.5	- 5.4	- 7.0	-1.7	-22.2	-17.3
1955	+3.9	-1.5	- 5.4	- 7.0	+1.3	-21.2	+66.7
1956	-4.1	-1.5	- 5.4	- 7.0	-1.7	-22.2	-17.3
1957	-4.1	-2.5	- 5.4	- 7.0	-1.7	-22.2	-17.3
1958	-0.1	-2.5	- 5.4	- 7.0	-1.7	+0.2	-12.3
1959	-0.1	-2.5	- 5.4	- 7.0	-1.7	+8.8	16.3
1960	+0.4	-2.5	- 4.1	- 7.0	-1.3	-13.2	+6.7
1961	-2.8	-2.5	- 5.4	- 7.0	-1.7	-22.2	+12.7
1962	+0.9	-2.5	- 5.4	- 7.0	-1.7	-12.2	+37.7
1963	-4.1	-2.0	- 5.4	+18.0	+18.3	-22.2	-11.3
1964	-4.1	+5.5	- 5.4	- 7.0	-1.7	-22.2	+0.7
1965	+3.9	-2.5	- 4.9	- 6.0	-1.7	+16.8	-17.3
1966	+29.9	-2.5	- 5.4	- 7.0	-1.7	+6.8	-17.3
1967	-4.1	+31.3	+27.0	- 7.0	-1.7	+10.8	-16.3
1968	- 4.1	- 2.5	- 5.4	+86.0	-1.3	+15.8	+22.7
Relative variability (%)	111.8	170.1	173.8	186.5	146.4	103.5	102.3
Mean rain (mm)	4.1	2.5	5.4	7.0	1.7	22.2	17.3

\+ rainfall above mean

\- rainfall below mean

TABLE 7(35)

Monthly rainfall variations from the mean (mm) and relative variability (%) at Dhahran (ARamco) (1952-68)

	J	F	M	A	M	N	D
1952	-15.3	-12.1	-5.8	+12.4	-1.0	-6.4	-10.3
1953	-18.8	-12.6	+8.6	-7.2	-3.1	-5.9	+83.2
1954	-21.4	+53.2	+0.3	-7.2	-3.1	+11.6	-7.5
1955	+12.4	-12.1	+4.1	-7.2	-1.3	-6.4	+45.1
1956	-6.4	-11.6	-5.6	-5.9	-3.1	-6.4	-10.3
1957	+6.6	+16.4	-5.3	-0.6	+14.2	+2.7	+5.9
1958	+36.5	-1.1	-1.5	-7.2	-3.1	-5.4	-13.4
1959	+87.3	-12.1	+1.3	-1.6	-0.2	+0.8	-15.9
1960	-20.6	-12.1	+1.1	-6.6	-3.1	-6.4	-15.4
1961	-13.3	+8.7	+5.3	+12.1	-3.1	+30.2	-10.6
1962	-21.9	-12.1	-6.3	+13.1	-3.1	+1.1	-15.9
1963	-21.9	-11.8	-6.6	+17.1	+21.1	+5.6	-13.9
1964	+4.3	+29.1	-6.6	-6.9	-3.1	-6.4	+37.2
1965	-13.5	-11.3	-6.3	-5.7	-3.1	-6.4	-15.9
1966	-21.6	+3.4	-6.3	+7.8	-3.1	-6.4	-15.9
1967	-20.4	-5.5	-0.8	+5.0	-0.8	+0.3	-15.9
1968	+47.4	-7.0	-4.8	-7.2	-3.1	+6.8	-11.1
Relative variability (%)	104.5	107.4	62.6	97.2	138.7	105.9	127.0
Mean rain (mm)	21.9	12.1	6.6	7.2	3.1	6.4	15.9

+ rainfall above mean

− rainfall below mean

TABLE 7(36)

Monthly rainfall variations from the mean (mm) and relative variability (%) at Riyadh Airport (1952-68)

	J	F	M	A	M	N	D
1952	-13.5	-13.7	-14.7	+1.2	-17.3	-11.1	-17.1
1953	-13.3	+120.3	+24.9	-11.2	-15.8	-11.1	-28.2
1954	-13.5	+4.1	-7.0	-12.2	-15.2	-11.1	- 1.1
1955	+33.9	-13.7	+27.4	-17.2	+26.6	-11.1	+17.3
1956	-1.6	-13.7	-3.4	-17.2	-17.5	-11.1	-8.2
1957	+8.0	+2.2	-5.9	+26.9	+19.8	+5.6	-8.1
1958	+43.7	-0.8	-14.7	-17.7	-17.5	+3.0	-7.3
1959	+11.3	-13.7	-12.2	-0.3	-17.5	+13.5	-11.1
1960	-10.4	-13.7	-7.1	-6.4	-5.8	-11.1	+2.9
1961	-10.2	-3.4	+14.3	-13.8	-15.1	+3.4	-13.1
1962	-12.5	-13.7	-8.7	+7.1	-17.5	+32.9	-13.1
1963	-13.5	-13.7	-14.7	-2.2	-3.5	+17.4	-13.1
1964	+38.6	+2.3	-7.6	-17.2	-16.5	-11.1	+56.9
1965	-7.5	-11.7	-14.7	+30.8	-17.5	+17.9	-11.1
1966	-12.5	-6.7	-14.7	-10.7	-17.5	-11.1	-11.0
1967	-13.5	-10.1	+69.8	+27.1	+51.5	-4.9	-11.1
1968	-13.5	-0.3	-12.2	+33.4	-11.6	-5.2	-8.1
Relative variability (%)	117.3	110.7	109.6	86.0	102.1	99.1	107.0
Mean rain (mm)	13.5	13.7	14.7	17.2	17.5	11.1	13.1

\+ rainfall above mean

\- rainfall below mean

When the relative variability of the rainy season at the three stations is compared, it is found that Jeddah is the station that shows the greatest monthly relative variability in rainfall and the longest period of most unreliable precipitation. This appears to be attributed to the location of this station on the northern extremity of the influences of the Red Sea Convergence Zone and on the southern margin of the effects of the Mediterranean depressions. The Red Sea Convergence Zone and the associated disturbances may extend northward and give occasional and exceptional heavy rainfall on few days during some years. The Mediterranean depressions may also travel southward and give a relatively heavy rainfall at this station on occasion. However, the occurrences on which large amounts of rainfall were received at this station were separated from each other by many rainless months during the period of utilised data. Dhahran and Riyadh stations show an overall lower monthly relative variability during most of the rainy period. The presence of the Arabian Gulf, that attracts the moist air of the cool season, either from the Mediterranean or from the Arabian Sea, may cause lower rainfall variability at Dhahran. It is also important to realise that Dhahran may come under the influence of a front that sometimes develops over the Arabian Gulf during the cool season, as has been discussed earlier in this study. Riyadh, on the other hand, is located at a height of more than 600 metres and, thus, shows more reliable rainfall during the months of April, May and November, when the convectional activity is at maximum within the relatively moist air. Convectional rainfall tends to be of greater frequency on the higher areas than on the low regions, though mostly of local nature.

In the Asir highlands there are a great number of stations but the majority have only short periods of record (3-5 years). The small number of stations with longer terms of rainfall records (10-16 years), such as Abha and Jabal-Salah, have interrupted runs of data. Jabal-Fayfa in this area has unbroken data for 13 years, from 1960 to 1972. Thus, it was selected to represent the Asir highlands in this section of the present study. When relative variability was worked out (Table 7(37)), it was found that Jabal-Fayfa shows an overall great monthly relative variability of rainfall with a maximum in the winter season (January relative variability 121.5%) and a minimum in the summer season (August relative variability 46.4%). During the winter season rainfall deviations from the mean can range for every month from 100% below the mean to values several times greater than the mean monthly rainfall. During the summer months rainfall deviations from the mean are not quite as great and rarely is it that deviations of 100% below the mean monthly rainfall are observed.

Fluctuations of monthly rainfall totals at Jabal-Fayfa in the Asir highlands may exceed 300% above the mean monthly rainfall on occasions during any month of the year. However, this station is located on the northern margins of the influences of the monsoon winds and the oscillatory Inter-Tropical Convergence Zone during the summer months. In the winter season, Jabal-Fayfa is, on the other hand, affected by the Red Sea Convergence Zone that may cause development of disturbances, rainfall, and sometimes hail. From Table 7(37) it can be seen that the rainfall given by the monsoon of summer is more reliable than the rains yielded from the disturbances of the Red Sea Convergence Zone. There is a remarkable decline in monthly relative variability of rainfall during the spring season and in particular in April, which is followed by further decrease. This reduction in variability from spring to summer at Jabal-Fayfa may be attributed to local convectional activity and the presence of the moist air from the monsoonal circulation.

To provide more clarity for the characteristics of rainfall in this aspect, an attempt was also made to show rainfall dispersion and, consequently, Figures 7(V), 7(VI), 7(VII) and 7(VIII) were drawn. From these diagrams it can be noticed that the desert stations show a rainy period from November until May; the June-October term is almost rainless. It can be also seen that during the rainy season there is a considerable rainfall dispersion above and below the mean monthly value. In the desert areas there are more occurrences of rainfall below the mean than above the mean. On a few occasions rainfall in one month may be the total for that year, or it may exceed the mean annual rainfall, while in many cases the rainfall may be zero. Exceptionally heavy showers on only a few occasions during the period of record can cause distortion of the mean.

In the Asir highlands, rainfall dispersion at Jabal-Fayfa station was worked out (Figure 7(VIII)). Rainfall in this area is expected to occur during any month of the year. As has been shown in the discussion on variability at this station, dispersion of monthly rainfall above and below the mean is greatest in the winter season though there are more monthly rainfall totals below the mean. Monthly rainfall values are less scattered in the summer months than in the winter season.

Attention has also been paid to the annual rainfall variability and, thus, Tables 7(38) and 7(39) have been worked out

Fig. 7 (V) RAINFALL DISPERSION 1952 - 1971
JEDDAH AIRPORT

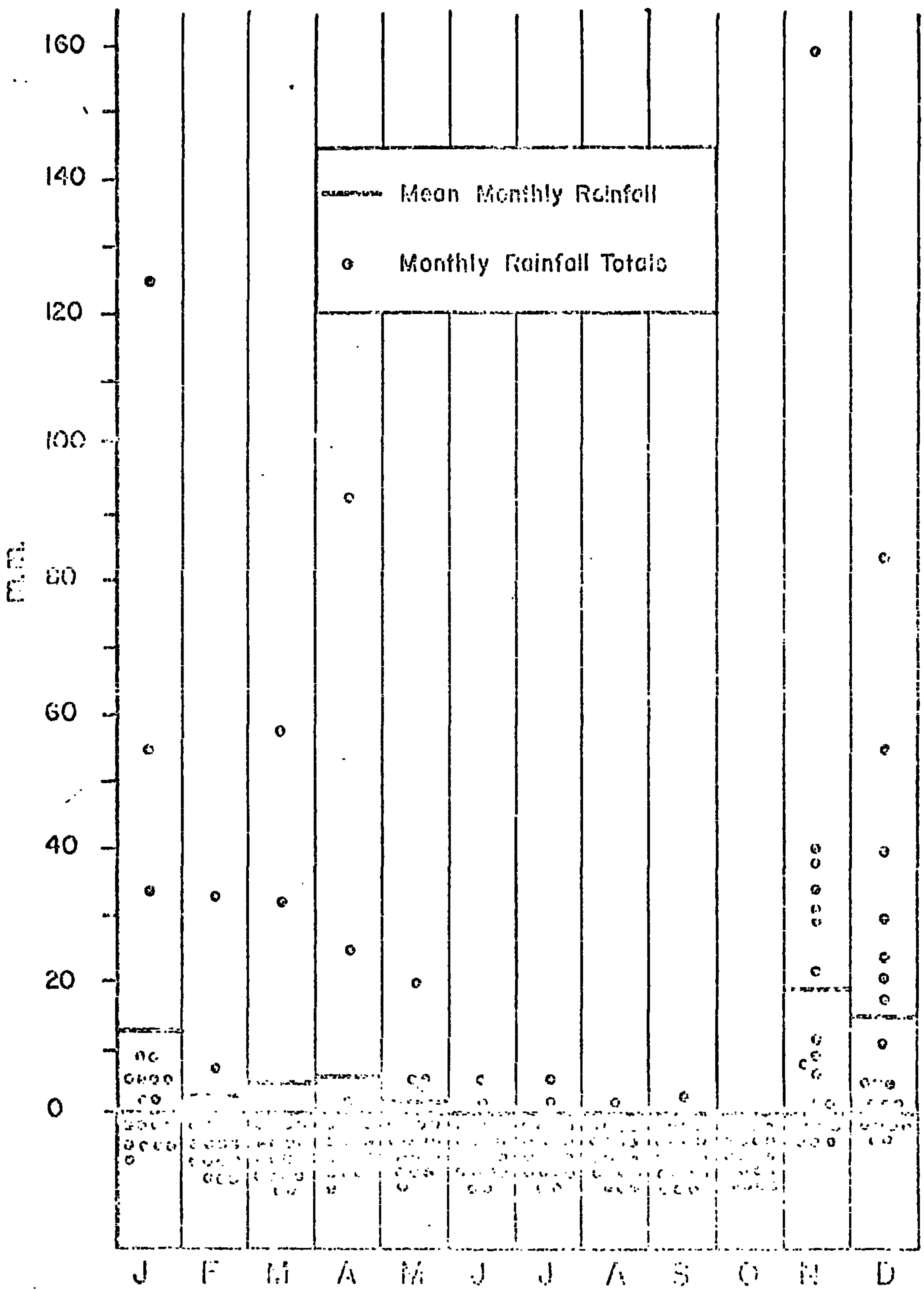


Fig. 7 (VI) RAINFALL DISPERSION 1951-68
DHAHRAN (ARAMCO)

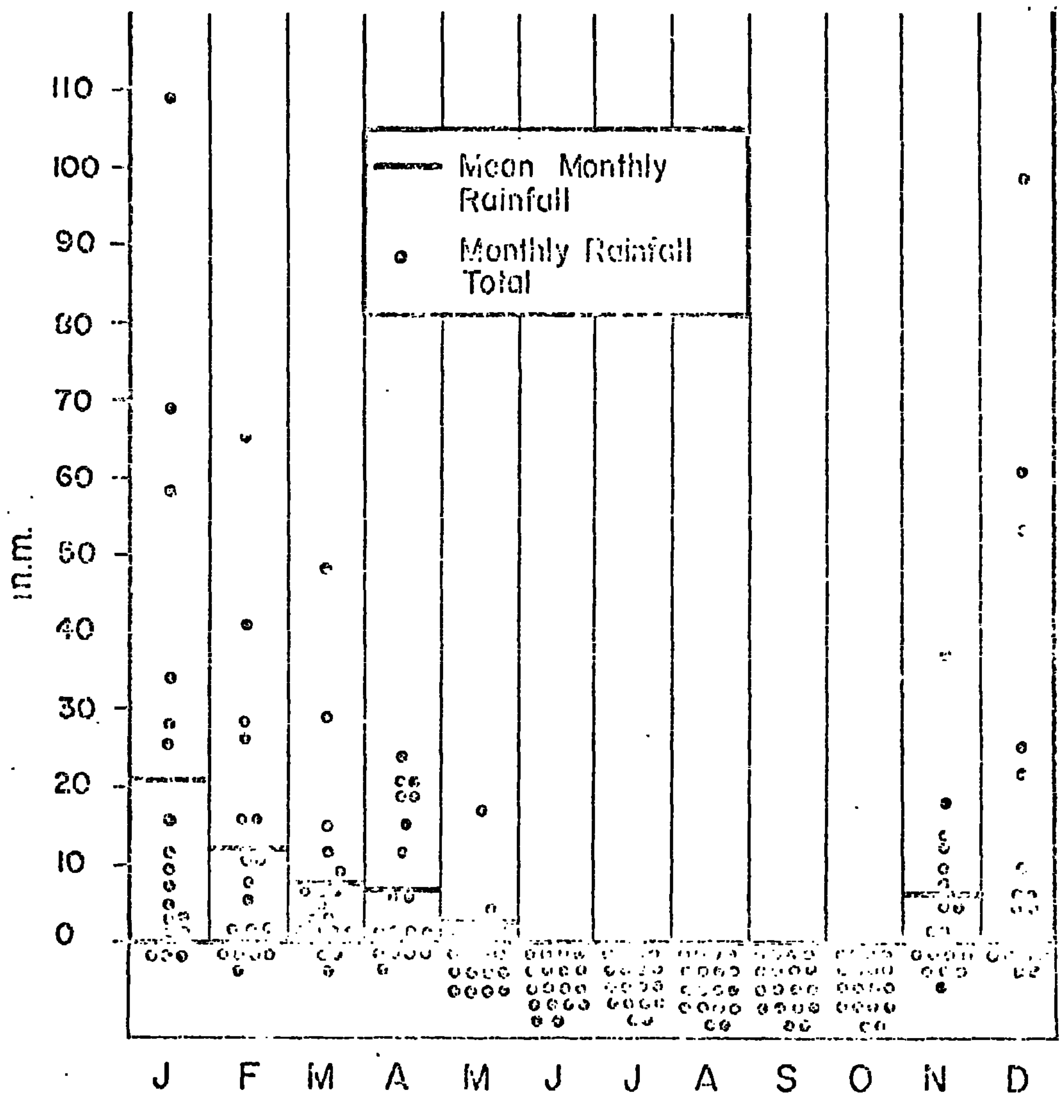


Fig. 7 (V II) RAINFALL DISPERSION 1952–71
RIYADH AIRPORT

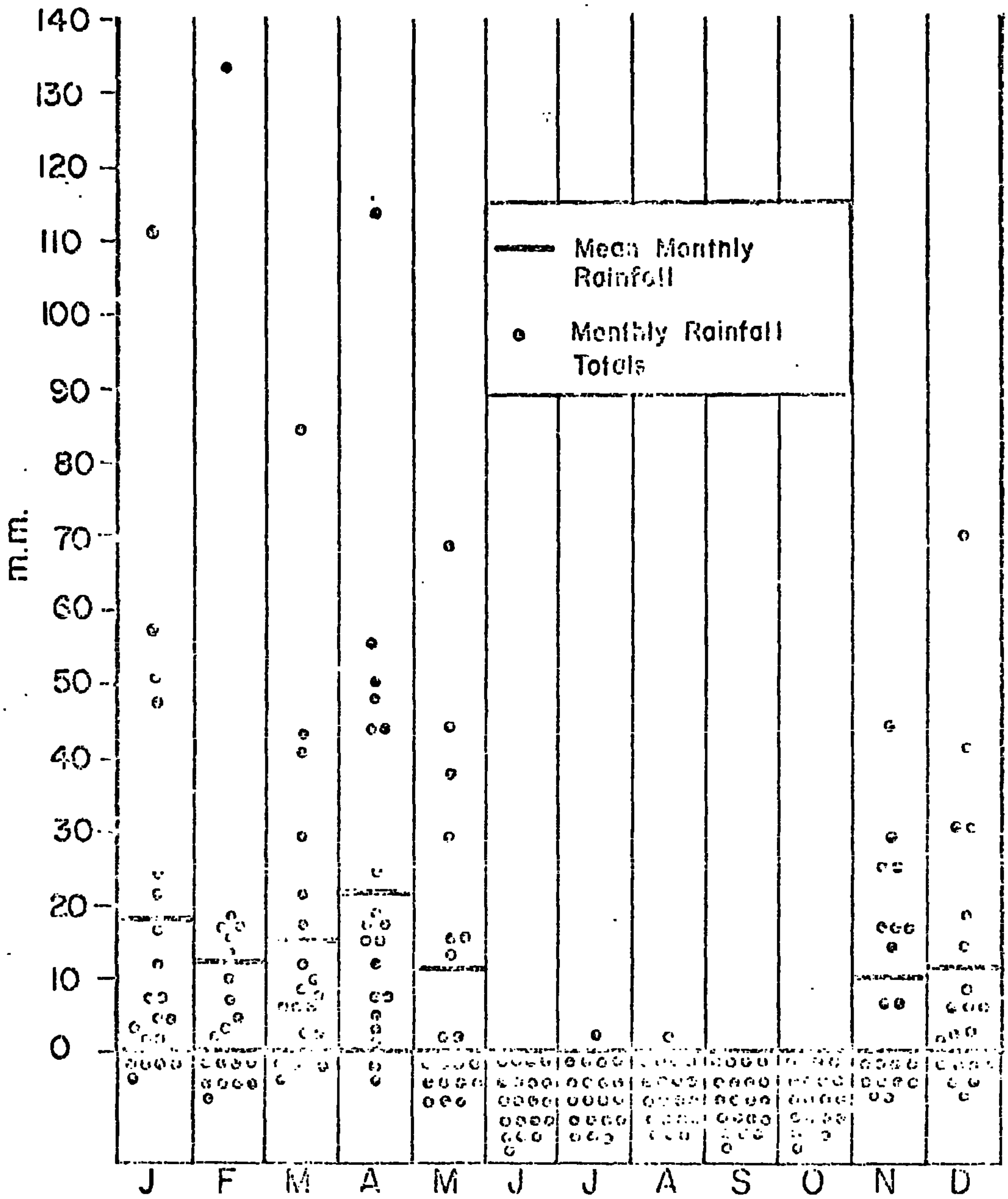
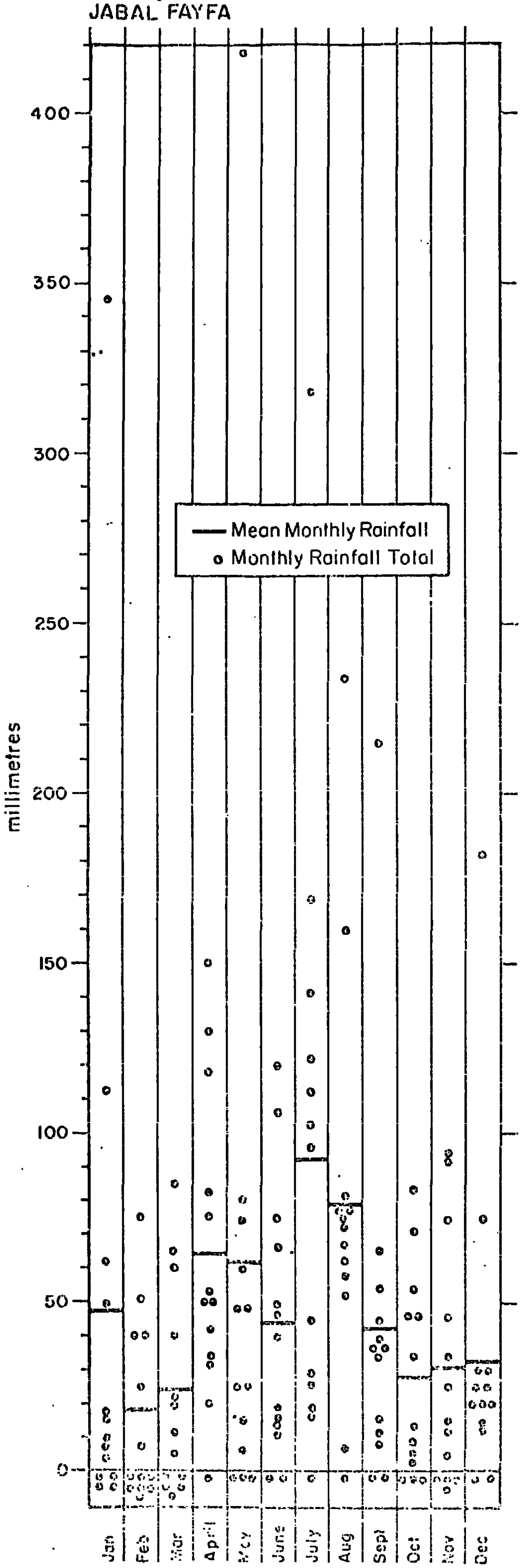


Fig. 7.VIII RAINFALL DISPERSION 1960-72
JABAL FAYFA



for the four stations. It can be seen from Table 7(38) that the rainfall stations in the desert areas show considerable rainfall fluctuations above and below the mean annual rainfall. However, it appears that amongst these stations, Jeddah, with 64% relative variability, has the most unreliable rainfall and experiences rainfall totals from zero to 173mm. Dhahran and Riyadh are both desert stations and, thus, show a striking rainfall above and below the mean. At Dhahran, for example, rainfall deviation from the mean ranged from between 13.7% in 1960 to 197% in 1955. Rainfall at Riyadh station was 233.1% of the mean in 1953 , though only 15% of the mean in 1966.

In the Asir highlands, Jabal Fayfa station shows a slightly lower annual relative variability from that shown by the desert stations (Table 7(39), namely, 44.2%. Rainfall deviation at this station ranged between 221.3% of the mean in 1966 to 40% of the mean in 1966.

No station that has been studied showed a reliable rainfall. In some years the rainfall of one or two months, during the rainy season at the desert station, may be sufficient to completely change a desert landscape to one that more clearly resembles grasslands. In other years the amount of rainfall is very small and the landscape of the desert areas does not change, and the rainy period may come to an end in many areas of the country without any showers.

Major parts of Saudi Arabia gain their rainfall from the Mediterranean depressions which occasionally have sufficient energy to invade the country and give considerable amounts of rainfall in the desert areas during some years. In other years the country may come under the effect of a relatively extensive blocking anticyclone

TABLE 7(38)

Annual rainfall variations from the mean (mm) and relative variability (%)
(1952-68)

	Jeddah (A.R)		Dhahran (Aramco)		Riyahd (A.R)	
	Deviation (mm)	Annual rainfall total	Deviation (mm)	Annual rainfall total	Deviation (mm)	Annual rainfall total
1952	+29.5	90.0	-36.9	36.7	-49.8	46.2
1953	+98.5	159.0	+55.0	128.6	+127.8	223.8
1954	-60.5	0	+26.0	99.1	-51.2	44.8
1955	+36.5	97.0	+71.2	144.8	+68.0	164.0
1956	-60.5	0	-49.7	23.9	-67.9	28.1
1957	-60.5	0	+38.5	112.1	+53.3	149.3
1958	-29.5	31.0	-04.6	78.2	-05.5	90.5
1959	-11.5	49.0	+65.5	139.1	-24.6	71.4
1960	-19.0	41.0	-63.4	10.1	-46.0	50.0
1961	-26.1	34.4	+28.9	102.5	-31.1	64.9
1962	+06.0	66.5	-47.7	25.9	-20.7	75.3
1963	-14.0	46.5	-15.8	57.8	-38.5	57.5
1964	-35.5	25.0	+47.4	121.0	+50.2	146.2
1965	-12.0	48.5	-62.6	11.0	-16.0	80.0
1966	+17.5	68.0	-42.5	31.1	-81.5	14.5
1967	-39.7	100.2	-39.1	34.5	+20.4	216.4
1968	+112.5	173.0	+20.6	94.2	+11.1	107.2
Relative variability %	64.0		57.2		46.7	
Mean rainfall (mm)		60.5		73.5		96.0

+ rainfall above mean

– rainfall below mean

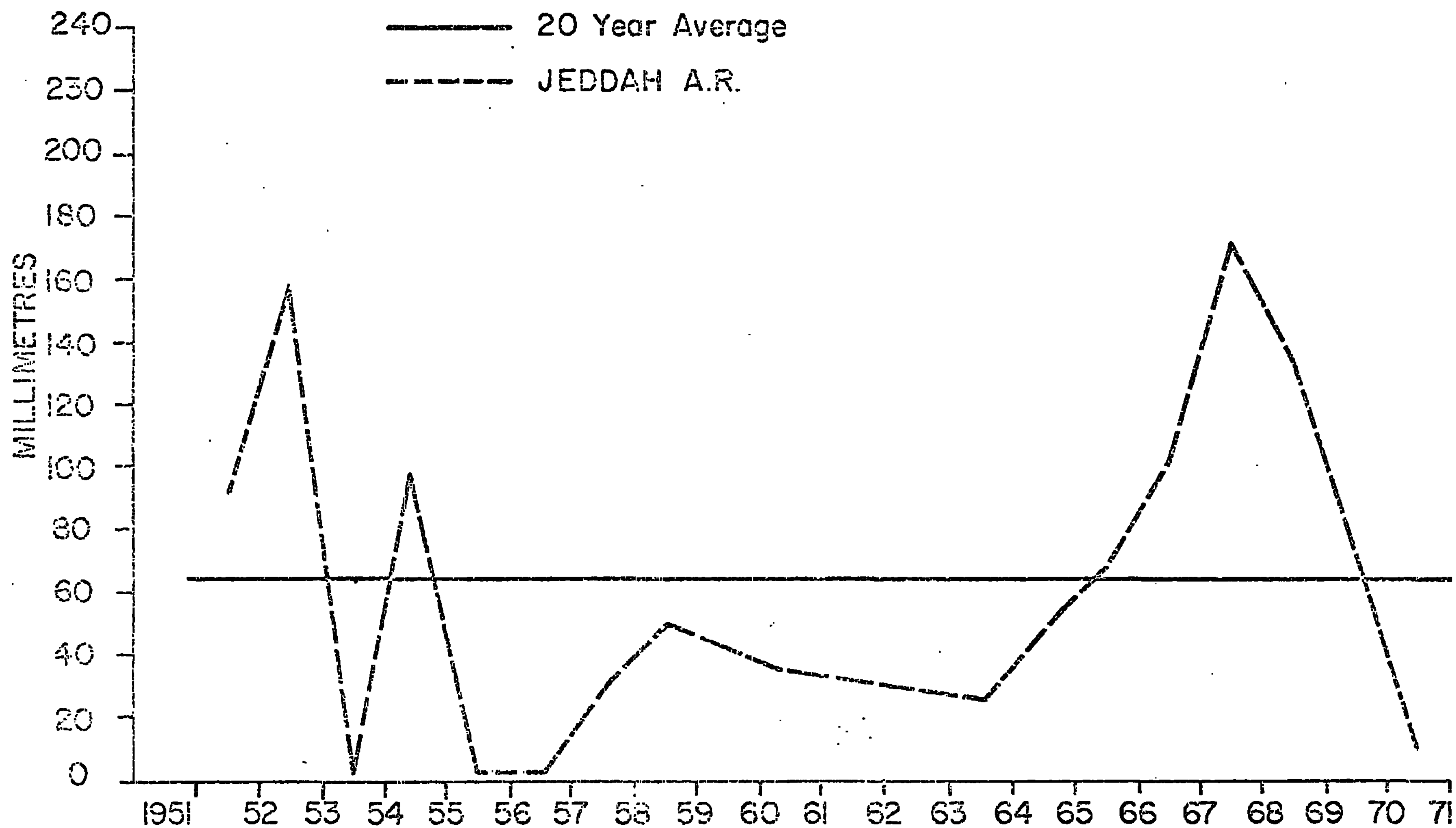
TABLE 7(39)

Annual rainfall variations from the mean (mm) and relative variability (%) at Jabal-Fayfa in Asir (1960-1972)

	Rainfall total(mm)	Deviation (mm)
1960	491.8	-74.8
1961	238.1	-328.5
1962	568.7	+02.1
1963	295.6	-27.1
1964	889.7	+323.1
1965	828.4	+261.3
1966	226.6	-34.0
1967	1000.4	+433.3
1968	1253.0	+686.4
1969	336.0	-230.6
1970	610.0	+43.4
1971	352.0	-214.6
1972	276.0	-290.6
Mean variability %		44.2
Mean rainfall (mm)	566.2	

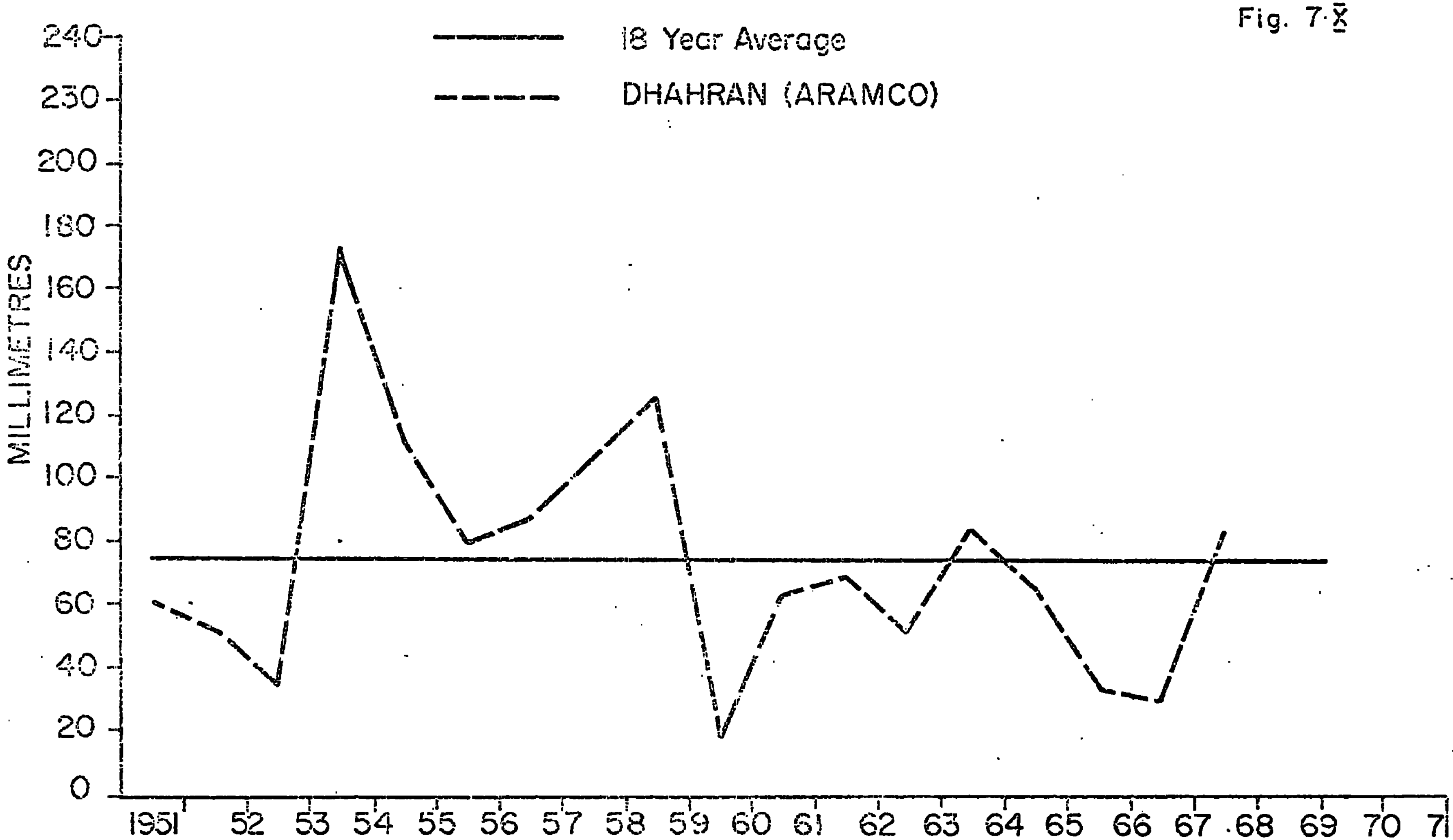
DEPARTURE OF ANNUAL TOTAL RAINFALL FROM THE AVERAGE

Fig. 7·IX



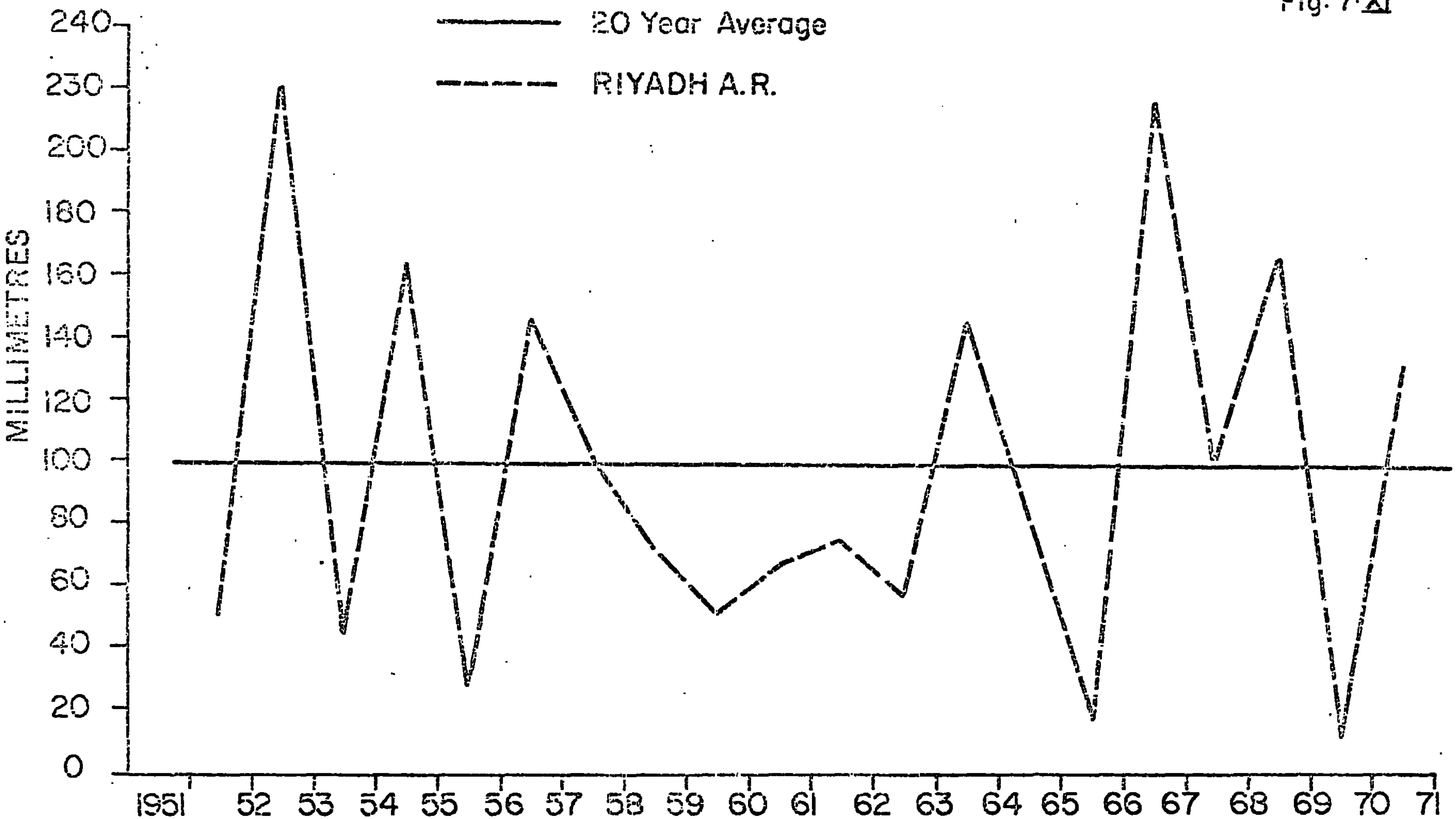
DEPARTURE OF ANNUAL TOTAL RAINFALL FROM THE AVERAGE.

Fig. 7·X̄



DEPARTURE OF ANNUAL TOTAL RAINFALL FROM THE AVERAGE.

Fig. 7·XI



when a cold ridge extends south-westward to Arabia from the anti-cyclone of central Asia during winter, which blocks the southerly passage of the Mediterranean depressions. The blocking effects may extend westward to Asir highlands in western Arabia during winter and, thus, rainfall in this area can also be variable.

However, because of the paucity of data it is impossible to arrive at any conclusive statements about the nature of the rainfall variability in Saudi Arabia, and it would also be unjustified to deduce from these short periods of record anything in the nature of periodicity. Seventeen to twenty years of records are insufficient to show accurate results about rainfall variability in an arid area such as Saudi Arabia. The fact is that the short-term records show that rainfall is unreliable and analyses of means tend to be deceptive for while rainfall is of small amounts over most of Saudi Arabia, distortions can be caused by exceptional heavy falls.

RAINFALL INTENSITY

An important aspect of the characteristics of rainfall is its intensity. In the arid zones, such as Saudi Arabia, an occurrence of rain within one day may amount to, or exceed, the mean annual rainfall. Sudden showers, combined sometimes with hail, may produce torrential floods to an area not used to it for several consecutive years. The danger to human and animal life is great when a random, sharp thunderstorm precipitates exceptional large amounts of rain on the villages or the camps of the pastoral tribes. The danger arises from the fact that once accustomed to the dry conditions, the inhabitants are never prepared to defend themselves against the imminent peril of the sudden occurrence of heavy showers and floods. Another reason is that the majority of human settlements in Saudi Arabia, whether villages or larger towns, are established almost always on the banks of the large wadis where underground water is normally available, and where the soil is more fertile. A third reason which increases the danger of the high intensity of precipitation is that most of the dwellings in the country are built from mud which easily becomes swept away by heavy showers. Sudden showers of violent intensity have resulted on many occasions in the deaths of many families, even in the capital of the country, because of the collapse of the dwellings on the inhabitants.

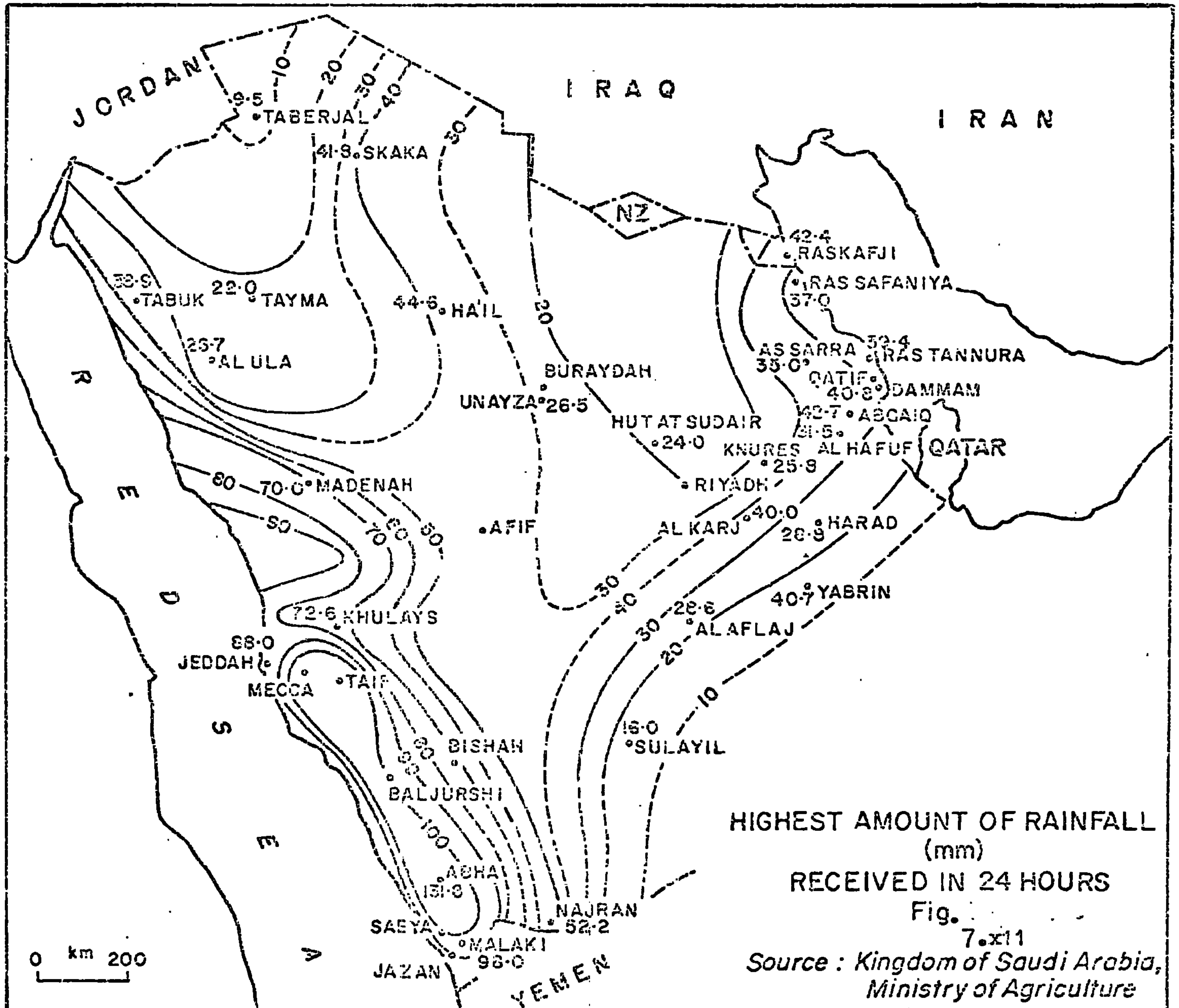
There are no sufficient recorded data concerning the intensity of the precipitation and the results of the sudden heavy showers in the country. Description of the effects of heavy showers is frequently found in historical and geographical books, and the scanty data recorded by the Ministry of Agriculture, Hydrology Division. All the writers of historical books wrote about the violent rain and the torrential floods and the results on people, animals and plants in the Najd area. Recorded data concerning the intensity of rainfall within 24 hours are available for some stations and are shown in Table 7(40) based on data from the Ministry of Agriculture and the Ministry of Defence, Meteorological Directorate. All recorded data indicate that, on one day, rain can exceed the mean annual of most of the stations in Saudi Arabia. Maximum intensities of precipitation which normally result in accidents or death to the inhabitants and the animals of the roaming pastoral tribes may be even greater. The following table shows one day's rainfall maxima at selected stations in the country.

TABLE 7(40)

One day's rainfall maxima at selected stations in Saudi Arabia

Station	One day's rainfall (mm)	Same month total	Date
Abha	131.8	230.7	12. 2.1968
AL-Alayyah	102.0	163.0	19. 1.1970
Bani-Malik	158.7	230.5	18. 4.1968
Al-Wajh	29.0	33.0	23.12.1971
Jeddah	83.0	83.0	3.11.1972
Madenah	38.0	38.0	12. 4.1971
Riyadh	57.0	117.3	8. 4.1971

Figure 7.11 shows the highest amount of rainfall received in 24 hours in Saudi Arabia. This map was constructed by the officials in the Ministry of Agriculture, Hydrology Division and can be taken as an initial indication only since it was made on the basis of short periods of records. In general, there is a remarkable coincidence between the highest amounts of rainfall received in 24 hours and the topography where the maximum is found to occur in the highlands of Asir and Hejaz. Tuwayq mountain in Najd plateau is seen to have a slight effect upon the rainfall intensity where there is an increase by 10mm above the surrounding lower areas. Another factor that may also increase the intensities of rainfall is proximity to the water bodies of the Red Sea and Arabian Gulf. When the two factors of the topography and the water bodies are found in one place, as in the western highlands



HIGHEST AMOUNT OF RAINFALL (mm) RECEIVED IN 24 HOURS

Fig. 7.x11

Source : Kingdom of Saudi Arabia, Ministry of Agriculture of the country, precipitation intensities reach their maximum. In the northern and southern sections of the country the precipitation intensities reach their minimum where these areas are lower in elevation and located far from the effects of the water bodies of the Red Sea and the Arabian Gulf.

CHAPTER VIII

CONCLUSION

From the foregoing analysis of the climatic conditions it has been found that there are considerable variations in the climatic characteristics between one region and another in Saudi Arabia. Some areas have high temperatures, low relative humidities and rainfall, while others demonstrate relatively low temperatures and high relative humidities, as well as comparatively large mean annual precipitation. Moreover, there are areas which receive their rainfall in winter, while summer is rainless, and there are others which experience the wettest period during the summer months.

The climate of any region results from the combination of various meteorological elements and, consequently, there is a considerable variety of climates over Saudi Arabia, but, in fact, the systems of the world's climatic classification have been applied in general on the Arabian Peninsula and, hence, the climatic regions that exist in the area under study have not yet been shown in any detail.

It is in this country that the monsoon climate of the south-west of Arabia degenerates into various kinds of desert climates, and it is in Saudi Arabia that the dry air of central Asia, the moist air of the Mediterranean and the humid air of the Arabian Sea meet each other. It is quite clear that the picture given for the climates in Saudi Arabia in the maps of the world's climatic classification is too generalised to express the opinion of the author concerned.

Lack of data on the climatic conditions in the country is the reason that it has been classified in general on the maps of the world's climatic classifications. Even in the present study the available data are insufficient for some areas, and may not be available for some others, especially in the Asir highlands and the Rub-al-Kali. Consequently, the results obtained are, to some extent, imprecise.

The present study, as has been pointed out, is based on a fairly small network of stations, adequate at least for parts of the vast territory of Saudi Arabia. The data used here belong generally to the same period of time which, although of short duration, must be regarded as of considerable importance in view of the remarkable lack of literature on the climatology of Saudi Arabia.

In this chapter an attempt will be made to classify Saudi Arabia into climatic regions on the basis of the methods of one of the world's climatic schemes. The well advanced and specific methods, such as Thornthwaite system, are impossible to be applied at present on Saudi Arabia since some parameters such as potential evapotranspiration have not yet been recorded by any one of the climatic stations in the country, and because evaporation has been recorded only by a small number of stations.

In applying other climatic systems, which use the parameters of temperature and precipitation, one encounters a problem which is, at present, difficult to resolve. There are stations which show high annual totals of precipitation in the high ranges of the Asir highlands, but, unfortunately, they have been installed recently and, consequently, one cannot, so far, determine specifically the season of the concentration of precipitation. This area is located on the northern flanks of the monsoon winds during the periods of March-August and in the southern margins of the influence of the moist westerlies of winter.

Precipitation in the Asir and southern Hejaz is experienced almost every month of the year and there are some stations in northern Asir and southern Hejaz which show a concentration of rainfall during the period of December-May, and there are other stations in southern Asir which show rainfall maxima during the period of March-August. Furthermore, some stations of short records show a rainfall maximum period from November until April, after which precipitation declines considerably in the summer season. The short duration of records on precipitation presents a confused picture in determining the period which is normally the time of rainfall concentration. Table 8(1) represents the annual and monthly totals of precipitation in 1972 at selected stations in the Asir highlands. It should be recognised that they are located not far from each other in this area.

The reverse situation of rainfall concentration in Table 8(1) can be easily seen in Table 8(2) which represents the annual and monthly rainfall totals in 1972 at other selected stations. While the stations in Table 8(1) are located on the high ranges of the escarpment, the stations in Table 8(2) lie on the western slopes and the foothills of the highlands of Asir.

TABLE 8(1)

Annual and monthly totals of rainfall in 1972 at selected stations in Asir (mm)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Annual Total
As-Swadah	8.2	40.0	181.0	154.0	77.0	35.0	34.0	44.0	20.0	15.0	40.0	39.0	688.0
Belesmer	45.5	67.0	27.0	152.0	110.0	20.5	1.0	6.0	0	11.0	41.0	73.3	554.0
Ibalah	13.6	65.2	48.6	292.4	151.0	29.4	0.8	4.8	1.8	10.4	41.6	67.8	727.6
Tenomah	77.3	80.0	76.6	152.5	72.0	6.5	0.3	10.6	0	14.0	25.0	121.8	636.7
Temniyyah	7.1	77.7	95.0	297.9	93.5	38.5	29.5	19.5	13.3	0	26.0	29.0	726.0
Ash-Shaf	6.2	60.2	89.2	137.4	25.4	73.6	39.0	39.4	0.8	22.2	90.0	49.2	634.6
Al-Mendak	21.7	40.9	56.0	131.0	20.0	19.5	10.5	12.0	6.5	20.1	129.8	220.6	688.8
An-Nimas	40.0	67.6	82.0	138.2	76.4	15.9	8.3	11.0	0	5.0	50.2	138.0	632.6
Al-Aja'edah	12.8	48.7	12.0	190.2	19.8	16.2	13.2	6.4	0	14.2	39.3	218.2	641.3

TABLE 8(2)

Annual and monthly totals of rainfall in 1972 at selected stations in Asir (mm)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Annual Total
Ardah	0	13.4	1.4	39.4	56.4	71.1	66.5	43.3	81.3	67.2	149.2	0	589.2
Mahayil	8.0	9.8	9.2	219.8	36.9	35.3	0	96.6	57.0	49.6	63.3	4.2	589.7
Jabal-Salah	3.8	31.2	8.7	47.4	116.5	13.3	52.7	48.1	31.5	19.8	121.8	26.0	520.8
Raysh	20.0	17.4	0.5	93.0	46.5	45.8	16.5	100.0	88.5	93.0	19.5	30.0	570.7
Majrarda	3.4	22.2	1.4	51.4	103.0	99.6	3.4	66.2	48.4	38.6	20.6	115.6	573.8
Khashel	1.2	7.4	6.2	65.6	79.0	101.0	95.8	100.2	122.2	114.0	8.0	6.0	706.6

It can be seen from Table 8(2) that the stations in the western slopes of the foothills of Asir show remarkable rainfall concentration during the period of April-November. The period of December-March is almost dry, though the stations in the northern section of these slopes may experience heavy precipitation during December or January.

Taking this variation into account it is easy to appreciate the complexity of climate in this small area of Saudi Arabia. The complexity of the climate of this area is caused by its location with respect to the marginal influences of the moist air of the Mediterranean and the marginal effects of the monsoon winds. In some years, the Mediterranean moist air of winter may dominate major parts of this area, while during other years it may come under the effects of the monsoon winds of spring and summer. Consequently, precipitation here is very variable, as has been discussed in another chapter. Another factor is highly responsible for this complexity, namely the topography. The configuration of the surface of this area is almost completely responsible for the seasonal distribution of rainfall and this is why the western slopes and foothills enjoy a rainfall regime which differs from that experienced in the high escarpment and the eastern slopes. Furthermore, the northern part of these highlands, where the moist westerlies are more intense in winter, experience a different rainfall regime from the southern section where the monsoon winds of spring and summer are dominant. It is so difficult, or, in fact, impossible at present, to recognise the separations between the area in which the period of March-August is the wettest period, the area in which the rainfall maximum is during the period of July-November or in which precipitation reaches its maximum during the period of November-April, because of the lack of adequate data concerning rainfall. Thus, when the area is classified in climatic regions, it has to be taken as an initial study until sufficient data on rainfall, evapotranspiration and temperature are available.

Table 8(3) represents the mean monthly and annual precipitation at stations with relatively longer periods of record in Asir and southern Hejaz highlands. It was hoped that they may give indications of the concentration of rainfall in the area. The period of record ranges between 3 and 13 years. They are arranged in groups, each of which represents an area.

When the year has been divided into two seasons, the winter season, October-March, and the summer season, April-September, it has been deduced that stations in Abha area show summer maximum rainfall, as can be seen from the following figures :

	Abha* (1955-70)	Al-Kam (1965-69)
Summer Rain %	57.5	72.0
Winter Rain %	42.4	28.0

In the Gamid area two stations, with longer period records, show winter maximum rainfall, and two other stations, with short terms of records, show evenly distributed rainfall, as can be seen from the following figures :

	Baljurshi** (1960-70)	Az-Zafir (1960-70)	Al-Aja'edah (1967-69	Al-Alayyah (1966-69)
Summer Rain %	33.2	31.8	48.9	49.3
Winter Rain %	66.8	68.2	51.1	50.7

* data for 1961 are unavailable ** data for 1966 are broken in summer

TABLE 8(3)

Mean annual and monthly rainfall at selected stations in Asir and southern Hejaz highlands (mm)

Station and period of utilised data		J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Group 1 : Stations represent Abha area														
Abha*	(1955-70)	43.1	20.4	43.4	77.4	32.3	13.5	50.9	46.6	2.0	2.5	39.4	15.4	386.9
Al-Kam	(1966-69)	12.9	41.6	18.8	65.6	62.7	24.0	80.2	77.0	15.5	4.4	48.9	0	451.6
Group 2 : Stations represent Gamid area														
Al-Alayyah	(1966-69)	40.3	65.8	38.2	94.5	72.1	41.7	17.0	14.2	0	4.7	67.0	30.2	485.7
Baljurshi**	(1960-70)	52.7	36.7	13.6	45.7	22.9	6.7	15.4	17.6	6.6	19.6	76.9	31.9	346.3
Az-Zafir	(1956-69)	84.6	48.6	19.8	60.0	38.7	9.2	17.0	23.9	7.3	16.1	110.8	55.2	491.2
Al-Aja'edah	(1967-69)	77.0	57.9	1.7	126.1	27.8	10.0	70.3	24.1	5.3	29.0	102.2	8.0	539.4
Group 3 : Stations represent southern Hejaz														
Farain	(1966-69)	61.4	25.0	9.4	63.9	24.2	14.1	1.2	39.9	14.8	57.6	53.9	3.5	368.9
Al-Hawiyyah	(1966-69)	34.0	22.3	25.6	10.6	63.3	17.3	6.8	14.4	1.0	17.2	63.2	5.0	280.7
Baqran	(1966-69)	44.2	29.0	15.5	69.1	15.7	4.3	10.0	0.1	0	6.5	50.1	2.3	277.0

* data for 1961 are not available

** data for 1966 are broken in summer

The stations in southern Hejaz escarpment show winter maximum rainfall as in northern sections of Asir, as can be noticed from the following figures :

	Farain (1966-69)	Al-Hawiyyah (1966-69)	Baqran (1966-69)
Summer Rain %	42.8	40.4	40.3
Winter Rain %	57.2	59.6	59.7

As has been already indicated, the western slopes of the escarpment enjoy different rainfall regimes from those shown by the above tables but, unfortunately, data concerning precipitation in this part of the highlands are not adequate.

However, the available scanty data show that the influence of the monsoon winds is sufficiently great to the extent that the summer rainfall is large enough on the western slopes to considerably exceed the winter rainfall, as can be seen from Table 8(4) which shows the mean annual and monthly precipitation at stations in the area.

The percentage of the summer precipitation decreases as one goes northward from Abha area to Gamid and southern Hejaz districts. On the western slopes, the percentage of summer precipitation decreases in the same direction, as can be deduced from the following figures, but it has to be realised that the relatively rapid decrease of summer precipitation on the high ranges of the escarpment does not exist in the western slopes where the decline in summer precipitation is more gradual.

TABLE 8(4)

Mean annual and monthly rainfall in the foothills of Asir highlands (mm)

Station and period of utilised data		J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
Jabal Fayfa*	(1957-70)	57.1	18.4	27.7	56.3	62.0	39.2	92.8	82.8	43.3	29.3	29.0	22.0	557.4
Jabal Salah**	(1957-70)	32.6	10.6	7.3	28.3	34.2	23.2	100.6	120.4	47.2	43.0	46.8	68.1	563.7
Thurayban	(1965-69)	35.6	63.1	8.8	45.3	44.6	65.1	70.2	74.1	75.2	26.6	108.7	9.2	627.5

* data are broken in 1959 in Spring

** data are unavailable in 1968

	Jabal Fayfa (1957-70)	Jabal Salah (1957-70)	Thurayban (1965-69)
Summer Rain %	67.6	63.6	59.8
Winter Rain %	32.4	36.4	40.2

It was considered advisable that in the final chapter of this study an attempt might be made at bringing the results of the previous analysis in the form of a map of climatic regions of Saudi Arabia. In the construction of the map of the climatic regions of the country (Figure 8(I)) stations with both rainfall and temperature records were utilised. Such stations are not, however, evenly distributed over the land surface of the country, as has been indicated in the first chapter. Furthermore, some stations in the Asir and southern Hejaz highlands show a high mean annual rainfall but, unfortunately, they do not have temperature records and, thus, estimations of the mean annual temperature were made on the basis of their altitude and their latitudinal locations.

For the purpose of classifying Saudi Arabia into climatic regions, Köppen's system of climatic classification was applied as an initial indication to the climatic regions in this country. For applying this system, records on temperature and precipitation are available for a large number of the climatic stations in the area under study.

Köppen's system is primarily based on mean annual and mean monthly values of temperature and precipitation and also their seasonal characteristics. He chooses certain numerical values of temperatures and rainfall for determining the limits between various climatic types. Such values are selected mainly in relation to their effect on vegetation. Köppen also takes into consideration the temperature of the warmest and the coldest months and the season of maximum precipitation. He works out formulae based on the relationship between temperature and precipitation, or on their combined effects, to determine the wet and the dry, and also between the desert and the steppe climates. In addition, he gives separate formulae for the summer and winter concentrations of precipitation.

Köppen's system, however, has been criticised in view of using the combination of temperature and the concentration of precipitation in the hot or the cool season to indicate the intensity of evaporation and, hence, the precipitation effectiveness on natural vegetation which is considered by Köppen as the best expression of the totality of a climate, so that many of the climatic boundaries are selected with vegetation limits in mind. This method of measuring precipitation effectiveness has been considered as not entirely satisfactory.

Köppen's methods, on the other hand, have been considered as a unique system in the light of the employment of an ingenious symbolic nomenclature in designating the climatic types and in the light of the construction of formulae of which each one has a precise meaning and, thus, makes unnecessary the coining of cumbersome descriptive terms (Trewartha, 1954).

The weakness of the indexes of aridity, based on the relationship between average values of temperature and precipitation was realised clearly by Angstrom (1936). He wrote, "such indexes have no physical meaning, tell us nothing about the physical process involved, and may easily be misleading in the hands of inexperienced people. Aridity should be expressed in terms of a relationship between precipitation and evapotranspiration". (Lockwood, 1974).

Lockwood (1974) has mentioned that since temperature is an approximate measure of the energy available for evapotranspiration through net radiation and sensible heat advection, indexes using it have proved useful for description of climates on a world scale.

However, since records on evapotranspiration are not available, Köppen's system has been applied on Saudi Arabia in the present study and until records on the parameters of evapotranspiration or evaporation become sufficiently available, different classifications can be applied on this country.

In this study the Asir and southern Hejaz highlands will be treated separately since they have different climatic conditions from those prevailing in the lower areas of the country.

Precipitation in the low areas is concentrated in the winter season with exception of the Jazan and Sabya districts which experience the wettest period during the summer season. The year in the low areas is divided into two periods; the cool season from November until April, and the hot season from May until October. With the exception of Jazan-Sabya areas, rainfall is almost restricted to the cool season in the low areas. The hot season is normally rainless, though May and October show low mean monthly precipitation at some stations. Table 8(5) represents the mean monthly and annual rainfall at stations which experience the cool season rainfall (following page).

It has been deduced that the mentioned stations in Table 8(5) show high percentages of the cool season precipitation which range between 78.8% at Riyadh and 96.8% at Jeddah.

Since precipitation is concentrated in the major part of Saudi ARabia during the cool season, Köppen's formula for winter

TABLE 8(5)

Mean monthly and annual rainfall in the desert areas (mm)

Station and period of utilised data		J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean	Cool Season Rain %
Badana	(1961-69)	4.3	0.5	5.2	5.6	2.9	0	0	0	0	0.5	5.0	5.2	29.2	88.3
Dhahran	(1964-69)	10.0	13.8	3.2	10.0	3.4	0	0	0	0	0	8.3	6.8	55.5	93.8
Jeddah	(1952-71)	14.8	0.5	3.4	4.0	1.7	0	0.1	0	0.2	0	21.2	17.9	63.8	96.8
Riyadh	(1952-71)	23.5	11.3	11.7	20.4	11.4	0.7	0.1	0	0	0	10.2	11.3	100.6	78.8
As-Sulayyil	(1965-70)	2.0	3.7	4.3	13.0	2.7	0	0	0	0	0	1.9	0	27.8	90.0

maximum rainfall was used. This formula is written as follows :

$$r = \frac{.44t - 14}{2}$$

Table 8(6) shows the results arrived at after applying this formula at selected stations in most of the arid zones of the country.

In the Köppen's classification of the desert climates, if rainfall is less than r, the climate is true desert. Consequently, all stations in Table 8(6) show arid climates. These stations are arranged in groups, every one representing an area of Saudi Arabia. Groups 1 and 2 represent the coastal plains of the Arabian Gulf and the Red Sea (to the north of latitude 18°N). Group 3 represents the central province, while Groups 4 and 5 represent the north and north-west of Saudi Arabia. It can be seen from Table 8(6) that there are no major differences in the index of aridity between one group and another. Extreme arid conditions predominate over the major part of Saudi Arabia. In fact, all stations mentioned in Table 8(6) represent the driest areas in the country.

In Jazan and Sabya districts, precipitation though is experienced almost every month of the year, but appears to be concentrated during the hot season, as can be seen from Table 8(7).

Consequently, Köppen's formula for summer maximum rainfall was used. It is written as follows :

$$r = \frac{.44t - 3}{2}$$

Table 8(8) shows the index of aridity at selected stations in Jazan and Sabya districts.

TABLE 8(6)

Index of aridity and type of climate at stations in the desert areas

	Stations	Mean Annual Temperature (F)	Mean Annual Rainfall (inch)	Index of Aridity (r)	Type of Climate
1.	Abqaiq	77.0	2.4	9.9	Arid
	Dhahran	80.6	2.3	10.7	Arid
	Qatif	77.0	3.2	9.9	Arid
2.	Al-Wajh	75.9	1.3	9.6	Arid
	Jeddah	82.4	2.6	11.1	Arid
3.	As-Sulayyil	78.8	1.1	10.3	Arid
	Hail	73.4	3.2	9.1	Arid
	Riyadh	77.0	4.1	9.9	Arid
	Unayzah	75.2	4.5	9.5	Arid
4.	Qurayyat	66.2	2.1	7.5	Arid
	Skakah	71.6	2.8	8.7	Arid
	Tabarjal	66.5	2.4	7.6	Arid
5.	Al-Ula	72.0	2.0	8.8	Arid
	Tabuk	69.8	1.3	8.3	Arid
	Tayma	69.8	2.0	8.3	Arid

TABLE 8(7)

Mean annual and monthly rainfall in Jazan-Sabya district (mm)

Station and period of utilised data	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean	Hot Season Rain %
Abu-Arish (1955-69)	9.2	2.1	4.7	1.5	12.3	1.6	50.3	62.8	23.0	10.0	11.8	24.3	214.1	74.7
Sabya (1965-69)	9.6	1.4	0	0.8	1.3	0	42.2	3.9	20.0	13.8	17.1	1.7	111.9	72.5
Suq-al-Jenub (1965-69)	0	15.0	0	11.0	25.5	15.0	67.7	12.5	17.5	18.0	25.5	0	207.7	75.2

TABLE 8(8)

Index of aridity and type of climate at stations in Jazan and Sabya districts

Station	Mean Annual Temperature (F)	Mean Annual Rainfall (inch)	Index of Aridity (r)	Type of Climate
Abu-Arish	81	8.5	16.3	Arid
Sabya	84	4.4	16.9	Arid
Saq-el-Jenub	80	8.2	16.1	Arid

Thus, from Table 8(8), the Jazan-Sabya areas experiences an arid climate. However, when one studies the climate of these two districts, it should be borne in mind that all the stations recording rainfall here are situated at low elevations and almost all of them are located at an altitude of less than 100 metres. Elevation in these areas is of great importance in increasing precipitation, as has been discussed previously. Another fact should be considered in these districts. The atmospheric humidity due to fog and mist occurs in almost every month and for several days, and the percentages of relative humidity are high throughout the year. The increases in the percentages of relative humidity, as well as the high frequency of the occurrence of fog and mist, have a remarkable effect on vegetation, and this can be realised easily in the arid zones. The reverse of this situation can be found in the interior of the country where the year may pass without one day with fog or mist, but normally with haze. Furthermore, the frequency of days with sand or dust storms, which is very high in a major part of Saudi Arabia, reach its minimum in these districts. Obviously, the high velocity of winds, and the sand or dust particles, both affect the climate of an area where they prevail. As has been discussed in another chapter of this study, these conditions prevail almost all over Saudi Arabia, with the exception of the south-western region of the country. The effectiveness of the atmospheric humidity, which is considered to decrease the extreme arid conditions in Jazan-Sabya areas, is considerably attenuated in the Arabian Gulf coastal plain because of the high frequency of sand and dust storms.

THE HIGHLANDS OF ASIR AND SOUTHERN HEJAZ

The Plateau areas : Elevation of the surface of the interior of the country increases toward the Asir and Hejaz plateaux. In Taif, Bishah and Kamis-Mushait areas the altitude is always above 1000 metres. In these circumstances, temperature decreases while rainfall increases and, hence, the degree of aridity becomes less than that found in the lower areas of Saudi Arabia. In these plateaux the year is divided into two periods, as in the Asir and southern Hejaz highlands : the cool season, from October until March, and the summer season from April until September. The summer season in the Asir plateau is the period of rainfall maximum, while the winter season is the period of rainfall concentration in the Hejaz plateau. However, Bishah station in Asir, with 15 years of records, does not show a significant concentration of rainfall in summer. This station is located in the northern section of this area and thus may receive considerable rainfall from the Mediterranean moist air of winter. Kamis-Mushait, on the other hand, is located in the southern section of the Asir plateau and gains more rainfall from the monsoon winds of summer and, thus, shows a significant summer concentration. Consequently, Köppen's formulae for evenly distributed rainfall and for summer maximum were applied to data from stations in this area. The formula for evenly distributed rainfall is

$$r = \frac{.44t - 8.5}{2}$$

In Hejaz plateau, Taif Airport station shows a significant winter maximum rainfall where this station has a record period of 10 years. Bissel, with only 4 years of records, shows insignificant winter maximum rainfall. Consequently, Köppen's formulae for evenly distributed rainfall and for winter maximum were used. Table 8(9) represents the percentages of the seasonal precipitation of winter and summer in the Asir and Hejaz plateaux.

TABLE 8(9)

Percentages of winter and summer rainfall at stations in Asir and Hejaz plateaux

Station and period of utilised date		Winter Rain %	Summer Rain %
Group 1 : Hejaz plateau			
Bissel	(1966-69)	54.0	46.0
Taif Airport	(1960-70)	66.0	34.0
Group 2 : Asir plateau			
Al-Ain	(1965-69)	47.6	52.4
Bishah	(1957-70)	44.7	55.3
Kamis-Mushait	(1965-70)	33.0	67.0

Table 8(10) shows the index of aridity at Asir and the Hejaz plateau stations.

TABLE 8(10)

Index of aridity at the Hejaz and Asir plateau stations

Station	Mean Annual Temperature (F)	Mean Annual Rainfall (inch)	Index of Aridity (r)	
			Winter Maximum	Evenly dist. rainfall
Group 1 : Hejaz plateau				
Bissel	69.8	7.1	8.2	11.1
Taif Airport	71.6	6.6	-	8.7
Group 2 : Asir plateau				
Al-Ain	62.0	8.7	12.1	9.4
Bishah	76.0	5.9	15.2	12.5
Kamis-Mushait	67.2	9.8	13.3	13.3

At all stations the type of climate may be described as arid

The escarpment of Hejaz is of considerable high altitude in the Taif area, but toward the north-north-west it becomes of relatively moderate height and, thus, the amounts of mean annual rainfall decrease while the mean temperature increases. To determine the boundary between the semi-arid climate in the high escarpment of Taif area and the arid climate in the lower regions to the north-north-west, the following stations were selected and Köppen's methods were applied. The year, in this area, is divided into two periods; the cool season from November until April, and the hot season from May until October. It is obvious that all stations located in the lower area to the north-north-west of the high escarpment of Taif area show rainfall concentration during the cool season, as can be seen from Table 8(11) and, consequently, Köppen's formula for winter rainfall maximum was used :

$$r = \frac{.44t - 14}{2}$$

TABLE 8(11)

Percentages of winter and summer rainfall in the escarpment of Hejaz to the north of Taif area

Station and period of utilised data		Winter Rain %	Summer Rain %
Al-Mosayjid	(1966-69)	81.6	18.4
Haddat-Ash-Sham	(1966-69)	85.3	14.7
Madrakah	(1966-69)	76.0	24.0
Malbanah	(1967-69)	92.5	7.5
Mecca	(1966-69)	95.4	4.6

Table 8(12) shows the index of aridity at the stations in the area.

TABLE 8(12)

Index of aridity and type of climates at stations to the north and north-west of Taif area

Station	Mean Annual Temperature (F)	Mean Annual Rainfall (inch)	Index of Aridity (r)	Type of Climate
Al-Mosayjid	78.0	4.2	10.1	Arid
Haddat-Ash-Sham	76.0	5.4	9.7	Arid
Madrakah	79.0	7.7	10.3	Arid
Malbanah	80.0	5.2	10.6	Arid
Mecca	81.5	8.4	10.8	Arid

Table 8(13) shows the mean monthly and annual rainfall at selected stations in the plateaux of Asir and Hejaz, as well as the lower mountains to the north, north-west of Taif escarpment. In the table the stations are arranged in three groups, of which every one represents a distinct area. Group 1 represents the Asir plateau which shows summer rainfall maximum (April-September), Group 2 represents the Hejaz plateau which experiences the wettest period during the winter months (October-March) and Group 3 shows the mean rainfall at stations in the lower mountains to the north-west of the high escarpment of Taif area. This group shows rainfall concentration during the cool season (November-April), while the hot season (May-October) is dry.

TABLE 8(13)

Mean annual and monthly rainfall at stations in Asir and southern Hejaz highlands (mm)

Station and period of utilised data		J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
GROUP 1 :														
Bishah	(1957-70)	12.2	4.4	13.4	39.0	24.3	1.7	12.0	1.1	0	2.1	25.2	9.9	145.3
Kamis-Mushait	(1965-70)	9.0	36.6	34.9	32.7	30.2	8.3	34.1	25.2	10.4	0.1	24.1	1.5	247.1
GROUP 2 :														
Bissel	(1966-69)	14.7	14.8	10.3	49.6	11.9	13.0	3.5	2.2	0	20.9	33.0	0	173.9
GROUP 3 :														
Al-Mosiayfid	(1966-69)	14.3	1.7	0	25.7	9.9	0	2.0	0	3.9	3.0	33.7	8.3	102.5
Malbanah	(1967-69)	24.2	7.0	0.4	35.3	3.7	0	0.8	0.7	0	4.4	38.0	13.3	127.8

The Escarpment of Asir and Southern Hejaz : From Taif area to the Saudi Arabian boundary with Yemen there is a high escarpment reaching an elevation of 3000 metres and even more at some peaks. This escarpment is very precipitous toward the coastal plain of the Red Sea, with a steep western face decreasing in altitude from 3000 metres on the high ranges to 500 metres in the foothills. Toward the east, altitude decreases gradually where the difference in elevation between the high ranges and the low slopes is about 800 metres.

The year in this area is divided into two periods; the winter season from October until March, and the summer season from April until September. In southern Asir, as has been indicated, rainfall maximum is during the summer season. In the northern Asir, as well as southern Hejaz escarpment, rainfall concentration is during the winter season, although at Alayyah and Al-Aja'edah in Gamid area there is a well-distributed rainfall throughout the year. The western slopes of the escarpment show rainfall maximum during the summer season. Consequently, three of Koppen's formulas were used, the formula for summer maximum, the formula for winter maximum, and the formula for evenly distributed rainfall.

Table 8(14) shows the index of aridity at selected stations in the escarpment. They are arranged in four groups. Groups 1 and 2 represent southern Asir and the western slopes which show summer maximum rainfall. Groups 3 and 4 represent northern Asir and southern Hejaz with winter maximum rainfall.

TABLE 8(14)

Index of aridity and type of climate at stations in Asir and southern Hejaz highlands

Station	Mean Annual Temperature (F)	Mean Annual Rainfall (inch)	Index of Aridity (r)	Type of climate
Group 1 : Southern Asir				
As-Sawdah	51.0	25.6	9.7	Humid
Abha	60.8	15.8	11.9	Semi-Arid
Al-Kam	59.0	18.5	11.5	Semi-Arid
An-Nimas	56.6	25.4	10.9	Humid
Ibalah	58.0	26.2	11.2	Humid
Temniyyah	56.0	26.4	10.8	Humid
Tenomah	59.5	22.6	11.6	Semi-Arid
Group 2 : Western slopes (below 1000 metres)				
Jabal Fayfa	69.8	22.8	13.8	Semi-Arid
Jabal Salah	69.2	23.0	13.7	Semi-Arid
Horub	69.8	24.5	13.8	Semi-Arid
Thurayban	67.0	25.7	13.2	Semi-Arid
Mokhwa	66.8	25.4	13.2	Semi-Arid
Group 3 : Northern Asir				
Al-Alayyah	59.3	19.9	6.9	Humid
Al-Aja'edah	59.0	22.1	8.7	Humid
Az-Zafir	56.0	20.1	5.3	Humid
Baljurshi	62.8	14.0	7.0	Semi-Arid
Qiddanah	56.0	18.5	5.3	Humid
Group 4 : Southern Hejaz				
As-Sut	68.0	12.6	8.0	Semi-Arid
Farain	66.0	15.0	7.3	Semi-Arid
Mahdam	66.0	14.6	7.5	Semi-Arid
Liyyah	68.0	9.4	8.0	Semi-Arid
Baqran	69.2	10.1	8.2	Semi-Arid

It can be deduced from Table 8(14) that all the stations which are located on the high ridges of the escarpment of Asir, such as As-Sawdah, An-Nimas and Az-Zafir, show humid climates. These stations are not, in fact, situated at the highest elevations on the escarpment; there are some ranges which have a greater altitude than these stations and probably receive larger amounts of precipitation whilst experiencing lower temperatures. Furthermore, the stations in the western slopes of the escarpment are situated at low levels and none of them has a height of more than 900 metres and, nevertheless, show semi-arid climate. Between the highest station in the western slopes - Jabal-Salah, 900 metres - and the peaks of the high ridges - 3000 metres - there is not even one station to show the climatic conditions prevailing on the western slopes at higher altitudes. Precipitation on these slopes should increase as elevation increases and temperature becomes lower as altitude becomes higher.

The stations on the eastern slopes of the escarpment of Asir, such as Abha and Baljurshi, show semi-arid conditions. While the semi-arid conditions in the western slopes are as a result of the considerable increase in air temperature, the semi-arid climate in the eastern slopes is caused by the great decrease in rainfall. Jabal Fayfa or Thurayban receive a relatively abundant annual precipitation, but temperature, because of low altitude, is high. Mean monthly temperature of the summer season, on the other hand, is normally less than 22°C (71.6°F) at stations on the eastern slopes such as Abha. Consequently, semi-arid conditions prevail on the eastern slopes and the low western slopes, but they are different from each other. The semi-arid climate in the eastern slopes is cool, while that which prevail in the western slopes is hot.

To the north of Gamid district in northern Asir is southern Hejaz escarpment which extends northward into Taif area. The stations of this section of the escarpment show semi-arid climate. It is possible that this type of climate dominates the whole area, although these stations do not offer adequate evidence as to the climatic conditions which exist on the high ridges to the west and south-west of Taif, since the stations which represent southern Hejaz in Table 8(14) are situated at a height of less than 2200 metres. However, since the highest ranges in southern Hejaz rarely exceed 2500 metres, it is likely that the semi-arid conditions prevail throughout the area.

In the whole area of the escarpment of Asir and southern Hejaz the boundary between the steppe and the humid climate can generally be defined as the area between the contour-lines of 2350 and 2450 metres. The semi-arid or the steppe climate has been found to dominate the slopes below 2350 metres, while the areas that exist above 2400 metres normally experience humid climatic conditions. However, it has to be stated that the boundary of the humid climate may extend downward on the western slopes to lower elevation where the atmospheric moisture, either in the form of rainfall or fog and mist, is of greater amounts. The transitional boundary between the steppe climate that exists on the western slopes below 1000 metres, and the humid monsoon climate that probably prevails on the western slopes of the escarpment in areas above 1000 metres, can be defined as the area between the contour-lines of 1000 and 1200 metres approximately.

On the basis of the results of the previous analysis of the index of aridity according to Köppen's formulas, three main types of climates have been recognised in Saudi Arabia. These main types are as follows :

1. BW (Arid Climate)
2. BS (Semi-Arid Climate)
3. C (Warm temperate rainy climate)

However, these three types of climate are not found in Saudi Arabia as simply as this. The differences between one region and another in the degree of aridity, the concentration of rainfall in the winter season or the summer months, and the differences in the conditions of air temperature have caused further subdivisions in almost every one of these main types. After considering the above-mentioned characteristics of every area of the country, the following climatic regions were recognised.

1. BWhse : This type of climate dominates most of Saudi Arabia, from the Arabian Gulf in the east to the Red Sea in the west, with the exception of Asir and southern Hejaz highlands as well as the Jazan-Sabya districts, and from the northern province in the north to the Rub-al-Kali in the south. The small letter h indicates that the mean annual temperature within this climate is over 64.4°F (18°C). The small letter s indicates that the summer season is dry, while the small letter e has been used by the author to show that this climatic region in Saudi Arabia is extremely arid or true desert where precipitation is very variable and normally ranges between 1 and 3 inches, and there are some years which may pass without rainfall. Moreover, within this climate the relative

humidity is very low and the mean annual is normally 30% and less. Within this climate the effectiveness of the atmospheric humidity is lowered by the phenomena of sand and dust storms, as has been pointed out previously.

2. BWhw : The prevailing climatic conditions in this climatic region are almost similar to those in the climatic region mentioned above, but in this region the frequency of sand and dust storms is very low, the frequency of fog and mist is relatively higher, and the amount of precipitation is considerably larger, either because of increases in elevations, as in the Kamis-Mushait area, or because of the proximity to the Red Sea, as in Jazan-Sabya districts. Moreover, rainfall concentration in this climatic region is during the summer season, while winter is dry (w). This climate is found in the eastern slopes of the escarpment of southern Asir and includes Bishah and Kamis-Mushait. It is also found in the southern section of the Red Sea coastal plain to the south of latitude 18°N and includes Abu-Arish, Sabya and Malaki.

3. BWhs : This climatic region is arid and hot (BWh) and shows winter concentration of precipitation while summer is dry (s). This climatic region exists in the eastern low slopes of northern Asir and southern Hejaz and is also found in the low mountainous areas to the north, north-west of the high escarpment of Taif area. It includes Taif, Bissel and Mecca in these areas.

4. BSkw : This climatic region is found in the high eastern slopes of southern Asir and includes Abha, Al-Kam and Tenomah. It is semi-arid and enjoys a cool climate (BSk) where mean annual temperature is under 64.4°F (18°C) and shows summer rainfall concentration while winter is almost dry (w).

5. BSks : The climatic conditions dominating this climatic region are similar to those which prevail in the above-mentioned climatic region. The only difference is that the rainfall concentration is during the winter season, while summer is dry (s). This climate is found in the high slopes of northern Asir and in the escarpment of southern Hejaz, and includes Baljurshi, As-Sut and Farain.

6. BShw : This climatic region exists in the low western slopes of the escarpment of Asir and southern Hejaz (below 1000 metres) and includes Jabal Fayfa, Horub and Thurayban. It is semi-arid (BS) and, because of the low altitude, it is hot (h). Rainfall concentration in this climatic region is during summer, while the winter season is almost dry (w).

7. Cwbx : This climatic region is found on the high ridges of the escarpment of southern Asir to the south-west, west and north-west of Abha. It is normally found on areas which have elevations of 2300 metres and more in Asir. This region includes As-Sawdah, An-Nimas, Ibalah and Temniyyah. The prevailing climatic conditions in this region are temperate where mean temperature of the coldest month is below 64.4°F (18°C), but above 26.6°F (-3°C), and the mean temperature of the warmest month is over 50°F (10°C). Rainfall

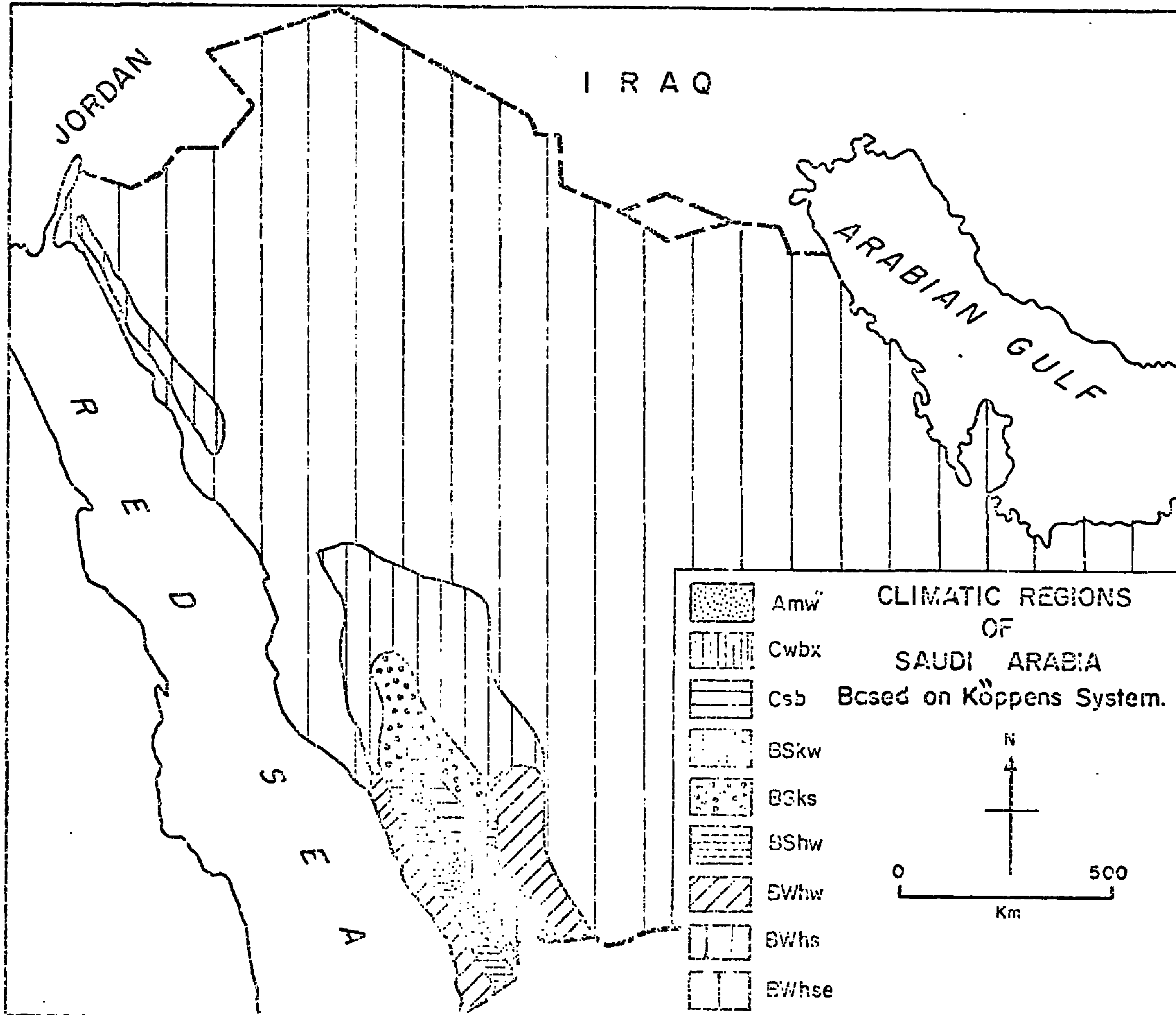
concentration is during the summer season while winter season is almost dry (w), and the summer months are cool (b) where mean monthly temperature of the warmest months is under 71.6°F (22°C). Rainfall maximum in this climatic region in Saudi Arabia is normally in late spring or summer (x).

8. Csb : The prevailing climatic conditions in this region in the country are similar to those dominating the climatic region of Cw. The only difference is that the rainfall concentration is during the winter season while the summer months are almost dry (s). This climatic region is found in northern Asir (Gamid area) on areas of high elevations (normally above 2450 metres) and includes Az-Zafir, Al-Aja'edah and Qiddanah.

Between Cw and Cs climatic regions on the high ridges of the escarpment of Asir and BSh climatic region in the low western slopes of this escarpment, there are no stations to show the climatic conditions prevailing in the area. BSh climatic region, in the low slopes of the western face of the escarpment, is normally found below 1000 metres, while Cw and Cs climatic regions are found on the high ridges of more than 2300 metres. Between 1000 and 2300 metres on the western slopes, climatic data concerning this area are not available. There are about 1300 metres on the western slopes of the escarpment without any climatic information. It is expected that this area has the climatic characteristics of C climates on the high ridges and BS climate on the low western slopes above the low foothills of the escarpment. Because of the increases in elevation in this area, rainfall increases while temperature decreases, and it is probable that the disturbances of the Red Sea Convergence Zone, which predominate in this area during the period of October-May, as has been discussed in another chapter of this study, are intensified by orographic effects of the escarpment. Furthermore, it is possible that the thunderstorms associated with the Inter-tropical Convergence Zone of the summer season, which appear to reach their maximum effects in Asir during the period of July-August, are also intensified by relief on the western slopes of the escarpments, when the moist air of this season is forced to ascend in a short distance up to 3000 metres. It is expected that there are two periods of heavy rainfall - the first is during the period of November-April, after which rainfall may decline in May and June, and the second is during the period of July-August, after which rainfall decreases considerably in the period of September-October. Consequently, it might be true to consider this area to experience the monsoon climate, and thus it may be correct to classify this area as follows :

9. <u>Amw''</u> : This climatic region is found on the western slopes of the escarpment of Asir in areas located above 1200 metres and below 2000 metres. This area enjoys the tropical rainy climate (A) of the monsoon type (m) and there are two distinct rainfall maxima (w''), November-April and July-August, separated by two dry periods, May-June and September-October. As a group, A climate show mean temperatures of the coolest month above 64.4^{o}F (18^{o}C), but in Saudi Arabia, A climate may show less than this value during winter in its highest limits on the higher slopes of the escarpment of Asir.

On the basis of the former classification, Figure 8(I) was constructed to show the climatic regions in Saudi Arabia according to Köppen's classification. A glance at the map under


JORDAN
IRAQ
ARABIAN GULF
RED SEA
Amw"
Cwbx
Csb
BSkw
BSks
BShw
BWhw
BWhs
BWhse
CLIMATIC REGIONS
OF
SAUDI ARABIA
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consideration will make it clear that of the five major climatic groups of Köppen's, three are represented in Saudi Arabia. It is only the D and E climatic groups or the cold climates of the high latitudes that are missing on the map. The boundaries between a climatic region and another have been drawn, sometimes on the basis of the evidence furnished by stations, while in other cases they are made after making estimations of mean temperature or precipitation of some areas in Asir and southern Hejaz, according to their latitudinal and altitudinal locations, as well as their positions relative to the moist winds.

From the foregoing description in the previous chapters it is clear that all the requisites for B climates are present in the major part of Saudi Arabia. It is, therefore, little wonder that the B climates form the dominant types on the map of the climatic regions of this country, and the arid or the desert climate represents about 98% of the surface area. The vast extent of the arid climates is an indication of the limited agricultural potentiality in Saudi Arabia. All over the arid section, agriculture can only be practised through irrigation. The desert portions are almost all barren and wasteland, sometimes with no sign of any natural vegetation. There is no surplus water within B climates to maintain a ground water level near the surface, with the result that no permanent streams exist in this climate. Evaporation within these climates greatly exceeds precipitation, with the result that nothing will be left to allow the modest vegetation of winter to thrive during spring or summer. In fact, for at least seven months of the year, within these climates in Saudi Arabia, there is not any appreciable moisture content in the soil and this, coupled with the lack of vegetation to transpire, means that relative humidity on many occasions during summer is very low.

The relatively large amounts of precipitation that normally are received in the humid climates in Asir escarpment are limited to small areas and are not of sufficient quantity to result in permanent streams, though perennial springs are found in the high ridges of these highlands.

APPENDIX

APPENDIX I*

LIST OF CLIMATIC STATIONS, THEIR GEOGRAPHICAL LOCATION, ALTITUDE, YEAR OF INSTALLATION AND THE TYPE OF DATA AVAILABLE

No.	Station	Latitude (north)	Longitude (east)	Elevation (metres)	Year of installation	Air Temperature	Rainfall	Relative humidity	Atmospheric pressure	Wind	Evaporation
1	Abha	18° 13'	42° 30'	2190	1955	x	x	x		x	x
2	Abqaiq	25° 56'	49° 36'	155	1952	x	x	x		x	x
3	Abu-Arish	16° 58'	42° 50'	69	1955		x				
4	Abu-Jeniah	19° 00'	42° 45'	1670	1966		x				
5	Abu-Saud	17° 28'	44° 10'	1300	1966		x				
6	Afif	23° 55'	42° 56'	940	1967		x				
7	Al-Aflaj	22° 17'	46° 44'	539	1965	x	x	x			x
8	Al-Aja'edah	19° 54'	41° 35'	2330	1967		x				
9	Al-Ain	18° 22'	42° 30'	2300	1965		x				
10	Al-Amir	18° 05'	42° 48'	2100	1967		x				
11	Al-Aqiq	20° 15'	41° 39'	1370	1966		x				
12	Al-Eyes	*	*	*	1967		x				
13	Al-Badi	22° 01'	46° 34'	550	1965		x				
14	Al-Bad'a	28° 28'	30° 01'	247	1966		x				
15	Al-Gadeer	21° 28'	40° 38'	*	1966		x				
16	Al-Gorrah	18° 06'	42° 53'	2060	1967		x				
17	Al-Haddar	21° 59'	45° 57'	690	1965		x				
18	Al-Hawiyyah	*	*	*	1966		x				
19	Al-Isawiyyah	30° 43'	37° 59'	559	1964		x				
20	Al-Kam	18° 16'	42° 29'	2200	1965		x				
21	Al-Kammasin	20° 28'	44° 48'	523	1965		x				
22	Al-Karj	24° 10'	47° 24'	430	1966	x	x	x		x	x
23	Al-Lith	20° 09'	40° 17'	6	1966	x	x	x			
24	Al-Majma'ah	25° 53'	45° 21'	688	1966	x	x	x			
25	Al-Modaylif	19° 32'	41° 03'	58	1966	x	x	x		x	x
26	Al-Mosayjid	24° 05'	39° 05'	*	1966		x				
27	Al-Nowayh	*	*	*	1966		x				
28	Al-Qasim Airport	24° 19'	43° 58'	580	1966	x	x	x	x	x	x

* The consistency of the names in Appendix 1 have been written according to the Ministry of Agriculture, Hydrological Division.

No.	Station	Latitude (north)	Longitude (east)	Elevation (metres)	Year of installation	Air Temperature	Rainfall	Relative Humidity	Atmospheric pressure	Wind	Evaporation
29	Al-Qalbah	*	*	*	1969		x				
30	Al-Ulayyah	19° 40'	41° 54'	1840	1966		x				
31	Al-Ula	*	*	900	1966	x	x	x		x	x
32	Al-Wajh	26° 13'	36° 27'	8	1966	x	x	x	x	x	
33	An-Nayriyah	27° 28'	48° 28'	50	1961	x	x	x	x	x	x
34	An-Nimas	19° 06'	42° 09'	2600	1966	x	x	x			x
35	Aqiq Road	20° 25'	41° 36'	1480	1966		x				
36	Ar-Ar	*	*	*	1966	x	x	x		x	x
37	Arwah	23° 54'	44° 40'	970	1967		x				
38	Arjah	24° 42'	44° 19'	940	1966		x				
39	Ashayrah	21° 46'	40° 38'	1160	1966		x				
40	As-Sayb Al-Kabir	21° 37'	40° 25'	1240	1966		x				
41	As-Sarrar	*	*	*	1966	x	x	x		x	x
42	As-Sulayyil	20° 28'	45° 34'	510	1965	x	x	x	x	x	x
43	As-Sut	20° 23'	41° 18'	1880	1966		x				
44	Az-Zafir	19° 58'	41° 30'	2533	1956		x				
45	Az-Zilfi	26° 18'	44° 48'	605	1965	x	x	x			x
46	Badanah	31° 00'	40° 59'	660	1961	x	x	x			x
47	Badr	23° 44'	38° 46'	119	1966		x				
48	Bahrah	21° 27'	39° 32'	*	1965		x				
49	Baljurshi	19° 52'	41° 33'	2400	1960	x	x	x			x
50	Bani-Hammam	17° 44'	43° 59'	1200	1965		x				
51	Bank-Thawr	20° 07'	41° 26'	2140	1966		x				
52	Baq-'a	27° 52'	42° 23'	720	1966		x				
53	Baqran	21° 08	40° 40'	*	1966		x				
54	Belesmer	18° 47'	42° 15'	2250	1966	x	x	x			x
55	Bir Bin Hirmas	*	*	*	1966		x				
56	Bir Bin Sarrar	19° 31'	42° 39'	1400	1966		x				
57	Bir Idamah	18° 30'	44° 12'	1160	1966		x				
58	Bishah	20° 00'	42° 36'	1040	1957	x	x	x	x		x
59	Bissel	21° 12'	40° 42'	1510	1966		x				

No.	Station	Latitude (north)	Longitude (east)	Elevation (metres)	Year of installation	Air Temperature	Rainfall	Relative Humidity	Atmospheric pressure	Wind	Evaporation
60	Buraydah	26° 20'	43° 58'	625	1966		x				
61	Dafinah	23° 18'	41° 58'	940	1966		x				
62	Darb-Zabaydah	21° 59'	40° 27'	1100	1966		x				
63	Dariyyah	24° 44'	42° 55'	*	1966		x				
64	Dawadmi	24° 29'	44° 23'	940	1966		x				
65	Dhahran	26° 17'	50° 09'	22	1950	x	x	x	x	x	
66	El-Abis	18° 04'	43° 16'	2350	1966		x				
67	Farin	21° 22'	40° 07'	*	1966		x				
68	Fawarah	26° 03'	42° 38'	810	1966		x				
69	Gadayrin	21° 18'	40° 18'	1900	1966		x				
70	Garith	21° 37'	41° 53'	1100	1966		x				
71	Haddat-Ash-Sham	21° 47'	39° 41'	*	1966		x				
72	Hafuf	25° 30'	49° 34'	160	1964	x	x	x	x	x	x
73	Hail	27° 31'	41° 44'	914	1955	x	x	x	x	x	x
74	Hamdah	19° 02	43° 37'	1280	1966		x				
75	Harjah	17° 56'	43° 22'	2350	1966		x				
76	Harrad	24° 04'	49° 01'	300	1966	x	x	x		x	x
77	Hawiyah	21° 26'	40° 31'	1540	1966		x				
78	Hotat-Sudair	25° 35'	45° 36'	660	1966	x	x	x			x
79	Jabal Fayfa	17° 16'	43° 05'	860	1956		x				
80	Jabal Nazim	18° 45'	43° 56'	1510	1966		x				
81	Jabal Qahar	21° 03'	41° 30'	1490	1966		x				
82	Jabal Salah	17° 03'	43° 07'	900	1957		x				
83	Jazan	17° 03'	42° 57'	5	1964	x	x	x	x	x	
84	Jeddah Airport	21° 30'	39° 12'	11	1952	x	x	x	x	x	
85	Jeddanah	*	*	*	1966		x				
86	Kabkebiyyah	20° 24'	45° 23'	605	1966		x				
87	Kadarah	17° 49'	44° 00'	1295	1966		x				
88	Kalkh	21° 19'	40° 48'	*	1966		x				
89	Kamis Mushait	18° 18'	42° 44'	1950	1965	x	x	x	x	x	x
90	Kayber	18° 46'	42° 53'	1650	1966		x				

No.	Station	Latitude (north)	Longitude (east)	Elevation (metres)	Year of installation	Air Temperature	Rainfall	Relative Humidity	Atmospheric Pressure	Wind	Evaporation
91	Kiyat	18° 44'	42° 53'	*	1966	x	x	x		x	x
92	Koff	24° 55'	44° 43'	755	1966		x				
93	Kulays	22° 08'	39° 70'	60	1966	x	x	x		x	x
94	Kurais	*	*	*	1966		x				
95	Kuramah	21° 55'	42° 02'	1060	1966		x				
96	Kwash	19° 00'	41° 53'	*	1966	x	x	x		x	x
97	Linah	*	*	*	1966	x	x	x			
98	Liyyah	21° 13'	40° 28'	1640	1966		x				
99	Ma'agla	*	*	*	1967	x	x	x		x	x
100	Madenah	24° 39'	39° 39'	672	1956	x	x	x	x	x	x
101	Malaki	17° 03'	42° 57'	178	1966	x	x	x		x	x
102	Medrekah	21° 59'	39° 59'	*	1966		x				
103	Mehdam	21° 02'	40° 40'	1880	1966		x				
104	Melbanah	23° 10'	39° 31'	*	1967		x				
105	Mesturah	23° 00'	38° 55'	*	1967		x				
106	Mecca	21° 26'	39° 49'	280	1966		x				
107	Mediq	21° 41'	40° 09'	690	1967		x				
108	Mowayh	22° 26'	41° 49'	970	1968		x				
109	Najran	17° 29'	44° 09'	1150	1958		x				
110	Nifi	25° 07'	43° 50'	780	1967		x				
111	Qatif	26° 33'	50° 00'	5	1967	x	x	x		x	x
112	Qaysumah	28° 19'	46° 07'	360	1961	x	x	x	x	x	
113	Qunizyyah	20° 03'	42° 17'	1200	1967		x				
114	Qurain	24° 40'	43° 47'	930	1967		x				
115	Qurayyat	31° 20'	37° 21'	549	1967	x	x	x		x	x
116	Quwyiyah	24° 05'	47° 14'	*	1967		x				
117	Rabiqh	22° 49'	39° 02'	8	1966		x				
118	Rafha	29° 39'	43° 30'	443	1961	x	x	x	x	x	x
119	Ranyah	21° 15'	42° 51'	810	1967		x				
120	Ras-Saffniyyah	28° 00'	48° 44'	5	1967	x	x	x			
121	Ras-Tanurah	26° 42'	30° 05'	5	1949		x				
122	Rayyan	23° 28'	45° 31'	*	1967		x				
123	Riyadh	24° 42'	46° 43'	609	1952	x	x	x	x	x	x

No.	Station	Latitude (north)	Longitude (east)	Elevation (metres)	Year of installation	Air Temperature	Rainfall	Relative Humidity	Atmospheric pressure	Wind	Evaporation
124	Sab'an	18° 37'	42° 19'	2200	1967		x				
125	Sabha	23° 15'	44° 39'	820	1967		x				
126	Sabya	17° 10'	42° 37'	40	1965	x	x	x			x
127	Samkh	19° 25'	42° 48'	1480	1967		x				
128	Samirah	26° 29'	42° 07'	950	1967		x				
129	Sanam	23° 41'	44° 47'	*	1967		x				
130	Sarat-Abidah	18° 10'	43° 06'	2400	1965		x				
131	Sayl-As-Saghir	21° 33'	40° 28'	1465	1967		x				
132	Shaqra	25° 15'	45° 15'	730	1964	x	x	x			x
133	Shwaq	27° 21'	36° 25'	479	1967		x				
134	Skaka	29° 58'	40° 12'	574	1956	x	x	x		x	x
135	Sulaymi	26° 17'	41° 21'	950	1967		x				
136	Suq-El-Jenub	16° 43'	58° 37'	40	1965		x				
137	Suq-Suwayq	*	*	*	1967		x				
138	Tabalah	28° 24'	36° 35'	774	1964		x				
139	Tabarjal	20° 01'	42° 14'	1305	1967	x	x	x		x	x
140	Tabuk	30° 31'	38° 17'	*	1967	x	x	x	x	x	x
141	Taif Airport	21° 29'	40° 32'	1395	1960	x	x	x	x	x	x
142	Tajar	18° 31'	42° 24'	2300	1967		x				
143	Tathlith	19° 32'	43° 31'	1080	1965		x				
144	Tawalah	20° 13'	41° 22'	2070	1967		x				
145	Tayma	27° 38'	38° 29'	820	1966	x	x	x		x	x
146	Tendahah	18° 18'	42° 51'	1900	1966		x				
147	Thamala	*	*	*	1967		x				
148	Thurayban	19° 27'	41° 50'	575	1965		x				
149	Thurabah	21° 13'	41° 39'	1130	1965		x				
150	Turaif	31° 41'	38° 39'	829	1961	x	x	x	x	x	
151	Um-Al-Birak	23° 26'	39° 14'	*	1967		x				
152	Um-Lajj	24° 04'	37° 13'	5	1966		x				
153	Um-Thalwiyah	21° 08'	40° 50'	1560	1966		x				
154	Unayzah	26° 04'	43° 59'	650	1956	x	x	x		x	x
155	Wadi-Ranyah	20° 15'	42° 09'	1340	1966		x				
156	Yabrin	23° 19'	48° 57'	200	1967	x	x	x		x	x

No.	Station	Latitude (north)	Longitude (east)	Elevation (metres)	Year of installation	Air Temperature	Rainfall	Relative Humidity	Atmospheric pressure	Wind	Evaporation
157	Yagra	18° 41'	42° 59'	1880	1966		x				
158	Yanbu	24° 07'	38° 03'	8	1966	x	x	x	x	x	
159	Zahran El-Janub	17° 40'	43° 37'	2020	1964		x				
160	Zalim	22° 43'	42° 10'	940	1967		x				
161	Zaymah	21° 37'	40° 10'	660	1967		x				

APPENDIX II

THE MONTHLY AND ANNUAL MEAN OF RAINFALL FOR SELECTED STATIONS IN mm.

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Abha	43.1	20.4	43.4	77.4	32.3	13.5	50.9	46.6	2.0	2.5	39.4	15.4	386.9
Abqaiq	8.4	12.6	4.6	11.3	2.7	0.0	0.0	0.0	0.0	0.0	5.6	14.0	59.2
Abu-Arish	9.2	2.1	4.7	1.5	12.3	1.6	50.3	62.8	23.0	10.0	11.8	24.3	214.1
Al-Ain	0.0	21.7	25.4	24.5	27.9	7.8	17.9	25.5	7.5	9.6	44.3	0.0	212.1
Al-Kam	12.9	41.6	18.8	65.6	62.7	24.0	80.2	77.0	15.5	4.4	48.9	0.0	441.6
Al-Majma'ah	40.0	6.0	10.7	4.4	4.6	0.0	0.0	0.0	0.0	0.0	28.0	2.6	118.1
Al-Wajh	3.3	4.5	0.3	2.5	4.7	0.0	0.0	0.0	0.0	0.0	10.7	5.5	31.5
Badanah	4.3	0.5	5.2	5.6	2.9	0.0	0.0	0.0	0.0	0.5	5.0	5.2	29.2
Baljurshi	52.7	36.7	13.6	45.7	22.9	6.7	15.4	17.6	6.6	19.6	76.9	31.9	346.3
Bishah	12.2	4.4	13.4	39.0	24.3	1.7	12.0	1.1	0.0	2.1	25.2	9.9	145.3
Dhahran	10.0	13.8	3.2	10.0	3.4	0.0	0.0	0.0	0.0	0.0	9.3	6.8	55.5
Hail	13.7	7.9	4.4	11.0	6.0	0.7	0.0	0.0	0.0	3.0	14.8	16.3	77.8
Jabal Fayfa	57.1	18.4	24.7	56.3	62.0	39.2	92.8	82.8	43.3	29.8	29.0	22.0	557.4
Jabal Salah	32.6	10.6	7.3	28.3	34.2	23.3	100.6	120.4	47.2	43.0	46.8	68.1	563.7
Jazan	0.0	4.2	0.3	15.0	0.0	0.0	4.6	1.3	17.7	0.7	1.7	0.1	44.6
Jeddah	4.8	0.5	3.4	4.0	1.7	0.0	0.1	0.0	0.2	0.0	21.2	17.9	63.8
Kamis Mushait	9.0	36.6	34.9	32.7	30.2	8.3	34.1	25.2	10.4	0.1	24.1	1.5	247.1
Madenah	7.7	0.1	4.4	4.0	4.3	0.3	0.1	0.0	0.0	0.2	9.0	4.0	34.1
Najran	19.4	3.9	3.0	8.6	2.8	0.1	1.4	1.0	0.9	0.0	2.0	0.0	43.1
Naujriah	23.7	7.1	0.2	11.8	0.3	0.0	0.0	0.0	0.0	0.0	1.2	5.8	50.1
Qaysumah	19.1	7.3	1.5	5.6	3.0	0.0	0.0	0.0	0.0	0.2	4.8	3.2	44.7
Ras-Saffniyyah	0.5	34.2	16.1	13.5	3.1	0.0	0.0	0.0	0.0	0.0	52.5	3.6	123.5
Riyadh	23.5	11.3	11.7	70.4	11.4	0.7	0.1	0.0	0.0	0.0	10.2	11.3	100.6
Sabya	9.6	1.4	0.0	0.8	1.3	0.0	42.2	3.9	20.0	13.8	17.1	1.7	111.9
Sarat-Abidah	7.4	50.5	6.5	31.3	28.2	7.9	13.2	9.2	1.2	4.0	19.0	0.0	168.4
Shaqra	28.5	14.6	19.3	13.7	6.1	0.0	0.0	0.0	0.0	1.3	11.5	1.5	96.5
Skaka	7.4	3.2	4.4	12.9	0.1	0.0	0.5	0.0	0.0	5.4	27.6	4.2	69.7
Sug-El-Jenub	0.0	15.0	0.0	11.0	25.5	15.0	67.7	12.5	17.5	18.0	25.5	0.0	207.7
Tabuk	7.1	3.6	1.9	4.0	2.8	0.0	0.0	0.0	0.0	1.7	10.9	0.0	32.0

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Tathlith	4.3	5.8	9.2	13.0	2.5	0.0	1.2	0.0	0.0	0.0	8.6	0.0	44.6
Taif	10.1	12.8	10.4	12.2	17.8	6.6	4.7	10.3	5.1	7.1	47.2	18.1	162.4
Thurayban	35.6	63.1	8.8	45.3	44.6	65.1	70.2	74.1	75.2	26.6	108.7	9.2	627.5
Turabah	16.2	4.6	15.1	27.1	10.2	0.9	0.0	0.0	3.5	0.2	19.2	1.1	98.4
Turaif	8.4	1.3	4.2	5.8	0.9	0.0	0.0	0.0	0.0	1.0	1.2	6.2	29.0
Unayzah	27.5	9.6	22.2	9.9	12.2	0.0	0.0	0.0	0.0	2.0	21.4	6.3	111.1
Zahran El-Janub	11.6	18.9	19.9	28.6	16.2	2.0	33.5	7.7	0.0	0.0	9.2	1.5	149.1

APPENDIX III

THE MONTHLY AND ANNUAL MEAN OF AIR TEMPERATURE (in °C)

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Abha	11	12	14	15	18	20	21	21	20	17	14	12	16
Abqaiq	13	14	20	25	30	35	36	36	32	27	21	13	25
Alaflaj	15	16	22	26	32	34	34	35	31	26	20	15	25.6
Alkarj	14	15	19	23	30	32	34	35	30	26	11	16	24
Al-Ula	11	14	18	22	27	31	32	30	28	21	18	14	22.3
Al-Wajh	18	19	22	24	26	28	29	29	28	26	24	20	24.4
An-Nimas	9	10	11	12	15	18	19	18	17	13	11	10	17.6
As-Sarrar	14	14	19	24	29	35	36	35	30	22	20	15	25
As-Sulayyil	16	20	23	27	32	34	35	35	32	26	22	18	26
Az-Zilfi	12	14	19	22	27	33	33	33	31	22	19	13	23
Baljurshi	12	12	15	17	20	22	22	22	19	16	15	13	17
Belesmer	10	11	12	12	15	18	19	18	18	14	12	10	14
Bishah	16	18	23	27	28	30	31	31	28	24	21	17	24.5
Dhahran	16	17	22	25	31	35	36	35	32	28	23	17	27
Hafuf	16	16	19	24	28	33	34	33	31	27	21	17	25
Hail	11	12	15	21	28	29	31	31	29	22	18	12	23
Hotat-Sudair	14	14	19	23	28	32	34	34	31	26	19	15	24
Jazan	25	27	28	30	32	35	34	33	32	31	28	26	30
Jeddah	23	24	25	28	29	31	32	32	31	28	27	25	28
Kamis Mushait	14	15	17	19	22	24	23	23	23	19	17	13	19
Linah	12	14	22	24	29	32	32	32	30	21	16	15	23
Ma'agla	12	14	18	24	28	33	33	34	30	23	19	12	24
Malaki	24	25	27	30	33	32	33	32	32	31	29	27	30
Madenah	15	15	19	21	25	28	28	28	27	22	17	15	22.4
Qatif	15	16	22	24	28	33	34	33	31	26	23	16	25
Qurayyat	6	8	14	20	22	26	27	27	26	16	12	8	19
Qaysumah	13	14	20	22	30	33	34	34	30	21	17	15	24
Rafha	12	14	19	20	27	31	32	32	30	22	16	14	23
Ras-Saffniyyah	14	16	22	23	26	32	33	33	31	29	20	16	24
Riyadh	14	16	20	25	30	33	34	34	31	25	19	15	25

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Sabya	25	25	27	31	33	34	34	33	32	29	28	28	29
Shaqra	12	13	19	22	28	33	33	33	30	23	18	12	24
Tabarjal	10	17	13	20	23	27	29	28	27	19	15	12	19
Tabuk	10	13	17	21	26	30	32	30	26	21	16	11	21
Taif	12	13	19.4	21	25	28	28	28	27	22	17.4	14	22.4
Tayma	9	11	16	19	24	29	29	27	26	23	17	10	21
Unayzah	14	15	19	23	28	30	32	32	30	24	21	15	24
Yabrin	16	18	21	26	30	35	35	35	31	25	20	17	26

APPENDIX IV

THE ANNUAL AND MONTHLY MEAN OF DAYS WITH SAND STORMS

	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
Al-Wajh	2.0	0.5	1.2	2.0	2.0	0.0	0.2	0.5	1.0	0.0	1.0	0.0	9.7
Badanah	2.2	4.2	7.0	4.2	7.5	4.0	3.3	1.5	1.2	2.0	0.8	2.5	40.5
Dhahran	2.3	4.6	7.8	5.6	7.8	13.6	13	7.7	5.4	2.8	1.9	2.2	73.0
Hail	3.0	1.8	4.8	2.8	3.5	0.5	0.8	0.2	0	1.2	0.0	0.0	18.7
Jazan	0.0	0.0	0.0	0.7	1.7	1.4	3.8	0.8	0.2	1.0	0.0	0.0	8.0
Jeddah	4.5	2.8	3.8	3.6	3.5	3.2	4.3	2.3	2.1	0.3	1.9	2.8	34
Madenah	1.1	0.1	1.4	1.9	1.0	0.5	0.7	0.3	0.2	0.1	0.5	0.5	8.6
Kamis Mushait	1.0	0.5	1.0	1.7	1.0	1.7	2.L	1.0	0.0	0.0	0.0	1.3	7
Qasim Airport	6.0	2.5	6.0	4.3	7.3	2.0	2.0	1.0	0.6	1.3	0.6	1.0	30
Qaysumah	0.8	2.0	2.2	4.0	3.0	4.0	2.2	0.5	1.0	0.2	1.0	0.8	21.2
Riyadh	5.2	5.2	6.6	10.0	8.3	9.8	7.7	5.8	2.6	1.8	2.6	3.6	68.6
Tabuk	3.2	1.5	4.5	2.5	2.0	2.5	0.5	0.1	0.5	1.0	0.8	1.5	20.5
Taif	0.3	0.1	0.0	0.1	0.0	1.4	0.6	1.0	0.1	0.0	0.1	0.5	4.3
Turaif	2.2	2.7	6.2	6.0	1.5	0.5	0.5	0.7	0.2	1.0	1.2	1.7	25

APPENDIX V

THE MEAN MAXIMUM AIR TEMPERATURE (C^o)

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Abha	16	16.5	19.6	20	23	26	26	26	26	23	19.5	17.8	21.8
Al-Aflaj	22	24	24	34	39.9	43	43	43.6	41	37	29	26	34
Abqaiq	18	19	26	31	37	44	45	44	40	35	28	19	32
Al-Karj	20	22	28	31	38	44	43.8	44	41	37	29	21	33
Al-Wajh	23.5	24	25.6	27.6	30	32.6	32	33	32	32	29	25.7	29
An-Nimas	13	15	18	19.5	23	26	26	25.9	25	21	18	17.6	20.8
As-Sarrar	18	19	26	32	38	44	45	45	42	37	29	21	33
As-Sulayyil	25	25	31	34	39.9	43.6	44	43.9	41	36.6	30	26	35
Baljurshi	15	16	19	21.6	25	28.6	26	27	27.9	24	19	18	22.6
Bishah	26.7	27.6	31	33	36	39	36.7	38.9	37	33	29.5	27	33
Dhahran	22	21	25	30	37	41	41.8	41.7	39.9	36	28.7	24	32.6
Hafuf	21	23	33.5	32.5	39	44	43	43	41.5	39.5	26.5	26	31
Hail	18.6	18	24	27	32.9	37	37.9	38	36.9	31.9	22.8	20	29.5
Jazan	29	29	31.9	34.5	36	37	36.5	36	36	34.8	32	29.7	33
Jeddah	28	28.8	30.5	32.9	33	35.9	36	36.6	35	34	32	30	33
Kamis Mushait	20	19	23.6	23.8	25.8	30.5	29	29	28.9	25.6	22.6	21	25.8
Linah	17	21	29	27	37	42	41	41	39	34	22	21	31
Ma'agla	18	19	24	29	35	42	42	43.5	40	35	25	18	32
Madenah	24	24.5	30	33	38.9	42.6	42.7	42.5	41.5	37	29	26	34.5
Malaki	31	32	36	37.6	40	41	39	39	38	37.7	34.9	33	36
Qasim Airport	19	18.8	29	28	35.6	40	42	40	39	34	24	21	32
Qaysumah	19	21	31	30	38	42	42	43	41	35	24	23	32
Qatif	20	21	24	29	34	39	39	41	38	35	27	21	31
Rafha	17	21	29	28.5	36	41	40	41.5	39	34	22	21	30.8
Ras-Saffniyyah	19	20	27	26	34	40	40	39	38	34	23	21	30
Riyadh	20.9	21	28	31	38	41	43	42	40	35	26.7	23	32.5
Sabya	31	32.8	36	37	40	41	39.9	40	39	37	34	33	36.8
Skaka	16	21.5	28	29	34	40	40.9	41	38	34	22	20	29.6
Tabarjal	16	20.6	27	28	33	39	38	39	37	33	23	18	29
Tabuk	18.8	20.5	24.8	29	33.8	38.7	39.6	37	37	31.5	24.5	20.6	29.6
Taif	22	22.8	26	28.5	32.9	35	34.7	34.6	34	29.9	24.5	22.9	29
Tayma	20	22	23.7	27.5	33.6	36.8	37	37.5	38	33.6	25	21	29.6
Yabrin	21	22.5	28.5	34	39	45.5	45	45	42	37	29	22	34

APPENDIX VI

THE MEAN ABSOLUTE MINIMUM AIR TEMPERATURE (C^{O})

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Abha	9	8.4	10	11	12.9	14.9	16.5	15.8	14	10.9	9	7	11.5
Abqaiq	8.5	8.5	15	19	23	26	28.5	28	23.5	18.5	15	8.5	18.5
Al-Aflaj	6	7	13	16	21	22	23.5	23	20	14	12	5.6	15.3
Al-Karj	7	7.5	12	16	21	23	23.5	22.7	17	14	11.6	8	15.2
Al-Wajh	13	13.4	15.6	18.7	21.7	24	24.5	24.8	23.8	21.4	18	14.9	19.5
An-Nimas	6	6	8.8	9	12	14	14.9	14	13	10	7	8	10
As-Sarrar	7	7	12.5	17.5	21	26	27	25	21	16	13	8.5	17
As-Sulayyil	9	11	14.6	18.8	22.6	24.8	26	25.9	21.9	16.7	13.8	9	17.9
Baljurshi	8	7.4	9.6	11.5	14	17.6	16.9	16.6	15.9	12.6	9.7	7.6	12.5
Bishah	11	12	15	18.8	21	22.5	23	23.4	20	15.6	13	10	17
Dhahran	12	12	16.6	19.7	24.8	28	29	29.5	26	23	19	14	21
Hafuf	8	8	13	17	21	23	25	25	21	17	13	7.9	17.6
Hail	5	5.3	9	14.7	20	22.6	22.8	22.9	20	16	11	7	15
Jazan	23	23	24	26.9	28.8	30.4	30	30	28.9	27	24.9	22	26.5
Jeddah	19.7	19	20.6	22	23.9	25	27.7	27.7	26	24.9	22.9	21	23.6
Kamis Mushait	8	7.3	11	12	14	16	16.5	16	15	11.8	10	7	12.5
Ma'agla	6	6.5	12	17	20	23	25	25.5	22	19	13	7	16.5
Malaki	20	21	22.7	25.8	27.8	28	28.5	29	26	25	23	21.5	26
Madenah	12	12.9	17	20	24	28.6	28.9	28.6	27.8	22.7	17	14	21
Qasim Airport	7	7.5	9.6	15	21	23	33.6	28	22	18.5	13	8	16.3
Qaysumah	7	9	13	18	22	23	25	24	20	17	14	5.5	16.4
Qatif	10	9	14.5	18	22	27	27.5	27.6	23.5	20	17	9	19
Rafha	6	7	10	16	19	20	23	21	19	16	12	7.6	14.7
Riyadh	9	10	14.8	18	23.5	25.7	27	26	24	19.5	15	12.5	18.9
Sabya	19	19.8	21.5	24	26.4	27	27	27.5	25	21.5	20	17.6	23
Shaqra	6	8	13	18.5	22.5	23	23	23	21	15	12.5	6.5	16.5
Skaka	2	3	8	15	17.6	22	22.6	23	20.5	17.6	10.5	4	13.6
Tabarjal	3	4	8	10	17	18	20	21	17	12	8	4	12
Tabuk	2.4	3.3	7.6	11.9	16.8	20	21.5	20.9	18	14.7	9	4	12.6
Taif	8	7.8	11.9	13.6	17.7	20.9	21	20.6	19	16	18	9	14.9
Tayma	3	3.2	7	13	17	20	21	19	15	13	10	8	18
Yabrin	8	7.8	14.5	19	21	23	23.5	23.5	20	16	12	8	17

APPENDIX VII

HIGHEST RECORD OF AIR TEMPERATURE (C^{o})

	J	F	M	A	M	J	J	A	S	O	N	D
Abha	22.2	22	23.5	25.8	30	31	31.8	31.8	30.5	27.5	22.8	22.5
Abqaiq	27	34.5	35	41.5	47.5	48	48	48	45	38	45.5	27.5
Al-Aflaj	30	34.5	35.8	39.3	43	44.7	47	45.8	44	39	34.4	30
Al-Karj	26.5	33	35.7	38.3	45.7	46.7	47	47	44	40.2	34.2	29
Al-Wajh	31.4	32	33	34	39	44	35	44	35	33	38	32
An-Nimas	17.2	17.8	20.4	24	27.8	27	30.8	29	28.6	25	21.4	19.2
As-Sarrar	25.5	33	36.5	38	46.5	47.5	48.5	48	46.5	40.5	34.5	30
As-Sulayyil	33.9	36	40.4	41.4	46.2	48	48	49	46.6	40.8	37	35.2
Baljurshi	19	21.6	25.8	28.2	32.4	33.2	30.4	31.8	30.2	28.2	24	23.8
Belesmer	23	22.8	21.4	22.6	28	28	28.7	27.8	27.3	23	26.6	19.8
Bishah	33.9	34	35.2	36.4	39	40	4o	4o	39	34	33.8	31
Dhahran	29	32	39	40	44.2	47	48	46	44.7	42	35	29.8
Hafuf	25.7	33.5	34.7	38.5	44	45	45.5	46.2	44.5	39	34.5	27
Hail	28.2	29	34	37	40	43	41.8	43	40.2	37	29.3	26
Jazan	30.3	35	39	40	40	41	41	39	39	38	35	32
Jeddah	33	33.8	36	38	41	48	44	41	44	38	36	33
Kamis Mushait	24.8	25	27	28.2	31.6	34	33.2	32	31.4	28.6	27	25.9
Ma'agla	25	31	34	35	44	45	45.5	46	43.5	39	35.5	27
Malaki	33	35.6	38.2	39.8	45	46.4	42.3	42.8	42	40.8	38.2	34.9
Madenah	30	33	37	39	43.5	46	46	47	44	40.5	35	32
Qasim Airport	28	32	37	37	42.2	44	45	45	44.4	38	33	28.5
Qatif	24	29.3	37.5	43.5	46.2	44.2	43.5	45	41	38.3	34	29
Rafha	25	32	36.5	41	41.5	44	42.5	45	44.5	41	30	28
Riyadh	30	32	37	39	43.3	49	46.7	45	43.8	39.5	34	30.8
Sabya	33	35	39	41	45	45	45	43	44.5	43	38.4	36.8
Shaqra	26	29	32	39	43	44	45	44.5	43	38.5	34	27.5
Skaka	25.5	29	32.4	36.8	39.9	41.4	42.8	44.2	44	39.6	33.8	29.3
Tabarjal	27	31	33.7	37	38.3	39.7	41.2	43.6	41	39	30	25.3
Tabuk	30	32	37	36.2	41	44	44.6	45	43	38	31	29.8
Taif	27.8	27.8	32	33	37.2	38.9	39.2	38	38	34	28.3	26.7
Tayma	24	29	31	40	43	43.2	45	44.7	44	39.6	32.7	32.8
Yabrin	28.5	36.5	38	41.5	45	47.5	48	47.5	45.5	40.5	35.5	28

APPENDIX VIII

LOWEST RECORD OF AIR TEMPERATURE (C°)

	J	F	M	A	M	J	J	A	S	O	N	D
Abha	1	0.6	2.8	1.2	3.2	6	10	10	4.4	6	3.2	2.2
Abqaiq	3	1.0	7	13.5	18	22	25	22	19	15	10	2.5
Al-Aflaj	-4.2	0	4.8	11	16.7	16.6	20	20	13.6	9.8	3.2	-3.5
Al-Karj	-3.5	-4	1.4	9	14.6	16	16.5	17.5	10	5.9	1.7	-6.3
Al-Wajh	8	8	10.6	13	12	18	19.5	22	20	17.4	10	9.2
An-Nimas	-5.6	-4.4	1.4	4	7.2	6.8	10.2	10	6	3	1.4	-6
As-Sarrar	0	-3	5.5	11.5	17	19	20	19	14	10	5.5	-2.5
As-Sulayyil	2.3	1	5.6	9	15	18.4	21	21	14	10	3	2
Baljurshi	2.3	1	-1.6	4.7	8.2	12	11.4	7	9.8	7.8	4	2.6
Belesmer	-2.2	-2	0.5	2.5	4	4.2	8.1	8	4	0.4	-7	-6
Bishah	3.5	2.2	4.5	10	15	14	16.5	15	10	6	5	2
Dhahran	5	4.6	10.5	12	17.4	23	25	24.6	21.8	18	9.3	3.7
Hafuf	2	-0.3	6	11	14	18	20.9	15	15	12	7	-0.4
Hail	-4	-4.4	0.1	5	12	15.5	17	17.5	13.2	8	1.5	-6
Jazan	19	19	17	21	21	26	24.8	27.8	26	24	21	19
Jeddah	14	13	14	16.5	16	23.2	23	24	21	22	19	16.8
Kamis Mushait	3	1.0	7	5	10	12.8	14	12.6	11	5.2	6.2	1.8
Ma'agla	1	-3.5	4.5	11	15	19.5	20	21	16	12	6	-3.5
Malaki	16.5	17	21	20.8	24	20	18	21	20	20	19	15.8
Madenah	5	5	8	11.5	15.5	23	24	24	23	18	12	7
Qasim Airport	-0.6	-2.5	1.7	5	5	16	17.2	17.8	18.3	12.2	8	-1.1
Qatif	4.5	3.6	6.7	11	16	17	22	21.5	17.5	11	11	2.4
Rafha	-1.0	-2.0	6	6	12.5	17	20	17	16	9.5	2.0	-3
Riyadh	-3.8	-3.5	2	9	15	17	17	18	14.5	7	3.8	-3.9
Sabya	17	14	19	20	20	21	23	25	21	18	18	12.6
Shaqra	-1	-1	4	13	15	20	20	20	14	11	5	4
Skaka	-3.7	-2.9	2.3	6.7	11.7	15	17.4	19.8	14	8.4	0.3	-5.6
Tabarjal	-8.9	-7.2	0.4	3.1	7	9.6	13	15.5	13	6.7	2.2	-13.3
Tabuk	-2	-2.5	0	5.2	10.2	16	17.2	17.8	15	8.5	3	-6
Taif	-2	1.7	2.2	5	8	12	13	13	12	7.8	6	-1.4
Tayma	-4.4	-4.4	2.2	4	8.9	11.6	12.8	12.7	10.2	-1.0	-4.2	-7
Yabrin	-1.0	0.0	5.5	13	15	19	18	20	16	12	5.5	-3

APPENDIX X

THE MONTHLY AND ANNUAL MEAN OF RELATIVE HUMIDITY (%)

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Abha	55	63	55	62	51	45	51	52	44	45	63	59	58
Al-Aflaj	45	36	38	49	26	18	15	16	19	26	44	43	35
Abqaiq	55	57	59	54	38	25	31	39	42	49	53	55	48
Al-Karj	48	41	48	46	31	23	18	19	22	28	49	50	33
Al-Ula	52	49	47	46	32	29	30	28	29	35	43	50	39
Al-Wajh	48	56	54	60	65	69	69	72	72	62	53	51	61
An-Nimas	66	62	61	65	61	58	58	59	51	51	68	63	55
As-Sarrar	42	46	46	45	43	19	15	17	19	28	49	40	33
As-Sulayyil	47	45	32	29	22	15	15	16	19	24	48	46	31
Az-Zilfi	49	46	42	47	28	18	17	16	18	26	45	47	37
Baljurshi	64	65	62	57	48	43	47	46	44	45	46	63	55
Belesmer	61	59	60	63	51	43	49	51	46	48	66	63	55
Bishah	49	43	44	49	44	35	24	27	26	35	48	51	39
Dhahran	64	62	57	51	42	35	41	43	47	58	56	60	52
Hafuf	57	53	52	48	34	24	20	29	42	52	55	58	44
Hail	56	49	34	35	25	15	14	15	18	28	57	57	35
Hotat-Sudair	56	48	46	48	31	21	15	17	22	25	51	53	36
Jazan	71	72	74	65	63	62	61	63	65	66	66	69	66
Jeddah	60	61	60	51	59	59	57	60	64	67	62	61	61
Linah	50	41	42	47	28	12	13	12	20	35	51	50	33
Ma'agla	60	53	49	50	36	19	14	18	17	24	54	60	36
Malaki	65	62	61	60	56	57	63	61	52	54	62	61	60
Madenah	49	47	35	32	27	17	16	15	19	25	45	50	31
Mudaylif	43	40	36	38	35	35	28	36	43	33	38	46	38
Qaysumah	50	48	43	40	26	15	16	16	17	27	56	49	33
Rafha	49	44	41	40	25	14	15	14	16	29	46	48	32
Ras-Saffniyyah	64	63	60	55	48	36	30	42	50	61	63	67	53
Riyadh	50	45	42	37	27	15	17	16	17	28	45	50	32
Sabya	68	68	66	60	57	51	56	58	60	62	66	67	61
Shaqra	53	45	44	45	37	20	18	16	19	23	49	56	35
Skaka	56	48	38	35	25	20	20	17	23	35	53	50	36
Tabarjal	50	48	46	42	29	26	28	29	31	40	51	53	43

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Tabuk	48	35	38	27	20	22	18	20	22	23	45	49	36
Taif	57	51	43	44	36	27	28	31	33	41	58	58	42
Tayma	50	49	39	34	26	26	31	28	25	42	53	51	35
Unayzah	52	46	36	42	38	18	16	18	18	23	46	46	32
Yabrin	51	46	49	32	30	14	15	24	33	32	50	59	35

APPENDIX IX

MEAN ABSOLUTE MAXIMUM RELATIVE HUMIDITY (%)

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Abha	82	87.8	83.6	85.6	73.6	66.6	72.4	77.4	68.8	70.8	84	82.8	81
Abqaiq	83.5	80.5	77	76	51	38	35.5	49.5	69	75.5	80.5	75.5	65.9
Al-Aflaj	67	63	48	45	43	27.5	21	22	29.5	36	58	60	43.3
Al-Karj	69	59.5	49	46.5	48.5	28	24.5	28	23.5	39.5	55	61.5	43.5
Al-Ula	84	63	68	68	55	42	43	37	45	61	69	83	62
An-Nimas	78	80	81.5	90.5	86.5	77	78	85	81.5	79.5	96.5	96	84
As-Sarrar	69.5	76	71	82	50	29	22.5	32	41.5	58	74	81	57.2
As-Sulayyil	58	60	44.8	45.5	35	22	22.7	24	27.7	38	64.8	68	42.5
Az-Zilfi	71	69	56	62	54	30	21	21	21	34	54	72	47
Baljurshi	82	84	79	77.5	73	69	62	73	70.5	69.5	78.5	80	74.9
Belesmer	76	71	80	82	66	67	71	74	70	68.2	81	82.9	74
Bishah	68.5	61.5	60.5	72	67	46.5	36.5	41	48.5	44	55	69	55
Dhahran	88	86	80.8	74.7	66	53	62	66.5	81	86.7	83	83.7	76
Hafuf	60	60	59.4	55.8	50.5	40.2	37.3	50.6	60.8	62.6	55	53.4	49.6
Hail	78.7	73.5	54.4	60	47	26.5	24	25	28	45.8	78	83	49.9
Hotat-Sudair	68	60	59.5	55	39	26	22	25.5	29	36	61.5	69	45.8
Jeddah	79.5	75.8	76.5	77.8	75.8	79.8	80	80	83.7	84	77	80	79
Kamis Mushait	82	88	86	81.3	79.7	62	63.7	70	53	58.3	83	85	72
Malaki	71	62.5	61	67	57	33.5	28.5	28	29	41.5	75	77	52.6
Madenah	59	56.7	43.5	44	35	24.5	24.5	25.5	26.7	32.8	60.2	56.5	40.9
Mudailif	92.5	90.5	86	88.5	84	87.5	80	83	92.5	93	89.5	93.5	88.3
Qaysumah	80.5	71	60	54.5	36.5	20.5	16.5	20	21.5	28	70	70	45.7
Qatif	88	84	81.5	84.5	76.5	54.5	52.5	80.5	85	89	87	85	79
Rafha	80.4	67.5	55	52	33	16.5	18	16	22	43	68	70	45
Sabra	93.5	88	89.5	86	78	83	77.5	81	93	92	93.5	91.5	95.6
Shaqra	63.5	57.5	55	66.5	46.5	31	27.5	29	33.5	41.5	68	66	48.3
Skaka	84	62	49	54	33	30	31	24	29	36	78	73	48
Tabarjal	63	55	52	58	67	45	51	55	53	58	68	68	56
Tabuk	82	77.5	67.2	59.7	53	45	45	48.8	58	65.8	76.5	76	62.9
Taif	84.7	78	65	67.7	58.8	43	39.5	42.5	46.5	68.8	84.8	84	63.4
Tayma	68	66	56	54	50	45	46	49	48	54	69	63	52
Unayzah	72.8	61.9	51.3	50.3	40	20.5	19.6	21.7	22	29.7	61.8	65	43
Yabrin	71	65	68.5	64	34.5	21	21	33.5	46	51	67	67	50.7

APPENDIX XI

MEAN ABSOLUTE MINIMUM RELATIVE HUMIDITY (%)

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL MEAN
Abha	47	43.8	37.7	39	27.5	25	32.8	29.8	22.5	22	43	36	33.4
Abqaiq	39	30	32	28	17	12	21	19	13	15	26	35	24.2
Al-Aflaj	26	21	20	25	15	8	8	10	10	17	28	27	18
Al-Karj	26	25	24	24	18	10	14	11	11	20	25	25	19.4
Al-Ula	29	28	26	30	21	15	11	15	23	32	45	39	26
An-Nimas	53	55	45	52	34	26	31	28	18	19	48	51	38.5
As-Sarrar	40	29	28	25	23	10	10	12	14	16	29	35	22
As-Sulayyil	30.6	28.6	20.6	18	14.6	11.4	11.6	12.4	12.4	20.4	32.4	36.2	20.6
Az-Zilfi	33	28	26	26	21	13	11	13	11	17	25	35	22
Baljurshi	36	31	30	35	21	19	22	21	15	21	32	32	26.2
Belesmer	45	27	36	40	36	16	17	21	15	22	44	46	30.4
Bishah	29	28	20	22	21	20	13	14	15	17	29	28	21.3
Dhahran	41	37.8	26.8	26.8	22	13	14.5	16.5	19	25	37	38	26.6
Hafuf	34	27	27	30	21	15	16	16	15	18	26	30	23
Hail	31.7	30.5	20	23	18	11	10	11	11	17.8	39	38	20.7
Hotat-Sudair	32	26	21	25	16	11	9	11	14	15	32	33	20.4
Jeddah	44.7	36.5	37.5	39	39.5	42	46	42.5	49	46.5	42	42.5	41.6
Malaki	43	43	43	35	36	36	34	39	23	24	36	36	36
Madenah	36	28	27	20	17	15	16	19	11	9	26	34	22.4
Mudailif	43	40	36	40	32	34	39	38	42	27	39	34	46
Qaysumah	38	27	22	18	9	8	12	8	7	19	28	27	19
Qatif	48	35	30	26	22	17	18	17	24	25	38	41	28.3
Rafha	32	25	18	16	9	8	8	9	9	20	33	34	18
Riyadh	29.5	28.5	18	23.5	20	9	10	12	9	13.5	26	26	19
Sabya	47	46	44	38	36	38	32	34	35	34	38	40	38
Shaqra	29	26	28	29	22	12	13	13	10	15	30	31	21.5
Skaka	40	34	27	16	16	10	8	11	16	20	33	41	22.7
Tabarjal	38	25	25	20	14	13	14	16	19	21	40	39	21.5
Tabuk	30.5	23.5	16.8	15.5	16.8	13	13	15	14	20	29.8	32	20.1
Taif	35	28	23	22.5	19	12	14	13.4	12.5	18	33	31.5	21.9
Tayma	29	24	22	16	14	16	19	16	11	11	29	20	19
Unayzah	28.5	24.8	23.5	19.4	17	10	8.7	9.7	10.6	14.4	28	23	19
Yabrin	23	35	26	22	10	9	11	14	10	14	27	28	18

APPENDIX XII

HIGHEST RECORD OF RELATIVE HUMIDITY (%)

	J	F	M	A	M	J	J	A	S	O	N	D
Abha	100	100	100	100	100	100	100	100	99	100	100	100
Abqaiq	95	98	99	97	98	89	63	100	100	99	99	95
Al-Aflaj	93	85	94	100	69	38	30	86	75	72	85	92
Al-Karj	100	94	99	97	68	42	35	65	75	67	96	100
Al-Ula	100	99	100	100	100	56	60	66	58	89	100	99
An-Nimas	100	100	100	100	100	100	100	100	100	100	100	100
As-Sarrar	99	100	98	98	89	78	57	78	95	100	100	100
As-Sulayyil	100	100	100	100	96	54	42	48	45	74	100	100
Az-Zilfi	98	96	99	100	100	72	47	48	48	78	100	100
Baljurshi	100	100	100	100	100	100	100	100	100	100	100	100
Belesmer	100	100	98	99	98	97	83	88	88	88	100	96
Bishah	100	97	100	96	100	87	64	80	63	82	91	99
Dhahran	100	100	100	100	94	92	95	100	100	100	98	100
Hafuf	98	100	97	95	84	57.5	77	88	98	100	97	94
Hail	97	98	95	100	95	65	44	42	43	95	100	95
Hotat-Sudair	96	82	86	96	72	52	41	39	63	62	100	96
Jeddah	99	92	93	91	99	100	100	100	100	100	94	96
Malaki	97	97	100	100	100	100	100	100	100	100	100	100
Madenah	95	90	86	90	61	60	40	37	32	71	94	89
Mudailif	100	100	100	100	100	100	100	97	100	100	100	100
Qaysumah	91	93	95	88	85	32	31	79	48	97	100	95
Qatif	98	92	94	93	93	92	82	95	97	96	97	94
Rafha	96	89	87	87	92	27	31	40	36	89	90	87
Riyadh	97	100	95	96	95	63	52	85	50	71	95	89
Sabya	100	100	100	100	100	100	100	100	100	100	100	100
Shaqra	81	64	88	97	74	44	36	48	45	62	100	100
Skaka	100	94	90	94	73	52	56	62	67	82	100	95
Tabarjal	100	96	100	100	100	100	98	85	89	93	100	99
Tabuk	99	93	97	90	100	84	93	65	85	96	96	93
Taif	100	96	95	96	95	89	70	86	77	90	100	100
Tayma	93	100	100	84	82	44	62	61	75	77	99	91
Unayzah	100	100	98	99	98	59	43	40	42	70	100	100
Yabrin	98	96	96	96	69	48	48	83	95	100	97	98

APPENDIX XIII

LOWEST RECORD OF RELATIVE HUMIDITY (%)

	J	F	M	A	M	J	J	A	S	O	N	D
Abha	8	14	8	16	4	6	11	9	7	5	1	2
Abqaiq	16	1	1	1	2	2	2	2	2	2	2	6
Al-Aflaj	4	6	2	4	1	1	0	2	5	6	14	6
Al-Karj	10	8	3	3	2	3	8	9	5	5	15	10
Al-Ula	6	2	2	6	4	6	6	0	4	10	18	15
An-Nimas	2	2	6	4	6	6	8	6	1	3	2	4
As-Sarrar	2	1	1	1	1	1	1	1	2	2	1	1
As-Sulayyil	12	11	4	3	4	4	5	2	6	8	15	12
Az-Zilfi	11	7	3	5	6	2	9	9	8	12	21	3
Baljurshi	8	2	9	11	1	9	5	6	4	1	7	5
Belesmer	8	6	10	16	16	5	3	12	9	8	22	19
Bishah	8	4	2	4	1	2	4	8	2	2	8	6
Dhahran	6	4	1	1	1	1	1	1	1	1	12	11
Hafuf	22	12	8	9	7	6.5	6.5	7.8	6	7.2	14	20
Hail	11	8	8	4	4	6	5	5	5	7	10	8
Hotat-Sudair	12	7	6	6	4	4	7	7	10	10	8	2
Jeddah	15	10	9	14	16	9	12	17	6	22	22	17
Malaki	12	5	5	10	2	12	8	26	3	1	16	9
Madenah	12	7	15	3	8	8	2	3	2	3	5	20
Mudailif	16	11	12	25	11	17	10	9	12	2	17	14
Qaysumah	10	6	1	1	1	1	1	1	1	1	9	2
Qatif	27	13	8	8	4	6	2	1	2	2	2	2
Rafha	10	1	1	1	1	1	1	1	3	5	16	8
Riyadh	8	7	5	7	6	4	4	6	5	7	7	9
Sabya	23	27	24	13	7	16	15	24	14	2	21	23
Shaqra	13	14	5	5	6	9	11	10	12	12	19	15
Skaka	12	5	1	1	0	0	1	2	4	6	7	5
Tabarjal	10	8	5	2	4	4	5	6	5	4	14	11
Tabuk	9	3	3	2	3	3	3	4	4	5	9	6
Taif	6	10	10	8	1	1	2	4	2	3	11	8
Tayma	14	11	10	5	7	9	15	10	15	8	13	5
Unaizah	2	2	0	0	2	3	2	4	3	6	8	10
Yabrin	5	1	1	2	2	2	2	2	2	2	2	4

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