RIVER REGIMES in IRAN

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Occasional Publications (New Series) No 1

DEPARTMENT OF GEOGRAPHY
UNIVERSITY OF DURHAM
1973

PUBLICATIONS OF THE
DEPARTMENT OF GEOGRAPHY
UNIVERSITY OF DURHAM

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Contents

ILLUSTRATIONS

River Regimes in Iran

Abstract

The drainage systems of Iran can be divided into Caspian Sea drainage, Persian Gulf drainage and drainage into the central part of the country. The first and last regions are areas of interior drainage. Winter is the rainy season in Iran, during which period at least two-thirds of the country receives more than half its annual precipitation total. The regime hydrographs of forty-five rivers reveal marked similarities, with peak discharges occurring mainly in the period Esfand through Ordibehesht (March through May), owing largely to the effect of snowmelt. Analysis of the river regimes reveals broad hydrographic regions which differ from the three major groupings based on direction of drainage. The largest runoff values per unit area are found to occur in the northern and central parts of the Zagros Mountains, and in the Elburz Mountains. The lowest runoff values are found in a belt around the desert regions of central Iran.

Introduction

Knowledge of the seasonal runoff characteristics of rivers in the major regions and countries of the world is still extremely limited. With few exceptions, it is confined to a small number of papers which have attempted to order available information within specific regions (Langbein and Wells, 1955; Ledger, 1964; Ward, 1968). Only Pardé, in *Fleuves et Rivières* and Guilcher, in *Précis d'Hydrologie*, have attempted a regional treatment on anything like a worldwide basis, while Beckinsale (1969) reviews the range of available information concerning river regimes. In the Middle East, where water is such an important resource, it is surprising that so little published information is found. That which does occur tends to be confined to the description and analysis of single river basins (Ionides, 1937: Hurst, 1952; Smith, 1966). During the past few years, with the construction of many dam and barrage projects, detailed hydrological studies on small basins have often been carried out; unfortunately, relatively little of this information has so far become generally available in scientific journals. However, a recent work on water resources and irrigation in the Middle East does attempt to synthesise the results of some of this work (Smith, 1970).

In Iran, although a recent paper has been published on the underground water provinces (Issar, 1969), little information exists concerning surface water hydrology, apart from two detailed studies dealing with the assessment of runoff and the prediction of evaporation in parts of Iran (Sutcliffe and Carpenter, 1967; Sutcliffe and Swan, 1970). Indeed, the only regionally comprehensive paper for Iran is a chapter by Oberlander in the Cambridge History of Iran, Volume I, "The Land of Iran", in which the major drainage characteristics of the country are outlined (Oberlander, 1968). This general lack of knowledge is surprising when one considers that, throughout the ages, population distribution in Iran has tended to reflect the availability of water. For at least three millenia, man in Iran has devised methods of water use which were both complex and yet in keeping with the demands of both agriculture and urban use. While Iran is regarded, quite naturally, as an arid country, it is important to realize that some areas do receive high precipitation totals. As a result, no single and unified method of water control and utilization could ever be applied to the country as a whole. Perhaps the best known method of irrigation and water use in Iran is the utilization of groundwater by the highly individual engineering construction known as the *qanat* (Beaumont, 1968, 1971; English, 1968). Quite different methods of water use do occur, however, in areas such as the Caspian Lowlands (Beaumont and Neville, 1968). While in the past the literature has tended to stress the importance of underground water sources, in many areas of Iran surface water supplies are of far greater importance to the rural and urban economy. In this paper, available information on the river regimes of Iran is analysed in an attempt to outline the major surface water hydrological characteristics of the country.

The Environment

Much of central Iran consists of a high upland plateau, flanked on the north and west by the lofty fold mountains of the Elburz and Zagros chains. In the north, the west to east trending Elburz, some 1,300 kilometres long, act as a barrier between the central plateau and the lowlands of the Caspian and central Asia to the north. Although a relatively narrow range, some 100 kilometres wide, the Elburz reach a maximum height of 5,771 metres at Mt Damavand and form a linear barrier with peaks often rising above 4,500 metres.

In contrast, the Zagros mountains consist of a series of parallel fold ranges, largely between 1,500 and 3,000 metres in height, which have a width of more than 500 kilometres. Composed mainly of Mesozoic and Tertiary sediments, they form an area of wide and high intermontane valleys and plateaux separated by spectacular canyons and gorges where streams have broken through the fold ranges (Oberlander, 1965). Many peaks in this area reach to more than 3,600 metres, but are not as high as in the Elburz.

Enclosed between these two mountain ranges and the Hindu Kush to the east is the central plateau of Iran. This is an area largely between 500 and 1,000 metres in elevation, which consists of a series of large and small basins of interior drainage. Some, like the Great Kavir and the Southern Lut, are huge basins hundreds of kilometres across, while others are small local sinks.

As a general rule, precipitation in Iran decreases from north to south and from west to east. However, in a number of areas the high relief of the Elburz and Zagros mountains has modified this pattern. On the map of precipitation (Fig 1) areas of moderate to high precipitation are delimited as linear belts by the 400 mm isohyet.

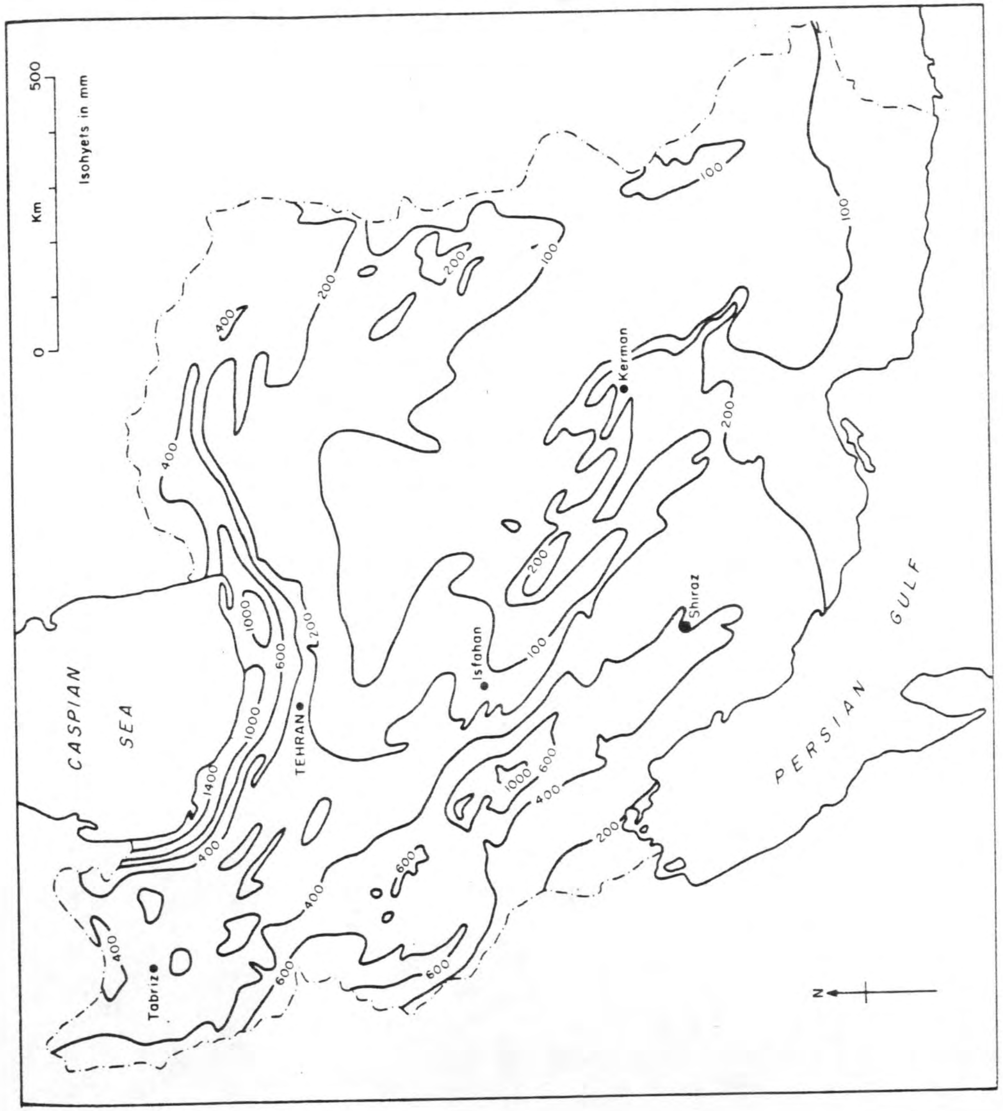

Fig 1 Mean annual precipitation in Iran (mm)

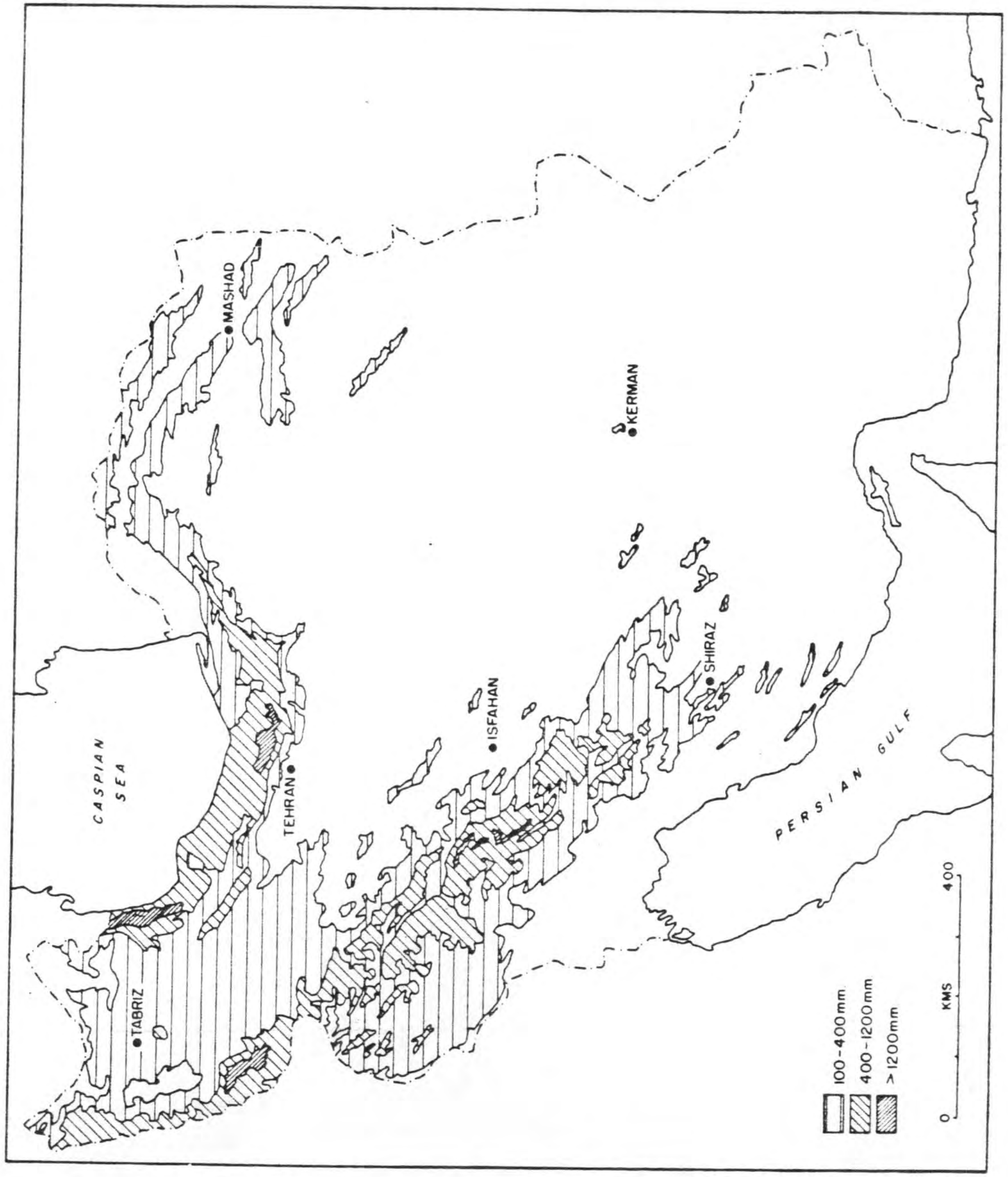

Fig 2 Mean annual water surplus (after Thornthwaite, C W, Mather, J R and Carter, D B, 1958)

The smaller belt, but the one with the higher totals, is found along the Caspian Sea coast and the northern flanks of the Elburz mountains. Precipitation totals are highest in the west, where they reach more than 1,800 mm near the mouth of the Sefid River. Pahlavi is the climatological station with the highest precipitation in Iran, and here an average figure of 1,900 mm is recorded. Annual totals fall to less than 500 mm on the eastern side of the Caspian Sea near Gonbad-e-Ghabus. The second belt is likewise greatly influenced by relief, and this follows the western flanks and summits of the Zagros mountains. In this area, precipitation amounts are thought to exceed 800 mm on some of the highest peaks and large areas receive more than 400 mm to the west of Shiraz. In the north-western highlands, between the two belts of high precipitation, is a zone of moderate precipitation receiving from 250 to 400 mm. The centre of Iran, the Great Kavir, is an area of pronounced aridity with precipitation totals almost everywhere less than 100 mm. Perhaps more importantly, this is an area where rainfall is extremely unreliable. Along the eastern borders of the Kavir, higher precipitation values are found in the highlands around Birjand and Zahedan.

Winter is a rainy season in Iran, during which period about two-thirds of the country receives more than half its annual precipitation (Ganji, 1968). This is a time when Iran is under the influence of mid-latitude westerlies and almost all the rain is brought by depressions moving eastward from the Mediterranean Basin. The percentage of precipitation falling in winter decreases from south to north and, while parts of southern Iran may receive as much as 75 per cent of their annual precipitation in the three winter months, along the Caspian the figure falls to less than 25 per cent; even so the Caspian coastal area is the wettest part of the country at this period. With the coming of spring there is a decline in cyclonic activity, but at this time temperatures rise rapidly, producing atmospheric instability which creates considerable amounts of convectional rainfall, especially over the highlands of the west and north. In the lowland areas, less precipitation occurs, except in the Caspian area, which, although receiving only 10 per cent of its annual total, still remains the wettest part of Iran.

Summer is the dry season everywhere in Iran except along the Caspian coast. It is characterized by cloudless skies, low humidities and high temperatures, and the upper air circulation being dominated by subsidence. Along the Caspian coast, summer orographic rains occur as air is forced to rise some 1,500 to 3,000 metres on meeting the Elburz mountains. As a result, some stations here receive more than 25 per cent of their annual precipitation during this period. In autumn, Mediterranean depressions become active once more over Iran. Initially, as rather weak systems, their effects are mostly felt in the west, in the Zagros and Azerbaijan Highlands and along the Persian Gulf coast, in the form of light rainfalls. It is at this period that the Caspian littoral receives its maximum seasonal rainfall as the result of cyclonic activity and the prevalence of moisture-bearing winds from the Caspian Sea, with some stations getting more than 50 per cent of their annual totals.

While the annual precipitation of a region gives an indication of the maximum amount of water input into a drainage system, it does not necessarily provide an accurate assessment of the volume available for streamflow. This latter value is, of course, a measure of water surplus, which is precipitation minus evapotranspiration. Water surplus estimates for Iran have been made as part of the detailed work of Thornthwaite, Mather and Carter in their production of three water balance maps of south-west Asia, and these are shown in Figure 2. From this it can be seen that the highest water surpluses of more than 1,600 mm per annum occur in short linear belts along the northern slopes of the Elburz mountains bordering the Caspian Sea lowlands. Disconnected belts of 800 to 1,600 mm per annum water surplus also extend throughout the Elburz mountains and to a lesser extent through the northern parts of the Zagros mountains. A surprisingly small amount of the country, about one third of the total receives more than 100 mm per annum water surplus; all of this is concentrated in the northern and western parts of Iran, clearly emphasising the fact that the central, southern and eastern parts are extremely arid.

Drainage Systems

The drainage systems of Iran can be divided into three main groups depending on the general direction of drainage (Fig 3). The first group flows into the Caspian and consists of relatively small, steep streams flowing down the northern flanks of the Elburz mountains. Only three major exceptions to the above generalization occur. In the west the Sefid river breaks through the main chain of the Elburz mountains in a spectacular gorge to drain a large portion of the north-west highlands of Iran. In the east, the Atrek river, forming the boundary with the USSR along part of its length, and the Gorgan river flow east to west along the margins of the Elburz and collect the drainage of northerly flowing streams.

The streams flowing into the Persian Gulf and the Gulf of Oman include a number of river basins of considerable size. Two of the largest are the Karkheh and the Karun, which between them drain almost all the area between Abadan and Kermanshah. Further south are found other large basins of the Mand and Shur rivers.

The central zone of Iran is an area of internal drainage, which covers by far the largest part of the country. Here very few large rivers occur and drainage lines are often indeterminate. In the extreme north-west, around Tabriz, is the best watered area of inland drainage centered on Lake Rezaiyeh. This is an isolated region separated from the main zone of inland drainage by the Sefid river. This major zone can be subdivided into a series of smaller basins. In the north-western portion is the drainage centered on the Kavir Masileh which include the large rivers of the Vagreghan and the Ghom. East of this is the Great Kavir, by far the largest basin in Iran with a hugh salt desert almost completely lacking in any form of life. Many important streams from the Elburz mountains drain into this zone. Southwards, towards Isfahan and Shiraz, two less well-defined and smaller basins are found. In the north is the basin of the Zayandeh river, which supports the oasis of Isfahan, and in the south the Kur River in the Niriz basin. In the extreme south is the Jaz Murian basin, a lowland area surrounded by a ring of highlands to form a well-defined drainage unit whose chief rivers are the Halil and the Bampur. To the north of this is the drainage basin of the Southern Lut; this is largely a sand and rock desert area where rainfall totals are very low and consequently river channels are not well developed. Finally, in the east, is the famed

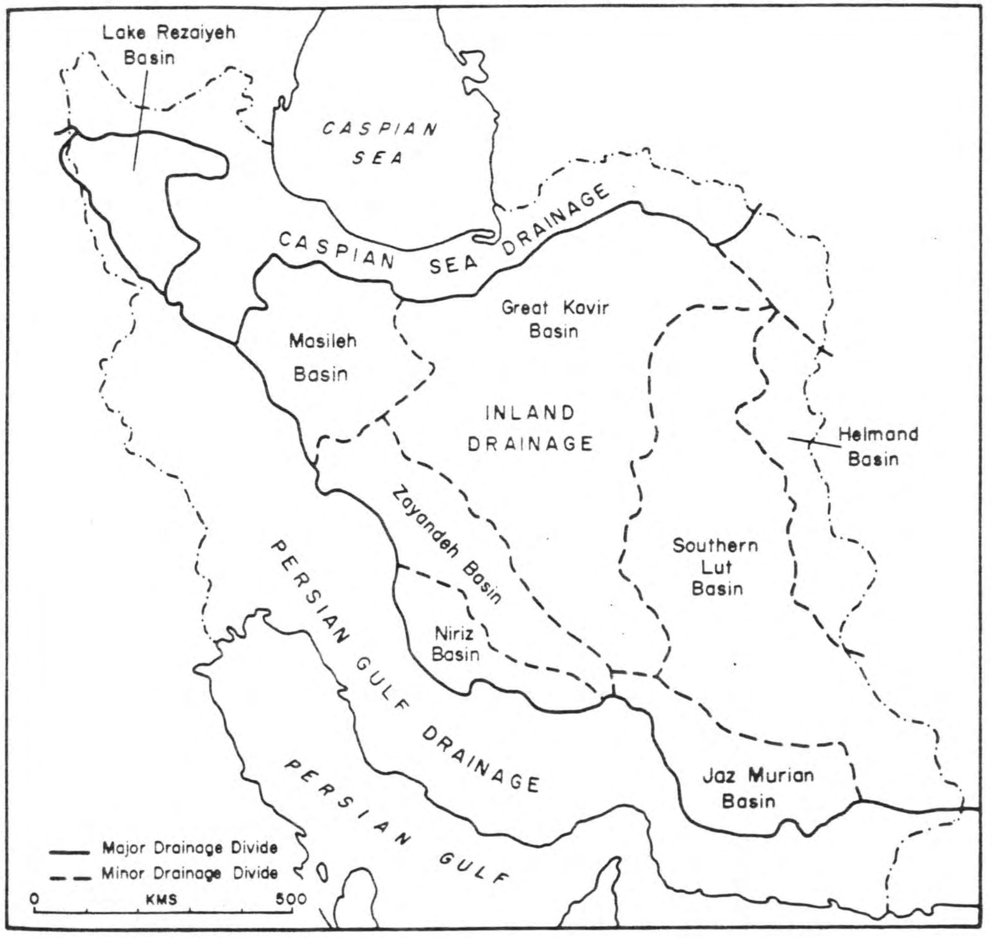

Fig 3 Drainage systems of Iran

Helmand basin, which, although fed largely by precipitation falling in Afghanistan, is mainly situated in Iran.

Stream Discharge

From this survey of the environment it can be seen that the rivers with the greatest discharge are likely to be situated in the north and west of the country, where relief and precipitation are greatest. Indeed this is the case and it is, therefore, in these areas where most data concerning stream discharge have been collected. Elsewhere, in the more arid regions of the east and south, water discharge measuring devices have only recently been installed and, as yet, adequate records are not generally available to allow comparative studies to be made.

The aim of the present study was to discover the nature of the river regimes of Iran, and to see the major differences existing amongst them throughout the country. Data or stream discharges used in this study were collected initially by the Independent Irrigation Corporation (Hydrographic Service of Iran) and, more recently, by the Ministry of Water and Power (Surface Hydrology Department).[1] This information has now been published in a series of Hydrographic Yearbooks (Ministry of Water and Power). For the purposes of the present study, the ten-year period October 1955 to September 1965 was selected for analysis. During this period station records were available for a total of 45 discharge gauging station situated in basins of more than 200 square kilometres (Fig 4). Unfortunately, for a number of reasons, such as the severity of environmental conditions, records are sometimes incomplete for individual months or even longer periods; in such cases the available data were averaged to give the results which were finally employed.

Data analysis consisted of calculating mean monthly and mean annual discharges for the ten-year period of study. For ease of reference the mean monthly discharge data were converted into a series of dimensionless diagrams expressing mean monthly discharge as a percentage of total discharge. From this information the months of highest and lowest average flow were obtained and also the ratio of the highest to lowest monthly flow. Using drainage basin area and mean annual flow, a figure of the annual runoff of water (in cubic metres per square kilometre) was obtained, together with values of the maximum and minimum mean monthly runoff (Table 1).

The river regimes for the three major drainage areas are shown in Figure 5. A characteristic feature of many of them is a pronounced discharge peak in spring and early summer. This peak can be identified in all three drainage regions, although its absolute size tends to vary. Only in the Caspian Sea drainage zone is there a tendency for a number of the catchments to lack a well-defined period of high discharge. Subjective comparisons of the river regimes show that very marked differences do occur, but unfortunately these do not provide a satisfactory basis for a meaningful classification. A very simple quantitative method of analysis of a river regime diagram is to calculate the ratio of the highest to lowest mean monthly discharge. This is a measure of the magnitude of monthly variations in flow and, being a dimensionless statistic, it permits comparisons to be made between the different rivers. For the Iranian rivers

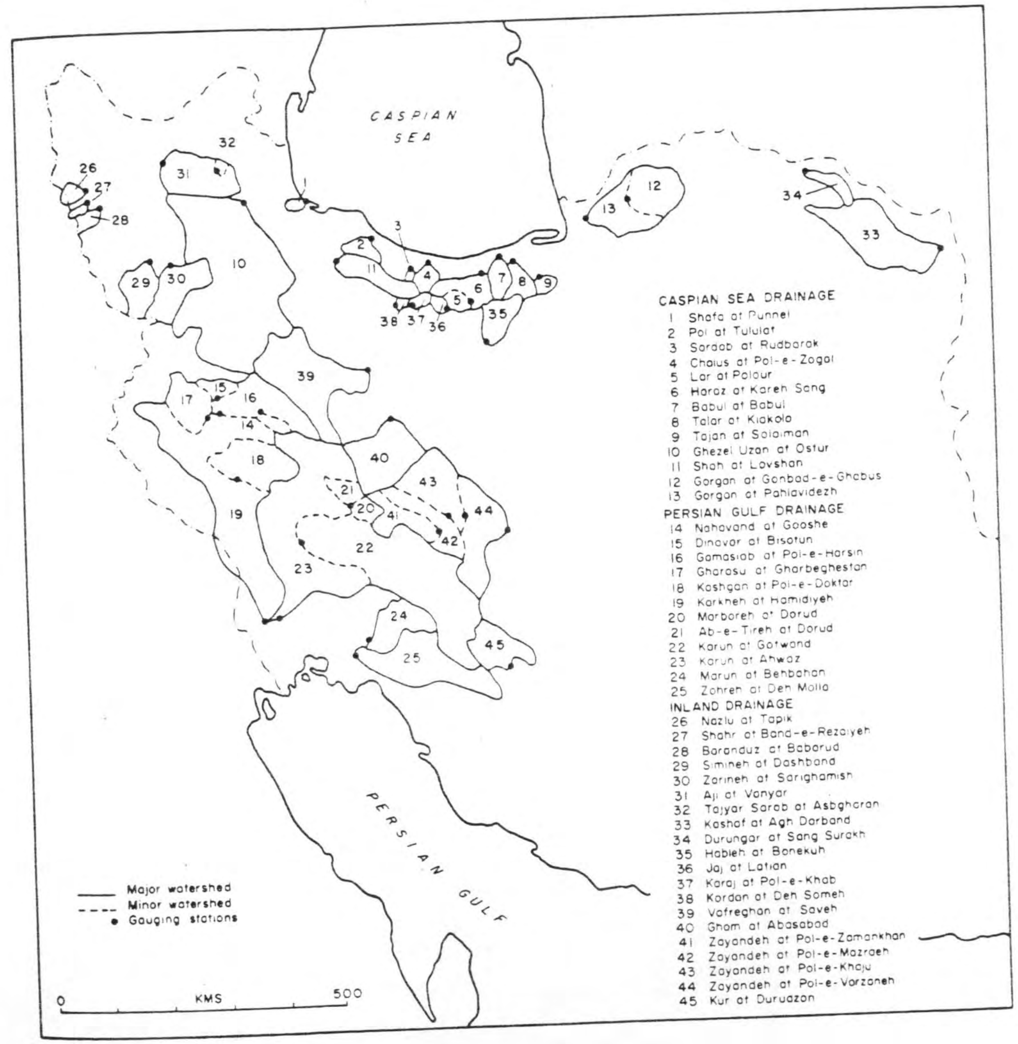

Fig 4 Drainage basins of detailed study

TABLE 1 : RIVERS OF IRAN

CASPIAN SEA DRAINAGE

River	Basin area (sq km)	Annual discharge (million cubic metres M C M)	Ratio of maximum to minimum mean monthly discharge	Annual runoff (cubic metres per sq km)	Month of maximum mean discharge	Month of minimum mean discharge	Length of record. Number of months with available data in ten-year period October 1955 to September 1965
Shafa at Punnel	350	192·50	3·50	550,000	Farvardin	Tir	108
Pol at Tululat	1,725	467·78	4·14	271,177	Ordibehesht	Dey	102
Sardab at Rudbarak	200	94·17	11·15	470,850	Khordad	Bahman	96
Chalus at Pol-e-Zogal	1,555	141·47	3·57	90,978	Ordibehesht	Dey	120
Lar at Polour	1,250	347·31	10·72	277,848	Ordibehesht	Esfand	108
Haraz at Kareh Sang	4,086	403·46	4·83	98,742	Ordibehesht	Bahman	120
Babul at Babul	1,430	227·18	3·63	158,867	Aban	Tir	120
Talar at Kiakola	2,845	113·13	6·16	39,765	Farvardin	Amordad	113
Tajan at Solaiman Tangeh	960	80·26	1·98	83,604	Farvardin	Tir	119
Ghezel Uzan at Ostur	41,590	2,110·49	129·73	50,745	Ordibehesht	Amordad	102
Shah at Lovshan	5,070	397·78	9·47	78,458	Ordibehesht	Shahrivar	120
Gorgan at Gonbab-e-Ghabus	5,310	123·00	32·61	23,164	Farvardin	Shahrivar	116
Gorgan at Pahlavidezh	10,200	89·49	66·21	8,774	Farvardin	Shahrivar	117

TABLE 1 (Continued)

PERSIAN GULF DRAINAGE

River	Basin area (sq km)	Annual discharge (million cubic metres M C M)	Ratio of maximum to minimum mean monthly discharge	Annual runoff (cubic metres per sq km)	Month of maximum mean discharge	Month of minimum mean discharge	Length of record. Number of months with available data in ten-year period October 1955 to September 1965
Nahavand at Gooshe	876	94·53	15·32	107,911	Farvardin	Amordad	120
Dinavar at Bisotun	2,094	272·59	89·12	130,177	Farvardin	Shahrivar	120
Gamasiab at Pol-e-Harsin	10,783	899·80	18·96	83,446	Farvardin	Shahrivar	120
Gharasu at Gharbaghestan	5,570	547·30	14·71	98,259	Farvardin	Shahrivar	120
Kashgan at Pol-e-Dokhtar	9,060	1,212·24	6·49	133,801	Farvardin	Shahrivar	120
Karkheh at Hamidiyeh	45,882	3,822·82	17·08	83,319	Ordibehesht	Shahrivar	118
Marboreh at Dorud	2,680	238·98	5·40	89,172	Farvardin	Mehr	120
Ab-e-Tireh at Dorud	3,340	423·15	24·89	126,692	Farvardin	Shahrivar	120
Karun at Gotwand	31,899	9,651·05	4·29	302,550	Farvardin	Mehr	120
Karun at Ahwaz	60,769	15,502·13	5·37	255,099	Farvardin	Mehr	119
Marun at Behbahan	3,650	948·14	8·22	259,764	Farvardin	Mehr	120
Zohreh at Deh Molla	12,600	1,694·75	6·32	134,504	Bahman	Shahrivar	120

TABLE 1 (Continued)

INLAND DRAINAGE

River	Basin area (sq km)	Annual discharge (million cubic metres M C M)	Ratio of maximum to minimum mean monthly discharge	Annual runoff (cubic metres per sq km)	Month of maximum mean discharge	Month of minimum mean discharge	Length of record. Number of months with available data in ten-year period October 1955 to September 1965
Nazlu at Tapik	1,777	474·53	23.94	267,040	Khordad	Mehr	120
Shahr at Band-e-Rezaiyeh	396	176·17	21·02	444,874	Khordad	Mehr	120
Baranduz at Babarud	666	222·33	30·84	333,829	Ordibehesht	Mehr	120
Simineh at Dashband	2,090	439·15	85·02	210,120	Farvardin	Mehr	120
Zarineh at Sarighamish	7,100	1,392·85	58·46	196,176	Farvardin	Shahrivar	111
Aji at Vanyar	8,100	472·70	51·05	52,803	Ordibehesht	Mehr	120
Tajyar Sarab at Asbgharan	777	44·83	30·40	57,696	Ordibehesht	Shahrivar	120
Kashaf at Agh Darband	14,800	75·83	115·80	5,124	Ordibehesht	Mehr	120
Durungar at Sang Surakh	1,009	29·02	2·81	28,761	Farvardin	Amordad	120
Hableh at Bonekuh	3,195	197·92	2·79	61,947	Farvardin	Shahrivar	120

TABLE 1 (Continued)

INLAND DRAINAGE (Continued)

River	Basin area (sq km)	Annual discharge (million cubic metres M C M)	Ratio of maximum to minimum mean monthly discharge	Annual runoff (cubic metres per (sq km)	Month of maximum mean discharge	Month of minimum mean discharge	Length of record. Number of months with available data in ten-year period October 1955 to September 1965
Jaj at Latian	710	256·10	9·90	360,704	Ordibehesht	Shahrivar	120
Karaj at Pol-e-Khab	725	384·78	8·47	530,731	Ordibehesht	Dey	120
Kordan at Deh Someh	380	107·91	39·27	283,974	Ordibehesht	Shahrivar	108
Vafreghan at Saveh	17,800	268·54	22·65	15,087	Farvardin	Shahrivar	120
Ghom at Abasabad	10,230	147·05	9·37	14,374	Farvardin	Shahrivar	120
Zayandeh at Pol-e-Zamankhan	4,850	881·94	4·41	181,843	Farvardin	Mehr	120
Zayandeh at Pol-e-Marzraeh	7,820	776·91	4·67	99,349	Farvardin	Shahrivar	120
Zayandeh at Pol-e-Khaju	14,320	362·98	27·40	25,348	Farvardin	Mehr	99
Zayandeh at Pol-e-Varzaneh	30,840	89·00	44·94	2,886	Farvardin	Mehr	120
Kur at Durudzon	5,100	667·50	4·28	130,882	Esfand	Mehr	120

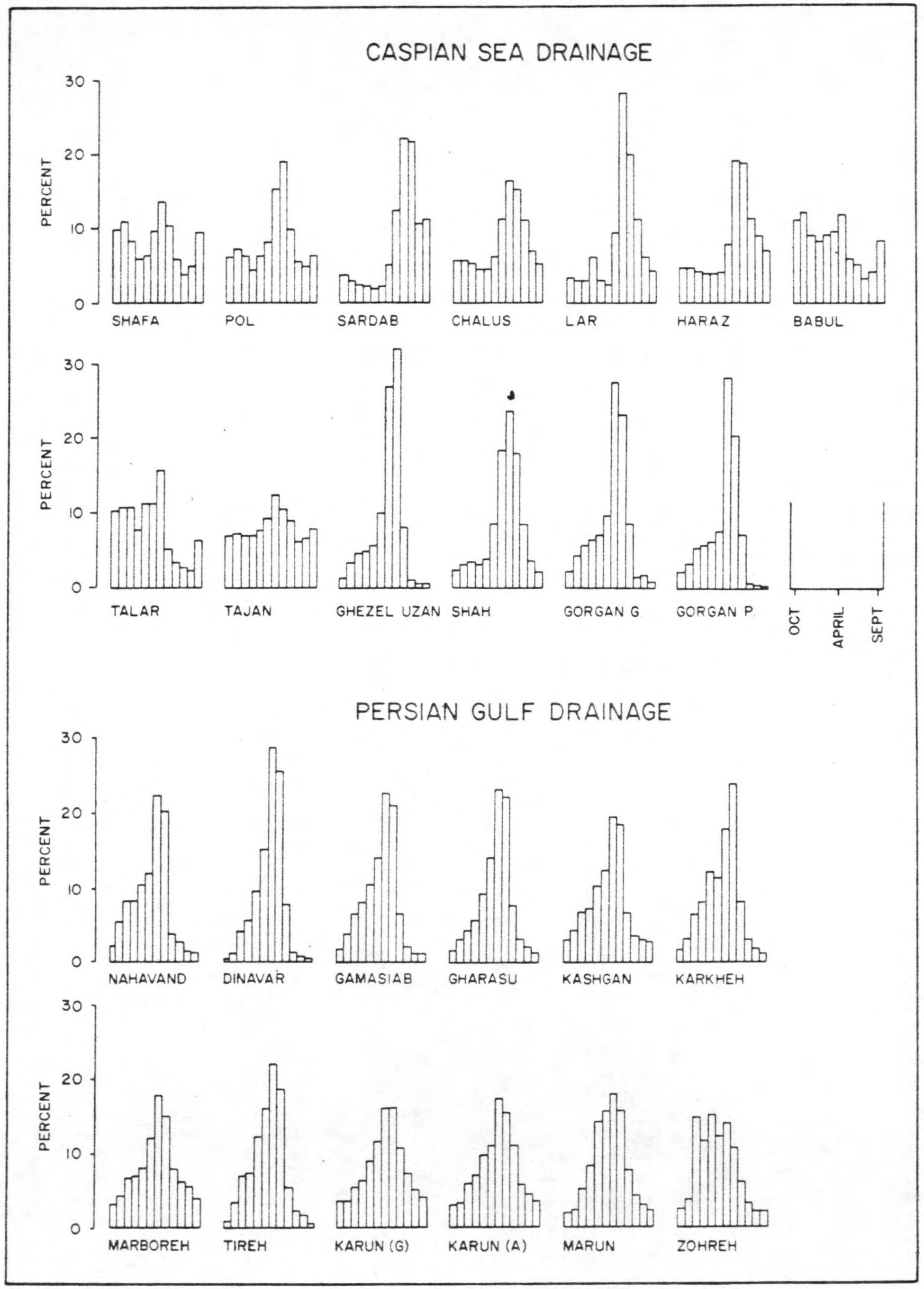

Fig 5a River regime hydrographs of Iran

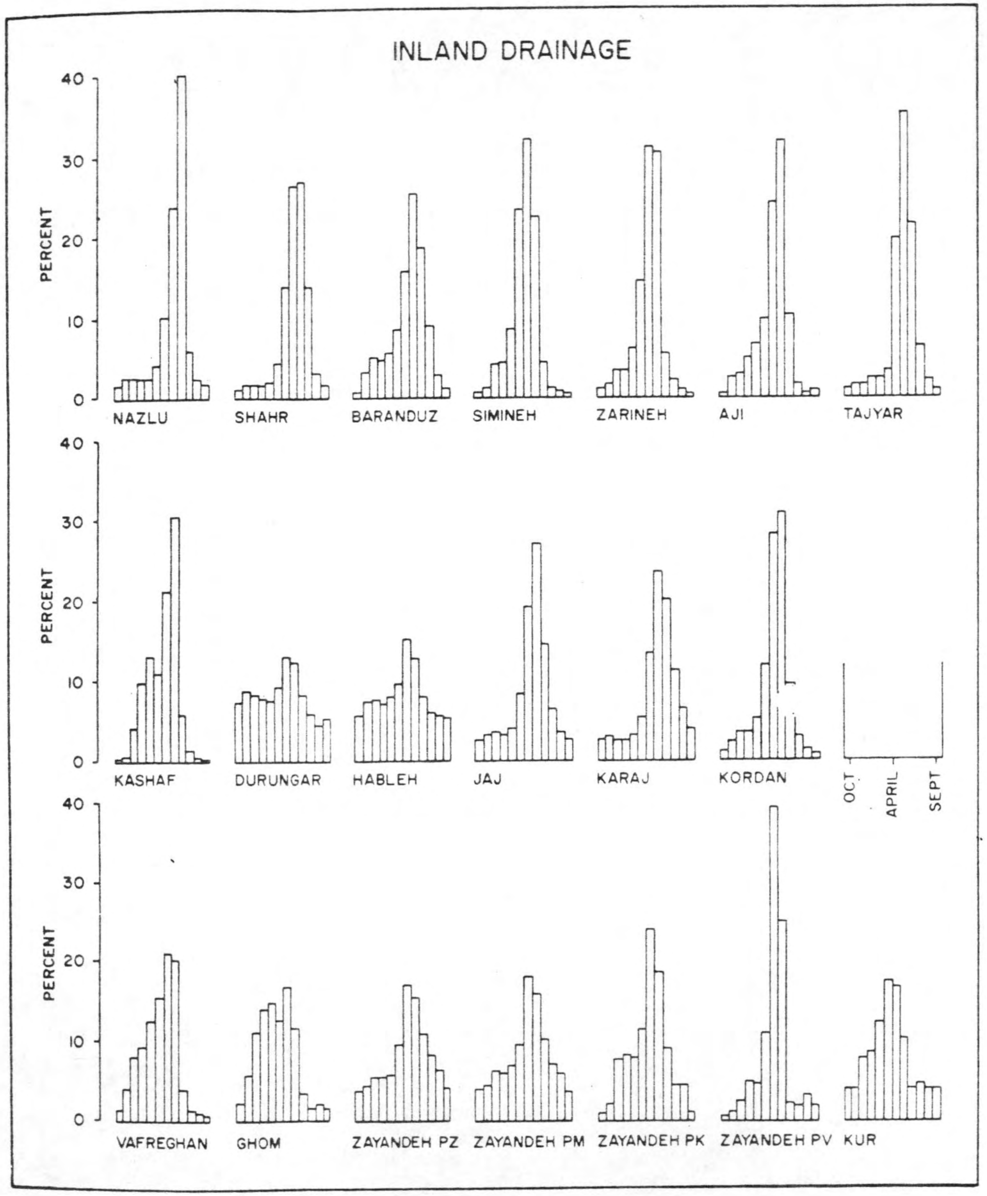

Fig 5b River regime hydrographs of Iran (continued)

which were analysed, this ratio varied from 1·98: 1 in the case of the River Tajan to 129·73: 1 on the Ghezel Ozan river (Table 1). The main deficiency of this method is that it considers only two of the twelve monthly values which are available and, therefore, wastes a considerable amount of information. It does, however, consider the two most critical months in the regime hydrograph.

To employ all the information contained in the regime hydrograph, a measure of the deviation of each individual basin hydrograph from a base hydrograph with equal distribution of discharge values in each month was calculated. The differences between the monthly values of the individual basins and the equivalent values of the base hydrograph were squared and summed to obtain a total deviation. The technique is extremely simple and provides a single numerical value which can be used for classificatory or comparative purposes. It also possesses the advantage of grouping together hydrographs of similar shape irrespective of the month of peak discharge. The only problem associated with the method is that it would provide similar results if the monthly values of any hydrograph were randomly sorted. Fortunately, however, most of the Iranian rivers reveal a single peak discharge.

The numerical values from the analysis are listed in Table 2 and certain groupings, which are arbitrary and for convenience only, are also shown in this table and in Figures 6 and 7. In the diagram, very clear differences can be noted, with the Group 1 regimes showing very little variation in discharge throughout the year in contrast to the pronounced peaks exhibited by Group 6. The basins in Groups 1 and 2 tend to be concentrated along the Caspian Sea coast and in the south-western parts of the Zagros mountains. The sizes of the basins are noticeably smaller in the former area. Groups 3 and 4 also reveal two distinct concentrations. One is a number of mainly small basins along the southern slopes of the Elburz mountains and the other a cluster of larger basins in the central part of the Zagros mountains. Finally, Groups 5 and 6 exhibit a single marked concentration in the north-western portions of the Zagros mountains, although isolated basins with high deviations are found in other parts of the country.

When the regime hydrographs are examined in detail it is found that the month of maximum discharge is almost always either Farvardin (March 21st - April 20th) or Ordibehesht (April 21st - May 21st) (Table 1). When these discharge peaks are compared with the available precipitation data, certain interesting features are noted. For comparative purposes mean monthly and mean annual precipitation totals were calculated for the period 1956 to 1965 and the result expressed in dimensionless diagrams (Fig 8). Precipitation data used in this analysis were obtained from Meteorological Yearbooks published by the Ministry of Roads, Iranian Meteological Department (Ministry of Roads) Along the Caspian Sea coast, maximum precipitation usually occurs in October, although the main feature of precipitation in this region is its uniform distribution throughout the year. Elsewhere throughout northern and western Iran, there is usually a precipitation maximum in April followed by a marked dry period from July to October inclusive. The only major exception to this rule seems to occur along the lower west-facing slopes of the Zagros, where a slight January maximum is sometimes found. It would, therefore, appear that there is a close correlation between the month of maximum precipitation and maximum discharge. To some extent though this is an oversimplification

TABLE 2

DEVIATIONS FROM THE HYDROGRAPH OF EQUAL MONTHLY DISCHARGE

Group 1	(0-199)
Tajan	36·3
Durunger	62·0
Shafa	89·8
Babul	96·9
Hableh	99·1
Talar	194·6

Group 2	(200-399)
Chalus	209·7
Zayandeh P Z	218·6
Pol	219·5
Karun G	224·1
Marboreh	224·6
Zayandeh P M	233·1
Karun A	251·7
Kur	280·1
Zohreh	301·4
Haraz	336·0
Kashgan	337·8
Ghom	374·9
Marun	399·4

Group 3	(400-599)
Zayandeh P K	540·0
Karkheh	544·4
Nahavand	549·4
Vagreghan	559·8
Karaj	572·7
Ab-e-Tireh	594·3

Group 4	(400-799)
Sardab	610·5
Jaj	611·3
Gamasiab	614·6
Shah	623·9
Gharasu	624·9
Baranduz	650·8
Lar	714·8

Group 5	(800-1199)
Gorgan P D	807·4
Gorgan G G	808·5
Shahr	977·8
Kashaf	1009·1
Aji	1060·0
Dinavar	1071·6
Kordan	1169·2
Ghezel Uzan	1196·3

Group 6 (more than 1200)	
Simineh	1249·4
Zarineh	1353·6
Tayjar	1359·7
Nazlu	1529·8
Zayandeh P V	1552·1

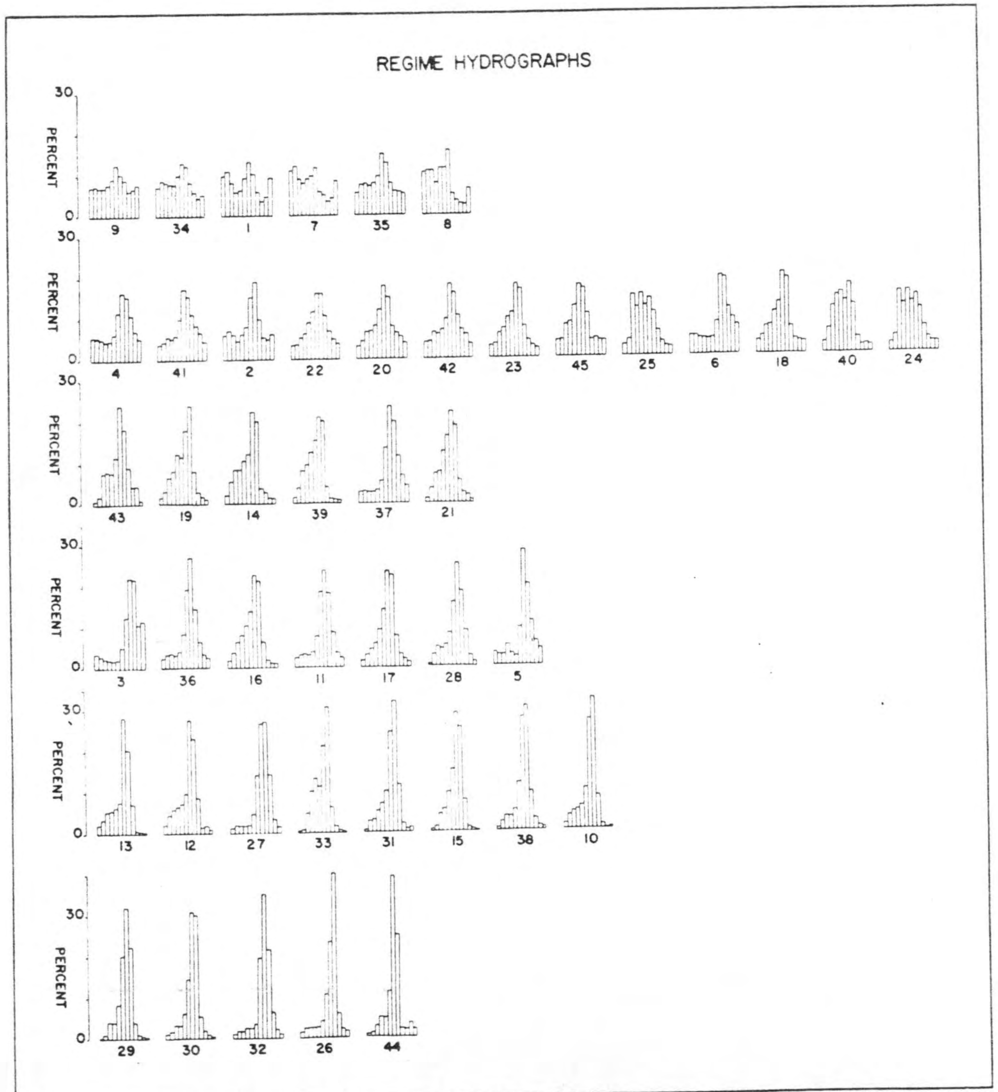

Fig 6 Regime hydrograph groupings : deviations from the hydrograph of equal monthly discharge

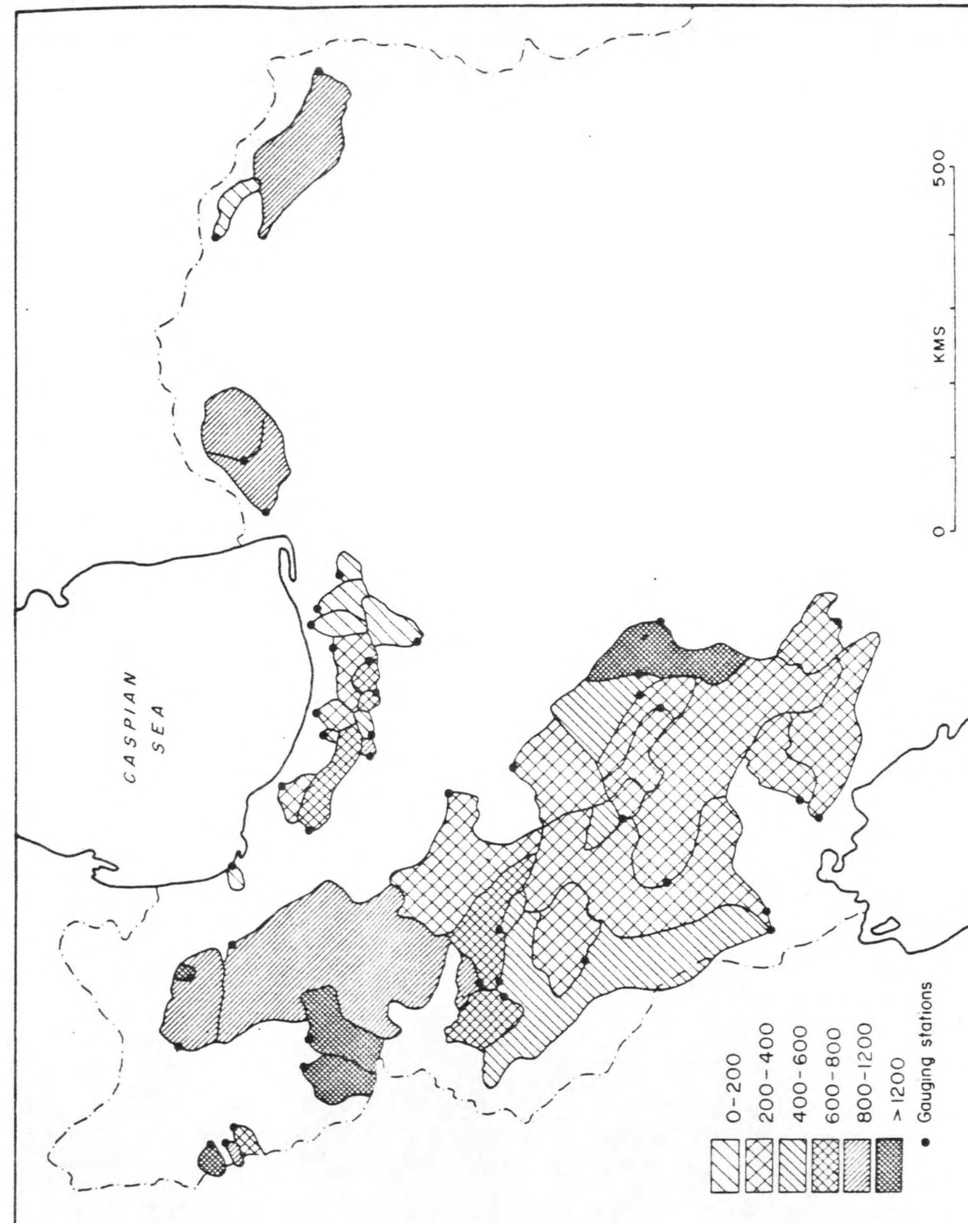

Fig 7 Distribution of regime hydrograph groupings

of the actual situation, since the April precipitation alone is in many case insufficient to account for the magnitude of some of the regime hydrograph peaks. The true explanation for the well-marked peak discharges would seem to be that there are really composite forms made up of varying amounts of snowmelt together with the addition of sometimes fairly large contributions of precipitation. The major reason for the importance of the snowmelt component is that almost all the streams considered in this survey rise, often at considerable elevations, in the Elburz and Zagros mountains. In these areas, winter precipitation, which usually forms a considerable portion of the total, is stored as a snow pack; with the rise in temperatures in spring and early summer, this snow begins to melt. The amount of water produced by this melting is often considerably increased by warm frontal rain from Atlantic or Mediterranean depressions falling on to a ripe snowpack. The result is to produce the well-marked peaks on the regime hydrographs which are characteristic of Groups 3, 4, 5 and 6. The size of the snowmelt/rainfall discharge peaks in Groups 5 and 6 is sometimes made so large by the fact that summer flows in the arid interior regions are very low (Fig 6 and Table 1).

The distribution of the differing types of regime hydrographs in Iran seems, from the above discussion, to be relatively easy to to explain. Along the Caspian Sea lowlands, the rivers almost always tend to register a snowmelt component, though this is frequently small. On the other hand, they reveal relatively high discharge values throughout the rest of the year, largely as the result of the high and uniform precipitation which occurs.

Everywhere else in Iran, one is basically dealing with a marked winter/spring precipitation maximum, which, together with a snowmelt component of varying size, is clearly reflected in the regime hydrograph. Outside the Caspian Sea zone, one of the few streams which does not exhibit the well-developed single discharge peak is the River Zohreh, which flows into the northern part of the Persian Gulf. On this stream a high discharge period occurs from January through to May. The early part of this peak is caused by late winter and early spring rainfall falling on to the mild alluvial lowlands foothill zone, while the latter part is a snowmelt component from the more elevated regions of the watershed in the Zagros mountains.

Although the regime hydrograph is a valuable and perhaps even under-utilised geographical tool, it does suffer from the fact that, like all methods using average values, it tends to oversimplify reality. This is especially true in terms of the fluctuations from year to year, which can often be of great environmental and human significance. To illustrate this point, Figure 9 shows the monthly discharge values for the period 1955 - 1966 of a number of selected streams in Iran. The Tajan is a small stream draining the eastern part of the Elburz mountains towards the Caspian Sea. Its regime hydrograph (Fig 5) reveals a slight April peak discharge, but it is perhaps more noteworthy for the fact that monthly discharges are remarkably constant throughout the year. When the monthly records of the ten-year period are examined (Fig 9), it is seen that a clear annual cycle is not always evident, although variations from year to year are surprisingly small. This stream contrasts markedly with the Babul, another Group 1 stream, with a similar regime hydrograph. The Babul has a larger catchment than the Tajan, but it too drains the northern slopes of the Elburz mountains. Over the ten-year observation period, the Babul shows little eivdence of any clear and repeating annual cycle, with a variety of different months experiencing maximum and minimum flow conditions. The amplitude of the variations between maximum and minimum flows is also considerably greater than for the Tajan. However, owing to the pronounced annual variations in the months of maximum and minimum discharge, this fact is not clearly registered on the regime hydrograph. Both the Tajan and the Babul are streams with regime hydrographs which are largely controlled by rainfall variations throughout the year, rather than by a single snowmelt event of great magnitude.

On the other hand, the Chalus, a Group 2 stream, but also from the Caspian drainage area, has a regime hydrograph with a more pronounced peak discharge during May and June. When the ten-year observation period is studied, it is noted that this marked peak, which is largely due to snowmelt, is registered every year, even though its size shows annual fluctuations. When the regime hydrographs are dominated by a single pronounced peak with a large snowmelt component, the rivers tend to show a much more stable pattern from year to year. The vast majority of the rivers under consideration in this study fall into this category. To exemplify this point, four streams have been chosen, one each from Groups 3, 4, 5 and 6; the ten-year record of all these streams exhibits a clearly marked annual cycle. This is particularly pronounced in the case of the Nazlu river, which registers a peak discharge in May on nine out of ten observations, and a regularly occurring minimum monthly value in September or October. With the Aji Chai, extremely low summer flows are recorded in some years.

The regime hydrograph can also be a useful method for studying the water balance of a drainage basin when it is expressed in terms of actual discharge values. Its great advantage is that it integrates the combined effects of precipitation and evapotranspiration and expresses the result in terms of a volume of water flow. Figure 10, on which total annual discharge is plotted against basin area, reveals little relationship between the two variables. Total discharge tends to increase as drainage basin area increases but not in a clear manner and, as a result, a wide scatter of points is observed. Using this information, it is possible to calculate runoff values per unit area of drainage basin, in this case cubic metres per square kilometre (Table 1). If these data are arbitrarily divided into three classes with equal numbers of observations in each, one can then plot the results in terms of drainage basins with high, medium and low runoff values per unit area (Fig 11). From this it is seen that the highest values tend to be concentrated in three regions. The first is in the north-western part of the Zagros mountains and includes a number of small- and medium-sized basins close to the Iraqi border. Here runoff values vary from 196,000 to 445,000 cubic metres per square kilometre (a runoff equivalent of between 196 to 445 mm of precipitation). Further south in the Zagros a second group is centred on the Zardeh Kuh, which includes the headwaters of the River Karun and which possesses runoff values between 225,000 and 303,000 cubic metres per square kilometre. Finally, along the Caspian Sea lowlands and in the Elburz mountains are a series of seven small catchments with annual runoff amounts ranging from 271,000 to 550,000 cubic metres per square kilometre. In contrast to these highland streams, the lowest runoff figures are concentrated in a ring of basins draining the plateau area of central Iran and including rivers such as the

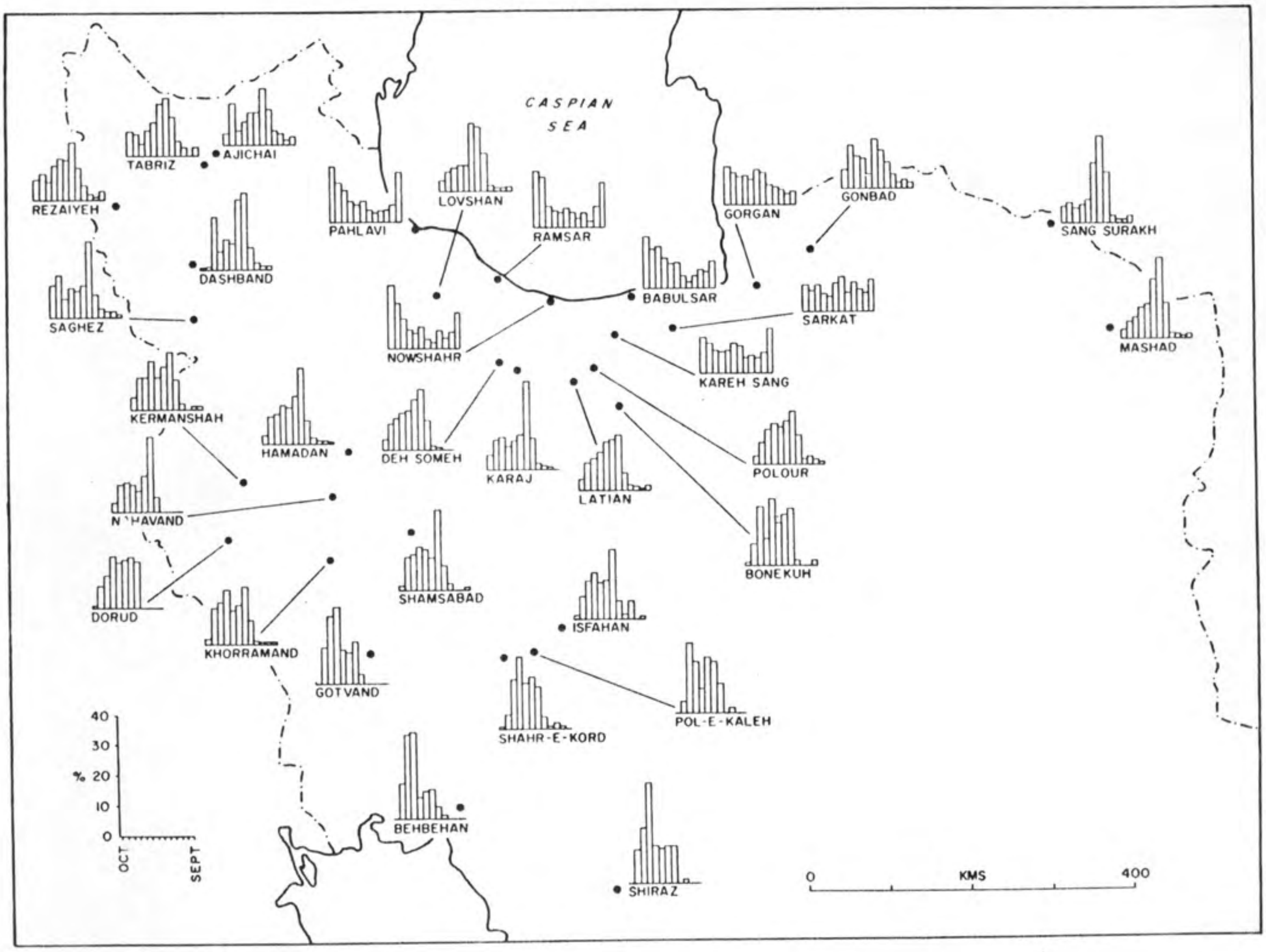

Fig 8 Mean monthly precipitation diagrams for 1956-65

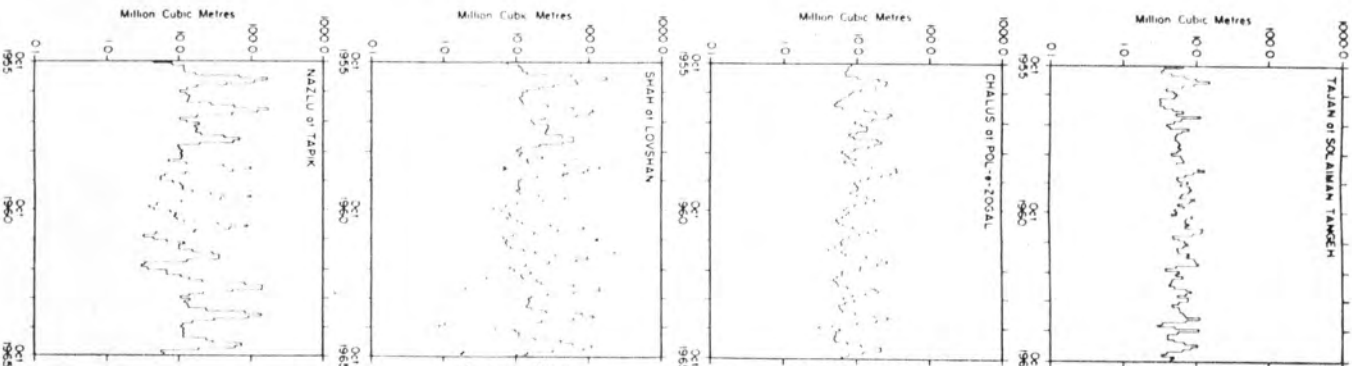

Fig 9 Monthly discharges of selected Iranian rivers, 1955-65

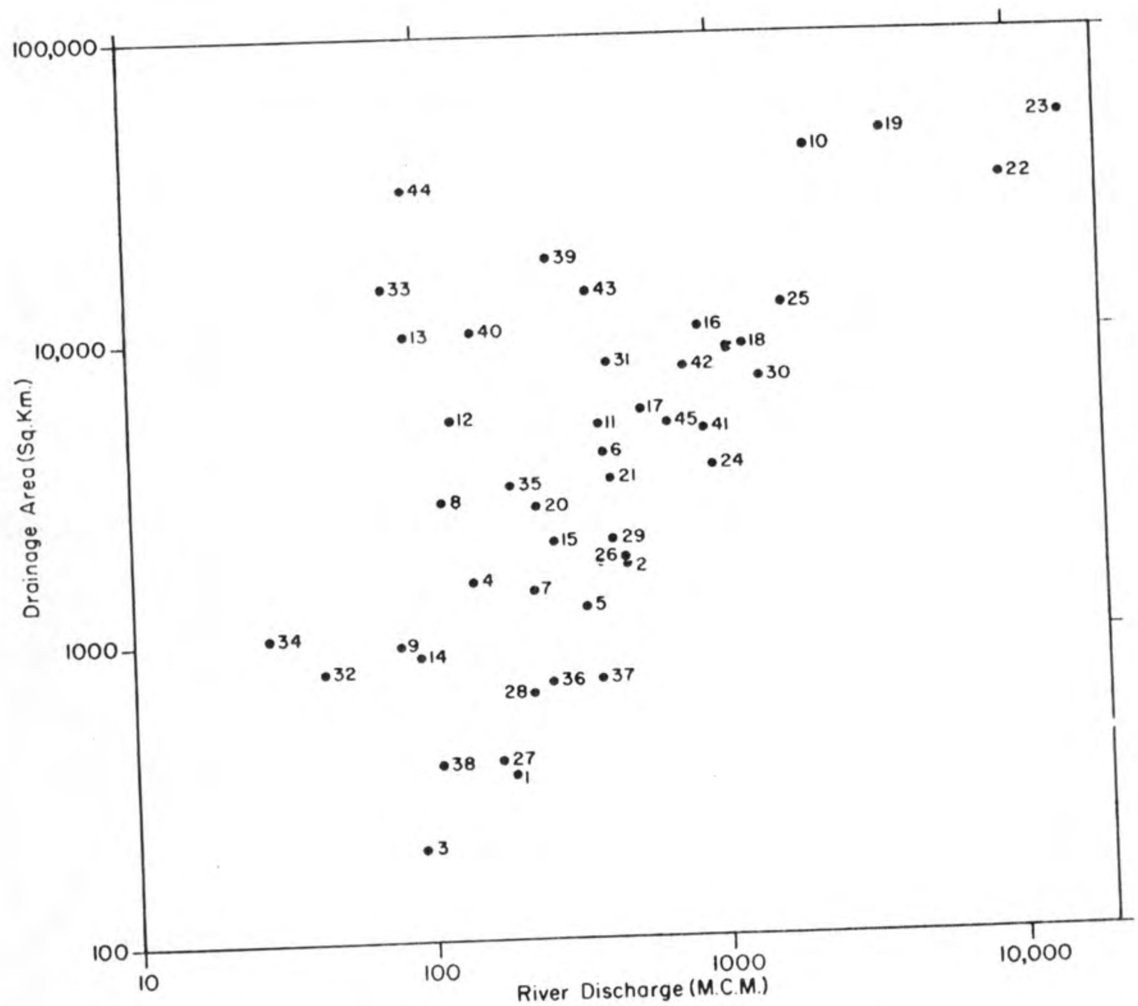

Fig. 10 Relationship between annual discharge and basin area

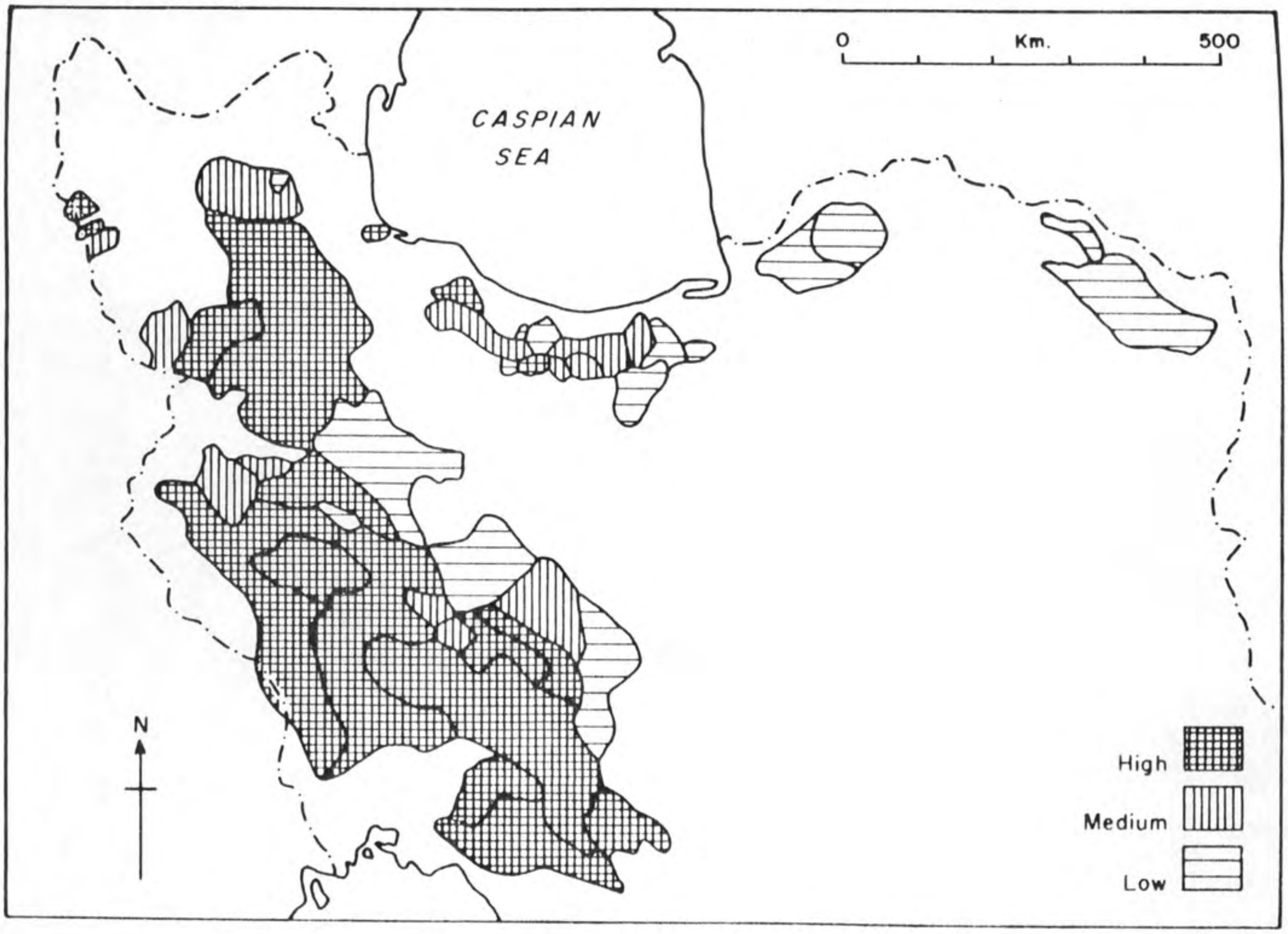

Fig 11 Runoff per unit area

Kashaf, the Gorgan, the Ghezel Uzan, the Vafreghan, the Ghom and the Zayandeh. Somewhat sruprisingly perhaps, the whole of the basin of the River Karkheh falls into this lowest category. The range of runoff data for these streams is from 3,000 to 83,000 cubic metres per square kilometre. All of the remaining river systems fall into the grouping of medium runoff values with figures falling between 83,000 and 182,000 cubic metres per square kilometres.

Conclusion

This analysis has revealed that the majority of the regime hydrographs of the river systems of north and west Iran are dominated by large snowmelt components which give rise to peak discharges, usually in April and May. Very low flows occur during the summer months at a time when the water contribution from precipitation is minimal; at this time most of the discharge is baseflow from groundwater sources. Only in the Caspian Sea lowlands and along the northern shores of the Elburz mountains do the rivers reveal discharge patterns which can be closely correlated with the distribution of precipitation throughout the year and which also tend to lack a clear annual rhythm. Maximum runoff values are all concentrated in the northern and western parts of the country along the lines of the Elburz and Zagros mountains, while very low flows are experienced in central Iran.

While these river regimes are considered representative of the natural environment, it is possible that the summer flows of a number of the streams under consideration may have such low values partly as the result of the activities of man. Throughout Iran water is abstracted from streams during the growing season for irrigation purposes. In many regions, especially in the central part of the country where precipitation totals are so low, these abstraction volumes must be considerable to be able to support the local human population needs. However, the total amounts of water involved are not known with any precision except for very small portions of the country where detailed surveys have been completed.

Note

The river discharge data are collected, tabulated and analysed by the Ministry of Water and Power in terms of the Iranian calendar. This calendar is, therefore, used for all discharge measurements and river regime diagrams in this paper.

Iranian month	Closest English equivalent	Actual dates
Mehr	October	Sept 23 - Oct 22
Aban	November	Oct 23 - Nov 21
Azar	December	Nov 22 - Dec 21
Dey	January	Dec 22 - Jan 20
Bahman	February	Jan 21 - Feb 19
Esfand	March	Feb 20 - March 20
Farvardin	April	March 21 - April 20
Ordibehesht	May	April 21 - May 21
Khordad	June	May 22 - June 21
Tir	July	June 22 - July 22
Amordad	August	July 23 - Aug 22
Shahrivar	September	Aug 23 - Sept 22

Acknowledgments

The receipt of a travel grant from the Centre for Middle Eastern and Islamic Studies, University of Durham, England, for fieldwork in Iran is gratefully acknowledged. I am also indebted to the Ministry of Water and Power, Iran, for generously providing information and assistance during the preparation of this work.

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