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# The Climate of Jordan in the Past and Present

## THE CLIMATE OF JORDAN IN THE PAST

### The Climate of Jordan in Geological Times

Jordan is located in the eastern Mediterranean basin between latitudes 29° 30′ and 32° 31′ N. The main characteristics of its present climate reflect the transitional location of the country between the Mediterranean climate in the west and arid climates in the east and in the south. The nature of the present climate is controlled by the general circulation of the atmosphere over the Mediterranean, which is chiefly an interrupted westerly circulation in winter, and a subtropical desert climate associated with the subtropical high pressure cells in summer. The planetary westerlies over the Mediterranean are strengthened in winter, as the Azorian high pressure center weakens and shrinks southward, resulting in frequent invasions of the region by cold polar air masses from Europe. The sharp temperature contrasts between the cold European polar air masses, which invade the eastern Mediterranean basin in winter, and the relatively warm Mediterranean air masses motivate frontogenesis. The energy released when a cold front of a polar trough enters the Mediterranean is usually sufficient for cyclogenesis in winter. Cyclones of mostly Mediterranean origin usually start affecting Jordan in mid October or early November and dominate the weather until late April.

In summer, the Azorian high pressure center is strengthened and expanded, blocking any activity of cyclogenesis in the eastern Mediterranean. The Icelandic low is weakened and shrunk northward causing the front to retreat to the north.

### The climate of Jordan in the Pre-Quaternary periods

Even though many aspects of the paleoclimatology of Jordan are highly speculative and details are still obscure, it can however be inferred from geological evidence that Jordan experienced arid or semi-arid climates during most of the geological periods which extended from the pre-Cambrian to the middle Cretaceous. This is clearly indicated by the dominance of colored sandstone deposits of Nubian facies in the country (Burdon, 1959). Determining the characteristics of the environment of sandstone deposition is not a simple matter, but it has reasonably been argued that most of the Nubean sandstone was deposited in terrestrial environments under predominantly desertic conditions of erosion cycle (Abed, 1982).

### The climate of Jordan in the Tertiary

Figure 1 shows major vacillations of the coast line between the Tethys and the Arabian Nubian land masses during geological times. Five major transgressions are depicted in the Paleozoic, but the last regression in the Permian brought arid and semi-arid conditions to the whole area. Three other transgressions which occurred in the Mesozoic brought the Tethys deeper inland. Although large parts of Jordan were covered by sea during the middle Triassic, deposits of Nubian sandstone in the upper Triassic and lower Jurassic indicate a terrestrial regime. Another major transgression occurred in middle and upper Jurassic when the sea had flooded most of Jordan. There was also another regression in lower Cretaceous with Nubian sandstone depositing over large areas of southern Jordan. Jordan was again submerged from mid Cretaceous into the Oligocene, but it can be inferred from the nature of sediments that the climate in the areas lying to the east and south was arid.

Climatic conditions during the Miocene are uncertain, but the terrestrial deposits of angular poorly-sorted hard chalk, limestone and flint, which were covered by the earliest basalt flows in Syria, indicate that deposition was occurring after short transportation which suggest arid or semi-arid climates. The inter-basaltic clay layers which were formed between successive flows of basalt in southern Syria and northern Jordan indicate that the climate of the Neocene was characterized by several periods of sufficient rainfall to permit forests to flourish. Periods of abundant rainfall were rare and discontinuous and were frequently interrupted by periods of arid or semi-arid conditions (Orni, 1972).

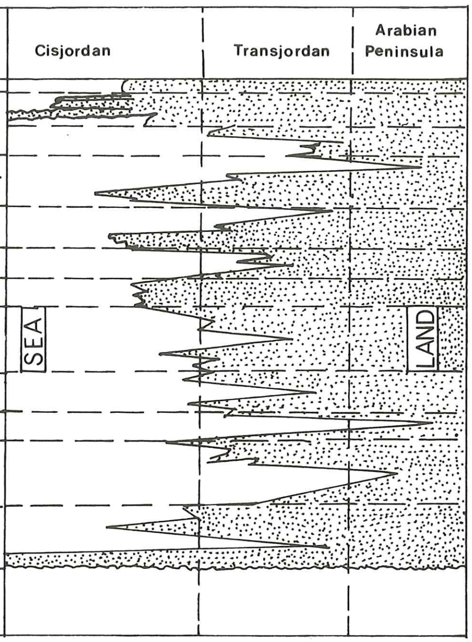
### The climates of the Quaternary

*Climatic fluctuations of the Pleistocene*

Several spectacular climatic oscillations of magnificent consequence occurred in the pleistocene. These oscillations were

1. Transgressions and regressions in the Middle East (Orni, 1971).

| Duration of time (million years) | Million years before today | Age | Period |
|---|---|---|---|
| 6 | 6 | | Quaternary |
| 17 | 23 | Cenozoic | Pliocene, Miocene, |
| 43 | 66 | | Oligocene, Eocene |
| 55 | 121 | Mesozoic | Senonian, Turonian, Cenomanian, Lower Cretaceous |
| 40 | 161 | | Jurassic |
| 35 | 196 | | Triassic |
| 30 | 226 | Paleozoic | Permian |
| 70 | 296 | | Carboniferous |
| 40 | 336 | | Devonian |
| 30 | 366 | | Silurian |
| 70 | 436 | | Ordovician |
| 60 | 496 | | Cambrian |
| ~2 000 | ~3 000 | Precambrian | Precambrian |




manifested in the high latitudes of the northern hemisphere by five major 'glacials' and 'interglacials'[1]. During the glacials, temperature had dropped sharply and ice-sheets of the ice-cap and the elevated areas of Eurasia and North America expanded enormously and advanced southward reaching areas in the middle latitudes which had never been glaciated before. Glacials were separated by interglacial periods in which temperature had increased and ice sheets shrank and retreated northward[2].

Glacials and interglacials of the high latitudes were associated—in the middle latitudes—with 'pluvials' and 'interpluvials'. Pluvials were defined as 'Periods of widespread long-term rainfall increase of sufficient duration and intensity to be of geomorphic significance' (Butzer, 1963). Climatic conditions during interpluvials were as dry as today or even drier than present conditions.

In the Levant, the main pluvial 'A' can be correlated with 'Riss' or both 'Riss' and 'Mindell'. Pluvial 'B' was only slightly developed and was probably connected with 'Wurm'. Anyhow, it is well known that no uniform pluvial phase spanned the 60,000 years of 'Wurm'[3]. Details of the paleoclimatology of the Levant during the Pleistocene are still incomplete, but the major changes in moisture regimes and precipitation intensities can be inferred from the findings of several works in geology, geomorphology, ecology and archaeology. The main characteristics of the climate of the Levant during the Pleistocene can be summarized as follows:

1) Pluvials were caused by more atmospheric depressions over the eastern Mediterranean and more numerous rainstorms passing eastwards[4].
2) Pluvials were associated with more frequent torrential rains in the rainy season, especially during the transitional seasons, but summers were no less dry than at present. Climatic conditions in the present deserts of the Levant and southwest Arabia were less arid.

The following evidence supports the hypothesis of abundant rainfall during the pluvials of the Pleistocene in the Levant:

a) High lake levels: The Dead Sea had—as geomorphological studies have indicated—many old strandlines at levels of 1,430, 540, 430, 300, 250 feet, as well as ten minor strandlines (Butzner, 1955, Schattner, 1962).
b) Fluctuations of the Mediterranean level. There are numerous indications of fluctuations in the Mediterranean level along the shores of Palestine and Lebanon during the Pleistocene.
c) Stratigraphy of geological deposits and paleolithic industries which were found in caves of the Mt Carmel

[1] The five major glacials of the Pleistocene are: Guns, Mindell, Riss and Wurm.

[2] Research in the paleoclimatology of the Pleistocene indicated that the division of the Pleistocene into five periods of glacials and interglacials was an oversimplification. Each glacial was actually characterized by a series of brief but intense cold spasms in which glacials had advanced and warm periods of glacial retreated (Butzer, 1963).

[3] The simple model correlating pluvials and interpluvials of the middle latitudes with glacials and interglacials of the high latitudes is inadequate. It is true that the main pluvial of the late Pleistocene was associated, in most cases, with major glacial thrusts in 'Wurm', but, in many cases, it was possible to show that pluviation was at a maximum in early 'Wurm' when the extent of continental glaciers was quite limited, and was at a minimum in periods of maximum world glaciation (Butzer, 1963).

[4] The southward expansion of glaciers in northern Europe to latitude 51°N, and the corresponding strengthening of the glacial anticyclone over the Laurentian and Fenno-scandinavian ice domes displaced the belt of cyclonic storms southward through a distance of about 15° of latitude from its present postion (Crowe, 1971).

group and studies of the rich faunal associations in the area provide a picture of moist and cool early glacial period in middle Paleolithic, a midway warm interval and a final intense cold phase in upper Paleolithic (Butzer, 1965).

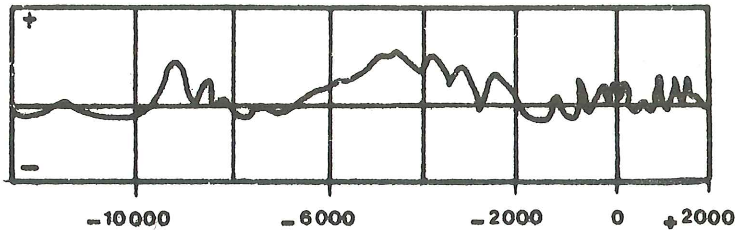
3) Traces of pluvials were strongest on the Mediterranean littoral but they decreased rapidly towards the interior.
4) The following geomorphological and ecological evidence suggests greater cold in the highlands of the Levant during the last glacial age, and pluvial conditions in the lowlands during the early glacial age:
   a) The glaciation of the high mountains of Lebanon and Mt Hermon indicate a snowline which is 1,000 meters lower than the present snowline.
   b) The presence of crocodiles in Palestine during the last interglacial age and again—apparently after an interval—in postglacial times.
   c) Deposits of flatish and angular limestone rubbles which are attributed to frost shattering in the high mountain caves.
   d) Plant impressions which were found in the high mountains from the last glacial age record only temperate woodland species such as oak, beech, elm and hazel (Butzer, 1965).

*Climatic fluctuations of the post-glacial periods*

Amplitudes of the climatic fluctuations which occurred during the post-glacial periods seem very small when compared with the grand oscillations of the Pleistocene. Nevertheless, important changes of the ecosystems in the areas of marginal climates like Jordan were attributed to them.

The following account of the climatic fluctuations in the Levant is mainly based upon the works of Butzer (1955, 1961) who reported that the recession of glacials at the end of 'Wurm' was followed, in the Levant, by a period of dry conditions which lasted through the late Paleolithic and early Mesolithic. Anvimeloch concluded from a study of prehistoric mollusca in Palestine that the early Mesolithic was characterized by a climate warmer and drier than the present climate. Similar results were reached by Picard from geological evidence in the Jordan Valley where the Pluvial 'B', which was associated with 'Wurm', was followed by a period of terra rossa formation (Butzer, 1955). The Mesolithic dry period which coincided in Europe with a warm interlude had ended in 8800 BC and was followed by a reversal of minor pluvial conditions during the late Mesolithic and Neolithic periods lasting well into the third millenium (FIG. 2). Miss Bate pointed to a faunal change in Natufian—Mesolithic times including the disappearance of a half dozen species of gazelle, a hedgehog and a species of hyaena, suggesting a more humid phase in late Mesolithic (Butzer, 1955). Picard identified a grey–black marshy loam in various alluvial deposits in the Jordan Valley which might have been connected with moister climate during late Mesolithic and Neolithic (Butzer, 1955).

2. Main trends of precipitation in the Near East since about 12000 BC (Butler, 1961).




Ancient civilizations of the Near East germinated in a moist fluctuation that had occurred in late Mesolithic and Neolithic, frequently termed 'Pluvial C' or the Mesolithic moist interlude and the Neolithic wet phase. Rainfall during that period was considerably greater than the average present precipitation, and what are now considered as marginal lands were densely populated. Moist conditions in the eastern Mediterranean continued through the Neolithic but suffered a sharp decline in the period between 4700–4200 BC. After regaining equilibrium, rainfall, in the Levant, remained remarkably uniform until 2500 BC. The period 2850–2650 BC, in which many cities were built in Palestine, was the last period of rainfall abundance.

Conditions during the period between 2500–1000 BC were drier than present conditions are. The onset of this dry period can tentatively be dated at 2100 BC and maximum aridity might have been achieved between 1800–1300 BC. Numerous towns in Palestine and Jordan were abandoned in the period between 2100–1800 BC and sedentary life in the marginal areas of Jordan was not existent until the 13th century BC. From 1000 BC to 900 BC rainfall in Jordan and Palestine was roughly equivalent to rainfall in the first half of this century.

Our knowledge of the climatic fluctuations during the late Chalcolithic and the Bronze ages is unfortunately vague and incomplete.

*Climatic fluctuations in the Christian era*

The climate in the 5th century BC was relatively moist, but the following three centuries were somewhat drier. In the beginning of the first century BC, rainfall improved and the first two centuries of the Christian era were moist; rainfall was probably somewhat greater than the present rainfall. This is clearly indicated by the prosperity of Jerash between 130–180 AD and by the several legends reported by al-Masʿūdi in 'Mūrūj al dhaheb' of running waters and numerous oases in the Syrian desert at that time. Much archaeological evidence dating from that period, including old Roman bridges and ruined piers on present dry wadis, and many well heads and houses indicating springs which do not exist today, support the claims of al-Masʿūdi.

The period of abundant rainfall ended by the beginning of the third century and simultaneously the level of the Dead Sea in 333 AD became as low as it is today. The period of low rainfall persisted until the end of the 6th and beginning of the

7th century AD reaching a maximum in 640 AD. Cessation of building activity and sedentary occupation in marginal regions in the Levant and the many reported droughts in northern Arabia indicate the increase of prevailing aridity in the last five centuries of the Christian era.

*Climatic fluctuations in the Islamic era*

Climatic fluctuations during the Islamic era were numerous, but none of them was long enough to introduce major modifications upon the landscape. However, the impact of these fluctuations upon ecosystems and land use was recognizable. The first two centures of the Islamic era were relatively moist and more humid than is the case today. This is clearly indicated by archaeological findings of many Umayyad palaces, hunting boxes and baths in the desert where no water or game exist today. These two moist centuries were followed by a period of dry climate which persisted through the 10th and 11th centuries AD, but was followed by another period of moist climate in the 12th and 13th centuries. Other fluctuations of moist and dry climates are listed in table 1.

**Table 1** Short-term rainfall trends of the Christian and Islamic eras (Butzer, 1955)

| Period | Rainfall | Period | Rainfall |
|---|---|---|---|
| 1–180 | Very moist | 1428–1460 | Very moist |
| 180–390 | Dry | 1460–1540 | Dry |
| 390–415 | Moist | 1540–1680 | Very moist |
| 415–670 | Very dry | 1680–1708 | Dry |
| 670–925 | Very moist | 1708–1838 | Moist |
| 925–1100 | Very dry | 1838–1875 | Dry |
| 1100–1310 | Very moist | 1875–1900 | Moist |
| 1310–1428 | Very dry | 1901– | Very dry |

*Climatic fluctuations during the period of instrumental record*

The recent trends of rainfall in Jordan during the period 1937–76 were investigated by Shehadeh (1978a). Results of the analysis revealed a clear tendency for a rainfall decrease; average annual rainfall in the period 1937–56 was statistically different from the average of the period 1957–76 (Table 2).

**Table 2** Average annual rainfall in the periods 1937–56 and 1957–76

| Station | $X_1$ | $X_2$ | t |
|---|---|---|---|
| Salt | 715 | 540 | 2.8 |
| Irbid | 485 | 357 | 2.7 |
| Shoubak | 367 | 275 | 2.1 |
| Hawara | 397 | 324 | 2.3 |
| Madaba | 398 | 293 | 2.7 |
| Kufrinja | 682 | 560 | 2.4 |

$X_1$ = Average annual rainfall in the period 1937–56, $X_2$ = Average annual rainfall in the period 1957–76, t = Student t Value. For further details see Shedadeh (1978a)

Table 3 shows that the number of years of above average rainfall has also decreased. The present trend of rainfall decrease was accompanied, as Table 4 shows, by an increasing trend of rainfall variability especially in the southern parts of the country.

**Table 3** Number of years of above average rainfall in the periods 1937–56 and 1957–76

| Station | $n_1$ | $n_2$ |
|---|---|---|
| Salt | 16 | 8 |
| Irbid | 11 | 4 |
| Shoubak | 13 | 7 |
| Hawara | 14 | 7 |
| Madaba | 14 | 6 |
| Kufrinja | 14 | 7 |

$n_1$ = number of years of above average rainfall in the first period.
$n_2$ = number of years of above average rainfall in the second period. See Shehadeh (1978a).

**Table 4** Coefficients of annual rainfall variation in the periods 1937–56 and 1957–76 in Southern Jordan (Shehadeh, 1978a)

| Station | $V_1$ | $V_2$ |
|---|---|---|
| Tafila | 31 | 66 |
| Buseira | 25 | 62 |
| Shoubak | 31 | 58 |
| Wadi Musa | 31 | 58 |
| Mazar | 26 | 40 |
| Kerak | 31 | 44 |

$V_1$ = coefficient of annual rainfall variation for the period 1937–1956.
$V_2$ = coefficient of annual rainfall variation for the period 1957–76.

The decrease of rainfall in Jordan in the 20th century seems to be a part of a decreasing trend in the whole area. This trend was revealed in Jerusalem rainfall in the period 1845–1960 (Neumann, 1960; Rosenan, 1963; Ionides, 1939). Annual discharge of the Nile and the Tigris showed decreasing trends. Butzer reported that the discharge of the Nile at Aswan dam in the period 1870–1904 was 30 per cent greater than it was in the period 1905–52 (Butzer, 1961).

The trend of rainfall decrease in the Middle East during the latter part of the 19th century and the 20th century could be part of a dry fluctuation like other fluctuations which had occurred in the Islamic era. The environmental impact of this dry fluctuation was supplemented by man's misuse of natural resources.

The trend of rainfall decrease in Jordan was accompanied by another trend of increasing temperature. Trends of temperature in Jordan and other countries in the eastern Mediterranean were investigated by Shehadeh (1978b) and Rosenan (1963). The trend of temperature increase in the 20th century seems to be a worldwide phenomenon which has been weakening and levelling off in many parts of the world, including Jordan and the rest of the east Mediterranean countries (Shehadeh, 1978b; Callender, 1961; Georgiades, 1977; Landsberg, 1967; Mitchel, 1953; Neumann, 1971; Spar, 1973).

## THE CLIMATE OF JORDAN IN THE PRESENT

The synoptic climatology of Jordan is part of the synoptic climatology of the eastern Mediterranean basin. Therefore, it is necessary to give a brief account of the synoptic situation in the eastern Mediterranean before any discussion of the climate of Jordan.

*The synoptic situation in winter*

Meridional circulation of the upper air over the eastern Mediterranean is related to the differential heating between the warm waters of the Mediterranean and the cold land masses of southern Europe and the Atlas mountains. Deep upper air troughs are correlated with the invasion of the region by cold polar air masses.

When a zonal circulation prevails, waves form over the Mediterranean and move rapidly toward the east causing light rainfall and near average temperatures. Main features of the pressure distribution during the winter are:

1) High pressure centers develop over Turkey, Armenia, northern Iraq and the Arabian peninsula.
2) Due to the thermal difference between the Mediterranean waters and the land masses lying to the north and south, low pressure centers develop over central and eastern Mediterranean.
3) The Azores high pressure center extends to the areas lying south of the Atlas mountains.

Due to the regional distribution of pressure fields, the eastern Mediterranean is invaded by different types of air masses including cold arctic air masses (cA) and cold polar air masses (cP) which are usually associated with anticyclones or ridges of high pressure. Continental tropical air masses (cT) which come from north Africa usually occur in occluding warm sectors, especially in fall and spring.

In winter, the Mediterranean is occupied by one of the normal frontal zones in which disturbances frequently develop and move eastward. Frontogenesis is connected with the sharp contrasts in temperature and humidity between continental tropical air masses and the cold polar air masses. Short fluctuations of low temperature which occur in Jordan during the winter are usually associated with cold fronts, but severe outbreaks of cold weather are caused by cold pools and cold lows.

The weather in Jordan and other eastern Mediterranean countries, is dominated in winter by a series of depressions which move along the Mediterranean front from west or southwest to east and northeast. Most Mediterranean depressions form as lee or wave depressions over the Mediterranean. The general conditions favoring cyclogenesis are: (a) the existence of a baroclinic or frontal zone; (b) air convergence on the leeward slopes of the Alps; (c) unstability of air masses.

The Mediterranean depressions may be grouped, according to their areas of formation, into the following groups (Meteorological Office, 1962):

1) Depressions of the western Mediterranean basin which are usually called 'Genoa depressions' do not usually reach the eastern Mediterranean and have no effect upon the climate of Jordan.
2) Khamasin depressions. These are frequently called 'Saharan depressions' because they form in the area south of the Atlas mountains and move along the southern shores of the Mediterranean. Most of these depressions, which account for 18 per cent of the Mediterranean depressions, occur during the spring.
3) Depressions of the central and eastern Mediterranean: lee depressions sometimes form in the northern Ionian Sea, the southern Aegean Sea and the region of Cyprus, but the formation of new depressions in this area is usually rare and what is more common is the rejuvenation of old weak depressions especially in the neighborhood of Cyprus. Most depressions move in the eastern Mediterranean along three main tracks:
   i) An annual average of 10.5 depressions move to the north east through northern Syria and southern Turkey.
   ii) 11 depressions move annually to the east and a few of them reach northern Iraq.
   iii) An average of 1.5 depressions move to the southeast.

The decreasing number of cyclones moving in southern tracks explains the decrease of annual rainfall in Jordan from north to south.

*The synoptic situation in summer*

The most stable season in Jordan is summer. The following major changes occur in the pressure fields over the eastern Mediterranean due to the intensive heating of land masses:

1) A center of high pressure forms over the Mediterranean.
2) A belt of low pressure extends from north Africa to Pakistan and India through the Arabian and Indian Oceans. This huge low pressure belt brings the eastern Mediterranean within the monsoonal belt of southern Asia and invites hot and dry northerly continental tropical air masses from the high pressure centers over Mesopotamia, Asia Minor and the low land around the Caspian Sea. Two centers of low pressure cut-off are formed over the northern Red Sea and Saudi Arabia bringing occasional invasions of very warm air masses which raise temperature to very high levels and cause heat waves.

*The synoptic situation in spring and fall*

Spring and fall are the two transitional seasons in Jordan. Characteristics of the pressure fields which occur in the eastern Mediterranean during the spring are:

1) Gradual northward shifting of the high pressure center which had centered over north Africa during the winter giving way to the development of a low pressure center and the formation of Khamasin depressions.
2) The extension of the Siberian high pressure center over the eastern Mediterranean starts to weaken.

In fall, the most striking feature in terms of pressure patterns is the 'fall break', which clearly appears in the curves of daily pressure over the northern and western Mediterranean. The fall break usually occurs on the 20th October; it marks the first invasion of the region by cold polar air masses and accompanies the first cold front. It ushers in the start of the unsettled period of the year in the western and central Mediterranean (Meteorological office, 1962).

## SPATIAL DISTRIBUTION OF RAINFALL AND TEMPERATURE

It goes without saying that discussion of the spatial distribution of all climatic elements is beyond the scope and size of this paper. Therefore analysis is restricted to the main features of the spatial distribution of the two most important climatic elements, rainfall and temperature.

### 1 Rainfall

The rainfall of Jordan is associated with the atmospheric depressions which reach the eastern Mediterranean. Thus, annual fluctuations of rainfall reflect the variation in the annual number and intensity of these depressions. This is clearly shown by comparing annual rainfall totals in two years of different atmospheric frequencies. Table 5 compares the annual rainfall in the wet year of 1961, which had 64 days of depression activities, with the dry year of 1962 which had only 25 days of depression activities (Tarazi, 1971).

**Table 5** Annual rainfall in 1961 and 1962 (mm)

| Station | 1961 | 1962 |
|---|---|---|
| Deir Alla | 283 | 233 |
| Jerash | 350 | 225 |
| Kerak | 210 | 102 |
| Zerqa | 176 | 108 |
| Sweileh | 461 | 357 |
| Tafila | 136 | 83 |

The major controls of the spatial distribution of rainfall, as shown in FIG. 3 are physiography and latitude. Areas of high elevation appear as islands of heavier rainfall, while most of the Jordan Valley which lies below Sea Level receives less than 200 mm. of rain. Rainfall decreases considerably from west to east and from north to south. The eastward decrease is mainly caused by the adiabatic heating of the moist winds on the lee slopes of the eastern mountains. The rate of eastward rainfall decrease is often very rapid and considerable. Annual rainfall in the University of Jordan is 474 mm. but it decreases to 290 mm. in Amman Airport which is less than 10 kilometers to the southeast. The decrease of rainfall from north to south is attributed to the increased distance from the main tracks of Mediterranean depressions and the small number of depressions which travel along the southern Mediterranean track.

*Variability of rainfall*

Not only does rainfall decrease from north to south and from west to east, but it also becomes more variable. The main controls of rainfall variability in Jordan, as shown in FIG. 4, are physiography and latitude. The area of the least variability is on the western slopes of the Irbid Mountains which are directly exposed to the Mediterranean through the gap of Marj Ibn Amer. The influence of this gap upon the increase of rainfall as well as the decrease of variability in the northern Jordan Valley is very clear. Variability in the southern and eastern parts of the country, where arid or semiarid conditions prevail, exceeds 90 per cent. The negative correlation between annual rainfall and its coefficient of variation is tentatively shown in FIG. 5 which represents such relation in a number of climatological stations in Jordan.

*Seasonality of rainfall*

Despite the fact that the rainy season usually starts in October or November and lasts till May, the bulk of annual rainfall is concentrated in the winter months. Concentration of annual rainfall from December to March exceeds 79 per cent in the northern and central parts of the country; however, it decreases to less than 63 per cent in the southern and eastern regions where the contribution of khamasin depressions to the annual rainfall is considerable. Early rainfall which is very critical to the success of dry farming forms more than 13 per cent of annual rainfall in the northern and central regions. It exceeds 20 per cent in the south and in the east[5], nevertheless late rainfall which is of vital importance to the success of summer crops forms 8 per cent of annual rainfall in the northern and central regions, but it exceeds 14 per cent in the southern and eastern regions. The monthly distribution of rainfall for four selected stations is shown in Table 6.

[5] Precipitation in October and November is termed 'early rainfall' and precipitation in the months of December to March is termed 'winter rainfall'. Late rainfall is the precipitation in the two months of April and May.

3. Average annual rainfall 'mm.'.

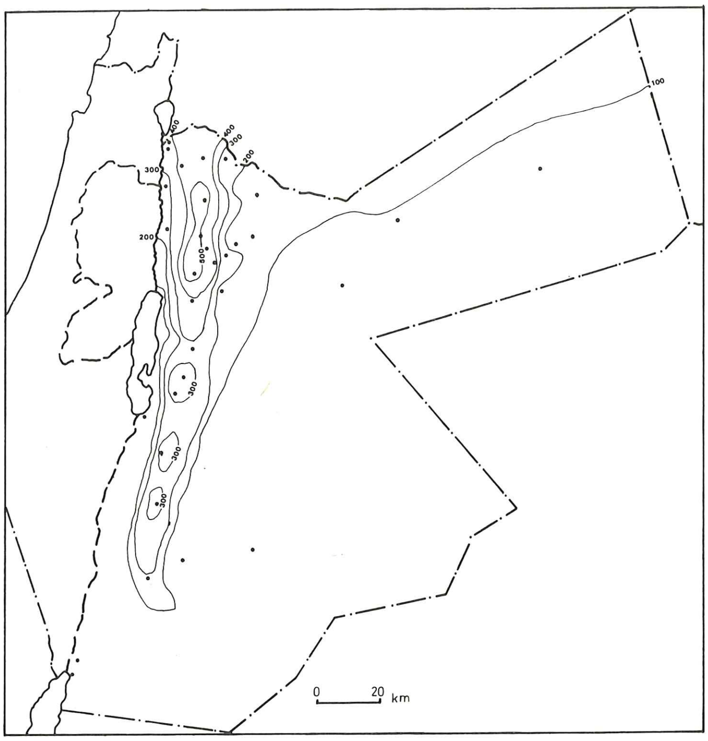



**Table 6** Monthly distribution of rainfall for the period 1952–74

| Station | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May |
|---|---|---|---|---|---|---|---|---|
| Ajlun | 1.82 | 9.57 | 19.43 | 25.26 | 18.28 | 17.68 | 6.72 | 1.19 |
| Salt | 1.15 | 8.79 | 19.38 | 26.82 | 19.01 | 17.93 | 6.08 | 0.80 |
| Shoubak | 1.34 | 6.79 | 27.09 | 26.41 | 16.66 | 17.57 | 7.43 | 1.69 |
| H4 | 6.79 | 12.64 | 12.14 | 15.97 | 15.69 | 15.24 | 13.84 | 7.65 |

*Variability of seasonal rainfall*

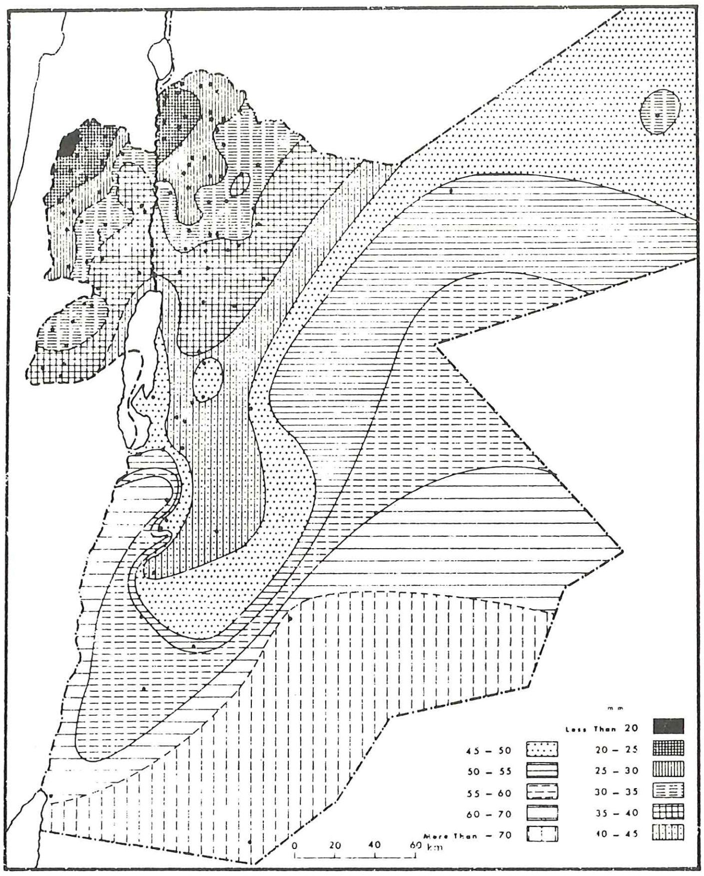
Variability of winter rainfall ranges from an average of 36 per cent in the northern and central regions to 55 per cent in the mountains of Kerak and Shoubak. In the Badia, especially in the southeast, it increases to more than 80 per cent. Variability of early rainfall averages 83 per cent for most of the country, but it reaches more than 128 per cent in the Badia. Late rainfall is more variable; its coefficient of variation exceeds 125 per cent in most of the country.

## 2 Temperature

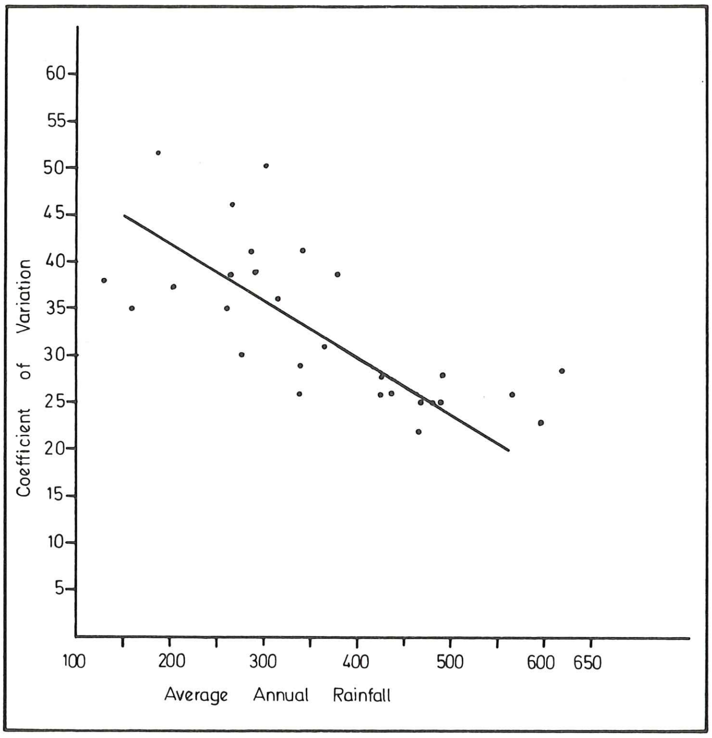
*Average temperature*

Topography seems to be the main control of the spatial distribution of temperature as clearly shown in FIG. 6. Isotherms of average annual temperature closely follow the contour lines and extend from north to south. Highest average temperature of 25.1 is found in Ghor al-Safi to the south of the Dead Sea and the lowest average temperature of 12.5 occurs in Shoubak which is 1,365 meters above sea level.

4. Coefficient of variation.




5. Relation between average annual rainfall and its coeffiecient of variation in Jordan.



### *Annual range of temperature*

The annual range of temperature defined here as the difference between average minimum temperature of the coldest month (January) and average maximum temperature of the hottest month (July), is illustrated in FIG. 7. The principal control of the spatial distribution of annual temperature range is longitude. Thus, the range increases rapidly from west to east; it is lowest in the mountains of Ajlun (24.5° C in Ras Muneif) and highest in the Badia (35.6° C in Jafr). The different roles latitude plays in the spatial distribution of average annual temperature and annual temperature range are masked by differences in elevation and longitude. Average annual temperature in Qurein which is located at 30° 06′ N and has an elevation of 1,510 meters is 14.6° C while it is 17.5° C in Irbid which is located at 32° 33′ N.

### *Continentality*

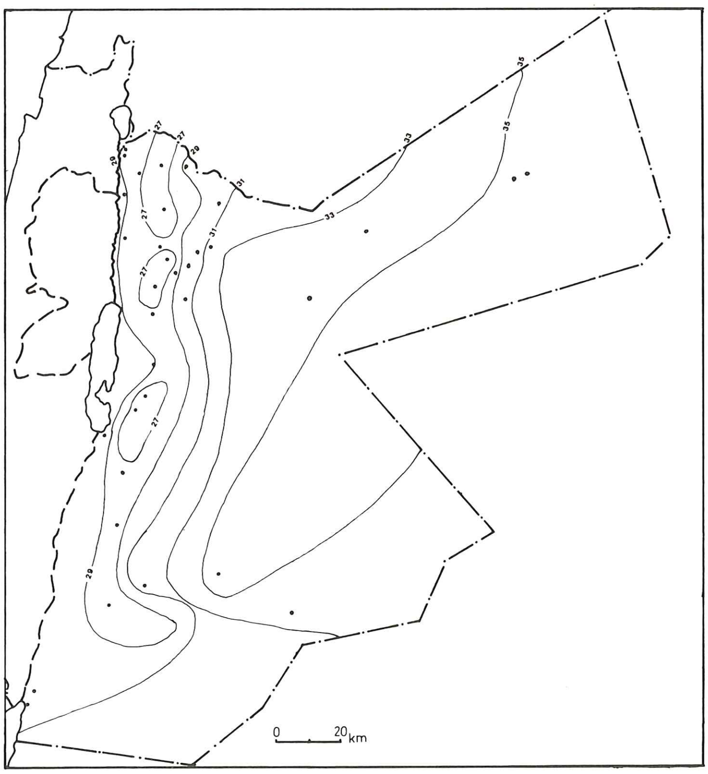
The annual temperature range has been used in computing an index of continentality for Jordan[6]. The spatial distribution of the Wallen's index of continentality is illustrated in FIG. 8. It ranges from 23 in Ajlun to 56 in Jafr. Continentality in the Badia considerably exceeds continentality in the Jordan Valley; it is 39 in Deir Alla and 39.2 in Ghor Safi, but it exceeds 50.1 in H5 and 56 in Jafr. The direct exposure of the northern Jordan Valley to the Mediterranean influence is clearly shown in the moderate continentality indices in Baqara (33) and Shuneh–North (34). Ajlun has the lowest index of continentality (23) and Jafr has the highest index of continentality (56).

### *Oceanicity*

The spatial distribution of oceanicity in Jordan is presented in FIG. 9 which shows the geographical distribution of an Oceanicity index that was developed by Kerner[7]. It is clearly shown in FIG. 9 that oceanicity is at a relative maximum in the northern part of the country which is directly exposed to the Mediterranean. Oceanicity is also high in the mountains of Ajlun and Balqa, but it decreases rapidly to the south. Shoubak which is 1,365 meters above sea level has an index of 20 and Ma'an has an index of 15. This lack of oceanicity in southern Jordan is partly due to the more frequent Khamasin depressions and the long trajectories of air masses which accompany the Mediterranean depressions over north Africa.

6. Average annual temperature (°C).

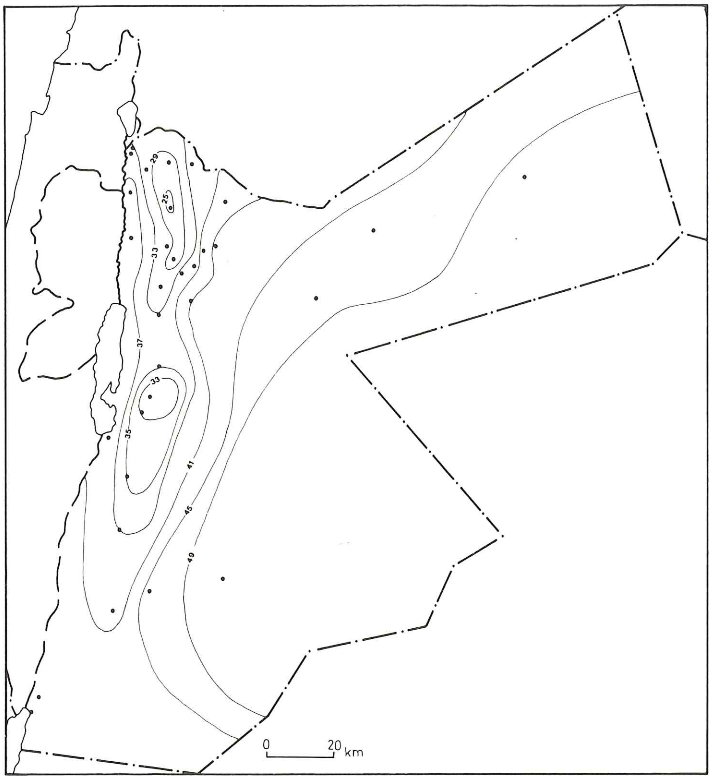

7. Annual range of temperature.



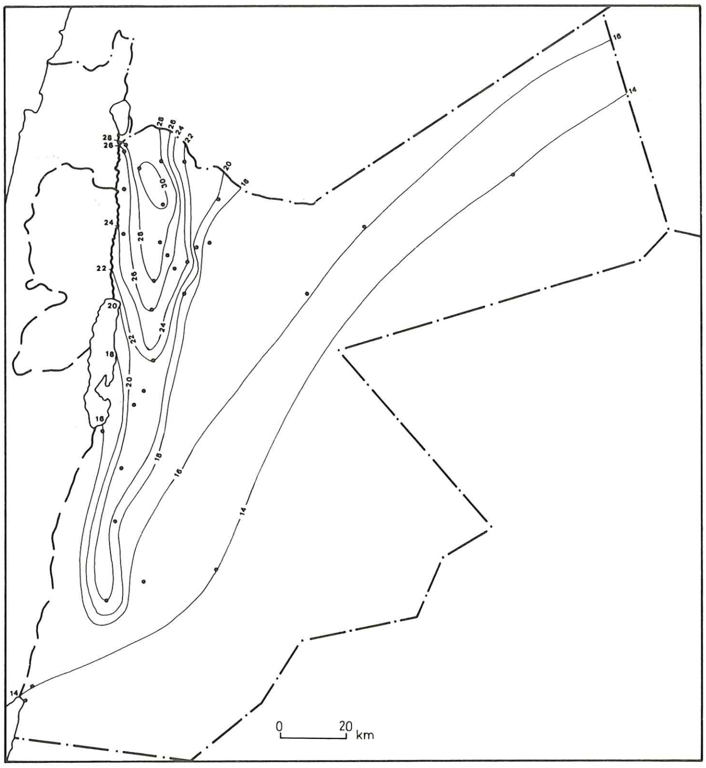

[6] The two indices of continentality as developed by Conrad (1962) and Wallen (1962) are used in this paper to investigate the spatial distribution of continentality in Jordan. Conrad's continentality index (K) is computed as follows: $K = (1.7 \times A/\sin(Q + 10°) - 14$. 'A' represents the annual temperature range computed as the difference between average temperatures of January and July. 'Q' represents the angle of latitude. Wallen's index of continentality 'C' is computed as follows: $C = (1.3 \times A/\sin Q) - 36.3$. 'A' represents the difference between the average minimum temperature of the coldest month (January) and average maximum temperature of July. Wallen's index has proved to be more suitable in illustrating the spatial distribution of continentality in Jordan.

[7] The Oceanicity index 'O' is computed as follows: $0 = 100 \times [(To - Ta) / A]$. 'To' and 'Ta' are the monthly mean temperatures of October and April, respectively. 'A' is the annual range of temperature (Landsberg, 1968).

8. Index of continentality.

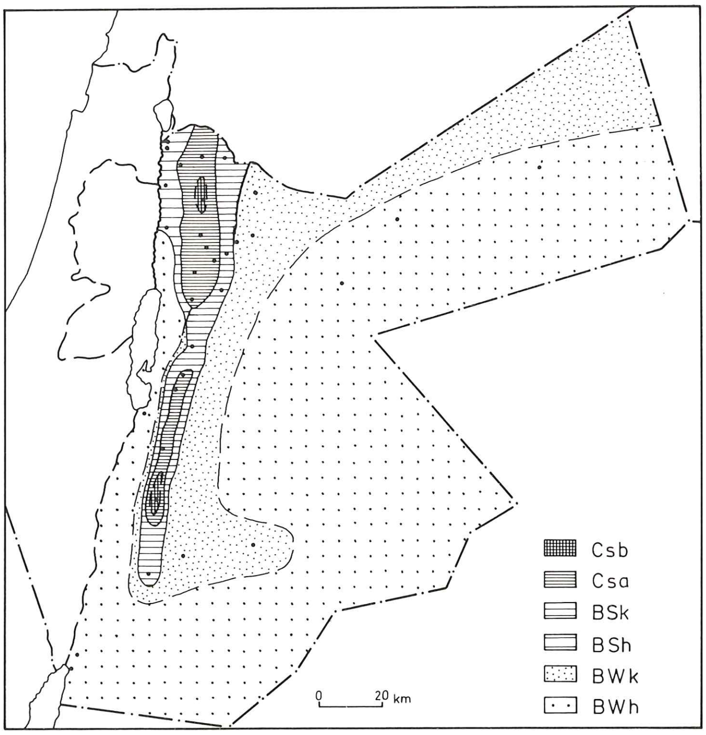



9. Index of oceanicity.




10. Temperateness of climate.


11. The climatic regions of Koppen.



*Temperateness of climate*
The index of temperateness which was developed by Bailey has been used to measure the temperateness of climate in Jordan (Bailey, 1964)[8]. The spatial distributon of this index is illustrated in FIG. 10 which shows that the most important control of the spatial distribution of climatic temperateness is topography.

The most temperate climate is found in the mountainous areas in Ajlun, Balqa, Kerak and Sharah. Climatic temperateness decreases rapidly towards the Jordan Valley in the west and towards the Badia in the east.

**The climatic regions of Jordan**
Two climatic classifications of recognized environmental applications are utilized in this paper to study the regional climatology of Jordan. Koppen classification is used to identify the main climatic regions, and the components of Thornthwaite soil moisture budget are utilized to compute the annual water need and other moisture indices. Available climatic data of the period 1966–80 for all the 31 stations of the Meteorological Department are used.

*The climatic regions of koppen*
The main features of the spatial distribution of koppen climatic regions in Jordan, as illustrated in FIG. 11 are[9]:

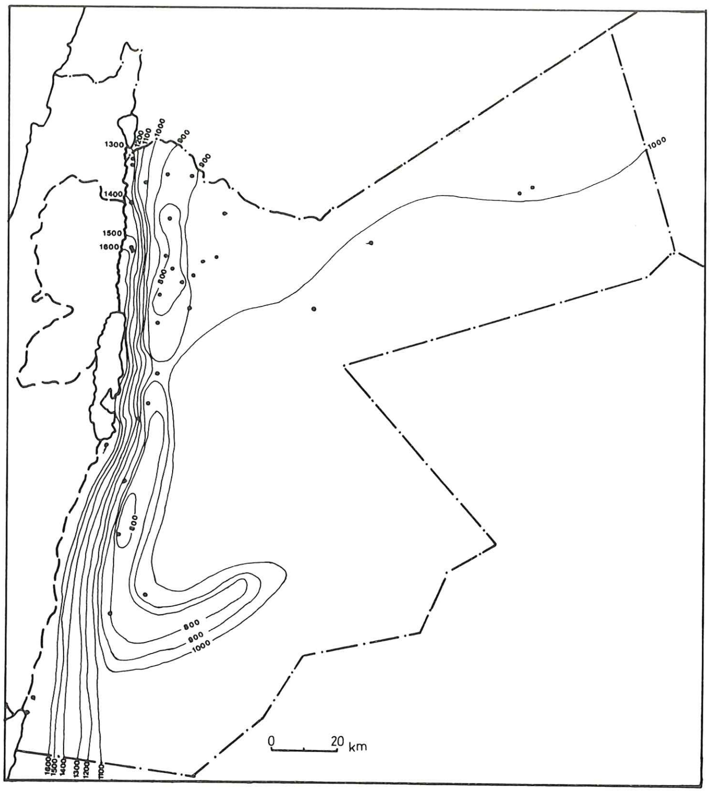
1 *The Cool Temperate Rainy Climate (Csb)* This Mediterranean climate which is mainly characterized by rainy winters and mild summers where the average temperature of the warmest month does not exceed 22° C is found in two small areas in the Ajlun Mountains in the north and the Shoubak area in the South. Average annual temperature in Ras Muneif in the Ajlun Area is 17.5° C and annual rainfall is 296 mm. Average temperature of July is 22° C but average temperature of January is 5.2° C. In the Shoubak area, despite that average annual temperature is 12.5° C and average temperature of July is 22° C, the average temperature of January drops to 3.2° C only. It is obvious that the mild temperature and low potential evapotranspiration in Shoubak compensates for the low precipitation which does not exceed 300 mm.

2 *The Warm Temperate Rainy Climate (Csa)* This climate which is another subdivision of the Mediterranean is found in a larger area than the 'Csb', especially in the Irbid and Balqa mountains. It is characterized by hot summers where the average temperature of July exceeds 24.9° C in Irbid and 25.7° C in Rabbah. Average annual rainfall in this region varies from 496 mm. in Irbid to 344 mm. in Rabbah in the south.

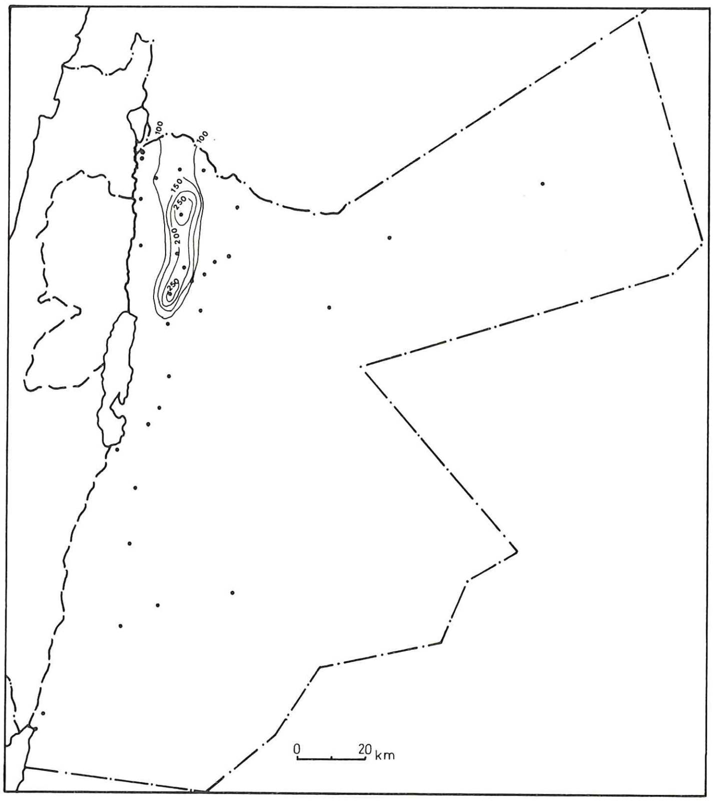
[8] This index of climatic temperateness was developed by Bailey in 1964. It is computed according to the following formula (Bailey, 1964).
$m = 30 \log [(Ty - 14)^2 + (A \times .366 + 1.46)^2]$
'Ty' is average annual temperature and 'A' is annual temperature range.

[9] The koppen classification is well known to geographers. The procedures of the classification can be found in any standard textbook on climatology (Shehadeh, 1983).

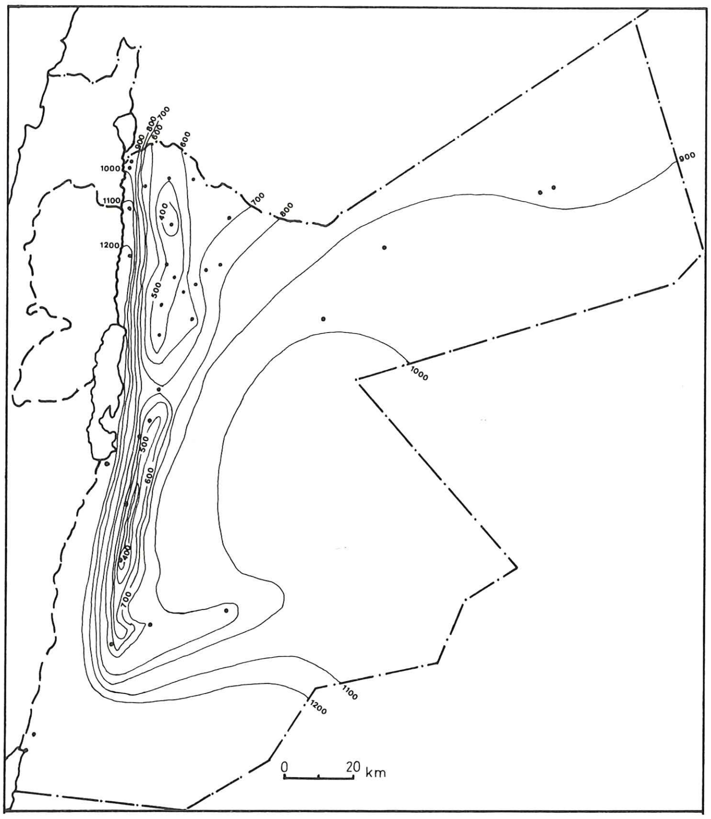
12. Water need or potential evapotranspiration 'mm.'. (Thornthwaite's model).



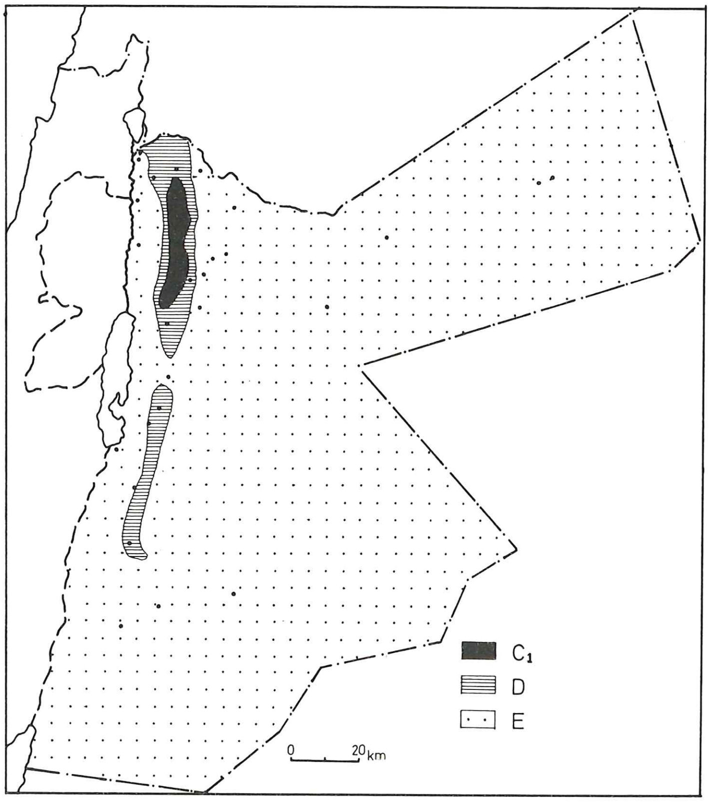

13. Moisture surplus 'mm.'.



14. Moisture deficiency 'mm.'.




15. The moisture index.




*3 The Cool Steppe Climate (BSk)* This semi-arid climate is mainly found in the lee slopes of the Eastern Mountain Ranges where average annual rainfall is less than 300 mm. and average annual temperature does not exceed 18° C. This region is not transitional only in its climate but also in its environmental ecosystems and agricultural potential. Due to the sensitivity of the environmental systems of this region, problems of soil erosion and desertification are present.

*4 The Warm Steppe Climate (BSh)* This is another subdivision of the steppe climate. It is mainly found in the northern and central Jordan Valley. In the southern Jordan Valley, it is found in a narrow strip along the western slopes of the eastern mountains. Rainfall in this region exceeds rainfall in the cool steppe climate, it reaches 280 mm. in Baqara and 350 mm. in Shuneh–North. Temperature in this region is high in summer and moderate in winter. Average annual temperature in Baqaura is 22° C but it reaches 23.6° C in Deir Alla. The average temperature of July exceeds 30° C in Baqaura and average maximum temperature exceeds 37° C.
*5 The Cool Desert Climate (BWk)* This climate is distinguished from the warm desert climate (BWh) by its moderate temperature. It is found in the elevated areas of the eastern slopes of the mountain ranges and the western and northern parts of the Badia, where average annual temperature is less than 18° C. Average annual rainfall is less than 200 mm. It decreases from 164 mm. in Mafreq to less than 38 mm. in Jafr.

*6 The Warm Desert Climate (BWh)* Together with the BWk climate this region covers most of the country. It spans most of the eastern and southern Badia and Ghor Safi in the southern Jordan Valley. Average annual temperature ranges from 25.1° C in Ghor Safi to 19.2° C in the oasis of Azraq. July average maximum temperature varies from 40° C in Ghor Safi to 36° C in Azraq. Rainfall is very scarce and natural vegetation is very poor.

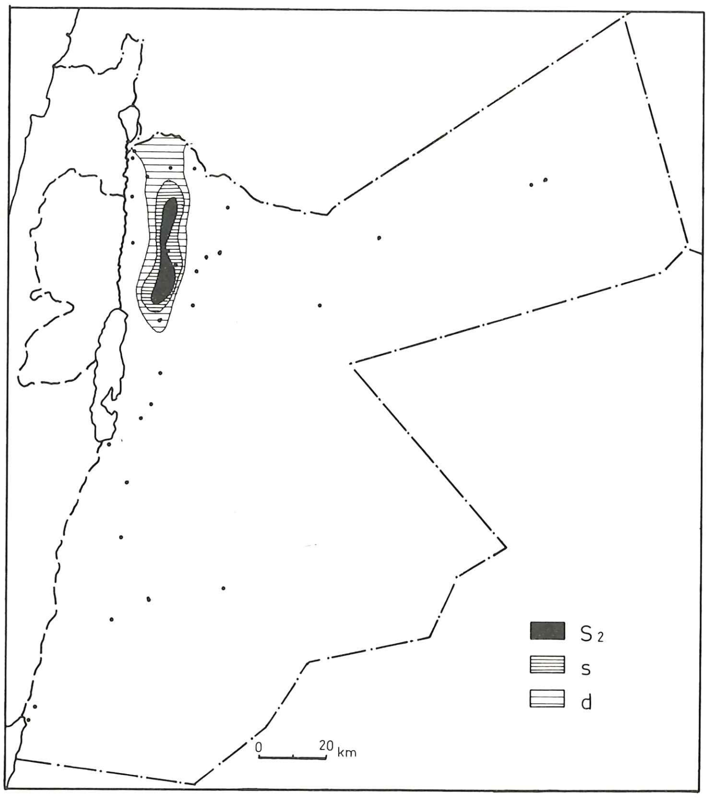
*Thornthwaite climatic regions*
The Thornthwaite system of climatic classification is based on the following terms of the soil moisture budget (Thornthwaite, 1955):

a) Potential evapotranspiration (PE).
b) Moisture index.
c) Seasonal variation of effective moisture.
d) Summer concentration of thermal efficiency.

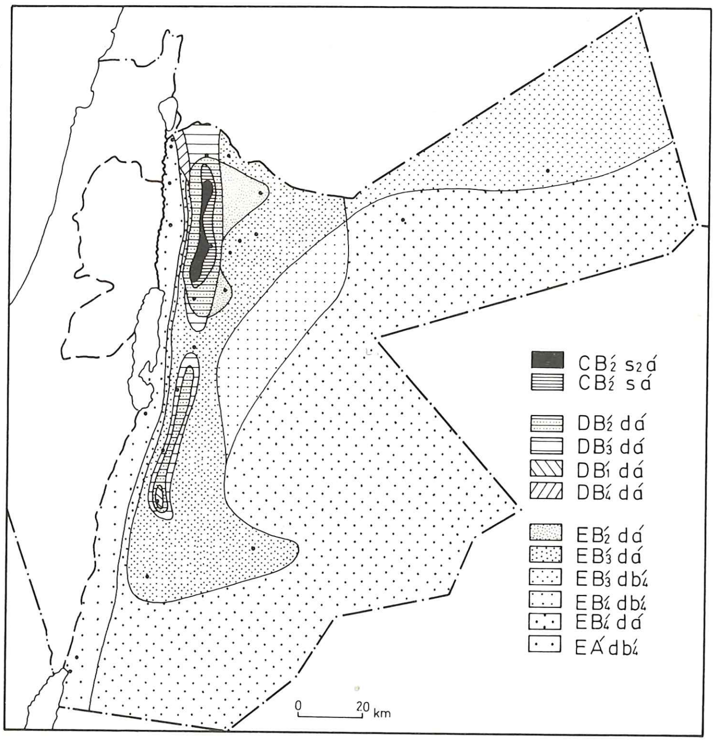
Other terms of the soil moisture budget which have environmental applications like the water surplus and water need are discussed[10].

[10] The 1955 modification of the Thornthwaite 1948 soil moisture budget is used in this paper (Thornthwaite, 1955b). Soil moisture budget is computed in this paper for all the 31 climatological stations of the Meteorology Department. Average climatic data for the period 1966–80 are utilized.

16. The humidity index.




17. The climatic regions of Thornthwaite.




*The water need (Potential Evapotranspiration)* The main characteristics of the spatial distribution of the Thornthwaite potential evapotranspiration as illustrated in FIG. 12 are:

a) Average annual 'PE' exceeds 1,600 mm. in Ghor Safi and part of the southern Jordan Valley[11].
b) 'PE' exceeds 1,000 mm. in most of the Badia.
c) 'PE' in the mountains of Ajlun, Balqa and Shoubak is less than 800 mm.
d) The close spacing of the isarithms of 'PE' in the western slopes of the Eastern Mountains reflects the steepness of these slopes and the rapid change of elevation.

*Water surplus and water deficit* Although neither the annual water surplus nor water need is an element in the system of Thornthwaite classification, both are of great environmental significance. The amount of annual moisture surplus gives a rough estimate of the average runoff of a place, while moisture deficiency provides information in irrigation needs and the inability of a place to depend upon its own water resources. It is clearly shown in FIG. 13 that most of the country has no water surplus. A small area of modest winter water surplus is found in the mountains of Ajlun and Balqa. The areas of 200 mm. moisture surplus are the areas of more than 500 mm. of annual rainfall.

Average annual moisture deficit, as shown in FIG. 14, is less than 600 mm. in the mountainous areas but it increases to more than 1,200 mm. in the Jordan Valley, and the Badia annual moisture deficit in the country varies from a minimum of 376 mm. in Ras Muneif and 414 mm. in Naur to a maximum of 1,827 mm. in Ghor Safi and 1,646 mm. in Aqaba.

*The soil moisture index* According to the Thornthwaite system of moisture index (Im) which is the most important component of his classification, Jordan is divided into three main regions (FIG. 15): (a) the arid region which occupies the Jordan Valley and all of the Badia; (b) the northwestern semiarid region in the areas of more than 300 mm. of annual rainfall. This region has been classified according to the system of koppen classification into a Mediterranean climate (Cs); (c) the small sub-humid region in the high mountains of Ajlun and Balqa where average annual rainfall exceeds 500 mm. and 'PE' is less than 800 mm.

*Seasonal variation of effective moisture* The second component of the Thornthwaite classification of arid regions is the humidity index (Ih) which reflects the seasonal variation of effective moisture. According to this index three moisture regions are found in the northwestern areas of Jordan (FIG. 16): (a) The areas of large winter water surplus in the high mountains of Ajlun and Balqa ($S_2$); (b) The areas of moderate

[11] It is known that Thornthwaite estimates of potential evapotranspiration in Jordan are less than Penman's estimates but they are used because of their role in computing other terms of the soil moisture budget and the climatic classification which follows (Shehadeh, 1983).

winter water surplus in the areas surrounding the above region which receive less rainfall than it does (s); (c) The areas of little or no water surplus in most of the semiarid region in the north (d).

*The climatic regions of Jordan*

The two other components of the Thornthwaite climatic classification are the index of thermal efficiency and its summer concentration. They are of little practical importance and are usually ignored. Nevertheless, the following two main types of climate are found in Jordan according to the thermal efficiency index; (a) The megathermal climate in the Jordan Valley where (PE) exceeds 1,140 mm; (b) Mesothermal climates in the rest of the country. According to the concentration of thermal efficiency, the region where the percentage of (PE) in summer is less than 48 per cent (a′) is distinguished from the other region of higher percentage of concentration (b′). The first region is mainly found in the areas of sub-humid and semiarid climates and in the northern parts of the Badia.

When the four components of the Thornthwaite classification are incorporated into one system, it produces the following main climatic types in Jordan (FIG. 17):

1) A dry subhumid mesothermal climate with large winter water surplus in the high mountains of Ajlun and Balqa ($CB'_2\ S_{2a}'$).
2) A dry subhumid mesothermal climate with moderate winter water surplus in parts of the Balqa mountains ($CB'_2Sa'$).
3) The semiarid mesothermal climates of little or no winter water surplus in parts of the Irbid, Balqa and Sharah mountains (DB′da′).
4) The arid mesothermal climates of the Badia (EBda).
5) The arid megathermal climate of the Jordan Valley (EAdb4) which is distinguished from the arid mesothermal region of the Badia by its high temperature and large water need.

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