Seasonal Rainfall Regime

in

the Central Elburz, Iran

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ABSTRACT

The area chosen for this study is the Central Elburz of Iran surrounding the southern end of the Caspian Sea. It includes an important rainfall dependent agricultural area and merges into the semi arid zone with a well defined boundary. From social and agricultural points of view rainfall is by far the most important climatic factor in many tropical and subtropical countries. An important aspect in the development of agriculture in the Central Elburz is the determination of the seasonal rainfall patterns. This thesis should be considered as a contribution to the study of the seasonal rainfall regime of Iran, with direct value to agriculture in the region. The purpose of this thesis is to examine the pattern of rainfall especially in relation to the growing season both in time and spatially. Also the thesis describes the variation in the availability of moisture for growth throughout this region.

The thesis examines annual, monthly and seasonal rainfall over the region. Multivariate analysis has demonstrated that the study area can be divided into three rainfall regions. Before considering any analysis which could allow prediction on probability of future rainfall amounts, it is important to consider whether or not there on trends or fluctuations. The result of this analysis is that, few stations show positive trends, others negative trends.

Rainfall variability has been quantified by the coefficient of variation index and analysed in a similar way to that of rainfall distribution. The results for most stations shown a relationship between variability indices and rainfall amounts. In relation to the study of variability, an assessment of rainfall probability and reliability has been considered with reference to rainfall critical for crops. Probability has a particular value in its application to agriculture. In this study 90% probability is examined and this is related to the economy of the agriculture units in the Central Elburz. Also 80 and 75 percent probability are presented. These spatial patterns of probability thus

provide maps of agricultural potential. Rainfall records are analysed to provide estimates, percentage points of rainfall totals, variation in the start, and end of the rainy season and or the probability of dry spells within the rainy season.

The estimation of potential evapotranspiration which are discussed and explained in this study are based on the Blaney- Criddle and Pan evaporation methods.

The water balance approach provides the most rational method of analysing seasonal pattern since it considers characteristics of the dominant crops in this area, wheat and citrus, and it examines effectiveness of rainfall for these crops. Blaney- Criddle and Pan evaporation have been used to estimate potential evaporation for wheat and citrus and compared to actual evapotranspiration to give potential water deficit. The adoption of probability analysis of potential water deficit provides a valuable description of water availability for crops in this region of variable rainfall.

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1. Introduction

The Iranian state covers an area of just under 628,000 square miles (1,648,000 km)^2 and extends between latitudes 25^0 to 40^0 N, and longitudes 44^0 and 63^0 E. Its size is more than six times the size of Great Britain and approximately three times the size of France, which is the largest country in Western Europe. It receives most of its rainfall during the cold months (November-April). It is under the climatic controls of tropical and extratropical latitudes, and includes a wide range of climatic regimes, from mountainous (in the Elburz, Zagros and Azarbijan mountains), humid in the Caspian Coastal Area, and to desert conditions in most of Central Iran and the Persian Gulf. During winter the cold Siberian anticyclone dominates the country while during the summer season a shallow heat low centred over west Pakistan and southern Iran is a dominant surface circulation feature. Another important controlling factor in the climate of Iran is the shift of the mean position of the subtropical jet stream in the upper troposphere. Iran (especially the south and centre of Iran) is affected by subsidence below the subtropical jet stream in summer. The westerly polar vortex and its accompanying cyclonic activity expands during winter, bringing the southern branch of the polar front jet stream over Iran. Also the regional climate is complicated by topography. In the northern and western portions of the country the higher mountains add to the severity of winters and block the humidity flux to the central parts of the country. All of these variations in the circulation modified by the topography of the territory, bring different kinds of air masses to the country. As a result of these diverse climatic controls, Iran harbours a surprisingly complex climate.

According to the Koppen classification, Mediterranean climate is found in the north, Northwest, and western highlands, while hot desert climates are found in the coastal strip of the Persian Gulf and the Oman Sea and the remaining areas have steppe climate (Alijani 1981).

Using the aridity index Dehsara (1972) classified the country into three broad regions of forest, steppe, and desert. The forest region covers the coastal area of the Caspian Sea and northern parts of the Zagros Mountains. The steppe regions cover all the mountainous slopes areas, while deserts cover the lowlands (see Figure 1-1). Also Adle (1960), Gangi (1961) have classified the climatic zone of Iran according to Koppen's system. Sabeti (1970) has attempted to classify the climate of this country by Emberger and Gaussin's system. All these general classifications indicate that the Coastal Area of the Caspian Sea has a humid or subhumid climate and Southern parts of Central Elburz a dry or semi dry climate. The seasonal distribution of rainfall has a fundamental role in the identification of these climatic areas.

In the arid and semi- arid lands of this country, which offer a great potential for development, water supply has been a limiting factor especially in agricultural activities and pastoral land use from ancient times. Apart from a number of pump, well, Qanats, channel and major irrigation projects which support forms of subsistence and commercial agriculture, the bulk of arable lands mainly depend on the amount and seasonal distribution of rainfall. However, in these lands, the social and economic development would be restricted by the imbalance between the water supply, in the form of rainfall and water demand for arable cropping and raising of livestock.

A successful harvest in any one season depends on the amount of rainfall received, its distribution throughout the rainy season and the length of the rainy season. Also in the long run, successful agricultural and water resources development policies rest on the seasonal rainfall regime. Rainfall is of great importance in tropical and subtropical agricultural production activities. Consequently the relevance of rainfall investigation in a subtropical country like Iran (especially the Central Elburz), where rain-fed cultivation occupies a dominant place in the national economy, hardly needs to be emphasised. Thus, in many parts of the world a detailed knowledge of the rainfall regime is an important prerequisite for agriculture planning (Dennet, *et al* 1983).

The seasonal rainfall in the Central Elburz and in most parts of south-west Asia is evident in that there are two known seasons, the wet and the dry seasons, primarily on the basis of rainfall occurrence and humidity. The climate of Iran is characterised by alternate wet and dry seasons, but there are considerable variations in the seasonal regime from place to place that depend not only on latitude but also on location (e.g. coastal, and desert area), on topography, and the associated meteorological factors that control the amount of rainfall distribution. These factors, have produced local contrasts in the seasonal rainfall regimes which can be used as a basis for regional rainfall studies.

1.1 Rainfall studies in Iran

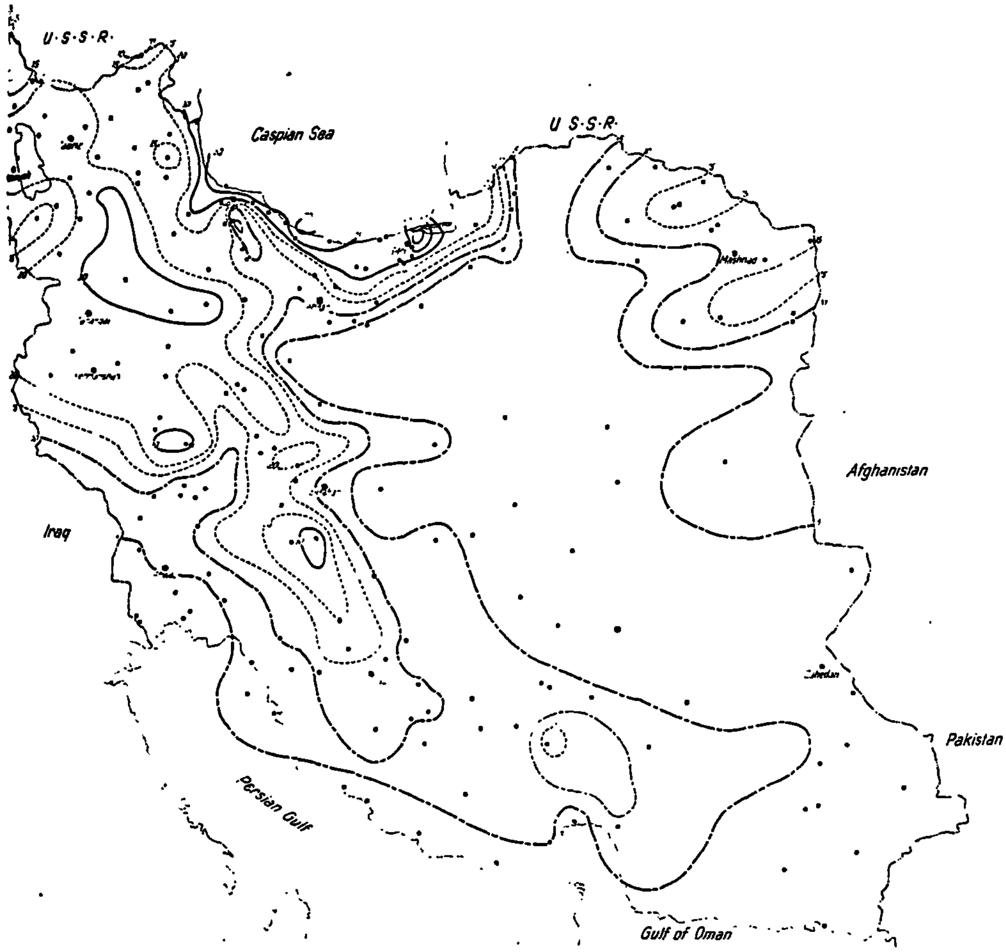
In comparison with other countries, such as the African nations, rainfall studies in Iran are relatively under researched. During the last 3 decades, meteorologists and climatologists have shown interest in the descriptive (Gangi 1954, 1968), synoptic (Alijani and Herman 1985) and quantitative (Kawiani 1988) aspects of rainfall over Iran. Gangi generally described the distribution pattern of the mean annual rainfall from a short period record for the whole country. In terms of rainfall variability and reliability very little research has been done. The only possible contribution in this respect has been presented by Kawiani (1988) on the annual rainfall over Iran. Previous studies of rainfall over Iran have tended to be descriptive rather than analytical. Most of them are no more than generalised descriptions of the mean monthly and annual distribution patterns over the country. These studies have usually been based on records for a few stations and covering a short period of time. Previous studies have tended to be generally concerned with investigating the broad scale conditions of rainfall over the country as a whole, with less emphasis being placed on the local or regional scales. The limitations involved in this approach may be very obvious in a vast area like Iran which experiences a remarkable diversity in the rainfall amount and seasonal distribution. In this respect, the duration and intensity of the alternating wet and dry seasons tend to vary considerably from north to south depending on the latitudinal location of the place, elevation and the associated meteorological conditions.

1.2 Data Recording for the Study

Unfortunately the climatic observations in Iran have not been collected for as long as in many comparable areas, such as European Countries, East Africa etc. However, climatic studies and observations are usually stimulated either by scientific interest or practical need. It is specially in the fields of agriculture that sound meteorological information becomes essential for long term planning and operations. Until the 1940s, neither of the above incentives to meteorological studies received much attention in Iran. In the early years of the war, however the country became a vital area, considered by the Allies the ''Bridge of Victory'' for the transport of essential wartime supplies to Russia. Roads had to be built under various climatic conditions, and traffic maintained in all kinds of weather. Soon a network of airways was established all over the country, and it was not long before Tehran became the largest and most strategic air base in the Middle East. A new era in the history of Iran's meteorological studies was initiated by sending 3 experienced Norwegian meteorologists in 1951 the under supervision of a UN advisor (Fisher 1968 quoting Gangi 1968). Finally, in March 1957 the Iranian Meteorological Department was formed in Tehran. Recently Iran has been chosen as the Centre of South West Asian Weather Climatic Studies by WMO from 1991. This will be very important for Iranian meteorological and climatological studies in the future.

Like all other disciplines, most climatological studies are limited by the amount of data, duration of records and the density of meteorological network available to the research worker. In Iran, the original climatic data are kept in the Meteorological Office. Practically all the data used in this investigation were obtained from the Iranian Meteorological Department in Tehran City. The climatological data includes daily and monthly rainfall and other elements such as monthly evaporation, monthly temperature and relative humidity. However the length of records vary considering for these parameters. The details of these records are discussed in the each section in the text of the following chapters. Among many other factors, the duration of records can have an enormous effect on the stability of the statistical measures used in any climatological investigation. For this reason the world Meteorological Organization has recommended a standard 30 year period as being sufficient for calculating long term averages. Taking into consideration the need to have an adequate areal coverage, this investigation is based on data of 29 stations (Table 1-1 and Figure 1-2) and covers more than a thirty year period between 1957 to 1987.

Table 1-1 and Figure 1- 2 show the duration of records for the climatic stations used and their local distribution in this study. Of these 29 stations, 22 provide information for periods that range between 30 and 45 years. The remaining 7 stations have between 24 to 26 years of records. Also daily rainfall investigation is based on data for 10 stations (Anzali, Babolsar, Gorgan, Ramsar, Rasht, Ghazvin, Karaj, Semnan, Tehran, and Varamin) covering a 10 year- period that extends between 1982 and 1991.



Forest Area ———
Steppe Area ··········
Desert Area – · – ·

Figure 1-1 Agro- Climatological Map of Iran after Desara (1972).

Table 1-1 The Distribution of Selected Meteorological Stations for study.

Stations	Latitude (N)	Longitude (E)	Altitude (m)	Length of record (years)
Anzali	37 28	49 28	-26.2	38
Astara	38 26	48 52	-25	30
Babolsar	36 43	52 39	-21	38
Ghaemshahr	36 29	52 53	50	31
Gonbad	37 15	55 10	150	31
Gorgan	36 51	54 16	105	35
Havigh	38 09	48 53	-15	26
Hashtpar	37 48	48 54	80	25
Lahijan	37 11	50	- 2	31
Noushahr	36 39	51 31	- 20	31
Ramsar	36 54	50 40	- 20	30
Rasht	37 15	49 36	- 7	32
Shirgah	36 17	52 54	223	24
Aminabad	35 26	51 34	1000	25
Damghan	36 13	54 22	1170	30
Dehsomeh	35 57	50 50	1500	31
Garmsar	35 15	52 20	856.5	30
Ghazvin	36 15	50	1304	31
Ghom	34 38	50 53	928	32
Karaj	35 48	51 10	1321	31
Latian	35 40	51 41	1600	32
Semnan	35 33	53 23	1138	30
Shahroud	36 25	55 2	1366	32
Takestan	36 04	49 12	1325	30
Tehran	35 41	51 19	1191	45
Varamin	35 19	51 39	1000	30
Abali	35 46	51 59	2450	26
Northern Kandavan	36 10	51 19	2750	26
Southern Kandavan	36 0.9	51 18	2900	26

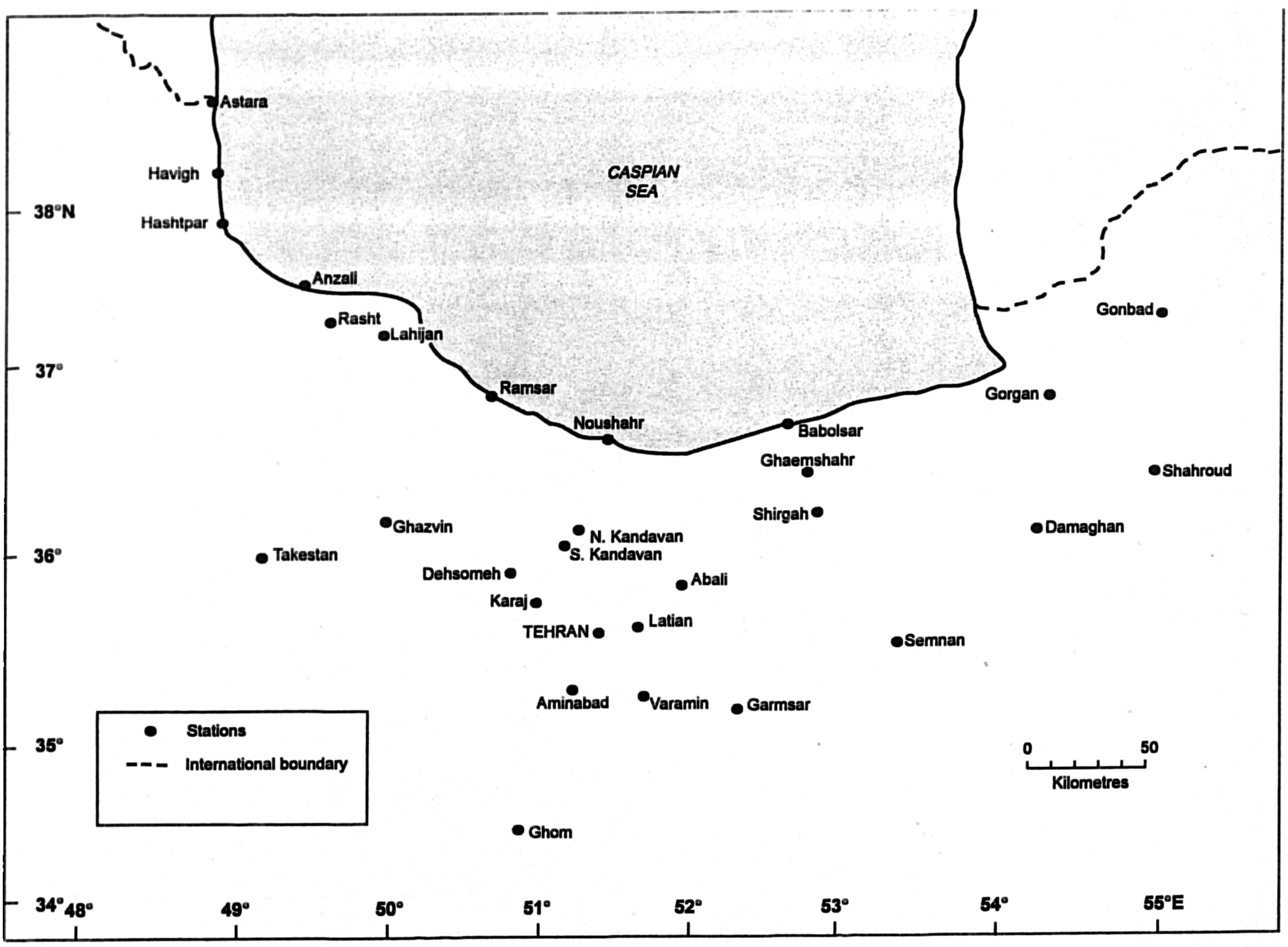


Figure 1-2 The Distribution of Selected Meteorological Stations.

1.3 The study Area

The Elburz is a system of mountains that encircle the southern Caspian Sea and continuing eastward to the northern highland (Kopet Dugh). The Central part of this great range forms an arc to the south of the Caspian Sea and separates the coastal plains from the Central plateau of Iran (see Figure 1-3). At the synoptic scale the ridge line of the Elburz mountains can be considered as the boundary between two different regions, southern and northern. This boundary is an interesting physical boundary particularly from the point of view of rainfall. The Central Elburz has created 3 climatic diversities and subsequent rainfall regimes as follows:

1) Higher altitudes (more than 2000 m above sea level, see Figure 1-4)

2) Coastal areas (less than 200 m above sea level)

3) Southern slopes (less than 2000 m above sea level).

This part of Elburz has not been studied by any climatologist properly and there is no reference to it in the literature. Also the Elburz range is a watershed between the coastal lowlands of the Caspian Sea and the Great Central plateau of Iran on the scale of synoptic meteorology.

The study of the Central Elburz of Iran has been chosen for several reasons:

1) moisture gradient and its importance agriculturally,

2) It has within it a boundary with aridity.

3) the density of network of stations is superior to other areas of Iran.

Figure 1-3 The Physical Map of Iran.

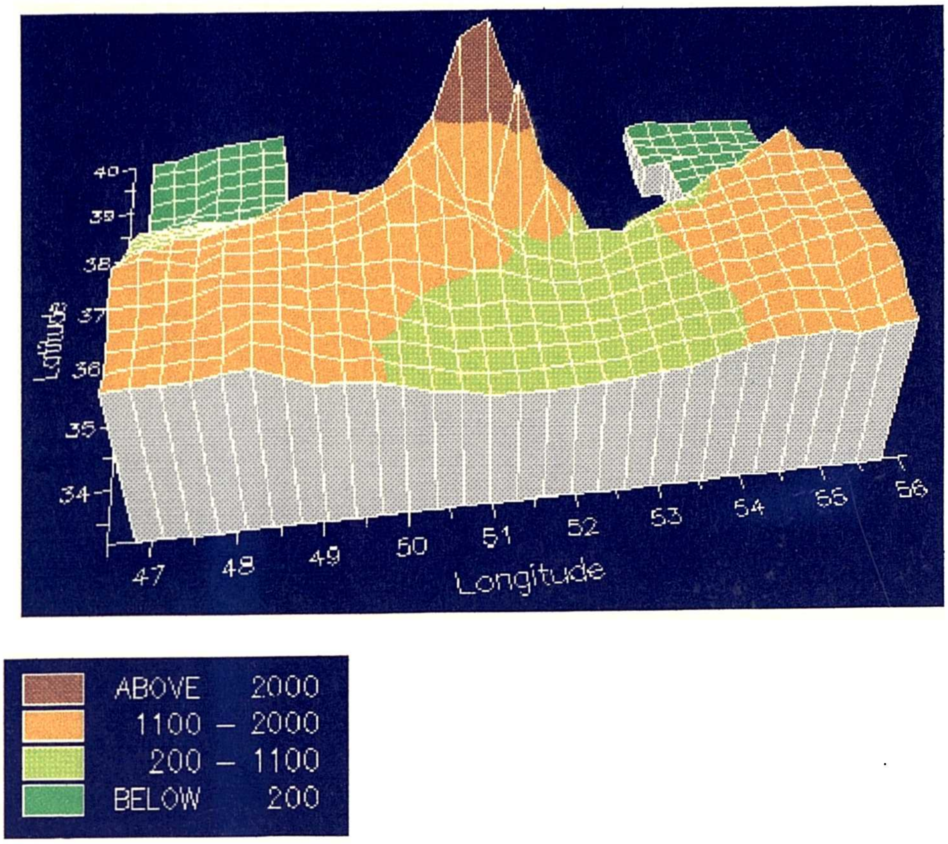


Figure 1-4 The Central Elburz Elevation Map*

* The Central Elburz Elevation Map has been provided by the Unimap Technique. Unimap Technique will be discussed and explained in Chapter 3.

1.4 Aims of Thesis

From a variety of social and agricultural points of view rainfall is by far the most important climatic factor in many tropical and subtropical countries. The amount of rainfall that is normally received decides which types of agriculture can be carried out and which crops can be cultivated in a region (Nieuwolt 1982).

Kenworthy (1968) considered the seasonal distribution of rainfall and its variability in amount and in distribution from year to year is not only important for overall assessments of agricultural potential, but also for improvements in farming practices as much in areas with good rainfall as in areas with marginal rainfall. The seasonal rainfall distribution regulates the agricultural calendar, and the rainfall variability from year to year is the main factor responsible for fluctuations in yields and total production. The distribution patterns of the rainfall can be very useful in agricultural planning and management. Also Stern, and Coe (1981) argued that the timing of the start of the growing season in seasonally arid countries is a problem of great importance in agricultural planning.

It is essential to study the rainfall climatology of the Central Elburz area, especially when agriculture is the dominant activity and way of life. Crops and livestock production in the area depend on adequate rainfall and its timing. Thus an important aspect in the development of agriculture in the Central Elburz is the determination of the seasonal rainfall patterns. The coastal areas of northern Elburz have the potential to increase food production towards national self sufficiency and for an export surplus to neighbouring, and other countries. However, knowledge of the agroclimatic conditions needs to be incorporated in the production processes in order to improve yields on a national basis.

Therefore the specific aims of this thesis are:.

a) to analyse data on rainfall to evaluate seasonal patterns.

b) to consider rainfall within the water balance and in relation to crop growing in the region. This makes the seasonal pattern relevant to agriculture.

This thesis should be considered as a contribution to the study and understanding of the seasonal rainfall regime of the Central Elburz Iran with direct value to agriculture in the region. However there are many aspects which can be developed from this initial research of the climatology in this region.

2

2. General Atmospheric Features of Iran

The climate of south-west Asia has been briefly discussed in a few general text books of climatology as part of the climatic regimes of Asia but has not yet been treated as an integrated subject and not described climatologically in any detail.

According to Takahashi and Arakawa (1981) the climate of Asia is affected by the following factors

1. The dominating pressure system in winter is the cold Siberian anticyclone over central Asia and to the south of this anticyclone depressions from the Mediterranean travel from west to east.

2. The large water surfaces surrounding the area act as sources of moisture and heat.

3. Orography largely determines the climate of some areas of the region but in other areas its effect on climate is limited.

However no single climatic regime prevails throughout the Middle East (Beaumont *et al* 1988). Indeed, the region is a transitional between the climatic controls of tropical and subtropical latitudes. According to Brice (1966) south-west Asia may be considered as an eastward extension of the Mediterranean region where winter, is in general the wet season, and summer the dry season. The main climatic difference between the Mediterranean region and that of the Middle East is that, while the former is subject to the tempering influence of the sea, the later experiences extremes of heat and cold and includes wide tracts of desert and semi - desert. In brief, the climate of the greater part of south-west Asia, with the exception of some coastal areas, may be defined as a dry continental variant of the Mediterranean type.

A particular characteristic of all subtropical latitudes of which the Middle East forms a substantial part, is the prevalence of aridity with a marked rainfall minimum over both the oceans and continents centred on 30 degrees of latitude. Much of the subtropical region is characterized by divergent air flow in the atmosphere at low levels. This implies the existence of converging and subsiding air aloft which being subjected to dynamic warming, will produce a lowering of relative humidity and stable atmospheric conditions. Under these circumstances convectional activity capable of producing rainfall is reduced to a minimum. According to Strahler (1992) the subtropical high pressure belt, which ranges between latitudes 25^0 to 40^0 N and S, are large stagnant, high pressure cells (anticyclones). In the centres of the cells winds are weak and are distributed around a wide range of compass direction and calms prevail as much as a quarter of the time. Iran is under this subtropical high pressure system which has surface divergent flow of air and widespread air subsidence. General subsidence occurs in the zone between 20 and 30 degree latitudes. This subsiding air is relatively dry and this zone is the site of the world's subtropical deserts.

The distribution of rainfall is closely linked to the pattern of atmospheric pressure. Thus the amounts of rainfall decline as the subtropical high pressure belt is approached from either a northerly or a southerly direction.

Between latitudes 35^0 to 60^0 N and S is the belt of prevailing westerly winds or westerlies. It is more accurate to say that, within the westerlies, winds blow from all directions of the compass but that the westerly components predominate. Rapidly moving cyclonic storms are common in this belt. The upper Westerlies move around both hemisphere in a series of long waves. The waves change only slowly in number and amplitude compared with surface systems, and they travel more slowly than the wind blowing through them. The dominating westerly flow aloft is mainly determined by the north-south temperature gradient between the cold polar and warm tropical regions (Musk 1988).

A belt of strong westerlies, known as the subtropical jet stream is found in the upper atmosphere in the Middle East, above the light and variable winds associated with the subtropical high pressure system that occurs at the earth's surface. The path of this Westerly Jet crosses Iran in winter (see Figure 2-1).

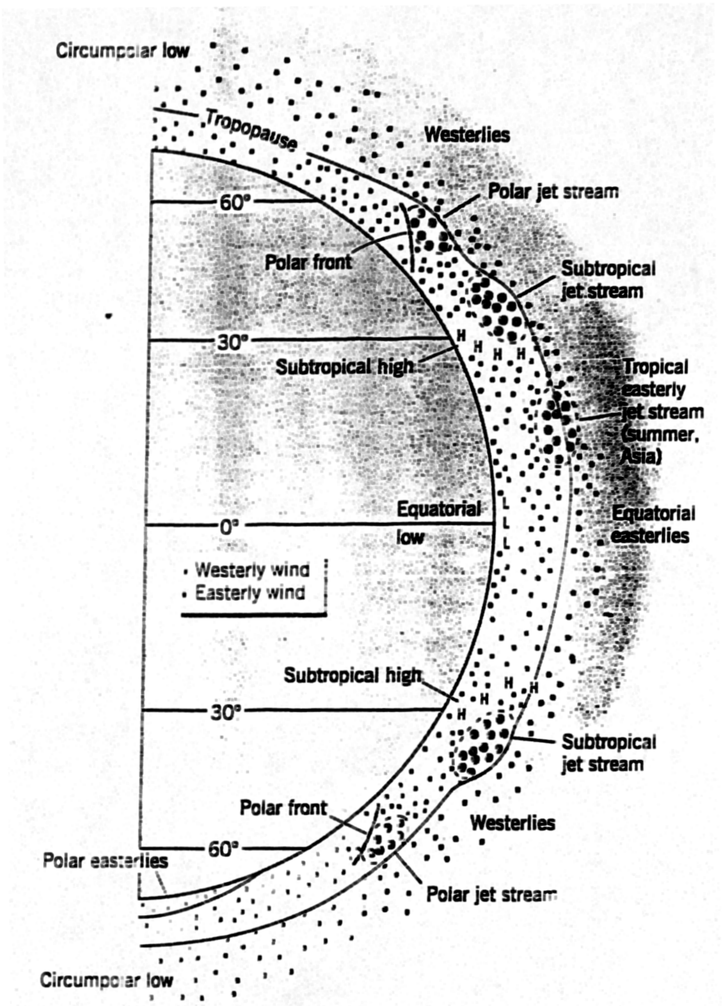


Figure 2-1 A Schematic Diagram of Wind Directions and Jet Streams after Strahler 1994.

2.1 Pressures Systems of South-West Asia

Over Central Asia in winter we find the Siberia high, with pressure exceeding 1030 Mb. In summer, pressure conditions are exactly opposite to winter, land areas developing low pressure centres due to land surface temperatures. The patterns of pressure over the earth change markedly from winter to summer. In January the strong Siberia high produces an air flow from the Asian continent and across the equator toward the I. T. C. This outflow of cool, dry continental air produces the dry winter monsoon for much of southern and south-eastern Asia. The latitudes of 30^0 N and S are the subtropical belt of high pressure, in which pressures exceed 1020 Mb.

2.2 The Middle East Subtropical High Pressure Characteristics

Between the latitudes of about 20 to 40 degrees, the mean surface pressure maps are dominated by a number of elliptical high pressure areas, elongated in the east-west direction usually called the subtropical highs. They persist throughout the year over the large ocean basins, where they show only minor seasonal changes in position. However they do fluctuate in intensity and size. In the northern hemisphere the seasonal variations are different. Over the oceans the subtropical highs cover large areas during the summer. In winter they are often connected with the continental highs at higher latitudes by high pressure ridges but no continuous belt results. The subtropical highs have subsiding air and horizontal wind velocities are generally low. The subsiding movements create stable and dry air and rainfall is extremely limited. The subtropical highs often extend to high elevations in the atmosphere and can be identified occasionally at the 300 Mb level. An important feature of the subtropical highs is the asymmetry in their internal structure. Near the earth's surface the centre of highest pressure is generally over the eastern parts of the ocean basin, but at higher levels the core of maximum pressure is further to the west (Nieuwolt 1982).

The plane of the orbital circulation from the centres is therefore not strictly parallel to the earth's surface, but sloping gently upwards to the west. Consequently, subsiding movements prevail mostly in the eastern half of the cell, but rising air currents occur frequently in the western sections. The result is that the western half of the cell has more unstable and humid air masses, yielding more rainfall than in the eastern half, where very stable air masses prevail almost continuously. In the subtropical high pressure belt we encounter large, high pressure cells (anticyclones). In the centres of the cells, winds are weak and are distributed around a wide range of compass directions; calms prevail as much as a quarter of the time. Dryness of climate is a dominant general characteristic of the subtropical high pressures belt and its cells with no further poleward progress possible, the eastward moving air tends to accumulate in the subtropical zone at about latitudes 20 to 30 degrees. The piling up of air causes a sinking motion, or subsidence to develop in this zone, which in turn creates a belt of increased pressure.

The subtropical cells are discernible at the 300 Mb level and are a fundamental feature of the global circulation and not merely a response to surface conditions. In the northern hemisphere the pressure gradients surrounding these cells are strongest between October and April. However in terms of actual pressure, oceanic cells experience their highest pressure in summer, the belt being counter balanced at low levels by thermal low-pressure conditions over the continents. In summer, the area of the Mediterranean and Caspian Sea lie under the influence of the Azores subtropical high-pressure cell and the frontal zone is absent. The characteristic west coast climate of the subtropics is the Mediterranean type with hot, dry summers and mild, relatively wet winters. It is interposed between the temperature maritime type and the arid subtropical desert climate. The Mediterranean regime is controlled by the westerlies in winter and by the subtropical anticyclone in summer. The seasonal change in position of the subtropical high and the associated subtropical westerly jet stream in the upper troposphere is significant to the climate of south-west Asia.

Winter weather in the Mediterranean is variable since the subtropical westerly jet stream is highly mobile and may occasionally even coalesce with the southerly displaced polar front jet stream. By mid-June the Mediterranean basin is dominated by the expanded Azores anticyclone to the west, while to the south a low pressure trough extends across the Sahara from Southern Asia.

2.3 The Middle East Jet Streams

The velocity of the meandering upper westerlies is not uniform everywhere, in certain regions the flow becomes concentrated in narrow cores of stronger than normal winds known as jet streams. These are regions some hundreds of kilometres wide and some 2- 4 km deep in which the wind is typically blowing at speed of over 80-200 knots, at a height of between 7.5 and 14 km above the surface, just below the tropopause.

A Jet stream has been defined by WMO as 'A strong, narrow current, concentrated along a quasi-horizontal axis in the upper troposphere or in the stratosphere characterized by strong vertical and lateral wind shears and featuring one or more velocity maxima (Musk 1988). They are characterised by the following criteria; jet streams are thousands of kilometres in length, hundreds of kilometres in width and some kilometres in depth, the vertical wind shear is of the order of 5-10 m/sec per km and lateral wind shear of the order of 5 m/sec per 100 km. An arbitrary lower limit of 30 m/sec [108 km/hr or 67 knots] is assigned to the speed of the wind along the axis of the jet stream.

The wind speed decreases rapidly both above and below the jet stream axis and on either side of it, so the jet stream may be regarded as a core of very strong winds embedded in lighter ones. However, it is important to realise that the axis of the jet stream (the wave in the upper flow) is neither a stream line nor a trajectory, for air rises into the jet in some areas and sinks beneath it in other areas. The jet stream is a pulse like flow of air. Velocity is highest in the centre line, or core of the jet stream, which is surrounded by a slower-moving zone. Maximum speed in the core is about

300 km/hr, altitude of the core is about 11 km. Thus the jet streams have widths that vary from less than hundred kilometres to ovẹr 500 kilometres and generally are only a few kilometres thick wind speeds are frequently in excess of 200 km per hour, but rarely exceed 400 km per hour.

Riehl (1979) defines a true jet stream as a narrow current in an otherwise resting medium or a tube of high velocity in a broad, slowly flowing environment. Depending on the season several jet streams usually control the climate of the Middle East including Iran:

1. the westerly subtropical jet stream, which occurs at about 200 Mb around latitude 30^0.
2. the polar jet stream, which normally reaches a maximum at 200-300 Mb between latitudes 40^0 and 60^0 in association with polar front depressions at the surface.

2.3.1 The Subtropical Jet Stream

The subtropical jet streams (STJ) are encountered near the margins of the inter tropical zone, they occur in both hemispheres between latitudes 25^0 and 30^0. The subtropical jet stream consists of the strong westerly winds at the 200 Mb level, which prevail throughout the year over 25^0 to 30^0 latitudes. Their cores of maximum velocity usually lying near the 200 Mb level i.e. at 12 km.

2.3.2 The Polar Jet Stream

As mentioned in previous pages the polar-front jet is observed in middle latitudes, at an average altitude of about 12 km and exhibits maximum speeds average about 60 m/s. In extreme cases, it is more than twice as fast, on some occasions this jet stream extends around almost the entire globe. The average position of the jet stream meanders northward and southward, it exhibits maxima and minima of wind speed along its path. In the polar jet stream the actual wind speed has been estimated to be about 265 knots (490 km /hr). The highest wind speeds ever measured in a PFJ are not far from 300 knots (550 km/hr) (Reiter 1961).

The polar front jet stream achieves its maximum force and extent in winter, when there may be two, or even three, distinct currents having wind speeds of 100 knots or more at their cores. In the northern hemisphere the main jet stream system undulates from north to south as part of the upper-level westerly wave, often swerving far equator-ward over the continents. The westerly polar front jet stream meanders around the mid-latitudes beneath the tropopause at or above 300 mb or 9-12 km. It exhibits areas of speed maxima and minima along its axis, and may not always be continued round the globe.

It is especially the western edges of the high-pressure cells which are characterized by confluence of polar and subtropical jets thus giving rise to especially intense jet streams. Jet streams are mainly fed from two source areas of cyclonic vorticity:

1. one located in polar,
2. the other in subtropical latitudes.

2.4 Position of The Subtropical Jet Stream over Iran

A belt of strong westerlies, known as the subtropical jet stream is found in the upper atmosphere in the Middle East, above the light and variable winds associated with the subtropical high pressure system that occurs at the earth's surface. The position of the core jet stream or line of maximum velocity of the jet stream varies over 10 to 15 degrees of latitude from summer to winter, especially over the eastern part of the region. Table 2-1 and Figure 2-2 show average speed and latitude of the subtropical jet stream. In July it is centred over the Caspian Sea, while by January it has moved southwards to lie over the northern part of the Persian Gulf.

This seasonal shift of the subtropical jet stream in the Middle East parallels the movement of the major climatic belts between their summer and winter positions.

The winter position over the northern part of the Gulf is maintained for approximately six to seven months from mid- October to April (Beaumont et al 1988). This is followed by a rapid shift of latitude to 10^0 the summer position over the Caspian Sea which is held for three to four months from June to the end of September. This rapid shift of the westerly jet stream concludes with the movement from south of the Tibetan Plateau to the north and has been associated with the onset of the summer monsoon in India.

Table 2-1 Average speed and latitude of subtropical jet stream over Iran (along 45^0 E) Weickman (1961).

Months	J	F	M	A	M	J	J	A	S	O	N	D
Knots	12 0	120	100	90	90	80	70	60	50	60	70	90
Latitude (N)	30	29	29	29	T*	39	40	40	39	T*	30	30

T = transitional period

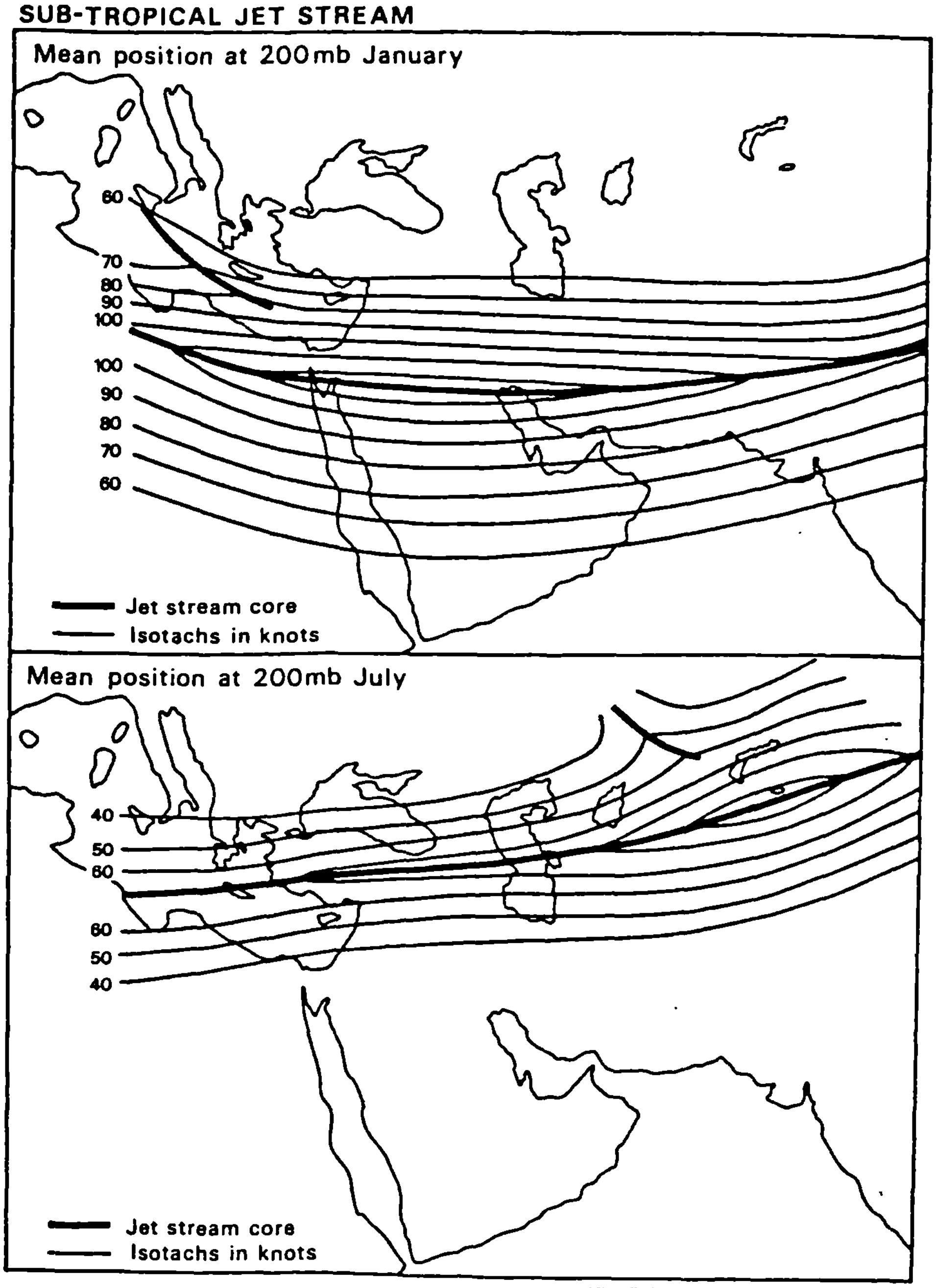


Figure 2-2 Position of the Jet stream core in winter and summer after Weickman 1961.

2.5 The Central Elburz - Its Topographic Characters

Much of Iran is a plateau with elevated mountain belts forming the country's borders. Generally speaking, there are two major mountain systems of different character in Iran these are Elburz, running almost from west to east and the Zagros, extending from Northwest to Southeast. The northern and western parts of Iran are specially mountainous with the Elburz Mountains paralleling the south coast of the Caspian Sea having elevations between 4000 and 6000 m.

Neighbouring the western border of Iran to the north of the Persian Gulf, are the highest part of the Zagros Mountains. The lowest areas are the Caspian plain north of Elburz, the lowlands west of the Zagros, and the broad interior plateau bounded roughly on 3 sized by the Zagros Mountains, the Elburz Mountains, and the north eastern upland.

The main feature of the topography can be summarised as a great plateau between two mountain ranges. In the west, Northwest and Southeast the Zagros Mountain extend over a very long distance. Most of this area is over 1800 m, with much over 3000 m and many summits exceed 3600 m. The great plateau, 1000 m above sea level occupies most of the country. Some parts such as the Dasht-e-lut and Sistan are only about 500 m above sea level (see Figures 1-2, 2-3 and 2-4).

The mountain ranges are very significant to the climate of Iran. The Elburz Mountains block the influx of moisture from the Caspian Sea to the interior of the country just as the Zagros Mountains block the westerlies from the Mediterranean Sea in winter. Consequently regions to the north of the Elburz Mountains and the western slopes of the Zagros Mountains have a moist mild climate while the interior parts are dry and desert. The north-eastern lowlands permit cold dry Siberian air to enter the country producing local temperature below freezing. The mountains exercise their influence very significantly during spring when the relatively cold atmosphere warms in the lower layers due to increasing isolation on the mountain slopes. Thus in the presence of moist air, convectional showers can develop throughout the mountainous areas.

The Elburz are a system of mountains that encircle the southern Caspian Sea and continue eastward to the northern highland (Kopet Dugh). The whole system consists of relatively narrow series of folds with extremely steep ridges and with a number of summits exceeding 3000 meters in height, only about 50 kilometres in a straight line from water of the Caspian Sea which is almost 30 m below sea level. The Elburz Mountains have long east - west ranges over 2000 m height but reach more than 6000 m in some places. The Elburz range is in fact a climatic border between the coastal plains of the Caspian region and the great central plateau of Iran. Also the Elburz range is part of a great fold mountain system which extends in the west to the Ararat mountain ranges on the border of Armenia and in the east extends to Hendukesh range in Afghanistan. The central part of this great range forms an arc to the south of the Caspian Sea and separates the coastal plains from the Central plateau of Iran. In the middle of range of this central part is the highest peak of the Elburz range, Damavand (5671m). The average altitude of Elburz is about 3000- 3500 m but there are many valleys with elevations of 2000 m.

In the south-western part of the Caspian region this range is cut by the wide valley of the Sefid- Rood. This valley widens to the north and reduces elevations to about 300 m in a very large area. This valley permits air masses to move from north to south. The north facing slope of the Elburz toward the Caspian Sea is very steep while the south facing slopes are more moderate. The northern slopes of Elburz are well wooded up to a height of 2100- 2400 m, but further south an abrupt change occurs and vegetation soon becomes less luxuriant, passing ultimately in the extreme south, into scattered patches of scrub, with most of the hillsides entirely bare. When water is available, many parts of the southern Elburz are extremely fertile, especially the alluvial cones and river terraces, where there is a thick deposit of rich soil (Fisher 1968). So in the synoptic scale the ridge line of the Elburz mountains can be considered as the boundary between two regions, southern and northern. This boundary is an interesting physical boundary particularly from the point of view of rainfall. The Elburz range provides two different distinct regimes. The characteristics of these two different distinct regimes are the subject of the following chapters. The

Elburz range is a watershed on the scale of synoptic meteorology. South of the Caspian Sea there is a narrow band of land about 30 m below sea level.

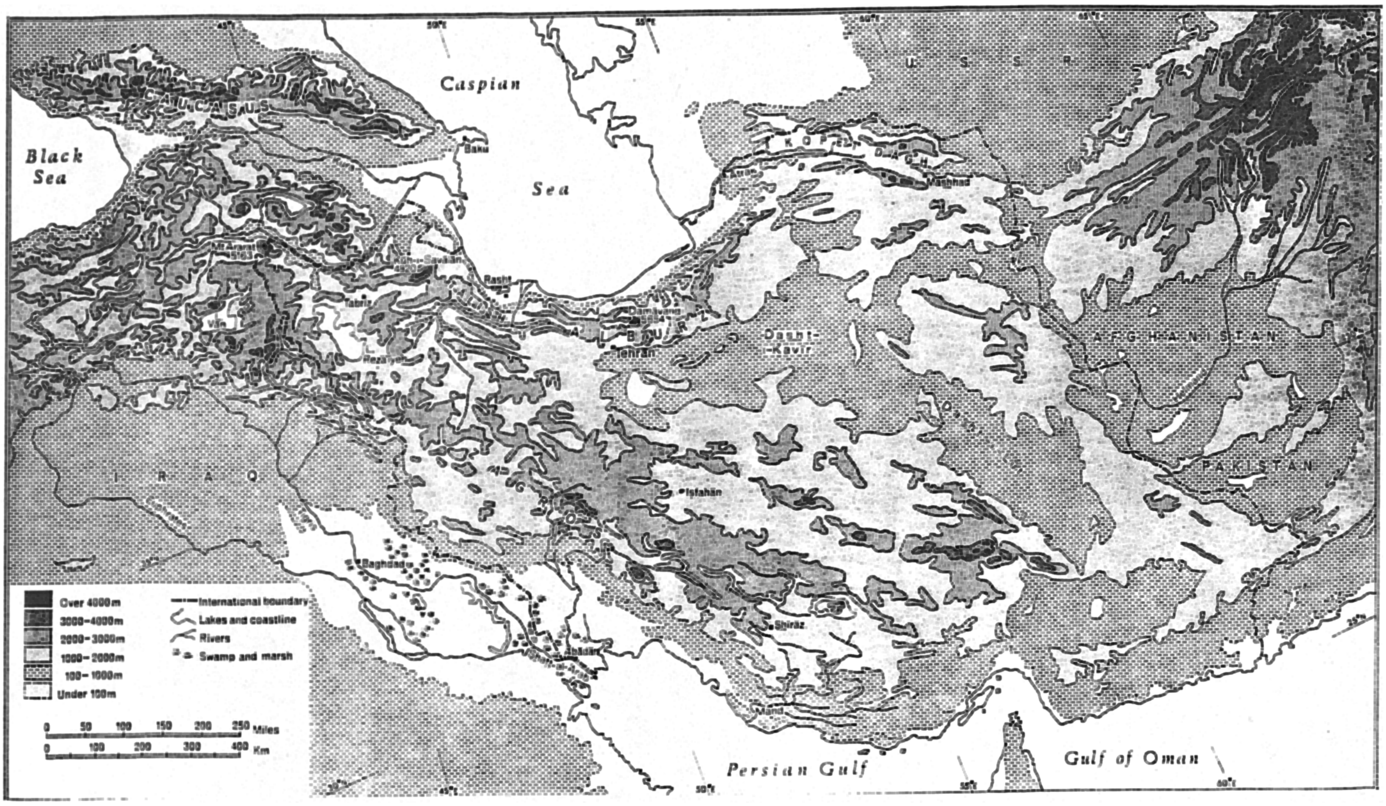


Figure 2-3 Iran Physiographical after Fisher (1968)

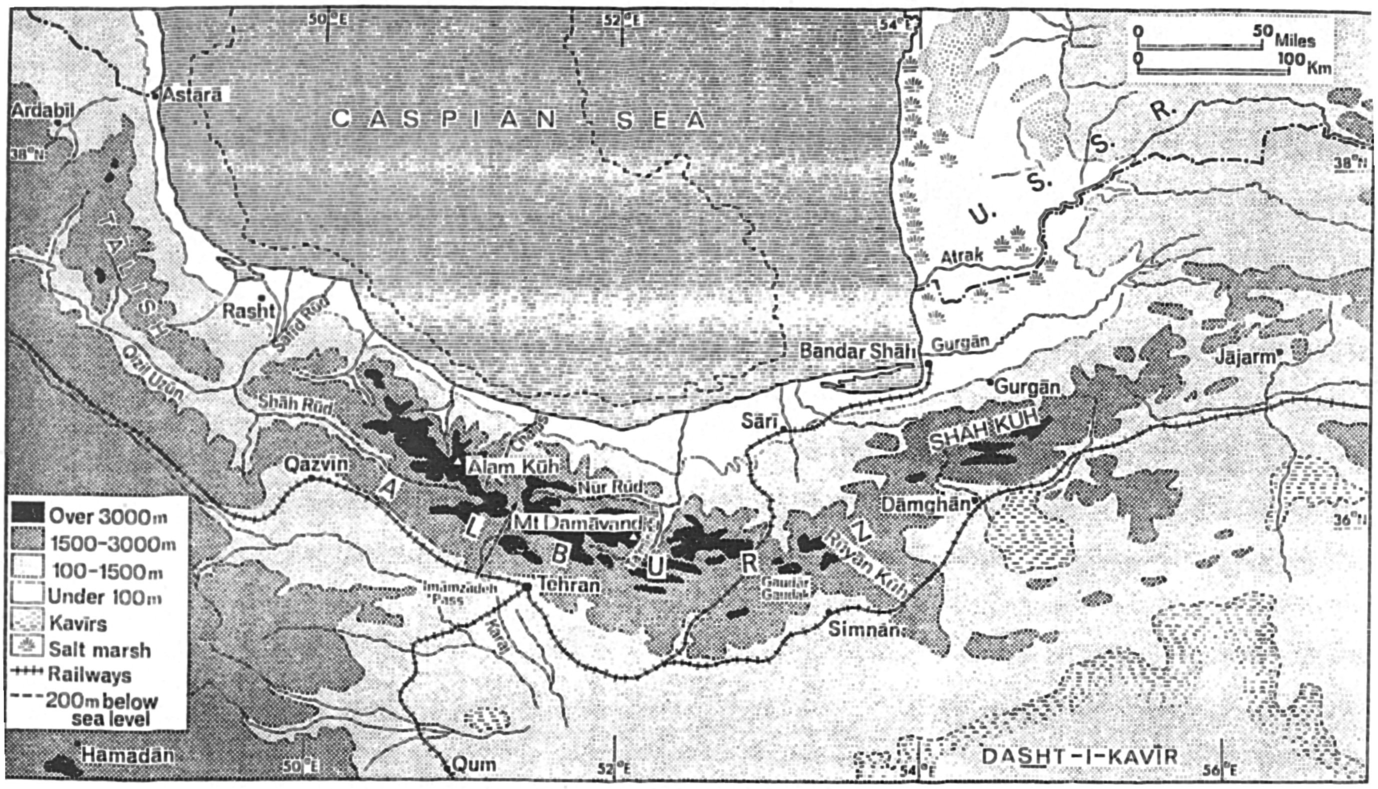


Figure 2-4 Elburz Topography after Fisher (1968)

2.6 Variety of Iranian Climates

The weather and climate of an area or a country cannot be understood without considering the factors responsible for it. Iran's physical geography has given it a variety of climatic regions. Several factors cause this diversity as follows:

1. Iran's latitudinal location brings it under the influence of tropical and subtropical systems during all seasons.
2. Its position in relation to Siberia and Central Asia to the north, the Sahara and Arabia to the south-west, the Mediterranean Sea to the west and the Indian region to the east affects its weather.
3. Also the situation, shape and elevation of topographic characteristic influence the surface circulation and different local climate elements including temperature and rainfall. In previous pages a detailed discussion has been given about the structure of relief and brief influences on the climate and rainfall of two parts of the Central Elburz.

2.7 Concept of Air Mass

An air mass is a body of air in which the horizontal gradients of temperature and humidity are relatively slight and which is separated from an adjacent body of air by a sharp transition zone, known as a front, in which these gradients are relatively large (Lockwood 1979). Horizontally homogenous bodies of air are produced by prolonged contact with an underlying surface of uniform temperature known as a source region.

Hidore *et al* (1993) defined an air mass as a large, relatively homogeneous body of air that may cover thousands of square kilometres and extend upwards for thousands of meters. They are most homogeneous in terms of temperature and moisture. The properties of an air mass are derived partly from the regions over which it passes. Source regions must have light winds and are therefore usually found in the permanent or semi- permanent high pressure system the subtropical, polar and winter continental anticyclones. Air masses over Southwest Asia have different source regions of which the central part of Asia and north Africa are regarded as the main sources for respectively polar continental and tropical continental air masses in winter. Consequently this leads to a general classification of air masses as a polar or a tropical maritime or continental are defined their basic temperature and humidity characteristics (see Figure 2-5). Air masses are usually of enormous size and their influence can be traced over the entire continents or even hemispheres. In this regard the discussion of air masses necessitates the consideration of the whole middle eastern area. It is customary to divide air masses according to their area of origin, either polar or tropical. Further division is then made on the basis of humidity- continental. Continental air is generally drier than that originating over ocean.

Air masses have not been specifically investigated for Iran so far, but several air masses have been described by authors on the Middle East and Iran, Ganji (1954), Becket *et al* (1956), Brice (1966), Fisher (1968,1978) Khalily (1974), Farhang (1974), Lockwood (1974,1979), Takahashi (1981), Kaviani (1982) and Beaumont *et al* (1988).

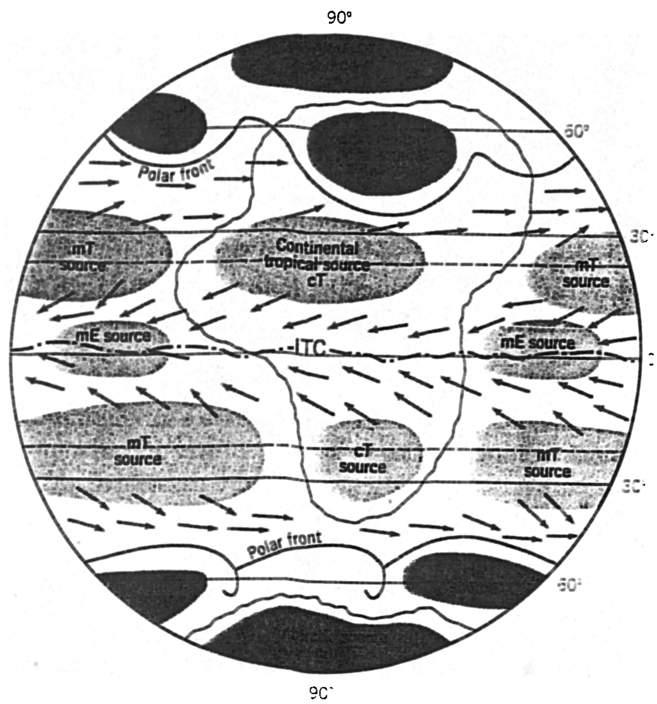


Figure 2-5 A Schematic Diagram of Global Air masses and Sources Regions after Strahler 1994.

2.8 Air Masses which Affect Iranian Climate

2.8.1 Tropical Maritime or Mediterranean Air Mass (mT)

This air usually originates over the Atlantic, passing into the Mediterranean by way of Europe, Spain or north- west Africa. There may thus be considerable differences in the air mass itself, some parts being polar and others tropical in origin. Tropical air originating over the oceans in the subtropical highs around 30-35 N and S is known as maritime tropical air. It is warm and moist near the surface. Maritime air mass blowing generally from a westerly direction penetrate the entire Middle East region between October and May. Closely influenced by the Subtropical Jet Stream vortices develop in this westerly from time to time and bring a mixture of air of differing types. Such air masses reach Iran in Autumn and continue until nearly end of Spring. These air masses enter Iran from the north- west and produce almost all of the cold period rainfall. They affect the west and north- west of Iran for at least 7 months. Most of the rainfall over Iran especially Zagros and Mountainous area is due to Mediterranean air mass.

2.8.2 Polar Maritime (mP)

Polar air originates in high latitudes and may be divided into maritime and continental polar based on the nature of the surface over which it formed. The maritime polar is only relatively cool and usually very moist and it feeds into poleward edge of temperate latitude westerlies. During winter mP air mass invades Asia Minor and the Black Sea occasionally and is considerably modified due to the long land trajectory. This is generally more humid than cP air mass and that follows the transitory Atlantic low- pressure system through Europe. Much of the perceptible water content is shed when the air masses are lifted by the mountain ranges. This air mass enters Iran during summer and autumn seasons. This air mass is similar to cP, but it is hotter and wetter than cp. In winter it meets other air masses from the Mediterranean and form frontal systems over Iran resulting is rain or snow throughout the country. Also this air mass affects parts of the south- west of Khazar and the Tallish mountain in the summer season producing an abundance of rain in this area.

2.8.3 Polar Continental (cP)

Polar continental air masses are formed over central Asia which in winter overflow into Iran and may for a short time reache the Mediterranean as well. The air is characterise by extremely cold air in the shallow layers. The cP air mass is generally derived from the Siberian anticyclone, thus very stable producing days of fine and clear weather. When it enters Southwest Asia it is modified. Over the Iranian and Anatolian plateau very low temperatures occur, but sunshine during the day mitigates the worst effects, since humidity is low.

The advection of cP over a warm moist surface (e.g., Caspian Sea) the surface inversion is destroyed by heating from below, while widespread cloudiness occurs as a result of moisture absorption. Most of the autumn rainfalls of the coastal Caspian are due to this air mass crossing the Caspian Sea. This air mass enters from Siberia at the beginning of autumn through the north east of Iran. It affects most parts of Iran for nearly 8 months of the year. When this air mass reaches Iran the weather becomes very cold and if it meets a Mediterranean air mass, it forms a front throughout the country which is given the general name polar front and it will rain or snow. This air mass sometimes damages vegetables and other crops because it may stay to the end of May. It delays the growth of vegetables and fruit trees or prevents them growing when it reaches Oromia (Capital city of The Iranian Western Azarbijan), the temperature decreases to -19 °C. It causes great damage to apples and other crops of the farmers in this part of Iran.

2.8.4 Tropical Continental (cT)

Extreme heating over the subtropical deserts can lead to the tropical continental air of which the main sources are north Africa and the Middle East in summer (Lockwood 1974). So continental tropical air forms over the large deserts of the tropics and it is characteristically extremely hot and dry at the surface. For the Middle East as a whole the general result in the extreme south is to produce several months of clear skies. Its outstanding characteristic is great heat often reaching 40 or 50 centigrade at the surface, which usually gives rise to extremely low relative humidities. Also this air mass forms in the Central Iran itself during summer and affects central parts of Iran. It is very dry, hot and stable without any rain but dusty crops may be withered in a day and a rise in the death-rate is often noticed in large cities. It has no benefit for the farmers. During this period farmers must irrigate their crops and vegetables. This air mass does not extend to the Central Elburz especially coastal area.

2.8.5 Equatorial Maritime or Monsoon Air Mass (mE)

Monsoon air, originating over the Indian Ocean and therefore tropical maritime, but occasionally modified by the time it reaches the area under consideration. This air mass always indicates moist, warm and sometimes during summer enters Southeast of Iran and causes heavy rainfall and as a result flooding in this part of Iran. This air mass affects the south east of Iran from June to the end of August. It reduces the heat in the region. However, it does not affect the Central Elburz.

2.9 Seasonal General Circulation of Iran

As mentioned in previous pages due to the country extending from about 25 to 40 degree latitude the transitional seasons of spring and autumn are very short through most of the areas. Therefore winter and summer dominate. In this regard in terms of circulation patterns spring and autumn are not single seasons. Hence only the circulation patterns for winter and summer are discussed.

1. Summer. According to Reiter (1961), in summer, Iran is under the dry hot continental tropical air mass. The aridity is widespread at this time except in the coastal areas of the Caspian Sea. Subsidence associated with the subtropical high pressure belt over spreads nearly the entire country as the subtropical jet stream moves to a position over the Caspian Sea and northern parts of Iran. The coastal areas are not completely under the subsidence and consequently occasional mid latitude disturbances invade the area to produce rainfall. Except for the coastal areas of the Caspian, summer is the driest season over most of the region,
2. Winter. According to Alijani (1978) the normal expansion of the mid- latitude westerlies during autumn, in turn permits the polar front jet stream to retreat southward, bringing depressions especially to northern Iran. The subtropical jet stream relocated near 30^0 N, with the strongest 200 Mb winds normally located over the Persian Gulf. As a result of these changes, winter is the wettest season.

Against this backdrop of local topography and regional circulation, the geography of the South Asian region governs the position and persistence of different air masses. As far as the Central Elburz is concerned rainfall is produced by air originate in either:

1. the Mediterranean Sea, or
2. the Caspian Sea

2.10 Seasonal Pressure and Local Winds of Iran

2.10.1 Winter Conditions

In winter, it is much more difficult to speak of pressure conditions, for this is the period when the region is crossed by a succession of cyclones and anticyclones. The patterns of pressure over Iran change markedly from winter to summer. In January the strong Siberia high produces flow of the Asia continent. This outflow of cool, dry continental air produces the dry winter over the interior of Iran but wet winter over the Caspian Sea. As previously mentioned during the winter months a high pressure belt that results from the intensive cooling of a vast continent (develops over the interior of Asia). Over the north of Central Asia in winter we find the Siberian high, with pressures exceeding 1030 Mb. Also the interior of the Iranian plateau is usually covered with a local centre of high pressure during the winter months. In contrast with these centres of high pressure, there are a number of low pressure systems that also influence the climate of Iran. In northern parts there is a relatively low centre over the warm waters of the Caspian Sea. Other centres of low pressure can be observed over the Persian Gulf and Oman Gulf (see Figure 2-6).

Laying within the Middle East pattern of pressure systems Iran may be said to have a pressure field in winter that declines in intensity from north to south.

2.10.2 Summer pressure conditions

Regarding the Figure 2-7 during the summer months a relatively simple pattern of pressure conditions predominates throughout the region. The main feature is a large belt of low pressure formed over the Persian Gulf, the adjacent lowlands and the Central Iran. Therefore in summer, cooler air over the Caspian Sea causes relatively high pressure in this part of country. While in the south the excessive heating of land produces one of the lowest thermal pressure centres in the world. One interesting point about the pressure systems of Iran is that, contrary to conditions in certain other parts of world, the pressure gradient increases in summer. So in winter Elburz is affected by a pressure gradient from the land to the Caspian Sea whilst in summer is the reverse.

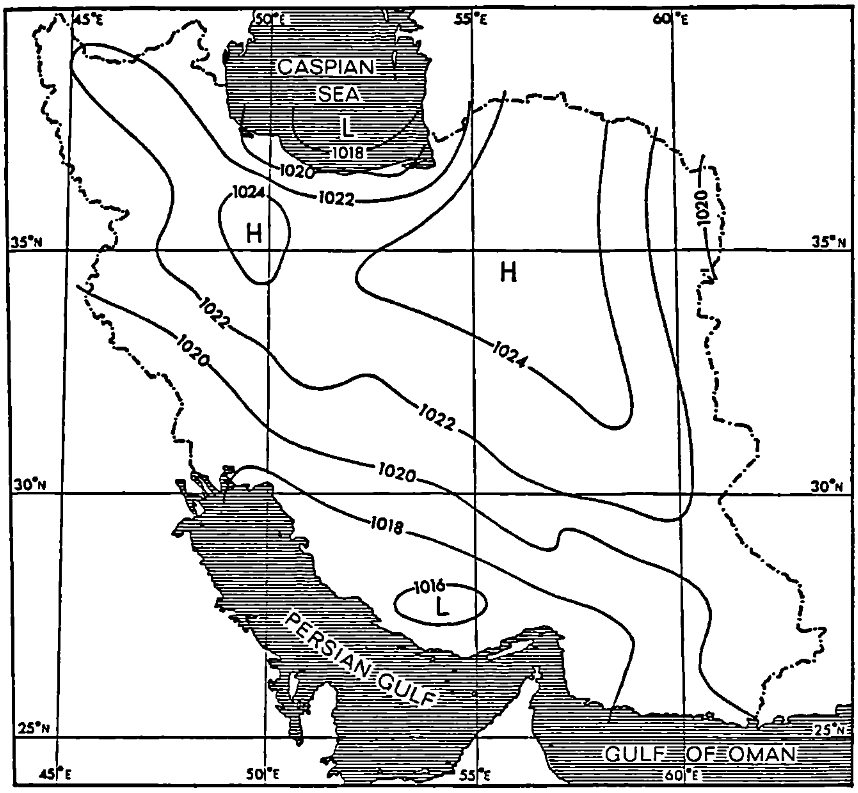


Figure 2-6 Shows the mean sea level pressure for January after (Ganji 1968)

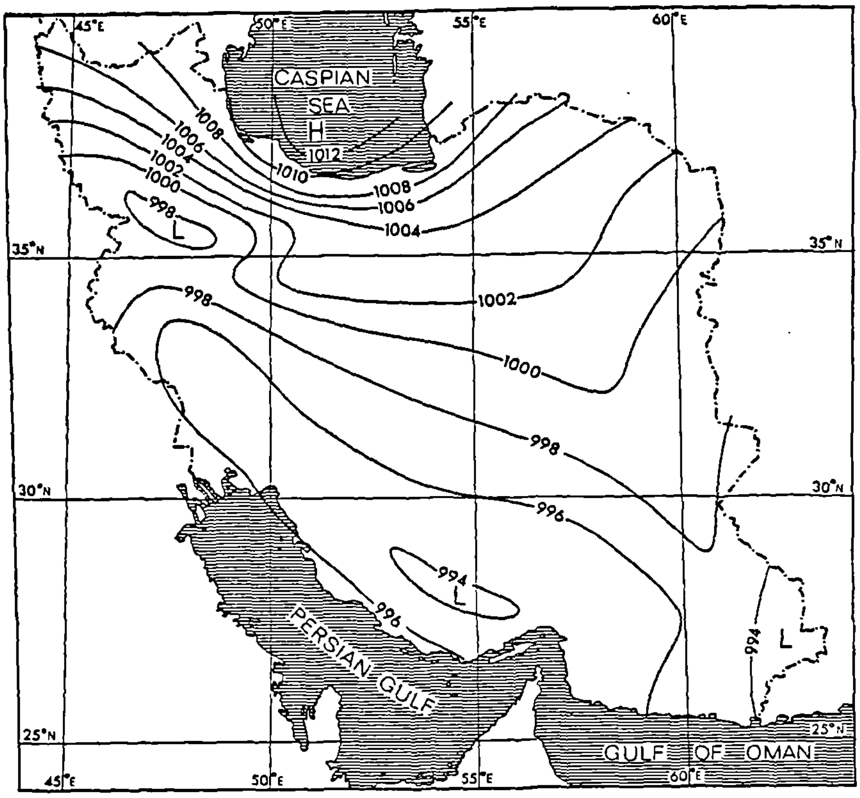


Figure 2-7 Shows the mean sea level pressure for July after (Ganji 1968)

2.11 Local winds

The Central Elburz acts as an orographic barrier across the paths of air masses; land and sea breezes play a vital role during the climatic year.

Mc Alpine *et al* (1983) explained the effect of land forms on climate is four fold:

1. the landmass presents a mechanical barrier to the large-scale winds, forcing areas of ascent, descent, turbulence and consequent thermodynamic modification of the air stream,
2. the direction of the large-scale flow from the sea is altered once the land mass is encountered because of greater frictional resistance to the flow,
3. local land sea breeze cells arise from the different thermal properties of the land and sea surfaces,
4. variations in the structure of the landform created anabatic, katabatic and mountain valley wind circulation and other topoclimatic effects. These exert an additional influence on local weather patterns over the land and sea.

In a country such as Iran where extensive flat deserts, highly complex mountain systems, closed basins, long valley, coastal plains, topography is a major modifying factor and therefore the actual surface winds which are almost in all cases causes by local topographical features. In the mountainous areas the effect of canalization of the wind in the narrow mountain valleys and gorges cause unexpectedly strong winds in certain localities. We introduce two local wind types:

2.11.1 Bade 120 Rouze or (Sistan Wind)

In summer despite the gentle pressure gradients, remarkably persistent local winds can develop at this time of year, towards the low pressure centres. This is one of the main reasons for the strong winds such as occur in the Sistan basin of Southeast Iran and known as the Bade 120 Rouze or Sistan (120-days wind). This wind blows from the north and Northeast, is extremely hot and owing to its high velocities heavily dust laden.

2.11.2 Bade Manjil (Manjil Wind)

The best example of channelling of local winds is to be seen in Manjil, where the Sefid-Rud valley provides a channel between the Caspian Sea and the interior systems. In summer a high pressure centre develops over the Caspian Sea because of its colder temperature. As a result the wind that blows from north to south is such a permanent feature of the Manjil gap that the branches of olive trees grow horizontally parallel to the ground and one can hardly find a single upright tree in the vicinity of the gap. This wind blows towards the low centre in the interior parts of Iran during the afternoon.

2.12 Elburz Temperature Conditions

A fundamental climatic control in any part of the world is that exerted by latitude. For latitude determines the amount of heat in the form of radiant energy received directly from the sun. Also after latitude, altitude is the most important contributor in the distribution of temperature. As previously mentioned in Iran due to the spatial disposition of the mountain ranges the influence of the seas tend to be limited to their immediate neighbourhood and it is seldom that maritime areas play an important role in controlling temperature other than narrow coastal strips. As earlier explained Iran, from time to time, is exposed to the movement of air masses that originate in distant places and are initially of totally different temperatures from those prevailing in different parts of Iran. Such air masses can exert a great influence on the pattern of temperature distribution in different parts of Iran especially during winter and summer seasons. This is best observed when Iran is invaded by cold continental air from central Asia, but warm air can also flow from outside the country during summer time.

The most critical months of the year from the point of view of temperature studies are the midwinter and the midsummer months during which extremes of cold and warm temperatures usually occur. January and February are the coldest months while July and August are the warmest months. However in the case of the central Elburz stations the analysis of temperature show July is the warmest for all stations.

Regarding to the Tables 2-2 to 2-4 and Figures 2-8 to 2-18 as a point of analytical discussion the average temperatures within Elburz stations can be of two different types:

1) January is the coldest month of the year for southern Elburz stations but the coldest month is February for the higher altitude and the Caspian Coastal stations.

2) July is the warmest month of the year for all of the central Elburz stations.

The study of maximum and minimum temperature provides some idea of the temporal condition for planning decision. Table 2-3 illustrates that the highest values can be seen in the southern slope stations. The highest monthly temperature are recorded during the months July and August. These highest temperature differences are so small that they are of little consequence. Also Table 2-4 indicates that the lowest values can be visualised in the southern slope and higher altitude stations. These values fall below zero during December, January, February and March. In this regard temperature usually decreases with elevation. Southern Elburz is higher than coastal area (as it has been shown in chapter 1). All southern Elburz stations have their elevations more than 850 m above sea level but the coastal area stations are less than 233 m) from elevation point. All coastal stations display very small ranges which increases with distance from the sea such as Gorgan and Gonbad stations. The lowest values of the Caspian Coastal stations do not fall below zero.

Table 2-2 Average Monthly Temperature (°C) Over the Central Elburz Stations.

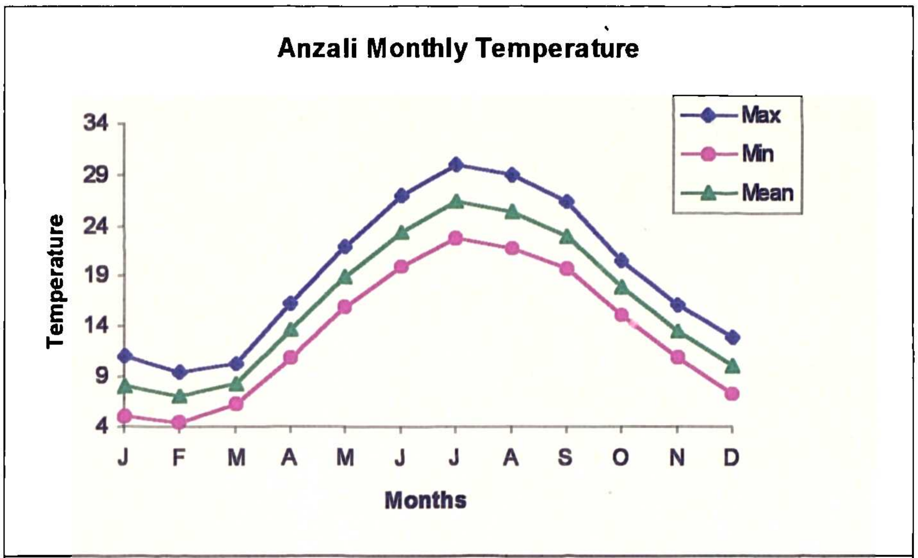
Stations	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	8.0	6.9	8.9	13.6	18.8	23.3	26.4	25.4	23.0	17.8	13.4	10
Astara	6.3	5.7	7.7	12.9	18.4	23.0	26.3	25.3	21.9	17.2	11.5	7.5
Babolsar	8.4	8.1	9.8	15.0	19.7	23.9	26.7	26.1	23.9	18.4	13.9	10.1
Ghaemshahr	6.7	7.2	9.1	15.0	19.6	23.0	25.7	25.5	23.1	17.4	12.5	8.7
Gonbad	8.6	8.1	10.2	15.4	20.6	26.4	29.2	27.9	24.9	18.7	13.8	9.6
Gorgan	8.6	8.4	13.3	17.0	20.9	25.1	28.1	27.4	25.0	19.0	14.1	10.2
Havigh	8.0	7.6	9.0	14.1	18.8	22.9	25.8	25.4	23.2	18.0	13.5	9.7
Hashtpar	7.7	7.3	8.7	13.7	18.2	22.2	25.0	24.6	22.5	17.4	13.1	9.4
Lahijan	8.2	8.8	9.7	15.2	19.7	22.8	25.7	25.2	22.8	17.3	13.4	11
Noushahr	7.8	7.2	8.5	13.6	18.2	22.3	25.4	25.0	22.8	17.8	13.4	9.5
Ramsar	7.6	7.0	8.3	13.2	17.9	22.0	25.0	24.7	22.5	17.6	13.2	9.4
Rasht	7.4	6.5	8.4	14.2	18.8	22.5	25.5	24.6	22.2	17.0	12.4	8.8
Shirgah	6.8	6.0	7.5	13.2	16.5	20.1	22.2	21.7	19.4	15.3	11.8	8.5
Aminabad	4.2	5.8	10.1	17.2	21.5	27.3	29.1	28.4	25.5	17.6	12.0	5.8
Damghan	2.0	4.5	8.6	16.3	21.0	26.0	28.8	28.2	23.5	16.7	10.6	5.4
Dehsomeh	-1.5	5.1	5.7	13.3	17.1	22.1	24.9	23.7	20.9	15.9	10.5	3.7
Garmsar	5.0	6.3	11.1	18.9	24.3	30.0	31.9	30.1	25.6	18.0	12.2	5.5
Ghazvin	0.8	2.6	6.7	13.5	17.5	22.4	26.3	25.0	21.5	14.5	8.5	2.5
Ghom	3.2	4.6	9.5	16.8	21.0	26.3	28.1	26.9	21.8	15.6	10.6	4.3
Karaj	1.1	2.5	6.9	13.8	17.9	23.0	26.6	25.2	21.9	14.9	9.1	2.3
Latian	5.0	4.3	9.1	14.5	18.6	23.1	26.9	26.0	21.9	15.1	11.1	6.6
Semnan	4.0	6.3	10.7	18.6	23.0	28.5	31.4	29.9	26.2	19.2	11.9	5.8
Shahroud	1.9	3.4	7.8	15.5	19.6	24.1	27.2	25.6	21.9	15.0	8.9	3.3
Takestan	-0.3	1.2	5.9	12.4	17.1	20.4	23.7	22.9	20.2	15.6	7.5	0.1
Tehran	5.6	6.8	12.3	19.8	25.2	29.3	33.7	32.3	29.6	23.1	12.8	6
Varamin	3.1	5.2	9.5	17.1	20.9	26.0	29.1	27.9	24.1	17.9	10.3	5
Abali	-2.8	-3.1	-0.2	6.9	11.6	17.5	20.6	19.8	16	8.7	3.8	-1.7
N-Kandavan	-3.3	-3.6	-0.7	6.4	11.0	16.9	20.0	19.2	15	8.2	3.4	-2.2
S- Kandavan	-3.6	-3.8	-0.9	6.2	10.8	16.6	19.7	18.9	15.	7.9	3.1	-2.4

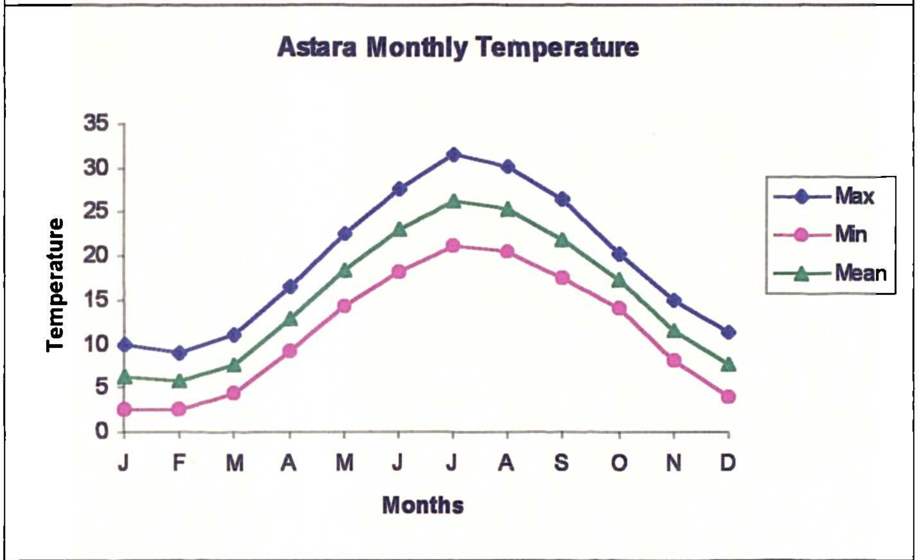
Table 2-3 Maximum Monthly Temperature (°C) Over the Central Elburz Stations.

Stations	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	11.0	9.4	10.2	16.3	21.8	26.9	30.1	28.9	26.4	20.6	16.1	12.8
Astara	10.0	9.0	11.0	16.6	22.5	27.7	31.5	30.2	26.4	20.2	15.0	11.2
Babolsar	12.8	11.7	13.1	18.8	23.5	27.8	30.9	30.2	28.3	22.9	18.0	14.6
Ghaemshahr	11.4	11.4	13.0	19.8	24.2	27.5	29.9	29.6	27.8	22.0	17.1	13.5
Gonbad	14.7	14.0	15.9	22.5	28.1	34.1	37.1	35.1	32.1	26.4	20.5	15.9
Gorgan	13.1	12.7	20.5	22.6	26.2	30.5	33.1	32.1	30.3	24.3	18.9	14.9
Havigh	12.2	11.0	12.1	17.6	22.4	26.7	29.8	29.2	27.2	22.0	17.4	14.1
Hashtpar	11.8	10.6	11.7	17.1	21.6	25.8	28.9	28.3	26.3	21.3	16.8	13.6
Lahijan	13.0	14.4	15.1	21.2	25.5	28.1	30.8	30.3	28.0	21.9	18.4	17.0
Noushahr	11.7	10.4	11.2	16.5	21.2	25.6	28.9	28.4	26.5	21.4	16.9	13.7
Ramsar	11.5	10.2	11.0	16.5	21.2	25.5	28.7	28.1	26.1	21.2	16.7	13.6
Rasht	11.2	9.6	11.4	18.2	22.8	26.5	30.0	28.9	26.5	20.5	16.3	13.0
Shirgah	12.4	11.4	12.9	20.4	24.7	28.5	30.1	29.5	27.5	22.7	18.4	14.5
Aminabad	9.5	11.3	16.1	24.1	28.9	35.4	37.0	36.9	33.8	24.5	18.2	10.8
Damghan	6.8	9.9	14.2	22.8	27.7	33.1	36.2	36.4	30.7	23.2	16.5	12.0
Dehsomeh	6.6	12.7	12.1	20.7	25.6	32.7	35.9	34.6	32.2	25.1	17.1	8.5
Garmsar	10.0	12.4	17.4	26.2	31.5	37.4	39.8	38.4	34.5	25.8	18.8	11.1
Ghazvin	6.0	7.8	12.5	20.5	25.0	31.3	35.6	34.2	30.7	21.9	14.1	7.3
Ghom	7.4	8.4	14.7	22.2	26.1	32.8	34.9	34.0	28.8	20.3	15.4	7.7
Karaj	6.0	7.6	12.6	20.4	25.1	31.7	35.1	33.5	30.1	21.7	14.8	6.7
Latian	8.7	8.3	13.4	19.9	24.8	29.7	33.7	32.4	27.8	19.6	15.7	11.6
Semnan	9.4	11.7	16.4	25.0	29.3	34.6	37.9	36.4	32.8	24.6	17.2	10.5
Shahroud	6.5	8.4	13.6	22.3	26.5	31.0	33.9	32.5	29.5	21.8	14.8	7.7
Takestan	4.3	5.9	9.9	17.6	22.0	27.4	30.8	29.3	25.8	18.3	11.4	5.7
Tehran	8.4	10.2	14.6	22.9	27.6	33.7	36.7	35.2	31.5	23.4	16.0	9.5
Varamin	9.2	11.4	16.3	25.0	28.7	34.9	38.3	37.2	33.9	27.1	17.8	11.1
Abali	1.6	1.0	3.6	11.0	16.1	22.6	25.7	25.1	21.2	13.0	7.4	2.1
N-Kandavan	1.4	0.9	3.1	9.7	14.2	19.9	22.6	22.1	18.7	11.5	6.5	1.9
S-Kandavan	1.3	0.8	2.9	9.0	13.2	18.5	21.1	20.6	17.4	10.7	6.1	1.8

Table 2-4 Minimum Monthly Temperature (°C) Over the Central Elburz Stations.

Stations	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	5.1	4.5	6.1	10.9	15.8	19.8	22.7	21.8	19.6	15.1	10.7	7.2
Astara	2.6	2.4	4.4	9.3	14.3	18.3	21.1	20.4	17.4	14.1	8.0	3.9
Babolsar	4.0	4.5	6.5	11.2	15.9	20.0	22.4	22.0	19.6	14.0	9.7	5.6
Ghaemshahr	2.0	3.1	5.2	10.2	15.0	18.5	21.4	21.4	18.4	12.7	8.0	4.0
Gonbad	2.4	2.3	4.4	8.3	13.0	18.8	21.4	20.7	17.7	11.1	7.1	3.4
Gorgan	4.1	4.0	6.2	11.3	15.6	19.6	23.0	22.7	19.6	13.7	9.3	5.6
Havigh	3.9	4.1	6.0	10.6	15.2	19.2	21.8	21.6	19.3	14.0	9.7	5.4
Hashtpar	3.7	4.0	5.8	10.3	14.7	18.6	21.1	20.9	18.7	13.6	9.4	5.2
Lahijan	3.5	3.3	4.2	9.2	13.9	17.4	20.6	20.0	17.7	12.7	8.4	5.0
Noushahr	3.9	4.0	5.9	10.8	15.3	19.1	21.8	21.6	19.1	14.1	9.9	5.4
Ramsar	3.7	3.7	5.5	10.0	14.6	18.4	21.3	21.2	19.0	14.1	9.6	5.2
Rasht	3.6	3.4	5.3	10.2	14.9	18.6	21.1	20.3	18.0	13.4	8.5	4.7
Shirgah	1.1	0.7	2.1	6.0	8.4	11.7	14.4	13.9	11.3	7.8	5.3	2.6
Aminabad	-1.0	0.3	4.2	10.2	14.1	19.2	21.2	19.9	17.1	10.6	5.8	0.8
Damghan	-2.8	-0.9	3.1	9.8	14.4	19.0	21.5	20.1	16.3	10.1	4.7	-1.3
Dehsomeh	-9.6	-2.5	-0.7	5.8	8.6	11.6	13.9	12.7	9.5	6.8	3.9	-1.2
Garmsar	0.0	0.3	4.8	11.6	17.1	22.5	24.1	21.7	16.6	10.3	5.5	-0.1
Ghazvin	-4.3	-2.6	0.9	6.4	10.0	13.5	17.0	15.7	12.4	7.2	2.8	-2.3
Ghom	-1.1	0.7	4.4	11.3	15.8	19.7	21.2	19.9	14.8	10.8	5.7	0.9
Karaj	-3.7	-2.7	1.2	7.2	10.8	14.4	18.1	16.9	13.6	8.1	3.4	-2.0
Latian	1.4	0.3	4.8	9.0	12.4	16.5	20.0	19.7	16.0	10.5	6.4	1.6
Semnan	-1.4	1.0	5.0	12.3	16.8	22.3	24.8	23.4	19.7	13.8	6.6	1.1
Shahroud	-2.7	-1.6	2.0	8.7	12.8	17.2	20.6	18.7	14.3	8.1	3.1	-1.2
Takestan	-6.3	-4.4	-0.4	5.0	8.9	11.6	13.6	13.5	10.7	8.0	2.1	-5.7
Tehran	0.3	1.5	5.3	12.4	16.4	21.1	24.8	23.5	20.1	13.3	6.7	1.9
Varamin	-2.9	-1.1	2.7	9.3	13.2	17.2	19.9	18.5	14.3	8.7	2.8	-1.2
Abali	-7.1	-7.1	-4.0	2.8	7.0	12.4	15.5	14.5	10.9	4.3	0.2	-5.5
N- Kandavan	-8.0	-8.0	-4.4	3.1	7.9	13.8	17.4	16.3	12.2	4.9	0.2	-6.2
S- Kandavan	-8.4	-8.4	-4.7	3.3	8.3	14.6	18.3	17.2	12.9	5.1	0.2	-6.5





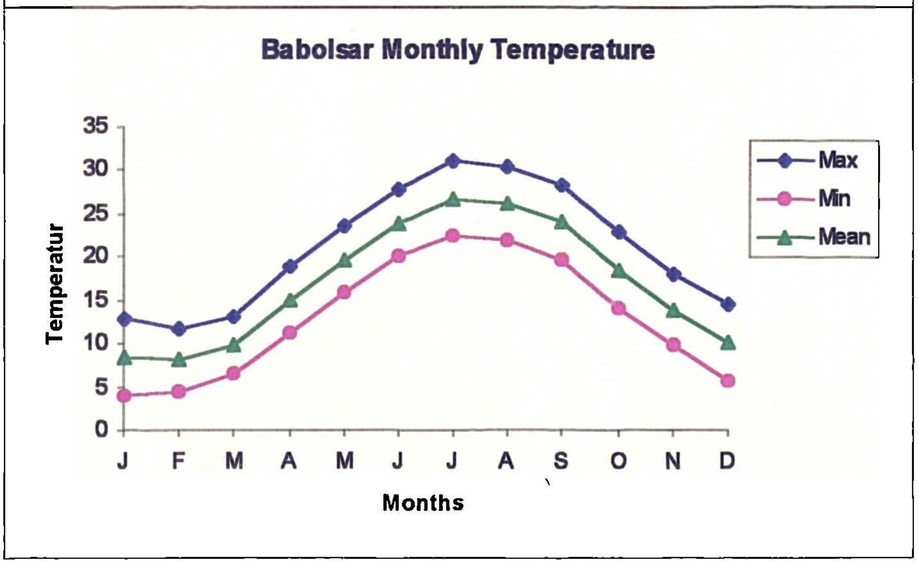


Figure 2-8 Monthly Temperature (°C) over the Central Elburz Stations.

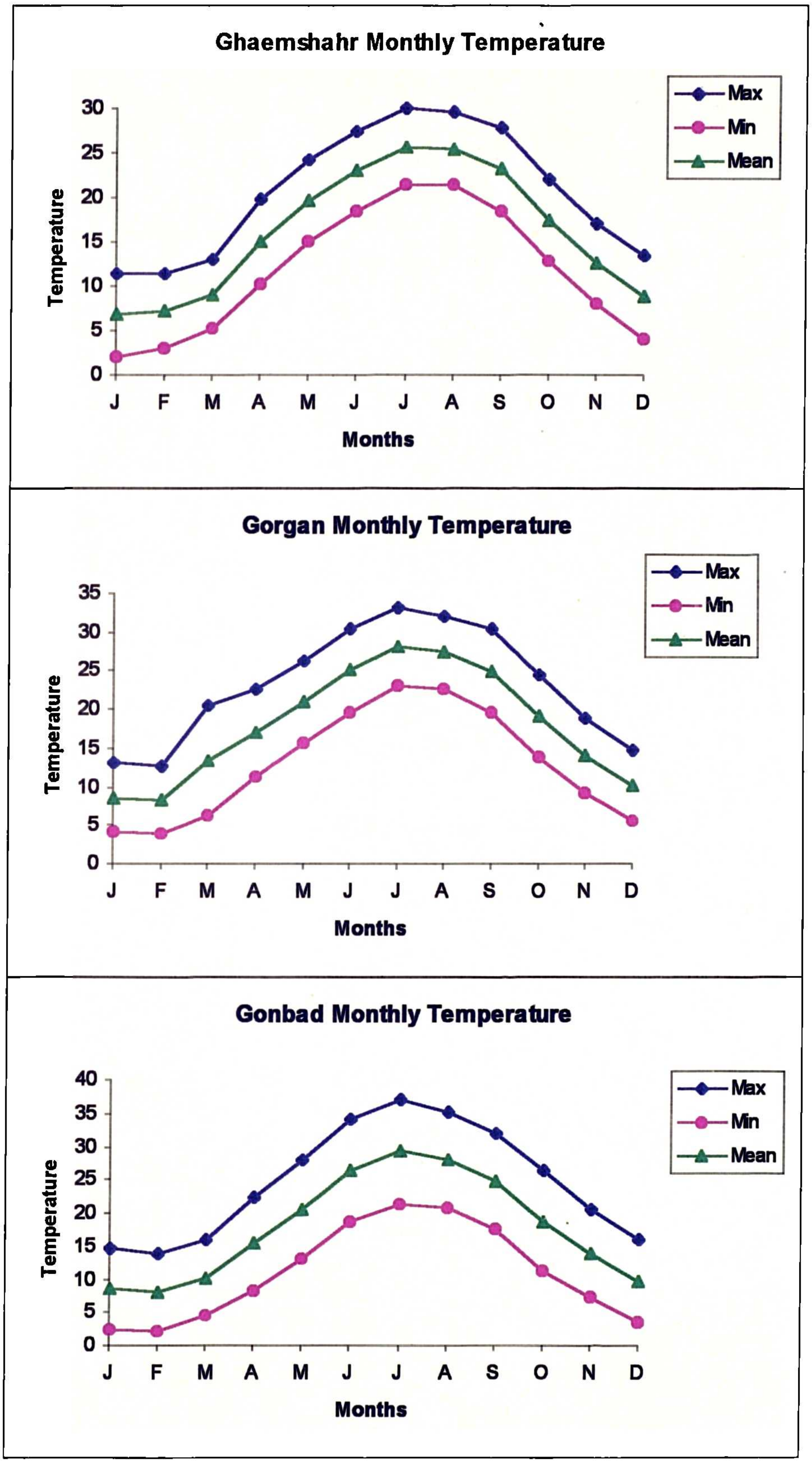


Figure 2-9 Monthly Temperature (°C) over the Central Elburz Stations.

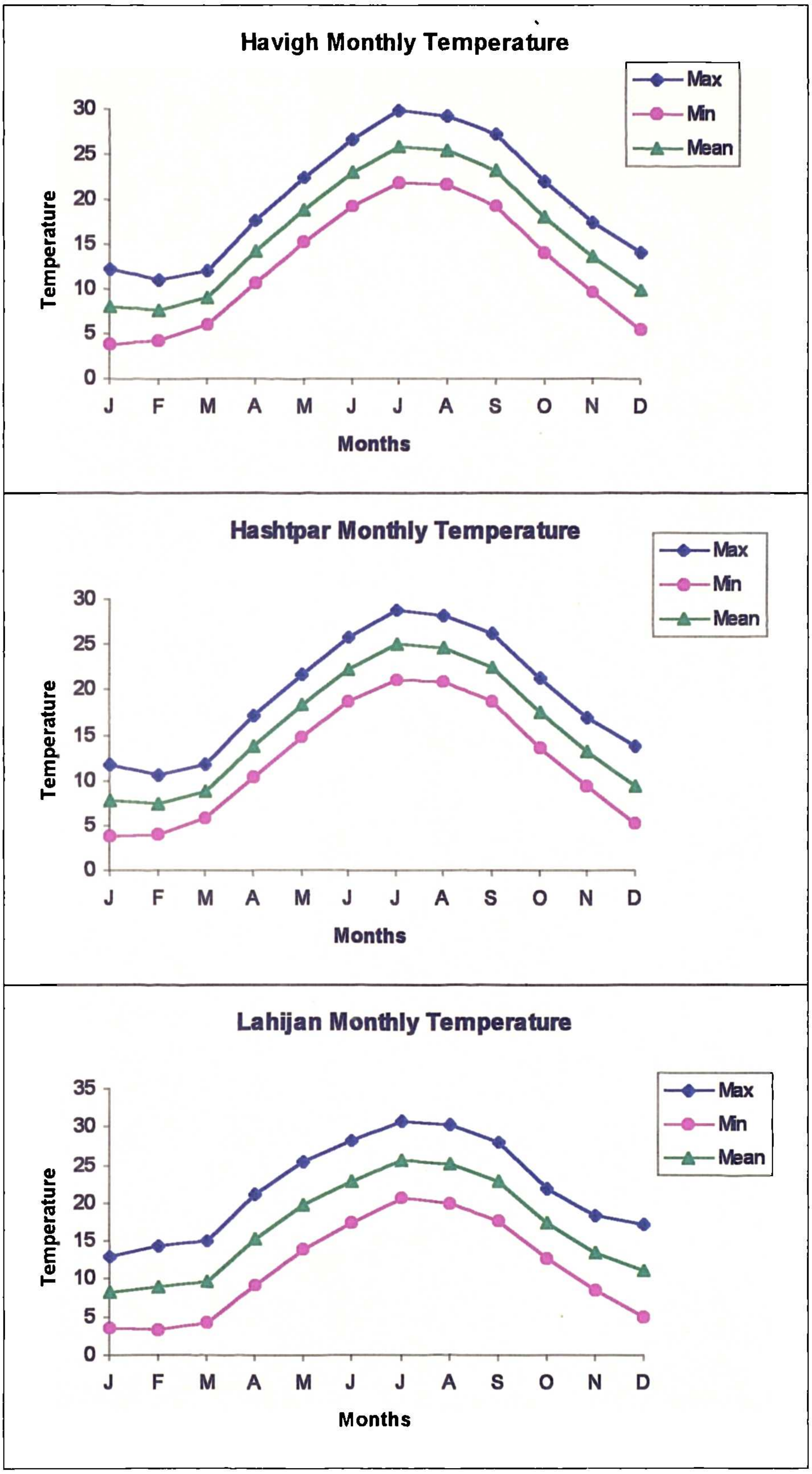


Figure 2-10 Monthly Temperature (°C) over the Central Elburz Stations.

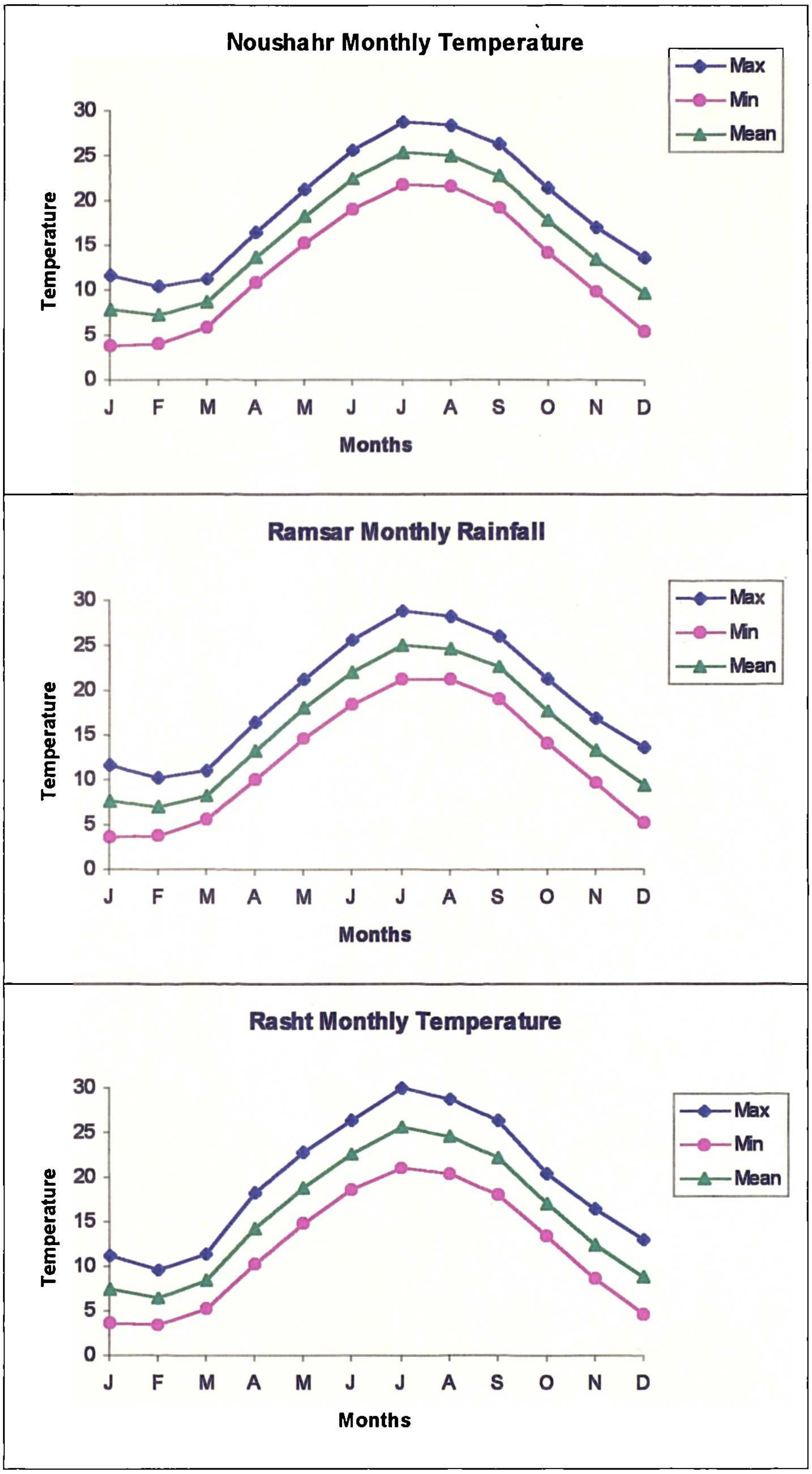


Figure 2-11 Monthly Temperature (°C) over the Central Elburz Stations.

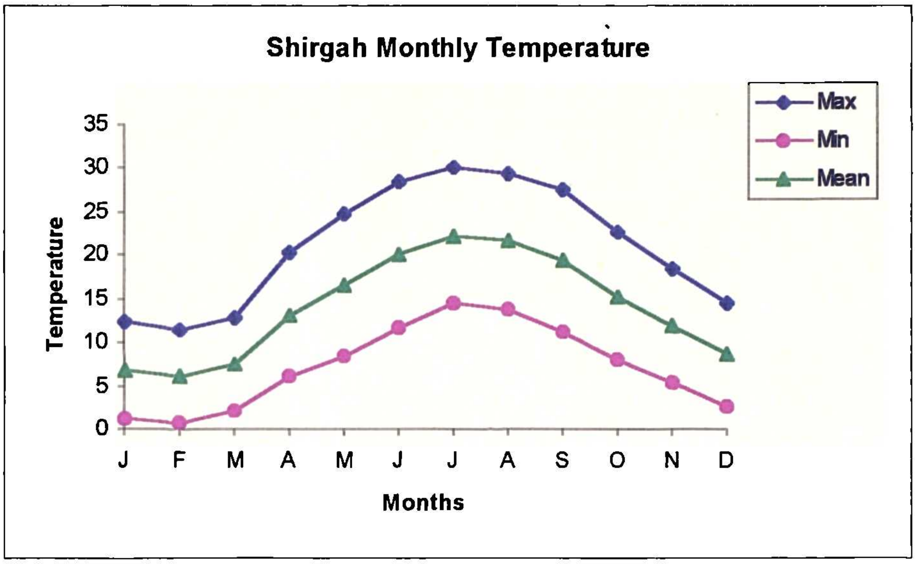


Figure 2-12 Monthly Temperature (°C) over the Central Elburz Stations.

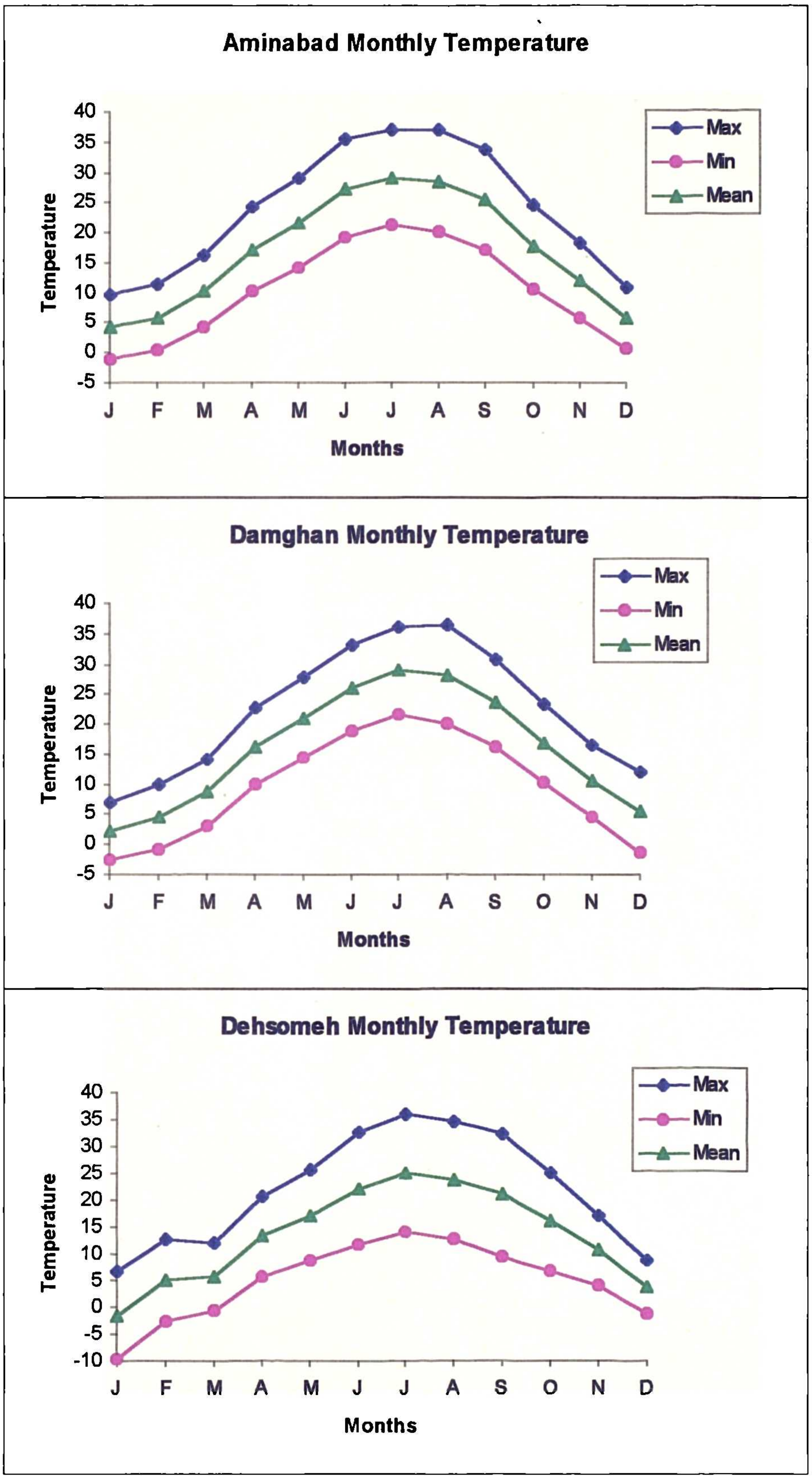


Figure 2-13 Monthly Temperature (°C) over the Central Elburz Stations.

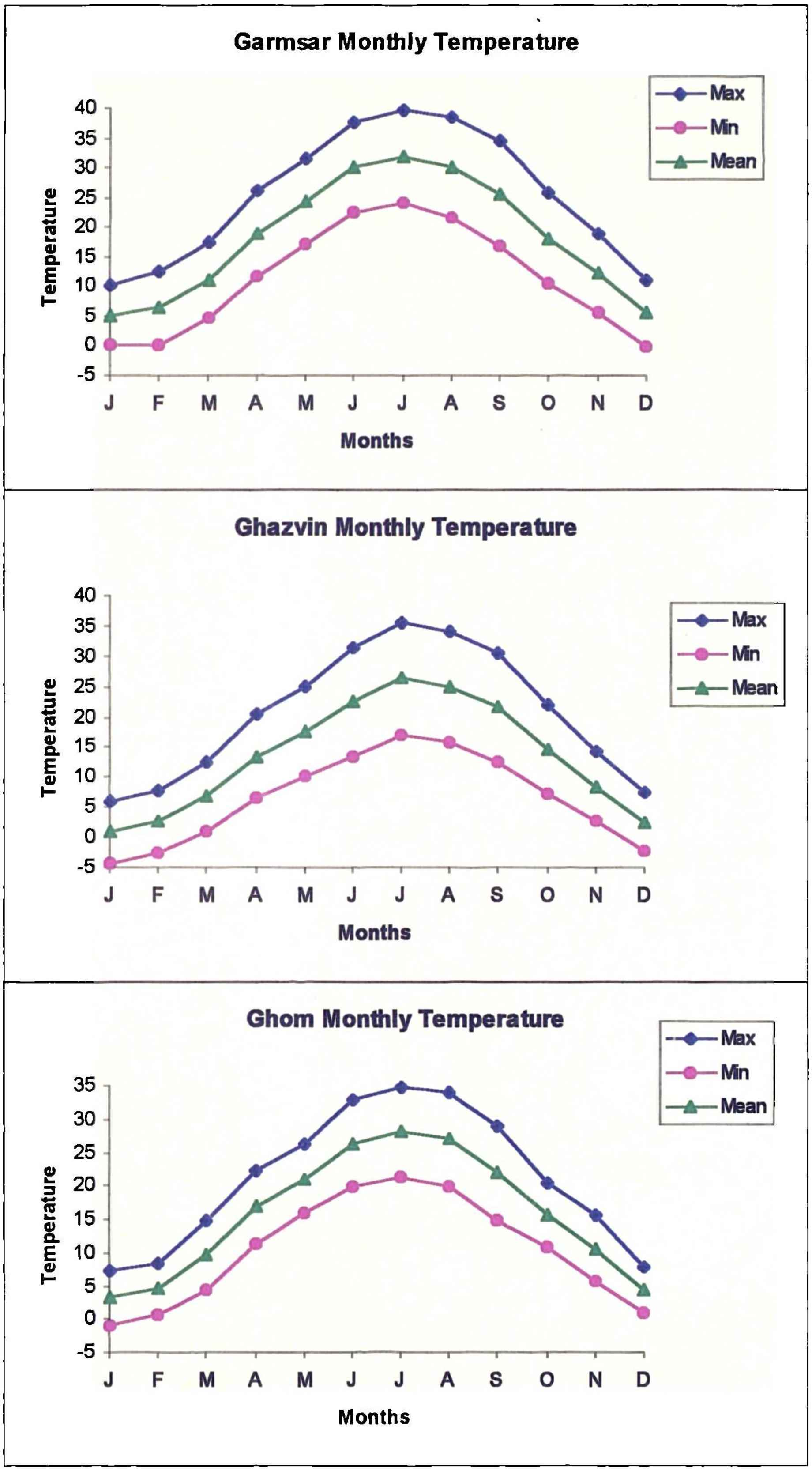


Figure 2-14 Monthly Temperature (°C) over the Central Elburz Stations.

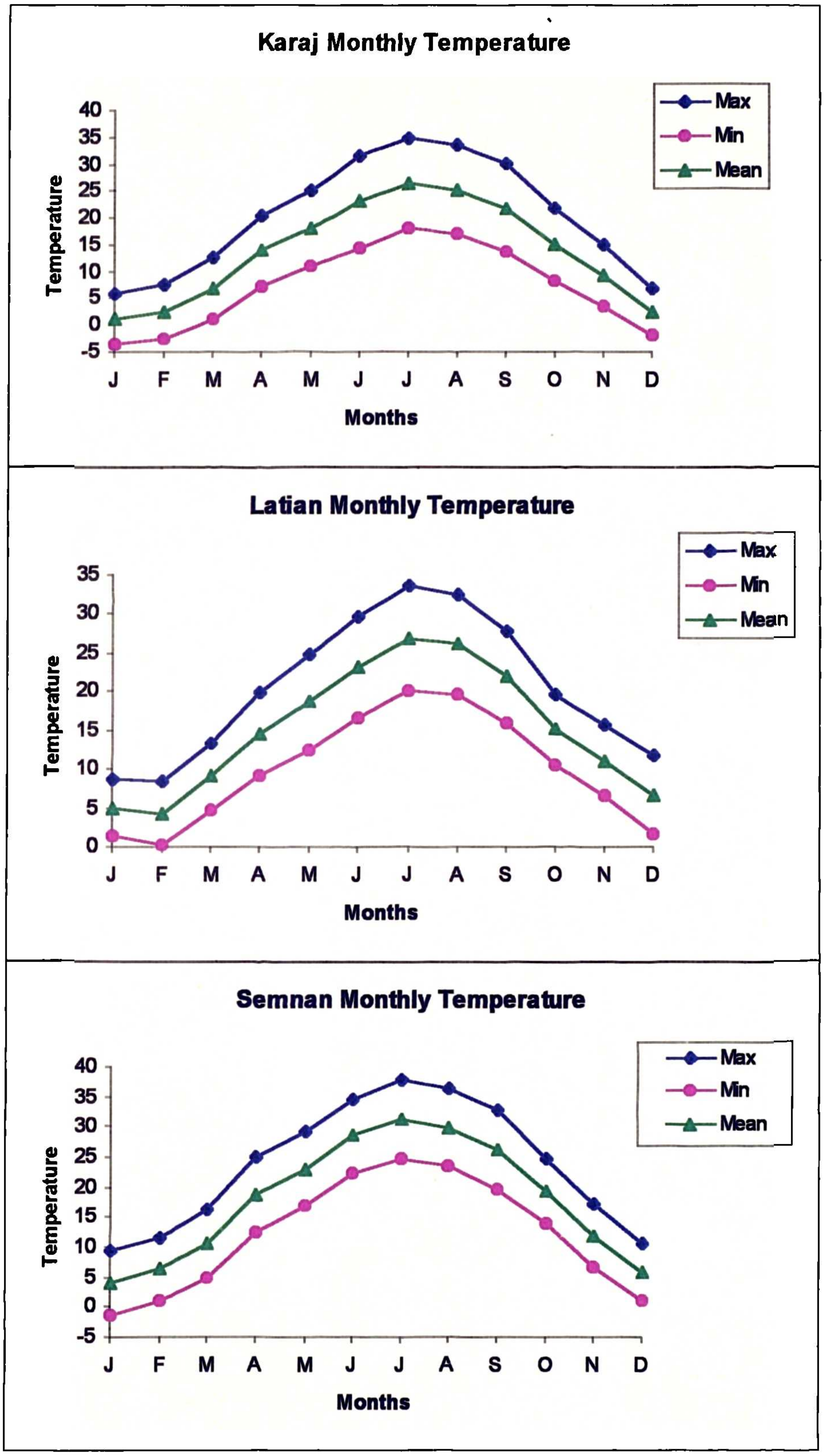


Figure 2-15 Monthly Temperature (°C) over the Central Elburz Stations.

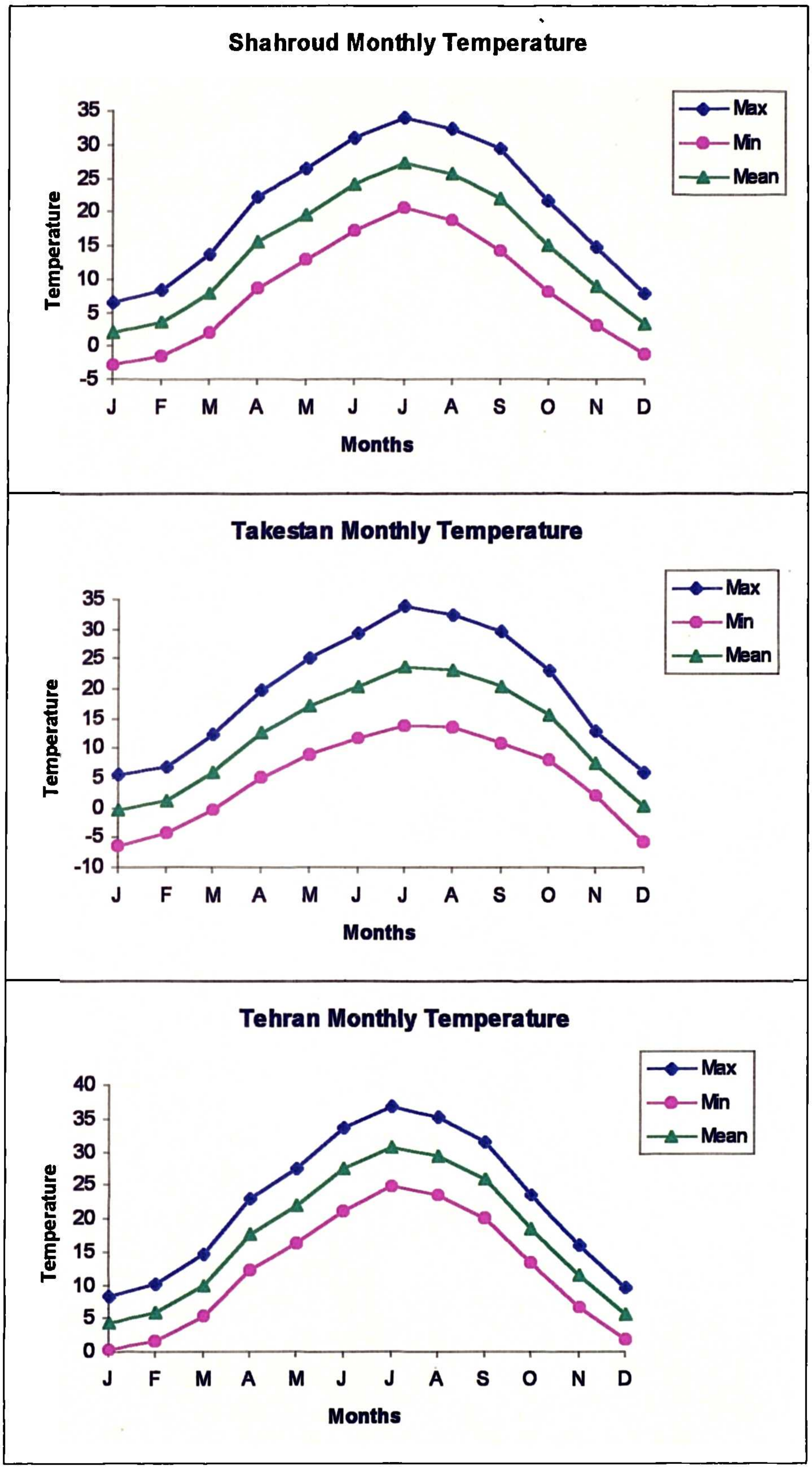


Figure 2-16 Monthly Temperature (°C) over the Central Elburz Stations.

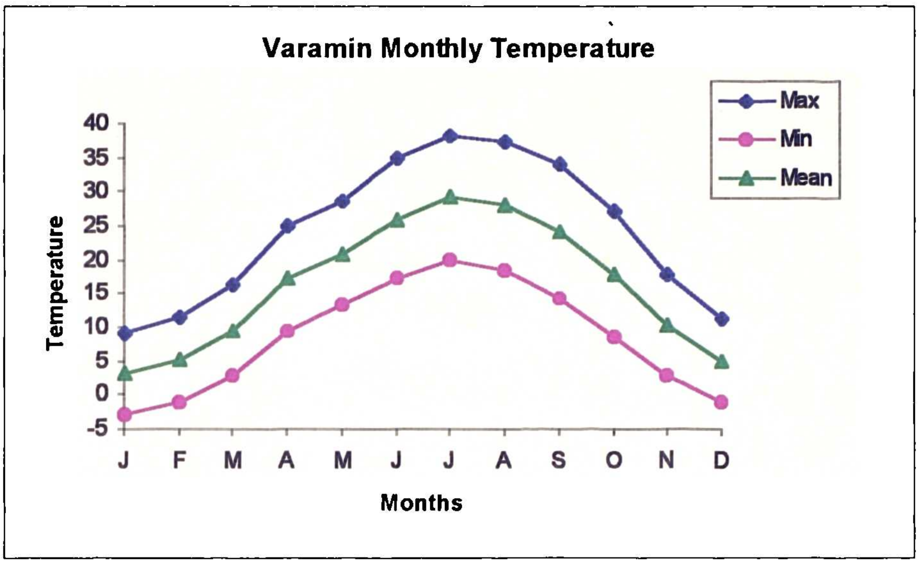


Figure 2-17 Monthly Temperature (°C) over the Central Elburz Stations.

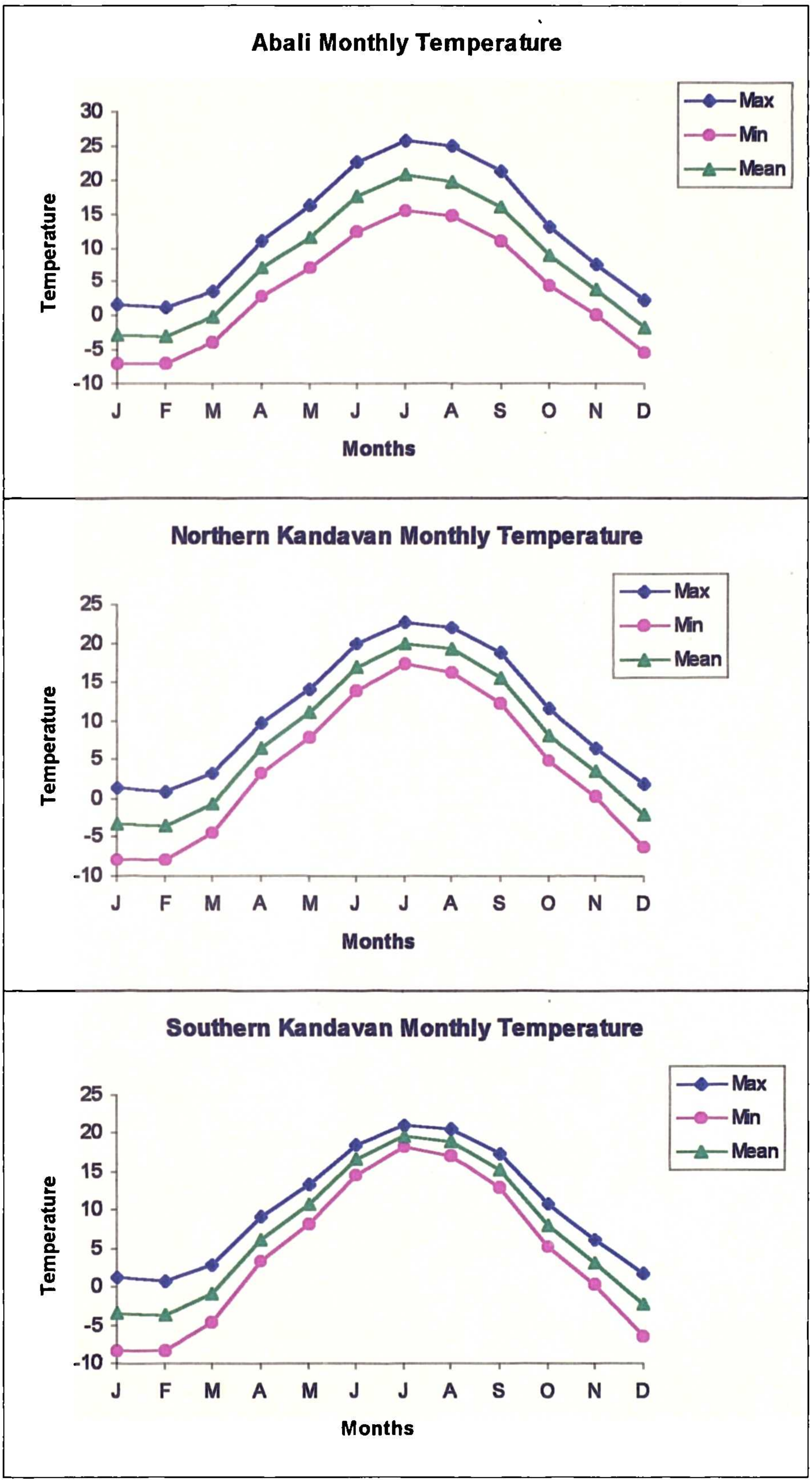


Figure 2-18 Monthly Temperature (°C) over the Central Elburz Stations.

2.13 Conclusion

The Elburz range is a watershed on the scale of synoptic meteorology. The country from time to time is exposed to the movement of air masses that originate in distant places and are therefore initially of totally different temperatures and moisture from those prevailing in Iran. Such air masses can exert a great influence on the pattern of temperature distribution in different parts of Iran especially during winter and summer seasons.

The most critical months of the year from the point of view of temperature studies are the midwinter and the midsummer months during which extremes of cold and warm temperatures usually occur. As a point of analytical temperatures Elburz stations can be of two different types:
1) January is the coldest month of the year for southern Elburz stations but the coldest month is February for the higher altitude and the Caspian Coastal stations.
2) July is the warmest month of the year for all of the central Elburz stations.

All Coastal stations display very small ranges which increases with distance from the sea such as Gorgan and Gonbad stations. The lowest values of the Caspian Coastal stations do not fall below zero.

The Caspian area, as a result of the presence of the Elburz range, and the Caspian sea which form a storm track for depressions, rainfall is very much higher. Moreover, the low altitude of the coastal plain gives winter temperatures more in keeping with the latitude. In summer rainfall occurs on a reduce scale, and the resulting cloud cover helps to reduce insolation, so that the high temperatures characteristics of the other parts of the Central Elburz are not found. A hot but not torrid summer and winter milder than in the adjacent areas, together with abundant rainfall, well distributed throughout the year, indicate that climatically the Caspian area stand apart from the rest of the Central Elburz, with conditions that are closer to those of the humid tropics.

The review of the meteorology and synoptic features affecting Iran provides the context for the study of rainfall. It is not possible to produce clear hypotheses which can be rigorously tested with rainfall data. However the statistical analysis of rainfall data, which has practical importance for agriculture, can provide some probable causal links as follows:

1) The subtropical jet stream is found above the light and variable winds associated with the subtropical high pressure system in the upper atmosphere in the Middle East. Iran is under this subtropical high pressure system which has surface divergent flow of air and widespread air subsidence. This subsiding air is relatively dry and this zone is the site of the world's subtropical deserts. The position of the core jet stream or line of maximum velocity of the jet stream varies over 10 to 15 degrees of latitude from summer to winter. This seasonal shift of the subtropical jet stream in the Middle East parallels the movement of the major climatic belts between their summer and winter positions. The winter position over the northern part of the Persian Gulf is maintained for approximately six to seven months from mid- October to April. This is followed by a rapid shift of latitude to 10^0 as the summer position over the Caspian Sea is held for three to four months from June to the end of September. Therefore Jet streams and air masses vary in their strength and position both seasonally and from year to year. It is possible that rainfall data will show variations which could be linked to jet stream activity and length of air masses.

The westerly jet stream can affect Iran and fluctuation in the seasonal rainfall could also be evident here. Thus fluctuation in the rainfall over the Central Elburz can have meteorological causes. Also the start of the rainy season and indeed interruptions in the rains can be caused by jet stream activity and air masses as well as the strength of the Asian high pressure system. However, these processes can not be quantified exactly by rainfall data.

2) Topographically the Central Elburz exercises an effect on wind movement and rainfall processes. Thus meteorological processes are modified or intensified by

topography. An examination of the spatial pattern and correlation between relief and rainfall are considered in following chapters. The effect of mountain barriers in creating boundaries is of particular important in this region. In this regard Elburz mountains can be considered as the boundary between two regions, southern and northern. This has created an interesting physical boundary particularly from the point of view of rainfall. The Elburz range provides two different distinct regimes. The characteristics of these two different distinct regimes are the subject of the following chapters.

3) Local winds could influence patterns of rainfall and more particularly evapotranspiration. Because of the scale of the study, dictated by the distribution of rain gauge sites, it is not possible to test these influences on water availability.

3

3. The Annual, MONTHLY AND SEASONAL Rainfall Distribution OVER THE CENTRAL ELBURZ

The main purpose of this chapter is to provide a description of the spatial distribution of the annual, monthly and seasonal rainfall over the central Elburz.

3.1 The Distribution Patterns of the Annual Rainfall

The total amount of rainfall received at a specific station is normally computed on an annual basis and indicated by the long-term annual mean. This is undoubtedly the most widely used rainfall figure (McGregor and Nieuwolt 1998) and is usually accepted as the most important indicator of rainfall condition.

The data used in this study were taken primarily from Iranian Meteorological Office for the period of 1957 to 1987. The mean annual rainfall for the Central Elburz stations has been provided in the Table 3.1-1 and Figure 3.1-1 for the period 1957 to 1987. Also the mean annual rainfall in the Central Elburz stations for during this period is 662.21 mm rainfall.

Table 3.1-1 Mean annual rainfall over the Central Elburz stations.

Stations	Mean annual rainfall (mm)
Anzali	1832.8
Astara	1300.3
Babolsar	835.7
Ghaemshahr	741.0
Gonbad	515.0
Gorgan	624.0
Havigh	1271.4
Hashtpar	1114.1
Lahijan	1325.3
Noushahr	1331.6
Ramsar	1231.7
Rasht	1342.0
Shirgah	996.5
Aminabad	187.3
Damghan	116.0
Dehsomeh	303.9
Garmsar	118.2
Ghazvin	321.5
Ghom	150.9
Karaj	236.1
Latian	365.9
Semnan	129.0
Shahroud	159.4
Takestan	242.8
Tehran	230.0
Varamin	150.3
Abali	547.7
Northern Kandavan	834.5
Southern Kandavan	649.6

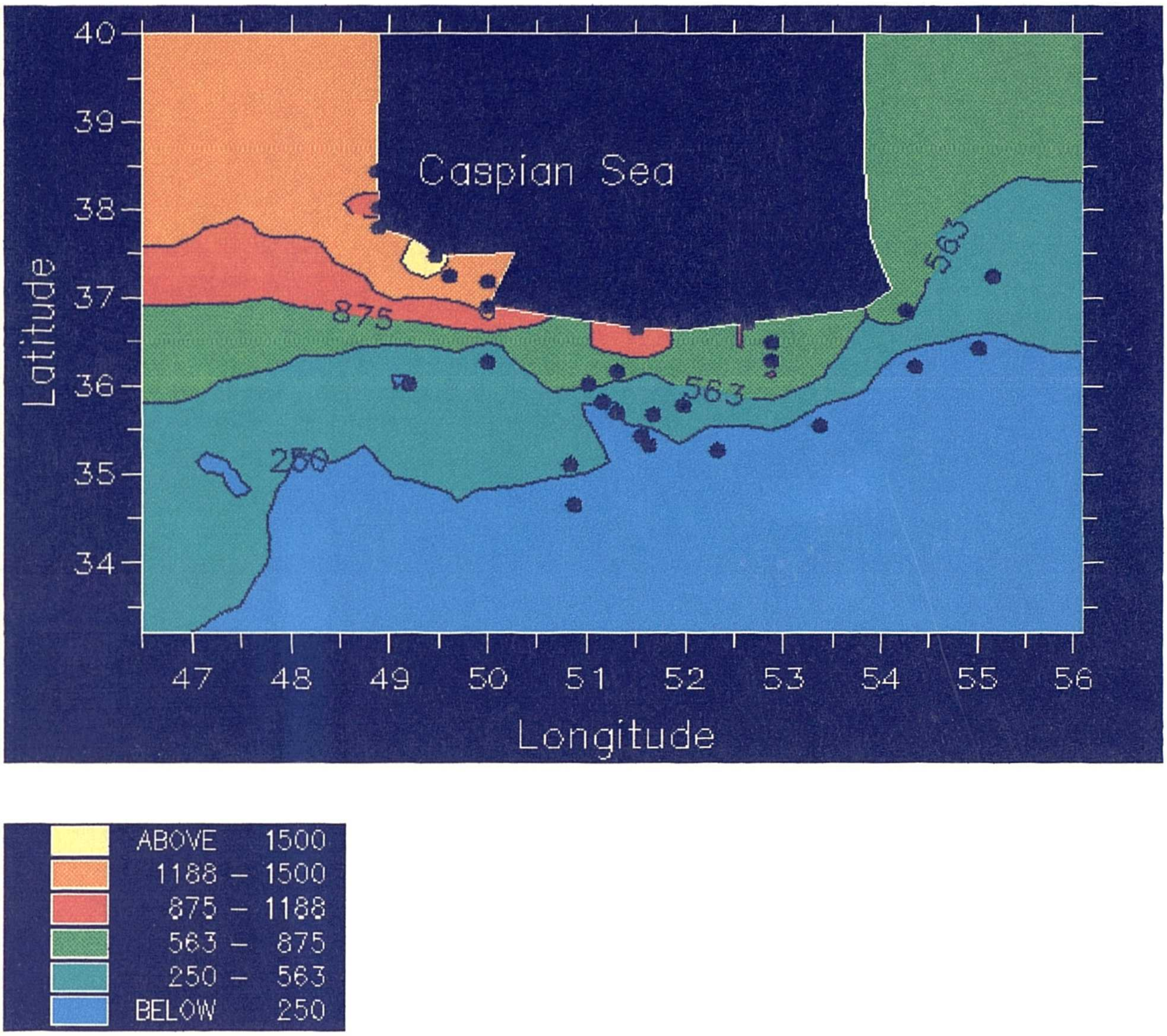


Figure 3.1-1 Mean annual rainfall over the Central Elburz stations.

3.2 Rainfall Mapping Technique

Regarding Chapter 1 most of the maps in this thesis have been objectively drawn by using the Unimap technique. It will be discussed and explained in following pages. Geography is a form of focused curiosity concerned with observing, describing analysing and explaining the differences and similarities between places on the Earth's surfaces. Maps lie at the heart of the subject. Both at the level of simple enquiry and in advanced research, a map is primarily a multipurpose tool of use for exploring spatial variations and for simulation and modelling of a range of scenarios.

There are many different methods for producing a map including traditional methods (manual) or computerised methods such as Auto-Cad, GIS etc. Mapping is in itself an important form of visualisation, and simple manipulation can often provide interesting and different visualisation of the same phenomena. Visualisation concerns the graphical display of information and allows the rapid interpretation of complex multidimensional data as well as the identification of patterns and trends which may be very hard to convey in purely numerical terms.

The Geographical Information System (GIS) is an advanced and comprehensive computer tool box which is capable of storing, retrieving, manipulating analysing and displaying all forms of geographically referenced information which can be used for decision making purposes. One of the most important roles of GIS is its provision of an organising structure for extremely large quantities of operational information. This allows one to perform many spatial operations of the data such as retrieving all information at a specific location or area and identifying areas which meet certain criteria. GIS are much-hyped and widely used computer systems for handling geographical data (simply, information which refers to specific places), which have seen enormous expansion since 1980 and are now a familiar part of geography study programmes. A GIS system is essential for efficient presentation and manipulation of geographical data. GIS can be classified into two categories:

a) raster based and

b) vector based.

These have different methods for data storage and manipulation. A raster based GIS stores and manipulates spatial data on a grid cell basis. An example of a raster- based GIS is Unimap (UNIRAS A/S., 1989). A vector based GIS stores spatial information in the form of points, lines and polygons. Spatial information can be accurately stored and represented in this type of system. It is also easy to associate textual, attribute and numerical data with the data base. However this system is usually more complex and spatial analysis is often difficult and requires more operational techniques. An example of a vector- based GIS is ARC/INFO. In the last decade, GIS have found wide application in many diverse field such as Urban Planning, Water Resources, Agriculture, Hydrology and so on.

Producing many types of climatic subject maps such as annual rainfall, coefficient of variation, probability etc., generally involves a presentation and interpolation of the rainfall values, and is performed automatically in two ways:

1) computer tools
2) manually by a climatologist.

The computer method has the advantage of incorporating numerical analyses and the possibility of utilising complex presentation and interpolation algorithms. The manual method is produced by a climatologist or a skilled person with experience and knowledge of rainfall characteristics. In this case isohytes are drawn by eyes. However today this method is usually under taken using computer programmes such as PC Coral Draw software as well.

In this study we have tried to develop a method that combines the advantages of the computerised mapping of Unimap 2000 package for producing different maps. It has been used for the first time in the rainfall climatic maps. Its benefit is that the high graphical resolution, better presentation and interpolation are more accurate than one used by traditional climatological methods. This package is installed on the UNIX workstation (HP) programme computers.

Unimap, a raster based interactive package in the Uniras suite of software (UNIRAS A/S., 1989), is a powerful package for producing better presentation, interpolation, generation of contour and gridded maps. It is extremely easy to use compared to many other GIS packages. Another valuable feature of Unimap is that new calculated regular data, can be easily mapped without any further interpolation. Irregular data is very commonly used, but regular data is needed to make a contour map. Interpolation can be produced by estimating regular data from the supplied irregular data. Unimap supports several interpolation methods namely Bilinear, Polynomial, Fault, Minimum curvature, Bicubic and Kriging. UNIMAP 2000 is an advanced technical mapping system with interactive menu package that can capture, model and analyse data addresses. UNIMAP 2000 provides a more advanced contouring and image display capability, demanded by sophisticated users, by providing technical and geophysical understanding and analytical visualisation of spatial data in 2 or 3 dimensions. It can also produce different coloured map by using the gallery menu. It includes comprehensive utilities for quick graphical analysis, including quick colour- shaded contour maps and quick image displays.

Unimap is completely self contained and a device independent of software graphics systems that can be adapted to work with all graphic output devices. It is, thus totally device independent. Indeed, Unimap application can run on any graphics output device from simple pen plotters to high resolution raster hardcopier and very high performance interactive displays. A data file is used in Unimap which will normally consist of three numbers on each line X, Y and Z. Thus the input data normally consists of points with three X, Y and Z values in which the parameters Z is a function of the parameters X and Y. The X and Y coordinates represent the 2D location of a point and the Z coordinate represents the factor to be visualised.

Regarding to section 3.1, the records for stations vary from 24 to 45 years (1942-1987), but 1 station had 24 years, 6 stations 25 to 30 years data and 22 of them more than 30 years data. With reference to Table 3.1-1 and Figure 3.1-1 mean annual rainfall varies between more than 1830 mm over the coastal area in the Anzali Station to less than 117 mm along part of the southern slopes at the Damghan. The highest annual rainfall is recorded to the south-west of the Caspian Sea, at Anzali, which has an annual mean rainfall of 1832.8 mm, or three times more than the mean of all stations of the central Elburz region (662.2 mm), and the lowest annual rainfall is recorded in the southern slopes stations at Damghan, which has an annual mean rainfall of 116 mm, or less than 10% of the highest mean annual rainfall record of the country, Anzali (1832.8), and 15% of the mean annual rainfall of the Central Elburz. Therefore, it is clearly seen that there is a difference in the amount of rainfall between the Central Elburz stations. The reasons for these differences can only be determined by the moisture content of different air masses, divergence of air and other meteorological factors such as the path of depressions, altitudes and distance from the Caspian Sea. Thus two main issues need further consideration:

1) meteorological causes of rainfall;

2) the effect of geographical location, altitudes and distance from the Caspian Sea and continentality.

3.3 Meteorological Causes of Rainfall

In describing, and explaining the distribution pattern of the annual rainfall over the central Elburz in the previous pages, references have often been made to the larger meteorological rain producing systems and other factors to which the pattern of rainfall distribution is broadly connected. Prevailing air masses and continentality are determinant of rainfall distribution of a place. In general, as well as in the central

Elburz, the further away a place is from the sea or atmospheric humidity resources, the less amount of rainfall received. In Iran particularly in the central Elburz, there are several main rainfall producing factors operative. Fisher (1968) quoted by Gangi (1968) has used very briefly some of them such as depression tracks to explain the pattern of rainfall distribution over Iran. In the middle latitudes, precipitation in the winter half-year is predominantly derived from advective situations (Barry 1981). Approximately all of the rainfall of Iran comes from depressions that originate over, or near, the Mediterranean Sea. Flowing air from the Siberian anticyclone is dry and gives no rainfall in the central Iran but in the Caspian coastal areas causes plenty of precipitation as will be explained in the following pages.

Fisher (1968) quoted Gangi (1968) classified rainfall events over Iran are cyclonic, convective and orographic and concluded that most of the cold season was basically cyclonic in origin. Gangi (1968) concluded that the summer rainfall was convective; he attributed the rainfall in the Caspian lowland to orographic lifting of unstable air arriving from the Caspian Sea. Khalili (1971), however, attributed this precipitation may be thermodynamic destabilization of Siberian cold air masses as they crossed the warmer sea surface (Alijani and Harman1985). Most of the summer rain that falls in the Southwest of the Caspian Sea is usually attributed to an intensification of the flow of unstable warm, moist air into the coastal area from the Caspian Sea. The summer drought is likely over most of the southern Elburz, and especially in southern slope stations. The short rainy seasons are succeeded by dry seasons when soil humidity is quickly wasted by high rates of evaporation.

Meteorological factors which can not be quantified have previously been explained (in chapter 2) are as follows:

a)- air masses:

1. cP (continental polar air mass) from the Siberia.
2. mP (maritime polar air mass) from the Northern Atlantic Ocean
3. mT (maritime tropical air mass) from the Mediterranean Sea.

4. E (the monsoon air mass) from Indian Ocean.

b)- jet streams:

1. the position of STJ (Subtropical jet stream).
2. the position of PFJ (Polar front jet stream).

c) - the position of STHP (Subtropical high pressure).

3.4 The Effect of Geographical location, Altitude and Distance from the Caspian Sea and Continentality

Relief provides a trigger movement for convection and uplift of air masses. Both of which are more active in the Caspian Sea area. The relief component is therefore related to distance from the sea and it is assumed that the altitude effect on rainfall diminishes with increasing distance from the sea.

Orographic influence is a well-known factor affecting rainfall distribution, the windward side of the mountains receiving more rain than the leeward sides. Local differences, such as dense forest areas, bare ground, the presence of cities and water bodies such as lakes and rivers, may also affect the formation, dissipation, and the paths of the line squalls, thunderstorms and rainfall (Odumodu 1983).

3.5 Rainfall-Elevation Relationship over the Central Elburz

Factors such as relief create not only marked spatial differences in rainfall but also result in different variability patterns. For example, nearby locations on opposite sides of a mountain range can receive much of their rain from very different weather patterns. In an individual season, a higher than average frequency of one weather type can produce above average rainfall at a point on one side of a mountain range but lack of this weather type at a nearby point on the other side many result in falls being below average. However, in the absence of permanent influences such as relief, over small distances where long term averages for periods of a month or more are similar, it is generally accepted the differences in amount and variability pattern existing for individual days will tend to even out. Clearly there would not be a complete evening out, but it might be anticipated that differences would be small enough to be of limited significance to agriculture and water resources. Usually, the amount of rainfall increases with height, and this increase appears to continue only up to a certain height, named the region of highest rainfall, above which there is a decline.

Empirical studies on mean annual precipitation changes with elevation have shown that on windward slopes in temperate latitudes, the relationship is positive at least up to 3000 m. However in most tropical climates, precipitation increases up to a particular level after which totals decline with further elevation (Puvaneswaran and Smithson 1991). This suggests that atmospheric process are different at higher elevations and in the case of many tropical locations subsiding air overlies the turbulent layers. Mountains and highlands receive more rainfall than nearby lowlands, at least on their windward slopes. This is the result of orographic lifting, a process which increases rainfall in all climates. But the effects show a significant difference between the tropics and extra- tropical latitudes. Outside the tropics the amounts of precipitation increase with elevation up to the highest levels of the mountains, while in the tropics the increase stops at a level of about 1000-1500 m, and above this elevation precipitation generally decreases with height (Nieuwolt 1982).

Orography is clearly a major factor in the distribution of precipitation in Iran, and its influence, immediately clear on all rainfall maps, should be emphasised in all climatic studies of the country. Relief becomes an important factor in the climate of any region, especially where highlands or mountain ranges lie across the paths of prevailing moist winds (Fisher 1968) quoted by (Gangi 1968). Barry (1981) states the amount of orographic precipitation depends on three factors operating on quite different scales:

1) air mass characteristics and the synoptic-scale pressure pattern;

2) local vertical motion due to the terrain; and

3) micro physical processes in the cloud and direction.

The contrast in precipitation-altitude relationships between tropical and temperate latitudes is believed to be caused by the differences in the upper atmospheric circulation in these areas. While both temperate and tropical region experience a decrease of specific humidity and therefore potential moisture supply with height, in temperate latitudes the westerly wind normally increases with height. Hence, more water vapour can be driven across a vertical area unit and condensed through ascending motion (Puvaneswaran and Smithson 1991). In middle latitudes, the general tendency for increased precipitation with height, often to the highest levels of observations, is modified considerably by a leeward or windward slope location. The relationship of rainfall to elevation has been the subject of much investigation in many different parts of the world Oyebande and Oguntoyinbo (1970), Ayoade (1973), Chuan and Lockwood (1974), Hill (1983), Smithson (1970, 1990a and 1990b), Oliva *et al* (1991), Barry and Chorley (1992), Sharon *et al* (1994), Singh *et al* (1995), Konrad (1996), Loukas and Quick (1996), Gunnell (1997), Singh and Kumar (1997). Usually the total precipitation only is discussed, especially when statistical prediction is attempted by regression methods (Barry 1981). The following model was used to demonstrate changes in the amount of rainfall over the central Elburz stations, and its relationship with altitude:

$$Y = aX + b$$

Where;

Y is the dependent variable, here calculated annual rainfall in mm,

X is the independent variable altitude of station in metres,

a is the gradient of the regression line and

b is the intercept of the regression line on the **Y** axis.

The basis of this linear regression is the hypothesis that increases in elevation will produce increases in rainfall. The slope of this line '**a**' is thus the increase in rainfall per unit of elevation. If the increase is of a uniform rate such a linear equation will correctly describe the relationship. The analysis results of this model are presented in the Figure 3.5-1 to Figure 3.5-3.

The equation for a simple linear regression for the southern slopes of the central Elburz is as follows:

$$Y = 0.29X - 142.5$$

$$R^2 = 0.61$$

With regard to the Figure 3.5-1 for the southern slopes of the central Elburz the correlation coefficient is equal to + 0.78 for a sample (n =13), and is significant at the 5% probability level. By including two higher altitude stations (Figure 3.5-2) on the southern slope stations of Elburz a more significant relation between rainfall and elevation occurs. This indicates that by increasing elevation, rainfall will be increased. The equation for a simple linear regression for the southern Elburz is as follow:

$$Y = 0.26x - 115.9$$

$$R^2 = 0.90$$

The correlation coefficient is + 0.95 in a sample (n =15), and is significant.

Figure 3.5-1 and 3.5-2 show the relationship between annual rainfall and altitude in the southern Elburz.

The regression estimation for northern Elburz, and southern Elburz were provided and presented separately. The calculation and figures show, that in the southern Elburz the effect of increasing altitude on rainfall is statistically demonstrated and also the zone of maximum rainfall can be taken 2400 to 2900 meters altitude. Figure 3.5-3 shows that, there is no relationship between annual rainfall and altitude in the coastal area stations, and also the zone of maximum rainfall would be about -2 to -26.2 meters altitude. The relief factor is probably less important than distance from the sea.

The equation of simple linear regression for the coastal area of the central Elburz is as below:

$$Y = -2.96X + 1214.73$$

$$R^2 = 0.26$$

The correlation coefficient is equal to -0.51 in a sample (n =13), and shows insignificant inverse relationship with altitude. It is a weaker negative association. In the Coastal area of Elburz the annual rainfall decreases with altitude, and maximum rainfall occurs at the stations of near the coast. Consequently, it is clearly seen that there is a difference in the amount of rainfall between stations that are located closer to or further from the coast. Therefore the relation between elevation and rainfall differs on north and south side of Elburz. Hence only southern Elburz stations have relationship to elevation. It can be concluded that the rainfall origin of the southern and northern Elburz are differences.

As previously mentioned, the elevation factor is probably less important than distance from the sea to test for this hypothesis we used multiple regression. Thus the following model has been used to demonstrate changes in the amount of rainfall for the coastal area stations, and its relationship with altitude and distance from the sea:

$$Y = a_1X_1 + a_2X_2 + \ldots\ldots + a_pX_p + b$$

The equation of multiple regression for the coastal area stations is as below:

$$Y = -0.85\,X_1 - 4.92\,X_2 + 1274.45$$

$$R^2 = 0.55$$

The correlation coefficient was found significant +0.74 with a value of (n = 13). Thus the multiple regression using two factors for the coastal area stations (elevation and distance from sea) is more significant than using elevation alone. Based on this multiple regression model the stations furthest from the sea (eastern Caspian stations) have lower annual rainfall than those near the sea. Therefore it is concluded that total annual rainfall declines with increasing distance and elevation.

As earlier mentioned relief becomes a significant element in the climate of any area, specially where highlands or mountain ranges lie across the paths of prevailing moist winds. Reference to the Figure 3.5-1 for the southern slopes of the central Elburz the correlation coefficient was equal to + 0.78 and was significant. The calculation and figures showed, that in the southern Elburz the effect of increasing altitude on rainfall has been statistically proved. So we did not test multiple regression in the southern slope stations for following reasons:

1) The simple linear regression was found significant between rainfall and elevation.

2) The distance factor from the Caspian sea is less important, due to the effect of blocking air masses by the Elburz mountains.

In summary the relationship between annual rainfall and altitude is significant in the southern slopes but results show it to be insignificant in the coastal area stations.

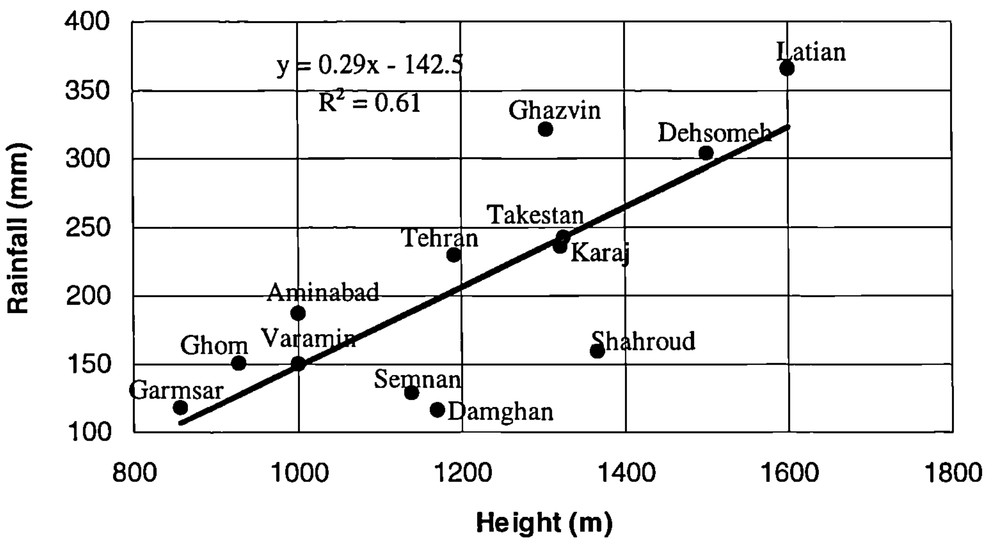


Figure 3.5-1 Rainfall-Elevation Relationship over the Southern Slope Stations.

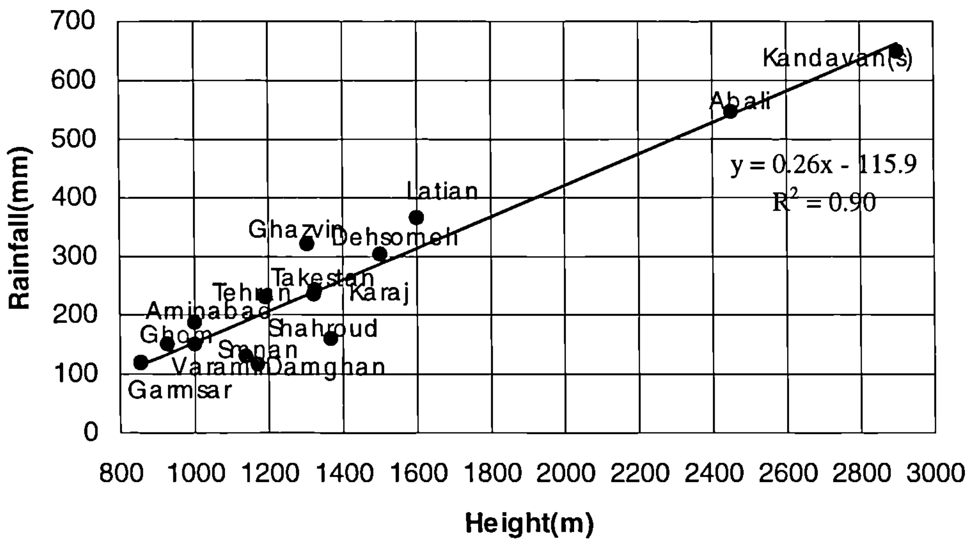


Figure 3.5-2 Rainfall-Elevation Relationship over the Southern Slope Stations

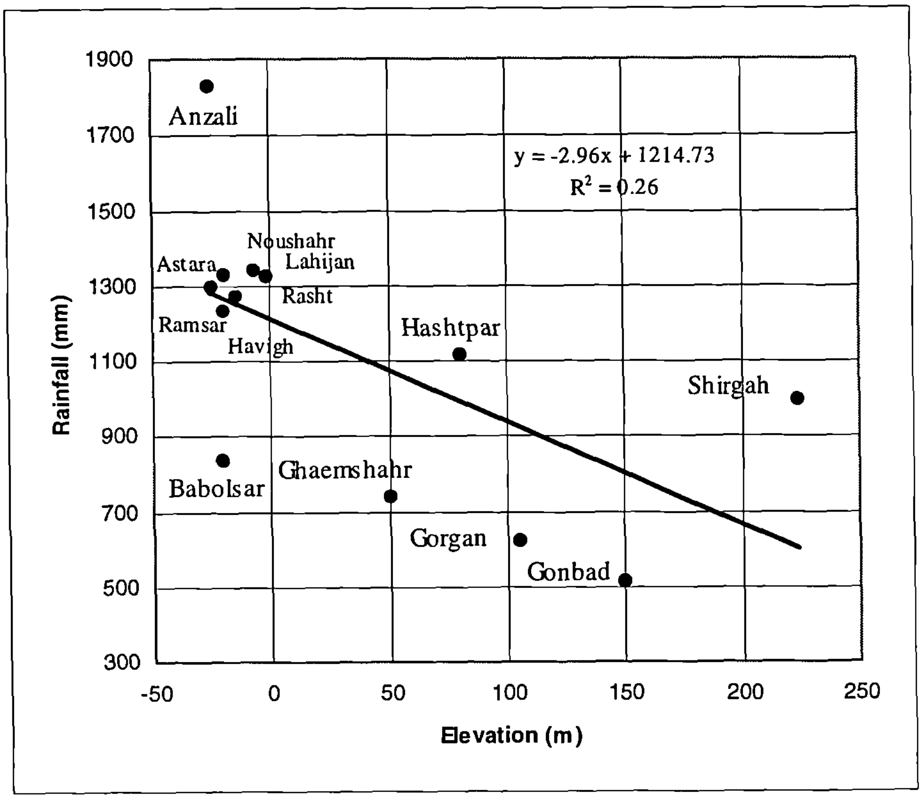


Figure 3.5-3 Rainfall-Elevation Relationship over the Coastal Area Stations.

3.6 Continentality Factor

Continentality is another determinant of rainfall distribution. In general as well as in the Central Elburz, a place further away is from the sea or ocean, less amount of rainfall is received. In this regard for estimating of Continentality over the Central Elburz stations the Gorczynski's Equation (Alaei 1994) was used as follows:

$$k = \frac{1.7A}{Sin\phi} - 20.4$$ where

k = coefficient of continentality;

A = annual range of temperature and

ϕ = geographic latitude.

The annual range of temperature defined as the difference between the temperature of the warmest months and coldest month, increases generally with an increase in latitude. This is due to differences between winter and summer insolation as the distance from the equator becomes greater. Also the distance from large bodies of water is an important factor that influences the annual range in temperature of any place on the earth's surface.

The maximum continentality is assumed to be 100% in the driest and 0% in the wettest place. The results of this equation have been shown in Table 3.6-1 and Figures 3.6-1 and 3.6-2. With regard to the Table 3.6-1 the stations based upon their Coefficient of Continentality can be divided into 3 categories as follows:

1) less than 40% including (Anzali, Astara, Babolsar, Ghaemshahr, Gonbad, Gorgan, Havigh, Hashtpar, Lahijan, Noushahr, Ramsar, Rasht, and Shirgah stations). All of thiese stations are located in the coastal area, Caspian Sea gives rain all years and moderate temperature.

2) between 40 and 50% (Latian, Abali, Northern Kandavan and Southern Kandavan). These stations are in higher altitudes, in winter, they are cold but in summer temperate.

3) more than 50% (Aminabad, Damghan, Dehsomeh, Garmsar, Ghazvin, Ghom, Karaj, Semnan, Shahroud, Takestan, Tehran, and Varamin stations). Adjusting to the Great Kavir (Great desert), distance from the sea and surrounding by Zagros and Elburz mountains are reasons that they are hot in summer, but severely cold in winter. Their rainfall is less and they occur during cold times. The analysis reveals that those stations have high rainfall such as mentioned in category 1 and 2 (coastal and higher altitudes stations) have less continentality but the stations inland far from the coastal and close the dry plateau have high continentality. Also Figure 3-6.2 is showing the relationship between rainfall and continentality. The correlation coefficient found was inverse significant with -0.86 value. The negative relationship indicates that stations with higher continentality experience lower rainfall, and vice versa for stations with lower continentality.

Table 3.6-1 The Coefficient of Continentality (k)over the Central Elburz stations.

Stations	The Coefficient of Continentality (k)
Anzali	34.0
Astara	36.0
Babolsar	32.4
Ghaemshahr	33.8
Gonbad	38.9
Gorgan	35.5
Havigh	30.1
Hashtpar	28.7
Lahijan	28.8
Noushahr	31.4
Ramsar	30.6
Rasht	33.1
Shirgah	26.2
Aminabad	52.6
Damghan	56.9
Dehsomeh	56.1
Garmsar	59.0
Ghazvin	53.0
Ghom	54.1
Karaj	53.8
Latian	44.7
Semnan	59.7
Shahroud	52.2
Takestan	50.1
Tehran	56.7
Varamin	56.0
Abali	48.5
Northern Kandavan	47.5
Southern Kandavan	48.1

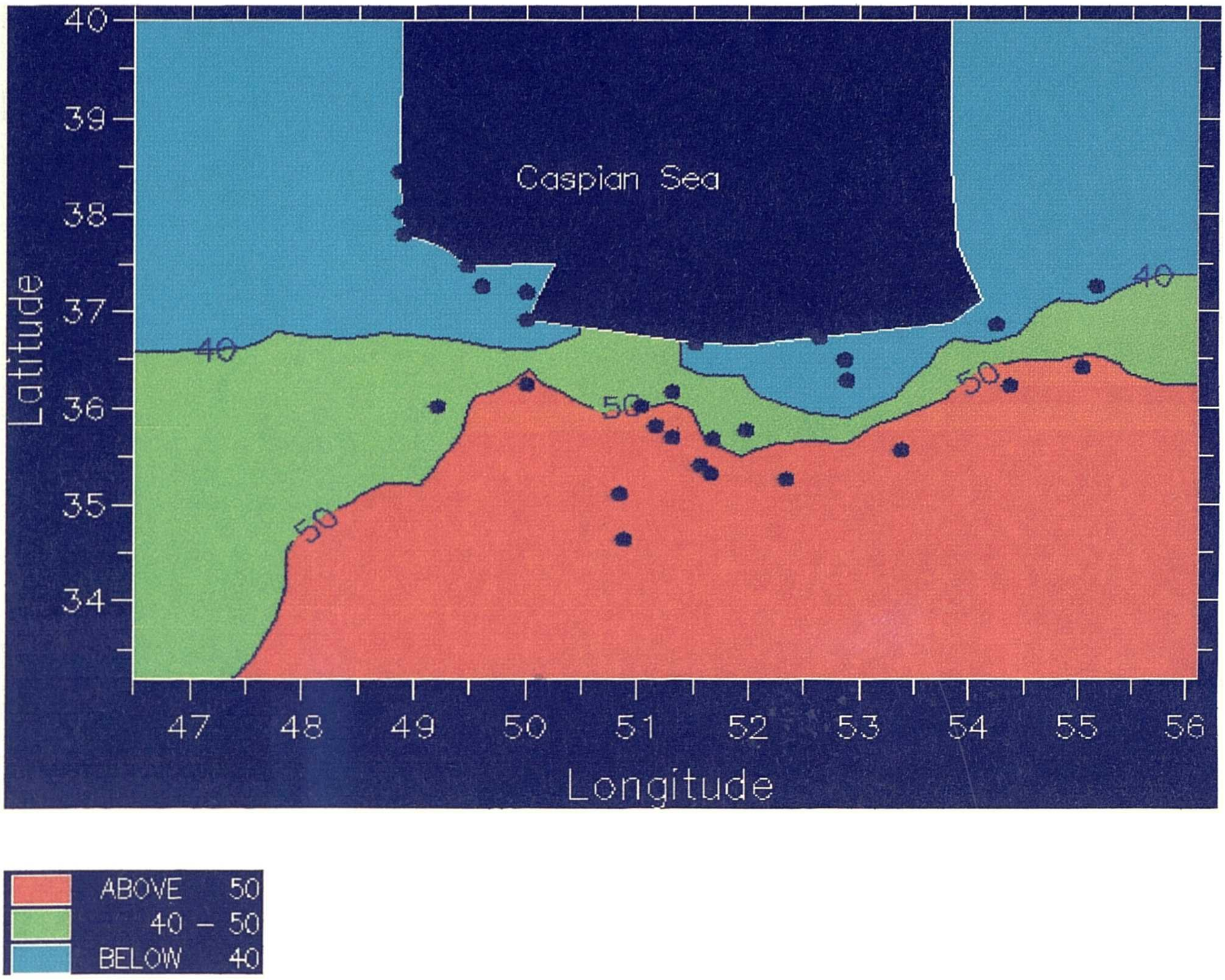


Figure 3.6-1 The Coefficient of Continentality (k) over the Central Elburz Stations.

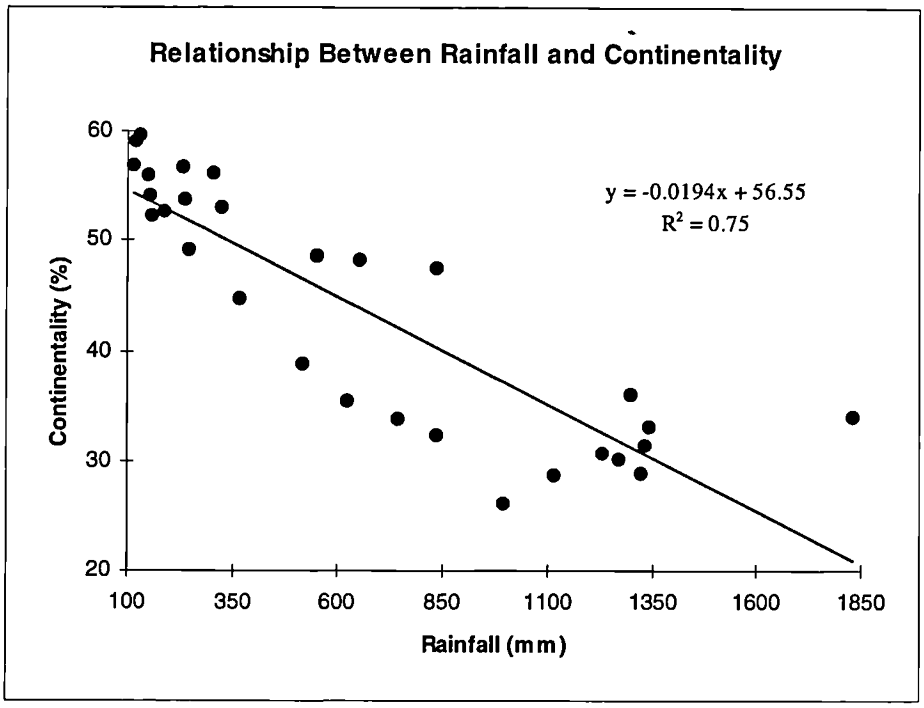


Figure 3.6-2 Relationship between rainfall and Continentality over the Central Elburz stations.

3.7 Annual Rainfall Pattern of the Central Elburz

As mentioned in chapter two in the synoptic scale the Elburz range is a climatic border between the coastal lowlands of the Caspian area and the great central plateau of Iran. It can be considered as the boundary between southern and northern areas. This boundary is an interesting physical boundary particularly from the point of view of rainfall. The Elburz mountains provide different district from the corresponding of amount and characteristic of rainfall regimes. Each district has especial and different climatological aspects from the point of view of start, end, duration and amount of rainfall. These regimes are justified to the traditional regional boundary. Based on total and characteristics of rainfall regimes Elburz stations can be grouped in the following three categories.

3.7.1 Caspian Sea area

Existence of an area of high rainfall, centred on Anzali in south-west of the Caspian Sea with a 1832.8 mm rainfall. Rainfall ranges between 515 mm from Gonbad to 1832.8 at Anzali. The mean annual rainfall of all coastal area stations is 1112.4 mm. Mean annual rainfall values decrease from west to east, and from north to south. The effects of the Caspian Sea on the rainfall of the surrounding area have never been clearly evaluated. Higher rainfall is evident on the north western shores, where storms generated over the sea are associated with the air flowing from north east to south west by the prevailing the Siberian Anticyclone. In autumn one branch of the Siberian Anticyclone air flow crosses the Caspian Sea from north east to south west. Because of the relative warmness of the Caspian Sea water, at this time of the year the advection of this air mass has two effects:

1) rapid evaporation of water and increased relative humidity.

2) rapid decrease in air stability.

This is common in autumn and produces the maximum rainfall. This air mass is humid and unstable, when it arrives in the southern parts of Caspian Sea, is forced to rise by the encircling mountains or by local frontal surfaces. Because of its geographical location relative to the path of the air mass and the mountains Anzali is particular affected by these processes. So it can be said that rainfall of this part of Iran is the result of the law of thermodynamics as well. Cole (1980) defined thermodynamic as an empirical branch of physics that deals with the relation between heat and other forms of energy. Based on thermodynamics air flow crosses to the natural direction of the heat flow, from a high temperature source to a low temperature sink, **cP** air mass is heating from below by passing over the Caspian Sea. Also heating from below acts to increase air mass instability. These changes can also occur through increased evaporation, the moisture being supplied either from the underlying surface or by rainfall from an overlying air mass layer. In reverse, the abstraction of moisture by condensation or rainfall can cause changes. Annual rainfall declines eastward, as a result of increasing distance from the sea. It was therefore, a reasonable that hypothesis that distance from the sea exerts more influence than altitude on rainfall in this part of the central Elburz. The coastal area due to the effect of the Caspian Sea is wetter than other areas of the central Elburz (Figure 3.7-1). The effect of the coast is demonstrated with deviation of individual stations from the mean. With reference to Figure 3.7-1 Babolsar, Ghaemshahr, Gonbad, Gorgan, Shirgah stations are under local mean annual rainfall.

3.7.2 Higher Altitudes

A secondary area of high rainfall exceeding with 834 mm rainfall is centred approximately on the highest parts of Elburz. In this area, rainfall ranges between 547.7 mm from Abali to over 834.5 mm at Northern Kandavan. The mean annual rainfall in this area is 650.71 mm. However, these figures are lower than the coastal stations. Regard to Figure 3.7-2 Abali is in fact lower than the local mean.

3.7.3 Southern Slope Stations

In this area the mean annual rainfall is 208.56 mm, rainfall changes from between 116 mm from Damghan to over 365 mm at Latian. There is an associated dry belt on the southern slopes, possibly intensified by the drying effects of air subsiding in subtropical high pressure. Aminabad, Damghan, Garmsar, Ghom, Semnan, Shahroud, Varamin stations are all under the local mean (Figure 3.7-3). In this area total annual rainfall increases with increasing elevation.

In contrast with claims by Fisher (1968) quoting Gangi (1968), and Nieuwolt (1982) that highest rainfall coincides with higher elevations in this analysis the maximum rainfall does not corresponded with the highest parts of Elburz, but occurs on the Caspian lowlands.

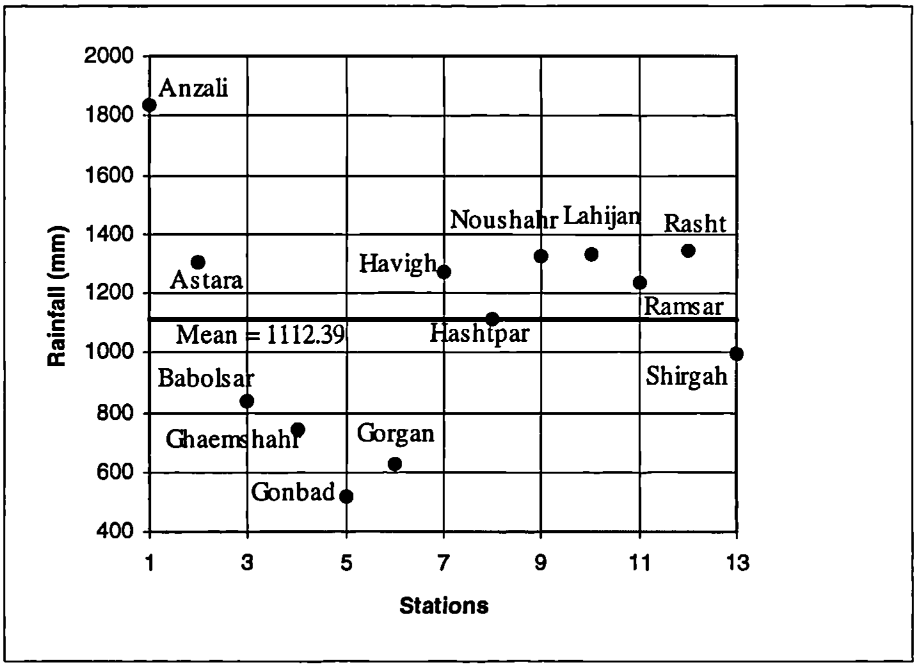


Figure 3.7-1 Distribution of Coastal Area Stations Deviation from local mean

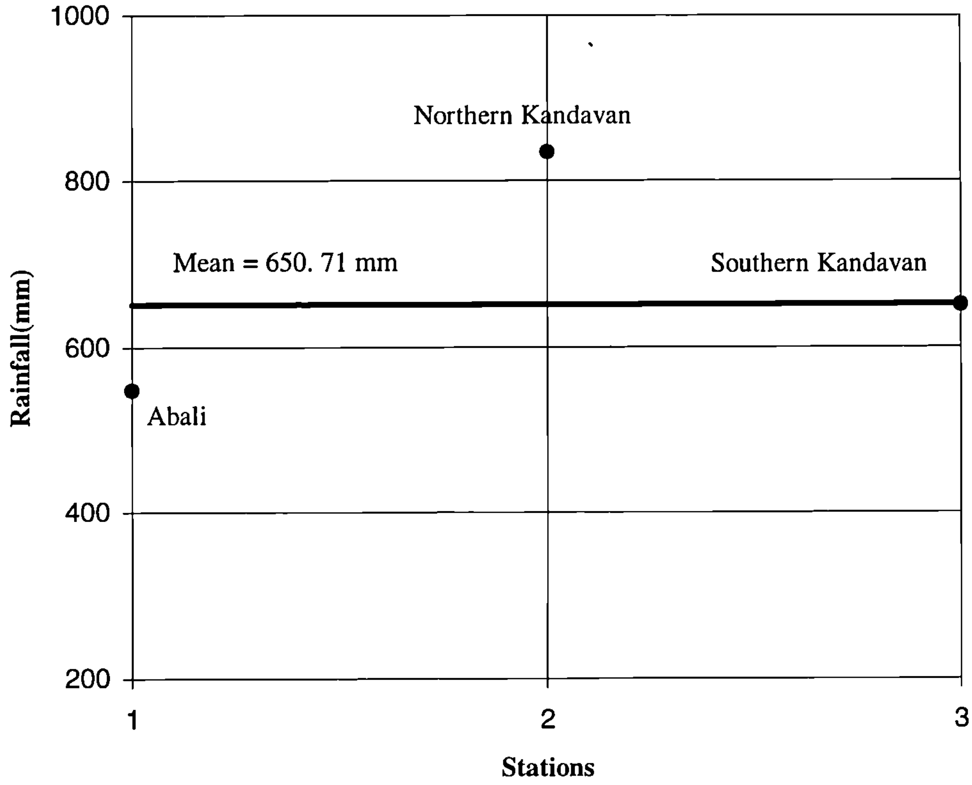


Figure 3.7-2 Distribution of Higher Altitudes Stations Deviation from local mean.

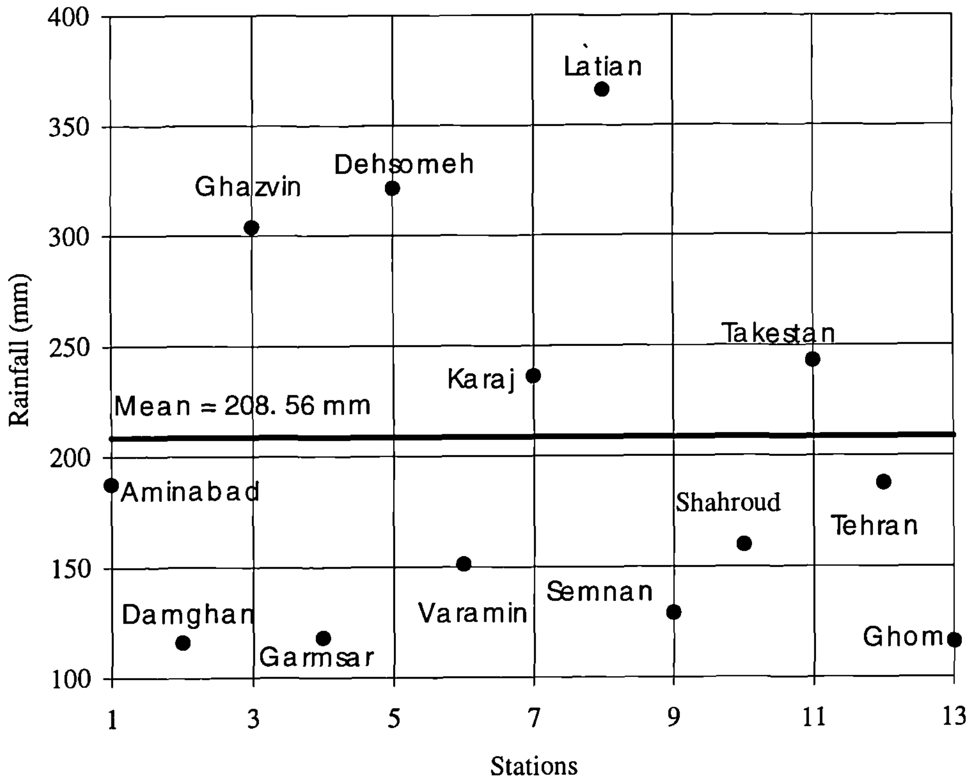


Figure 3.7-3 Distribution of Southern Slope Stations Deviation from local mean

3.8 Monthly Rainfall Pattern

Monthly analysis allows detailed examination of the pattern of distribution within the year. The monthly mean conditions distributions of rainfall amounts from month to month for selected weather stations in the Central Elburz, are presented in Tables 3.9-1 to 3.9-3, and Figures 3.9-1 to 3.9-12. The use of monthly means in climatological data analyses are usually considered quite appropriate for the study location. The monthly rainfall distribution over the central Elburz comprise two sets of tables and figures:

a) the first set illustrates the mean monthly distributions of rainfall amounts over the central Elburz stations for each month. The average monthly values are set out in Tables 3.9-1 to 3.9-3.

b) the second set illustrates the percentage that, the mean monthly amounts of rainfall forms of the mean annual rainfall for all stations in the Tables 3.9-1 to 3.9-3. It can be deduced from Tables 3.9-1 to 3.9-3 and Figures 3.9-1 to 3.9-12 that, in most part of the central Elburz, a substantial proportion of the annual rainfall (more than 5 per cent of mean annual rainfall) is received between October and May. However, in April, some of stations that are located in the coastal area such as Anzali, Ghaemshahr, Noushahr, Rasht have less than 5 per cent of the mean annual rainfall. In August and September these stations have more than 5 per cent of mean annual rainfall.

With regard to the Tables 3.9-1 to 3.9-3, and Figures 3.9-1 to 3.9-12 of the monthly rainfall distribution of the central Elburz, the distribution shows the northward progression of the rainfall at the beginning of the wet season and their southward retreat at the beginning of the dry season over the central Elburz stations.

3.9 Discussion of Monthly Rainfall Distribution

In this section monthly rainfall distribution has been considered to show the pattern of the rainfall in each month, characteristics of the rainfall regime and to find how regional patterns vary according to altitude and distance in each location. As previously mentioned the variations in mean conditions rainfall from month to month over the central Elburz are depicted in Tables 3.9-1 to 3.9-3, and Figures 3.9-1 to 3.9-12. In the January Figures, and Tables show that widespread wet conditions occur everywhere, when southern slope stations receive at least 12.53 mm in Damghan, coastal area 50.14 mm in Gonbad, and Higher Altitudes 67.22 mm in Abali, this forming rather more than 5 percent of annual mean in the coastal area, 10 percent in southern slopes, and 12 percent at Higher Altitudes. In February, while the mean general rainfall in southern slopes stations receive at least 13.13 mm in Damghan, the coastal area 54.26 mm in Gonbad, and Higher Altitudes 72.68 mm in Abali, this forming rather more than 5 percent of annual mean in the coastal area, 10 percent in southern slopes, and 13.27 percent in Higher Altitudes. In March, the mean rainfall increases, and this is the result of an increase frequency of thunderstorms and squall lines have become more frequent and stronger in the whole of region especially the southern Elburz. Rainfall in southern slope stations receive at least 19.19 mm in Damghan, coastal area 62.57 mm in Babolsar, and Higher Altitudes 87.45 mm in Abali, this forming rather more than 7 percent of annual mean in the coastal area, 12.67 percent in southern slopes, and 15.95 percent in Higher Altitudes.

In April, most of the stations have more than 11.60 mm rainfall, there is a decrease when compared with monthly mean of the March. Spatial variation exists in rainfall amounts between stations. Southern slope stations receive from between 11.60 mm, in Garmsar to 52.40 mm in Dehsomeh. The coastal area receive from 32.43 mm in Babolsar, to 81.30 mm, in Havigh. At Higher Altitudes, 69.25 mm in Abali to 123.57 mm in Northern Kandavan. This is greater than 3.09 in Anzali to 11.48 in Gonbad percent of annual mean in the coastal area, Garmsar with 9.8 to Takestan with 17.3

percent in Southern slopes, and 12.64 in Abali to Northern Kandavan with 14.81 percent at Higher Altitudes.

May is a month when rainfall values are relatively similar over the central Elburz, and rainfall shows a decrease over previous months. Also this decrease in coastal area is greater than in the southern slopes, and Higher Altitude stations. Southern slope stations receive between 8.07 mm (at Garmsar) and 37.79 mm (at Takestan). Coastal area stations receive between 20.86 mm (in Babolsar) and 77.81 mm (at Havigh). At Higher Altitudes rainfall ranges from 57.61 mm in Abali to 85.50 mm in Northern Kandavan, this forming receive rather more than 2.50 in Babolsar to Gonbad 8.46 percent of annual mean in coastal area, Tehran with 6.69 to Damghan with 16.33 percent in Southern slopes, and 10.52 in Abali to Southern Kandavan with 10.83 percent in Higher Altitudes

In June there is a decrease due to widespread dry conditions in the central Elburz. This decrease is usually more than May that experienced from the previous months.
In the coastal area the mean rainfall is different between Babolsar and Havigh which experiences 26.11 and 74.75 mm of rainfall respectively. Southern slope stations receive between 1.88 mm in Ghom and up to 9.39 mm in Latian. Higher Altitudes stations receive from 13.92 mm in Abali and up to 20.67 mm in Northern Kandavan, this forming rather more than 3.12 in Babolsar to Hashtpar 6.32 percent of annual mean in the coastal area, Tehran experiences 1.17 and Takestan with 3.57 percent. In southern slopes, Northern Kandavan experiences 2.48 and Southern Kandavan with 2.63 percent at Higher Altitudes Stations. None of the Southern Elburz stations receives over 5 percent of annual mean in June. However, a few coastal area such as Ghaemshahr, Gorgan, Gonbad, Havigh, Hashtpar, and Shirgah stations receive more than 5 percent of annual mean in June.

In July, usually disturbances such as line thunderstorm events are absent and rainfall totals values tend to be lower than those of June. July is actually the driest month throughout the northern part of Iran. The rainfall in this area is substantially reduced from June. Ramaswamy (1965) recognized July is normally a month of very low rainfall in Iran. During this month, the precipitation occurs under the influence of middle-latitude eastward moving systems whose centres lie far to the north of Iran. In the coastal area the mean rainfall differs between Gonbad with 15.67 mm and Shirgah with 66.65 mm. It would seem that in this part of Elburz this is the driest month of year, and at least an embryonic little dry season which is particularly noticeable for the rice crop. Southern slope stations receive less than 4 mm, and Higher Altitudes stations receive about 7 mm. With the exception of Shirgah, none of the Elburz stations receive less than 5 percent of annual mean rainfall.

The month of August is the driest in the southern Elburz where the mean monthly total receives between at least 0.16 mm in Garmsar to 3.60 mm in Semnan, and Higher Altitudes stations receive from 5.92 mm in Northern Kandavan to 8.79 mm in Abali. In coastal area the rainfall gradually increases in this month, and the mean rainfall exceeds in Gonbad with 26.55 mm to Anzali with 119.09 mm. This indicates that more than 3.20 mm in Babolsar to Shirgah 8.67 percent of annual mean in coastal area. Except Babolsar all of the Northern Elburz stations receive more than 5 percent of annual mean rainfall, but none of the southern Elburz and higher altitudes stations receive more than 5 percent of annual mean rainfall.

The September rainfall figures, and tables indicate that the rain belt is now increasing in whole of the central Elburz. The northern stations of Elburz now have more than 3.28 mm percent of annual rain. The highest totals are found in the northern part (especially southern-west of Caspian Sea), where rainfall exceeds 249.6 mm in Anzali. Except Gonbad all the coastal area stations receive their rainfall more than 5 percent of the year. All of the southern stations receive less than 5 percent of the annual rainfall.

In October, as the whole of country enters into a completely new weather season, the rainfall distribution also drastically changes. Although the area of highest rainfall concentration is located on the South-west of the Caspian Sea stations, the whole area receives more rainfall (39.46-331.06 mm) than the previous month. Southern slope stations experience between 5.94 to 22.35 mm rain. In the higher altitudes rainfall varies from 38.11 to 54.42 mm.

The percentage falls in Table 3.9-3 indicate that the coastal area receive more than 14% of annual fall, and Southern Elburz stations receive more than 5 percent. Therefore, October can be regarded as a wettest month of the northern stations which is highly significant as far as agricultural practices are concerned.

November all parts of the central Elburz receive more than 7.57 mm of rainfall whilst the maximum concentration is located in the areas around south-western the Caspian Sea. The progressive increases in November rainfall, as a wet month, shows with a slight increase over the rainfall total of October, and December in the Southern Elburz. It can also be noticed that the coastal area receive more than 12% of annual fall, and Southern Elburz stations receive less than 9 percent.

December is the transitional month of the Autumn to winter season in Iran, in the other hand December is the commencing month of the winter season, and as much as rainfall distribution is concerned it can be termed as a wet month of the Iran particularly Elburz stations. All parts of the central Elburz receive more than 12.12 mm of rainfall while the maximum concentration is located in the areas around south-west of the Caspian Sea. In the coastal area stations the actual rainfall values change between with 41.83, and Anzali with 205.75 mm, whilst the southern slope stations represent between Damghan with 12.12 mm to Latian with 46 mm of rain, and in the Higher Altitudes stations the actual rainfall values varying from 69.22 mm in Abali to 80.23 mm in Southern Kandavan. The percentage of rainfall in Table 3.9-3 illustrated that the coastal area stations receive more than 10% of year's rainfall, and Southern Elburz stations receive more than 12 percent. In the coastal area the rainfall gradually decreases in this month due to colder air surrounding the Caspian Sea, and the existence of Siberian cold air masses, but the Southern Elburz rainfall is gradually increasing because of the Mediterranean Systems affecting the whole of region during the cold seasons, particularly winter. Thus so far has treated months independently. However seasonal patterns need to be stabilised and this is attempted in next section.

Table 3.9-1 The Average Monthly Rainfall (mm) Distribution of the Central Elburz

Stations	No of years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Coastal Area:														
Anzali	38	165.49	128.31	115.59	56.62	47.42	59.17	46.56	119.09	249.62	331.06	308.07	205.75	1832.83
Astara	30	99.58	104.09	103.24	79.94	63.67	48.42	42.26	95.03	226.14	238.74	132.60	80.85	1300.3
Babolsar	38	84.77	68.77	62.57	32.43	20.86	26.11	28.61	53.45	76.75	141.81	121.61	117.89	835.67
Ghaemshahr	31	96	64.88	72.71	39.34	35.60	43.30	29.79	51	68.83	100.81	82.70	82.96	740.98
Gonbad	31	50.14	54.26	73.22	59.10	43.57	26.62	15.67	26.55	16.91	39.46	43.63	54.77	514.96
Gorgan	35	56.70	60.18	78.72	52.49	45.48	35.16	25.94	29.52	37.24	74.46	66.60	61.42	623.95
Havigh	26	67.43	75.29	91.32	81.30	77.81	74.75	53.17	111.89	180.82	237.39	134.11	86.02	1271.36
Hashtpar	25	69.96	78.36	91.22	65.38	75.02	70.41	43.86	84.19	137.08	188.80	125.15	84.61	1114.08
Lahijan	31	106.35	104.03	119.83	67.41	55.15	61.36	44.40	76.16	161.36	228.18	177.46	129.10	1325.32
Noushahr	31	110.71	95.73	96.18	45.26	42.82	61.39	50.88	86.74	149.45	253.33	191.97	147.07	1331.60
Ramsar	30	83.46	76.40	89.19	47.81	43.87	58.24	35.78	78.20	177.96	237.56	180.71	122.43	1231.65
Rasht	32	129.36	113.70	117.23	60.60	55.94	42.93	40.46	70.01	143.95	227.09	181.32	159.34	1341.99
Shirgah	24	65.60	93.14	84.63	53.37	59.54	57.15	66.65	86.37	107.45	128.36	98.13	96.06	996.49

Table 3.9-2 The Average Monthly Rainfall (mm) Distribution of the central Elburz(continued)

Southern Slopes													
Aminabad	25	39.85	28.54	33.30	21.4	20.34	13.62	3.21	1.4	2	14.52	16.36	23.68	187.28
Damghan	30	12.53	13.13	19.19	18.94	18.94	2.47	1.83	1.58	1.95	5.94	7.33	12.12	116
Dehsomeh	31	36.86	38.58	47.87	52.40	33.78	5.75	1.08	2.80	0.60	15.85	29.11	39.16	303.88
Garmsar	30	30.16	17.03	20.11	11.60	8.07	2.29	0.45	0.16	0.54	6.85	7.57	13.36	118.22
Ghazvin	31	42.37	35.37	54.21	42.97	37.09	6.63	2.77	1.76	1.14	22.35	31.92	42.89	321.52
Ghom	32	25.47	16.98	27.17	26.08	13.79	1.88	2.11	0.25	0.30	7.52	12.55	16.68	150.94
Karaj	31	31.08	25.64	39.00	35.45	23.69	4.10	1.60	1.13	0.94	17.21	23.68	32.49	236.05
Latian	32	54.53	50.82	64.62	51.47	27.54	9.39	3.98	1.72	1.87	19.57	34.38	46.00	365.94
Semnan	30	20.52	17.51	20.66	14.46	15.23	2.78	1.24	3.60	1.46	6.36	8.25	16.86	128.96
Shahroud	32	19.14	19.04	27.28	25.69	22.97	4.63	1.71	1.59	2.11	7.75	10.53	17.39	159.44
Takestan	30	24.45	26.67	30.77	41.35	37.79	8.68	0.87	0.57	1.81	22.25	23.35	24.22	242.81
Tehran	45	36.80	29.63	37.15	29.53	15.39	2.68	1.71	1.68	1.20	10.80	25	38.43	230.00
Varamin	30	25.96	20.34	22.28	20.21	13.12	4.40	0.98	0.41	0.47	8.19	13.37	20.58	150.33
Higher Altitudes													
Abali	26	67.22	72.68	87.45	69.25	57.61	13.92	8.79	8.79	4.33	38.11	50.28	69.22	547.73
Northern Kandavan	26	106.11	115	154.01	123.57	85.50	20.67	7.48	5.92	5.71	54.42	73.51	82.50	834.45
Southern Kandavan	26	88.86	77.98	108.78	89	70.38	17.11	6.92	8.42	8.48	39.98	53.40	80.23	649.57

Table 3.9-3 Monthly Distribution of Rainfall Expressed as Percentage of Annual Rainfall.

Stations	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Coastal Area:												
Anzali	9.03	7.00	6.31	3.09	2.59	3.23	2.54	6.50	13.68	18.08	16.81	11.23
Astara	7.66	8.01	7.94	6.15	4.90	3.72	3.25	6.22	17.39	18.56	10.90	8.22
Babolsar	10.14	8.23	7.49	3.88	2.50	3.12	3.42	3.20	9.18	16.55	14.55	14.11
Ghaemshahr	12.96	8.76	9.81	5.31	4.80	5.84	4.02	6.88	9.29	13.60	12.16	12.34
Gonbad	9.74	10.54	14.22	11.48	8.46	5.17	3.04	5.16	3.28	7.66	8.47	10.64
Gorgan	9.09	9.65	12.62	8.41	7.29	5.64	4.16	4.73	5.97	11.93	10.67	9.84
Havigh	5.30	5.92	7.18	6.39	6.12	5.88	4.18	8.80	14.22	18.67	10.57	6.77
Hashtpar	6.28	7.03	8.19	5.87	6.73	6.32	3.94	7.56	12.30	16.95	11.24	7.59
Lahijan	8.02	7.85	9.04	5.09	4.16	4.63	3.35	5.75	12.18	17.22	13.39	9.32
Noushahr	8.31	7.19	7.22	3.40	3.22	4.61	3.82	6.51	11.22	19.04	14.42	11.04
Ramsar	6.78	6.20	7.24	3.88	3.56	4.73	2.91	6.35	14.96	19.29	14.67	9.94
Rasht	9.64	8.47	8.74	4.52	4.17	3.20	3.01	5.22	10.73	16.92	13.51	11.87
Shirgah	6.58	9.35	8.49	5.36	5.97	5.74	6.69	8.67	10.78	12.88	9.85	9.64
Southern Slopes												
Aminabad	13.28	13.24	15.78	10.43	10.86	5.27	1.71	0.75	1.07	7.75	7.12	12.64
Damghan	10.80	11.32	16.54	16.33	16.33	2.13	1.58	1.36	1.68	5.12	6.32	10.49
Dehsomeh	12.13	12.70	15.75	17.24	11.12	1.89	0.36	0.92	0.20	5.22	9.58	12.89
Garmsar	25.51	14.41	17.01	9.81	6.83	1.94	0.38	0.14	0.46	5.79	6.42	11.30
Ghazvin	13.18	11.00	16.86	13.36	11.54	2.06	0.86	0.55	0.35	6.95	9.93	13.34
Ghom	16.87	11.25	18.00	17.28	9.14	1.25	1.40	0.17	0.20	4.98	8.31	11.06
Karaj	13.17	10.86	16.52	15.02	10.04	1.74	0.68	0.48	0.40	7.29	10.04	13.76
Latian	14.90	13.89	17.66	14.07	7.53	2.57	1.09	0.47	0.51	5.35	9.39	12.57
Semnan	15.91	13.58	16.02	11.21	11.81	2.16	0.96	2.79	1.13	4.93	6.40	13.07
Shahroud	12.00	11.94	17.11	16.11	14.41	2.90	1.07	1.00	1.32	4.86	6.60	10.94
Takestan	10.07	10.98	12.67	17.03	15.56	3.57	0.36	0.23	0.75	9.16	9.42	9.94
Tehran	16.00	12.88	16.15	12.84	6.69	1.17	0.74	0.73	0.52	4.70	10.87	16.71
Varamin	17.27	13.53	14.82	13.44	8.73	2.93	0.65	0.27	0.31	5.47	8.89	13.69
Higher Altitudes												
Abali	12.27	13.27	15.97	12.64	10.52	2.54	1.60	1.60	0.79	6.96	9.18	12.66
Northern Kandavan	12.72	13.78	18.46	14.81	10.25	2.48	0.90	0.71	0.68	6.52	8.81	9.88
Southern Kandavan	13.68	12.00	16.75	13.70	10.83	2.63	1.07	1.30	1.31	6.15	8.23	12.35

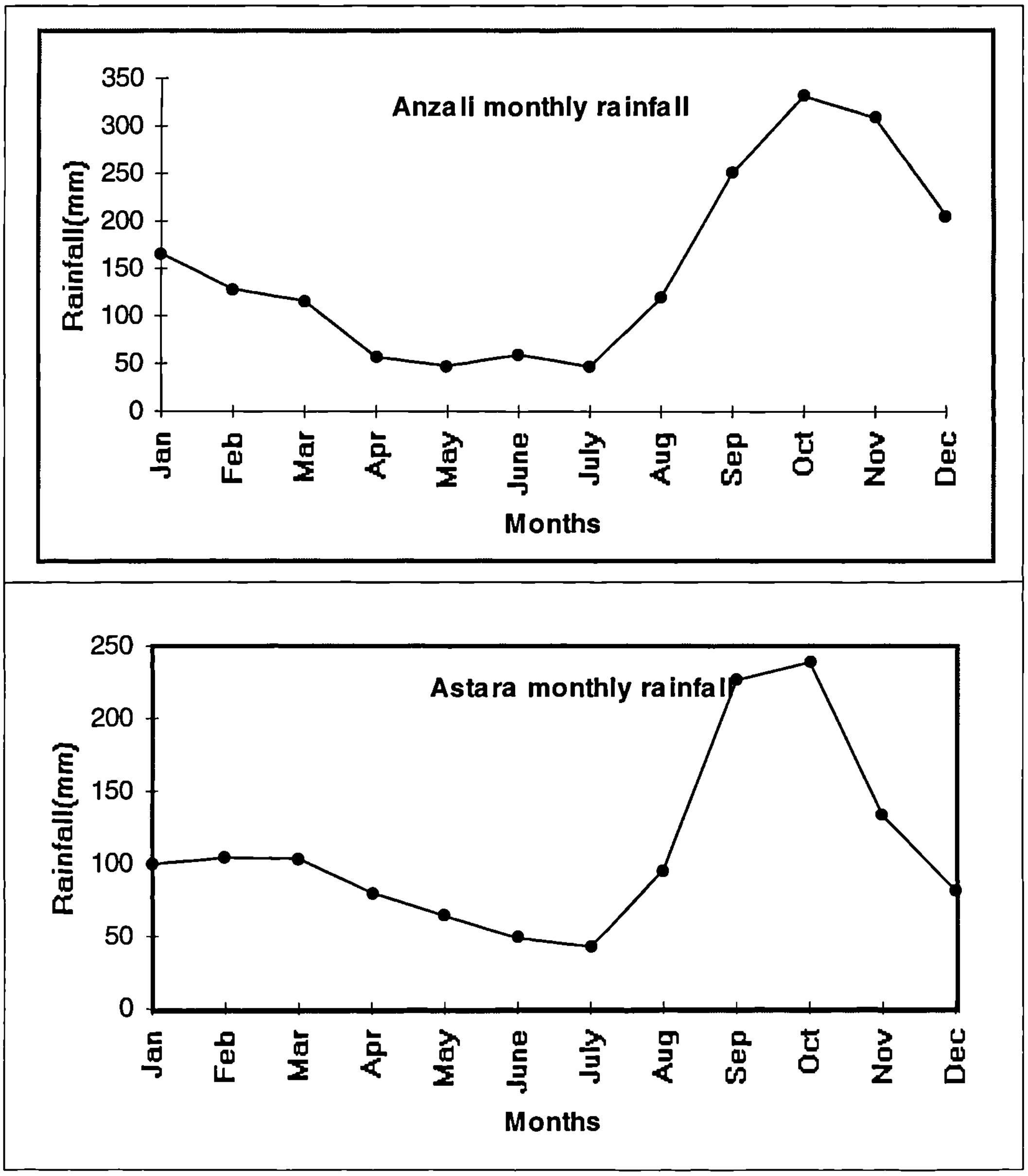


Figure 3.9-1 Coastal Area average monthly rainfall

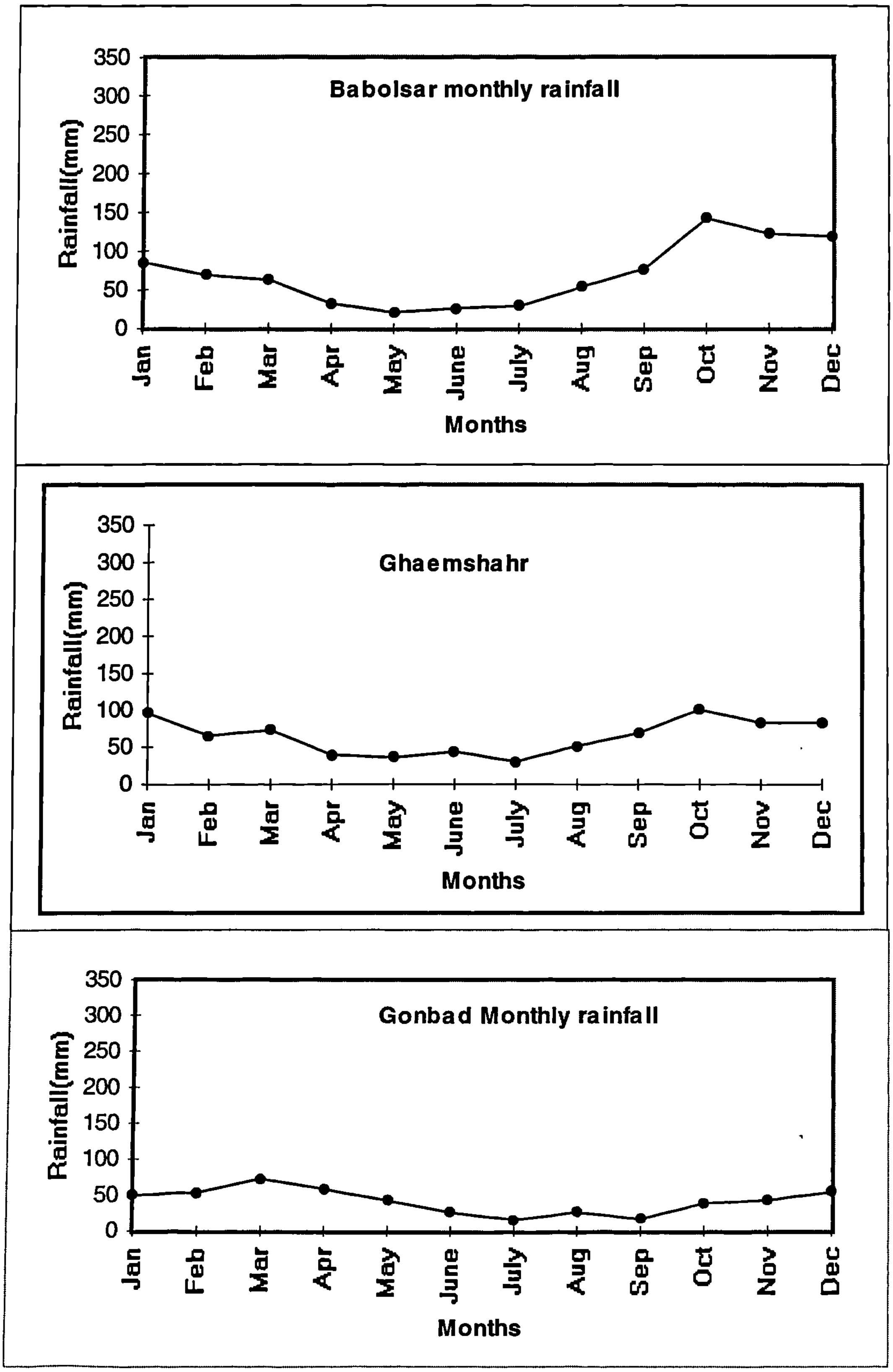


Figure 3.9-2 Coastal Area average monthly rainfall

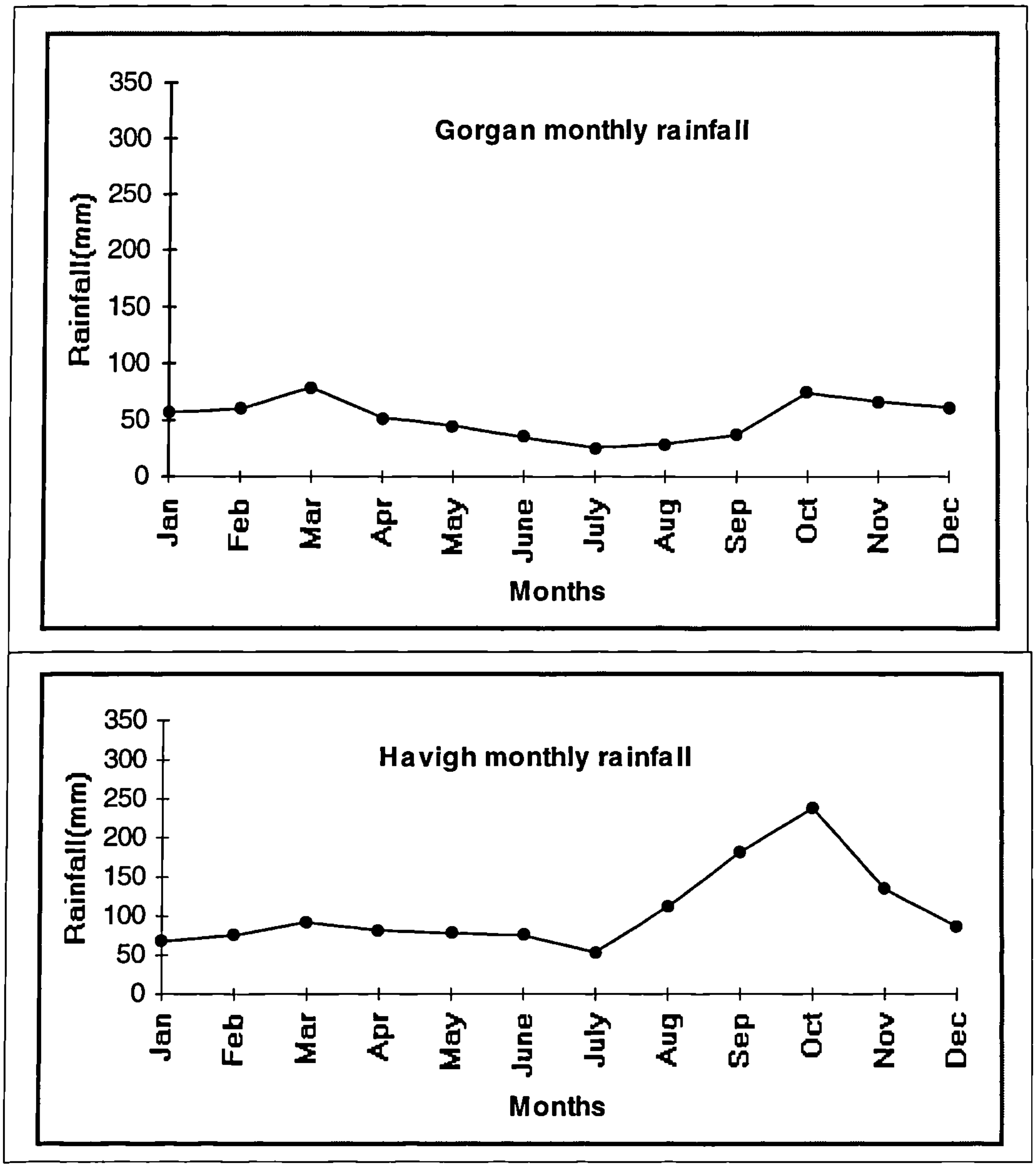


Figure 3.9-3 Coastal Area average monthly rainfall

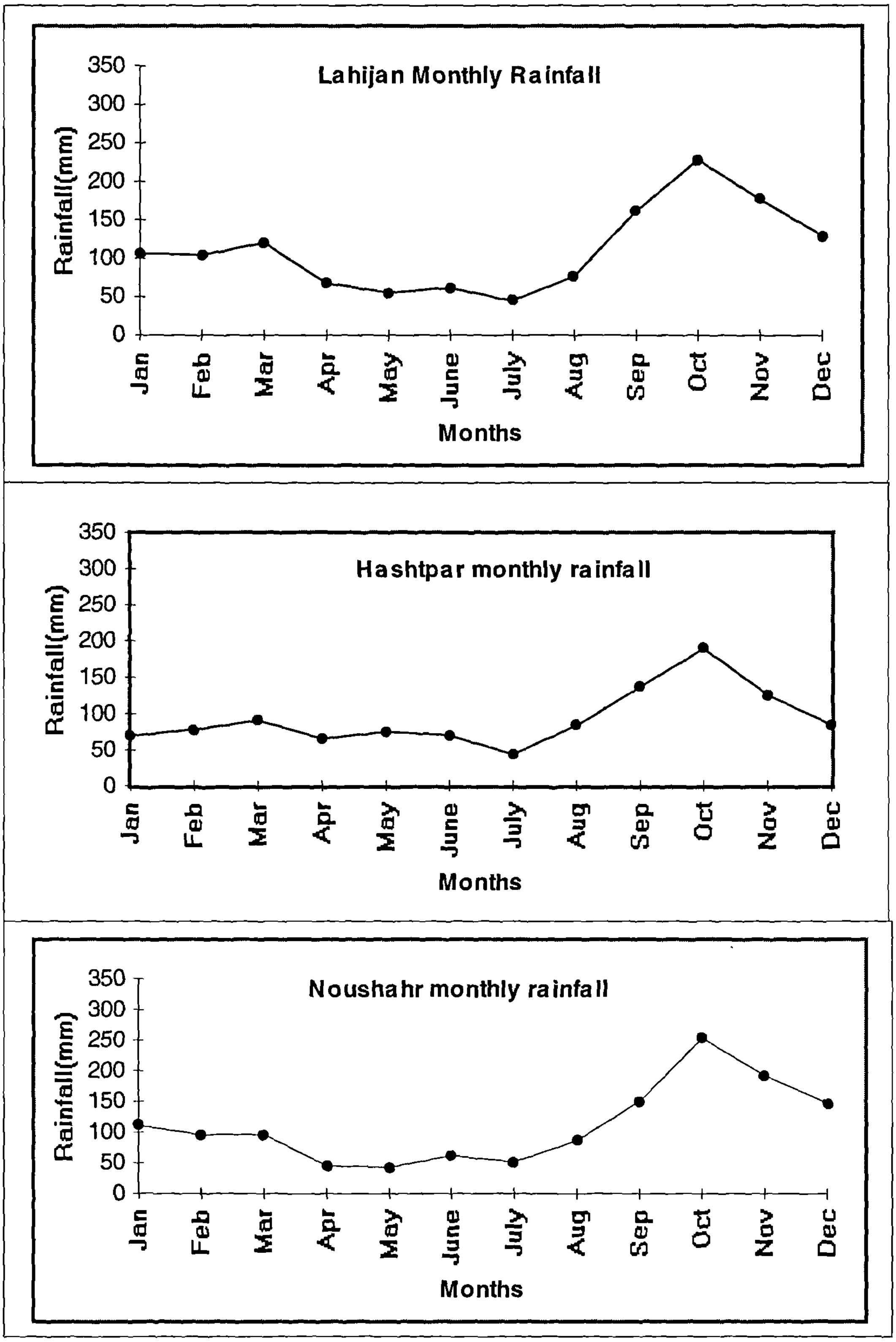


Figure 3.9-4 Coastal Area average monthly rainfall

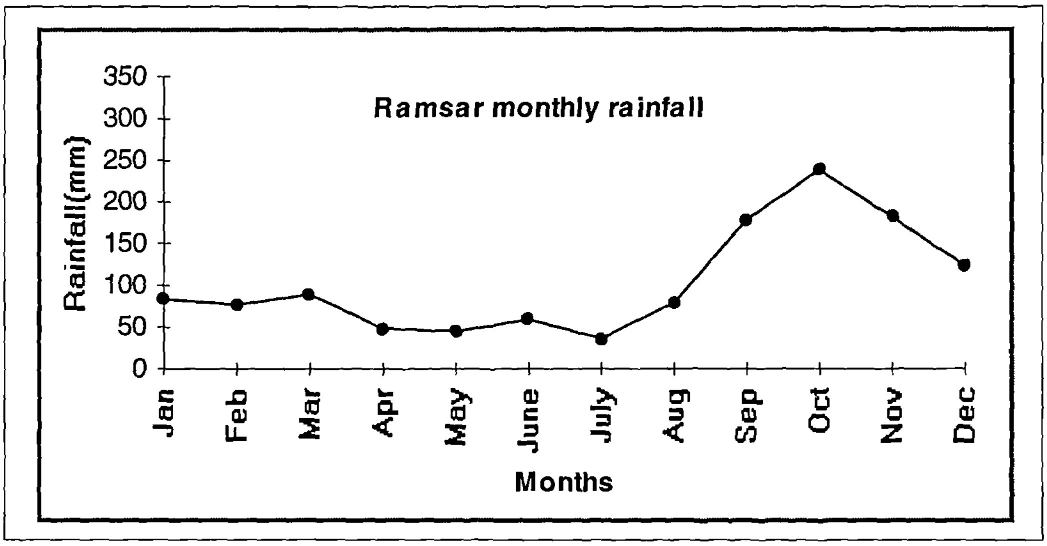


Figure 3.9-5 Coastal Area average monthly rainfall

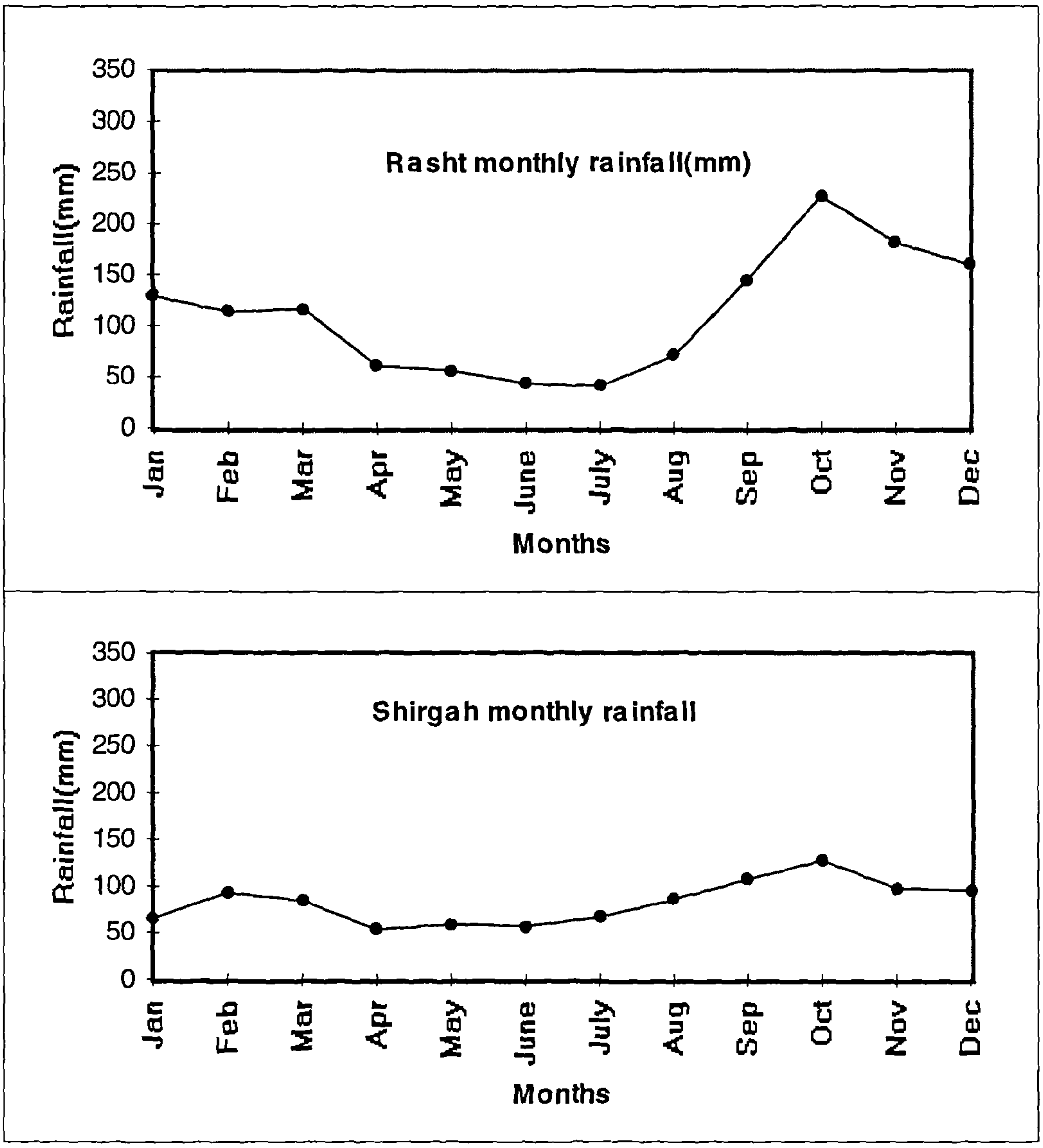


Figure 3.9-6 Coastal Area average monthly rainfall

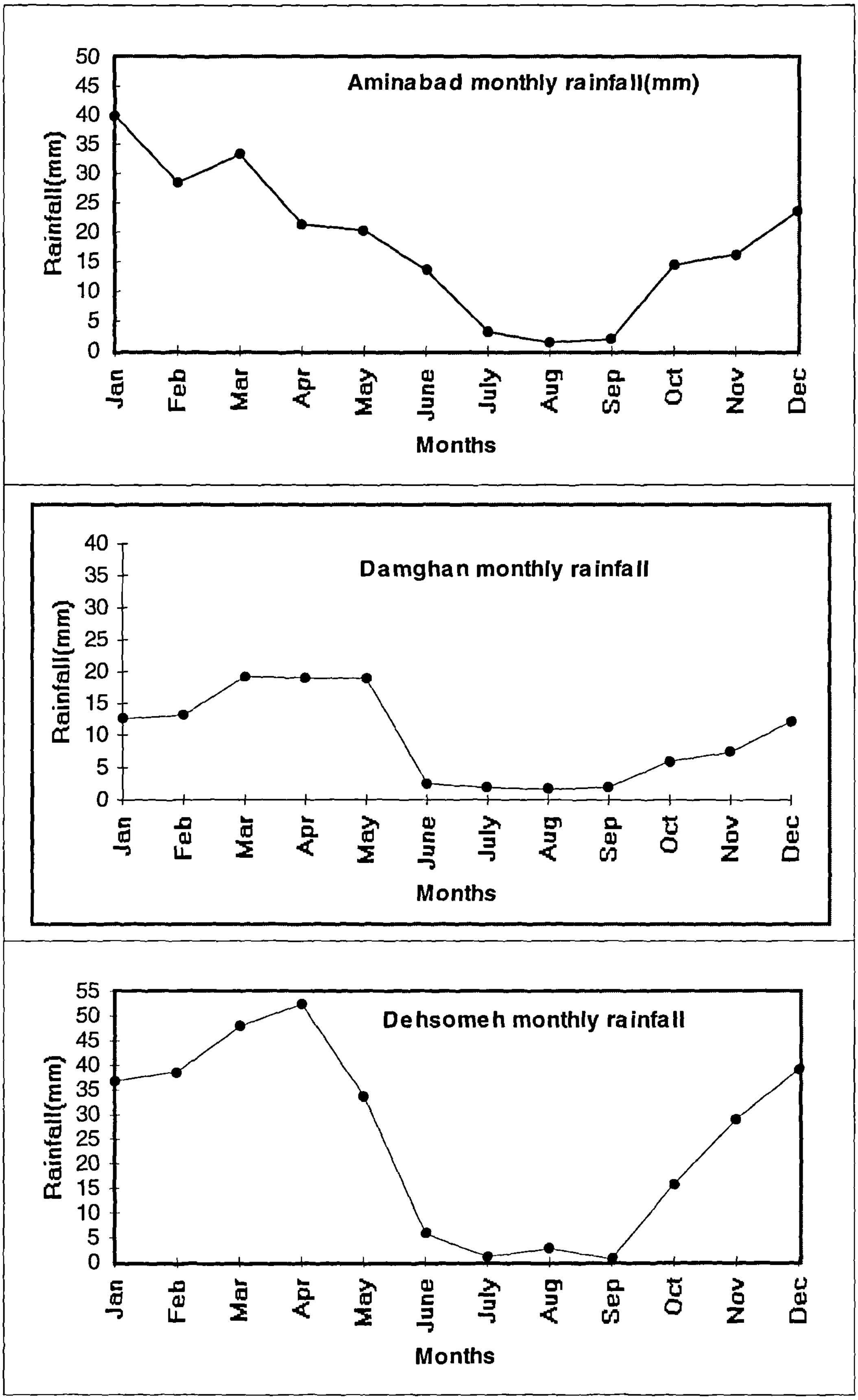


Figure 3.9-7 Southern Slope stations average monthly rainfall

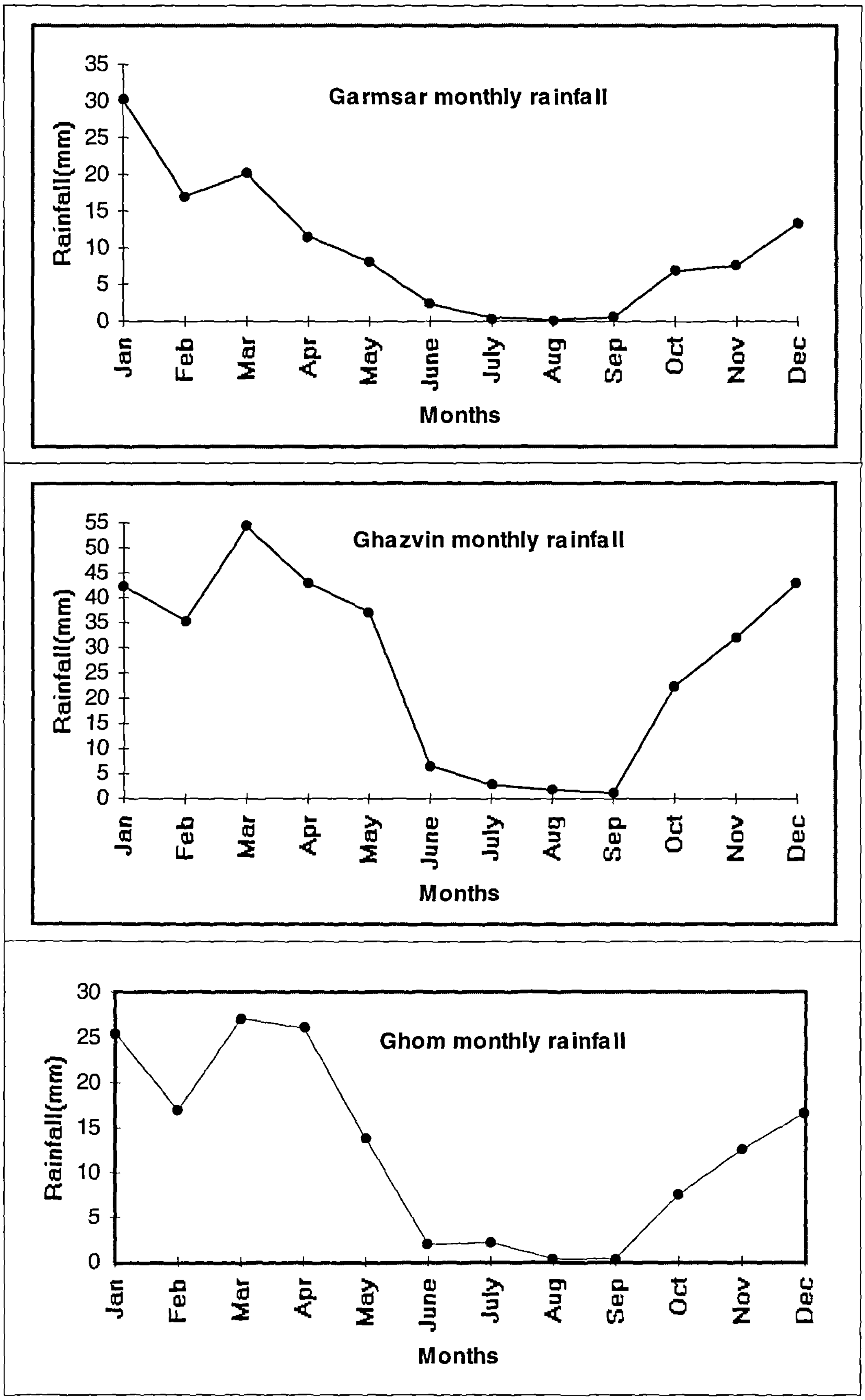


Figure 3.9-8 Southern Slope stations average monthly rainfall

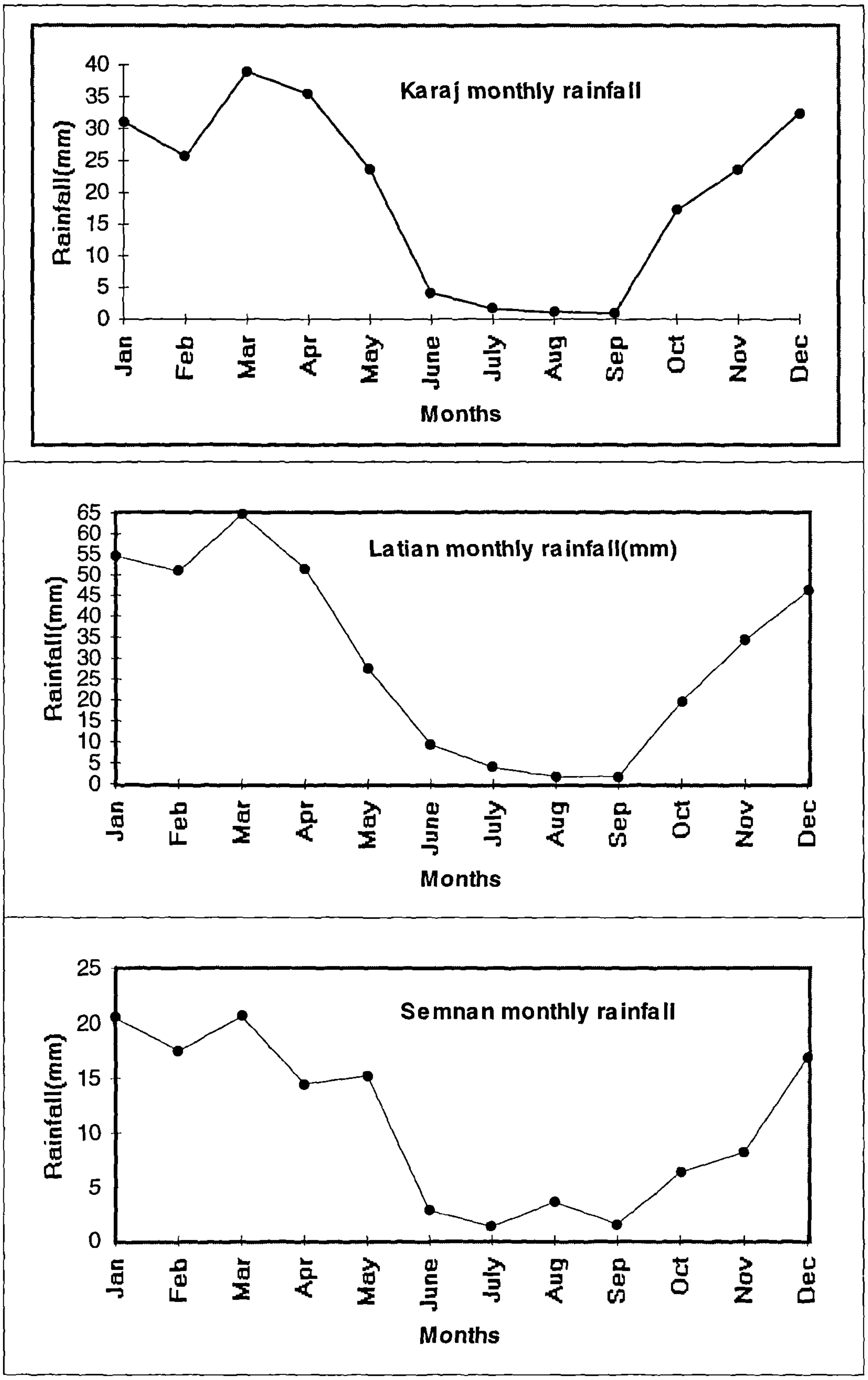


Figure 3.9-9 Southern Slope stations average monthly rainfall

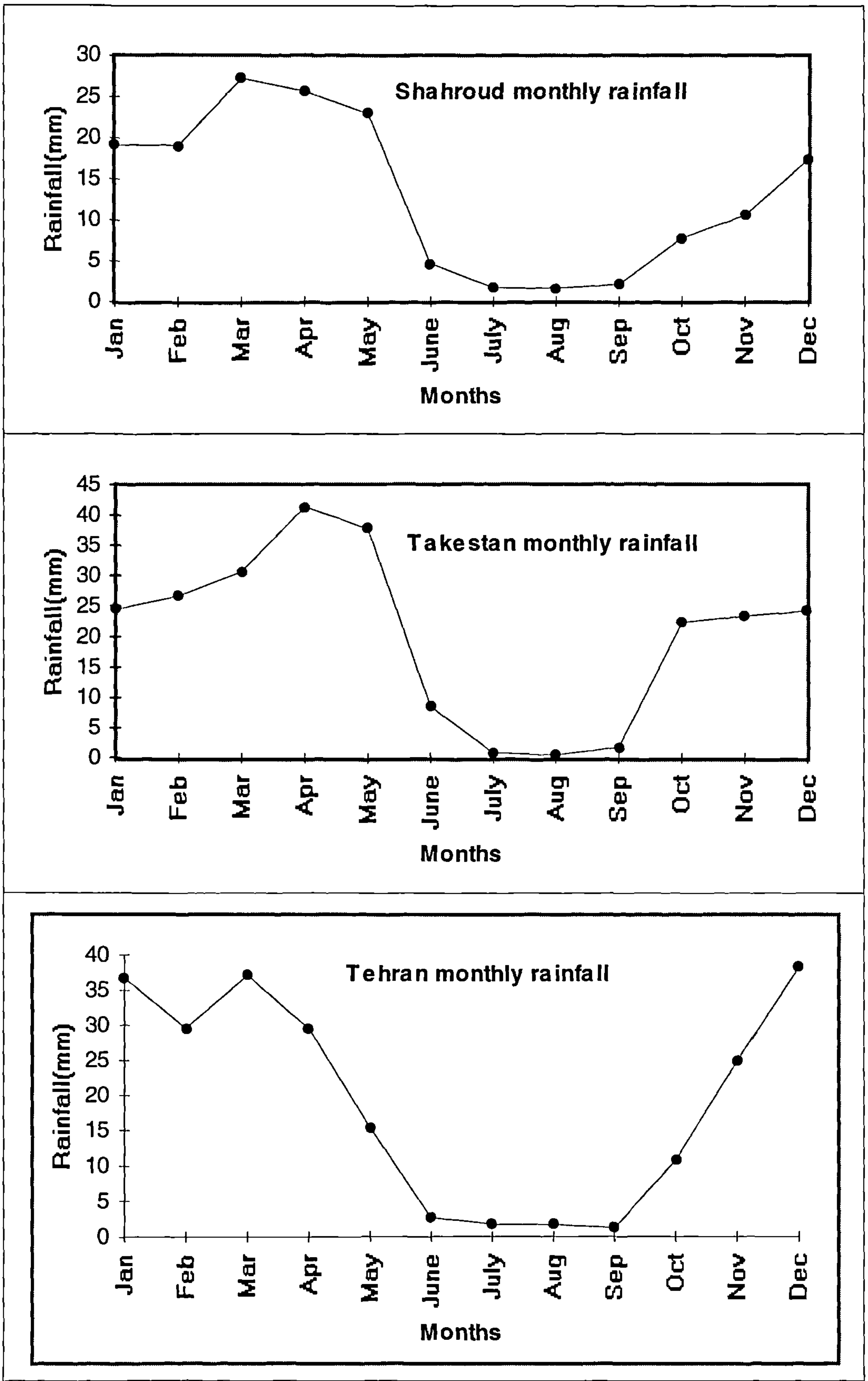


Figure 3.9-10 Southern Slope stations average monthly rainfall

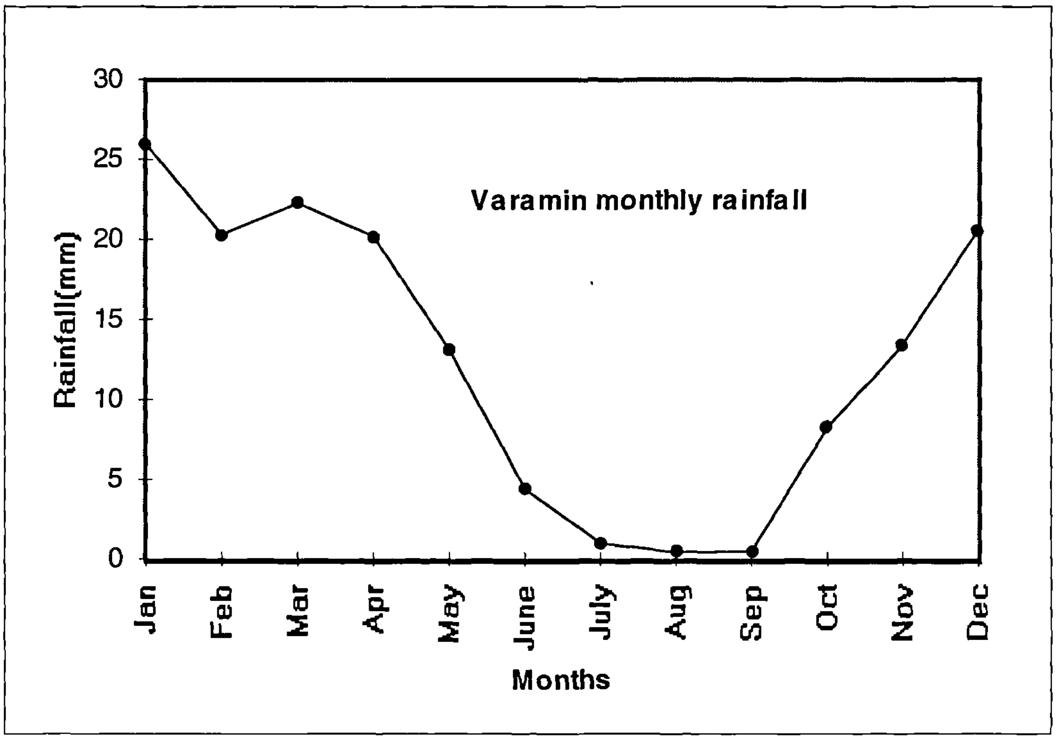


Figure 3.9-11 Southern Slope stations average monthly rainfall

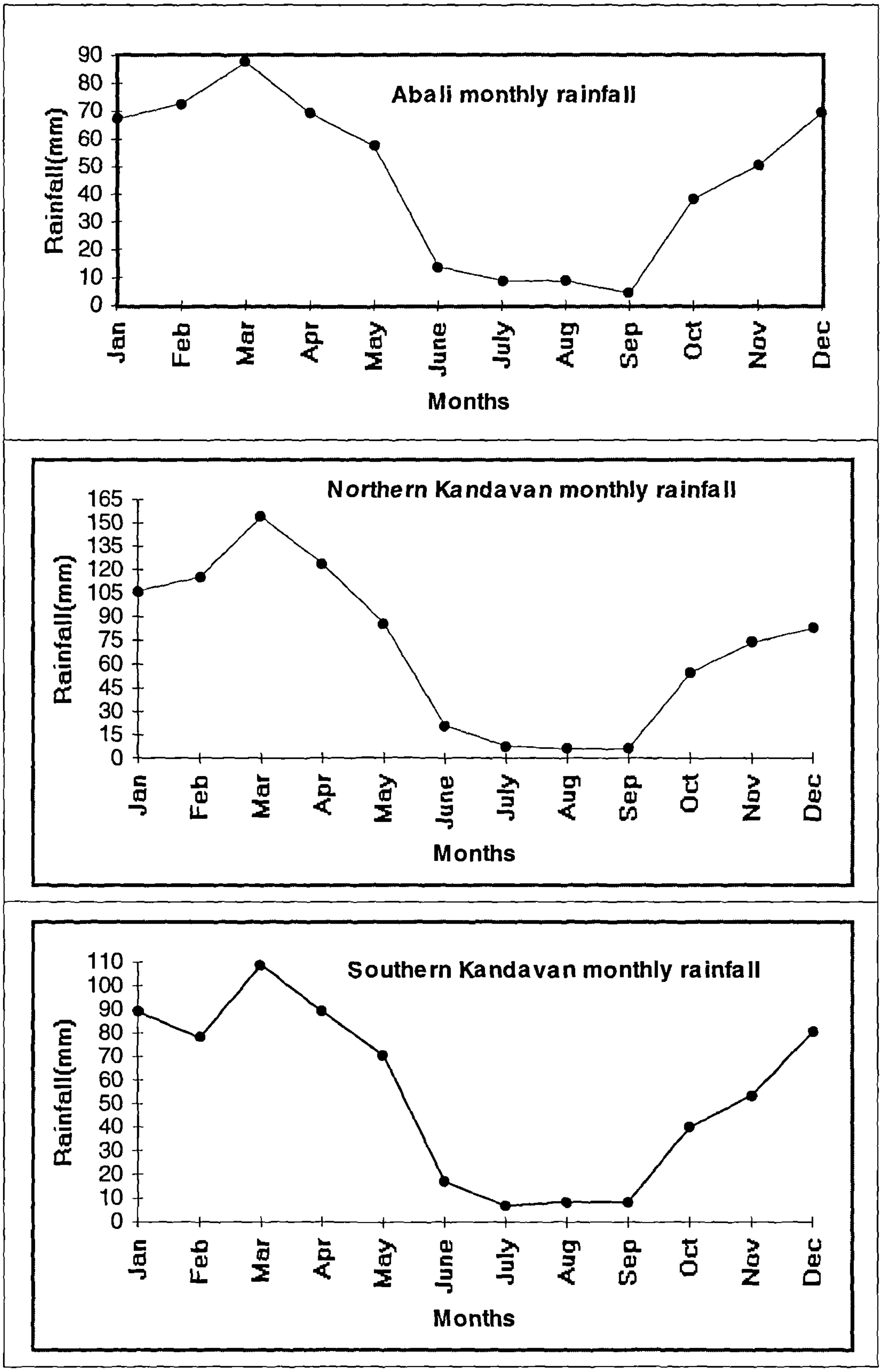


Figure 3.9-12 Higher Altitudes stations average monthly rainfall

3.10 Seasonal Rainfall Pattern over the Central Elburz

Reference to the monthly rainfall conditions indicate that the Central Elburz experiences a dry summer, with only occasional precipitation, and a wet winter, with the rainy season conventionally taken from November to May. The season usually starts in a rather erratic manner, with isolated showers in November, although October rains are not unknown. However, the details of the start and end of rain will be explained in later chapters. Generally March and April have squall-lines producing heavier rains than other months. March is traditionally taken as the wettest month, although sometimes the occurrence of dry spells during March has caused concern to agriculture. The season closes rather suddenly in June.

The climate of Iran is characterized by alternate wet and dry seasons, but there are considerable variations in the seasonal regime from place to place that depend not only on latitude but also on location and are the results of topography, and meteorological factors. These factors, have produced local contrasts in the seasonal rainfall regimes which can be used as a basis for regional rainfall studies. There are different methods of analysis of seasonal rainfall for regional studies. The length of the wet season is important for agriculture. The wet season is a group of successive wet months. Therefore the criteria used for defining a wet month is necessary.

3.11 The Definition of Wet, and Dry Months

The definition of a wet or dry month or period can be related to the conditions of each individual area and not to an arbitrary numerical value. Usually the wet season in a rainfall climatology will be different from that by a water balance definition, since a wet season in water balance describes the soil water conditions from an agricultural point of view. The criteria used for defining a wet season or a dry season month vary from one author to another. Criteria can be classified according to the rainfall and water balance or ecological factors.

3.12 Criteria Based on Rainfall

The wet season in a rainfall climatology is based on rainfall alone. As referred to various criteria have been used for defining a wet month by many investigation workers in different countries. Kenworthy and Glover (1958) have defined a wet month as having a standard deviation less than 50% of the mean value on the assumption that a dry month is likely to be non normal, i.e., skewed and so yields a value of more than 50%. Kendrew (1961) suggested that a month is defined as wet if it has 54 mm or more of rainfall. Manning (1956) defined the wet month as any month that the rainfall is more than 2 inches. However, the method for specifying a certain amount of rain to be expected during a wet season may suffer from some problems. The threshold values used are in most cases arbitrary and have no climatic significance. To avoid this problem some authors have related the definition of a wet or dry month to the general rainfall conditions at the particular places, rather than using an arbitrary chosen amounts of rain for every places. This is done by the applications of isopercentages by mean monthly rainfalls, which are expressed as percentages of the mean annual rainfall at a specific place. Thus, Gregory (1964) defined wet season months as those with more than 10 per cent of the annual rainfall and dry season months as those with less than 5 percent. Gregory (1983) defined that, a rainy month is defined as one with a mean rainfall that is at least 10 percent of the mean annual rainfall, and dry months is defined as those with less than 5 percent. In other words, if a month receives more than 5% of the annual mean rainfall, its rainfall could be treated as a wet month, and conversely a month having a value less than this amount would rank as a dry month. Also Gregory (1965) in his study of rainfall over Sierra Leone, consequently used the first and last months in the year with an average rainfall of at least 4 inches as the limits of the wet season. It is not surprising therefore, that in his Mozambique study, Gregory had to use the percentage of the annual rainfall in the individual months as a secondary supporting criterion for defining the duration of the wet season. Bowden (1964) in his paper on a dry season month is defined as one with an average rainfall of less than one inch (25 mm). Also he explained a wet season month is defined as one with an average rainfall equating to 8.5 percent of the average annual rainfall. Bazuhair and Al-Gohani (1997) defined for Saudi Arabia, whenever there is appreciable rainfall in a month it is considered a wet month, otherwise zero monthly rainfall amounts indicate a dry month. In summary, from the above methods and discussion of wet month, it is necessary to consider the rainfall effectiveness as a supporting criterion in the definition of a wet month. Also, the mean rainfall value at any particular month should offset the water losses through evaporation and transpiration before it is considered as a wet.

3.13 Criteria Based on Agricultural Need or Water Balance

An important aspect in the development of agriculture in the Central Elburz is the determination of the seasonal rainfall patterns. The coastal areas of northern Elburz have the potential to increase food production towards national self sufficiency and for an export surplus to neighbouring, and other countries. However, knowledge of the agroclimatic conditions needs to be incorporated in the production processes in order to improve yields on a national basis.

Almost everywhere rainfall is restricted in its seasonal distribution, and variation in the total amount of rainfall in a given season depends on its distribution in the year. As previously mentioned, there are differences between the wet season based upon rainfall climatology and water balance definition, subsequently a wet season in water balance considers the soil water from an agricultural aspect, it is a more valuable assessment. However, water balance delimitation is equally difficult, and may even be arbitrary. Any plant growth or agricultural activity requires a given rainfall values in nearly all years for its effective development respond to the pattern and quantities rather than mean conditions. For agricultural purposes water balance can be calculated for a crop, its stage in the growing season, but in practice planting is usually determined by the arrival of sufficient rainfall to allow farm operations and germination, and the decision to plant a crop depends on whether or not a long enough period of adequate water can be reasonable expected. In this regard water crop requirement and wet months based upon water balance assessment, will be discussed in following chapters.

'Bowden (1964) defines an ecologically dry season as a period when plant do not find in the soil the quantities of water which are necessary to them. The dry season is so important for the ecology and agriculture of regions that criteria giving approximations to the ecologically dry season must surely be valuable. Hanna (1976) has defined that a month can be considered wet if rainfall and soil water satisfies potential evapotranspiration which means no potential water deficit. Appreciation of the seasonal distribution of rainfall and its variability in amount and in distribution from year to year is not only important for overall assessments of agricultural potential, but also for improvements in farming practices as much in areas with good rainfall as in areas with marginal rainfall (Kenworthy 1964). For developing agricultural planning in one area, adequate understanding of the climatic conditions is essential. However, in recent decades attempts have been made to more better understanding emerging information on the agroclimatic conditions in developing countries such as Iran. There is still a long way to go before the dynamics of the climate are fully understood, but detailed analyses of rainfall records in special localities are now able to provide the initial weather knowledge that has previously been lacking.

The actual pattern of rainfall in any one season can not be predicted with correctness and choice of planting date will always be a risk. It may be necessary to wait for a critical build up of humidity in the soil, but planting just before the rains ensures that an annual crop can be advantaged from the release of available nitrates associated with rainfall succeeding a length dry duration. Rainfall criteria for the wet month will be adopted in this section and water balance will be explained in the following chapters.

3.14 The Seasonal Rainfall Pattern over the Central Elburz

It is apparent from the preceding discussion of the monthly rainfall patterns in the Central Elburz that rainfall is highly seasonal in its incidence in most parts of the country. The main feature of the seasonal pattern over the Central Elburz is division into wet and dry seasons as indicated by the changing monthly rainfall conditions. The problem is one of defining when the change over from one season to another usually occurs as well as the length and intensity of each season. There are great problems in attempting to quantify seasonal patterns throughout a region in which the timing of the wet and dry seasons is not uniform (Hanna 1975).

According to the monthly rainfall data in most parts of the Central Elburz, the annual rainfall is received between October and May but this is not uniform for all stations. For example the coastal area stations have rainfall in other months such as July, August and September as well. The seasonality of rainfall amounts at the representative stations in Figures 3.9-1 to 3.9-12 indicates that the winter is the highest precipitation amounts, especially in southern and higher altitudes over the Central Elburz stations. Also summer is clearly the dry season. This seasonality is less in the coastal area stations, where summer has some rainfall. However, in order to present the seasonal rainfall characteristics over the whole Central Elburz, it is desirable to have a common wet season period rather than periods varying from one area to another. Regarding Tables 3.9-3 to 3.15-1 and Figures 3.9-1 to 3.9-12 the months November-May and September-December are as a period of wet months for southern Elburz and coastal area stations. As will be discussed in next pages, most of the southern Elburz and coastal area stations receive their peak rainfall during these months. As previously explained these differences in seasonal rainfall patterns between southern and coastal area of the Central Elburz is to be expected in view of the diverse climatic conditions and other factors affecting rainfall. However, the problems of defining the wet season and dry season and quantifying the seasonal incidence of rainfall in Iran have not been discussed by many authors. Walloon (1968) suggested that a month is defined as wet (in the Middle East) if it has 25 mm rainfall. Khalily (1973) believes a wet month has more than 20 mm rainfall. Ghaemi (1997) believes that a wet month is defined as one with a mean rainfall more than 8 percent of the mean annual rainfall. Jafarpour (1978) believes a wet month should be defined as one with a rainfall index of greater than **1**. Thus in this study 2 methods have been adopted and their results have also been compared:

1) 8.5 % of the annual rainfall as a wet month.

8.5 % of the annual rainfall has been chosen to represent a wet month based on the work of Bowden and the personal communications with the other Iranian meteorologists. The wet months based upon 8.5 % of the annual rainfall has been selected by Table 3.9- 3 that previously have been done by author.

2) Rainfall index above **1** as a wet month.

The index of rainfall has also been used because of its adoption by Jafarpour for the Sehaneh station of the western part of Iran.

Monthly rainfall index can be calculated by following formula:

$$I_i = \frac{365\overline{P_i}}{n\overline{P}}$$

where,

I_i = Rainfall index,

$\overline{P_i}$ = Rainfall Average for a given month

n = Number of days in a given month and

$\overline{P}$ = Annual average rainfall of station.

Based upon this formula those months their rainfall index above or below **1** are called wet and dry months. This formula has been calculated for the Central Elburz stations and its results are shown in Table 3.15-1.

3.15 Wet Months as Defined by 8.5 % of the Annual Total and Rainfall Index Methods

With regard to Table 3.9-3 about 7 wettest months (these are the months from November to May inclusive) over the southern Elburz and the 5 wettest months (these are the months from September to January inclusive) for the coastal area have been grouped together as constituting the wet season. Also February and March are wet in some stations as well. However, the rainfall amount of the dry months of the Caspian area is even more than the wet months in the southern Elburz and the remaining months of the year constitute the dry season. Consequently there are differences between southern Elburz and the Caspian coastal area in the start and end of the wet season. Considering to the Table 3.15-1 that has been provided by rainfall index wet months are September to December in the Coastal area stations and for some stations this continuing to March as well. While it is from November to May for Southern Elburz. The comparison between 8.5% annual in Table 3.9-3 and the rainfall index in Table 3.15-1 shows that the results of both methods to be similar and close.

Table 3.15-1 Monthly Rainfall Index Distribution

Stations	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	1.06	0.91	0.74	0.37	0.30	0.39	0.29	0.76	1.65	2.12	2.04	1.32
Astara	0.9	1.04	0.93	0.74	0.57	0.45	0.38	0.86	2.11	2.16	1.24	0.73
Babolsar	1.19	1.07	0.88	0.47	0.29	0.38	0.4	0.75	1.11	1.99	1.77	1.66
Ghaemshahr	1.52	1.14	1.15	0.64	0.56	0.71	0.47	0.81	1.13	1.6	1.35	1.31
Gonbad	1.14	1.37	1.67	1.39	0.99	0.62	0.35	0.60	0.39	0.90	1.03	1.25
Gorgan	1.06	1.25	1.48	1.02	0.85	0.68	0.48	0.55	0.72	1.4	1.29	1.15
Havigh	0.62	0.77	0.84	0.77	0.72	0.71	0.49	1.03	1.73	2.19	1.28	0.79
Hashtpar	0.73	0.91	0.96	0.71	0.79	0.76	0.46	0.88	1.49	1.99	1.36	0.89
Lahijan	0.94	1.02	1.06	0.61	0.48	0.56	0.39	0.67	1.48	2.02	1.62	1.14
Noushahr	0.97	0.93	0.85	0.41	0.37	0.56	0.44	0.76	1.36	2.23	1.75	1.3
Ramsar	0.79	0.8	0.85	0.47	0.41	0.57	0.34	0.74	1.75	2.27	1.78	1.17
Rasht	1.13	1.1	1.02	0.54	0.49	0.38	0.35	0.61	1.3	1.99	1.64	1.39
Shirgah	0.77	1.21	0.99	0.65	0.7	0.69	0.78	1.02	1.31	1.51	1.19	1.13
Aminabad	2.5	1.98	2.09	1.39	1.27	0.88	0.2	0.08	0.12	0.91	1.06	1.48
Damghan	1.27	1.47	1.94	1.98	1.92	0.25	0.18	0.16	0.2	0.6	0.76	1.23
Dehsomeh	1.42	1.65	1.85	2.09	1.3	0.23	0.04	0.1	0.02	0.61	1.16	1.51
Garmsar	3.0	1.8	2.0	1.19	0.8	0.23	0.04	0.01	0.05	0.68	0.77	1.33
Ghazvin	1.55	1.43	1.98	1.62	1.35	0.25	0.1	0.06	0.04	0.81	1.2	1.57
Ghom	1.98	1.46	2.1	2.1	1.07	0.14	0.16	0.02	0.02	0.58	1.01	1.3
Karaj	1.55	1.41	1.94	1.82	1.18	0.21	0.07	0.05	0.04	0.85	1.22	1.62
Latian	1.75	1.81	2.07	1.71	0.88	0.31	0.12	0.05	0.06	0.62	1.14	1.48
Semnan	1.87	1.76	1.88	1.36	1.39	0.26	0.11	0.32	0.13	0.58	0.77	1.53
Shahroud	1.41	1.4	2.01	1.89	1.69	0.34	0.12	0.11	0.15	0.57	0.77	1.28
Takestan	1.18	1.43	1.49	2.07	1.83	0.43	0.04	0.02	0.09	1.07	1.17	1.17
Tehran	1.88	1.67	1.9	1.56	0.78	0.14	0.08	0.08	0.06	0.55	1.32	1.96
Varamin	2.03	1.76	1.74	1.63	1.02	0.35	0.07	0.03	0.03	0.64	1.08	1.61
Abali	1.44	1.72	1.87	1.53	1.23	0.3	0.18	0.18	0.09	0.81	1.11	1.48
Northern Kandavan	1.49	1.79	2.17	1.8	1.2	0.3	0.1	0.08	0.08	0.76	1.07	1.16
Southern Kandavan	1.61	1.56	1.97	1.6	1.27	0.32	0.12	0.15	0.15	0.72	1.0	1.45

3.16 Wet Rainfall Season over the Central Elbruz Stations

a) the Southern Elburz;

Table 3.9-3 and 3.15-1 show that March has the highest and May has the lowest amount of rainfall during wet months in the southern Elburz. Also the wet season is from November to May.

b) the Caspian Coastal area;

Tables 3.9-3 and 3.15-1 demonstrate that October has the highest totals and December has the lowest wet month of the Caspian coastal area. The wet season lasts from September to December. Therefore the seasonal rainfall is November-May for the southern Elburz but is September-December at the coastal area stations of the Central Elburz stations.

It has been found from the above analysis that the wet season varies from the coastal area and southern slopes over the Central Elburz. It thus seems to be very unrealistic to adopt one common wet season period which applies satisfactorily to the area as Walloon (1968) suggested for all of the Middle East.

3.17 Rainfall Regimes over the Central Elburz Stations.

Tables 3.9-3 and 3.15-1 demonstrate that the seasonal distribution of rainfall over the Central Elburz is a useful criterion for the identification of climatic areas. With regard to the monthly figures and amount of seasonal rainfall the average variation in rainfall for all the selected stations, can be grouped into three categories:

1) the Caspian coastal areas rainfall regime; comprises a first maximum in Autumn and a second maximum in winter while in this area the driest month of the year receives more than 20 mm of rainfall and there is no real dry season.

2) the Southern slope stations rainfall regime; is characterized by a dry period of between 3 to 6 months, that often coincides with the warm season of the year. However, as we have mentioned in previous chapters, this region has Mediterranean conditions; an arid and semi-arid area of the STHs with a short rainy season in the high sun period and a long dry season. The winter is the wettest season, and rainfall occurs mostly in the cold period of the year.

3) the Rainfall regime of Higher Altitudes is similar to the southern slope stations. Also the Mediterranean depression, affects the whole of Iran during the cold season of the year, particularly winter, and it causes similar amount of rainfall for both parts of Elburz Higher Altitudes.

3.18 Classification and Regionalization

In previous pages the characteristics of the rainfall regimes for the different parts of the Central Elburz stations has been explained. In this section we attempted to divide the stations into groups and regions based on their long time rainfall data. Regionalization and classification have been attempted over a long period of time in every field of geography. Classifying objects according to their likeness seems to have been for all time a step in the human processes of acquiring knowledge.

Classification is the processes of relating the separate items within the mass of data collected to the definition of various categories (Hannagan 1997). In the widest sense, a classification scheme may represent simply a convenient method for organising a large set of data so that the data is simplified. Classification, the assignment of an object to one of a number of predetermined groups, is of fundamental importance in many areas of science and technology. Although classification has a very wide application it is often difficult for a specialist to see that the task in hand is a classification problem. The trouble lies in the application of the idea of assessing an object to a group that it originates from. At its most simple the problem presents itself in terms of objects and groups. It is possible to think up any number of procedures for classifying an object into one of a number of groups, ranging from random allocation to an arbitrary rule using any of the measurements. The problem is to select one of the set of possible classification rules based on its performance. In other words we would like to use the classification rule that is in some sense 'best', which rule we choose depends very much on the interpretation given to the word 'best'.

The subject of classification in its broadest sense is very wide indeed and we should narrow the field to some extent by considering what the statistician can contribute to it.
Depending upon the types of data and the aims of the researcher there are various techniques of grouping or classifying locations such as Principal Components, Factor analysis, Discrimination analysis and Cluster analysis. Nowadays these techniques are used in many different fields. Also these various methods of grouping or classifying locations can be used in the different climatological subjects including rainfall climatology. These methods can be seen as a wide literature in different disciplines; (Kendal 1975, Ryzin 1977, Jonston 1978, Ikeda 1980, Jackson and Borgatta 1981, James 1985, Jullife 1986, Morrison 1990, Everitt and Dunn 1991, Jobson 1992, Johnson and Wichern 1992, Everitt 1993, Reyment and Joreskog 1993, Van Cutsem 1994, Hair *et al* 1995 and Openshaw 1995).

3.19 Aim of the Classification

This is always a difficult question to answer in sufficient detail to guide the subsequent classification processes. There is obviously no unique and correct single set of variables to use. Different people use different variables for the same purposes based upon their experiences of locations and intuition. In deciding which areas to classify, one should bear in mind the problems associated with data heterogeneity. Careful consideration is needed in the choice of spatial scale and of the domain of the study.

The aim of classification is to group observations into categories comprising similar individuals and thereby to separate dissimilar individuals into different categories. The classification procedure just outlined suggests that one takes every possible grouping and evaluates each in terms of the analysis of variance model. The important point is that any classification is a division of objects or individuals into groups based on a set of rules and should be judged largely on the usefulness of results. Given a collection of **n** objects individuals such as animal, plants etc., each of which is described by a set of **p** characteristics or variables, derive a useful division into a number of classes. The formation of items into groups is a natural mental activity. This is possibly one reason for the plethora of classification methods available, many of them of a very ad hoc nature. It is frequently stated that classification is one of the fundamental process in science. Facts and phenomena must be ordered before we can understand them and to develop unifying principal explaining their occurrence and apparent order. From this point of view classification is a higher level intellectual activity necessary to our understanding of nature. It is useful to outline in general terms a number of different practical and potentially useful approaches to data reduction relevant to a classification and regionalization theme. Indeed it is possible to recognize several different types of data reduction methodologies. Simplify by reducing the M variables to K new ones that represent most of the useful information contained by the original M (K<M). Reducing the number of observations by grouping together those cases which have similar profiles in terms of either the original M variables or the K new factor based ones.

3.20 Data and Method for Rainfall Classification and Regionalization over the Central Elburz Stations

As previously pointed out there is a long tradition of geographical interest in regions which are usually defined as a contiguous area whose parts share similar characteristics on defined criteria. Contiguous are only groups if they are contiguous or one member of one group is contiguous with a member of another group at the later stages when groups are being grouped. This involves grouping the observations into categories such a research procedure that has a long history in geography where there is a continuing interest in grouping similar places to form regions and areas with characteristics in common, the relevant characteristics having been defined prior to the analysis.

When rainfall totals are collected for many sites over an area, it is possible simply to map those totals. Analysis of the maps may then lead to subjective visual grouping of a possibly quite complex pattern in order to identify regions of different rainfall regimes. It is not always sufficient to know the time period totals, but also some indication as to when the rainfall can be relevant in the identification and classification of regions. In any one systematic study of rainfall beyond an area it is described that such an area can be divided into a number of groups or regions, so that each region's rainfall may be treated entirely separately agricultural or purely climatological discussions. It is in this sense that the Central Elburz area, which experiences a remarkable diversity in the distribution of total rainfall should be divided into well defined rainfall stations groups and regions.

Methods of classifying areal units according to univariate or multivariate phenomena are an integral part of the geographer's quest for greater understanding of the order and interaction of spatially distributed variables. In this regard this part is concerned with exploring the possibilities for the geographer of hierarchical classification analysis, which is one of a number of classificatory methods that have been used for multivariate classification in many fields. Main part of this section is an attempt to classify or group rainfall stations using a range of rainfall characteristics. However, attempts have not previously been made to classify rainfall regimes in Iran and this analysis is the first application of such procedure rainfall climatology in Iran. A major aim is to investigate whether the use of a multivariate approach produces a classification that might have been anticipated by the use of a few variable. Also this research seeks to asses problems associated with such methodologies and the possibilities of interpreting the characteristics of the resulting groups. So the main aim of this section is to classify rainfall stations. The technique of Hierarchical Clustering analysis has been applied to classify the Central Elburz stations into a number of rainfall regions. And also Ward's method was chosen to minimize the within cluster differences and to avoid problem with chaining of observations found in linkage method.

The clustering algorithm assumes that each element at the beginning is a cluster itself. These initial clusters are grouped in the following steps until an optimal number is reached. This will be detected when there is a relatively high homogeneity among the members of every cluster and at the same time, a high heterogeneity between clusters. These are formed by using distance matrices and a similarity function which is extensively discussed in Kalkstein *et al* (1987).

The primary goal of cluster analysis is to partition a set of objects into two or more groups based on the similarity of the objects for a set of specified characteristics. Cluster analysis is an objective methodology for quantifying the structural characteristics of a set of observations. In cluster analysis any object can be compared to any other object through the similarity measure. Cluster analysis is a tool for exploring data and should be supplemented by techniques for data visualisation. Certainly it is often useful to begin the search for clusters in multivariate data by examining some relative simple graphical displays.

The aim of clustering data is to group the individuals or objects represented by the n rows of a data matrix X. Which gives the variable values for each of the objects or individuals under investigation. In short, this method compares the average squared Euclidean distance between all possible pairs of observations within two different clusters. Two clusters will be joined when they have the minimum average distance.
This analysis is based upon the monthly and annual rainfall totals for the 30 years period 1958- 1987 at the 29 stations (as 42 input variables). In attempting to classify these 29 stations into a number of homogenous groups a choice had to be made between a very large number of possible method. None of them is best and none of them is wrong they are merely alternative. The choice of Ward's algorithm was related

to its basic simplicity and ease of operation. The grouping procedures and the solutions obtained from this method are discussed in the following sections.

3.21 Clustering analysis Discussion

Searching the data for a structure of natural groupings is an important exploratory technique. Groupings can provide an informal means for assessing dimensions, identifying outliers and suggesting interesting concerning relationships. Classification pertains to a known number of groups and the operational objective to assign new observations to one of these groups. Grouping is done on the basis of similarities or distance. The inputs required are similarity measures or data from which similarities can be computed.

The development of the many classification systems in itself indicates that none have fulfilled the requirements of an acceptable and flawless scheme. In other words the imperfection of the existing classification system urges researchers to find new schemes to solve all the shortcoming which exist in conventional classification schemes. In this process an approach to tackle the clustering techniques has emerged. This advanced analysis technique allows the use of number of variables together to solve and classify long- term rainfall and to subdivide rainfall stations in a meaningful and objective way.

Cluster analysis techniques deal with a set of observed similarities (or distances) between N items to find a representation of the items such that the inter item proximities nearly match the original similarities. Consequently, Cluster analysis techniques attempt to find configuration in $q \leq N-1$ dimensions such that the match is as close as possible. Cluster analysis covers a variety of techniques encompassed in the area of multivariate data analysis. In the main the development of the theory of cluster analysis has rested in the hands of the biological sciences. Thus Cluster analysis such as other methods of classification is now becoming more popular and is extending into areas other than its traditional place in the biological sciences. The literature of cluster analysis is now vast and continues to grow at a considerable rate and the cluster analysis techniques have become a popular method of data analysis in many field such as Social Science, Ecology, Education, Archaeology, Biology, Engineering, Business, Hydrology, Meteorology and different sub-disciplines of geography particularly climatology. Cluster analyse have been widely used in various types of climatic classification and regionalization studies. Galliani and Filippini (1985) explained that for a high number of stations with different rainfall that not simply on geographical areas, the cluster analysis technique makes it possible to obtain valuable experimental data for the study of the meteorological causes of differences in rain amounts. Stooksbury and Michaels (1990) used temperature and precipitation by cluster analysis, to define and classify general climate for the southern United States of America. Periago et al (1991) used cluster analysis to classify and regionalize rainfall stations in Catalonia (NE Spain), using average monthly rainfall as a variable, and found 7 groups. Jackson and Weind (1994) used cluster analysis to determine tropical rainfall stations in groups with similar characteristics, by using some rainfall variables. McBoyle (1971), Wiltshire and Berena (1987), Kalkstien *et al* (1987), White and Perry (1989), and Spellman (1998) also used cluster analysis in their studies.

In both a physical science or social science the analyst is searching for a natural structure among the observations based on a multivariate profile. In this regard the cluster analysis is the most commonly used technique. The purpose of clustering observations is to help the investigator to classify observations into groups, when the groups are not initially known. The intention is to group objects in the same cluster which are more like one another than they are like objects in other clusters.

Many methods of cluster analysis begin not with the raw multivariate data matrix, X , but with a matrix containing numbers indicating the similarity or dissimilarity of each pair of individuals or objects which are to be clustered. In some problems no initial grouping is imposed on the data but the object of the analysis is to see whether the individuals can be formed into any natural system of groups. The number of groups may not be specified in advance. The individuals could be grouped in an entirely arbitrary way, but the investigator seeks a system such that the individuals within a group resemble each other more than do individuals in different groups. Cluster analysis may also be used to cluster variables rather than individuals that is to arrange the variables into groups such that the variables in each group measure a similar or closely related feature of the individuals while separate groups represent different features. In cluster analysis the concern is to find groups whose members are in accordance with some predetermined measure of likeness, which are as similar to each other as possible. Cluster analysis is the modern statistical technique for partitioning an observed sample population into disjointed or overlapping homogeneous classes, so as to produce an operational classification. This classification is generally of assistance in finding out the homogeneous rainfall stations by region and area in a spatial context.

3.22 Similarity Criterion and Algorithm

Attempts to develop techniques for automatic classification necessitated the quantification of similarity. Similarity hierarchical grouping of objects is helpful in identifying object types and subtypes. In much classificatory work, it would be impractical to obtain estimates of taxonomic similarity in an assemblage of objects from a sample of subjects. So an approach is required to quantify (estimates resemblance) through attempts to find the basis for similarity judgements. The term proximity often is used to refer to both the similarity and the dissimilarity. Proximity literally means nearness in space, time or in some other way. The nearness of objects, individuals, stimuli needs definition and measurement prior to statistical analysis. In some situations this is straightforward but in others difficult and controversial. Measures of proximity are of two types: similarity and dissimilarity with obvious interpretation of measuring how similar or dissimilar objects are to each other.

The objects under consideration comprise a set O. The similarity and dissimilarity measure between two objects is then a real definition on O $\times$ O giving rise to similarity S_{rs} or dissimilarity δ_{rs} between the **r**th and sth objects. Usually $\delta_{rs} \geq 0$, $S_{rs} \geq 0$, and the dissimilarity of an object with itself is taken to be zero, i.e. $\delta_{rr} = 0$. Similarities are usually scaled so that the maximum similarity is unity, with $S_{rr} = 1$. Similarities (dissimilarities) are constructed from a data matrix for the objects. These are then called similarity (dissimilarity) coefficients.

A narrow definition of cluster analysis is the search for a low dimensional space (usually Euclidean), in which points in the space represent the objects. One point represents one object, such that the distances between the points in the space, (d_{rs}), match as well as possible the original dissimilarities (δ_{rs}).

The basic information for an analysis is generally contained in an objects $\times$ variables array. The objects are described by the rows of the array that is by their profiles (the set of values of the variables for these objects) and are represented by a point in a relevant space, the product of the spaces in which the variable take their values. The likeness between two objects is characterised by the likeness of their profiles in this representation space. If we define a measure of the proximity in this space, we get an objects $\times$ objects array which contains quantitative form information on the proximities.

The most common measure of the relationship of one object (stimuli, etc.) to another is a proximity measure. This measures the ''closeness' of one object to another and can either be a similarity measure where the similarity of one object to another S_{rs} is measured, or a dissimilarity measure, where the dissimilarity δ_{rs} between the two objects is measured. A set of **n** objects have dissimilarities δ_{rs} measured between all pairs of objects. A configuration of **n** points representing the objects is sought in a **p** dimensional space. Each point represents one object with the **r**th point representing object **r**.

3.23 Hierarchical clustering and Ward's method

Hierarchical clustering analysis are ideal for the exploratory stage of research. Ward (1963) proposed a clustering procedure seeking to form partitions $P_{n,}$ $P_{n-1,}...P_1$ in a manner that minimizes the loss associated with each grouping, and to quantify that loss in a form that is readily interpretable. It is a Hierarchical procedure that begins with each object or observations considered as a separate cluster. In subsequent steps, object clusters that are closest together are combined to build a new aggregate cluster. At each step in analysis, the union of every possible pair of clusters is considered and the two clusters whose fusion results in the minimum increase I information loss are combined. This method tends to produce tight spherical clusters and is widely used. Hierarchical clustering techniques are more popular, with Ward's method and being probably the best available. Hierarchical clustering techniques attempt to minimize a measure of discrepancy between the observed dissimilarities and the fitted alternative distances. In Ward's method the distance between clusters is the sum of squares differences between the two clusters summed over all variables. At each stage in the clustering procedure, the within cluster sum of the squares is minimized over all partitions (the complete set of disjoint or separate clusters) obtainable by combining two clusters from the previous stage. This procedure tends to combine clusters with a small number of observations. It is also biased toward the production of clusters with approximately the same number of observations.

Ward's method is Hierarchical clustering procedure when the similarity is used to join clusters is calculated as the sum of squares between the two clusters summed over all variable. The Euclidean distance is used to calculate several specific measures, one being the simple Euclidean distance and the other is the squared. Clusters with the greatest similarity are combined at each stage.

The Euclidean distance between two p- dimensional observations **X** = $[X1, X2,\ldots, Xp]$ and **Y** = $[y1, y2,\ldots, yp]$ is

$$d(\mathbf{x}, \mathbf{y}) = \sqrt{(x1-y1)^2 + (x2-y2)^2 + \ldots + (xp-yp)^2}$$

For the Ward method, at each clustering step, the aim is to form a group such that the sum of the squared within group deviations about the group mean of each variable is minimized for all the variables at the same time (Jackson and Weinaned 1995).

In Ward's method the technique joins clusters that minimize the within- sum of squared distances:

$SS = \sum (X_i - \bar{X}_i)^2$. Consequently, Ward's method has a tendency to form clusters of relatively equal size.

In Ward's linkage, the distance between two clusters is the sum of squared deviations from points to centriods. The objective of Ward's linkage is to minimize the within-cluster sum of squares. In terms of distance matrixes,

$$d_{mj} = ((N_j + N_k)d_{kj} + (N_j + N_l)d_{lj} - N_j d_{kl}) / (N_j + N_m)$$

This method determines how the elements, d_{mj} of the new row, m are calculated from the elements d_{kj} and d_{lj} of the deleted rows k and l. In the formula N_j, N_k, N_l and N_m are the number of observations in clusters j, k, l, and m.

At each stage in the clustering procedure the number of groups is reduced by one by joining together or fusing the two groups considered to be the most similar or the closest to each other. In a Hierarchical classification the data are not partitioned into a particular number of classes or clusters at a single step. Instead the classification consists of a series of partitions which may run from a single cluster containing all individuals, to **n** clusters each containing a single individual. Hierarchical procedure is stepwise clustering procedure involving a combination or the objects (clusters). Since the clusters at any stage are obtained by the fusion of two clusters from the previous stage, these methods lead to a hierarchical structure for the objects. The result is the construction of a hierchicy or treelike structure composed of separate clusters.

The nature of cluster analysis can be illustrated by graphic presentation. Hierarchic classification may be represented by a two dimensional diagram known as a dendrogram which illustrates the fusion or division made at each successive stage of analysis. This is particularly so in applications where graphs and diagrams of various kinds can facilitate the understanding and interpretation of the results obtained from clustering algorithms. In this regard one useful visualisation of such a hierarchy is a tree diagram, more commonly known as a dendrogram. The dendrogram representation of the results of a clustering procedure involves the vertical axis representing the objects or individuals and the horizontal axis the number of clusters at each step of the procedure. In general the dendrogram provides a reasonable summary of the observed similarities or dissimilarities the groupings and the distance levels at which they occur, are clearly illustrated by the dendrogram.

3.24 Analysis of Hierarchical Clustering

As mentioned in previous pages it has been attempted and to define regionalization and classification rainfall stations over the Central Elburz in a rigorous manner by using the technique of Hierarchical Clustering analysis. The classification of a given set of data, characteristized by a set of variables, entails the formation of distinct, homogenous groups. The various available clustering procedures vary considerably, some methods divide and dissect a large data set into smaller groups, while others agglomerate and start within individual data points which are eventually built into groups.

Cluster analysis (Ward's method) is a computer grouping which groups items according to the Euclidean distance between them that is the square- root of the sum of the squared differences between the values of the clustering variables. As in the agglomeration process, a dendrogram is produced and Ward's method also assigns a reference number for each case according to their cluster groups. Ward's minimum variance method is the most frequently used hierarchical clustering technique for climatic classification. At each clustering step, the within- cluster sum of squares, is minimized. Ward's minimum variation technique has been the most used clustering technique in climate research (Kalkstein *et al* 1987).

Ward's clustering method was used in this study to achieve an objective classification. Therefore a classification of rainfall region and groups stations for the Central Elburz is derived in an objective manner which uses the available rainfall data as input the variables. Such a scheme gives meaningful and objective results. In cluster analysis, as in most multivariate analysis, the choice and number of variables will strongly influence the results. 42 rainfall variables (including 30 annual rainfall and 12 monthly for each station) as variables have been used to the 29 rainfall stations. Thus Cluster analysis was performed and carried out for the 42 × 29 data array, producing homogenous rainfall regions and classification using SPSS, SAS and Minitab version 11. In this regard we did not try to decide beforehand which stations to develop the groups around. We were interested in the groups forming naturally according to their characteristics. Table 3.24-1 contains the results of the cluster analysis, including the cases being combined at each stage of the process and clustering similarity and distances. At each step, two clusters are joined. The table shows which clusters were joined, the distance between them, the corresponding similarity level, the identification number of the new cluster (this is always the smaller of the two numbers of the clusters joined), the number of observations in the new cluster and the number of clusters. Amalgamation continues until there is just one cluster.

Agglomarative clustering of observations begins with all observations each forming its own separate cluster. In the first step, the two observations closest together are joined. In the next step, either a third observation joins the first two, or two other observations join together into a different cluster. Each step results in one less cluster than the step before until at the end all cases are combined in one cluster. Once two observations are combined in a cluster, they may join with other observations, but they will always remain together. The final grouping of clusters, also called the final partition, is the grouping of clusters which will, hopefully, identify groups whose members share common characteristics. The Table 3.24-2 summarises each cluster. The first cluster has 9, the second has 7 and the third has 13 observations. To calculate the within cluster sum of squares, we use just the number of observations in cluster one, two or three. In general, a cluster with a small sum of squares is more compact than one with a large sum of squares. The centroids for all the clusters are printed in the column 4 and 5 of Table 3.24-3. Also the distance between the 3 clusters is represented on Table 3.24-3.

The Figure 3.24-1 (complete dendrogram) shows the amalgamation of observations from many clusters to just one. Producing a dendrogram or tree diagram, showing the amalgamation steps. Finally, Figure 3.24-1 shows the dendrogram for the final 3 clusters solution. It provides a quick visual overview of the clustering process and shows which observation are found in each cluster.

The dendrogram and Amalgamation Table provide identifying outliers in the sample. The dendrogram permits a visual inspection for outliers. In the Amalgamation Table the researcher can ascertain the presence of single- member clusters. At the first step of the analysis the two closest cases are combined into a single cluster, resulting in 28 clusters. The first row of the Amalgamation Table represents stage 1, the 28 cluster solution.

The results of the clustering analysis are summarised in the Amalgamation Steps which identifies clusters being combined at each stage. Table 3.24-1 shows similarity and distance level on the left side of agglomeration and at the right side of the cluster being combined and forming a new cluster. For the Ward method, each clustering step, aims to form a group such that the sum of the squared within group deviations is minimised for all variables at the same time. Thus, the two clusters for which fusion leads to the least increase in the within cluster sum of the squares are combined.

The similarity level is the squared distance between pairs of observations. The similarity between two clusters is the average of similarity coefficients for all pairs of cases, one from each cluster. In this study the resulting computer output was used to partition the 29 stations into 3 subsets of regions (categories) by the Ward's method of cluster analysis from dendogram producing. The characteristics of each variable and cluster are described in Tables 3.24-1 to 3.24-3 and Figures 3.24-1. These could be further grouped into major geographical regions corresponding to:

1) the wet northern territories including coastal and higher altitude areas;

2) the dry southern parts of the Elburz.

Dendrograms provided by Clustering analysis clearly suggests 3 homogeneous rainfall groups for the Central Elburz stations. Since, in a multivariate sense classification and regionalization of these three groups (region) is meaningful, further classification method were not required. For the purpose of detailed analysis, the 3 clusters were labelled A to C on Figure 3.24-2 according to the their clusters membership:

3.24.1 Subgroup A

This subdivision (including Anzali, Astara ,Havigh, Hashtpar, Shirgah, Lahijan, Rasht, Noushahr, Ramsar stations) covers the Caspian coastal area particularly its western part. This region (A) has noticeably the highest rainfall and contain the wettest area of the Central Elburz stations as rainfall decreases from west to the east parts of the Caspian Coastal area. As was previously mentioned this region experiences rainfall in all seasons. An interesting case is the Anzali Station which is some distance from other stations within its group, it has a high rainfall record within the region which as we previously mentioned is produced by Macroclimatology and Microclimatology aspects of area.

3.24.2 Subgroup B

This subgroup (including Babolsar, Ghaemshar, Gorgan, Gonbad, Abali, Northern and Southern Kandavan stations) represents the two different geographical aspects including the higher altitude and eastern coastal stations:

a) the 3 higher altitude stations (Abali, Northern and Southern Kandavan stations) due to the higher altitudes of the areas, being strongly influenced by different air masses and exhibiting a progressive rainfall with the major physical units during winter to spring time.

b) Eastern coastal stations (Babolsar, Ghaemshar, Gorgan and Gonbad stations) from the coastal have joined this subgroup. As previously mentioned the stations from the eastern coastal area have the amount of rainfall less than western parts of the coastal area and also some different characteristics based on distance and geographic points of view. Eastern parts of the Caspian Sea due to increasing distance from the sea and influencing different air masses from the central parts of Asia have less rainfall than western parts.

3.24.3 Subgroup C

This subgroup (including Aminabad, Damghan, Dehsomeh, Garmsar, Ghazvin, Ghom Karaj, Semnan, Shahroud, Tehran, Takestan, and Varamin stations) prevails over the southern slope of the Central Elburz and illustrates that a fair amount of rainfall seems less pronounced compared with region A and B. The rainfall distribution of this area is concerned as the driest parts of the Central Elburz. It is characterized by a relatively cold winter and rainfall during winter and spring. All of the Southern slopes form one group it agrees by their geographical aspects. Regarding chapter two this cluster contains the arid stations, they all have less rainfall, experiences subsidence characteristics and increasing amounts of rainfall with elevation.

Table 3.24-1 Amalgamation Steps

Step	Number of Clusters	Similarity Level	Distance Level	Clusters Joined		New Cluster	Number of Obs. in new Cluster
1	28	99.91	0.385	22	26	22	2
2	27	99.88	0.503	20	25	20	2
3	26	99.84	0.685	15	23	15	2
4	25	99.83	0.724	15	22	15	4
5	24	99.76	1.023	16	18	16	2
6	23	99.71	1.249	15	19	15	5
7	22	99.63	1.593	15	17	15	6
8	21	99.48	2.228	14	20	14	3
9	20	99.37	2.725	14	24	14	4
10	19	99.36	2.782	16	21	16	3
11	18	98.91	4.707	5	27	5	2
12	17	98.52	6.387	9	12	9	2
13	16	98.15	7.976	4	6	4	2
14	15	98.04	8.444	10	11	10	2
15	14	98	8.633	14	16	14	7
16	13	97.1	12.509	5	29	5	3
17	12	97.07	12.631	8	13	8	2
18	11	97.01	12.881	3	4	3	3
19	10	96.71	14.217	9	10	9	4
20	9	95.71	18.508	2	7	2	2
21	8	93.97	26.031	14	15	14	13
22	7	93.71	27.13	2	8	2	4
23	6	91.47	36.823	3	5	3	6
24	5	90.8	39.717	2	9	2	8
25	4	87.93	52.079	3	28	3	7
26	3	75.67	104.998	1	2	1	9
27	2	15.98	362.55	3	14	3	20
28	1	-266.58	1581.88	1	3	1	29

Table 3.24-2 Final Partition (Number of cluster)

Clusters	Number of observation	Within cluster sum of squares	Average distance from centroid	Maximum distance from centroid
Cluster 1	9	116.016	3.293	6.831
Cluster 2	7	63.487	2.869	4.724
Cluster 3	13	24.280	1.278	2.407

Table 3.24-3 Distances Between Cluster Centroid

Clusters	Cluster 1	Cluster 2	Cluster 3
Cluster 1	0.0000	7.6634	13.3554
Cluster 2	7.6634	0.0000	6.3120
Cluster 3	13.3554	6.3120	0.0000

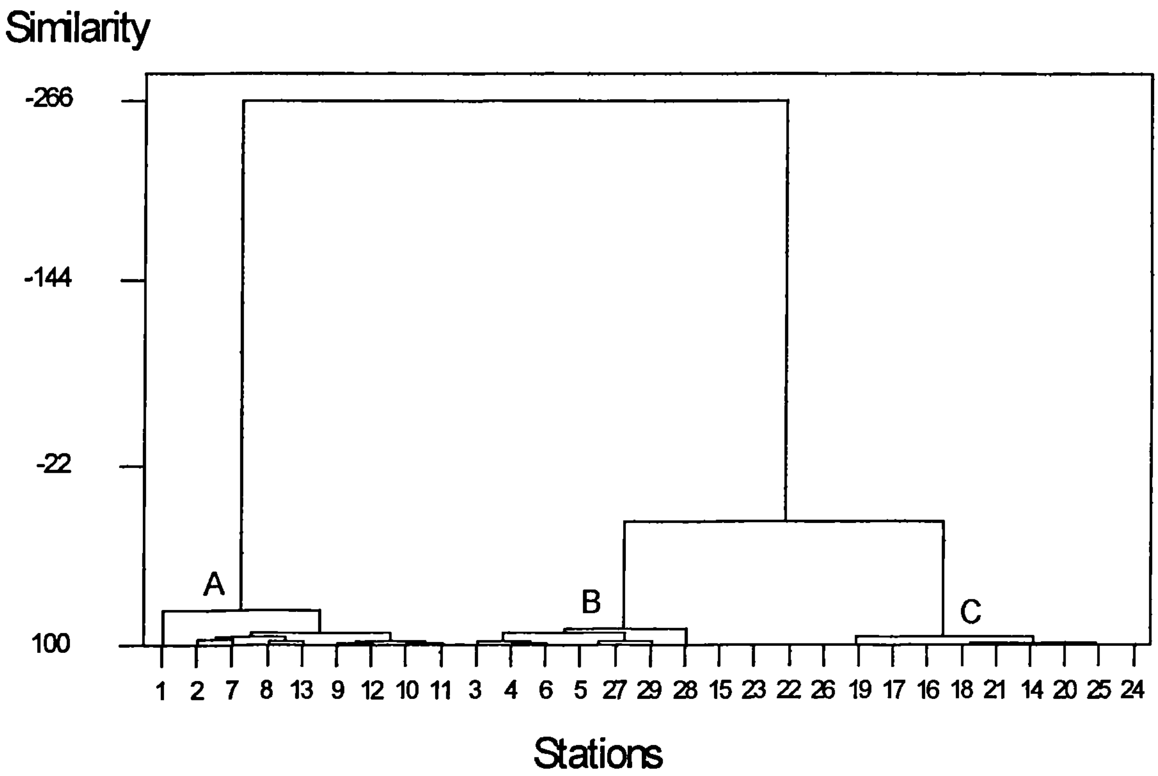


Figure 3.24-1 Dendrogram Resulting from Cluster Analysis over the Central Elburz stations

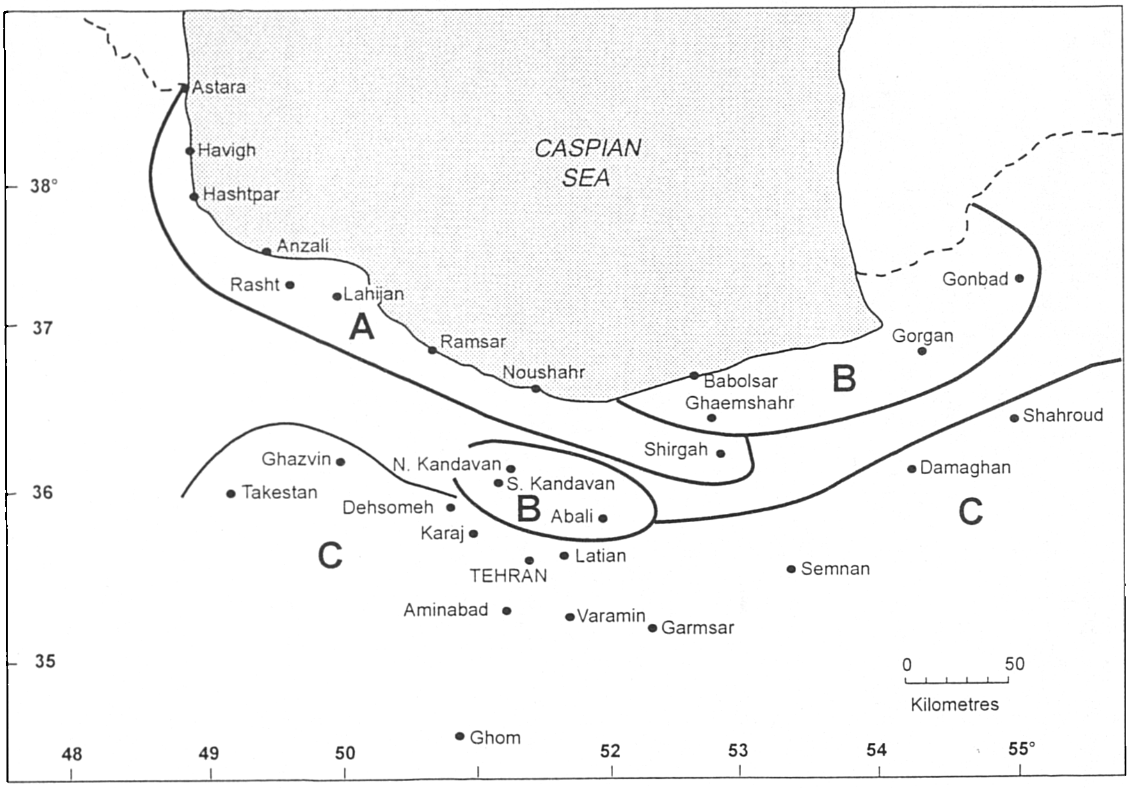


Figure 3.24-2 the Central Elburz stations Subgroup

3.25 Summary and Conclusion

As discussed, in contrast with the claims of many authors, the highest rainfall coincides with higher elevations. In this analysis the maximum rainfall did not correspond with the highest parts of the Elburz, but occurs on the Caspian lowlands. Annual rainfall increases linearly with elevation in the southern slopes of the Central Elburz but decreases with elevation in the coastal area. Also rainfall decreases in the eastern parts of the coastal area because of increasing distance from the Caspian Sea. Thus the relief factor is less important than distance from the sea in the coastal area. The relationship between annual rainfall and altitude is significant in the southern slopes but results show it to be insignificant in the coastal area stations. It is clearly seen that there is a difference not only in the amount of rainfall but also in the occurrence of maximum rainfall in relation to elevation between the southern slopes and the coastal area.

The monthly and seasonal rainfall indicate two different categories of rainfall regimes over the Central Elburz stations as follows:

1) the Caspian coastal area rainfall regime comprises a first maximum in Autumn and a second maximum in winter while Spring is the driest season in coastal area.

2) the southern slope stations rainfall regime is characterized by a dry period of between 3 to 6 months, the winter is the wettest season, and rainfall occurs mostly in the cold period of the year.

Rainfall of the southern Elburz is cyclonic in origin and is attributed mainly to Mediterranean disturbances, but the Caspian coastal rainfall is attributed to thermodynamic destabilization of the Siberian cold air mass as it crosses the warmer Caspian Sea surface. Based on the analysis of the two methods, the seasonal rainfall period is November-May for the southern Elburz but is September-December at the coastal area stations of the Central Elburz stations.

Consequently there are differences between Southern Elburz and the Caspian coastal area in the beginning and end of the wet and dry seasons. It is necessary for land managers in the area to consider the time of crop failure in the region essentially in the periods of May- July in the coastal area, and June- October in the southern Elburz.

The Hierarchical Clustering technique was applied to classify the Central Elburz stations into a number of groups. This advanced analysis technique allows the use of number of variables together to solve and classify long-term rainfall and to subdivide rainfall stations in a meaningful and objective way.

The Hierarchical techniques follows a basic steps routine:

1) The Euclidean distance between all entries (stations) is calculated.

2) The two closest entries are merged to form a new cluster.

3) The distance between all entries is recalculated.

4) The step 2 and 3 are represented until all entries are merged until one cluster.

In this study Dendrogram's provided by the Ward's method Clustering analysis was clearly suggested 3 homogeneous rainfall groups for the Central Elburz stations as follows:

1) Group A (including Anzali, Astara ,Havigh, Hashtpar, Shirgah, Lahijan, Rasht, Noushahr, Ramsar stations) covers the Caspian coastal area particularly its western part. The region A has noticeably the highest rainfall and contains the wettest parts of the Central Elburz stations.

2) Group B (including Babolsar, Ghaemshar, Gorgan, Gonbad, Abali, Northern and Southern Kandavan stations), represents the two different areas including the higher altitudes and eastern coastal stations.

3) Group C (including Aminabad, Damghan, Dehsomeh, Garmsar, Ghazvin, Ghom Karaj, Semnan, Shahroud, Tehran, Takestan, and Varamin stations) this subgroup prevails over the southern slope of the Central Elburz and rainfall distribution of this area is experienced as the driest parts of the Central Elburz.

4

4. Annual Rainfall Trend

A sequence of devastating droughts in the Sahel in the last two decades have provided the impetus for studies of climatic fluctuations and trends over the West Africa region and different parts of world as well. Also various trend detection studies have been carried out in different parts of the world, mostly for identification of climatic change if any. Some of these cases have shown significant trend components especially during the last 40- years period.

Time series have been analysed for different purposes in climatological studies. A time series is a collection of observations made sequentially in time (Chatfield 1984). They have also been defined as successive observations of the same phenomenon over a period of time (Hammond and McCullagh 1978). Kottegoda (1980) describes a time series as set of observations that measure the variation in time of some aspect of a phenomenon and Caswell (1989) describes it as the recording of a series of measurements of a variable over a period of time. However a time series defined in this way may or may not exhibit time dependence (Matthews 1984).

Time-dependence can take a variety of forms:

a) long-term trends

b) irregular fluctuations

c) cyclic fluctuations.

The Climatologist's interest in time series stem from two considerations:

1) explanation involves the study of process and sequence, and these occur through time. The explanation of the present is rooted in the past.

2) Change through time is a basic characteristics of a place, and different rates of change in different places create a major spatial variable.

Much time series analysis involves the use of graphs, the horizontal scale (x-axis) measures time, and the vertical scale (y-axis) the magnitude of the variable being studied (in this case rainfall). Several aspects of time series analysis are usually studied, such as:

a) measurement of growth and decline.

b) identification of trends and fluctuations.

c) projections and predictions.

Ayoade (1973) considers the following aims of analysis of time series:

1) to understand their properties such as their variability, the characteristics of their periodic and irregular oscillations and the trend over time in the fluctuations of their values.

2) to predict the future behaviour of the time series taking into consideration their basic properties. However, the later aim of analysing time series for rainfall, and climatic subjects is too difficult, because climates often change gradually and groups of wet or dry years sometimes occur. Also short period data does not give confident results. Usually the principal aim of the time series analysis is to describe the history of movement in time of some variable at a particular site. Rainfall sequences are characterised by variability and fluctuation behaviour. This highlights the importance of studying time series, the properties of which are of great significance in planning, designing and operation of water resource systems.

Kottegoda (1980) considers the main objective in studying time series is to understand the mechanism that generates the data and also not necessarily, to produce likely future sequences or to forecast events over a short period of time. To do this it is necessary to make inferences regarding the underlying laws of the stochastic process from one or more sequences of recorded observations and then postulating a model that fits the data, which are then used for estimation purposes. At first it is necessary to identify and analyse the different components of time series (in this case rainfall on successive years). Because of analysing a set of data over a period of time we need to know if there are trends. Probability analysis depends on a random distribution would be meaningless if a strong trend exists in the data.

4.1 Components of time series

In general, a time series can be divided in to a deterministic component which is one that can be determined for predictive purposes and a stochastic component consisting of chance and chance-dependent effects. The deterministic component may be consistent types of non periodic behaviour, the most common example being trend which is, in effect, a long smooth movement lasting over the span of the observations. The two practical cases of trend are a rising trend in which, as a general rule, values tend to increase with time and a falling trend to which the reverse situation applies. This is the one of main purpose of this chapter.

4.2 Definition of Rainfall time series

A rainfall time series is a sequence of rainfall measurements taken in time. For example, the total amount of rain falling on each day , each month, each year over a period of time could be recorded. Such a record constitutes a daily, monthly, and annual rainfall time series. In hydrology rainfall is the most important input variable to a mathematical model, so that understanding of rainfall time series is necessary in a wide range of hydrological or engineering applications and agricultural studies.

4.3 Rainfall Trend Studies

The occurrence of wet series or dry series of years is important for agricultural planning, especially if this can be practical. This raises the question as to whether identifiable fluctuations or trend in rainfall exist. This aspect has received considerable attention in recent years with the occurrence of drought conditions in the Sahel and other tropical areas (Jackson 1989). When droughts persist, alternatives must be sought either through a change of agricultural practices or by selecting crop varieties that are more resistant to low moisture conditions. Such decisions are made when there is an understanding of general trends in rainfall occurrence and departures from the mean. Long-term fluctuations are a feature of regional rainfall and this information is of vital importance for the planning and operation of irrigation and water resources projects.

Trends have implications for water resources and agriculture, and if they exist it is dangerous to rely on short period rainfall records in planning water resource development. If a trend is identified, extrapolation in to the future is dangerous since there may be no justification for assuming its persistence. Hence persistence will be considered in following sections as well. Therefore, identification of physical causes of changes is important for future prediction. As was earlier mentioned the possible existence of trend has important implications for water resources, for agriculture and for rainfall probability and reliability estimate. The practical importance of trend, over the period considered and in the future if it continues, is difficult to assess. The magnitude and rate of change must be considered. Vegetation and human activities may adjust fairly easily to a gradual change over a long period but not to rapid fluctuations. A trend may simply be part of a long-term fluctuation (Jackson 1989). It is sometimes useful to analyse a time series in parts, which may include oscillations about the trend, seasonal effects and a random component. Possible mechanisms for such features in hydrology and climatology time series might include some of the following :

Gradual natural or human induced changes in the environment can produce a trend in time series. Urbanisation on a large scale may result in changes in rainfall. A jump in a time series may result from any sudden change in the environment such as closure of a new dam, starting to pump ground water, forest fire etc. Also global warming, changes in air masses, and jet streams may be relevant to trend.

Kottegoda (1980) indicated a steady and regular movement in time series through which the values are, on average, either increasing or decreasing is termed a trend. This type of behaviour can be local, in which case the nature of trend is subject to change over short intervals of time, or, on the other hand, a global trend may be long lasting. Hammond and McCullagh (1978) recognise three components in a time series:

(i) the over-all or long-term trend, sometimes referred to as the secular trend;

(ii) periodic fluctuations of a rhythmic nature, associated with daily, seasonal or other cyclic variations;

(iii) irregular or random variations. So a steady and regular movement in a time series through which the values are on average, either increasing or decreasing is termed a trend. This type of behaviour can be local in which case the nature of the trend is subjected to change over short intervals of time or on the other hand, we can visualise a global trend that is long lasting. If a trend in a rainfall time series appears, it is in effect, part of a low frequency oscillatory movement induced by climatic factors. Annual data is used for the analysis of trend. Since this award the complication of seasonal patterns. Moreover annual data is independent of the timing of the wet season and its length.

4.4 Methods of Annual Rainfall Trend Study

There are many methods for rainfall trend study, these methods vary from graphical methods to statistical and also in mathematical elegance and the degree to which they generalise the fluctuations in time series.

Graphical methods aim show the trends but can not be used to show the spatial distribution patterns of the nature of the trends. In order to examine over-all trend in annual rainfall linear regression (linear trend) analysis method is used for annual rainfall series of the central Elburz stations. Mann-Kendal Rank method will be also considered. Although the trends in climatic data are seldom linear, the linear regression method has been used to search for significant trends. The graphs of rainfall trends have been provided (Figure 4-1 to Figure 4-13) to give a visual judgement. Thus two methods were used in studying rainfall trends over the Central Elburz Stations, as follows:

a) linear regression

b) Mann- Kendal Rank

4.4.1 Rainfall Trend using Linear Regression

The over- all trend in a time series is examined in this study by the use of linear regression analysis where the values in the series are regressed on time. Ayoade (1973) considered this the most appropriate method of studying the over- all trend in a time series. Also Brook and Mametse (1970), Bunting, *et al.* (1976), Nicholson (1980), Dennet, *et al.* (1985) and Hess (1995) used linear regression in their studies. However some caution is needed in the interpretation of any linear trend. The trend may not be statistically significant, or the actual trend may be irregular rather than linear so that the linear regression may mask periodic variations over the time period. This can be tested by significance. For a given time series assuming a linear relationship the trend equation is the form:

$$Y = aX + b$$

Where '**a**' is the gradient of the regression line, '**b**' is the intercept of the regression line on the **Y**- axis, **Y** is the dependent variable, here, rainfall, and **X** is independent variable, here, time in years. If the years involved under **X** and appropriate rainfall under **Y**, then the number of units (**b**) which **Y** will be increase per unit increase of **X** will be obtained by this formula:

$$\mathbf{b} = \frac{\sum(X-\overline{X})(Y-\overline{Y})}{\sum(X-\overline{X})^2},$$

This formula will ensure that the resulting regression line fits the least squares requirement. Also the regression coefficient (**b**) and the correlation coefficient(**r**) between **Y** and **X** are related by the equation b= r $=\frac{\sigma y}{\sigma x}$, where σy and σx are the standard deviations of y and x respectively. Both the regression coefficient and the correlation coefficient can be statistically tested for significance using a two-tailed trend test. For no trend to exist in the data series the P- value should exceed 5% significance level (P- value$\rangle$ 0.05). The P- value for individual years has been provided in Table 4-1 and Figure 4-12. As demonstrated by the Table 4-1 and Figure 4-12, those stations which have a P- Value less than 0.05 are considered to show a trend. Based on Table 4-1 and Figure 4-12 stations of Gorgan, Gonbad, Shirgah, Damghan, Karaj, Semnan, Takestan, Tehran, Northern Kandavan, and Southern Kandavan have a significant trend.

4.4.2 Rainfall Trend using The Mann-Kendal rank statistic

Trend analysis has been carried out for the 30 years rainfall series of the central Elburz stations for the same period as the time series analysis. Mann-Kendal rank method is a powerful technique, as it can be used for linear or non-linear trends. This method is widely used in climatic studies, for example W.M.O (1966), Winstanley (1973), Tyson *et al* (1975), Parathasarathy and Dhar (1976), Kousky and Shin Chu (1978), Ogalo (1979), Dhar. *et al* (1982), Oladipo (1987), Olaniran (1989), Anyadike (1993a), Anyadike (1993b) and Kadioglu (1997).

The presence or absence of trends in annual rainfall series in the region of Elburz has been determined by using the Mann-Kendal rank statistic,τ. 'This shows (over the time period under consideration), whether there is a monatonic increase or decrease in the average value between the beginning and end of the series' (Anyadike 1993).
For a sequence X1, X2,....XN, the standard procedure is to determine the number of times, it is said p (in Kottegoda 1980) or ni (in Anyadike 1993a) in all pairs of

observations (Xi, Xj, j 〉 i) that Xj is greater than Xi ; the ordered (i,j) subsets are (i = 1, j = 2, 3, 4, ..., N), (i =2, j =3,4,5,...,N), .., (i =N-1, j =N). The maximum possible number of such pairs occurs for a continuously increasing sequence. This is a rising trend where succeeding values are throughout greater than preceding ones. The statistic is computed from:

$$\tau = \frac{4ni}{N(N-1)}$$

Where ni is the number of values larger than the i^{th} value in series subsequent to its position in the series of N values.

The expected value of τ in a random series is zero, and its variance is given by following formula:

$$\sigma\tau^2 = \frac{(4N+10)}{9N(N-1)}$$

The ratio of τ to its standard deviation $\sigma\tau$ (i.e.τ /$\sigma\tau$) is an indication of trend in the data. When there is an absence of trend in the data series, the ratio lies within the limits of +/- 1.96 at the 95 % level of confidence and 5 % level of significant.

Computed values of τ and $\sigma\tau$ for the individual years are shown in Table 4-1. Based on Table 4-1 and Figure 4-13 stations with a significant trend are Gonbad, Shirgah, Damghan, Karaj, Semnan, Takestan, Tehran, Northern Kandavan and Southern Kandavan.

4.5 Discussion of Analysis

The trend analysis was carried out with all individual rainfall stations for annual rainfall for the period of 1958 to 1987, and the equations of the lines of best fit regression for rainfall and results of Mann-Kendal rank have been shown in Table 4-1 and Figure 4-1 to 4-13 and also the results of the Mann-Kendal rank and regression trends methods have been compared. The results of the trend analysis show that some of the annual series examined indicated some form of fluctuation rather than any particular significant trend. However the analysis results using both regression and Mann Kendal are similar. 0.05 significant level, was adopted for the rank, and regression trend test. A significant trend showed only 1o out of the all stations using regression analysis, and 9 out of the stations using Mann-Kendal rank in Mann-Kendal rank, Gorgan has no trend but it does have a trend in the regression study.

Stations with a significant trend are as follows;

a) Coastal area stations;

3 of these stations are located on the coastal area (Gorgan, Gonbad, Shirgah), Gorgan, Gonbad and Shirgah are located to the East of the Caspian Sea due to distance from sea, and proximity of central Asia deserts they have high rainfall variability, continental conditions.

b) Southern slope stations;

5 stations located on the southern slopes (Damghan, Karaj, Semnan, Takestan, Tehran), they have dry climates where year to year variability of rainfall is high, because of air subsidence and distance from humidity resources.

c) Higher Altitudes;

2 stations are located in higher altitudes (Northern Kandavan, Southern Kandavan). It may be affected by Siberian cold anticyclone, subtropical jet stream, the polar front jet stream and these have high rainfall variability. In this study those stations have high rainfall variability, therefore refer to significance of trends. However, it must be noted that some of stations indicating significant trends are adjacent to stations indicating no significant trends and the spatial distribution of significant trends followed no particular pattern. This makes it difficult to give a climatological explanation for the observed trends in the annual series. For this reason it is not possible to examine the general circulation parameters in relation to these trends.

Dennet, *et al.*(1985) quoting Newell and Kidson (1984) suggest that subsidence in the subtropical regions may be stronger in the north during Sahelian dry periods and in southern hemispheres during wet periods, thus linking Sahelian rainfall variability to a modulation of the general circulation. It is possible for trends in this study area to arise from local factors, but it is impossible to test that the trends in recent years are part of long-period fluctuations due to the limited data available. This investigation of trend in rainfall has been necessary before the considerations of probability and seasonal patterns. The fact that no trend would appear to be consistent throughout the region suggests that probability of annual rainfall can be based on the run of years from 1957 to 1987. However the period of climatic data, is insufficiently long for forecasting. For example, in 30 years annual rainfall data in Tehran and Gorgan stations there is a trend (for Tehran P-value 0.02, and Gorgan P-value =0.03), while 44, and 37 years annual rainfall data in Tehran, and Gorgan there is not any trend (P-value 0.26, P- value = 0.90). This is similar to Ogalo (1979) quoted by Tyson *et al* (1975) in observations that the tendency for occurrence of a trend in South African rainfall trend decreased with the increase in the length of records. This suggests that for South Africa short term fluctuation is the cause of any trends observed in short term records. It would appear that this may also be true of Iran. The trend seen in short term record may in fact be a fluctuation in a longer run of data. Kottegoda (1980) recognized shifts in the position of the jet stream and changes in the number of its loops affect precipitation from the Sahara to the Middle East, India and America, bringing about same fluctuations on climate. 'In view of the assertion by Olarniran, and Sumner (1989) quoted by Winstanley (1973) that rainfall declines over the Northern Hemisphere part of tropics from 1930 to 2030, the secular trend in the deviation series was first investigated for the period 1939-1985. However, it was noted that the stations indicating significant trends were near those indicating no significant trends and their spatial distribution had no particular pattern. Trend may have prevailed in this part of Northern Iran in the last 40 years, but the magnitude of this trend is uncertain, mainly because of the possibility that the Takestan series might have been affected by changes in the rain gauge site (c.f. the data section) or by other local factors.

According to Lamb (1966) the rainfall changes since 1960 are related to a change of the general wind circulation affecting most parts of the world. Lamb (1973) also illustrated the shift in climatic belts but he did not state whether they followed any particular pattern or trends. He found that for the period 1951-1969 the northern subtropical anticyclone moved near the equator bringing decreased rainfall along the southern parts of the desert margin in Africa. Rao (1963) found no evidence of change in either annual rainfall over arid and semi- arid regions of India during the last 80 years. Agnew and Anderson (1992) considered in arid parts of West Africa there is much evidence for a long- term decline in precipitation but rainfalls elsewhere in the arid realm show no clear trends. Dennet, *et al.*(1985) did not find statistically significant trend for 5 stations in the Sahel. Bunting, *et al* (1982) have shown no established trends or periodicities in their investigation about rainfall trend in the West African Sahel. Anydike (1993 a) results of trend analyses over Banjul have shown that the monthly and annual rainfall series exhibit significant decreasing amounts. Also Anydike (1993 b) in his Seasonal and annual rainfall variation over Nigeria investigation found a significant tendency towards decreasing annual rainfall totals. However there has not been any investigation of climatic change and rainfall trend in Iran. The mechanism suggested for trends evidenced elsewhere and in particular for West Africa may have some relevance to Iran. This is particularly may be true of the jet streams. However if one of this mechanism has affected rainfall trends in Iran we would expect the results to be seen throughout the region and certainly for a larger proportion of stations than shown in this study. The fact that there is no consistent trends makes it impossible to recognize any climatic change in Iran. Recently Alijani (1997) concluded by analysing temperature data for some parts of Iranian stations there has not been fond any climatic change over Iran during 40 years period.

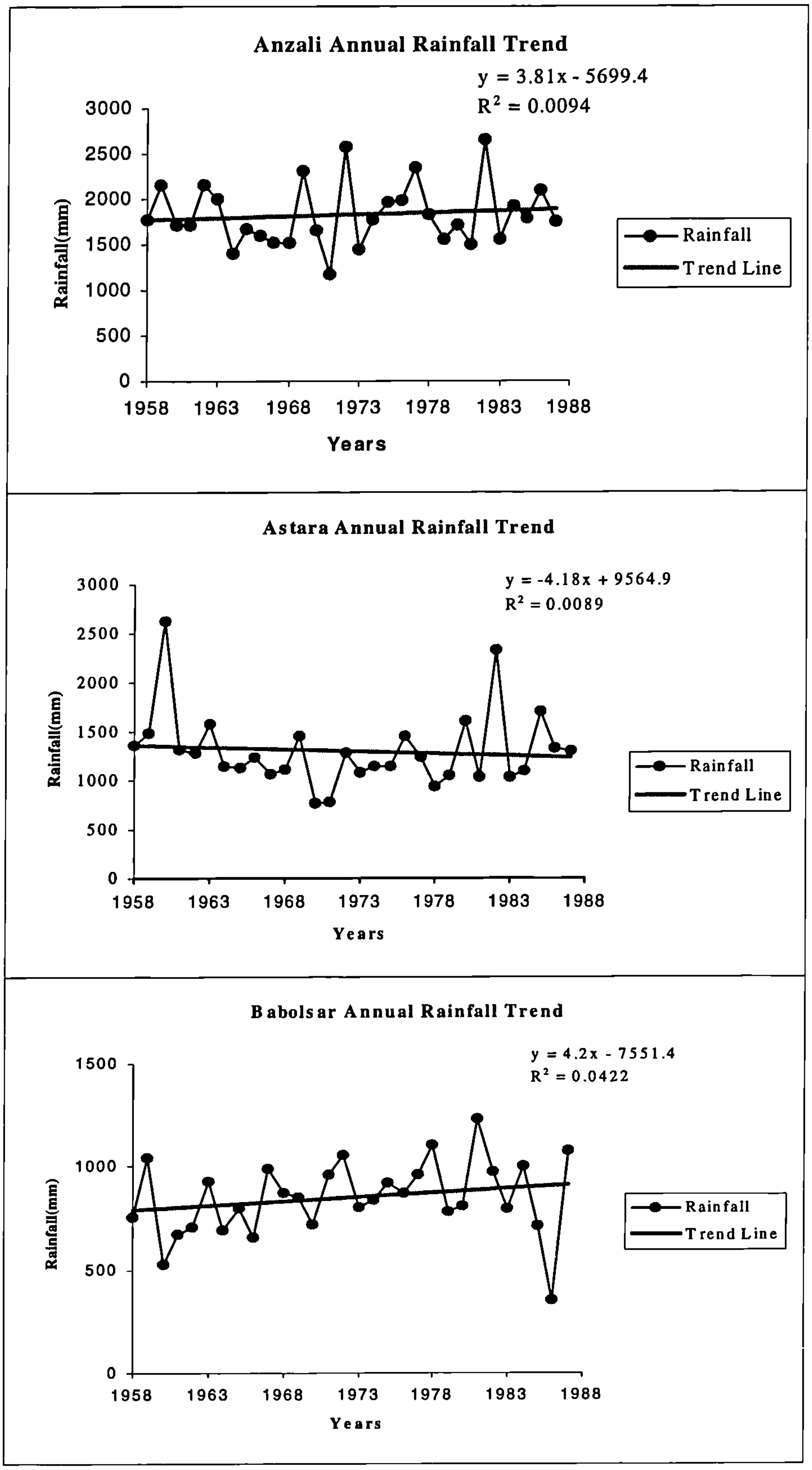


Figure 4-1 Coastal Area Annual Rainfall Trend.

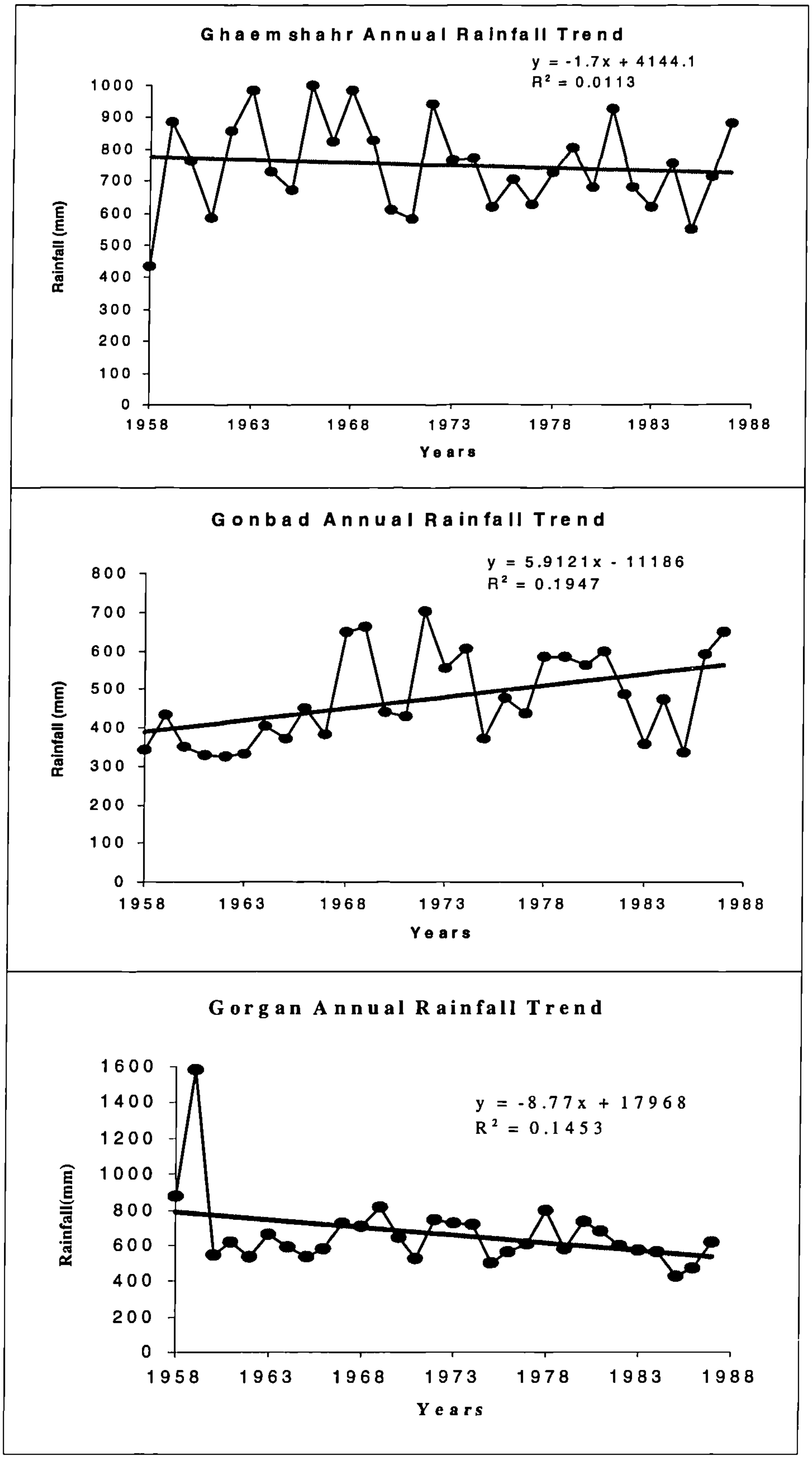


Figure 4-2 Coastal Area Annual Rainfall Trend.

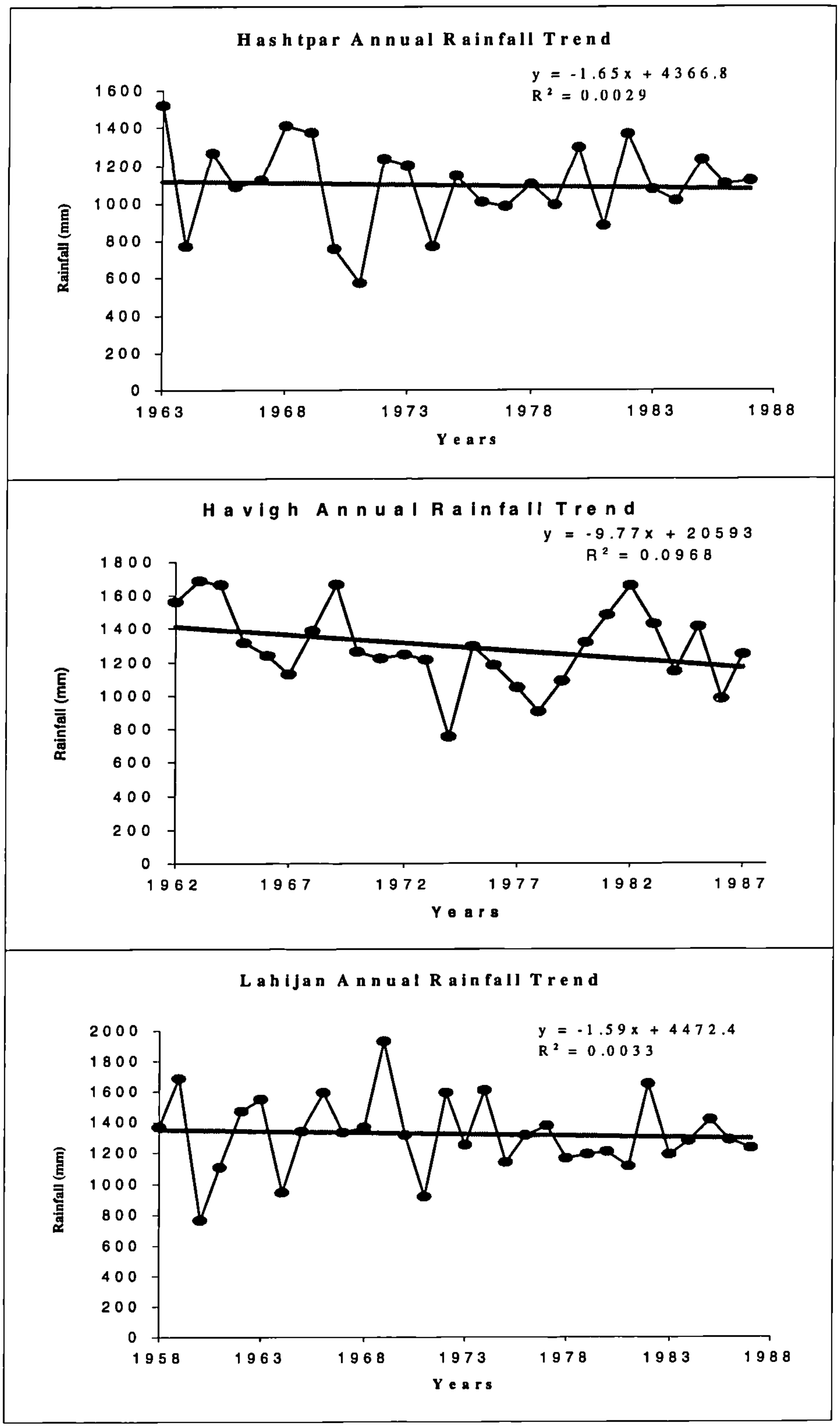


Figure 4-3 Coastal Area Annual Rainfall Trend.

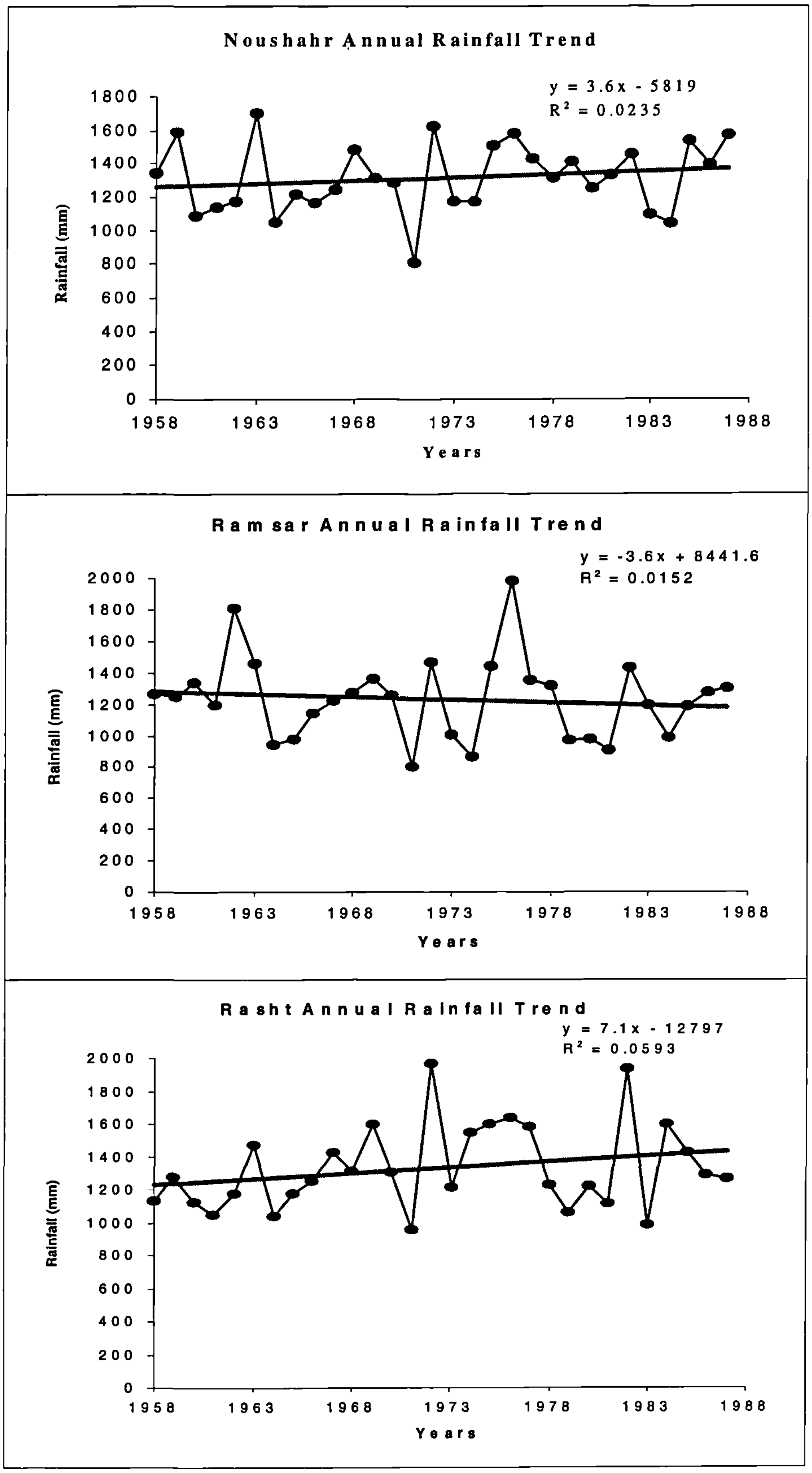


Figure 4-4 Coastal Area Annual Rainfall Trend.

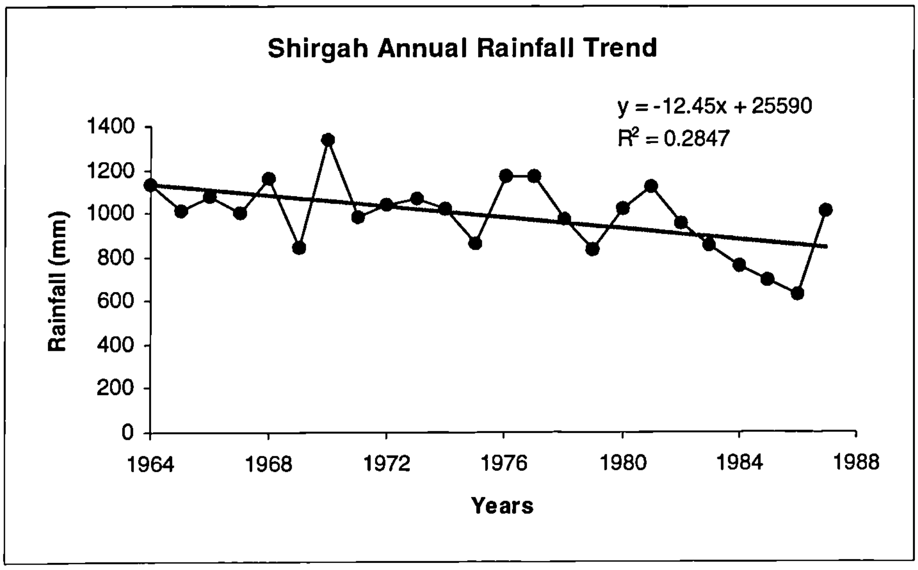


Figure 4-5 Coastal Area Annual Rainfall Trend.

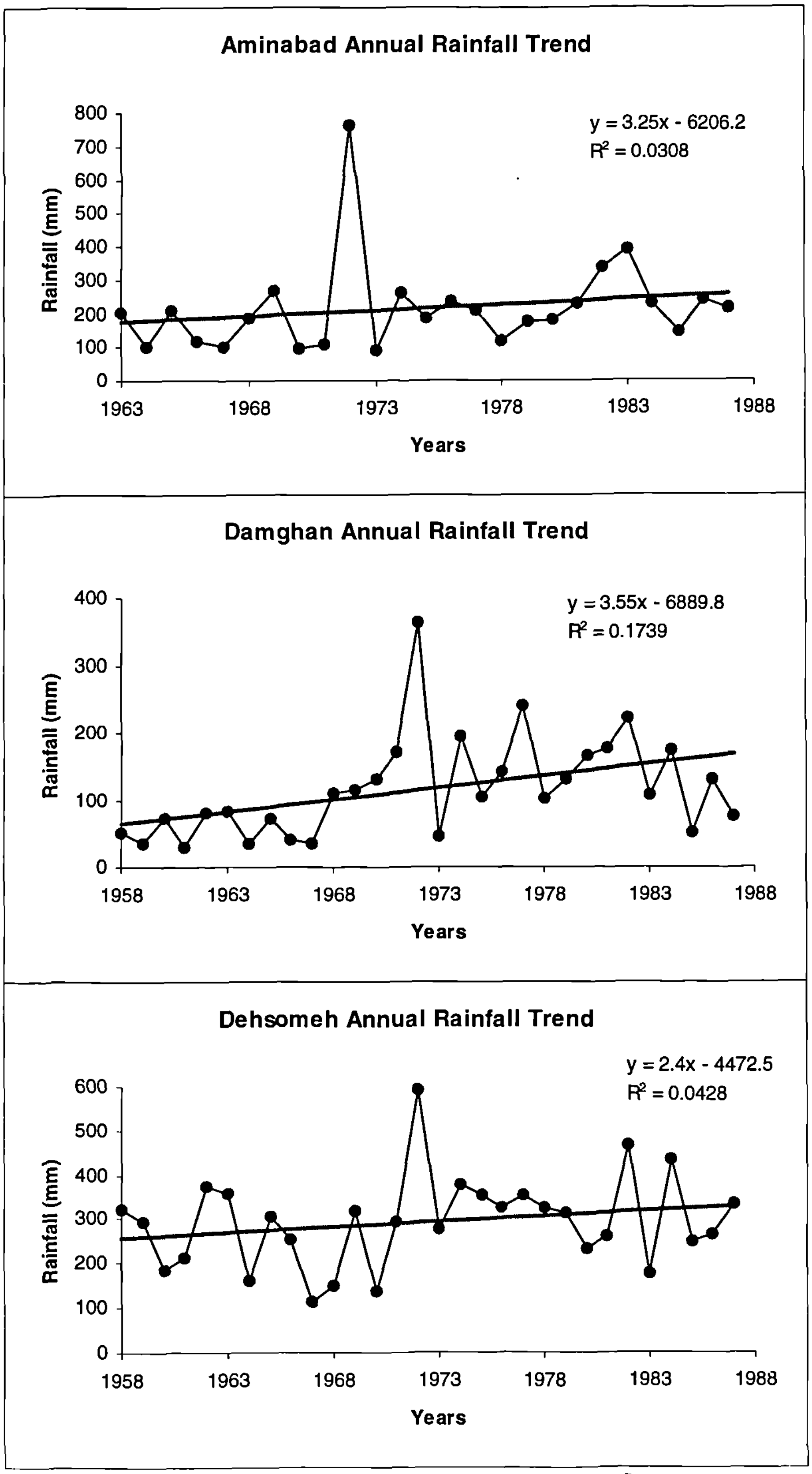


Figure 4- 6 Southern Slopes Annual Rainfall Trend

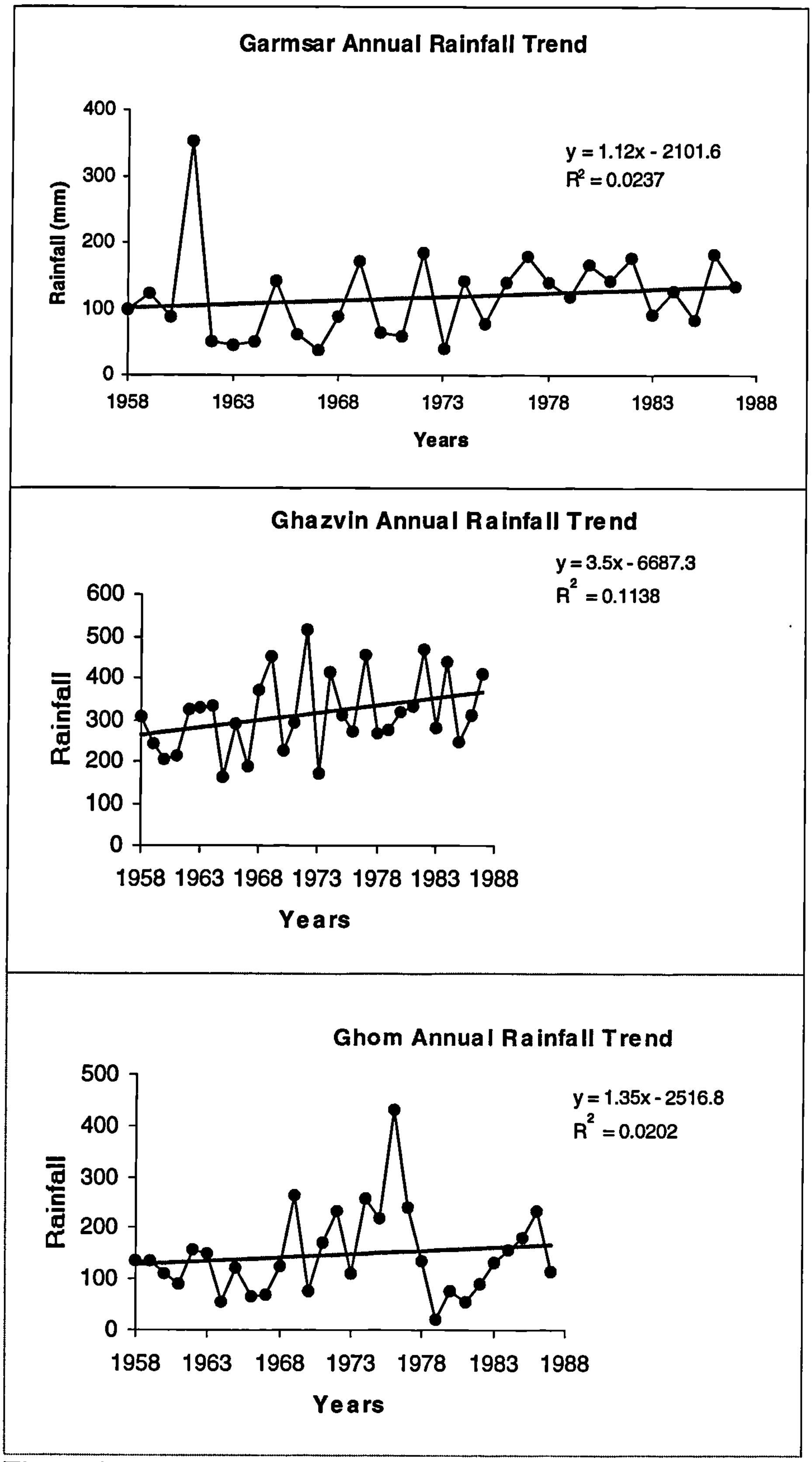


Figure 4- 7 Southern Slopes Annual Rainfall Trend

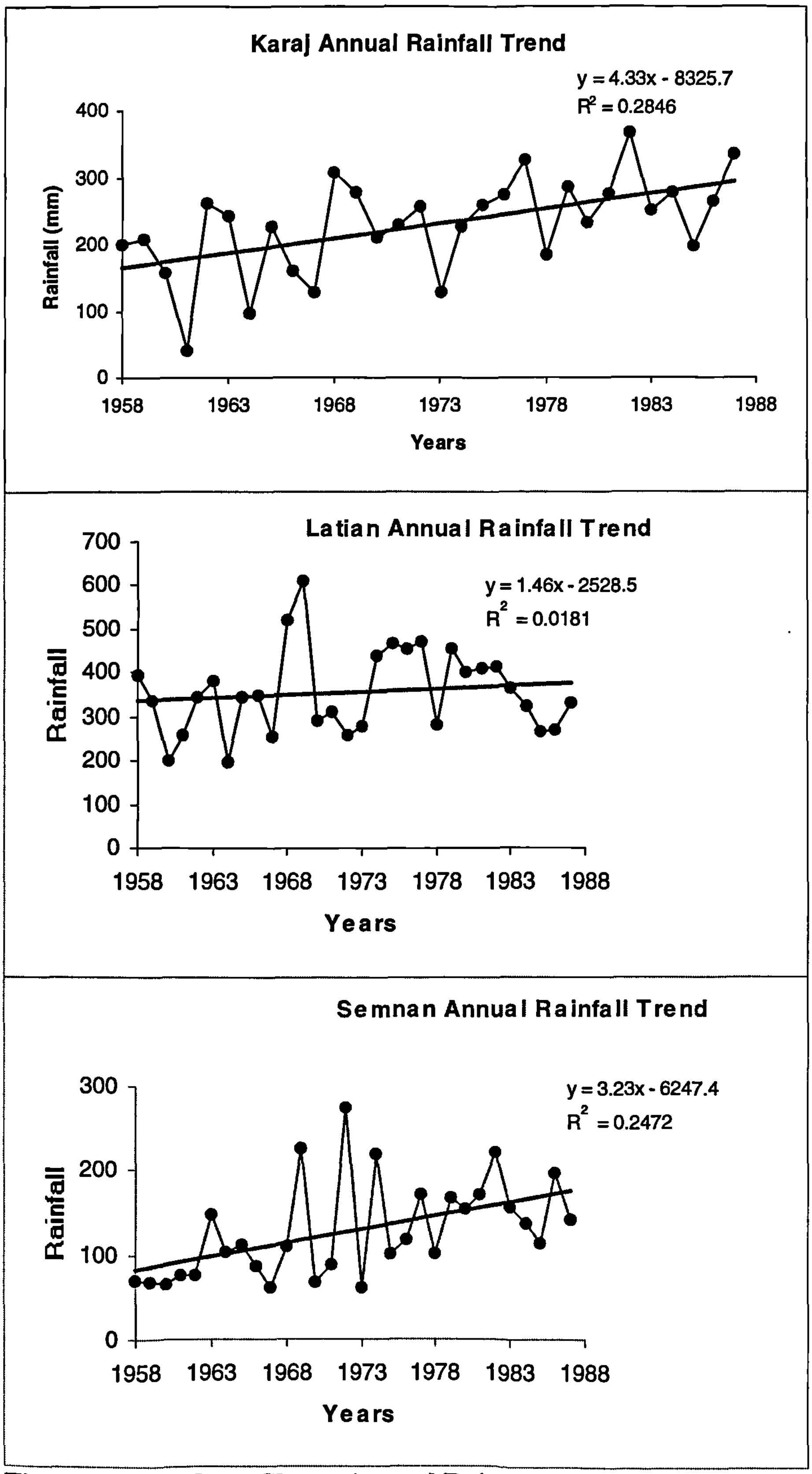


Figure 4-8 Southern Slopes Annual Rainfall Trend

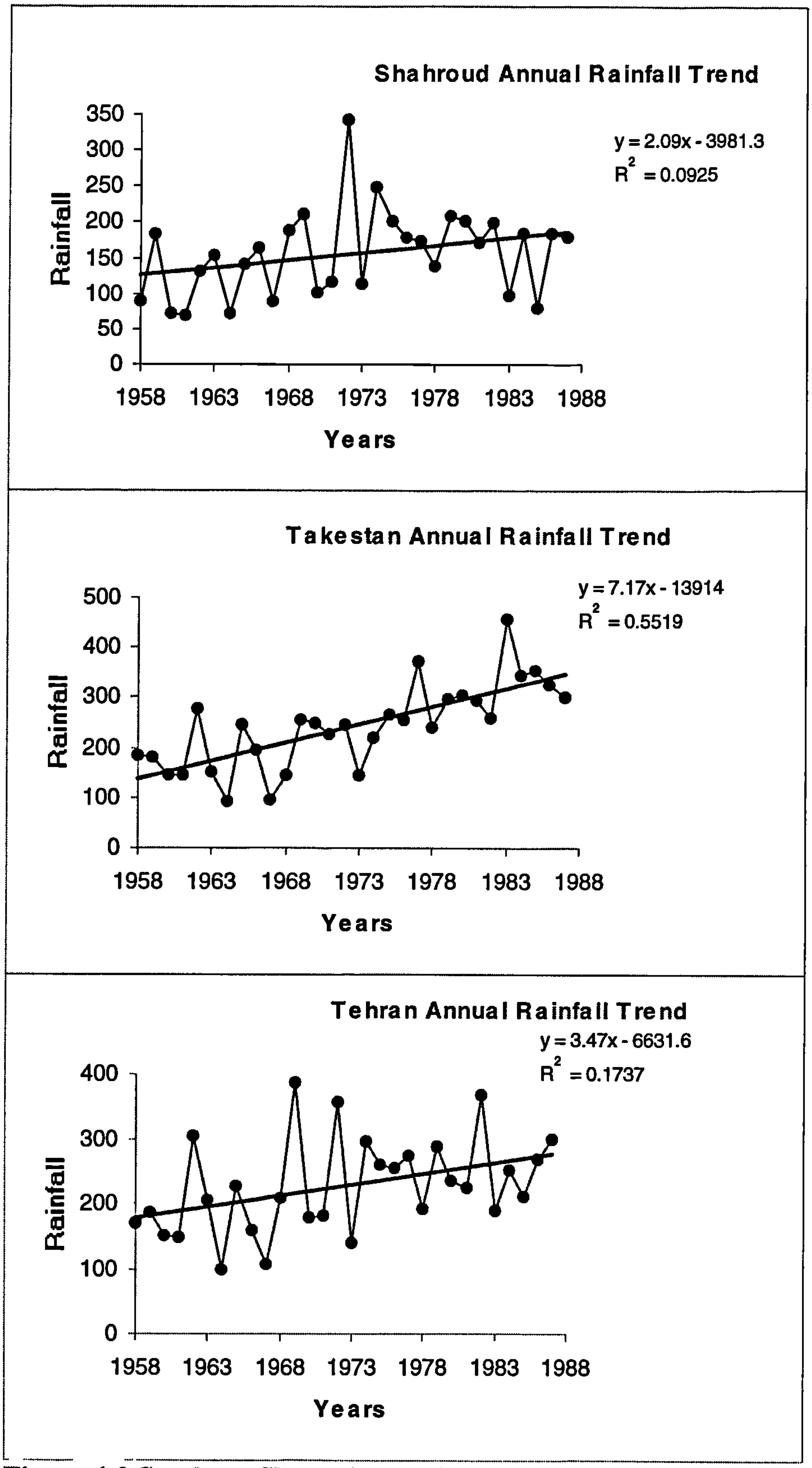


Figure 4-9 Southern Slopes Annual Rainfall Trend

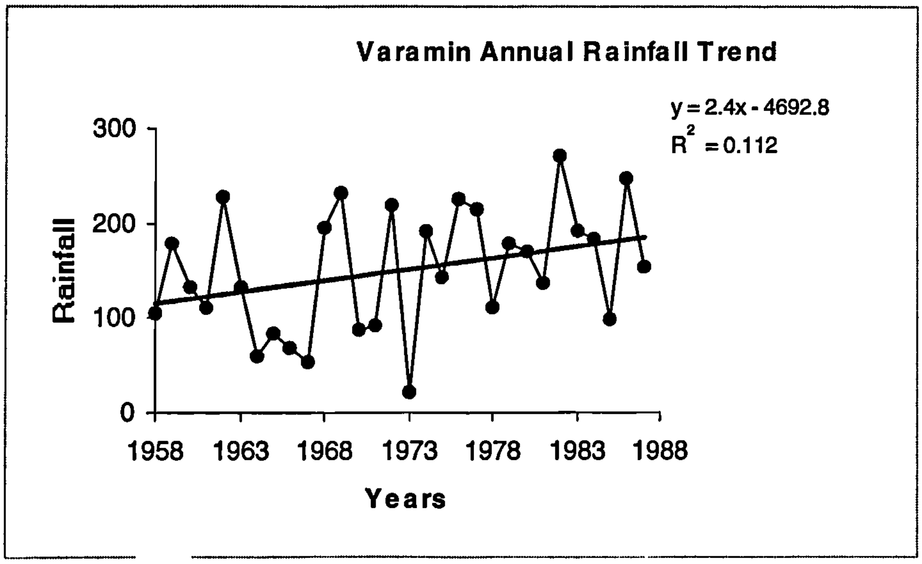


Figure 4-10 Southern Slopes Annual Rainfall Trend

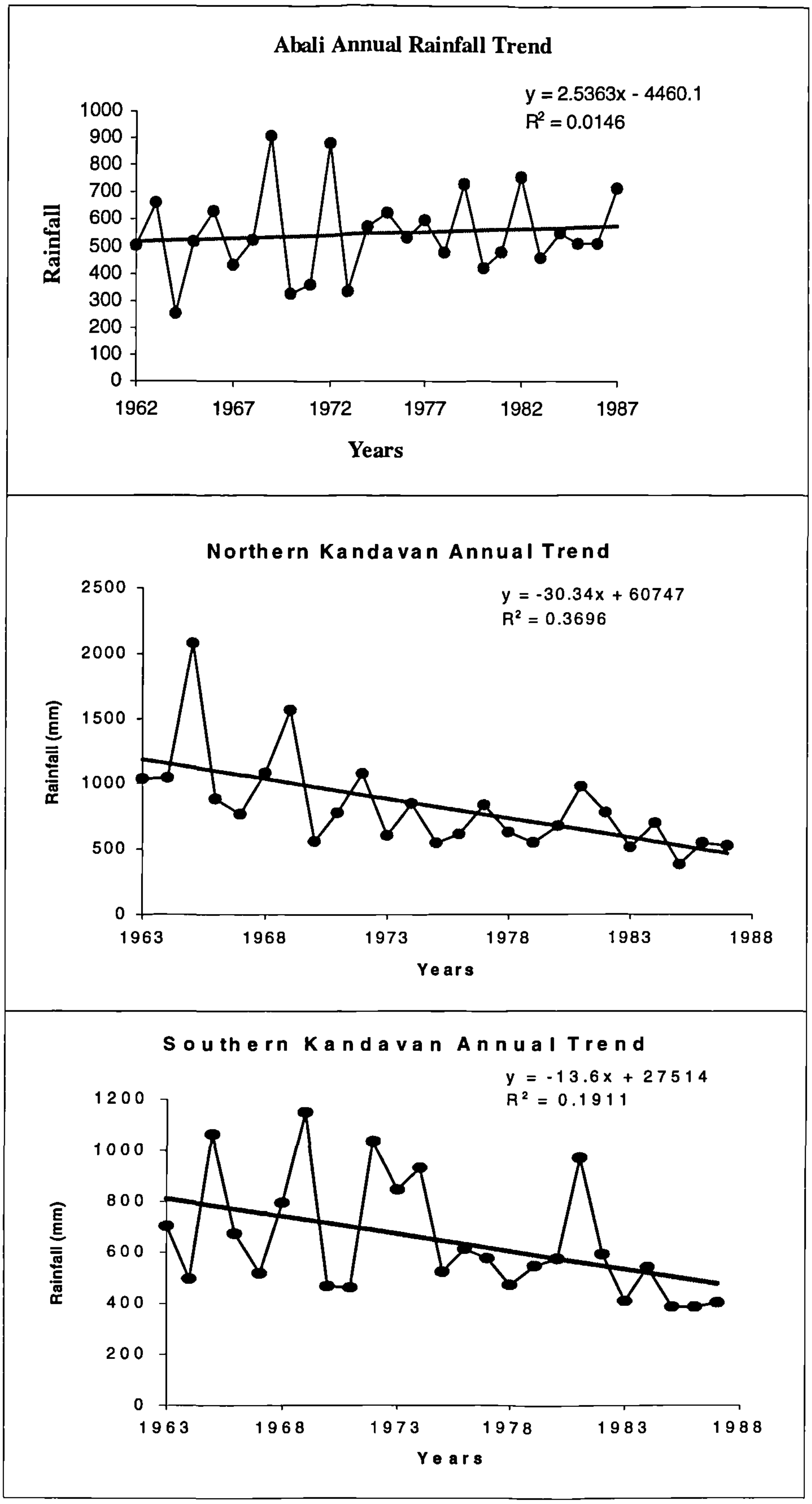


Figure 4-11 Southern Slopes Annual Rainfall Trend

Table 4-1 Regression Coefficient and Mann-Kendal Rank Statistic Trend Analysis.

Stations	**P-Value**	τ / σ
Anzali	0.61	0.196
Astara	0.51	-1.08
Babolsar	0.27	1.73
Ghaemshahr	0.57	-0.55
Gonbad	0.01*	2.47*
Gorgan	0.03*	-1.266
Havigh	0.07	1.78
Hashtpar	0.41	-1.16
Lahijan	0.76	-0.58
Noushahr	0.41	1.08
Ramsar	0.51	-0.48
Rasht	0.19	1.40
Shirgah	0.01*	-2.23*
Aminabad	0.4	0.68
Damghan	0.02*	2.97*
Dehsomeh	0.27	0.66
Garmsar	0.41	1.62
Ghazvin	0.06	1.40
Ghom	0.45	0.41
Karaj	0.002*	2.90*
Latian	0.47	0.66
Semnan	0.005*	3.01*
Shahroud	0.10	1.90
Takestan	0.000002*	4.3*
Tehran	0.02*	2.44*
Varamin	0.07	1.51
Abali	0.55	0.63
Northern Kandavan	0.008*	-2.75*
Southern Kandavan	0.026*	-3.85*

* Stations significant at 5% probability.

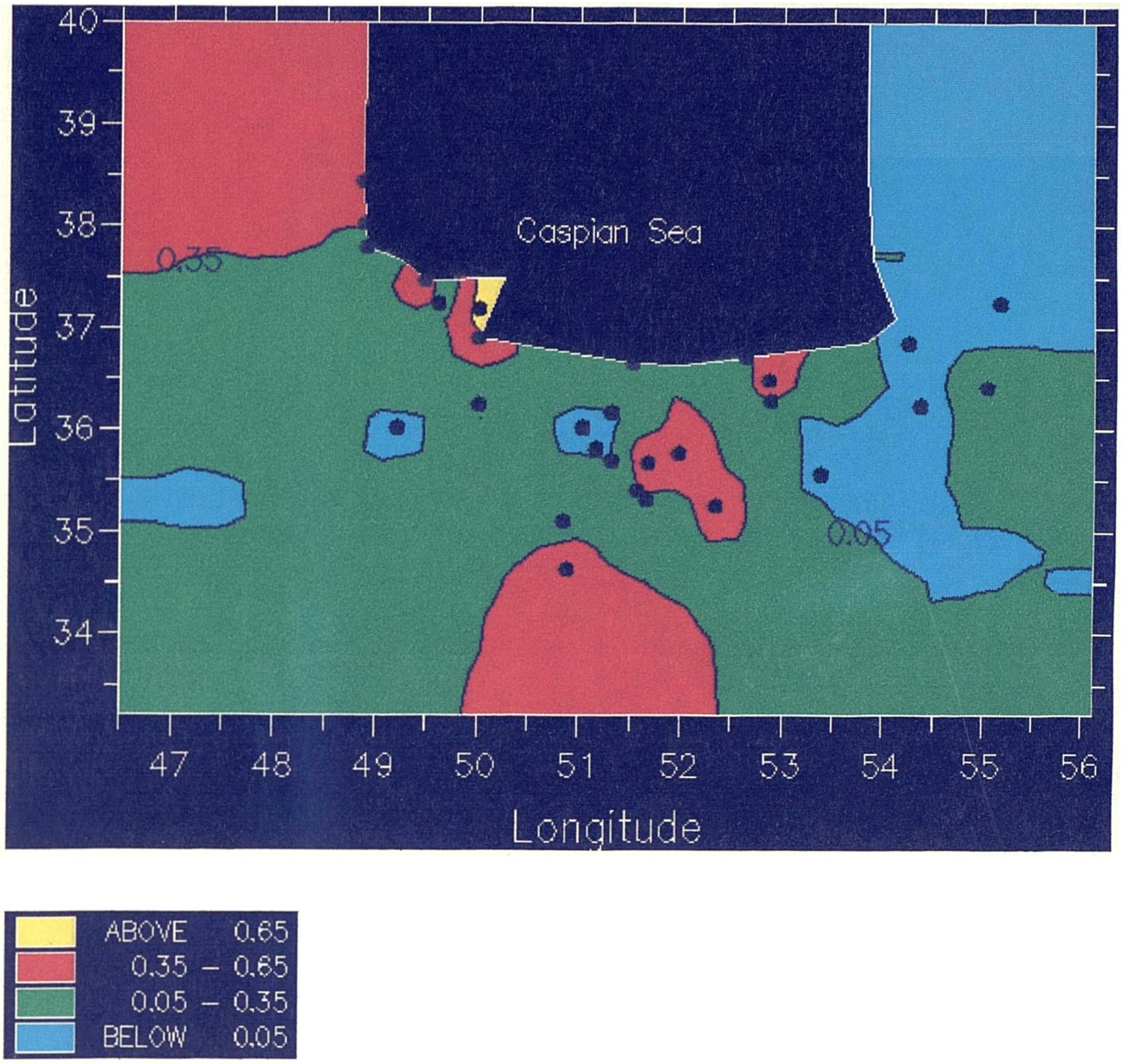


Figure 4-12 P-Values Annual Rainfall Trend

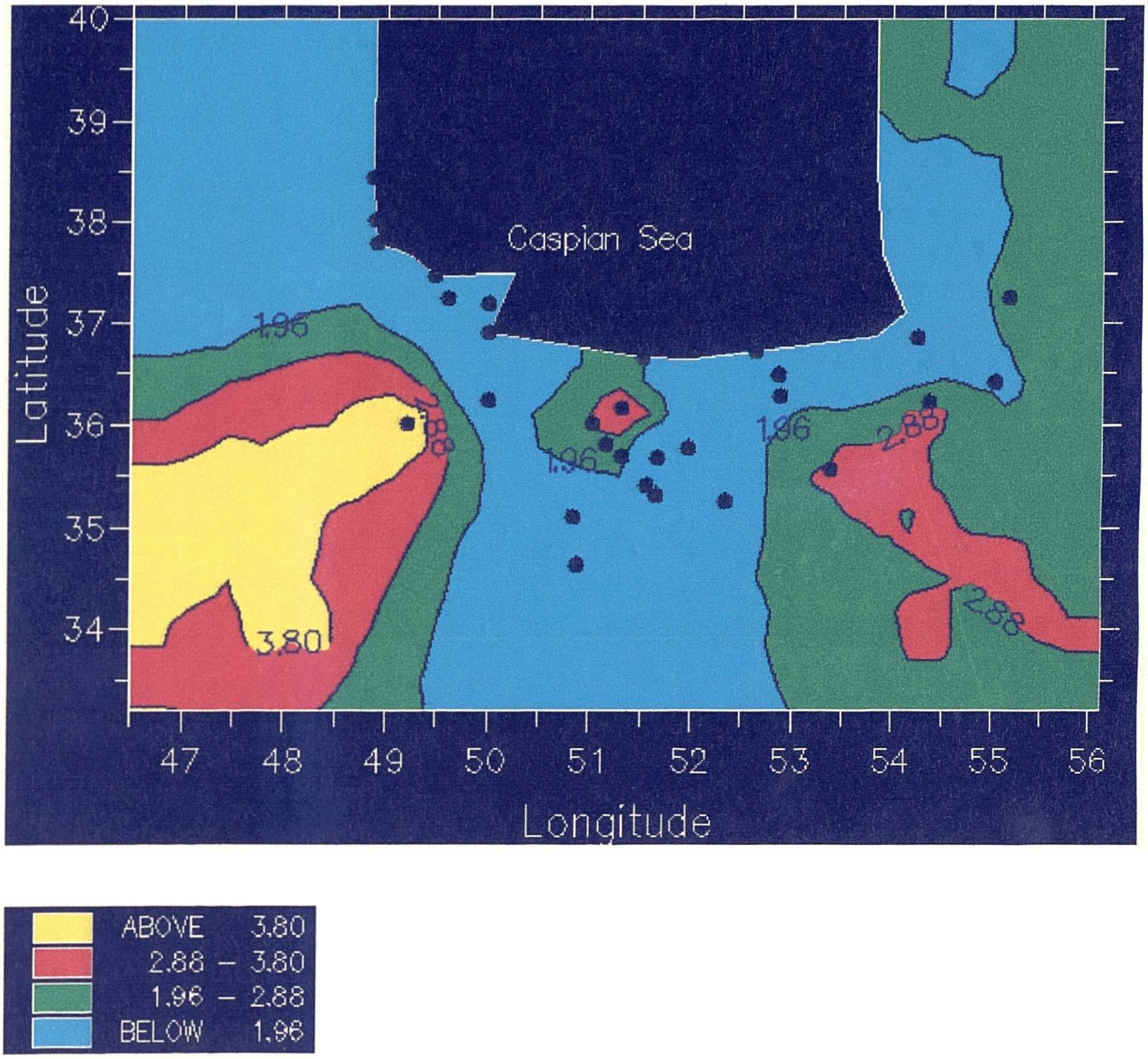


Figure 4-13 The Mann- Kendal Rank Statistic Trend

4.6 PERSISTENCE

As previously mentioned the practical importance of trend over the period considered and in the future if it continues, is difficult to assess. Consequently information about persistence is very important when considering water resources, rainfall probability and reliability for agricultural planning. Persistence is the tendency for successive values of climatological series to remember their antecedent values and to be influenced by them (Giles and Flocas 1984). Thus large values of an element such as rainfall tend to be followed by large values and vice versa, so that runs of values of similar magnitude tend to persist throughout the sequence. The best known measure of this tendency is the lag-1 auto-correlation that sometimes is refereed to as serial correlation, which measures the statistical relationship between observations in a single data series. The idea in auto- correlation analysis is to calculate a correlation coefficient for each set of ordered pairs (z_t, z_{t+k}).

The lag-1 auto-correlation or serial correlation, r_l is given by the following equation:

$$r_l = \frac{1}{N}\sum_{i=1}^{N-1} (Y_i - \bar{Y})(Y_{i+1} - \bar{Y}) / V^2$$

where,

N = the length of time series,

Y_i = the annual rainfall value respectively for the i^{th} year,

$\bar{Y}$ = the N- year mean of Y_i and

V^2 = the variance of each series over N years.

The significance of r_l is tested by using of the succeeding equation:

$$(r_l)_t = \frac{-1 \pm 1.645\sqrt{(N-2)}}{N-1}$$

Negative values of r_1 are indicative of marked high frequency (i.e.short- period) oscillation in rainfall series. Conversely, positive values indicate long- period oscillations and so point to persistence or Markove linear type persistence. Anyadike(1993) quoted by Gilman *et al* (1963) have suggested that this persistence has the property $r_n = (r_1)^n$. Accordingly the serial correlation's of lag- 2 (r_2) and lag- 3 (r_3) were computed and compared with $(r_1)^2$ and $(r_1)^3$ respectively. If the relationships $r_2 \propto (r_1)^2$ and $r_3 \propto (r_1)^3$ are satisfied then Markove persistence can be assumed. In other words a large annual rainfall total for one year would be followed by an equally large total for the next year.

The results of calculating lag-1 to lag-3 have been shown in the Table 4-2 which shows annual rainfall time series for all stations. Also the results of the significance test of r_1 have provided in Table 4-3. Considering Table 4-2 and 4-3, the computed values of r_1 for the annual rainfall time series are seen to be positive for Gonbad, Gorgan, Havigh, Hashtpar, Northern Kandavan and Southern Kandavan stations. However the values of r_2 and r_3 are greater than $(r_1)^2$ and $(r_1)^3$ respectively. The relationships between r_2 and $(r_1)^2$, r_3 and $(r_1)^3$ are not satisfied, thus Markove persistence can not be assumed. With regard to the Table 4-2 lag-1 shows all stations are not significant at the 95 % confidence level. Thus the rainfall series may be considered to be random.

Table 4-2 The Analysis Results of Auto- Correlation (r_1).

Stations	Lag 1	Lag 2	Lag 3
Anzali	-0.278	-0.136	0.104
Astara	-0.021	0.044	0.238
Babolsar	-0.061	-0.120	0.172
Ghaemshahr	-0.050	-0.174	0.14
Gonbad	0.355	0.183	0.077
Gorgan	0.162	-0.019	-0.110
Havigh	0.411	0.110	-0.057
Hashtpar	0.199	-0.173	0.058
Lahijan	-0.188	-0.184	0.027
Noushahr	-0.141	-0.015	-0.161
Ramsar	0.162	-0.245	-0.185
Rasht	-0.210	0.165	0.021
Shirgah	0.220	0.218	0.046
Aminabad	-0.191	-0.061	0.073
Damghan	0.168	0.404	0.219
Dehsomeh	-0.061	0.001	0.284
Garmsar	-0.175	-0.031	-0.057
Ghazvin	-0.238	0.034	0.188
Ghom	0.367	0.220	-0.044
Karaj	0.120	0.033	0.333
Latian	0.268	-0.092	-0.034
Semnan	-0.070	0.182	0.312
Shahroud	-0.128	0.153	0.327
Takestan	0.513	0.416	0.491
Tehran	-0.119	-0.056	0.385
Varamin	-0.053	0.012	0.135
Abali	-0.459	-0.266	0.517
Northern Kandavan	0.227	0.113	0.264
Southern Kandavan	0.127	-0.141	0.171

Table 4-3 The Significance Test of r_1.

Stations	Negative Values (-)	Positive Values (+)
Anzali	-0.33	0.27
Astara	-0.33	0.27
Babolsar	-0.33	0.27
Ghaemshahr	-0.33	0.27
Gonbad	-0.33	0.27
Gorgan	-0.33	0.27
Havigh	-0.36	0.28
Hashtpar	-0.37	0.28
Lahijan	-0.33	0.27
Noushahr	-0.33	0.27
Ramsar	-0.33	0.27
Rasht	-0.33	0.27
Shirgah	-0.37	0.28
Aminabad	-0.37	0.28
Damghan	-0.33	0.27
Dehsomeh	-0.33	0.27
Garmsar	-0.33	0.27
Ghazvin	-0.33	0.27
Ghom	-0.33	0.27
Karaj	-0.33	0.27
Latian	-0.33	0.27
Semnan	-0.33	0.27
Shahroud	-0.33	0.27
Takestan	-0.33	0.27
Tehran	-0.33	0.27
Varamin	-0.33	0.27
Abali	-0.36	0.28
Northern Kandavan	-0.37	0.28
Southern Kandavan	-0.37	0.28

4.7 Summary and Conclusion

Time series analysis were applied to the annual rainfall. The possible existence of trend has important implications for water resources, agriculture. In this study it is particularly important as it must be assessed before conclusion on rainfall probability and reliability are made. The practical importance of trend, over the period considered and in the future if it continues, is difficult to assess. The magnitude and rate of change must be considered. The over-all trend in a time series was examined in this study by the use of linear regression analysis where the values in the series are regressed on time. Also trend analysis has been carried out by Mann- Kendal rank.

0.05 significant level, was adopted for the rank, and regression trend test. A significant trend showed only 1o out of the all stations using regression analysis, and 9 out of the stations by Mann- Kendal rank. The results of the trend analysis showed a weak statistically significant that some of the annual series examined indicated a form of fluctuation rather than any particular significant trend. However the analysis results using both regression and Mann Kendal were similar.

Stations with a significant trend are as follows;

a) Coastal area Stations;

3 of these stations are located on the coastal area (Gorgan, Gonbad, Shirgah), Gorgan, Gonbad, and Shirgah are located to the East of the Caspian Sea due to distance from sea, and proximity of the Central Asia deserts they have high rainfall variability, continental conditions.

b) Southern Slope Stations;

5 stations located on the southern slopes (Damghan, Karaj, Semnan,Takestan and Tehran), they have dry climates where year to year variability of rainfall is high, because of air subsidence and distance from humidity resources.

c) Higher Altitudes;

2 stations are located in higher altitudes (Northern Kandavan, Southern Kandavan). It may be affected by Siberian cold anticyclone, subtropical jet stream, and the polar front jet stream. However, it must be noted that some of the stations indicating significant trends are adjacent to stations which indicated no significant trends and the spatial distribution of significant trends followed no particular pattern. Trend may have prevailed in this part of Northern Iran in the last 40 years, but the magnitude of this trend is uncertain, mainly because of the possibility that the Takestan series might have been affected by changes in the rain gauge site (c.f. the data section) or by other local factors, for example for Gonbad effects of over grazing and loss of forest by fire may be main reasons. This makes it difficult to give a climatological explanation for the observed trends in the annual series. For this reason it is not possible to examine the general circulation parameters in relation to these trends. The trend seen in short term record may in fact be a fluctuation in a longer run of data. It is possible for trends in this study area to arise from local factors, but it is impossible to test that the trends in recent years are part of long-period fluctuations due to the limited data available. However the period of climatic data, is insufficiently long for forecasting. Also persistence has been investigated because of its important information when considering water resources, rainfall probability and reliability for agricultural planning. Analyses of results did not find persistence nor provide a satisfactory basis significance for forecasting from the data series.

5

5. Rainfall Variability statistical assessment

The average conditions of seasonal rainfall distribution pattern have been previously considered for the different stations of the Central Elburz. However, considerable variation may occur from year to year, for each of the wet and dry season rains, so that consideration of variability is necessary. In the Central Elburz where seasonal rainfall is highly variable and often unreliable, it is also important to find out the variability pattern of the rainfall distribution and assessment of this variability as an essential aspect of rainfall climatology. This is especially true for the southern slope stations of the Elburz where rainfall is marginal for crop growth.

A knowledge of the degree of variability of the rainfall of a particular area is of more importance than information on the annual rainfall. Unfortunately no detailed studies have been done by any investigator on this important aspect of climatology except by Kaviani (1988) using a short period data collected (1961-1976) throughout Iran. The purpose of this chapter is to examine the spatial patterns of annual, and monthly rainfall variability over the northern Iran part of the Central Elburz, over the past 40 years using the coefficient of variation.

5.1 Definition of Variability

Variability is a measure of the dispersion around the central tendency of a set of data, it gives the likelihood of the mean value being repeated each year, season, or month (Ayoade 1988). The concept of rainfall variability is closely linked to that of rainfall reliability or probability. The important thing about variation is that it allows comparison between stations. Since it is expressed as a percentage of the mean and it is independent of annual total rainfall. It is thus possible to map the pattern of variability.

5.2 Rainfall Variability Discussion

The importance of variability has been expressed by many authors e.g. Kenworthy (1964), Cochem (1966), El Tom (1972), Nieuwolt (1972), Woodhead (1982), Odumodu (1983), Bradzil and Samaj (1985), Chacon and Fernandez (1985), Chan (1985), Acheampong (1987), Kaviani (1988), Mcgregor (1989), Sutherlan, *et al* (1991), Anyadike (1993), Turkes *et al* (1995) and Turkes (1996). Variability has also been used in studies of agricultural productions. Odumodu and Griffiths (1980) in Odumodu (1983) have identified year to year fluctuation in the weather (especially in precipitation) as the most important factor causing variation in food production in the state of Texas and Oklahoma.

Across the broad, physically- differentiated land of Iran rainfall is highly variable. In Iran, as elsewhere in the Southwest of Asia, moisture availability is a major climatic control on agriculture. The problem of rainfall variability is possibly one of the most sensible and complicated aspects of the rainfall climatology of the Central Elburz its agriculture plays the most important role in economic development. In this part of Iran, the climate is suited for the production of field crops such as rice, wheat, tea, cotton, kiwi, different varieties of citrus, and different fruits which are extensively cultivated throughout the coastal region. They are usually exported to other regions of the country, and neighboring countries. Variation in the annual, monthly and seasonal rainfall in every year are reflected in the extent of water control measures. Most of the coastal lowlands of the Caspian which contain more than 90 percent of the land area of the Southern Elburz lack adequate artificial irrigation, consequently, crop production depends directly on rainfall for moisture. Yields of rain fed crop are severely affected by variation in rainfall.

Forecast assumes that we can predict events, variability merely expresses the risk in percentage terms. However, it provides a general idea of the probable advantages of improvement through irrigation. Also variation of the yields of most of the major crops to a large extent is due to rainfall variability the climatologist role is to develop objective techniques and methods for assessing variability of seasonal, annual and monthly amounts.

5.3 Application of Rainfall variability to agriculture

The seasonal rainfall distribution regulates the agricultural calendar, and the rainfall variability from year to year is the main factor responsible for fluctuations in yields and total production. Variability of rainfall creates uncertainty and a number of problems, particularly for communities without the financial and technical resources to overcome them (Jackson 1985). The importance of variability is highlighted during periods of failure or excess with associated drought and flooding but its effects are felt to a more limited extent in many other years, by fluctuations in agricultural yield. This is specially true of the Southern Slopes of the Central Elburz of Iran where droughts have lead to great problems of food supply for the population.

In the Central Elburz, agriculture provides the greatest source of foreign commerce and is also the largest employer in the economic sector. Food crops, are important in keeping down the level of imports. Given the economic importance of agriculture, a study of climatic variability is justified.

The northern Elburz (coastal area) and most of southern Elburz (southern slopes that most crop production such as wheat, barley, cotton, cucumber, tomato, melon etc. are obtained from dry land farming.) are highly dependent on rainfall. However, commercial crop agriculture in Iran is largely restricted to the Central Elburz coastal areas. Compared with other areas in the coastal districts experiencing a large average annual rainfall, the Caspian lowlands have the following climatic advantages:

1) the widespread occurrence of deep, fertile, humus-rich, and moisture retentive black soils;

2) a less variable rainfall, both seasonally, and annually;

3) more rainfall, a longer rainy season and rainfall distribution throughout the year.

Thus knowledge of monthly, annual, and seasonal rainfall amounts received at a given place is of little use in planning agricultural and other uses of water resources unless the variability and probability of receiving such amounts of rainfall are also known. Long period rainfall records from the study area have been analyzed in this study to establish the climatological pattern of rainfall distributions, variability, and probability of rainfall. Variations in amount of rainfall from year to year are considerable in the Southern Elburz and this variability is more critical here than in the coastal area.

5.4 Measures of Variability

The importance of rainfall variability cannot be over emphasized in the Southern Elburz where rainfall appears to vary more widely than in the other Elburz areas and where its incidence within the year is highly seasonal. The effectiveness of rainfall for agriculture depends primarily on whether the rainfall received is enough to offset evaporation losses. However, the reliability of rainfall, as measured by its variability from year to year, is also an important factor since rainfall is much more variable than evaporation. The concepts of rainfall reliability and variability are intertwined. The less variable the rainfall at a place is, for example, the more reliable it is. In other words, the index of variability of a phenomenon about its mean value is a measure of the degree of likelihood of the mean amount being repeated. The variability of rainfall can be expressed by a number of indices, some of them are simple subjective and the variability of rainfall at two or more sites can not be objectively compared. Thus different graphical and statistical techniques are described in the literature for measuring the indices of variability:

a) Graphical methods, e.g. the dispersion diagram, depend on the visual interpretation of plotted values. Therefore, these graphical methods as previously mentioned are largely subjective and the variability of rainfall at two or more sites can not be objectively compared.

b) Statistical methods, vary in their degree of mathematical sophistication and the measure of central tendency around which they are calculated.

Usually the variability techniques require a relatively long period of records. In the case of the present study a long series of data is available for the selected stations of the Central Elburz that gives reliable results of variability coefficients.

Rainfall variability is expressed as a percentage of the mean using 2 indices as follows:

1) The variation coefficient (C.V.) $C.V. = \frac{\sigma}{\bar{X}} \times 100$ (Standard Deviation (S.D)

$$\sigma = (\sqrt{\frac{\sum(X-\bar{X})^2}{N}})$$

2) Relative Variability $= \frac{M.D}{\bar{X}}$ (Mean Deviation (M.D) $= (\frac{\sum(X-\bar{X})}{N})$

$C.V. \frac{\sigma}{\bar{X}} \times 100$ where,

C.V. = The variation coefficient

σ = the standard deviation

$\bar{X}$ = the mean rainfall amount.

The statistics based on the arithmetic average are the most useful because they allow further analysis. Compared with other measures due to their limitations the coefficient of variation is the best index of variability. Balogun in Odumodu (1983) showed that the use of the coefficient of variation is the most appropriate measure of variability when examining the spatial variability of rainfall. The coefficient of variation indicates deviation from the mean and it gives an imagination from rainfall regime. One of the major advantages in using the coefficient of variation is that further analyses of rainfall probability assessments could be considered in the following chapter. Chan (1985) has compared various indices of variability and concluded that the CV was theoretically the best index. In his analysis, he compared the values of the various variability indices of two nearby stations, which had similar rainfall patterns and found that the CV was the most stable and repressive of all the indices. The CV has also been popularly accepted as being mathematically the most versatile index and is preferred by researchers in discussing the variability of climatic elements.

Kaviani (1988) indicated that without considering information of the coefficient of variation any farming planning in Iran is at risk. Thus coefficient of variation have been adopted in this study for assessing the spatial variability of rainfall in the Central Elburz.

5.5 The Analyses of Annual Rainfall Variability over the Central Elburz

The analysis of annual rainfall variability over the Central Elburz was carried out using all the available years at the 29 selected stations the time span for these stations varied from 26 to 45 years. According to Chan (1985) quoted by Glover and Robinson (1953) the mean rainfall for the year, season or month is no guide to the agricultural potential of an area, and a measure of rainfall variability is also required. The coefficient of variability of annual rainfall in the Central Elburz is presented in Table 5.9-1 and Figure 5-1. The variability pattern of annual rainfall of the Central Elburz shows that rainfall variability increases in this region from north to south. This means that the coastal area experiences a lower variability in rainfall than its counter part in the southern slope stations.

One of the earliest studies on the variability of rainfall based on the C.V. in Iran was by Kaviani (1988) using data collected for 15 years (1961-1976) throughout the country. However, there were only a few stations from the Central Elburz. In his annual map he depicted a range in northern Iran from 20 to 30 percent C.V. in the East and West of the Caspian Sea. He also found that the Persian Gulf coastal and central parts of Iran have more than 80 percent of C.V. However in this Central Elburz study the Caspian coastal area show C. V. values 37% to 18%. The general rule suggested by Cochem (1966) that variability increases with decreasing mean annual rainfall applies only very approximately.

The analysis results of annual rainfall variability for the Central Elburz Stations based on amounts and their characteristic are as follows:

5.5.1 Coastal Area Stations

The Table 5.9-1 and Figure 5-1 show the coefficient of variation of the annual rainfall over the Central Elburz. In contrast with Kaviani's finding, the highest coefficients (of 30 percent variation of the annual rainfall and above) are found in the North-eastern part of the Caspian Sea. The lowest coefficients of variation of the annual rainfall (of less than 17 percent) are found in the South-west of the Caspian Sea. Most coastal stations have coefficients variation of annual rainfall of 22 percent. Usually the coefficient of variation of annual rainfall varies from between 16.53 and 37.78 percent. Also the coefficient of variation of the annual rainfall in the coastal area increase from West to East.

5.5.2 Southern Slope Stations

Table 5.9-2 and Figure 5-1 show that the coefficient of variation of annual rainfall for the southern slope stations. In this part of the Central Elburz the amount of variation coefficient is generally high. The highest coefficients (50 percent and above) are observed in stations that are located closest to the desert area. The lowest coefficients (less than 29 percent) are found around the slope of the mountains. In general, annual coefficient of variation varies from Latian Station which has a C.V. value of 28 to Damghan station with a C.V. value of 64.

5.5.3 The Higher Altitude Stations

In this area the coefficient of variation is less than for the southern slope stations. The highest coefficient (43.52 percent) is observed in the Northern Kandavan, while the lowest coefficient (29.28 percent) is found in the Abali Station. Usually the amount of C.V. of the annual rainfall varies from between 29.28 and 43.52 percent. In addition the amount of variation coefficients of the annual rainfall in the Higher altitude stations decreases with height.

5.6 Correlation between Coefficient of Variation and Annual Rainfall

The relationship between coefficient of variation and annual rainfall are plotted on the Figure 5-2 and Figure 5-3. It can be seen that, usually the variation coefficient decreases while the annual rainfall increases. The correlation coefficient is 0.81 for the southern slope and 0.64 in the coastal area stations.

The analyses of the area distribution of coefficient of variation shows that, in general, there are two important out comes:

1) in the coastal area stations, the coefficient of variation is much lower than on the southern slope stations and ranges from 16.53 to 37.78. These stations also have high average rainfall total.

2) in the southern slope stations the coefficient of variation is much higher and varies from between 28.09 and 64.62 for the different stations, and rainfall amount is low. The result is in agreement with other findings in the literature namely that areas of high rainfall are associated with a low coefficient of variation and vice versa Kenworthy (1964), Nieuwolt (1972), Woodhead (1982), Chang (1985) and Kaviani (1988) etc. However, in some cases this is not strictly applicable in the Higher Altitude stations. For example, northern Kandavan which receives an annual average rainfall of 834.45 mm experiences the highest (43.52%) variability while Abali and southern Kandavan that receive a comparatively low rainfall (Abali 547.73 and Southern Kandavan 649.57 mm) has a low coefficient of variation (Abali 29.28% and Southern Kandavan 34.57%).

5.7 Monthly Coefficient of Variability over the Central Elburz

The monthly rainfall distribution are positively skewed and the variability measurement often show C.V. greater than 100% in the dry months especially in the southern slope stations. The coefficient of variability of monthly rainfall in the Central Elburz is presented in Tables 5.9-1 and 5.9-2. The monthly rainfall variability is generally higher than the annual variability. The coefficient of variation is normally highest for the month with the lowest rainfall and lowest for the month with the highest rainfall. Generally speaking, the drier month has the greater rainfall variability. Rainfall during the dry months (June-October) especially in southern Elburz station, are rare events, and therefore rainfall variability is very high. This is due to the tendency of the monthly rainfall distributions particularly of the dry months to be positively skewed and sometimes the variability amounts demonstrate C.V. greater than 100 percent. Nevertheless, the variations in the magnitude of this index from one place to other place give an idea of the spatial variation in rainfall variability.

5.8 The Analyses of Monthly Rainfall Variability in the Central Elburz

Despite the measures for calculating statistical annual variability over the Central Elbruz Stations, measures of monthly variability have been also calculated for the long series data for the Central Elburz stations.

The analysis for each station in the Central Elburz presented in Tables 5.9-1 to 5.9-2 and also the Figures 5- 4 to 5-9 has been provided.

In January the C.V. varies from 51 percent (Ghaemshahr in the coastal area stations) to 141 percent (Garmsar Station in the Southern Elburz). The C.V. for the month of February changes from between 43% (Shirgah in the coastal area stations) and 135% (Aminabad in the southern Elburz). In March the minimum C.V. occurs in Babolsar (the coastal area stations) 37% and a maximum of 91% in Ghom (southern Elbruz). In April C.V. ranges between 48 (Southern Kandavan in Higher Altitudes) to 159 percent (Astara in the coastal area stations).

The values of the C.V. in May are generally higher than April. Only a few stations have CVs below 60%. These are found in the coastal station districts, and Higher Altitudes Stations. In June, as rainfall decreases over whole of the Central Elburz, the values for the C.V. increases further. The lowest values are not found less than 58 percent. All stations of Southern Elburz have values over 100 percent while stations in the coastal area have values of less than 100 percent.

In July, usually disturbances and thunderstorm line events are absent and total rainfall values tend to be lower than those in June. July has been identified as the lowest rainy month throughout the northern part of Iran (Ramaswamy 1965). During this month, the precipitation occurs under the influence of middle-latitude eastward moving systems whose centers lie far to the north of Iran. The values for C.V. are relatively high and the entire region has values of between 60 to 358 percent. The highest CVs of more than 125% are found in the Southern Elburz stations. In August (as explained previously) the rainfall amount is lowest in the Southern Elburz but in coastal areas the rainfall gradually increases. Also in the Southern Elburz rainfall is more variable than in the coastal area. The values for C.V. are high and the whole region has values of between 61 (Rasht in the coastal area) and 455 percent (Dehsomeh at the southern Elburz). The CVs values in September are lower than in August. The minimum C.V. of 45% occurs in Shirgah (coastal area stations) and a maximum of 387% in Ghom (Southern Elburz). This proves the previously determined conclusion that C.V. increases with a decrease of rainfall.

In October, the change of season due to air masses and the circulation of depression from west and north is significantly reflected in the variability pattern. Only a few stations in the coastal area experience variability greater than 60 percent while, all of the Southern Elburz Stations have more than 100 percent variability when the coefficient of variation varies from between 41 (Shirgah) to 201 percent (Varamin).

As mentioned already, November is a wet month in Iran and with the increase of rainfall over the Central Elburz the C.Vs. amounts therefore decrease. The variability pattern in November varies from between 49 in Noushahr (the coastal area) to 169 percent in Damghan (the Southern Slope Stations).

The pattern of the C.V. for December resembles that January, February and March which are wet months. There is a distinct tendency where the values of the C.V. decreases sharply particularly in the southern slope stations. In the coastal area with the exception Gonbad all stations have values of less than 60 percent. The southern Elburz stations have values ranging from 41 to 119 percent.

Finally referring back to the wet months previously discussed in Chapter 3, section 5.7 and Figures 5-4 to 5-15, rainfall during the months of June-October (in the southern slope stations) and May-July (in the coastal area stations) is less because of absence of frontal storms events, and hence rainfall variability is very high. In contrast during November- May (the wet season in the southern slope stations) and August-December (the wet season in the coastal area stations) have comparatively low CVs due to different airmasses and circularity patterns entering this area (referring Chapter 2). Therefore monthly rainfall variability is likely to be related to synoptic scale meteorological controls. Analysis of the areal distribution of coefficient of monthly rainfall variability shows that, in general, rainfall variability is much lower on the coastal area stations than on the southern slope stations. The coefficient of variation is normally greatest for the month with the lowest rainfall and least for the month with highest rainfall. During wet months as rainfall increases over area, the values for the C.V. decreases further.

5.9 Summary and Conclusion

The mean rainfall for the year, season or month is no guide to the agricultural potential of an area, and a measure of rainfall variability is also required. As the rainfall of some parts of the Central Elburz is subject to marked seasonality, it was also necessary to determine the variability pattern of the rainfall distribution as well.

Analyses of the variability pattern of annual rainfall over the central Elburz shows that rainfall variability increases in this region from north to south. Rainfall variability is much lower on the coastal area (where rainfall amounts are also high) than on the southern slope stations which the variability is high (where rainfall amounts are also low). The result is in agreement with other findings in the literature namely that areas of high rainfall are associated with a low coefficient of variation and vice versa. The annual rainfall variability is generally less than the monthly variability.

The monthly rainfall distribution are positively skewed and the variability measurement often show C.V. greater than 100% in the dry months especially in the Southern Slopes. The monthly CV patterns indicate that with lower mean rainfall have relatively high CVs while months with higher rainfall have considerably lower CVs values. Thus, a decreasing rainfall towards the Southern Elburz stations in both the annual and monthly. Months with the lowest rainfall such as May, June, July, August and September have a high variation coefficient while the wet months of October, November, December, January, February, March and April have a comparatively low coefficient of variation. Also the coastal area stations with higher monthly rainfall have considerably lower C.V. values.

The greatest monthly values of the coefficient of variation are observed during April-August and the lowest values in during September-March.

Agricultural production, both of crops and livestock, varies notably from year to year and rainfall is usually the primary factor responsible for these variations. Either a deficit or a surplus of rain can cause crop failure, as has been the case during the last few years. As a result drought is frequent in the Central Elburz especially over southern slope stations and this district has rainfall variability. There are also occasional excessive falls of more than 10 mm within a week occur on an average at least once a year. These falls cause serious water logging of soils and local flooding on irrigated land. More suitable choice of crops and by a policy for planning introduction of agricultural methods which provide better protection against a shortage or an excess of rain. The advantageous position of the coastal area stations is clear with more rainfall, a longer rainy season and lower variability of rainfall than the southern Elburz stations should be brought to the attention of agriculturist, economist and planers. It appears that these factors have so far been disregarded in most economic plans in this part of the Central Elburz. In the southern Elburz stations with lower rainfall, a shorter rainy season and higher variability of rainfall than the coastal area stations policy for planning should be:

a) changing cropping patterns away from longer growing season varieties to shorter season variety,

b) easing grazing pressures on pasture lands while shifting from cattle towards more drought resistant animals.

Table 5.9-1 The Monthly and Annual Coefficient of Variation rainfall distribution of the Central Elburz

Stations	No of years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Coastal Area:														
Anzali	38	62.74	63.18	55.76	88.04	61.69	88.62	105.07	80.92	57.08	53.39	60.55	51.57	18.59
Astara	30	73.56	88.51	55.18	159.16	99.18	82.35	128.15	91.34	76.87	43.81	52.07	46.04	30.05
Babolsar	38	60.76	53.49	37.42	75.09	89.76	103.94	119.97	86.12	79.77	68.21	64.69	53.37	21.14
Ghaemshahr	31	51.78	50.90	43.48	64.66	69.70	82.29	88.10	76.20	74.65	65.95	56.70	54.15	20
Gonbad	31	77.14	58.13	43.62	85.10	89.64	119.53	133.67	129.86	108.64	110.32	72.98	62.57	37.78
Gorgan	35	86.55	50.40	42.43	55.05	78.53	98.96	110.90	78.47	59.60	78.74	67.77	49.77	35.80
Havigh	26	53.67	50.73	40.88	69.35	72.41	71.15	76.74	65.29	60.77	48.50	57.12	57.43	20.23
Hashtpar	25	57.46	50.10	40.54	63.16	46.40	66.96	105.30	74.65	63.02	48.47	53.59	45.98	19.42
Lahijan	31	54.47	68.75	45.90	82.01	60.48	85.55	135.21	67.65	60.14	55.73	50.13	46.80	19.78
Noushahr	31	61.91	67.27	43.85	59.66	66.09	73.27	134.70	71.72	53.18	52.65	46.24	39.93	16.49
Ramsar	30	60.32	68.27	42.51	68.63	57.65	63.26	156.92	77.81	61.12	50.41	65.66	58.97	21.22
Rasht	32	58.89	64.84	46.64	86.36	61.07	80.00	126.03	61.45	59.43	56.28	59.81	57.59	19.30
Shirgah	24	53.34	43.65	43.71	65.97	62.25	58.86	60.40	54.76	45.34	41.49	96.82	49.31	16.53

Table 5.9-2 The Monthly and Annual Coefficient of Variation rainfall distribution of the Central Elburz (continued)

Southern Slopes													
Aminabad	25	78.36	135.18	71.76	74.71	160.62	371.31	263.33	340.69	278.38	188.87	98.22	69.67	43.29
Damghan	30	108.67	130.85	86.87	104.51	121.49	176.44	215.97	277.05	215.61	149.46	169.46	102.65	64.62
Dehsomeh	31	75.58	59.91	59.07	76.46	94.90	184.65	199.23	455.78	364.56	170.76	86.88	52.61	37.60
Garmsar	30	141.27	109.94	80.49	108.20	111.58	209.80	306.52	353.85	249.38	168.10	149.67	71.65	54.43
Ghazvin	31	75.05	57.45	63.02	63.78	76.31	115.77	305.67	165.95	293.13	111.02	96.39	62.56	31.59
Ghom	32	101.63	88.18	91.83	85.83	113.23	221.65	263.01	324.03	387.52	164.96	151.25	96.50	55.48
Karaj	31	70.20	62.71	62.13	75.17	87.46	138.28	273.04	314.60	229.28	157.53	93.94	57.83	33
Latian	32	51.52	64.16	60.36	54.64	81.13	105.17	262.64	303.34	160.18	116.34	67.53	58.31	28.09
Semnan	30	94.76	70.77	76.78	69.93	92.07	132.61	244.91	270.05	215.82	155.55	130.53	93.53	44.38
Shahroud	32	80.08	97.57	66.13	72.21	91.33	127.19	180.55	221.16	170.47	124.10	99.40	100.02	39.18
Takestan	30	64.15	70.56	56.89	56.07	74.15	110.74	246.76	260.56	310.45	109.39	84.95	75.71	35.02
Tehran	45	73.60	74.09	74.22	78.90	84.18	155.31	328.16	297.40	276.07	181.07	101.30	119.16	39.24
Varamin	30	89.25	78.76	88.89	130.67	99.16	156.66	358.6	309.35	362.68	201.03	115.34	73.60	42.96
Higher Altitudes													
Abali	26	59.61	43.98	66.16	57.44	72.02	111.87	181.8	139.22	198.61	118.64	57.93	46.90	29.28
Northern Kandavan	26	117.55	70.15	72.53	59.22	50.21	136.04	125.6	185.86	134.26	103.31	69.43	41.23	43.52
Southern Kandavan	26	106.68	54.57	68.34	48.35	61.95	183.08	202.5	161.88	203.33	111.25	74.41	53.61	34.57

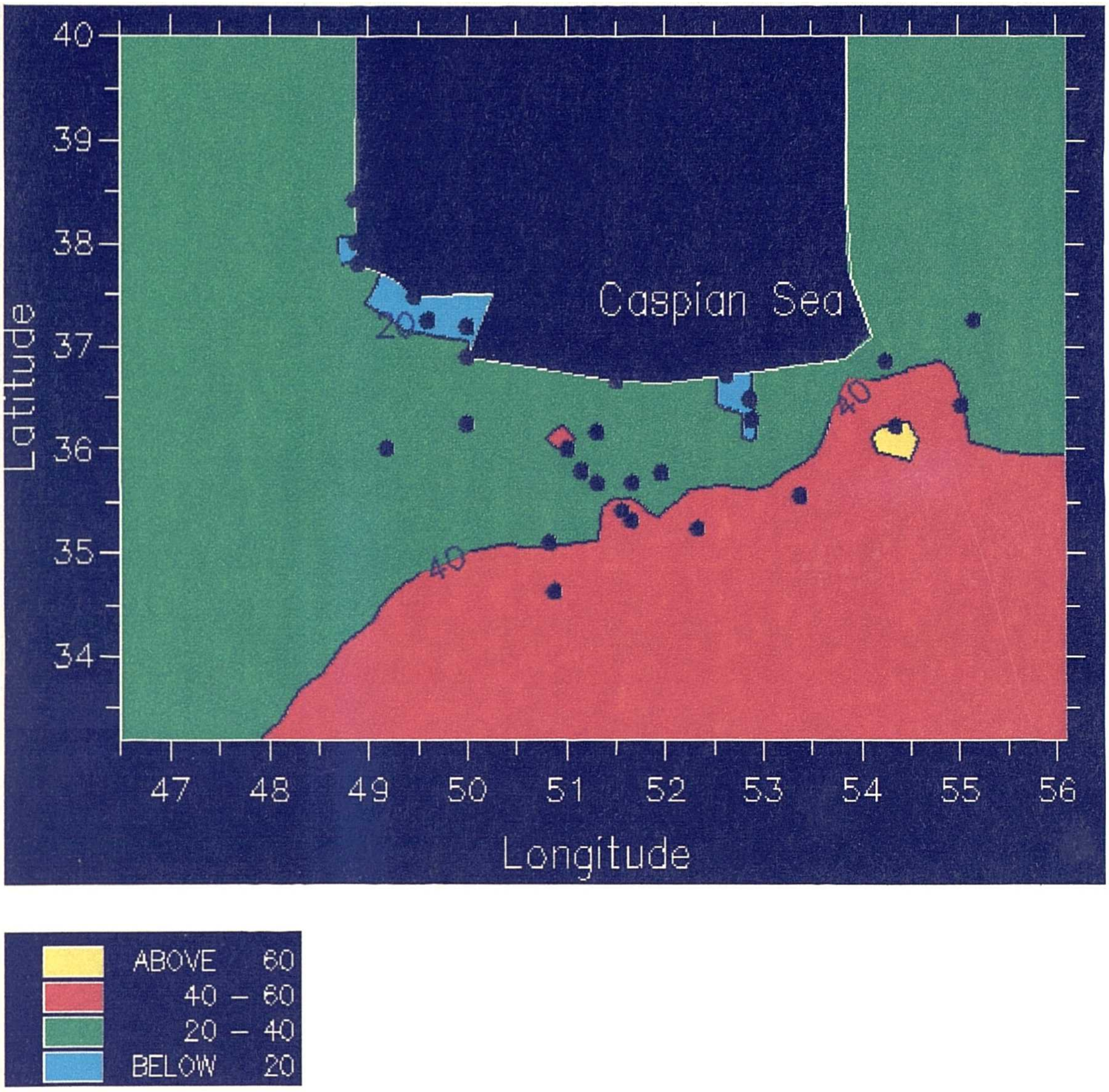


Figure 5-1 Annual Rainfall C.V. over the Central Elburz Stations.

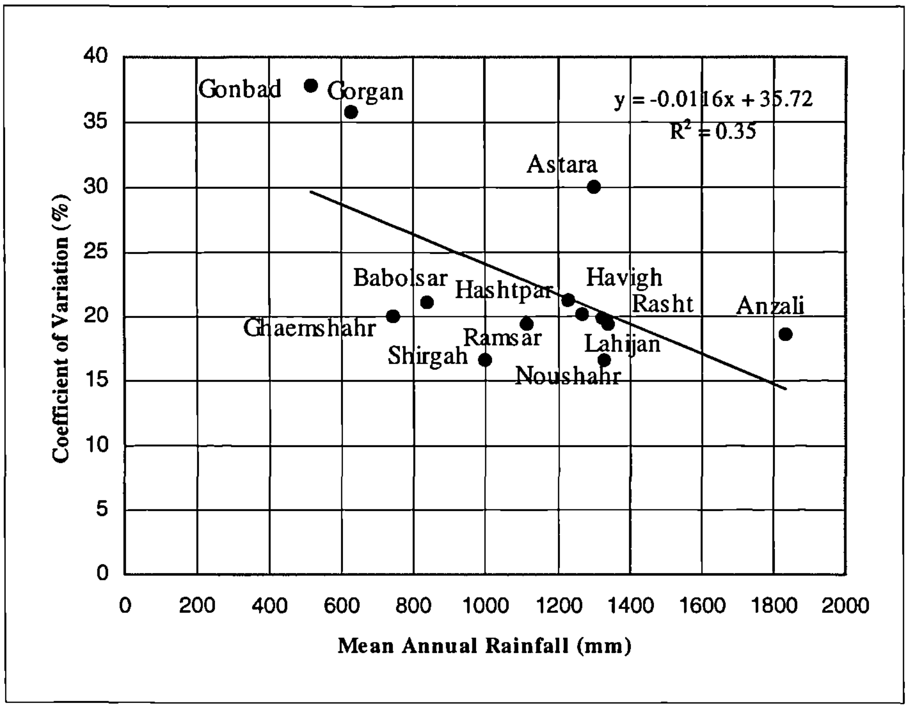


Figure 5-2 Relationship between C.V. and Annual Rainfall in Coastal Area Stations.

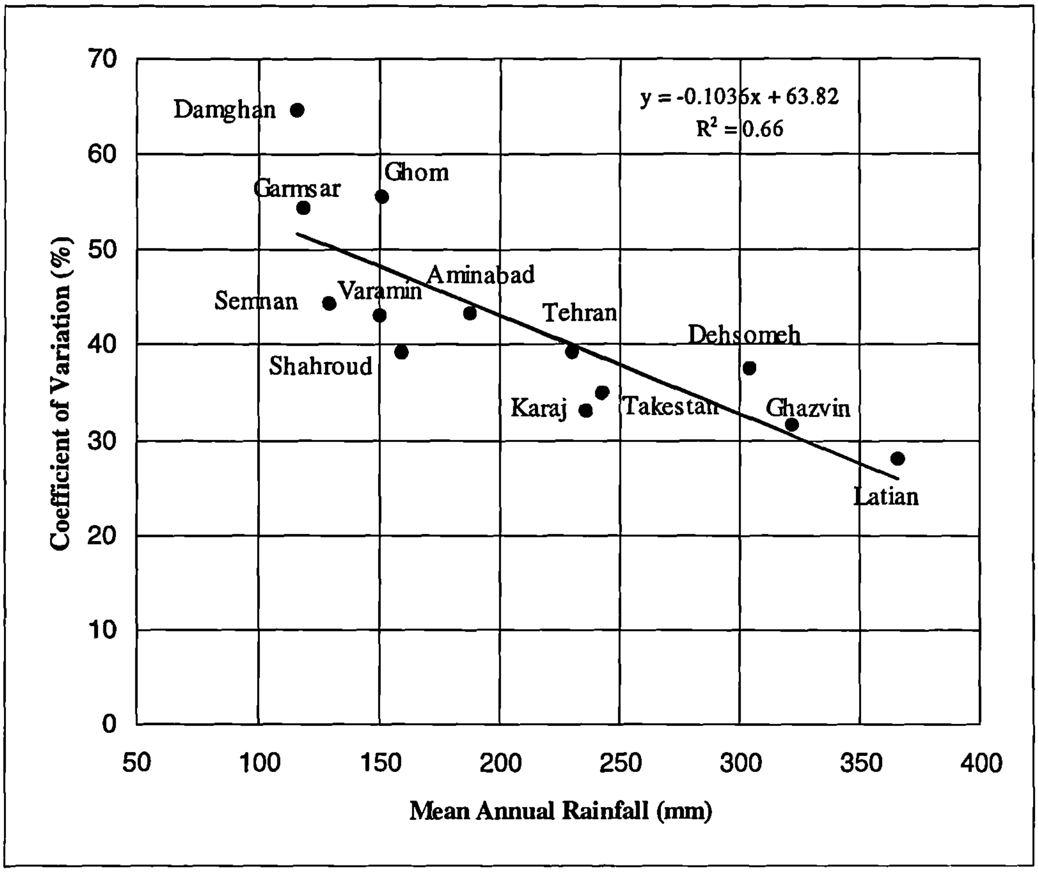


Figure 5-3 Relationship between C.V. and Annual Rainfall in Southern Slope Stations

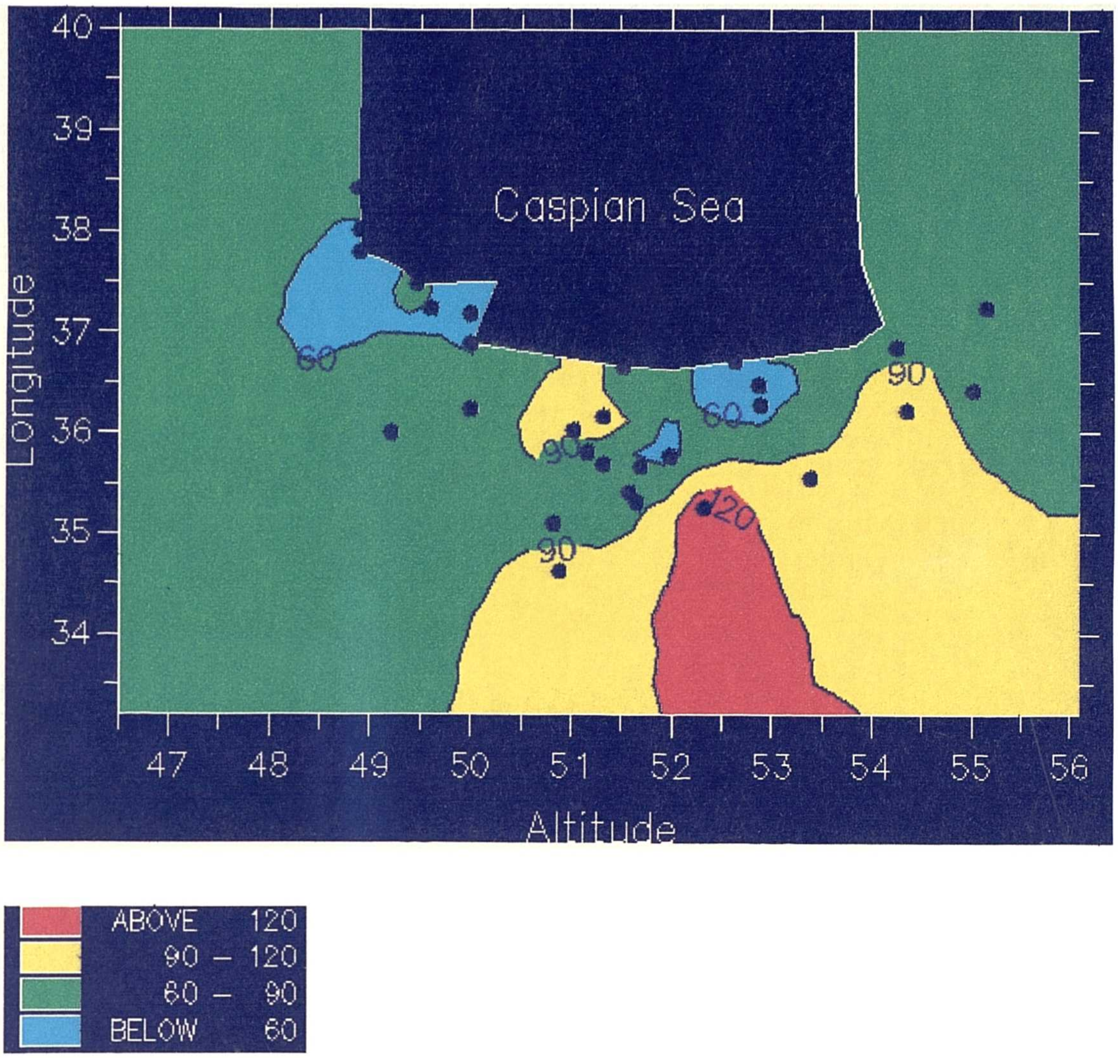


Figure 5-4 January Monthly Rainfall C.V. over the Central Elbruz Stations.

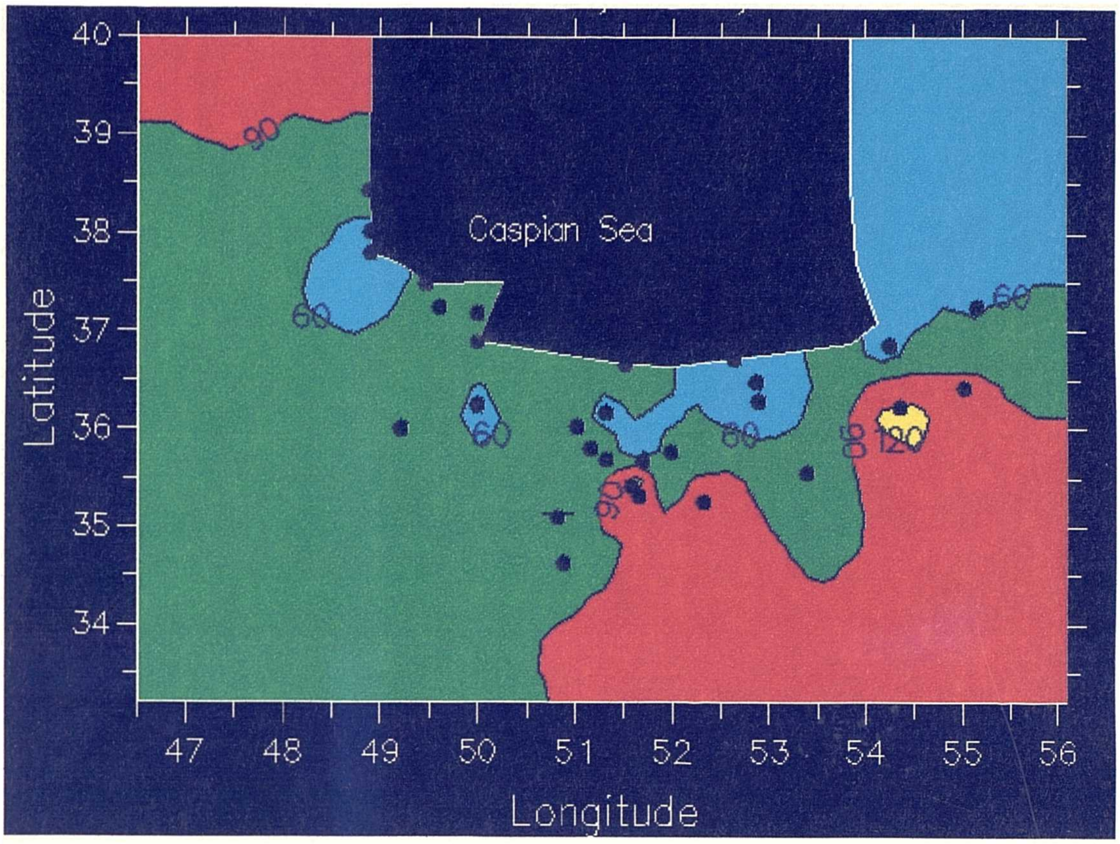
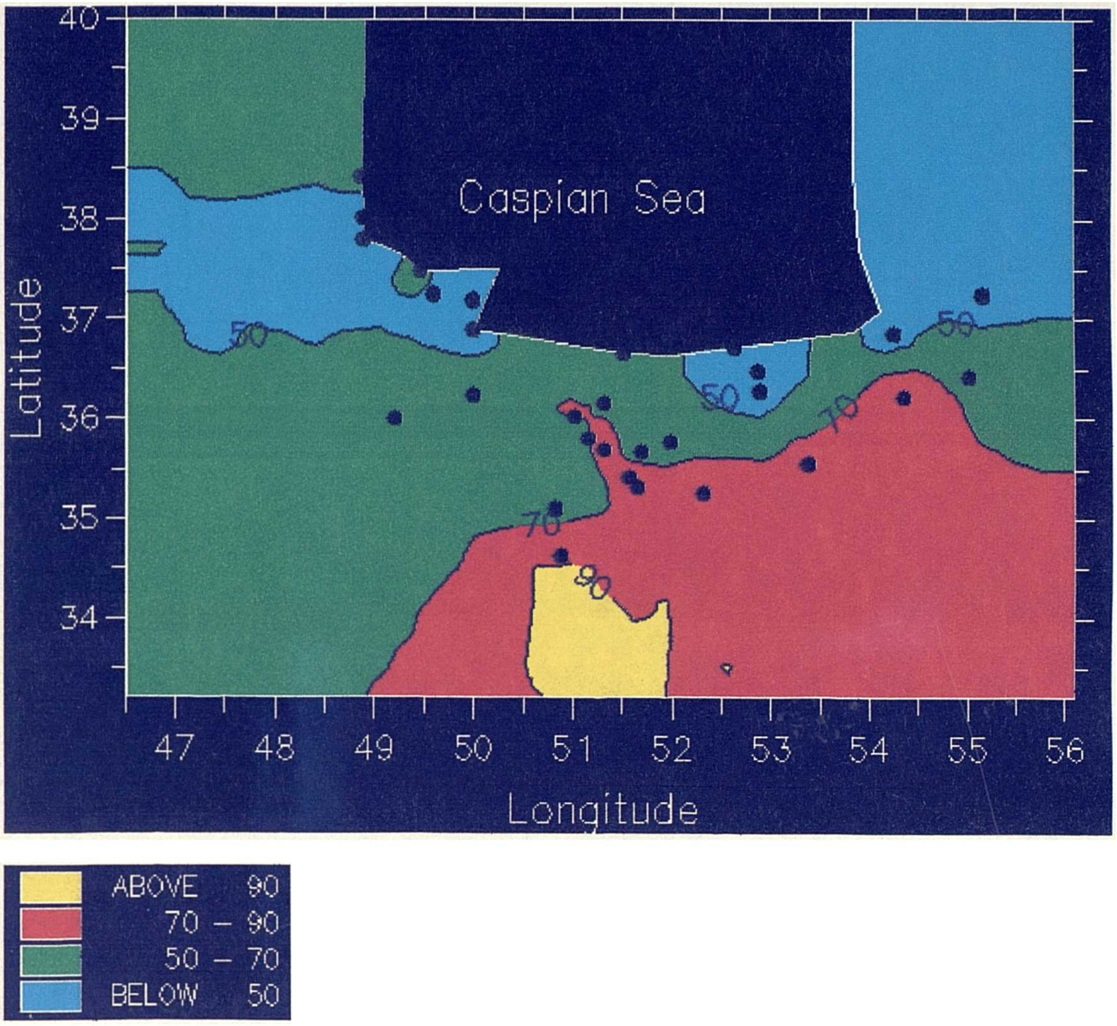
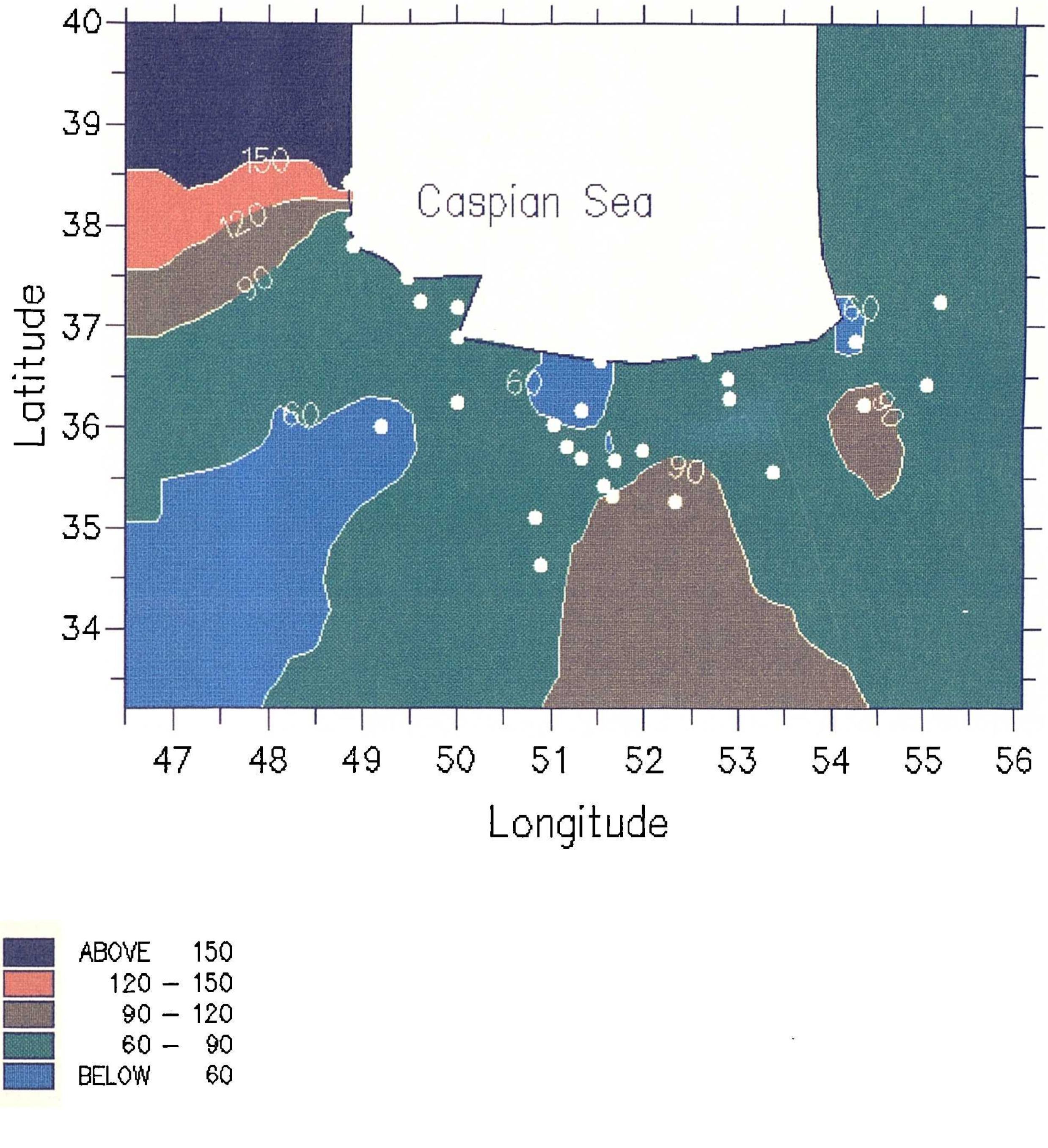


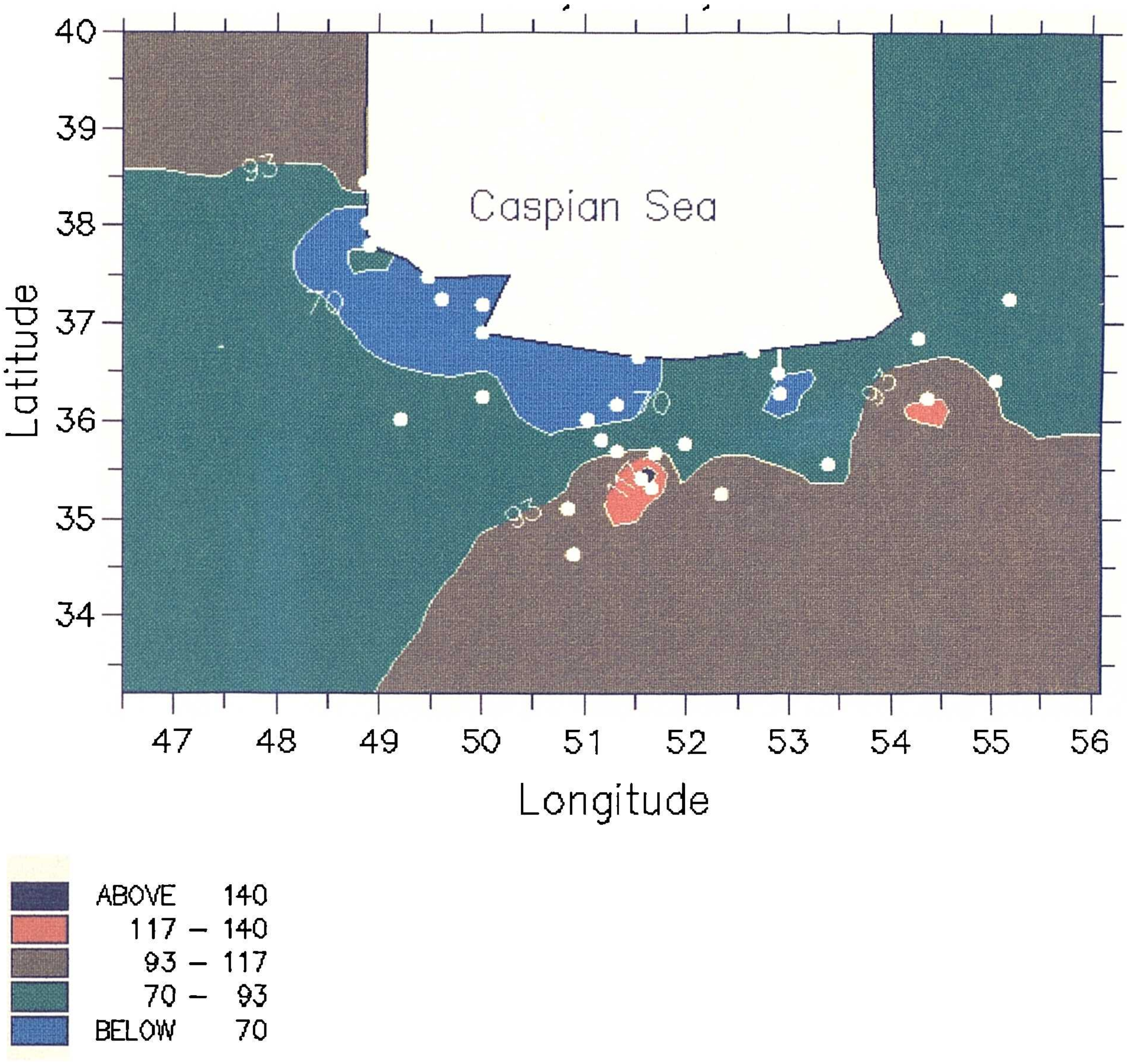
Figure 5-5 February Monthly Rainfall C.V. over the Central Elburz Stations.



Figurer 5- 6 March Monthly Rainfall C.V. over the Central Elburz Stations.



Figurer 5- 7 April Monthly Rainfall C.V. over the Central Elburz Stations



Figurer 5- 8 May Monthly Rainfall C.V. over the Central Elburz Stations

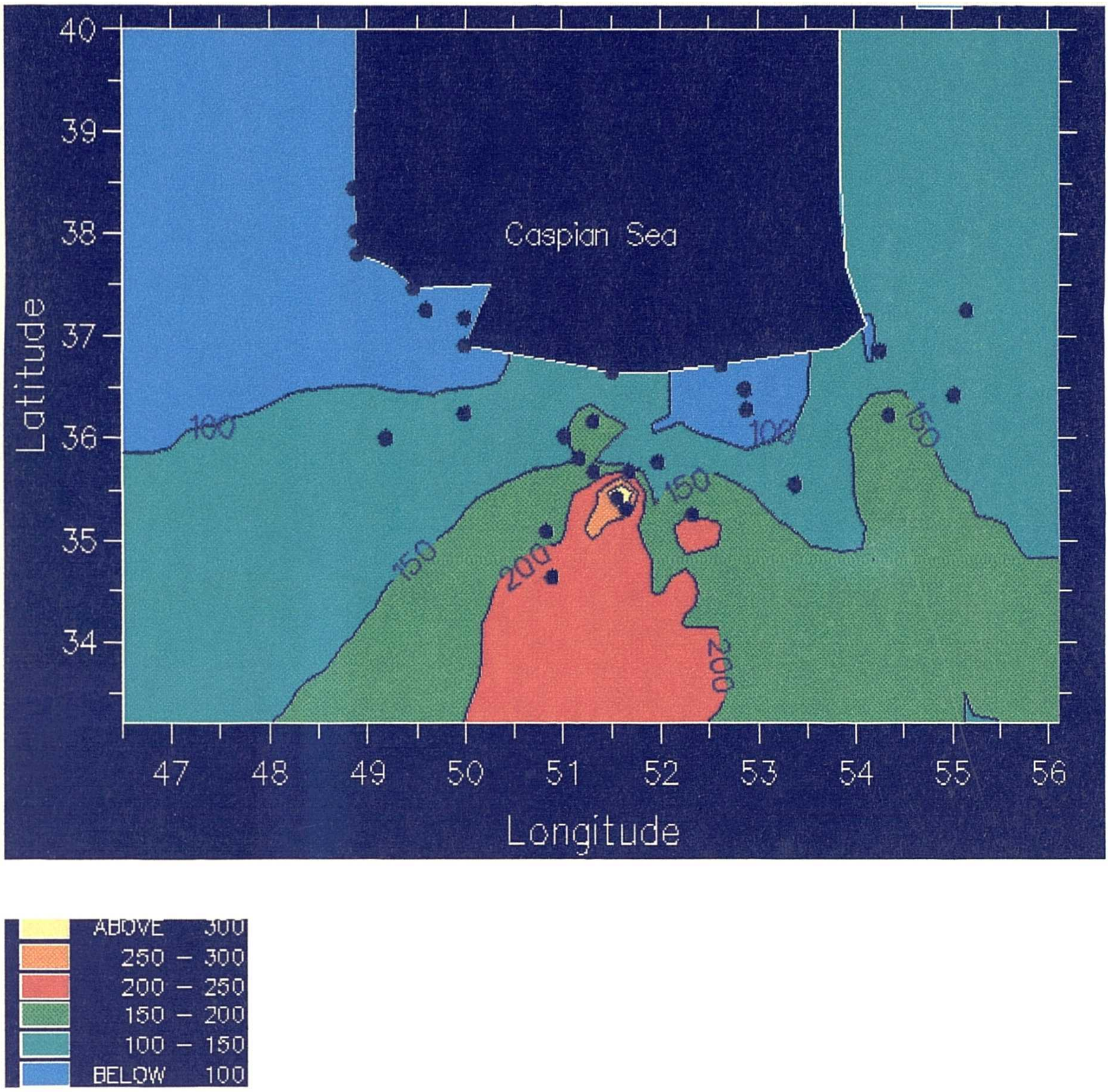


Figure 5-9 June Monthly Rainfall C.V. over the Central Elburz Stations

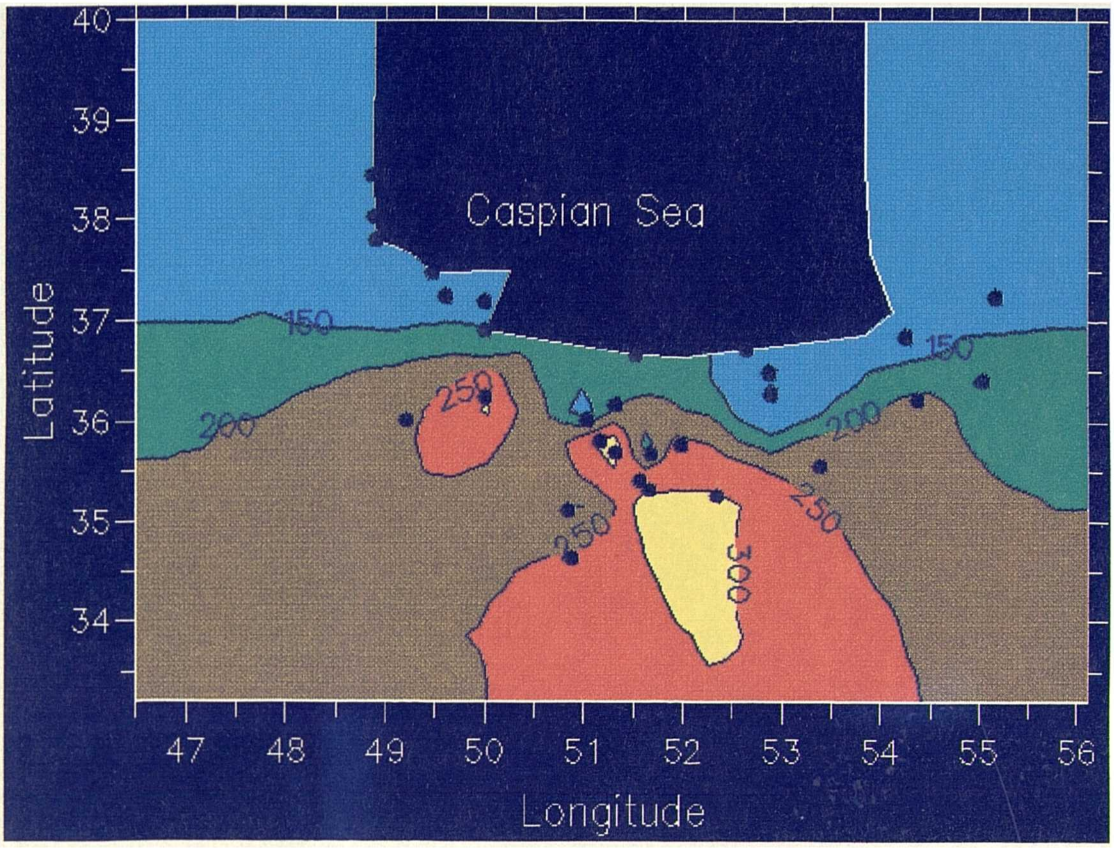


Figure 5-10 July Monthly Rainfall C.V. over the Central Elburz Stations

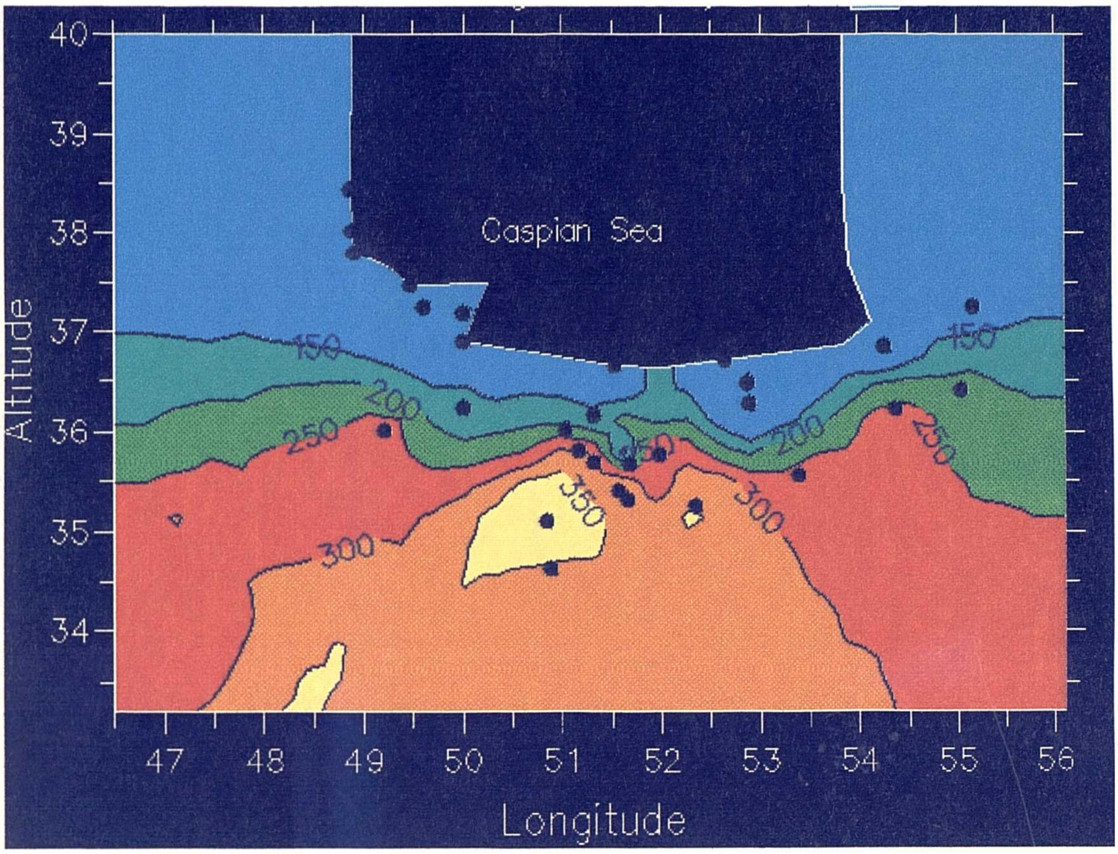


Figure 5-11 August Monthly Rainfall C.V. over the Central Elburz Stations

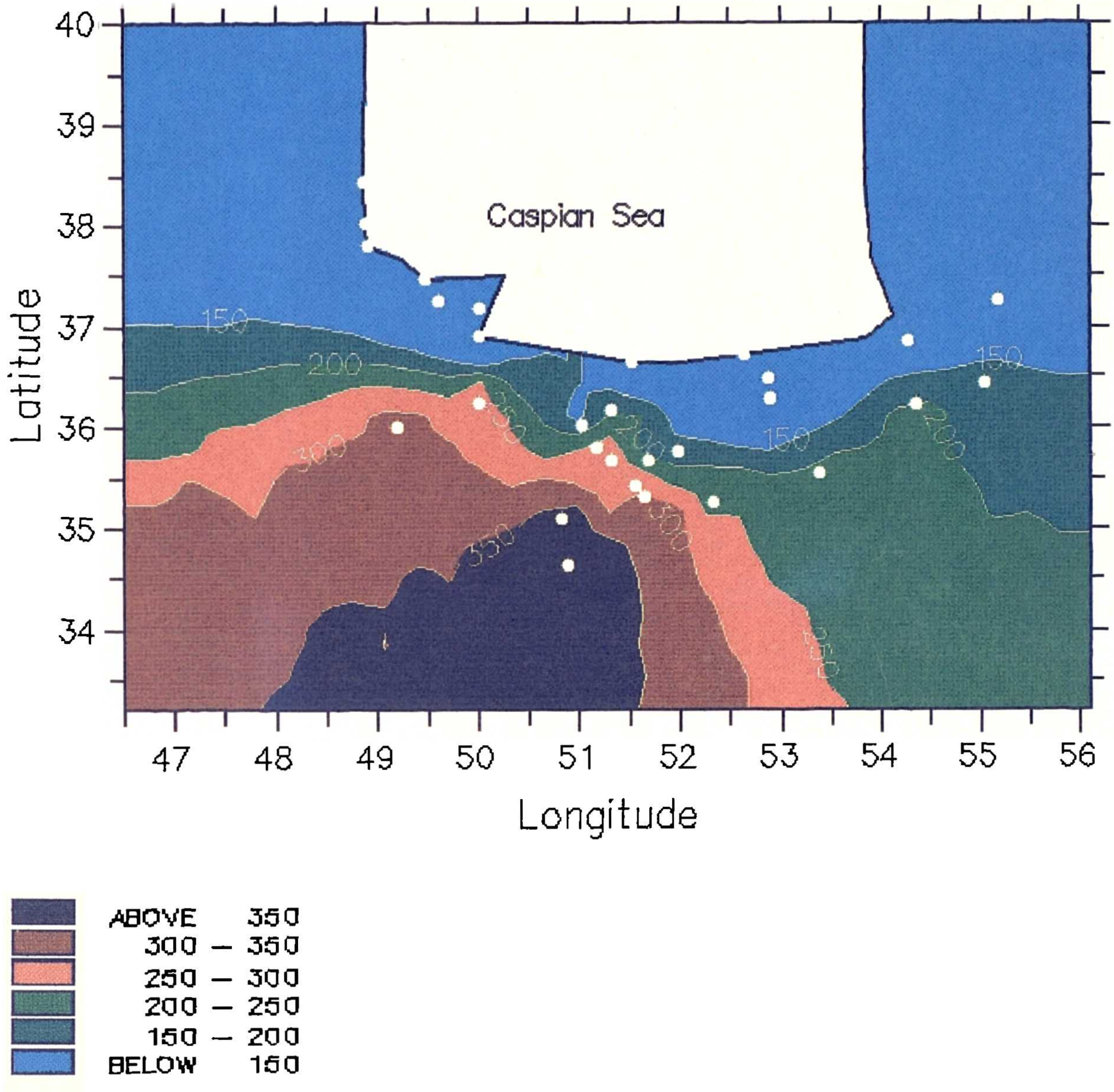


Figure 5-12 September Monthly Rainfall C.V. over the Central Elburz Stations

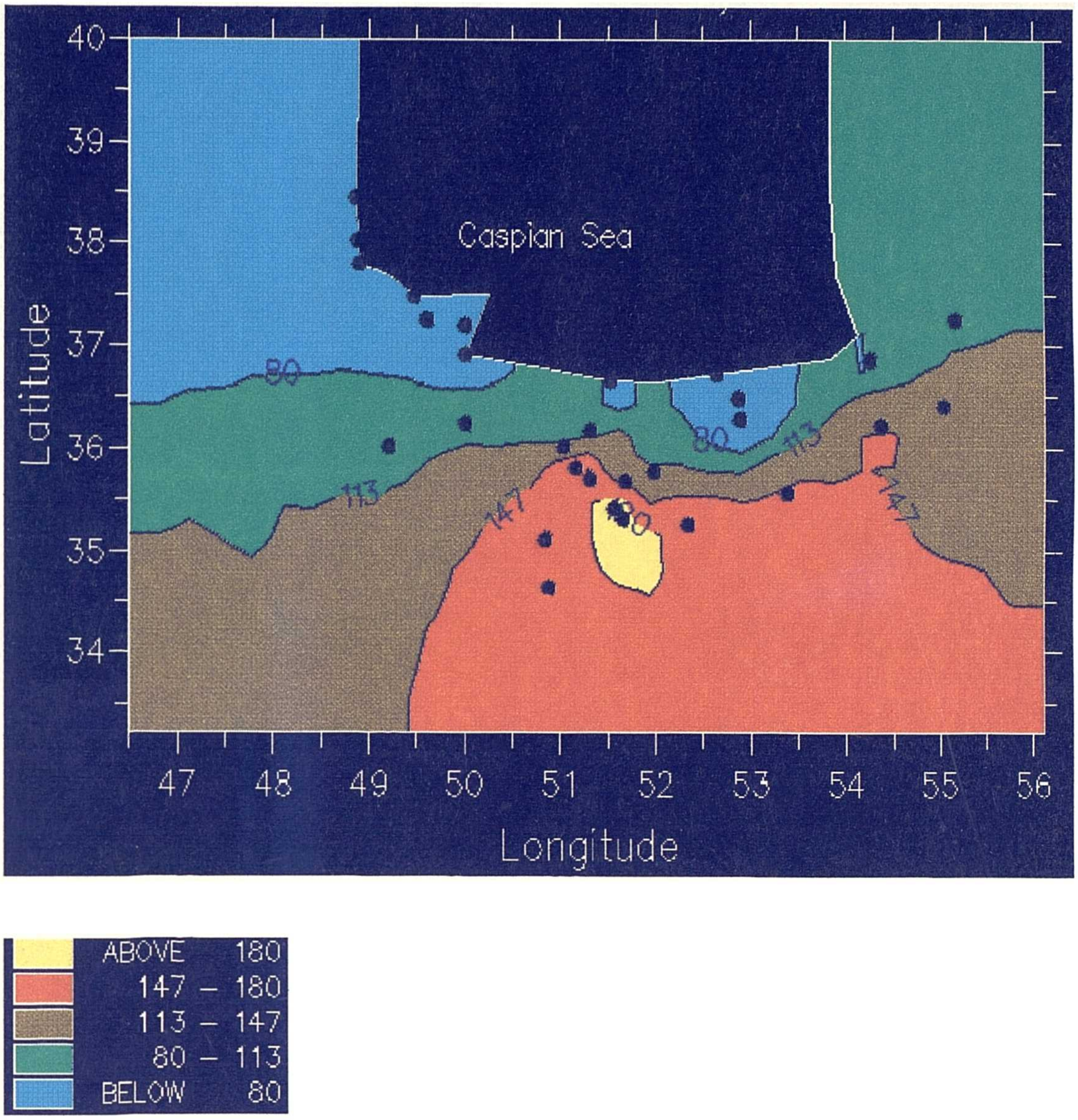


Figure 5-13 October Monthly Rainfall C.V. over the Central Elburz Stations

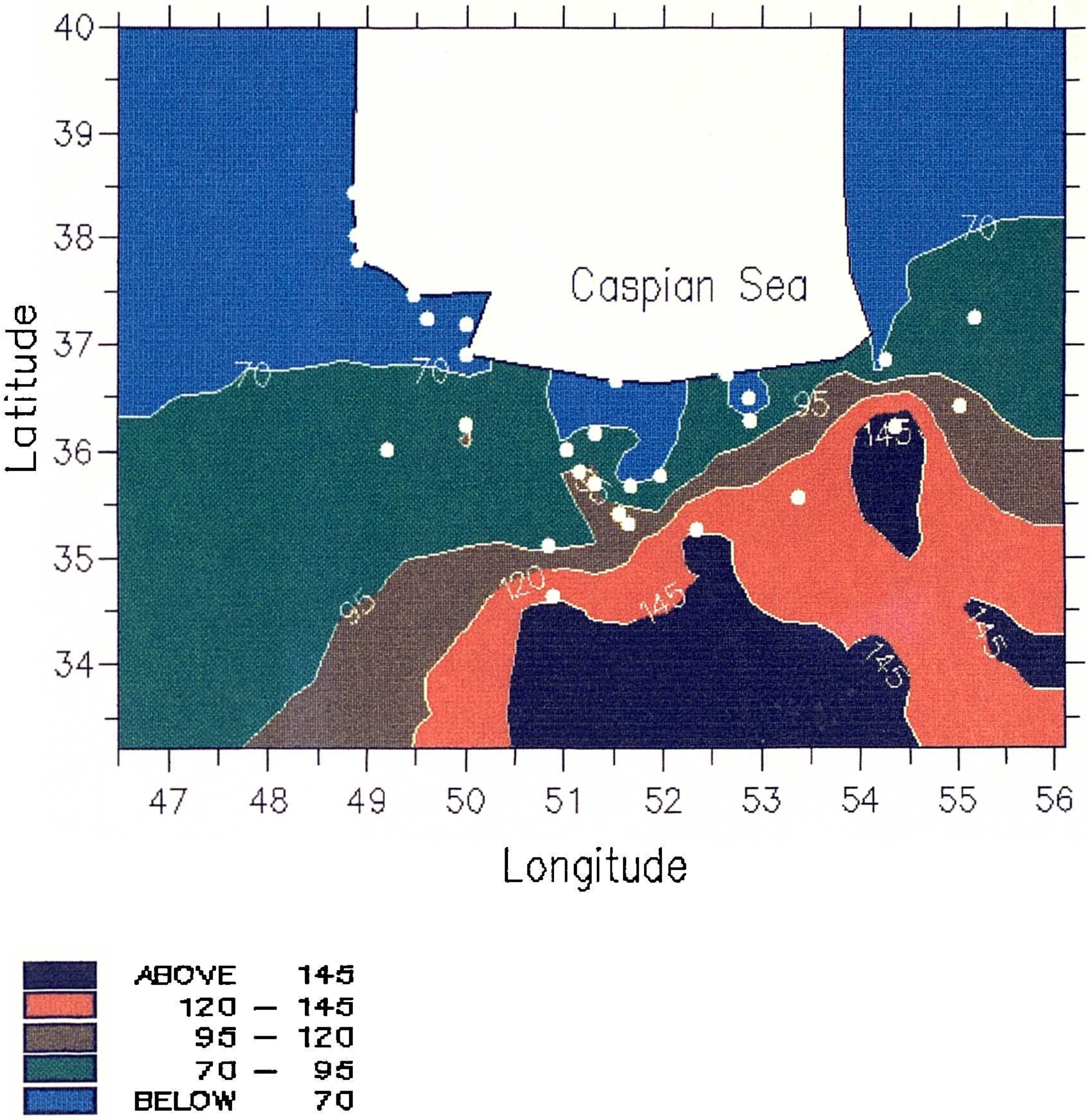


Figure 5-14 November Monthly Rainfall C.V. over the Central Elburz Stations

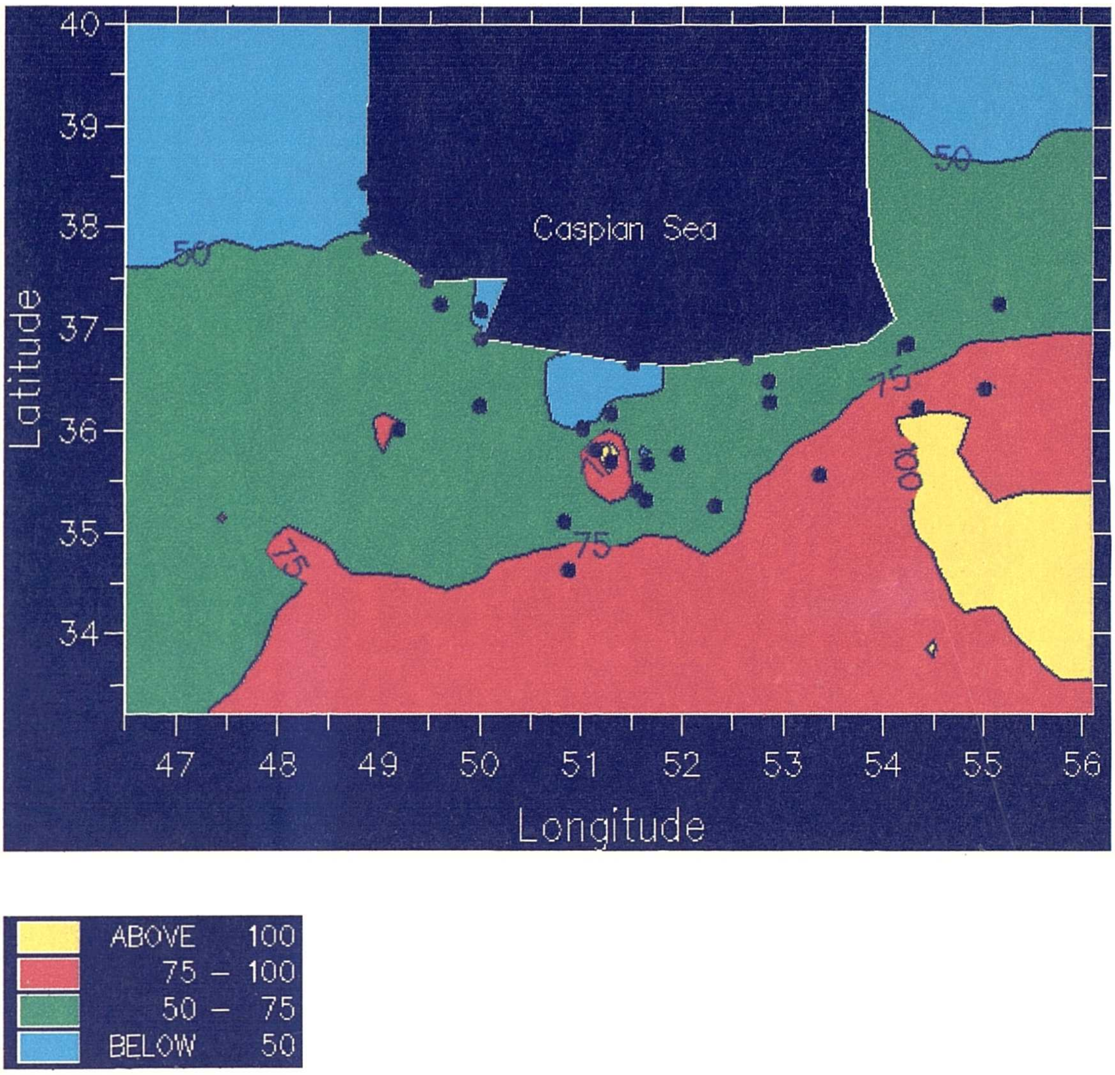


Figure 5-15 December Monthly Rainfall C.V. over the Central Elburz Stations.

6

6. Rainfall Probability and Reliability

Knowledge of daily, monthly, annual, and seasonal rainfall amounts received at a given place is of little use in planning agricultural and other uses of water resources unless the variability and probability of receiving such amounts of rainfall are also known. Thus for this reason a rainfall probability approach is far more useful in any application of rainfall statistics. Dennett *et al* (1983) indicated such analyses are often unconvincing to an agronomist or farm manager. Whilst conceding that they provide estimates of the long term probabilities, they argue that decisions must be made for the current year. In the absence of reliable, physically based seasonal forecasts, his decisions must be based on statistical assessment.

Long period rainfall records from the study area have been used in this study to establish the climatological pattern of rainfall distributions, reliability and probabilities. Rainfall records are analysed to provide, for example, percentage points of rainfall totals, reliability and probability of rainfall, using all the available years of record.

The present study is based on the assumption that probability estimates can allow planning. It has long been realized that the climatological averages, as such, are generally unsuitable for direct usage, particularly in the field of agriculture. There has always been a need for additional information that may throw light on the variability and the reliability of these averages. This is specially so in agricultural developing countries like Iran where the rainfall reliability is of great importance, on account of the economic and the social aspects involved. Thus average rainfall alone can not be used for agricultural planning and it is more important to know the chances of getting sufficient rainfall amounts required for crop growth. If crop requirement is just below the average rainfall for the crop season it is of the utmost importance for farmer to know how often this will or will not be attained Glover, *et al* (1954). Rainfall probability and reliability would, therefore be of great value and relevance to the objective assessment of the agricultural potential in the Central Elburz of Iran. The method and construction of rainfall reliability and probability to aid in agricultural development was first pioneered and largely developed in East Africa by the work of Glover and Robinson (1953), Glover, *et al* (1954), Kenworthy and Glover (1958), Jackson (1970), Woodhead (1970), Nieuwolt (1978) and extended to other tropical areas by Gregory (1969), El Tom (1972), Shaw (1982), Dennett, *et al* (1983) and Odumodu (1983). Despite the existence of these rainfall studies for East Africa, it is surprising that the techniques devised have not been more widely applied elsewhere in the African Continent. Also outside the African Continent the technique surprisingly has received little attention and very limited application. Chia (1978), Chuan (1981), Chan (1981) ,Chan (1984) and Jones *et al* (1996) have used the concept in assessing the probability and reliability of receiving certain critical amounts of annual rainfall over Malaysia and different parts of world. Most of the above studies are based on annual rainfall. This chapter considers only annual rainfall to provide a spatial pattern of rainfall expectation in the Central Elburz but subsequent chapters examine the timing of the seasons and the monthly pattern of rainfall and crop water needs to determine the probability of water deficit.

It is the aim and objective of this chapter to make an assessment of the probability and reliability of receiving or exceeding critical annual rainfall amounts in the Central Elburz stations and to calculate probability and reliability tables and figures that may provide a basis for future planning of the water resources and agricultural potential in this area.

6.1 The Definition of Probability Theory

Probability can be defined in both the general and the mathematical sense (Shaw and Wheeler 1985), but scientists prefer to use the word in the rigorous mathematical fashion, attaching a numerical value to the probability of an event. This numerical probability can be expressed in either of two ways:

1) on an absolute scale of zero to 1

2) on a percentage scale of zero to 100.

Probability theory is a fundamental concept that provides the basis for inferential statistics, and the probability of an event may be defined as the proportion of times that it will occur in the long period.

6.2 Application of Probability Theory in Hydrology and Rainfall Climatology Studies

The probability of an event can be defined as the degree of certainty of its occurrence. In meteorology in which very few events, if any, are certain, a more suitable definition of the probability of an event is the proportion of time it will occur in the long run. The theory of probability has been applied in many areas in climatology, quantitative forecast of rainfall, frequency of extreme rainfall and the studies of rainfall reliability. Also mathematical statistics and probability theory have found wide application in hydrological studies. This is because the random nature of hydrological events is particularly appropriate for such analyses, hydrological phenomena such as flood peaks, dry periods and rainfall events of varying magnitudes being regarded as random variables. In its simplest form, a random variable is a function whose value depends on the outcome of a chance event. In other words, its value is not perfectly and unambiguously fixed by the factors given for the determination of the phenomenon but, as a result of the variation of the characteristic conditions not taken into consideration, i.e. those omitted from the determination of the phenomenon, this variable will assume a different value from time to time. For rainfall, the amount received for a particular event depends on not just the physical factors of site and location, but on the interaction of the meteorological phenomena which affect the rainfall over the station, and those meteorological phenomena are stochastic in nature. Hence a satisfactory stochastic description of the local process of precipitation has yet to be accomplished because of the inherent complexity of the natural phenomena. Thus the probabilistic and stochastic nature of hydrological phenomena can not be fully understood, described and applied to water resources conservation, development and control without the extensive use of methods of probability theory (Chuan 1981).

In climatology we usually deal with samples but the theoretical population is infinite and can not be observed. But the longer the period of records on which our calculations are based, the nearer will be our sample mean and standard deviation to those of the theoretical population. In this study, 29 stations having records for periods varying from 24 to 45 years have been used.

Usually there are different types of probability distributions developed in statistics the well-known and most frequently utilised is the normal distribution. The normal distribution assumes that the data series used is continued random variable. For calculating the rainfall probabilities of certain minimum or critical amounts, it is essential to assure that the appearance of distribution a series of years is sufficiently near to the normal frequency distribution. Thus a simple test of normality carried out and showed that the annual rainfall series are normally distributed. It will be discussed in the next section.

6.3 The Normality Test

The data for 29 stations have been subjected to a normality test. The succeeding Table 6-1 gives the different statistical properties to evaluate the nature of time series data such as maximum, minimum, mean, standard deviation, skewness, kurtosis, median and normality. A simple test of normality, regarded as the most convenient method (Anderson Darling Normality Test on Minitab Manual, 1994) to check the normality distribution of the annual rainfall. According to this method if the proportion of P-

Value is 0.05 or above the distribution may be treated as normal. The computed ratios show variation from 0.053 to 0.93 for all the 29 stations which inform the distribution of the long term rainfall series is not significantly different from the normal distribution.

Table 6-1 Some Statistical Properties of the Annual Rainfall Series over the Central Elburz.

Stations	Max	Min	Mean	S.D	Kurtosis	Skewness	Median	Normality
Anzali	2658.6	1166.28	1832.8	336.63	0.0588	0.475488	1768.8	0.42
Astara	2618.5	761	1300.3	390.83	4.60741	1.876148	1234.7	0.65
Babolsar	1228.2	353.3	353.3	176.71	0.44053	-0.17419	807.75	0.90
Ghaemshah	998.4	433.7	740.98	148.20	-0.5828	-0.01084	728.7	0.93
Gonbad	854.6	323.1	487.92	134.45	0.07434	0.73795	449.6	0.054
Gorgan	1581.7	123	623.95	223.39	10.0512	1.93524	596.9	0.42
Havigh	1692.5	752.5	1271.3	257.26	-0.1496	-0.06571	1253.6	0.57
Hashtpar	1519.5	573.4	1114.1	216.40	0.04653	-0.36871	1104	0.70
Lahijan	1933.6	762.9	1325.3	262.19	0.29358	0.10841	1315.9	0.56
Noushahr	1767.7	811.9	1331.6	219.58	-0.2632	-0.04638	1318.6	0.91
Ramsar	1981.7	803.1	1231.6	261.42	1.47324	0.826682	1252.4	0.18
Rasht	1966.6	957.8	1341.9	259.06	0.05460	0.75353	1271.6	0.14
Shirgah	1338.1	632	996.49	164.80	0.24844	-0.42787	1014.5	0.49
Aminabad	760.9	89	215.93	136.31	10.61	2.83	202	0.28
Damghan	364	29	116	74.96	2.72880	1.364008	105.8	0.064
Dehsomeh	591.8	112.9	303.88	114.27	1.06117	0.761179	307.7	0.46
Garmsar	351.7	36.8	118.22	64.35	4.65438	1.561554	120.8	0.12
Ghazvin	564.3	160.1	321.52	101.59	-0.1502	0.584848	308.7	0.28
Ghom	430	20	150.94	83.75	2.54901	1.25996	134.6	0.19
Karaj	435.7	56.9	236.05	79.52	0.81496	-0.00035	243.2	0.346
Latian	608.7	198.5	365.94	102.79	0.03179	0.56062	347.5	0.71
Semnan	275.6	60.5	128.96	57.23	-0.0100	0.81461	112.65	0.07
Shahroud	342.9	68.5	159.44	62.48	1.06567	0.694908	167.5	0.13
Takestan	458.7	93	242.81	58.04	0.11467	0.281924	247.1	0.68
Tehran	489.6	91	230.00	83.35	0.90784	0.75901	227.6	0.80
Varamin	269.8	21.8	150.33	64.58	-0.9273	-0.068	148	0.604
Abali	906.4	253.9	547.73	160.41	0.16385	0.476828	520.9	0.54
N-Kandavan	2078	387.5	834.45	363.18	4.79961	1.908873	771	0.08
S-Kandavan	1151	388	649.57	224.58	-0.3400	0.872923	578	0.053

6.4 The Concept of Rainfall Probability and Reliability

As it was explained in previous pages, in the Central Elburz, as in all subtropical areas, rainfall amounts based on average values alone can be misleading to the farmer, planner and farm management who especially want to know their chances of getting sufficient rainfall amounts required for the suitable growth of cultivated crops. The mean rainfall for the year, season or month is no guide to the agricultural potential of an area, and some measures of rainfall variability are required in the interpretation of the recorded data. Rainfall variability does not specify the chances of receiving the rainfall amount selected to approximate the minimum threshold of water to allow a successful planting season. As mentioned in previous pages, probability is a fundamental concept that provides the basis for inferential statistics, the probability of an event may be defined as the proportion of times that it will occur in the long period. The probability of obtaining a certain amount of rainfall for a given station can be interpreted as the degree of reliability of receiving that rainfall amount at the station.

The concept of rainfall reliability at selected levels of probability provides a more objective and accurate assessment of rainfall. The greater the probability of obtaining the required rainfall for a particular crop, the more reliable would be the rainfall and the greater the success of the planting season. As previous pointed out the study of rainfall probability and reliability has received considerable attention in Africa and elsewhere. For a study in East Africa Glover *et al* (1954) considered reliable rainfall as the minimum amount of rainfall that can be expected at 95 percent probability. Manning (1956) defined the rainfall reliability, on the other hand, as the 95% probability or more to achieve a given amount of rainfall which he called the confidence limit of expected rainfall. Gregory (1964) regards as reliable the amount of rainfall which can be expected in nine wet seasons out of ten, with 90% probability. According to Chan (1981) all probabilities above 80% are classified as reliable and all probabilities below 80% classified as unreliable rainfall. However, probabilities between 70 and 79 percent are classified as marginally reliable. Kawiani (1988) believes reliable rainfall as the minimum amount of rainfall that can be expected at 90 percent probability or more to achieve a given amount of rainfall for a successful agricultural planning in different parts of Iran. Also he suggests for any farm plan less than 90 percent probability of receiving adequate rainfall is at the risk. Thus 90 and 80 percent probability has been considered necessary for successful agricultural planning and 75 percent probability is the marginal for traditional and small farmers. This definition of rainfall reliability may be appropriate for assessing the agricultural possibilities in various parts of the Central Elburz stations.

6.5 Critical Thresholds of Rainfall

Dry land farming or crop cultivation with limited marginal precipitation is characteristic of and most extensively practised in the semi-arid of the world (Tivy 1990). The farmer is entirely dependent on receiving enough rain to satisfy his crop requirements within the set period of the growing season in the Southern Elburz. If crop requirements are not satisfied in the wet months, the deficiencies can not be made up in other months. Beaumont (1989) has suggested that dryland farming takes place in areas of scanty precipitation and acknowledges that it could be misleading to use annual rainfall because of its unreliable nature. However averages have been used to define dry land farming.

It has been indicated by Wallen (1968) that an average amount of 230 mm may be regarded as sufficient for rain cultivation in the dry land farming of Iran. Kawiani (1988) suggested that a mean annual rainfall of 300 mm annual rainfall can be assured with a reasonable degree of certainty. Taghizadeh (1991) has demarcated the limit of the rain grown dry land farming in Iran (wheat) by the 240 mm isohyet. It is more useful to consider the crop water requirement and then examine the probability of receiving this amount. However, actual data on crop water requirements for rain grown crops are not available for different stations in the Elburz region.

Nevertheless Agnew and Anderson (1992) quoted from Willis (1983) note that at least 180-250 mm of soil water is required to produce grain for wheat and similar crops in Middle East dry land farming.

The main agricultural activities in the semi- arid area are cereal production and stock-raising while in the arid area stock raising predominates except for the irrigated area. These activities, which are traditional in these regions have resulted in the transformation or destruction of the natural vegetation.

According to Wallen (1968) in the Mediterranean climate such as Iran the annual precipitation amount is approximately the same as the amount received during the growing season and thus annual total rainfall its reliability is related to the dry-land farming possibilities. Wheat is still the dominant crop of the temperate dry-farming areas, which produce 90 percent of the world's bread flour and also it produces in different parts of the Central Elburz.

Cereals, mainly wheat, barley and rice are the most important crops and account for at least half the cropped area in the many places of the Central Elburz. Planting of cereals takes place in September and October and harvesting in June and July. In the wetter part of this area successful rain-fed agriculture has been carried out at a number of sites, probably continuously for 10000 years. This has been based on cereal cultivation, chiefly wheat, barley and rice, with many other crops such as melon, water melon, cucumber, citrus, tobacco, tomato, cotton and vegetables grown as well. Pastoral activity, especially with sheep, cattle, camel and goats has been closely associated with cultivation. The most important cereal crops in terms of value, production and area occupied are those food crops which give a high return of storable produce per unit effort and satisfy the basic nutritional needs of humans and livestock. Wheat and rice are the most important food grain, as they have a higher protein content compared with other crops. However the quality depends on the variety and the environmental conditions under which they are grown. Cereals which represent the staple for most of the people, can be cultivated intensively in this region. They can be grown with variable degrees of certainty over areas of the Central Elburz. Wheat is distinguished by its ability to mature in a shorter time than other cereals, and it can be successfully cultivated at higher altitudes up to 2000 meters and in more arid areas which preclude rice.

Rice is unique among the cereals in its ability to grow and germinate successfully partially submerged in water. Usually there are two types of rice; paddy and dry land rice. Although dry land rice requires less water than paddy for successful cultivation, it is more susceptible to drought and needs sufficient precipitation for 3- 4 months of its growing period. It is therefore the restricted to the wettest area of the Central Elburz.

Wheat, a major world cereal food, is grown profitably, mostly in the subhumid to semi- arid grasslands of the mid-latitudes. In such continental areas of world, year to year fluctuation in the weather is the most important factor causing substantial variations in wheat production (Odumodu and Griffiths 1980).

According to Kaveh (1974) the amount of annual rainfall required for wheat varies from 200 to over 600 mm in different places of Iran. Also Kaveh (1974) recognized on the basis of the amount of rainfall, the rainfed wheat acreage can roughly be classified in different parts of Iran as follows:

1) areas having over 500 mm of rain 10 %
2) areas having between 400- 500 mm of rain 10%
3) areas having between 350- 400 mm of rain 20%
4) areas having less than 350 mm of rain 60%

In this regard the Eastern coastal area has more than 400 mm annual rainfall and the southern slope has less than 350 mm in Kaveh's classification. However, Kaveh's classification is general for whole of Iran not specific area. This study concentrates on crops of wheat, rice, citrus, and cotton due to their food and commercial importance in the national economy. However, because of the absence of accurate data on water requirements of these crops and also the divergence of opinion between different authors, three thresholds of rainfall amounts, i.e., 240 mm is adopted for wheat, 300 mm for cotton and reasonable degree of certainty of successful dry- land agricultural and also 1000 mm for rice and citrus. They are based on the opinion of local farmers, agriculturist and farm management have been adopted in this study as minimum water requirements, provided that soil and weather conditions are favourable for crops of wheat, cotton, rice and citrus. However based on experience there is no relationship between amounts of rainfall and the crop production but the distribution of the timing of rain is more important. For example in many years the area has had more than 240 mm rainfall in winter but during spring there was no rainfall. Consequently it reduced the wheat production in area. The probability and reliability of receiving these critical rainfall amounts, will be determined for different parts of the Central Elburz in following pages.

6.6 Rainfall Probability

In a further analysis of some definite aspects of the rainfall reliability in the Central Elburz an attempt was made to find out the extent to which the atmospheric water supplies may effectively control the economic development of the country. It seems that a determination of the probability of receiving certain amounts of rainfall per annual minimum will, for example, provide a suitable measure of the extent to which rain cultivation may be practised with some degree of certainty. Through this, it is also possible to delimit the areas where no agriculture can be practised without the provision of artificial means of irrigation. In between these extremes will obviously lie the transitional areas, where artificial irrigation is of minor significance and so may only be needed during certain times of the year or during certain phases of the agricultural cycle. The same principle may be applied to delimit the areas suitable for the production of any demanding crop that can only be grown within known, critical rainfall values.

6.7 Methods of Measuring Rainfall Reliability

There are two approaches to rainfall reliability:

1) One way of measuring the reliability of rainfall was suggested by Glover (1953 and 1954) who applied it to East Africa in an attempt to determine the percentage probability of receiving rainfall amounts above or below certain levels that he considered critical for crop growing. Also this method has been used in various cases of climatic subjects by many investigators. The technique using by Glover was applied to the annual rainfall for the Central Elburz stations. However the critical levels adopted for the Central Elburz were different as explained in 6.5. In order to calculate the percentage probability of receiving a specified critical rainfall amount may be estimated by applying the following expression for each station:

$$Z = \frac{X - \bar{X}}{\sigma} \quad \text{where,}$$

Z = the number of deviations that the critical specified rainfall is above (for positive z) or below (for negative z) the mean rainfall,

X = the critical rainfall amount (the minimum rainfall requirement);

$\bar{X}$ = the mean rainfall, and

σ = the standard deviation.

The formula is used in conjunction with a table of probabilities, so that the required percentage probabilities that rainfall will be equal, less or more than the critical value may be determined by looking up the figures that correspond to the amount of the standardized differences in these tables. Percentage probabilities calculated in this way has been shown in Table 6-2 to Table 6-4 and Figures 6-1 to 6-2. This approved to rainfall reliability may introduce a practical way of assessing the agricultural possibilities in different stations of the Central Elburz.

2) Alternatively reliability can be calculated in terms of the amount of rainfall that can be expected or exceeded at a given level of probability. The choice of the percentage level depends on the ability to cope with crop failure. In the case of the

Central Elburz, 75%, 80% and 90% probability provides security in agriculture and is thus adopted in this analysis. The value of reliable rainfall that can be expected to occur or be exceeded at 90%, 80% and 75% probability may be estimated by applying the following formula which is a slight modification of the previous expression:

$X = Z.\ \sigma + \bar{X}$ Where,

X = is the value which can be expected to be received or exceeded at 75%, 80% and 90% probability;

$\bar{X}$ = is the mean rainfall;

σ = is the standard deviation and

Z = is the number of deviations that the specified rainfall is above or below the mean rainfall. The results of percentage probabilities 90%, 80% and 75%, have been shown in Table 6-5 to 6-7 and Figures 6-3 to 6-5.

6.8 Probability and Reliability Analysis of the Rainfall Data over the Central Elburz

The rainfall data has been analysed using both approaches:

1) in terms of the percentage probability that some specific rainfall total will (or will not) be exceeded and;

2) in terms of the values of rainfall that will (or will not) occur at a given degree of probability.

6.9 Results and Discussion of Percentage Probability Analysis of 240 mm Rainfall over the Central Elburz

As was mentioned in the previous pages the critical value of 240 mm rainfall has been chosen due to its significance in the production of the most important food crop cereal such as wheat in dry and semi- arid land of Iran. Wheat is by far the most important crop, with barley grown on thin and dense soils and where low rainfall predominates. In the Central Elburz, especially the Eastern coastal area and the southern slope stations, wheat can be grown without irrigation. In these parts 240 mm annual rainfall is sufficient for successful wheat cultivation. The short season cereal, maturing in 3 months requires at least 180 mm of rainfall while the long season cereal such as wheat, maturing in more than 3 months requires 240 mm annual rainfall. However the experience has proved there is no relationship between the total amount of rainfall and wheat yields the evidence indicates that the best cereal crop are obtained under some optimum timing of rainfall during the growing season (especially April).

In terms of rainfall probability over the Central Elburz the Table 6-2 and Figure 6-1 show that almost all of the coastal area stations have more than 90% probability of exceeding the 240 mm annual rainfall. Therefore the coastal area stations have higher chances (more than 90% probability) of receiving 240 mm rainfall. Also Table 6-2 and Figure 6-1 show that over the southern slope stations, the probability of 240 mm annual rainfall varies between 2 and 89 percent. Thus the probability of receiving 240 mm is everywhere less than 90%. The lowest values of probability levels are found in the southern and eastern stations of the southern slope stations with less than 10 percentage probability of receiving the 240 mm annual rainfall. However, the probability of receiving this amount increases sharply from the southern and eastern parts to the west and northwards. Thus for a critical level of 240 mm rainfall level of reliable rainfall is restricted to a few stations along the west and northern part of area where the percentage probability exceeds 71%. In the west the probability of receiving 240 mm is within the range of 71% to 81% while in the north, it is more than 89%. The remaining part of the area, with less than 50% probability, indicates clearly that this area is unreliable for the critical 240 mm annual rainfall. In this area percentage probability of receiving 240 mm rainfall increases with altitude. For example the analysis of rainfall for those stations have more altitudes (Dehsomeh, Ghazvin, and Latian) shows that the percentage probability of 240 mm rainfall is more than 70%. Also percentage probability of 240 mm rainfall is more than 90%. for the higher altitudes stations such as Abali, Northern Kandavan and Southern Kandavan. So in the southern slope stations and the higher altitudes stations probability of receiving 240 mm annual rainfall increases sharply with altitude.

6.10 Percentage Probability of Receiving 1000 mm Rainfall over the Coastal Area Stations

The 1000 mm rainfall minimum levels was selected as being of most interest agriculturally, because in the Caspian coastal area stations annual totals of this order if well distributed in the rainy season appear sufficient to permit the adequate growth of rice and also citrus as well. It is realized, of course, that this level of rainfall is more important to the local farmer dependent on rice production. The probability of receiving this amount of rainfall is only considered for the Caspian coastal area stations. Since it is not relevant in other areas which depend on other crops. Rice is cultivated intensively in this area of the Central Elburz. The rice production of this area is exported to Arab countries because of its aromatic (fragrant) and excellent quality. According to the local experience of farmers there is no relationship between the total amount of rainfall and rice yields the evidence indicates that the best grain yield are obtained under some optimum timing of rainfall during the growing season.

Table 6-3 shows that the highest values, more than 80% probability are found in the western stations of the Caspian Sea. However the lowest values, less than 50% are found in the eastern area of the Caspian Sea lowlands. This agrees with the observed differences between west and east of the Caspian coastal area from the point of view of quantity and quality of grain production.

6.11 Percentage Probability of Receiving of 300 mm Rainfall over the Coastal Area Stations

Since cotton thrives under hot, sunny conditions; it is cultivated intensively in the Gonbad and Gorgan distinct it is also grown in the some parts of the southern slopes. Because of its very great economic importance in different parts of Iran, the effects of water on cotton yields have received significant attention, particularly in terms of water requirements and irrigation. Since irrigation water is often in short supply, determination of the minimum requirement for optimum results is of great importance.

Farmers experience indicates that the beginning of flowering and during boll development are the best time to irrigate to ensure good growth. Usually a minimum of 300 mm annual rainfall is required, with 100-150 mm well distributed during the growing season. As is shown in Table 6- 4 and Figure 6-2 the highest values are found in the western stations of the Caspian Sea with amount of 100% probability of receiving 300 mm annual rainfall. However, the lower values are found in the eastern stations of the Caspian Sea where there is less than 92% of probability of receiving this critical rainfall. In comparison to the Eastern Caspian coastal area stations the western stations are not suitable for crop cultivation in spite of high rainfall due to high moisture. The eastern Caspian coastal area stations are very important places for providing cotton crops, not only for Iran but also for the whole Middle East region. Also Table 6-4 and Figure 6-2 indicate that all of the southern slope and higher altitude stations have a value of less than 50% probability except Dehsomeh, Ghazvin, Latian, Abali, Southern Kandavan and Northern Kandavan.

6.12 Annual Rainfall Expected to be Reached or Exceeded with 90% Probability over the Central Elburz Stations.

The assessment of the probability of a specified or critical rainfall indicates the expected chances of failure to get the required amount over a long period of time. On the other hand the assessment of the value of rainfall expected to be received or exceeded with a given probability will be the amount that can be depended on. Therefore definition of the dependable rainfall is the value of rainfall that can be received or exceeded in 90 percent of the years. This argument concerning at a 90% level has been discussed in previous pages. With regard to Table 6-5 and Figure 6-3 the rainfall amount which can be expected at 90% probability is low over most of the

Central Elburz Stations with the lowest amounts being in the Southern slope stations and the highest values in the Caspian coastal area stations.

Table 6-5 and Figure 6-3 demonstrate the values of rainfall that can be expected with 90 percent probability in the Central Elburz stations. Most of the Caspian coastal stations exceed 258 mm of rainfall, ranging from Gonbad with 196 mm to Anzali with 1281 mm rainfall. In the southern slope stations rainfall which can be expected with 90 percent probability is less than 197 mm. This amount of rainfall emphasises the dryness of the southern slope stations of the Central Elburz. Highest amounts are found in the Latian, Ghazvin and Takestan stations which are at relatively higher altitudes. The range of expected rainfall is from 13 mm in Garmsar to 197 mm rainfall in Latian. In the Higher Altitudes locations, the 90% expected rainfall is more than 239 mm, with Abali having the highest amount with 285 mm 90% expected rainfall greater than the Southern Slope Stations. It varies from 239 mm in Northern Kandavan Station to 285 mm in the Abali station.

As it can be seen by the Table 6-5 and Figure 6-3 the amount of rainfall varies between Garmsar Station with (13 mm) and Anzali stations with (1281 mm) at 90% probability level. So the coastal area stations are more important than the southern slope stations from point of the view of agricultural planning.

6.13 Annual Rainfall Expected to be Reached or Exceeded with 80% Probability over the Central Elburz Stations.

Table 6-6 and Figure 6-4 demonstrate the values of rainfall that can be expected with 80 percent probability in the Central Elburz stations. The Caspian Coastal stations exceed 374.86 mm expected rainfall. The amounts of rainfall expected ranges from Gonbad with 374.86 mm to Anzali with 1590.46 mm rainfall. In the southern slope stations rainfall which can be expected with 80 percent probability is less than 291.93 mm. The range of expected rainfall is from 62.03 mm at Damghan to 291.93 mm at Latian. In the Higher Altitude locations, this value is greater than 432.23 mm, and varies from 432.23 mm at Abali to 572.96 mm at Northern Kandavan Stations.

6.14 Annual Rainfall Expected to be Reached or Exceeded with 75% Probability over the Central Elburz Stations.

Table 6-7 and Figure 6-5 show the values of rainfall that can be expected with 75 percent probability over the Central Elburz stations. The Caspian Coastal stations are more than 374.86 mm expected rainfall. The amounts of rainfall expected ranges from 383.61 mm at Gonbad to 1605.6 mm rainfall at Anzali. In the Southern slope stations rainfall which can be expected with 75 percent probability is less than 296.56 mm rainfall. The range of expected rainfall is from 65.4 mm at Damghan to 296.56 mm rainfall at Latian. In the Higher Altitudes locations, this value is more than 432.23 mm. It changes from 432.23 mm at Abali to 572.96 mm at Northern Kandavan Stations.

In a further analysis of some aspects of the rainfall reliability in the Central Elburz an effort was made to determine the extent to which the atmospheric water supplies might effectively control the economic development of the Central Elburz region. It seems that a determination of the probability of receiving certain amounts of annual rainfall will provide a suitable measure of the extent which rain cultivation may be practised with some degree of certainty. As rainfall decreases in the southern Elburz stations, the chances of crop failure increase, successful cultivation is not really possible on a long term basis. Along this same gradient the importance of irrigation increases. Farmers should be prepared for the possible occurrence of dry years and consequent crop failure except where additional water supplies can be obtained when needed. Over the southern Elburz stations the risk is quite considerable and artificial irrigation should be the rule rather than the exception. Here crop production is dependent on the availability of artificial means of irrigation except areas close to Qanats or seasonal streams, where soil moisture is normally sufficient for crop growing. Any particular crop may be grown with a high or at least a reasonable degree of certainty, provided that minimum water requirements of that crop can be expected or an acceptable level of probability which in this area is assumed to be 90%. The detailed pattern of rainfall within the years is also a considerable factor in the success of rainfall agriculture. Analysis of the timing and duration of moisture and the frequency and incidence of dry periods during the growing season is thus essential and this forms the basis of chapter seven.

6.15 Application of The Binomial Frequency Distribution on the Rainfall Climatology Study

The analysis of annual rainfall reliability and maps indicate a wide range of minimum rainfall amount that are likely to occur with 90%, 80% and 75% probability in different stations over the Central Elburz stations. This would imply a 10, 20 and 25 percent probability of failure to receive the critical rainfall limit or that there is the possibility of inadequate rainfall occurrence in one, two and 3 years out of ten.
It may be expected in rainfall agriculture, that crop failure due to deficient rainfall may be tolerated if it occurs once, two, or three years in a decade. If yield losses because of inadequate rainfall happen in two or 3 years in succession, crop failure can have a serious effect on the economy and social life of the region. The possibility of such conditions occurring more than once within any particular ten years period can be evaluated by the binomial frequency distribution method. Therefore the binomial frequency distribution method can be useful in determining critical time periods of receiving inadequate rainfall amounts.

As previous mentioned there are different probability distribution. The normal distribution assumed that the data series used is a continuous random variable, while the frequency distribution of a discrete random variable is reasonably explained by the binomial or Poisson frequency distribution. Moreover these three frequency distribution methods are said to be one family and consequently they are associated to each other.

The binomial frequency distribution has been discussed in many text books such as Patel *et al* (1976), Gregory (1978), Hammond and McCullagh (1980), Kottegoda (1980), Bancroft and Paihan (1981), Freund (1984), Rowntree (1984), Grant and

Leavenworth (1988) Pagano (1990), Subrahmaniam (1990), Mendenhall and Beaver (1991), O'Brien (1992), Ross (1993), Pitman (1993), Devore and Peck (1993), Weiss (1996) and Metcalfe (1997) etc. One of the commonest probability distributions is associated with the repetition of events where there are only two possible outcomes it is called the binomial frequency distribution. The frequency distribution of a discrete random variable is appropriately described by the binomial. The outcomes are mutually exclusive and there is independence between the outcomes of each trail, when these requirements are met the binomial distribution tells each possible outcome of the N trails and the probability of getting each of these outcomes.

Number of outcomes with x successes can be as follows = $\frac{n!}{x!(n-x)!}$

where for any positive whole number m the symbol m! = m(m- 1)(m- 2) ......(2)(1)

Thus each distribution gives two types of information:

1) all possible outcomes of the N trails and

2) the probability of getting each of these outcomes.

The probability of getting x successes in n independent trail is:

$$P(x) = \binom{n}{x} p^x (1-p)^{n-x} \qquad \text{for } x = 0, 1, 2, ..., \text{or } n$$

n identical independent success failure with the probability of success on any given trail being equal to p.

x denote the total number of success in the n trails.

x has the binomial distribution with parameters n and p. While p is the constant probability of success for each trail. Also the above formula can be represented by another way: $P(x) = C_x^n p^x q^{n-x}$ where

x, the number of successes in n trails may take values 0, 1, 2, ..., n

p is the successes on a single trail; C_x^n is defined as $\frac{n!}{x!(n-x)!}$

In the formula for p(x) the quantity $p^x q^{n-x}$ represents the probability observing an event with x successes and (n- x) failures; the term C_x^n describes the number of x successes can result from n trail.

The probability p(x) = $C^n_x p^x q^{n-x}$ associated with a particular value of x in n independent trail is the term involving p in the series expansion of the binomial $(p + q)^n$. This mathematical expression allows simple calculation of the probabilities of all combination of outcomes from trails. This expression is called the binomial expansion. The binomial frequency distribution may be generated for any n, p and q by using the binomial expansion. As previously indicated the binomial expansion can be given by following formula:

$$(p + q)^n \text{ where,}$$

p = probability of one of two possible outcomes on a trail,
q = probability of the other possible outcome (1-p),
n = number of trails.
If n = 1 the above formula is: $(p + q)^1 = p + q$
If n = 2 the above formula can be: $(p + q)^2 = p^2 + 2pq + q^2$
If n = 3 the above formula is: $(p + q)^3 = p^3 + 3\,p^2q + 3\,pq^2 + q^3$

The letters of each term (p or pq or q) tell the kinds of events that comprise the outcome; the exponent of each letter tells how many of that kind of event there are in the outcome and the coefficient of each term states how many ways there are of obtaining the outcome. The probability of getting each of these possible outcomes is found by evaluating their respective terms using the numeric value of p and q.

In fact it can be said that the probabilities associated with all possible outcomes of n events are given by the terms in the expansion of $(p+ q)^n$. So as previously mentioned this is known as the binomial expansion. The binomial distribution represents the frequency with which one would expect values or events to occur in the long run, it is a hypotethical distribution and mathematically derived and is perfectly regular. Different critical probability of annual rainfall over the Central Elburz stations has been discussed in earlier pages. For example 1000 mm and 240 mm annual rainfall are regarded as sufficient to appropriate the water requirements of rice and wheat and there is a 10 percent probability of rainfall below this value occurs one in ten years. For example probability of happening of similar insufficient rainfall two consecutive years for a successful agricultural, over the Central Elburz stations in a decade can be assessed from applying the following binomial form:

$$(p + q)^2 \text{ where,}$$

p = 0.1, a 10 percent probability of rainfall occurrence below 240 mm,

q = 0.9, a 90 percent probability of rainfall occurrence above 240 mm,

2 = number of trails or probability of receiving deficient rainfall occurrence in two successive years. Consequently by inserting the appropriate numerical values of these forms the binomial distribution frequency is as follows:

	Probability
Two years below 240 mm = $p^2 = (0.1)^2$ =	0.01
Two years above 240 mm = $q^2 = (0.9)^2$ =	0.81
One year above 240 mm and one year below = 2pq =	0.18
$2 \times 0.1 \times 0.9$ =	
Total probability =	1.00

The above analysis indicates that there is:

1) 1 percent probability of inadequate rainfall event over two successive years,

2) 81 percent probability that any two years receive required rainfall amount in a decade,

3) in any pair of years, the probability that one year is above and the other below the critical value is estimated as 18 percent. In this case the conditions that may lead to the occurrence of low rainfall over two successive years in a decade are probable to occur very infrequency despite the overall 10% of failure rainfall.

The previous analysis method can be used to determine the possibility of receiving insufficient rainfall in three successive rainfall over a decade by expanding the another binomial formula:

$$(p + q)^3 = p^3 + 3\,p^2q + 3\,pq^2 + q^3$$

All statement conceivable combination of probability conditions can be determined as follows:

	Probability
Three years below 240 mm = $p^3 = (0.1)^3$ =	0.001

Three years above 240 mm = $q^3 = (0.9)^3$ = 0.729

Two years below 240 mm and one year above = $3p^2q = 3 \times (0.1)^2 \times 0.9$ = 0.027

Two years above 240 mm and one year below = $3\ pq^2 = 3 \times 0.1 \times (0.9)^2$ = 0.243

Total probability = 1.00

It can be indicated from the above analysis that;

1) probability of one in a thousand that three successive years receive below the required amount of rainfall,

2) Approximately 73 percent probability of 3 consecutive years receiving rainfall above the critical amount,

3) the probability of two years below and one year above the critical value is nearly 3 percent.

4) the probability of two years above and one year below the amount of rainfall is 24 percent.

In conclusion the frequency distribution of rainfall events over a period of time can be described by the Binomial distribution. Therefore it can be employed the Binomial theorem in estimating of the probabilities of various frequencies of the event. The application of the Binomial frequency distribution can be useful in determining critical time periods of receiving deficient rainfall amounts. The binomial frequency distribution method could be objectively utilised for the long term estimating of unusually rainfall failure conditions and also it may be for a better planning of the agricultural resources over the Central Elburz stations.

Table 6-2 Percentage Probability of Receiving 240 mm Rainfall

Stations	No of years	Annual Mean	Standard deviation	Variation Coefficient	Percentage of probability
Anzali	38	1832.83	336.63	18.59	100
Astara	30	1300.3	390.83	30.05	100
Babolsar	38	835.67	176.71	21.14	100
Ghaemshahr	31	740.98	148.20	20	100
Gonbad	31	514.96	194.58	37.78	92
Gorgan	35	623.95	223.39	35.80	96
Havigh	26	1271.36	257.26	20.23	100
Hashtpar	25	1114.08	216.40	19.42	100
Lahijan	31	1325.32	262.19	19.78	100
Noushahr	31	1331.60	219.58	16.49	100
Ramsar	30	1231.65	261.42	21.22	100
Rasht	32	1341.99	250.06	19.30	100
Shirgah	24	996.49	164.80	16.53	100
Aminabad	25	187.28	81.08	43.29	25
Damghan	30	116	74.96	64.62	4
Dehsomeh	31	303.88	114.27	37.60	71
Garmsar	30	118.22	64.35	54.43	2
Ghazvin	31	321.52	101.59	31.59	81
Ghom	32	150.94	83.75	55.48	14
Karaj	31	236.05	79.52	33	48
Latian	32	365.94	102.79	28.09	89
Semnan	30	128.96	57.23	44.38	2
Shahroud	32	159.44	62.48	39.18	10
Takestan	30	242.81	58.04	35.02	52
Tehran	45	230.00	83.35	39.24	46
Varamin	30	150.33	64.58	42.96	8
Abali	26	547.73	160.41	29.28	97
Northern Kandavan	26	834.45	363.18	43.52	95
Southern Kandavan	26	649.57	224.58	34.57	96

Table 6-3 Percentage Probability of Receiving 1000 mm Annual Rainfall.

Stations	No of years	Annual Mean	Standard deviation	Variation Coefficient	Percentage of probability
Coastal Area					
Anzali	38	1832.83	336.63	18.59	99
Astara	30	1300.3	390.83	30.05	78
Babolsar	38	835.67	176.71	21.14	18
Ghaemshahr	31	740.98	148.20	20	4
Gonbad	31	514.96	194.58	37.78	1
Gorgan	35	623.95	223.39	35.80	5
Havigh	26	1271.36	257.26	20.23	85
Hashtpar	25	1114.08	216.40	19.42	52
Lahijan	31	1325.32	262.19	19.78	89
Noushahr	31	1331.60	219.58	16.49	93
Ramsar	30	1231.65	261.42	21.22	81
Rasht	32	1341.99	250.06	19.30	91
Shirgah	24	996.49	164.80	16.53	49

Table 6-4 Percentage Probability of Receiving 300 mm Annual Rainfall

Stations	No of years	Annual Mean	Standard deviation	Variation Coefficient	Percentage of probability
Anzali	38	1832.83	336.63	18.59	100
Astara	30	1300.3	390.83	30.05	100
Babolsar	38	835.67	176.71	21.14	100
Ghaemshahr	31	740.98	148.20	20	100
Gonbad	31	514.96	194.58	37.78	86
Gorgan	35	623.95	223.39	35.80	92
Havigh	26	1271.36	257.26	20.23	100
Hashtpar	25	1114.08	216.40	19.42	100
Lahijan	31	1325.32	262.19	19.78	100
Noushahr	31	1331.60	219.58	16.49	100
Ramsar	30	1231.65	261.42	21.22	100
Rasht	32	1341.99	250.06	19.30	100
Shirgah	24	996.49	164.80	16.53	100
Aminabad	25	187.28	81.08	43.29	8.23
Damghan	30	116	74.96	64.62	7
Dehsomeh	31	303.88	114.27	37.60	51.2
Garmsar	30	118.22	64.35	54.43	2
Ghazvin	31	321.52	101.59	31.59	58
Ghom	32	150.94	83.75	55.48	4
Karaj	31	236.05	79.52	33	21
Latian	32	365.94	102.79	28.09	74
Semnan	30	128.96	57.23	44.38	1
Shahroud	32	159.44	62.48	39.18	1.3
Takestan	30	242.81	58.04	35.02	17
Tehran	45	230.00	83.35	39.24	20
Varamin	30	150.33	64.58	42.96	1.1
Abali	26	547.73	160.41	29.28	94
Northern Kandavan	26	834.45	363.18	43.52	93
Southern Kandavan	26	649.57	224.58	34.57	94

Table 6-5 Annual Rainfall Expected to be Reached or Exceeded at 90% Probability

Stations	No of years	Annual Mean	Standard deviation	Variation Coefficient	Annual Rainfall
Anzali	38	1832.83	336.63	18.59	1281
Astara	30	1300.3	390.83	30.05	659
Babolsar	38	835.67	176.71	21.14	546
Ghaemshahr	31	740.98	148.20	20	498
Gonbad	31	514.96	194.58	37.78	196
Gorgan	35	623.95	223.39	35.80	258
Havigh	26	1271.36	257.26	20.23	849
Hashtpar	25	1114.08	216.40	19.42	759
Lahijan	31	1325.32	262.19	19.78	895
Noushahr	31	1331.60	219.58	16.49	972
Ramsar	30	1231.65	261.42	21.22	803
Rasht	32	1341.99	250.06	19.30	932
Shirgah	24	996.49	164.80	16.53	726
Aminabad	25	187.28	81.08	43.29	54
Damghan	30	116	74.96	64.62	18
Dehsomeh	31	303.88	114.27	37.60	117
Garmsar	30	118.22	64.35	54.43	13
Ghazvin	31	321.52	101.59	31.59	154
Ghom	32	150.94	83.75	55.48	14
Karaj	31	236.05	79.52	33	106
Latian	32	365.94	102.79	28.09	197
Semnan	30	128.96	57.23	44.38	35
Shahroud	32	159.44	62.48	39.18	57
Takestan	30	242.81	58.04	35.02	148
Tehran	45	230.00	83.35	39.24	93
Varamin	30	150.33	64.58	42.96	44
Abali	26	547.73	160.41	29.28	285
Northern Kandavan	26	834.45	363.18	43.52	239
Southern Kandavan	26	649.57	224.58	34.57	281

Table 6-6 Annual rainfall expected to be reached or exceeded at 80% probability.

Stations	No of years	Annual Mean	Standard deviation	Variation Coefficient	Annual Rainfall
Anzali	38	1832.83	336.63	18.59	1590.46
Astara	30	1300.3	390.83	30.05	1018.9
Babolsar	38	835.67	176.71	21.14	708.44
Ghaemshahr	31	740.98	148.2	20	634.28
Gonbad	31	514.96	194.58	37.78	374.86
Gorgan	35	623.95	223.39	35.80	463.11
Havigh	26	1271.36	257.26	20.23	1086.13
Hashtpar	25	1114.08	216.4	19.42	958.27
Lahijan	31	1325.32	262.19	19.78	1136.54
Noushahr	31	1331.6	219.58	16.49	1173.51
Ramsar	30	1231.65	261.42	21.22	1043.43
Rasht	32	1341.99	250.06	19.30	1161.95
Shirgah	24	996.49	164.8	16.53	877.83
Aminabad	25	187.28	81.08	43.29	128.91
Damghan	30	116	74.96	64.62	62.03
Dehsomeh	31	303.88	114.27	37.60	221.61
Garmsar	30	118.22	64.35	54.43	71.89
Ghazvin	31	321.52	101.59	31.59	248.37
Ghom	32	150.94	83.75	55.48	90.64
Karaj	31	236.05	79.52	33	178.79
Latian	32	365.94	102.79	28.09	291.93
Semnan	30	128.96	57.23	44.38	87.75
Shahroud	32	159.44	62.48	39.18	114.45
Takestan	30	242.81	58.04	35.02	201.02
Tehran	45	230	83.35	39.24	169.99
Varamin	30	150.33	64.58	42.96	103.83
Abali	26	547.73	160.41	29.28	432.23
Northern Kandavan	26	834.45	363.18	43.52	572.96
Southern Kandavan	26	649.57	224.58	34.57	487.87

Table 6-7 Annual rainfall expected to be reached or exceeded at 75% probability.

Stations	No of years	Annual Mean	Standard deviation	Variation Coefficient	Annual Rainfall
Anzali	38	1832.83	336.63	18.59	1605.6
Astara	30	1300.3	390.83	30.05	1036.49
Babolsar	38	835.67	176.71	21.14	716.39
Ghaemshahr	31	740.98	148.2	20	640.94
Gonbad	31	514.96	194.58	37.78	383.61
Gorgan	35	623.95	223.39	35.80	473.16
Havigh	26	1271.36	257.26	20.23	1097.71
Hashtpar	25	1114.08	216.4	19.42	968.01
Lahijan	31	1325.32	262.19	19.78	1148.34
Noushahr	31	1331.6	219.58	16.49	1183.38
Ramsar	30	1231.65	261.42	21.22	1055.19
Rasht	32	1341.99	250.06	19.30	1173.2
Shirgah	24	996.49	164.8	16.53	885.25
Aminabad	25	187.28	81.08	43.29	132.55
Damghan	30	116	74.96	64.62	65.4
Dehsomeh	31	303.88	114.27	37.60	226.74
Garmsar	30	118.22	64.35	54.43	74.78
Ghazvin	31	321.52	101.59	31.59	252.94
Ghom	32	150.94	83.75	55.48	94.41
Karaj	31	236.05	79.52	33	182.37
Latian	32	365.94	102.79	28.09	296.56
Semnan	30	128.96	57.23	44.38	90.33
Shahroud	32	159.44	62.48	39.18	117.27
Takestan	30	242.81	58.04	35.02	203.63
Tehran	45	230	83.35	39.24	173.74
Varamin	30	150.33	64.58	42.96	106.74
Abali	26	547.73	160.41	29.28	439.45
Northern Kandavan	26	834.45	363.18	43.52	589.31
Southern Kandavan	26	649.57	224.58	34.57	497.98

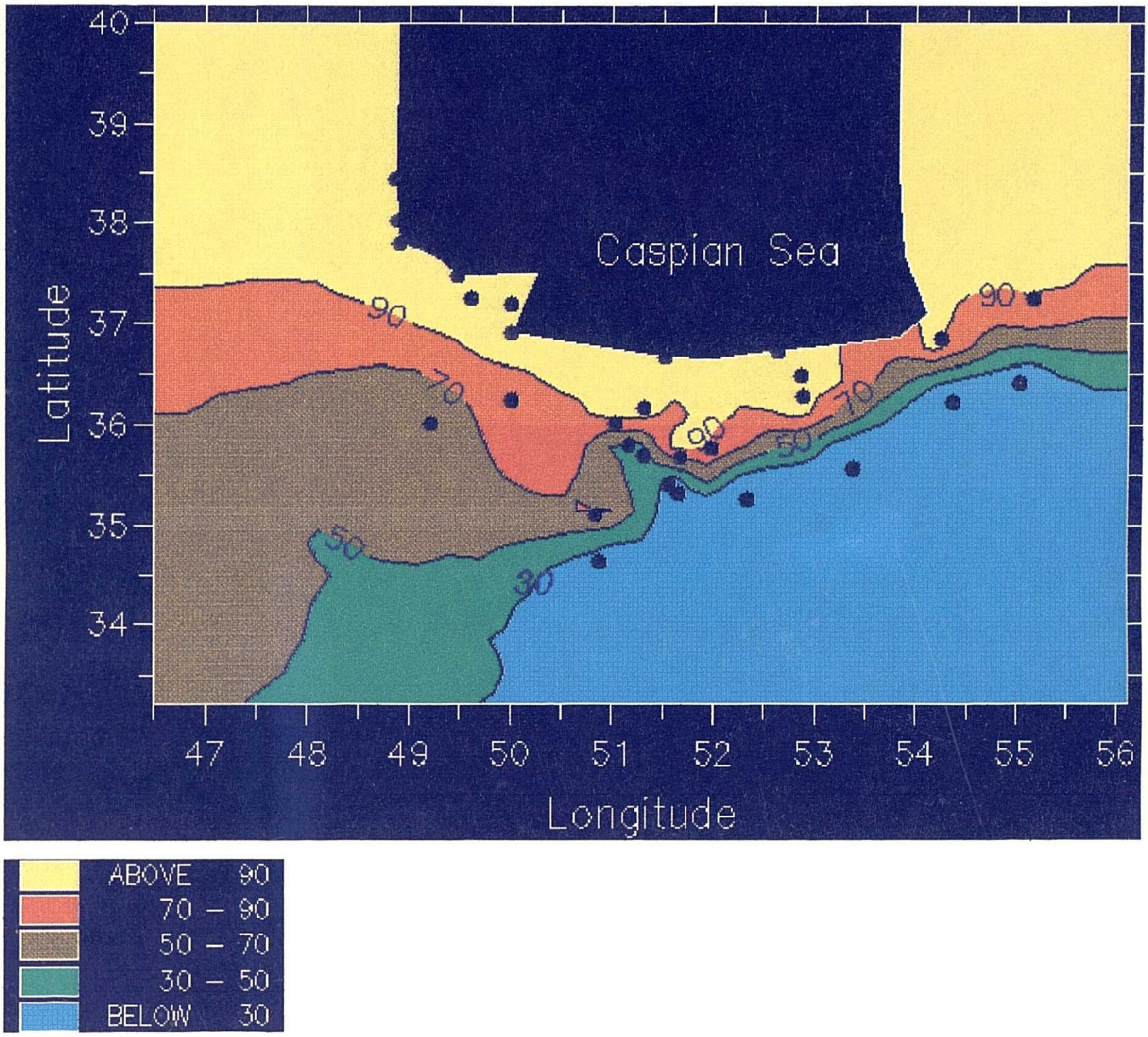


Figure 6-1 Percentage probability of receiving 240 mm rainfall in the Central Elburz Stations

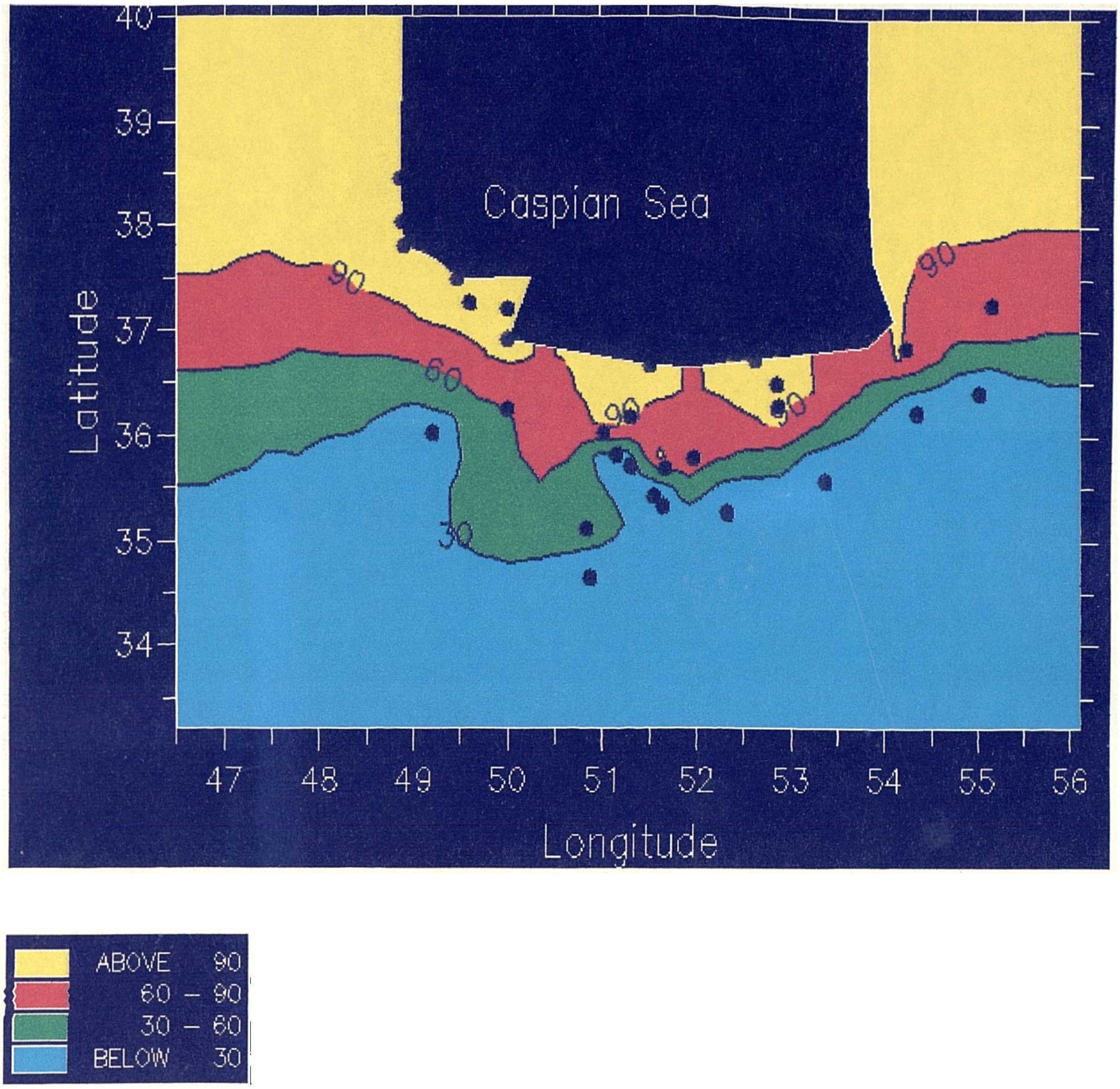


Figure 6-2 Percentage probability of receiving 300 mm rainfall in the Central Elburz Stations

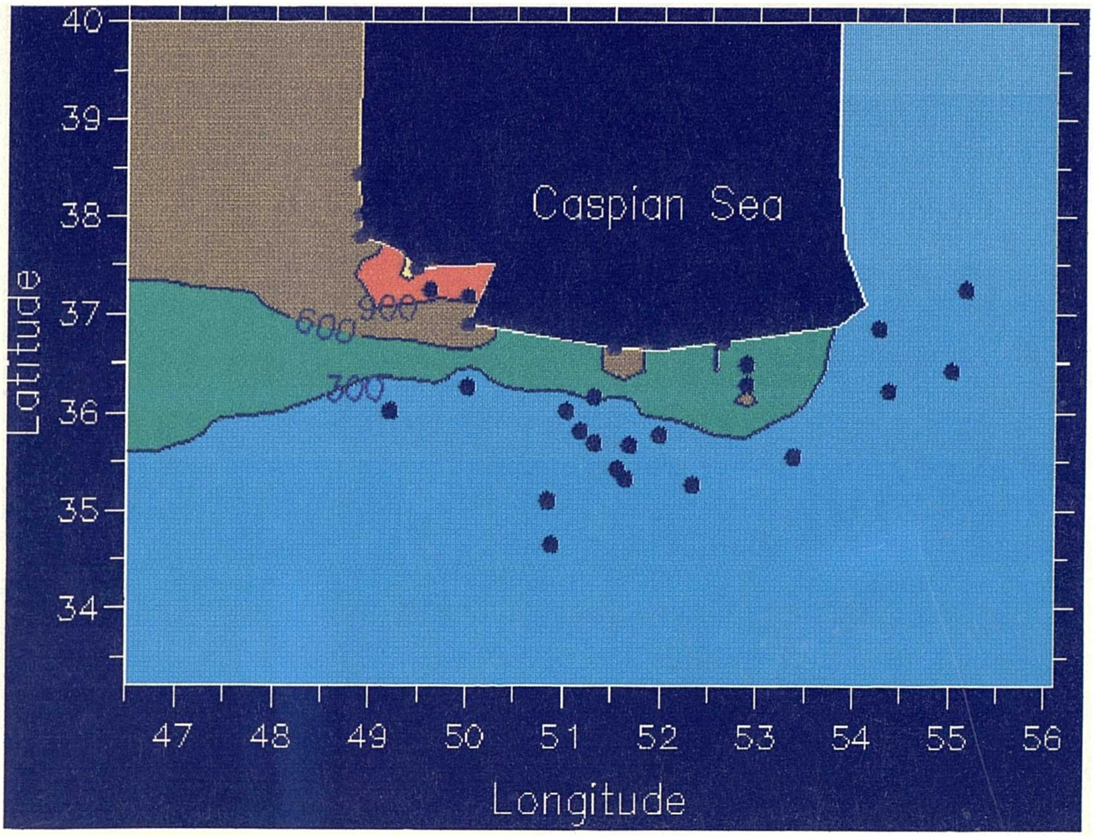


Figure 6-3 Annual rainfall expected to be reached or exceeded at 90% probability.

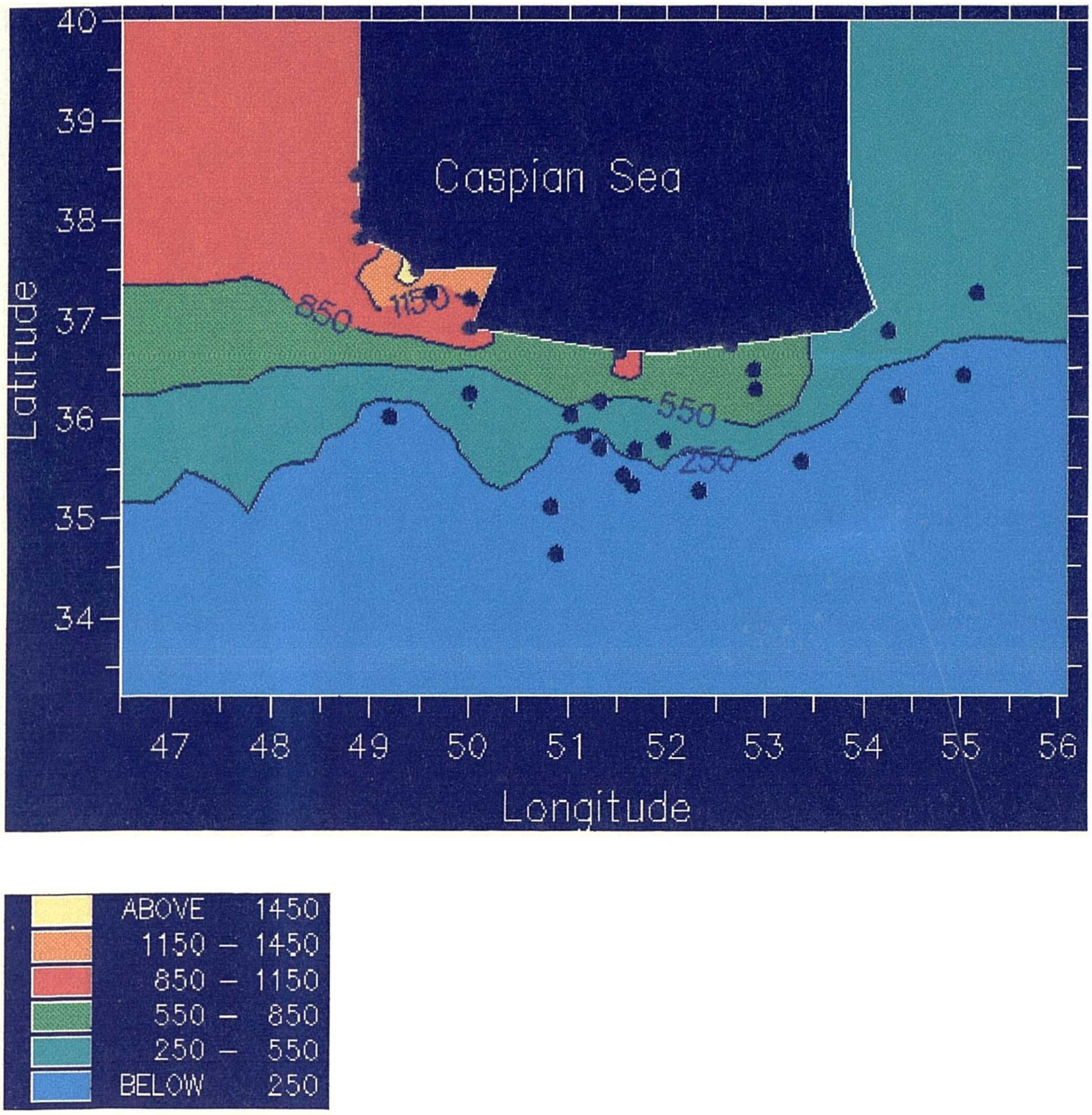


Figure 6-4 Annual rainfall expected to be reached or exceeded at 80% probability.

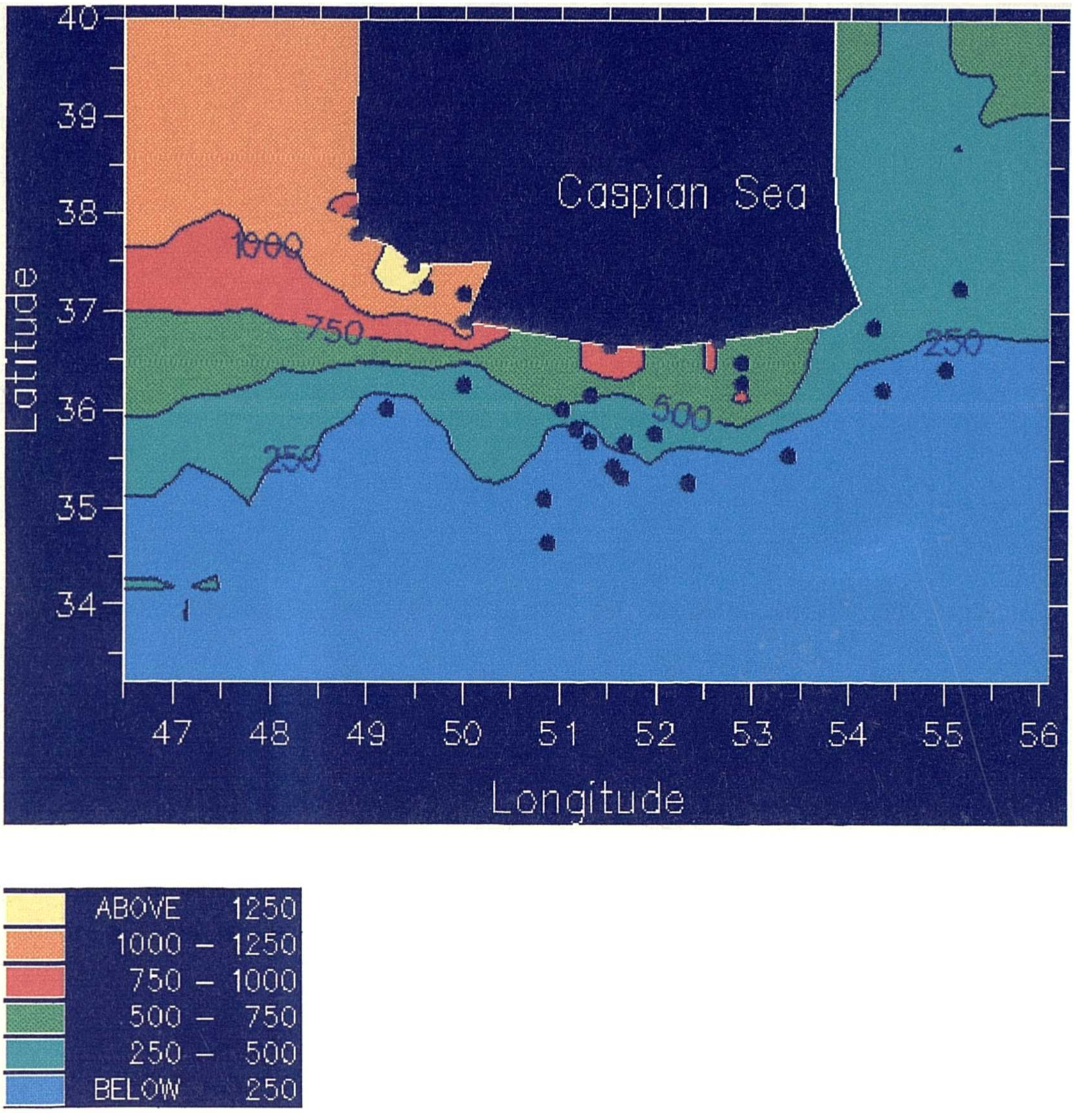


Figure 6-5 Annual rainfall expected to be reached or exceeded at 75% probability.

6.16 Summary and Conclusion

It has long been realized that the climatological averages, as such, are generally unsuitable for direct usage, particularly in the field of agriculture. There has always been a need for additional information that may throw light on the variability and the reliability of these averages. Rainfall probability and reliability would, therefore be of great value and relevance to the objective assessment of the agricultural potential in the Central Elburz of Iran. It was the aim and objective of this chapter to make an assessment of the probability and reliability of receiving or exceeding critical annual rainfall amounts in the Central Elburz stations and to calculate probability and reliability tables and figures that may provide a basis for future planning of the water resources and agricultural potential in this area.

This study concentrated on crops of wheat, rice, citrus and cotton due to their food and commercial importance in the national economy. Three thresholds of rainfall amounts, 240 mm is adopted for wheat, 300 mm for cotton and 1000 mm for rice and citrus.

Reliability can be calculated in terms of the amount of rainfall that can be expected or exceeded at a given level of probability. The choice of the percentage level depends on the ability to cope with crop failure. In the case of the Central Elburz, 90% probability provides security in agriculture and also 80 and 75 percent of probability have been adopted in this analysis.

Almost all of the coastal area stations have more than 90% probability of exceeding the 240 mm annual rainfall. In the Southern slope stations, the probability of 240 mm annual rainfall varies between 2 and 89 percent. The lowest values of probability levels are found in the southern and eastern stations of the Southern slope stations with less than 10 percentage probability of receiving the 240 mm annual rainfall. However, the probability of receiving this amount increases sharply from the southern and eastern parts to the west and northwards. Thus for a critical level of 240 mm rainfall level of reliable rainfall is restricted to a few stations along the west and northern part of area where the percentage probability exceeds 71%. In the west the probability of receiving 240 mm is within the range of 71% to 81% while in the north, it is more than 89%. In this area percentage probability of receiving 240 mm rainfall increases with altitude. In the Higher Altitudes the percentage probability of 240 mm rainfall is more than 90%.

The 1000 mm rainfall minimum levels was selected for rice and citrus as being of most interest agriculturally, because in the Caspian coastal area stations annual totals of this order if well distributed in the rainy season appear sufficient to permit the adequate growth of rice. The highest values, more than 80% probability are found in the western stations of the Caspian Sea. However the lowest values, less than 50% are found in the eastern area of the Caspian Sea lowlands.

Cotton is cultivated intensively in the Gonbad and Gorgan distinct it is also grown in the some parts of the Southern Slopes. Because of its very great economic importance in different parts of Iran, the effects of water on cotton yields have received significant attention, particularly in terms of water requirements and irrigation. Usually a minimum of 300 mm annual rainfall is required, with 100-150 mm well distributed during the growing season. The highest values are found in the western stations of the Caspian Sea with amount of 100% probability of receiving 300 mm annual rainfall. However, the lower values are found in the eastern stations of the Caspian Sea where there is less than 92% of probability of receiving this critical rainfall.

The assessment of the probability of a specified or critical rainfall indicates the expected chances of failure to get the required account over a long period of time. On the other hand the assessment of the value of rainfall expected to be received or exceeded with a given probability will be the amount that can be depended on. Therefore definition of the dependable rainfall is the value of rainfall that can be received or exceeded in 90, 80 and 75 percent of the years.

Usually the rainfall amount which can be expected at 90% probability is low over most of the Central Elburz Stations with the lowest amounts being in the Southern slope stations and the highest values in the Caspian coastal area stations.

The amounts of rainfall expected ranges from Gonbad with 196 mm to Anzali with 1281 mm rainfall in the Caspian Coastal Area Stations.

The rainfall which can be expected with 90 percent probability is less than 197 mm rainfall in the Southern Slope Stations. This amount of rainfall emphasises that the Southern Slope Stations of the Central Elburz are very dry areas. Highest amounts are found in the Latian, Ghazvin and Takestan Stations which are at relatively higher altitudes. In the Higher Altitudes locations, the 90% expected rainfall is greater than 239 mm, with Abali having the highest amount of 285 mm 90% expected rainfall is higher than the Southern Slope Stations. It differs from 239 mm in Northern Kandavan Station to 285 mm in the Abali station.

The application of the Binomial frequency distribution can be useful in determining critical time periods of receiving deficient rainfall amounts. Thus the Binomial frequency distribution have been used for the probability of happening insufficient rainfall two consecutive years for a better planning of the agricultural resources, over the Central Elburz stations in a decade.

7

7. The Timing of the Rainy Season and its Duration in the Central Elburz

A detailed knowledge of the rainfall regime is an important prerequisite for agriculture planning. In previous chapters the wet and the dry seasons were defined on the basis of monthly rainfall. As already stated, an important though often neglected aspect of the Central Elburz rainfall is the character of the seasons.

In seasonally arid parts of the world the date of the rains is an important agroclimatological variable. Rain is required for presowing cultivation and for sowing. Thus the timing of the start of the growing season in seasonally arid countries is a problem of great importance in agricultural planning. For an agriculturist, the important questions about rainfall are concerned with the start, end and length of the rainy season the distribution of rainfall amounts, and the risk of dry spells in the growing season. In spite of the importance of such information for the planning of agricultural projects, so far no investigations about the dates of the start, the end and the duration of the rainy season over the Central Elburz have been attempted. For rain-fed agriculture in the Central Elburz, the start and end of the growing season are important considerations for good crop yields. A false start for planting could be encouraged by the occurrence of early rains only to be followed by dry spells of about five days or more during which the top soil could dry out and prevent the germination and development of plants. On the other hand, late planting reduces the risk of crop failures, but yields can decline for the following reasons:

1) The beneficial effect of soil nitrate content, which is high at the beginning of the rains, is missed. The build up of nitrates during the dry season will be available to plants during the beginning of the rainy season. However, once dissolved in soil water they can be rapidly leached out by heavy rainfall to soil horizon below rooting depth out of the soil by through flow and stream discharge.

2) The crops may fail to mature as a result of the shortening the growing season. For example, Wrightly (1969) showed that delaying planting from 6th to 25th January reduced cotton yields by 47 percent and Kassam (1973) presented data to show that groundnut yield begins to decline significantly with a reduction of 20 days or more in the length of the growing season for the savanna areas of Nigeria (Olaniran 1984).

A successful early planting can produce an earlier crop which may have a higher yield. Later planting reduces the risk of early crop failures, but yields can decline with late planting. The review presented above raises two issues:

a) that a balance is desired between a false start and late planting of crops, and

b) planting of crops which can not mature by the end of the growing season should be available. Also there are two extremely critical periods when water shortage can cause wilting of the plant and reduce yield:

1) The first occurs immediately after sowing when the plant is germinating. A dry spell at this time can halt germination and create the need for replanting of the crop.

2) The second critical period occurs during flowering when a water deficit can severely reduce yields of crops.

Most researchers on the subject assume, the start of the rains as marking the beginning of the growing season. They therefore use these terms interchangeably. The terms end of rains and end of the growing season are often employed in the same sense

(Olaniran1983 and 1984). It is the purpose of this study to be more critical of the definition of rainy season.

In the Central Elburz where rainfall assumes significance in nearly every phase of agricultural activities from the timing of cultivation, planting and harvesting operations to the timing of fertiliser application, variety selection, and transplanting, the importance of the timing of rainfall can not be over emphasized. Most crops are sensitive to weather conditions both during their growth and as they reach maturity. There is an optimum moisture range in which field preparation should begin and an optimum time for sowing and harvesting operations of various crops. When soils are either too wet or too dry field operations usually prove inefficient and harmful to the growth processes of crops whilst continuous rains often delay the harvest. This is true for wheat, rice and cotton cultivation in the Central Elburz stations and accounts for the seasonal variability in crop yields. Moreover, since most crops require varying periods of time for harvest, continuing rains will not only slow the harvest operation but will also create a favourable environment for the growth of moulds and fungi. This will in turn cause a reduction in the quality of the harvested crops. In this regard the action of the rainfall belt therefore, provides a framework for the correct timing of the operations. Timing of rainfall occurrence will be analysed in the following ways:

1) the time of the onset of the rains and the variations of this time over the Central Elburz area.

2) the timing of the end of the rainfall and its variation in the Central Elburz.

3) the length of the rainy season.

The objective of this chapter is to examine daily rainfall data over the Central Elburz of Iran in order:

1) to determine the start, end and length of the rainfall based on daily rainfall over a period of 10 years at selected stations in the Central Elburz.

2) to study the frequency and probability of dry spells within rainy season.

7.1 Data and Methods

The above objectives were accomplished by an analysis of ten years of daily rainfall data for the 10 stations over the Central Elburz. These climatic stations are located within 2 major agricultural areas over the two different parts of Central Elburz as follows:

a) Stations located of the Caspian coastal area (Anzali, Babolsar, Gorgan, Ramsar, and Rasht). This area has a flat topography with an average elevation of less than 8 m above sea level. The elevation varies from -26 metre (below sea level) at Anzali to 105 m (above sea level) at Gorgan station. Many field crops such as rice, citrus, wheat etc. are extensively cultivated throughout the coastal plain.

b) Southern slope stations (Ghazvin, Karaj, Semnan, Tehran, and Varamin). This area has a ridge topography with an average elevation of more than 1190 m above sea level. The elevation changes from 1000 m (above sea level) at Varamin to 1321 m at Semnan Station. Many scope crops such as cereal (especially wheat), water melon, melon and cotton which are extensively cultivated throughout this area. All of the stations have recorded about 10 or more years of continuous daily rainfall data. Details of the 10 sites in the Central Elburz are given in Table 7-1.

Table 7-1 Stations used in the analysis for the period 1982 to 1991.

Stations	Altitude (m)	Latitude (°N)	Longitude (°E)	Mean Annual (mm)	Mean of rainy day
Anzali	- 26	37.28	49 28	1816	137
Babolsar	- 21	36.43	52 39	901	95.4
Gorgan	105	36.51	54 16	514.8	99
Ramsar	- 20	36 54	50 40	1177	117
Rasht	- 7	37 15	49 36	1415	124
Ghazvin	1304	36 15	50	340	74.5
Karaj	1321	35 48	51 10	231.6	50
Semnan	1138	35 33	53 23	154.8	40
Tehran	1191	35 41	51 19	261.6	56
Varamin	1000	35 19	51 39	196	48

'A rainy day was defined as a day with more than 0.1 mm of rain'.

A great deal of research has been devoted to a study of the start of the rains in areas outside Iran most of them based on monthly data and only a few have been based on daily data. Most of these studies discuss the start of rains only. In all cases using daily data periods of five, seven or ten days at beginning of the rains have been analysed, which is perhaps understandable considering the large arrays of numbers that must be manipulated. The use of daily values of rainfall in this way will give an accurate determination of the start of the rains for individual places, but would be impracticable for a regional study. Rainfall amounts on a daily rainfall basis can not be analysed in probability terms. What is most important is the sequence of rainfall days. Thus the analysis must use an interval of 5, 7 or 10 days. Plant water requirements over periods of about ten days can usually be met by both rainfall and water stored in the soil, thus agroclimatic studies use this interval. Also in this study daily rainfall is used for establishing the risk of dry spells, the distributions of the dates of the start, end and length of the rains. Daily data was used to define rainfall events, which has advantages notably on the start, end of rains and dry spells. It is on this basis that the methods of determining the start of the growing season for the Central Elburz have been derived by Stern *et al* (1981,1982a and 1982b) and Dennett *et al* (1983). These methods broadly define the crop growing season without considering the specific requirements of particular crops. According to Stern *et al* (1981,1982a, and 1982b) the start of rains is defined as the occurrence of 20 mm of rain on one or two successive days. Dennett *et al* (1983) defined the start of rains as the first occasion when a total of at least 20 mm of rain falls within a five day period and there are no dry spells of 10 or more days beginning within the subsequent five days.

The start of the rainy season was defined by Stern *et al* (1982) in the following way :

a) an event, **E**; that indicates a potential start date, defined as the first occurrence of at least **X** mm totalled over **t** consecutive days and;

b) the potential start could be a false start if an event, **F**, occurs afterwards; where **F** is defined as a dry spell of **n** or more days in the next **m** days. It is possible to choose the earliest possible starting date and also to express the probability of a successful planting. For example 1 May could have 20 mm in two consecutive days and only one ten day dry spell in the subsequent 30 day period thus could allow sowing and the successful emergence of a crop.

7.2 Definition of the Start of the Growing Season

The timing of the start of the growing season in seasonally arid countries is a problem of great importance in agricultural planning (Stern and Coe 1981). There are many possible definitions of the start of the rains in the literature. The simplest is a threshold for the amount of rain received.

Walter (1967) defined the earliest start of the rains in West Africa as being when accumulated rainfall reached two inches (51 mm). Illesanmi (1972) explained that the onset of rainfall at every station begins (in Nigeria) with an accumulated 7-8 percent of the annual rainfall. Illesanmi adopted the following procedures for deriving the time of the onset of rainfall:

1) derivation of the percentage of the mean annual rainfall that occurs at each 5 days interval;

2) accumulation of the computed percentage at 5- day intervals;

3) plotting the cumulative percentage at 5 day intervals through the year; and

4) identification of the time of onset of rainfall as the first point of maximum curvature on the plotted graph. This however depends on the nature of the rainfall distribution.

Davey, *et al* (1976) defined the start of the rains as being that 10 day period which first received 20 mm or more rainfall. Benoit (1977) defined the start of the growing season as the date when accumulated rainfall exceeds and remains greater than one half of potential evaporation for the remainder of the growing season, provided that no dry spell longer than five days occurs immediately after this date. This does take account of the water requirement of crops. Stern *et al* (1981) defined it in terms of the time of occurrences of a specified amount of rain (20 mm) within two successive days. Stern (1982) defined the start of the rains as the first day, or two day rain spell, in which greater than a specified total amount of rain occurs.

Stern *et al* (1982) quoted by Kowl and Knabe (1972) defined the start as the first ten-day period with more than 25 mm, provided that rainfall in the next ten day period exceeded half the potential evapotranspiration. Stern and Coe (1982) defined this event (start of rains) as 20 mm of rain falling on one or two successive days.

The start of the rains is defined as the first occasion when a total of at least 20 mm of rain falls within a five day period and there is no dry spell of 10 or more days beginning within the next five days (Dennet *et al* 1983). Show (1982) defined the start of the rain in each season is defined as the date when accumulated rainfall exceeds 10 percent of the seasonal total for each season. Olaniran and Sumner (1989) computed the percentage of the mean annual rainfall occurring for 5 day interval and accumulating and plotting the computed percentages throughout the year, the time of onset of the rainy season is taken to be the first point of maximum curvature on the plotted graph, provided that this date is not followed by a dry spell of 10 days or more. Also Virmani (1975), Dennet *et al* (1984), Singh (1986), Sivakumar (1989, 1990 and 1992) and Jolliffe and Sarria-Dodd (1994) have used similar definition. Therefore from the above definitions and discussions it can be concluded that all of them are common with the start of the rainy season is defined as the first occasion when a total of at least 20 mm of rain falls within a five day period when there is no dry spell of 5, 7 or more days beginning within the next 5-7 days.

7.3 Start of the Rains Over the Central Elburz Stations

The common element in all of these is to use a time interval of 5 and 10 days and to define a threshold in terms of accumulated total rainfall. These methods broadly define the crop growing season without considering the specific requirements of particular crops. These definitions attempt to eliminate early starts to the rains by considering dry spells which are particularly important over the Central Elburz due to the intermittent and variable character of its rainfall. The aim of this chapter is to investigate for the Central Elburz stations daily rainfall to determine the date of start, end and duration of rainy season. The method of determining the start of the growing season for the Central Elburz derived by Stern *et al* (1982a and 1982b) and Dennett *et al* (1983) has been used in this analysis due to the fact that it considers both the total rainfall and the subsequent dry spells which are both important to local farmers in this region. Thus the start of rains is defined as the first occasion when a total of at least 20 mm of rain falls within a five day period and there is no dry spell of 10 or more days beginning within the next five days. It is possible to calculate the frequency distribution of the date of the start of the rains and to assess the probability of rains starting on different dates.

Start dates of the rainy season were found annually by searching the records for each year. The distribution of the start of the rainy season for the 10 stations are shown in the Table 7-2 to 7-4 and Figure 7-1 to 7-10.

Reference to Table 7-2 to 7-4 and Figure 7-1 to 7-10 show that the start of the rainy season differs for southern slope and coastal area stations over the Central Elburz based up on their characteristics as follows:

a) Coastal Area;

In most years the rainy season starts between July and September but in some stations it can occur as late as October or November (Gorgan and Babolsar).

At Anzali the start of rains is defined as the first occasion after 27 July when a total of at least 20 mm of rain falls within a five day period and there is no dry spell of 10 or more days beginning within the next five days. And also the onset ranged from day 27 July to day 26 August with a mean start day 11 August. At Babolsar the starts ranged from 2 August to 2 November with a mean start day 4 September. The start of rainfall at Gorgan varies from 12 Sep to 31 Oct. with a mean start 28 Sep. At Ramsar these are ranged from 15 July to 29 Sep with a mean start day 20 Aug. At Rasht the rainy season starts between 30 July to 29 Sep. with a mean start 22 Aug.

b) the southern slopes;

The dates of the beginning of rain vary from year to year in different locations over the 10 years period under investigation.

At Ghazvin rainfall onset varies from 8 October to 18 Dec. with a mean start 8 Nov. At Karaj the starts are ranged from 8 Oct. and 17 Dec. with a mean start 22 Nov.

While at Semnan is between 9 Oct. and 25 Dec. with a mean start 25 Nov. Tehran rainfall start changes from 8 Oct. to 30 Nov. with a mean start 12 Nov. At Varamin the starts are ranged from 9 Oct. and 18 Dec. with a mean start 16 Nov. Therefore the rainy season starts early in the coastal stations and progressively later southwards (southern slope stations). The months of August and September in most parts of the coastal area stations and months of October and November in most parts of the southern slope stations state of the Central Elburz signal the beginning of the rainy season. On the other hand the rainy season begins in the coastal areas stations in summer and, in the southern slope stations in Autumn. It is very important for the southern slope stations due to the cultivating of wheat at the end of summer and early Autumn in this dry area.

Regarding the above analysis and discussion, the start of rains is an event which occurs each year. This type of analysis involves searching the date of occurrence start of rain. The mean starts of the rainy season for the southern slope stations is November but this differs from August to September at coastal area stations. No simple definition can be put forward to define the differences between start of the rainy season in individual years and the mean start of the rains. The date of start of rains varies from year to year over the 10 year period under investigation for each station. By calculating the mean date and finding the early and late start of rains in individual years it will be possible to estimate the start of rain for each location. With reference to Chapter 2 (air masses) and Chapter 3 (wet months) the variation is probably due to the arrival of different air masses which alternately brings the stations under the influences of the hot and dry air and the moist air bringing rain. This discussion may be helpful to explain the start of the rainy season in individual years. As an example, the data for the year 1985 can be considered again for all stations. Reference to Tables 7-2 to 7-4 and Figures 7-1 to 7-10 show the start of rain (for 1985) as follows:

a) Coastal area stations (Anzali 30 July, Babolsar 20 August, Gorgan 21 September, Ramsar 29 July and Rasht 15 September). The start of rain varies from Ramsar (July 29) to as late as Rasht (Sep 15).

b) Southern slope stations (Ghazvin 18 December, Karaj 26 November, Semnan 13 November, Tehran 14 November and Varamin 18 December). The start of rain differs from Semnan (November 13) to as late as Ghazvin and Varamin (Dec 18). Howevr, there is no uniform pattern of early or late starts of the rains for individual years throughout the Central Elburz. As previously pointed out these differences between stations is due to entering different air masses and local condition.

Problems for farmers arise from variability in onset dates of the main rainfall seasons, and with in the rainy season from dry spells interspersed with periods of excessive rainfall. Adequate precipitation does not always coincide with crop growth stages due to annual variability in the onset dates and advance of the rainfall season (Shaw 1987).

7.4 End of the Rains Over the Central Elburz Stations

As previously pointed out, despite a few references most of the studies discuss about the start of the rain only and it is generally assumed that it is possible to apply the procedure to determine the end of date. The definition of the date of the end of the rains may also depend on the particular application. In some studies, e.g. (Walter 1967) the end of the rainy season is defined as the last date on which a threshold amount is exceeded. Another possibility suggested by Stern *et al* (1981) is to use the first occurrence of a long dry spell after a specified date. For example, if the criterion is taken as fifteen consecutive dry days after mid-June as used by Stern *et al* (1982) end of rainy season is (see Table 7-3) 9 July. This definition would agree with the situation in the Central Elburz and is this adopted for this study. Table 7-2 to 7-4 and Figure 7-1 to 7-10 indicate that the end of the rainy season differs for the southern slope and coastal area stations. It ends early in the southern slope and late in the coastal area stations as follows:

a) Coastal Area Stations;

In the coastal area stations the end of rainy season begins in the first week of May (6 May) and in the third week of July (19 July).

At Anzali, the end of rains is defined as the first occasion after 22 May and 19 July with a mean end day 25 June. At Babolsar station the end ranged from 29 April to 14 July with a mean end 28 May. At Gorgan station end of rainy season varies from between 11 May to 8 July with a mean end 14 June. While at Ramsar is between 20 June to 19 July with a mean end day 1 July. At Rasht the rainy season ends from between 12 May and 19 July with a mean end day 9 June.

b) Southern Slope Stations;

In the southern slope stations, the end of the rainy season starts between the first week of May (7 May) and the first week of July (7 July) .

At Ghazvin, the end of rains is defined as the first occasion after 14 May and 7 July with a mean end 6 June. At Karaj station the end of rainy season ranges from 20 May to 16 June with a mean end 27 May. Semnan station end of rainy season varies from between 7 May and 1 July with a mean end 24 May. At Tehran station the end of rains are ranged from 22 May to 5 June with a mean end day 3 June. At Varamin the rainy season ends from between 11 May to 2 June with a mean end day 24 May.

Following this discussion is based on individual year for end of rainy season at each station some general discussion is required for the whole of the Central Elburz region. With Regard to Tables 7-2 to 7-4 and Figures 7-1 to 7-10 these show that the average end of rain is the months of May, June and July for 10 locations, but this varies in individual years in each station. It can be said that the period of the end of rainy season varies markedly over the Central Elburz stations. Therefore there is no uniform pattern of early and late end of rainy season in each location. According Gangi (1968 and also, refer back to Chapter 2 and 3 about origin of rains and wet and dry months), during October to April-May Iran is under the influence of the middle-latitude westerlies, as a result all rains which occur over this region during this period are caused by depressions moving over the area after forming in the Mediterranean Sea. In April- May Mediterranean depressions, which during January-March have frequented the country, begin to retreat. Ganji (1968) stated 25 depressions reach Iran during winter while these reduce to 12 during April-May and thus cyclone activity declines. Furthermore, depressions are weak during these months, they are less able to penetrate far into the interior of Iran. Also, with the approaching summer season the upper air circulation over region becomes dominated by the subtropical centre of high pressure. The subtropical jet stream is located to the north, in the high levels of the troposphere and the rainy season ends with the northward migration of this jet stream. Thus, it can be concluded that the end of rainfall in each station is related to the overall influences of meteorological aspects in this area.

7.5 Length of Rainy Season

Having adopted definitions for the start and end of the rains (rainy season or growing season) in previous pages, the length of rains is calculated simply by subtracting, for each year, the date at which the rains begin from the date at which they end.

Length of rainy season (Z) is taken as the difference (Y-X) where Z = Y-X

Z = Length of rainy season

X = The date of starting of the rainy season;

Y = The date of ending of the rainy season

Considering Table 7-3 to 7-4 and Figure 7-1 to 7-10 show that the duration of the rainy season differs for southern slope and coastal area of the Central Elburz stations:

7.5.1 Coastal Area Stations

At Anzali, the length of rains differ from 288 to 340 days with a mean 317 days. At Babolsar station the length of the rainy season ranges from 204 to 324 days with a mean 266 days. Gorgan station duration of rainy season varies from 215 to 299 days with a mean 257 days. At Ramsar station the length of rainy season varies from 267 to 342 days with a mean 314 days. At Rasht the rainy season lasts from 253 to 335 days with a mean 290 days. Anzali station with a mean 317 value rainy season days and Gorgan with 257 rainy season days are the highest and lowest coastal area stations.

7.5.2 Southern Slope Stations

At Ghazvin, the length of rainy season is differed from 167 and 272 days with a mean 209 days. At Karaj station the duration of the rainy season ranges from 167 to 235 days with a mean value 190 days. Semnan station duration of rainy season varies from 140 to 232 days with a mean value 180 days. At Tehran station these vary from 187 to 238 days with a mean 204 days, while at Varamin it ranges from 132 to 232 days with a mean 190 days. Ghazvin station with a mean value of 209 rainy season days and Semnan with 180 rainy season days are the highest and lowest length of rainy season in the southern slopes stations.

As explained and shown in Tables 7-2 and 7-4 and Figures 7-1 to 7-10 the length of rainy season differs for each station. The length of rainy season is more than 250 days in the coastal area stations while it is less than 250 days in southern slope stations. Regarding sections 7.3 and 7.4 several factors affect the start and end of rains. Also the enter and retreat of same factors can affect the duration of rainy season in this region. Considering the length of rainy season in the coastal area and the southern slope stations needs further attention. The length of rainy season varies between 257 to 317 days in the coastal area stations while it is 180 to 209 in the southern slope stations. The long rainy season in the coastal area stations indicates that the Caspian Sea effect as an oceanic influence (as pointed out in Chapter 3) over this area is the prime factor in enhancing rainfall activities. But the southern slope stations due to being closer to the interior Iranian plains and subsidence associated with the subtropical high pressure especially during summer do not experience a longer duration of the rainy season. However, topographical influences affected some stations such as Ghazvin and Tehran and hence they experience a longer duration of the rainy season than their surroundings stations, although they receive more rainfall.

7.6 Duration-Start and Duration-End of the Rainy Season Relationship over the Central Elburz.

With regard to different start and end of rains over the Central Elburz stations, the relationship between start, end and duration was considered. Thus, the objective of this section is to investigate the relationship between the start date and end date of rains and the duration of the rainy season in the Central Elburz stations. For the 10 locations, we have observed a strong association between the date of start of rains and the duration of rainy season. In this regard it has been provided Table 7- 5 and Figures 7-11 to 7-18. With regard to the Figures 7-11 to 7-18 and Table 7-5, the correlation coefficients for the Central Elburz stations are as follow:

a) the correlation coefficient between duration and start of rainy season are significant for all stations. The results of relationship between start and duration of the rainy season indicate that early start of rains, relate to the longer duration of rainy season. In years when start rains are delayed the length of rainy season in many cases will be shorter.

b) the correlation coefficient between duration and end of rainy season are significant at Anzali, Babolsar, Gorgan, Rasht, Ghazvin and Varamin but not significant for Ramsar, Karaj, Semnan and Tehran. This indicates that if the end of rainy season continues longer the duration of rainy season will be longer as well. However it is arbitrary for some stations.

Table 7-2 Start, End and Length of Rainy Season in specific years over Coastal area stations of the Central Elburz (1982-1991).

Years	Anzali			Babolsar			Gorgan			Ramsar			Rasht		
	Start	End	Length	Start	End	Length	Start	End	Length	Start	End	Length	Start	End	Length
1982	9 Aug	9 July	334	17 Sep	28 May	259	12 Sep	8 July	299	14 Sep	30 June	289	9 Aug.	6 July	329
1983	26 Aug	30 June	308	23 Aug	29 Apr	246	27 Sep	1 July	266	31 July	29 June	333	30 July	30 June	335
1984	3 Aug	5 July	335	3 Aug	24 June	324	7 Oct	6 July	271	11 Aug	4 July	327	4 Aug	21 May	292
1985	30 July	5 July	340	20 Aug	20 May	271	21 Sep	11 May	233	29 July	5 July	342	15 Sep	25 May	253
1986	24 Aug	3 July	312	29 Sep	27 May	241	29 Sep	5 July	268	20 Sep	28 June	280	29 Sep	24 June	267
1987	16 Aug	31 May	288	13 Aug	6 May	264	19 Sep	26 May	260	29 Sep	24 June	267	19 Aug	12 May	267
1988	27 July	1 July	340	5 Aug	6 May	275	31 Oct	23 May	215	15 July	20 June	339	- -	- -	- - -
1989	17 Aug	10 June	297	14 Aug	7 June	295	15 Sep	28 May	266	18 Aug	28 June	313	- -	- -	- -
1990	31 July	22 May	297	2 Oct	14 July	285	20 Sep	27 May	260	31 July	7 July	341	- -	- -	- -
1991	26 Aug	19 July	327	2 Nov	24 May	204	10 Oct	26 May	239	10 Sep	19 July	312	- -	- -	- -
Mean	11 Aug	25 June	317	4 Sep	28 May	266	28 Sep	14 June	257	20 Aug	1 July	314	22 Aug	9 June	290

Table 7-3 Start, End and Length of Rainy Season in specific years over Southern slope stations of the Central Elburz (1982-1991).

Years	Ghazvin			Karaj			Semnan			Tehran			Varamin		
	Start	End	Length	Start	End	Length	Start	End	Length	Start	End	Length	Start	End	Length
1982	8 Oct	7 July	272	-----	----	----	9 Oct	29 May	232	8 Oct	23 May	228	9 Oct	29 May	232
1983	14 Nov	11 June	210	----	---	----	12 Dc	2 July	172	26 Nov	21 June	206	26 Nov	30 May	185
1984	19 Oct	26 May	220	----	----	----	15 No	27 May	193	1 Dec	5 June	187	22 Nov	3 June	193
1985	18 Dec	20 June	183	26 Nov	20 May	176	13 Nov	22 May	186	14 Nov	22 May	190	18 Dec	29 Apr	132
1986	29 Nov	19 June	201	30 Nov	16 Jun	199	29 Nov	15 June	198	30 Nov	18 June	199	29 Nov	31 May	183
1987	8 Oct	4 July	269	8 Oct	30 May	235	26 Oct	1 Jun	218	18 Oct	30 May	218	26 Oct	1 Jun	218
1988	17 Oct	14 May	199	17 Dec.	22 May	180	17 Dec.	8 May	142	-----	-----	-----	-----	-----	-----
1989	2 Dec.	23 May	172	6 Dec.	21 May	167	4 Dec	20 May	167	----	----	----	-----	-----	-----
1990	29 Oct	17 May	200	29 Oct	24 May	208	25 Dec	14 May	140	----	----	----	-----	-----	-----
1991	9 Dec	24 May	167	10 Dec	25 May	167	12 Dec	21 May	160	----	----	----	-----	-----	-----
Mean	8 Nov	6 June	209	22 Nov	27 May	190	25 Nov	24 May	180.8	12 Nov	3 June	204	16 Nov	25 May	190

Table 7-4 Extremes of Rainy Season Statistics over the Central Elburz (1982-1991).

Stations Names	Rainy season parameter	Mean occurrence	Earliest date/ longest length	Length of departure from mean (Days)	Year	Latest date/ shortest length	Length of Departure From mean (Days)	years
Anzali	Start	11 Aug	27 July	15	1988	26 Aug	15	1983-91
	End	25 June	22 May	27	1990	19 July	23	1991
	Length	317	340	23	1988	288	29	1987
Babolsar	Start	4 Sep	2 Aug	28	1988	2 Nov	60	1991
	End	28 May	29 Apr	32	1983	14 July	47	1990
	Length	266	324	58	1984	204	120	1991
Gorgan	Start	29 Sep	12 Sep	17	1982	31 Oct	32	1988
	End	14 June	11 May	34	1985	8 July	24	1982
	Length	257	299	42	1982	215	42	1988
Ramsar	Start	20 Aug	15 July	36	1988	29 Sep	40	1987
	End	1 July	20 June	10	1988	19 July	18	1991
	Length	314	342	28	1985	267	47	1987
Rasht	Start	22 Aug	30 July	39	1983	29 Sep	38	1986
	End	9 June	12 May	28	1987	6 July	27	1982
	Length	290	335	45	1983	253	37	1985
Ghazvin	Start	8 Nov	8 Oct	31	1982-87	18 Dec	30	1985
	End	6 June	14 May	23	1988	7 July	31	1982
	Length	209	272	63	1982	167	42	1991
Karaj	Start	22 Nov	8 Oct	45	1987	17 Dec	26	1988
	End	27 May	20 May	7	1985	16 June	20	1986
	Length	190	235	45	1987	167	23	1989-91
Semnan	Start	25 Nov	9 Oct	47	1982	25 Dec	30	1990
	End	24 May	7 May	17	1988	1 July	38	1983
	Length	180	232	52	1982	140	40	1990
Tehran	Start	12 Nov	8 Oct	35	1982	30 Nov	18	1984
	End	3 June	22 May	12	1985	21 June	18	1983
	Length	204	228	24	1982	187	17	1984
Varamin	Start	16 Nov	9 Oct	38	1982	18 Dec	32	1985
	End	24 May	11 May	13	1985	2 June	9	1984
	Length	190	232	42	1982	132	58	1985

Table 7-5 Correlation Coefficient of Duration- Start and Duration- End of Rainy Season over the Central Elburz Stations.

Stations	Duration- Start	Duration- End
Anzali	0.54	0.80
Babolsar	0.71	0.49
Gorgan	0.69	0.74
Ramsar	0.95	0.21
Rasht	0.76	0.69
Ghazvin	0.50	0.70
Karaj	0.90	0.41
Semnan	0.94	0..40
Tehran	0.73	0.22
Varamin	0.94	0.79

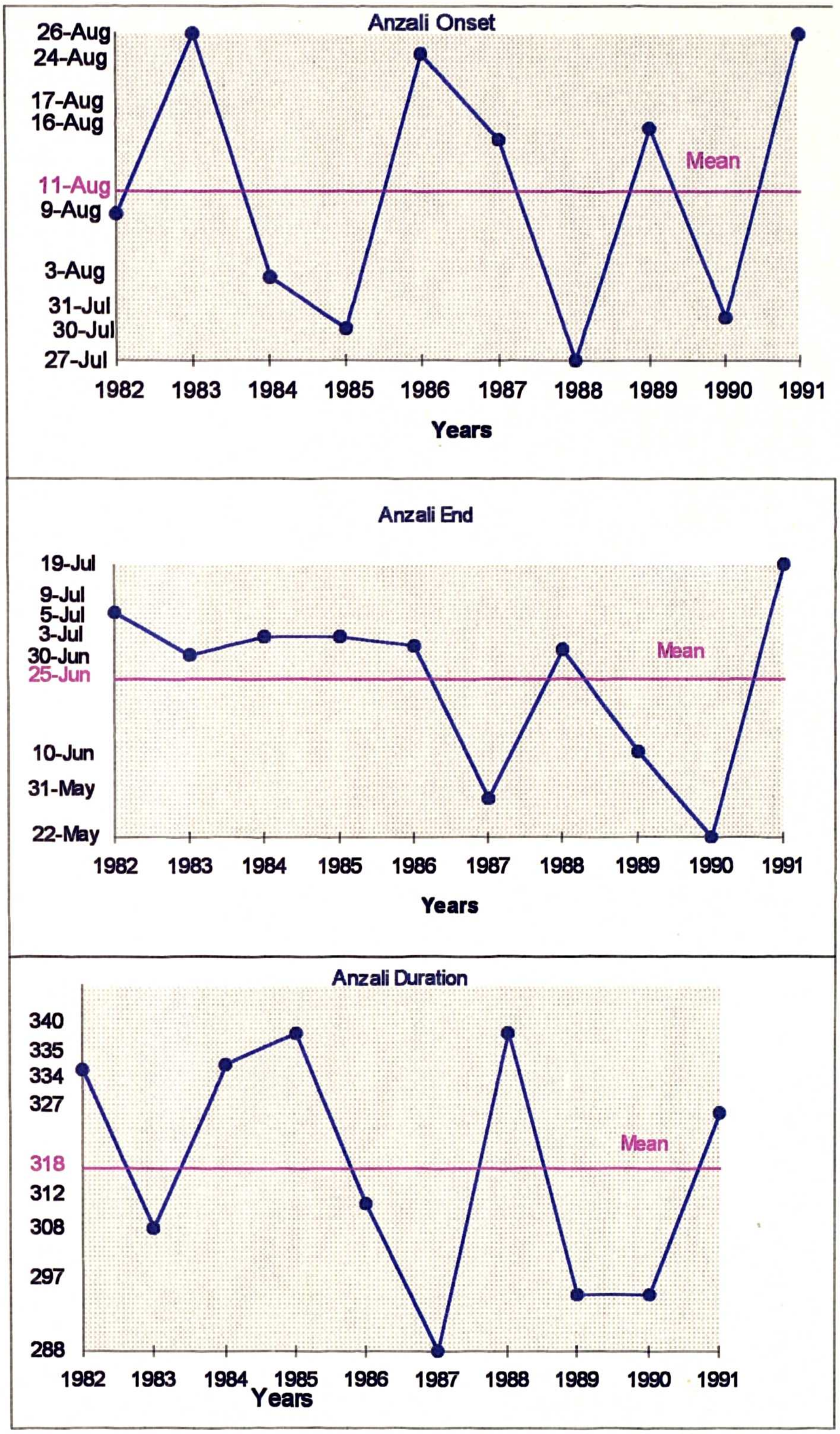


Figure 7-1 Fluctuations of the rainy season characteristics over the Coastal Area Stations.

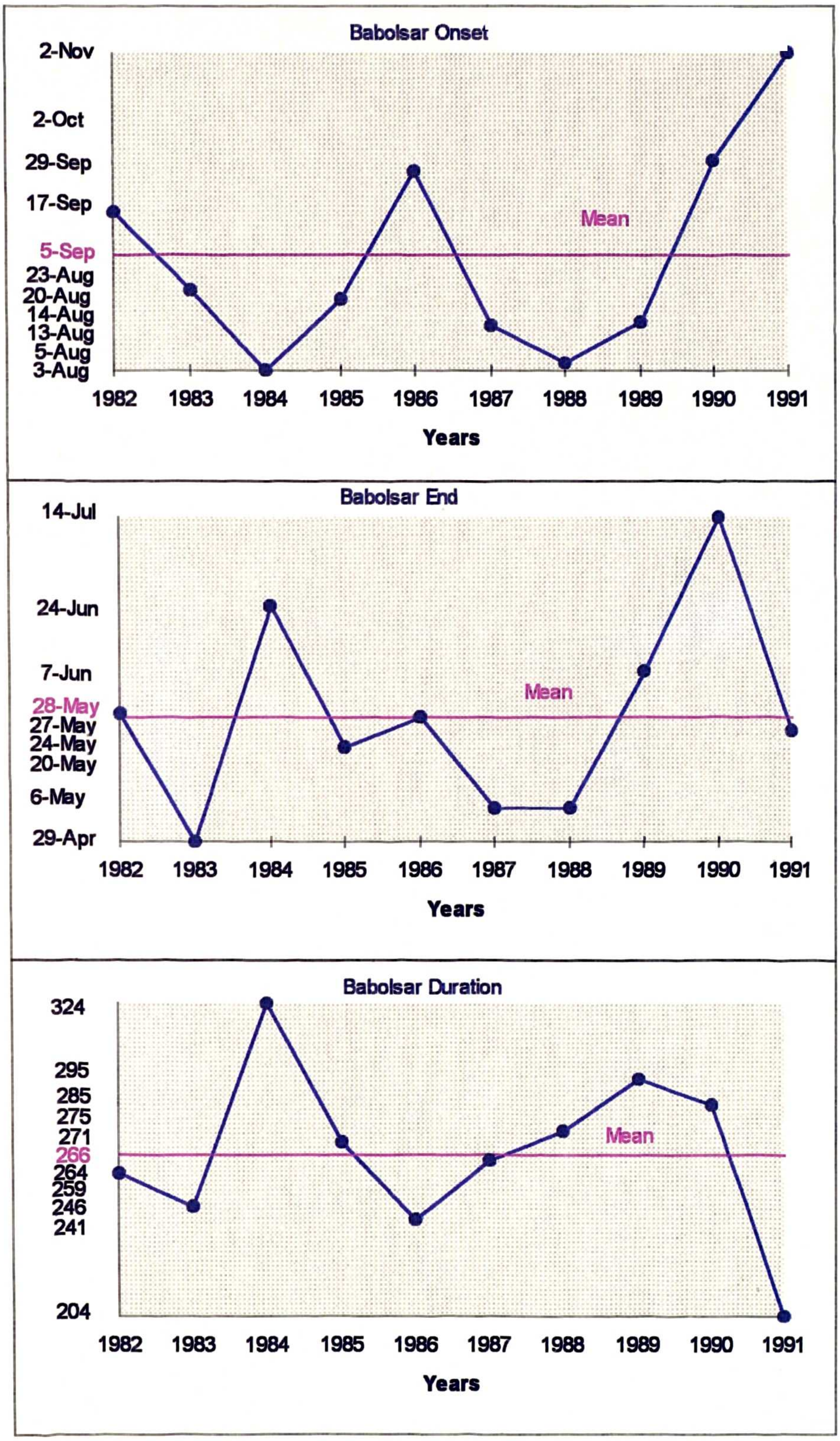


Figure 7-2 Fluctuations of the rainy season characteristics over the Coastal Area Stations

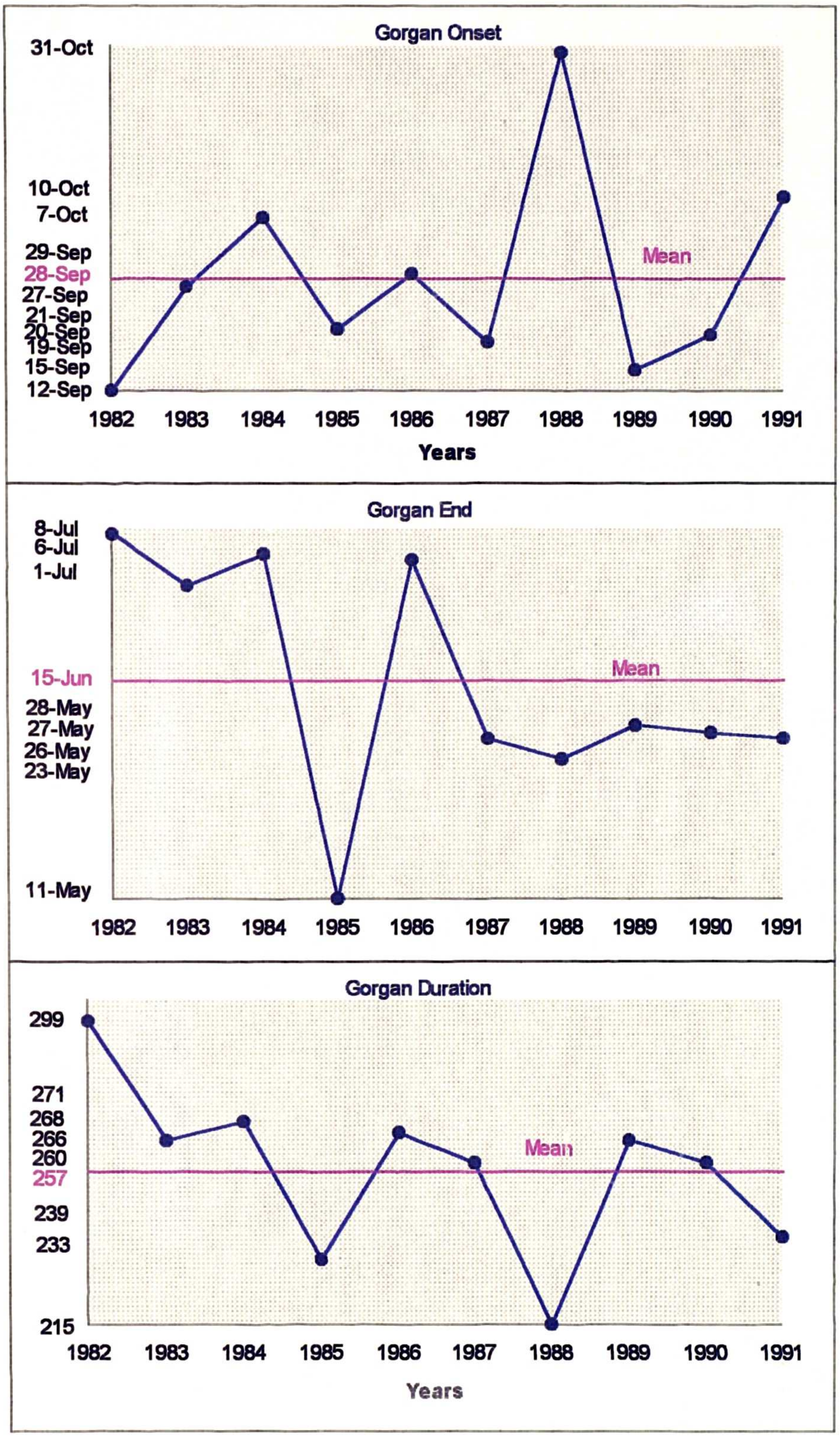


Figure 7-3 Fluctuations of the rainy season characteristics over the Coastal Area Stations.

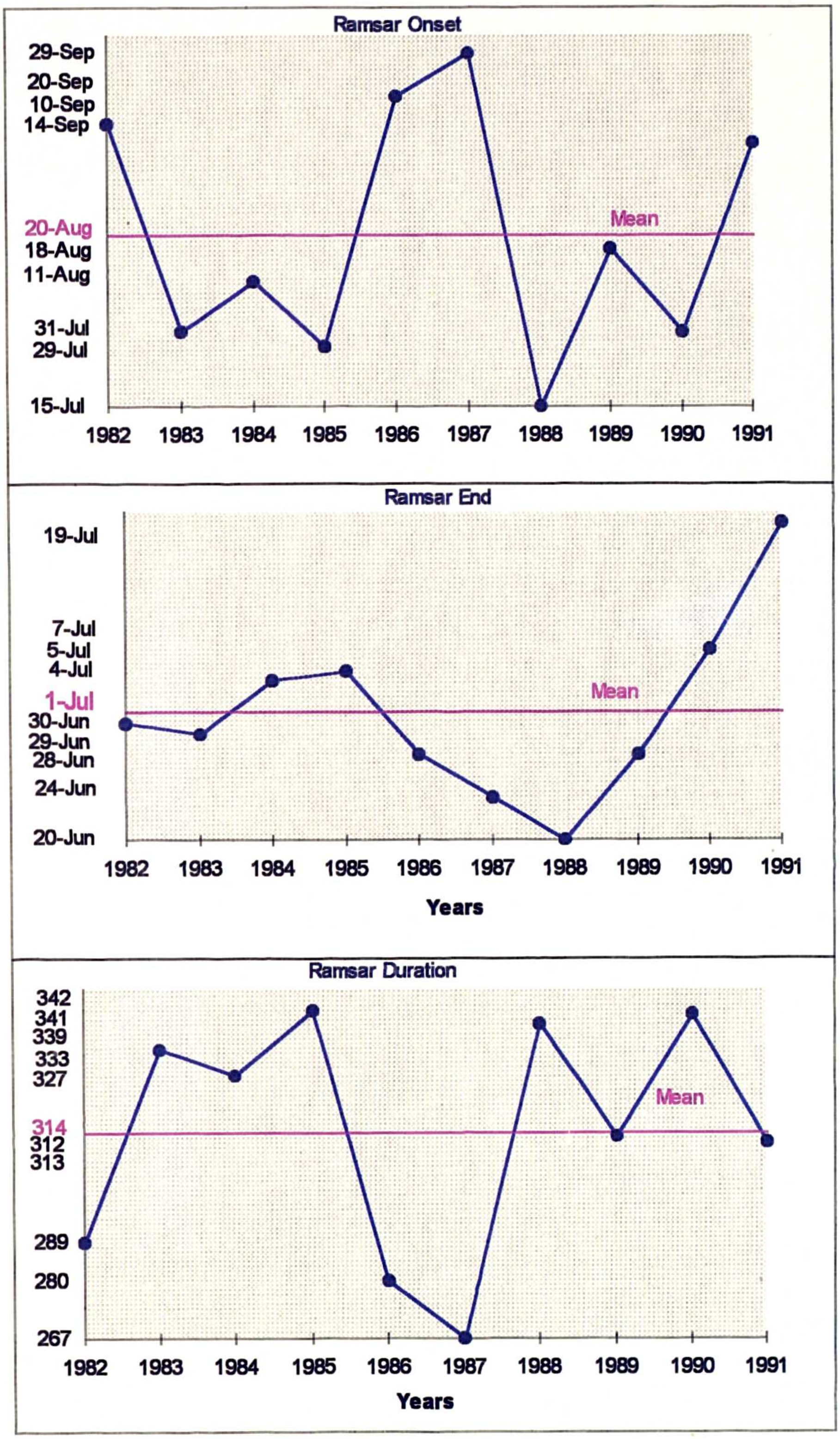


Figure 7-4 Fluctuations of the rainy season characteristics over the Coastal Area Stations.

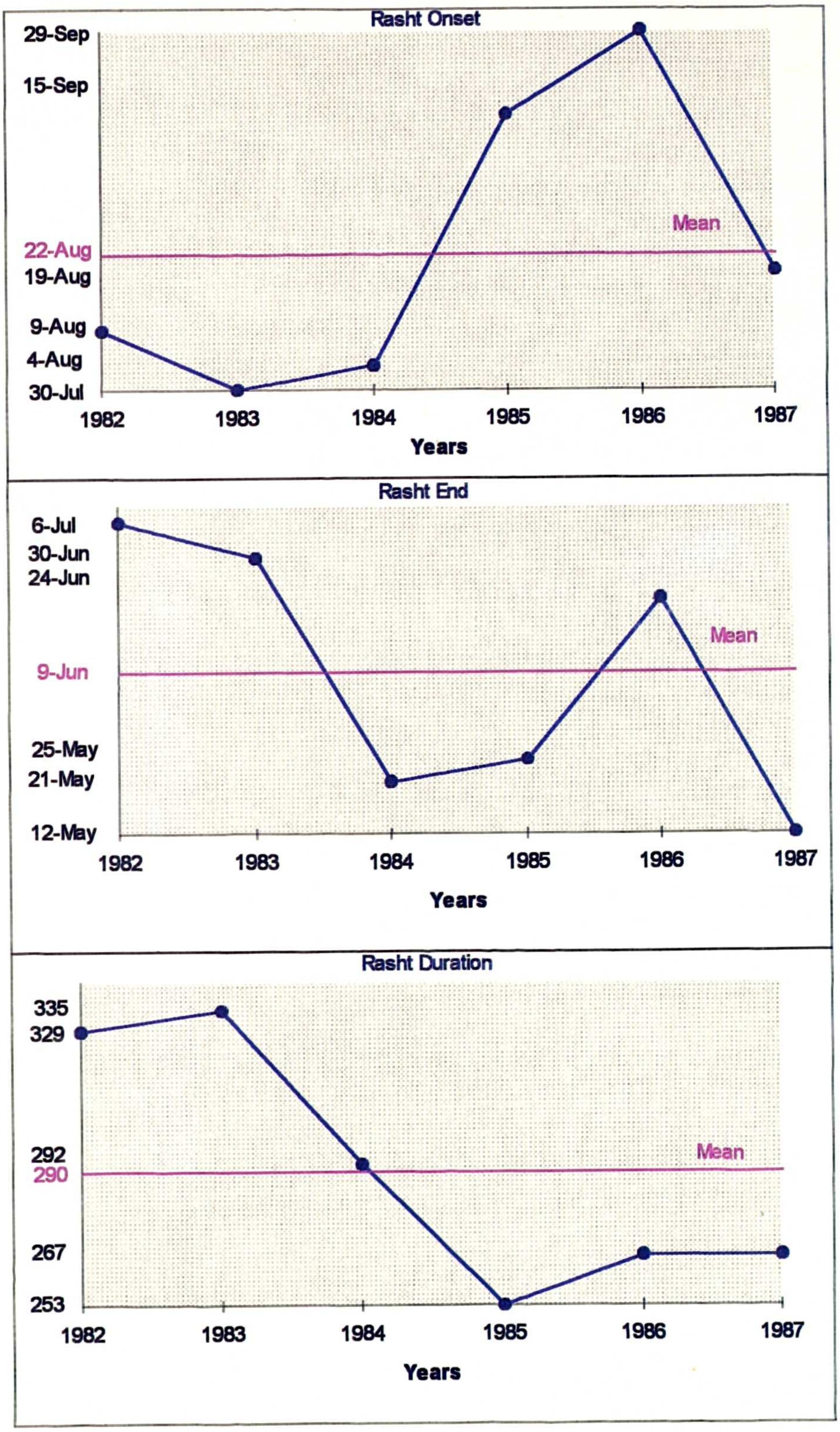


Figure 7-5 Fluctuations of the rainy season characteristics over the Coastal Area Stations.

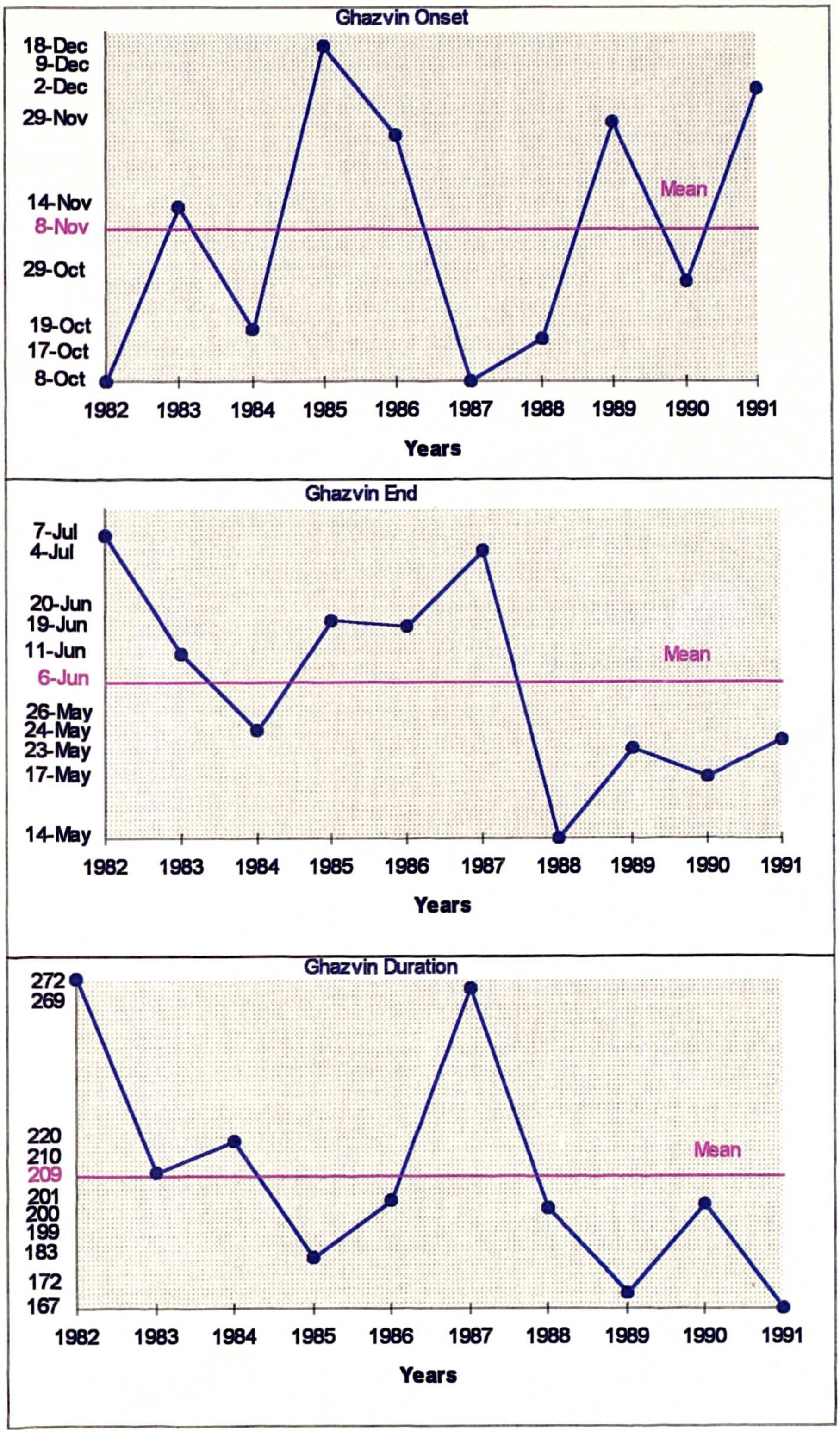


Figure 7-6 Fluctuations of the rainy season characteristics over the Southern Stations.

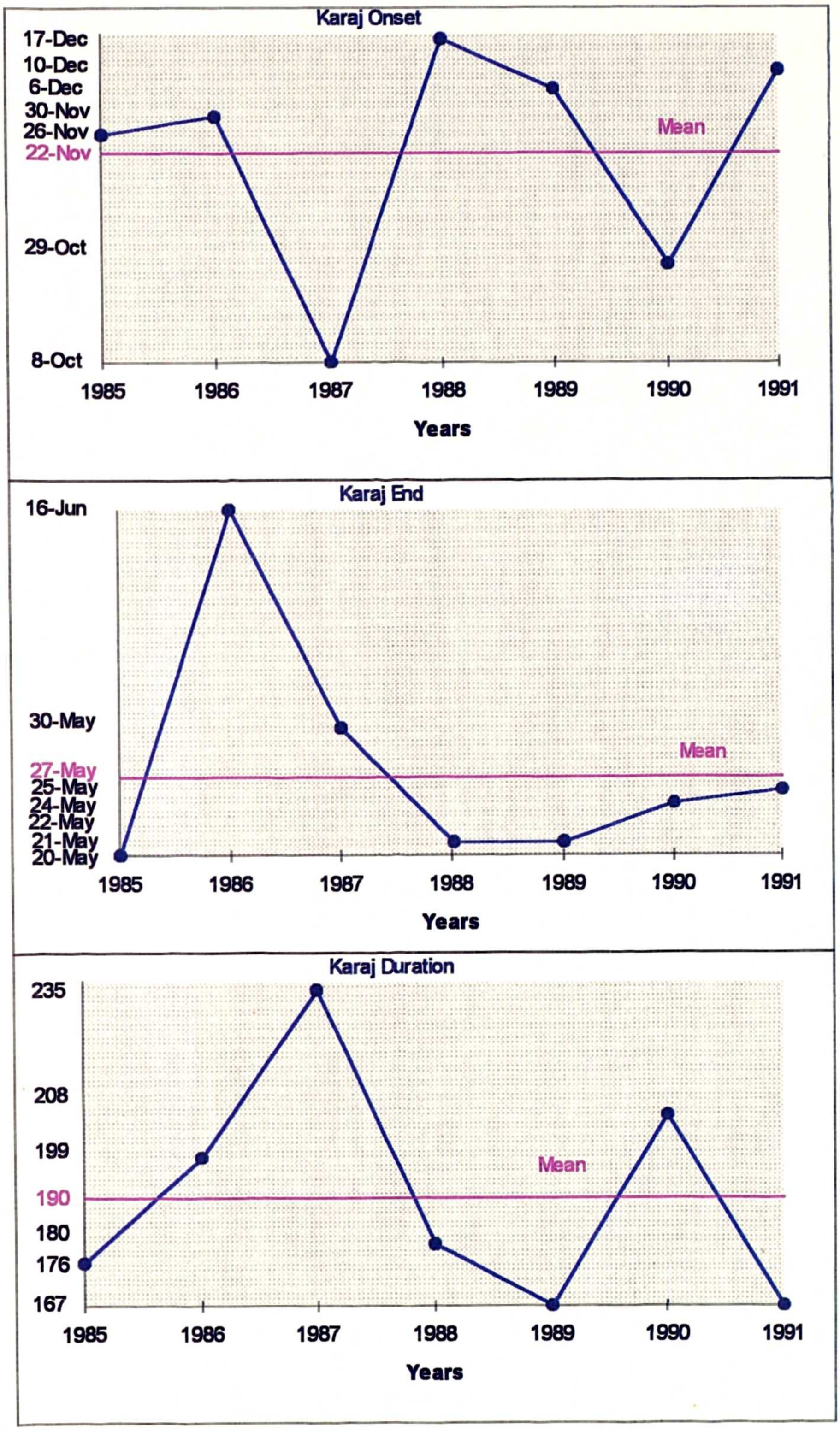


Figure 7-7 Fluctuations of the rainy season characteristics over the Southern Stations.

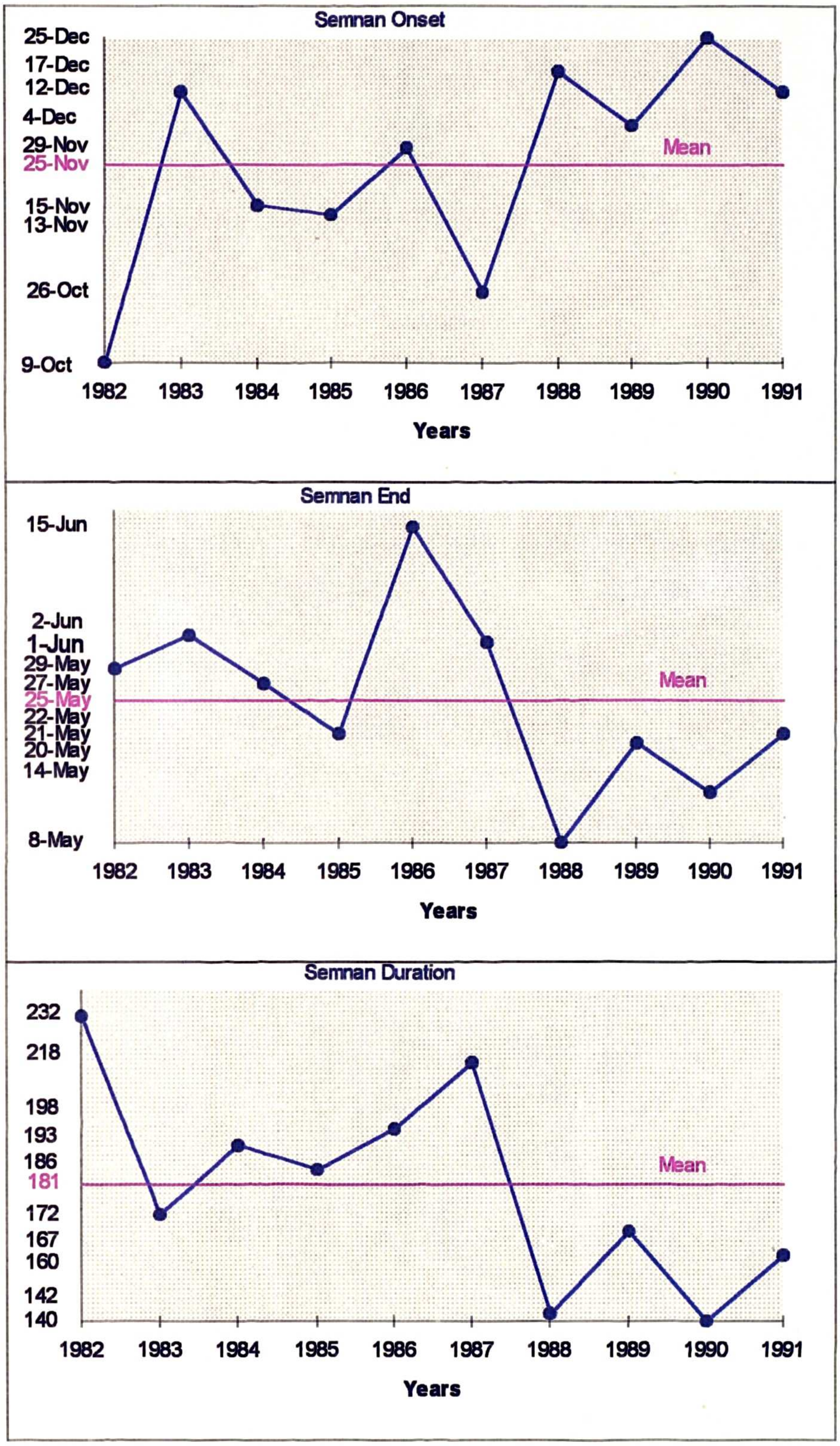


Figure 7-8 Fluctuations of the rainy season characteristics over the Southern Stations.

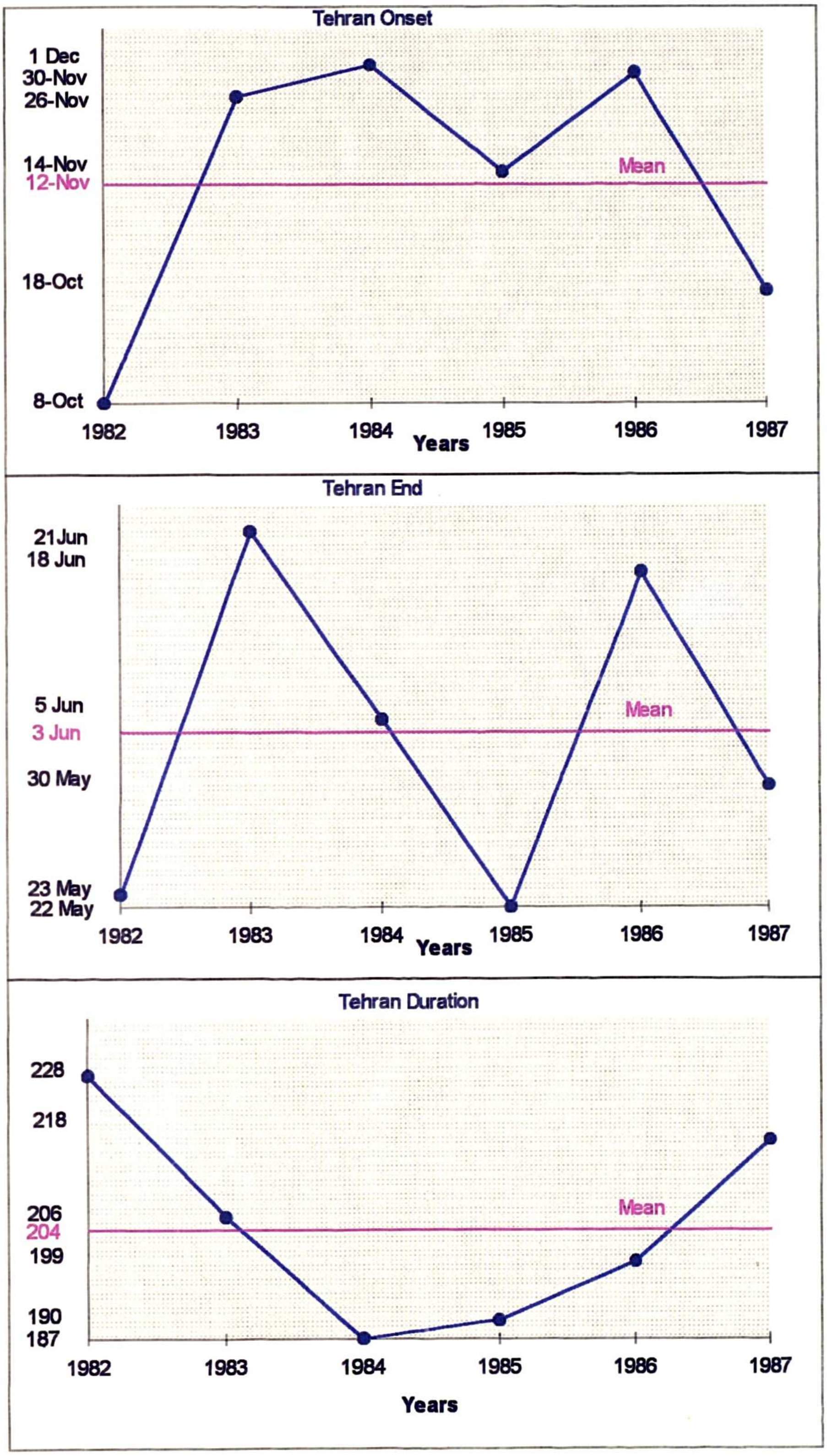


Figure 7-9 Fluctuations of the rainy season characteristics over the Southern Stations.

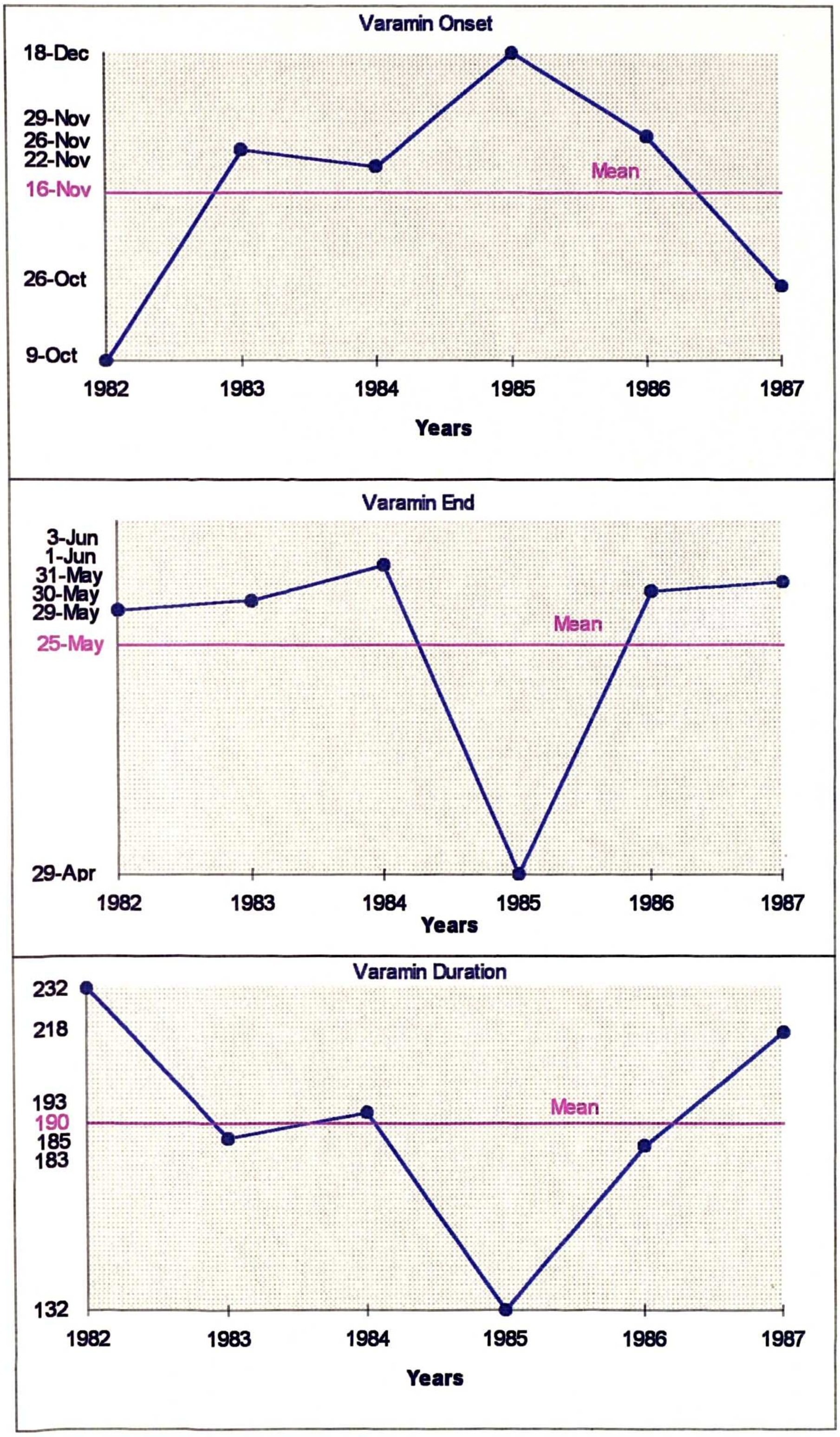


Figure 7-10 Fluctuations of the rainy season characteristics over the Southern Stations.

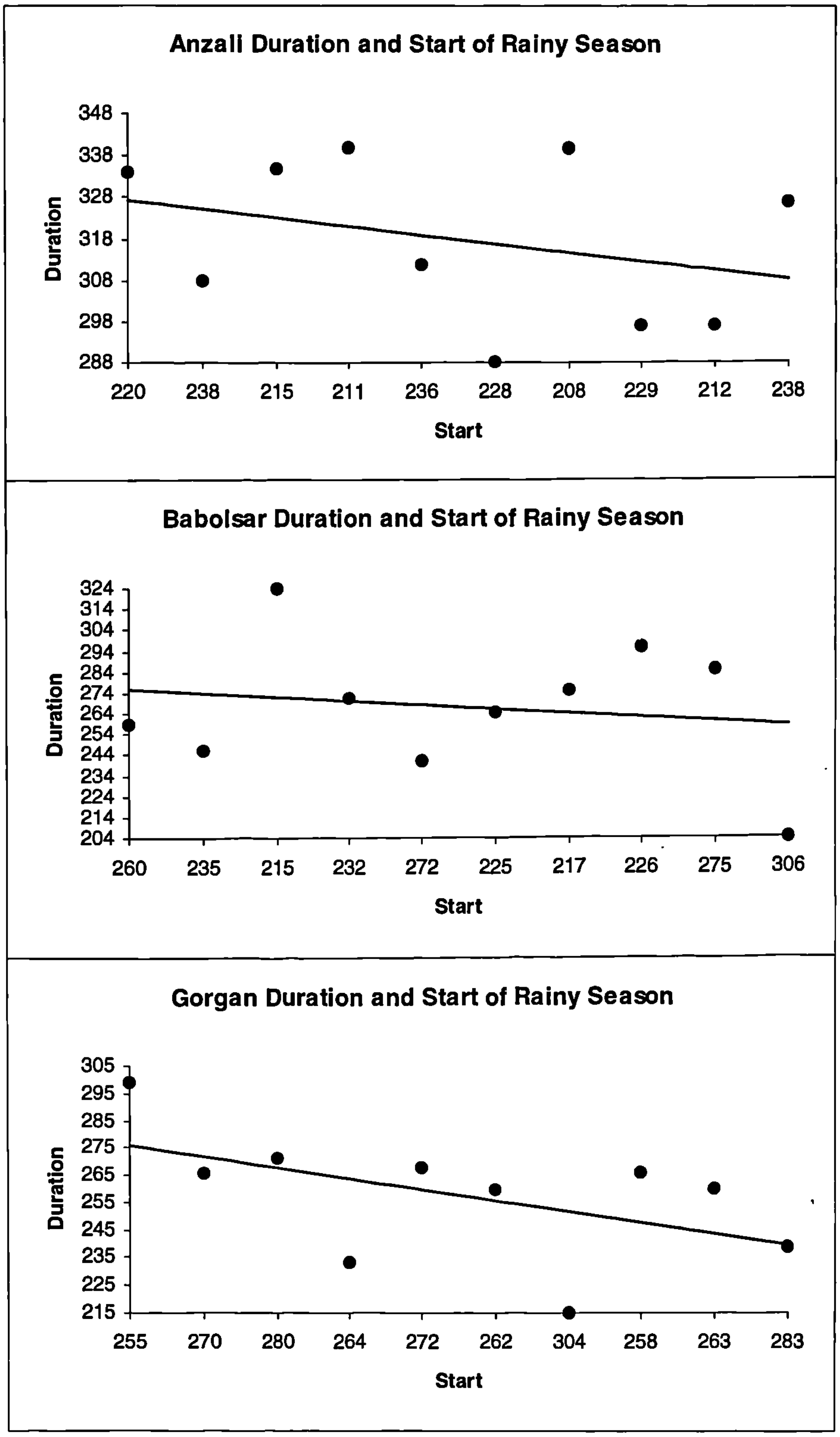


Figure 7-11 Relationship between Duration and Start of the rainy season over the Coastal Area Stations.

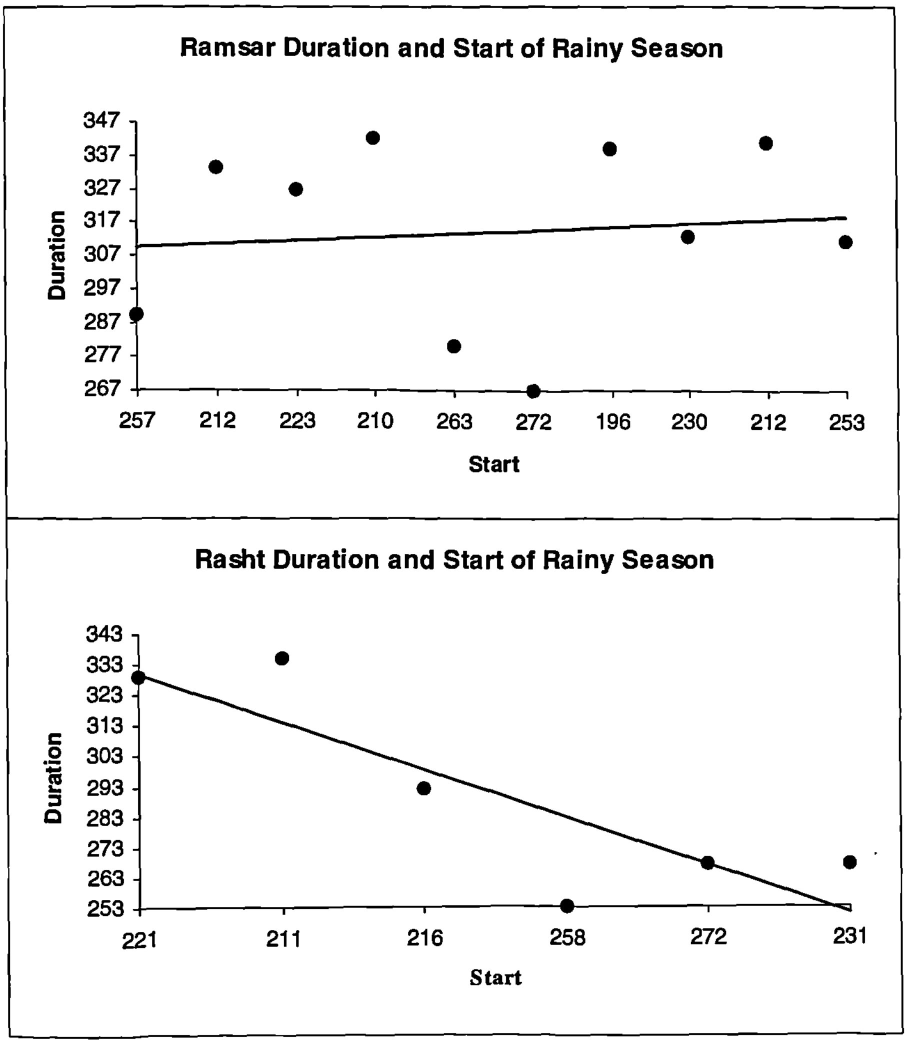


Figure 7-12 Relationship between Duration and Start of the rainy season over the Coastal Area Stations.

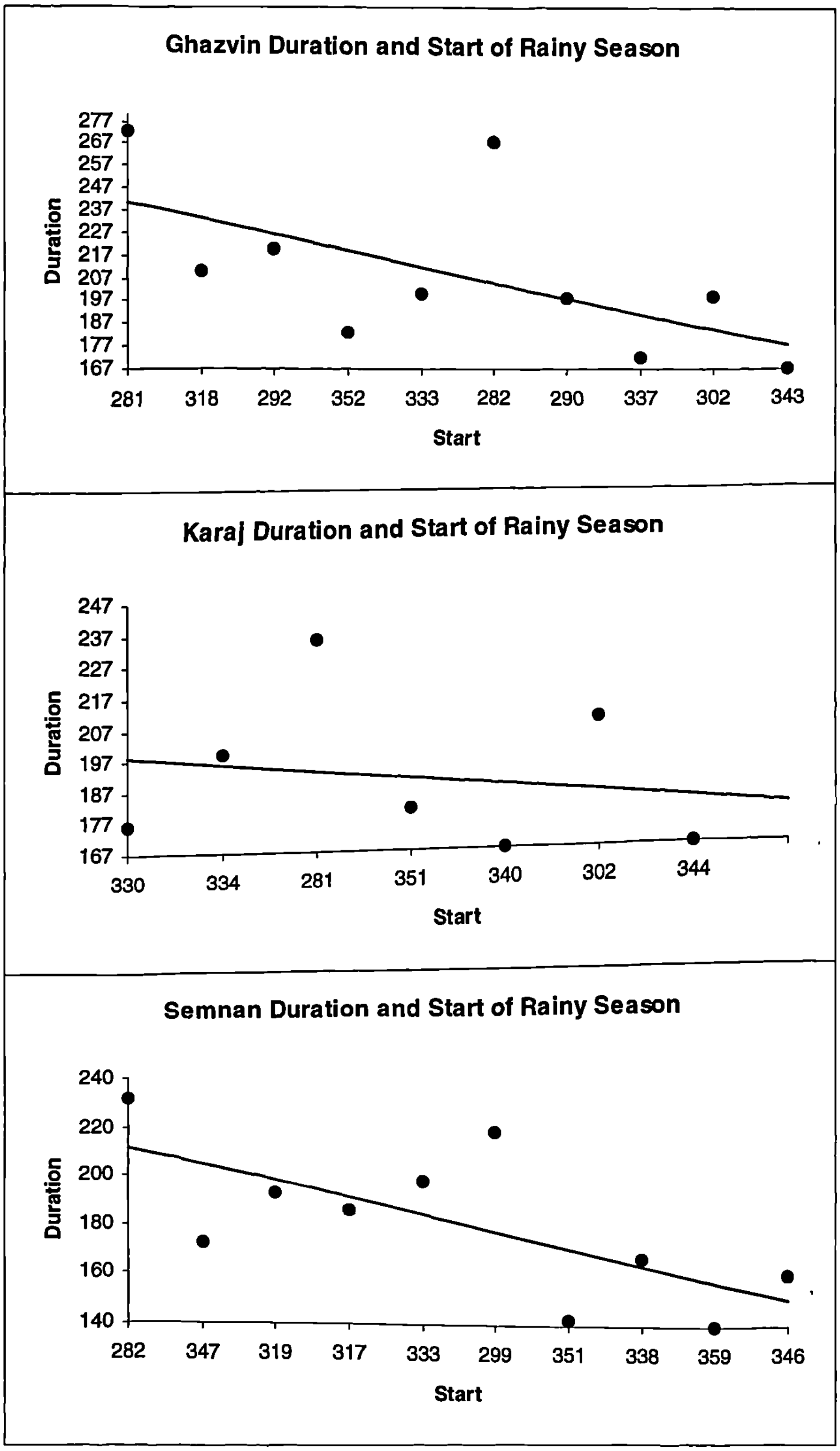


Figure 7-13 Relationship between Duration and Start of the rainy season over the southern slope stations.

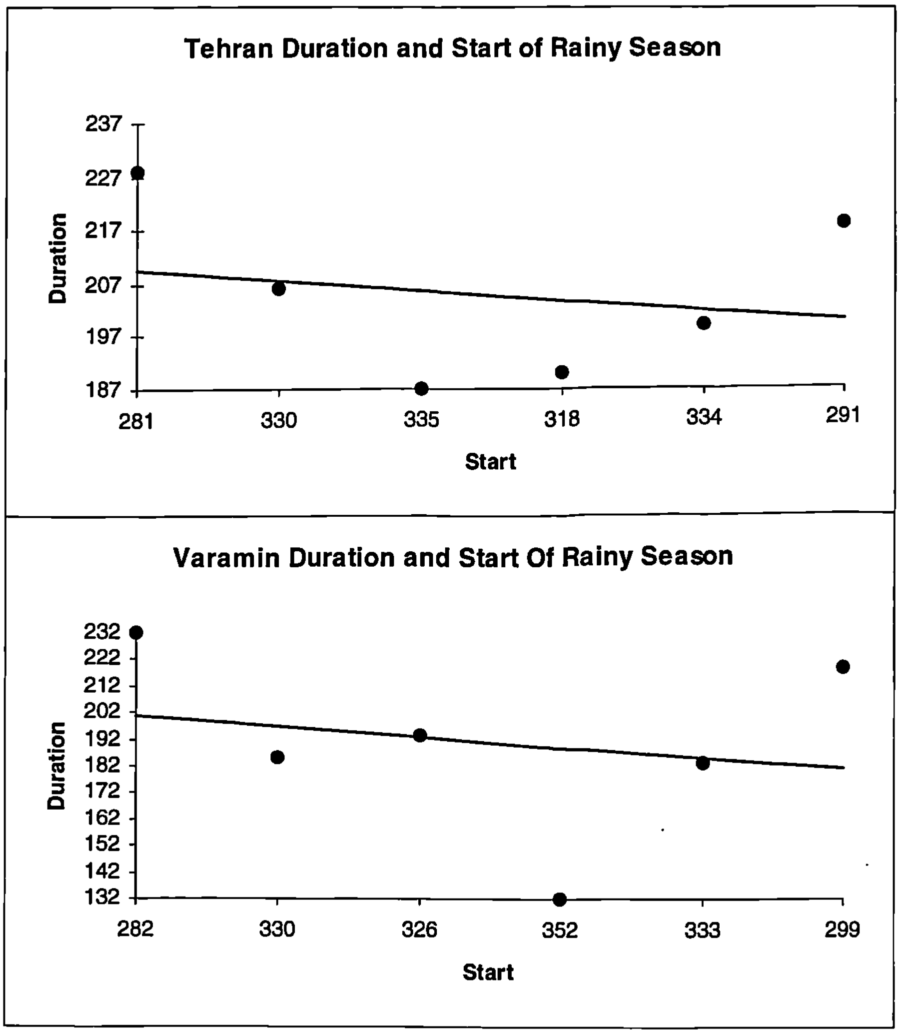


Figure 7-14 Relationship between Duration and Start of the rainy season over the southern slope stations.

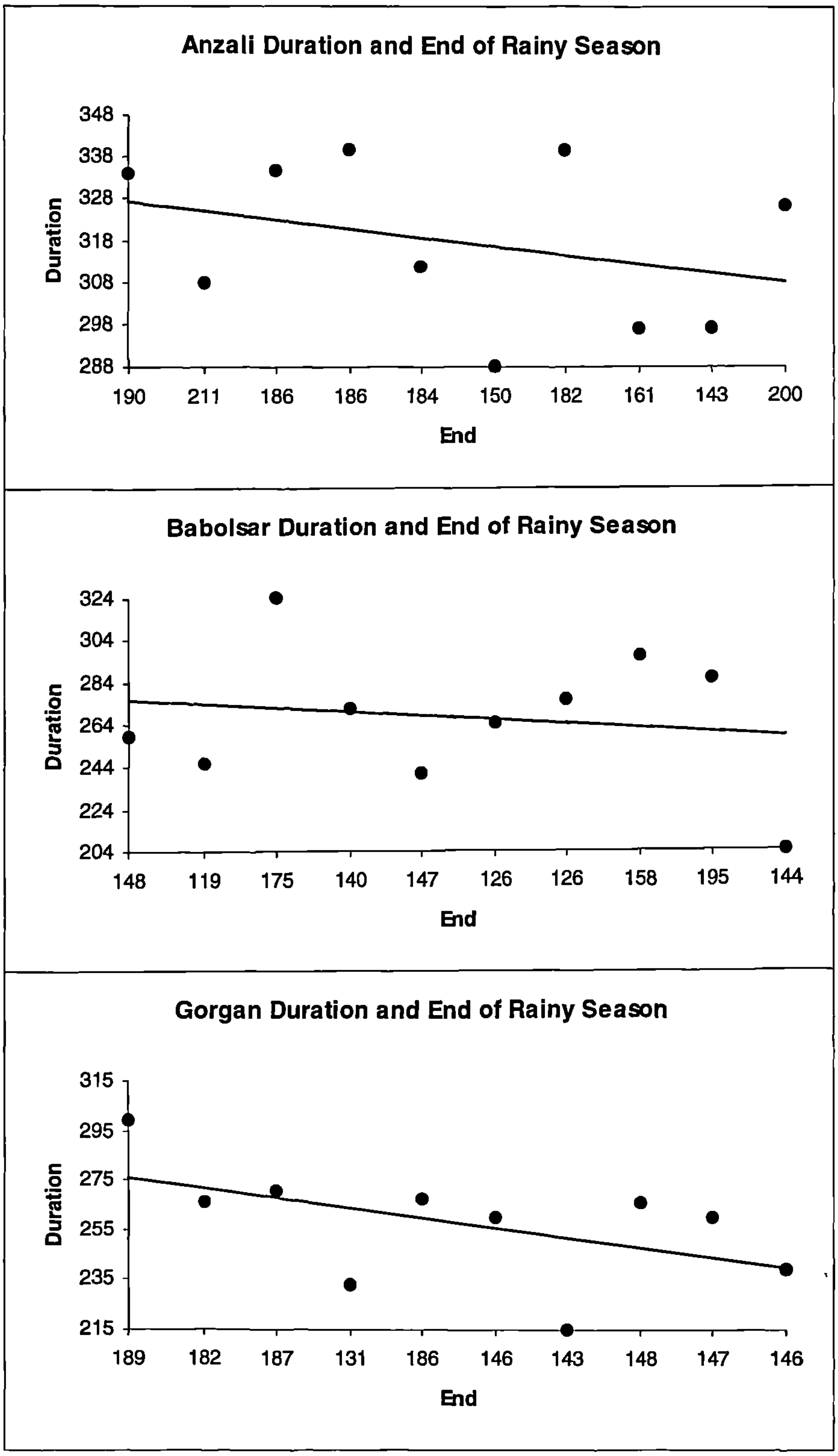
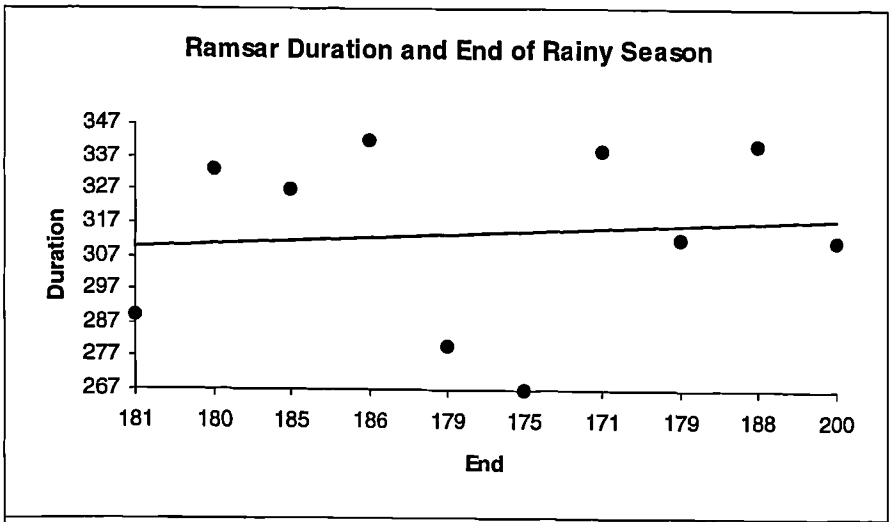


Figure 7-15 Relationship between Duration and End of the rainy season over the Coastal Area Stations.



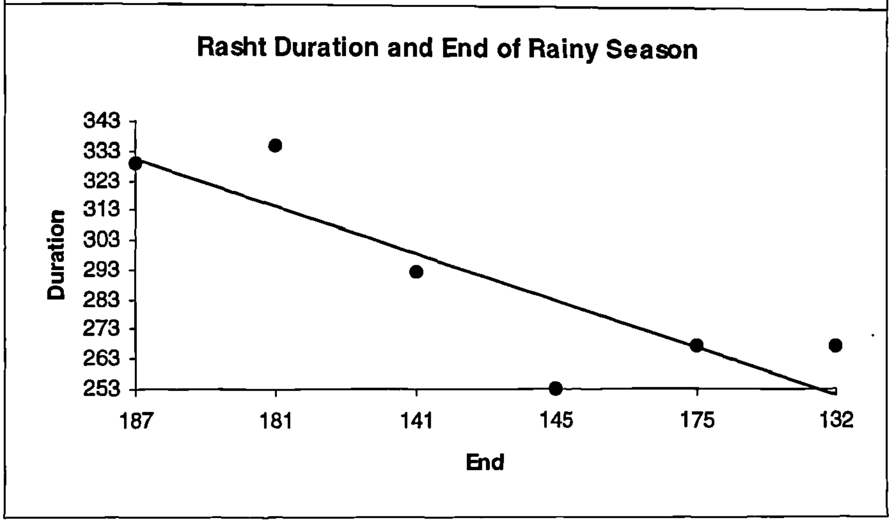


Figure 7-16 Relationship between Duration and End of the rainy season over the Coastal Area Stations.

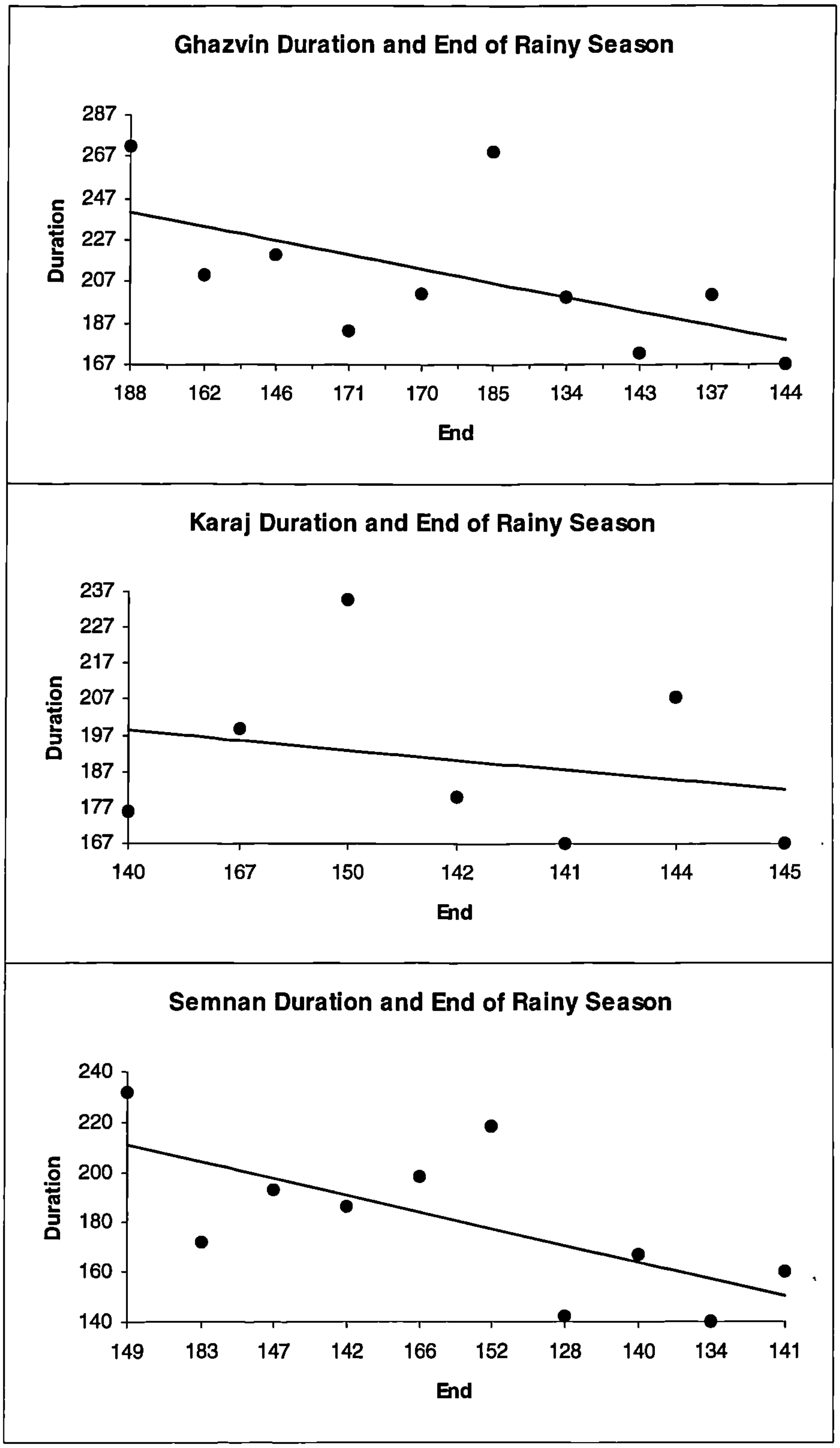


Figure 7-17 Relationship between Duration and End of the rainy season over the southern slope Stations.

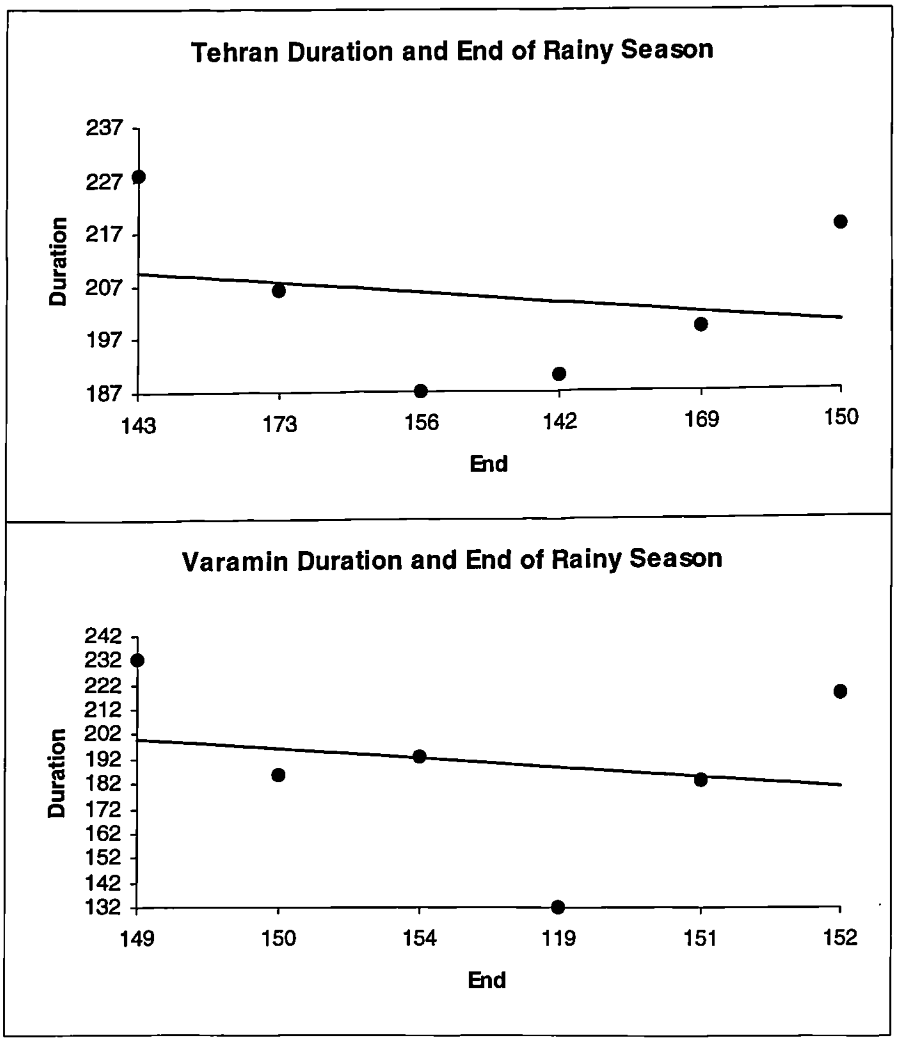


Figure 7-18 Relationship between Duration and End of the rainy season over the southern slope Stations.

7.7 The Summary and Conclusion of the Rainy Season over the Central Elburz

This chapter provides a framework for the assessment of the Central Elburz stations rainfall patterns from the beginning, end and duration of rains. It provides a pattern of seasonal rainfall. From the onset, to the end, and over the duration, the mean of the rains and the variations of this time have been calculated for the stations over the Central Elburz for the first time.

In the coastal area stations, the rainy season occurs between July and September during most years but in some stations it can occur as late as October or November (Gorgan and Babolsar). In the southern slope stations rainfall occurs in the Autumn months. In most years the rainy season occurs between October and November but in some stations it can occur as late as December. Therefore the rainy season starts early in the coastal stations and progressively later in the southern slope. The months of August and September in most parts of the coastal area and the months of October and November in most parts of the southern slope stations state of the Central Elburz signal the beginning of the rainy season. On the other hand the rainy season begins in the coastal area stations in summer and the southern slope in Autumn.

The end of the rainy season begins in the first week of May (6 May) and in the third week of July (19 July) in the coastal area stations. But the end of the rainy season occurs between the first week of May (7 May) and the first week of July (7 July only for Ghazvin station) in the southern slope stations.

The length of rains differs from 204 to 340 days in the coastal area but ranges from 132 to 272 in the southern slopes. So the distribution characteristics of the rainy season are as follows:

1) there is a north-south movement in the rainy season, first it advances northward then moves south (coastal area to southern slope).

2) the coastal area stations have a relatively longer rainy season compared to the southern slope. The computed rainy season is 9-10 months in the coastal area stations and 6-7 months in the southern slope stations.

3) the rainy season is spread over a long period at the coastal area stations and concentrated over a short time period at the southern slope stations.

4) The length of rainy season decreases from west to east in the Central Elburz Stations.

5) the analysis shows that all stations have variable length from year to year.

Finally in comparison with Wallen (1968), it was indicated that the start of the rains for the Middle East is usually in November or early December, and the end of the rainy season is May or even the middle of June. According to this present analysis this is true for the southern slope stations. But Wallen's results do not agree with the present analysis for the coastal area stations. When most authors have discussed about the climatology of Iran, they have considered the climate of Iran as a unit climatology of the Middle East. But they did not pay attention to climatology of different parts of Iran. In this regard the climate of Caspian coastal area has never been clearly evaluated by climatologists.

The extreme dates of the rainy season over the Central Elburz are shown in Table 7-4. Table 7-4 indicates earliest, latest date and length of departure from mean, this information is very important for agricultural planning.

The correlation coefficient between duration and start of the rainy season over the Central Elburz stations are significant. The results of relationship between start and duration of the rainy season indicate that if they start early, the duration of rainy season will be longer.

The correlation coefficient between duration and end of the rainy season are significant at Anzali, Babolsar, Gorgan, Rasht, Ghazvin and Varamin but not significant for Ramsar, Karaj, Semnan and Tehran. The daily analysis does not differ from monthly analysis.

7.8 Analysis of Dry Spells in the Central Elburz Stations

Analysis of the start of the rains, though it considers dry periods immediately following the first rains, may not be sufficient as a guide to the sowing of crops. Rainfall sufficient to define the beginning of the rainy season may be followed by long dry spells which prevent crop growth. The consequences of drought are often woven into the economic and social fabric of a region, these are referred to as an important order effect. For example price increases, increased food imports, surges in rural to urban migration rates etc. The analysis of this occurrence of drought within the growing season is thus important in assessing agricultural potential.

In many parts of the world, long dry spells occurring during the wet season are a major agricultural hazard. The probability of a dry spell of length **d** days occurring in the next **m** days may be obtained by using the recurrence relations Stern and Coe (1982). Where **d** may be = 7, 10, 15, 20, 30 and **m**, 30 days.

To investigate dry spells, we must first define a threshold of daily rainfall below which a day may be considered dry. The smallest amount of rain that can be recorded is 0.1 mm, so this is one possibility, and is used here. Although this level means that days with little or no water added to the soil are considered dry. The effect of this on plant is likely of be considerable and this will increase with the length of the speed. Recording values of 0.1 mm are often considered unreliable this makes the definition of wet and dry days uncertain. Conrad and Pollack (1950) used a variety a wet spell they define as a period of consecutive days with at least 0.1, 0.2, 0.5, etc., mm of rain. Also a dry spell means a period of at least five consecutive rainless days. A dry spell is a period of at least 15 consecutive days to none of which is credited 0.04 in. rain or more.

The risk of a dry spell can easily be calculated by the probability of a dry spell of any specified length occurring within any specified period following a rainy day. The pattern of the occurrence of dry spells after the start of the rainy season is usually investigated. For this purpose two categories of dry spells are distinguished;

1) a short dry spell of 7 days which will produce maximum drought risk after planting and;

2) a long dry spell of more than two weeks which will cause crop failure after planting.

The objective of this section is to make an empirical analysis of probabilities, length and frequencies of dry spells in over the Central Elburz stations. In this study, the analysis of dry spells has been carried out using daily rainfall data for the selected 10 locations in the Central Elburz to assess the risk of , 7, 10, 15, 20 and 30 days dry spell for each year. Seyyedan (1992) has used 7, 10 and 15 days dry spells calculated with same way as Stern et al (1982), Stern and Coe (1982), and Sivakumar (1988) for Meshed of Iran. All these researches have analysed the number of rainless days after a rainy day and also the probability of a dry spell of any specified length occurring within any specified period following a rainy day. A rainy day was taken as over with more than 0.1 mm. For calculation of the occurrence of dry spells in the Central Elburz Stations both the amount and distribution of rainfall in a given period is considered. Simple empirical analysis of long term rainfall data for dry spells provide information useful for agricultural applications, but no studies of this nature for the Central Elburz stations have previously been made. For example, dry spell lengths could be employed as a guide in breeding varieties of various maturity duration for different stations. Information on dry spell lengths could also be used in decision making with respect to supplementary irrigation and field operation such as harvesting.

7.9 Conclusion of Dry Spells in the Central Elburz Stations

The probability of dry spells exceeding 7, 10, 15, 20 and 30 days within the 30 days for each month of the years at the Central Elburz stations of Iran are presented in Table 7.9-1 and Table 7.9-2 and Figure 7.9-1 to Figure 7.9-5. The results of these Figures and Tables show that the values of short time (7-10 days) dry spell are at high level but the long time (15-20 days) are less. In the winter months dry spells are less than summer. It is valuable to estimate the risk of drought and crop failure and thus the value of investment in supplementary irrigation. As previously mentioned the selected stations are in two different sites as coastal area (group 1) and southern slopes (group 3). The probability of occurrence a long dry spell of more than two weeks in the southern slopes (group 3) are more than coastal area (group). High probability of getting a dry spell more than 15 days of during end of September after planting wheat will be a killing drought (without irrigation).

Table 7.9-1 The percentage probability of Duration of dry spell days over Coastal Area Stations

Months	Anzali					Babolsar					Gorgan				
	7	10	15	20	30	7	10	15	20	30	7	10	15	20	30
Jan.	90	82	62	39	7	85	79	66	47	21	95	91	79	58	18
Feb.	68	59	54	32	11	88	81	63	43	11	92	85	63	37	5
Mar.	79	68	50	32	7	89	82	65	47	13	89	81	63	42	10
Apr.	87	79	61	41	10	94	91	79	61	22	96	92	80	40	18
May	74	71	58	46	21	97	94	85	69	28	90	85	72	59	23
Jun.	86	81	70	58	33	97	94	85	70	30	92	87	77	64	34
Jul.	98	95	86	69	26	90	87	77	65	38	96	93	84	70	35
Aug.	79	74	59	50	27	89	84	72	57	27	93	89	79	63	29
Sep.	81	72	55	38	11	95	91	80	62	23	97	94	84	67	26
Oct.	71	63	50	36	14	90	84	71	54	21	95	91	80	63	25
Nov.	56	59	50	38	20	80	73	60	47	20	85	80	68	53	26
Dec.	70	63	51	40	19	89	82	68	50	17	87	81	68	51	22

Table 7.9- 1 (continue)

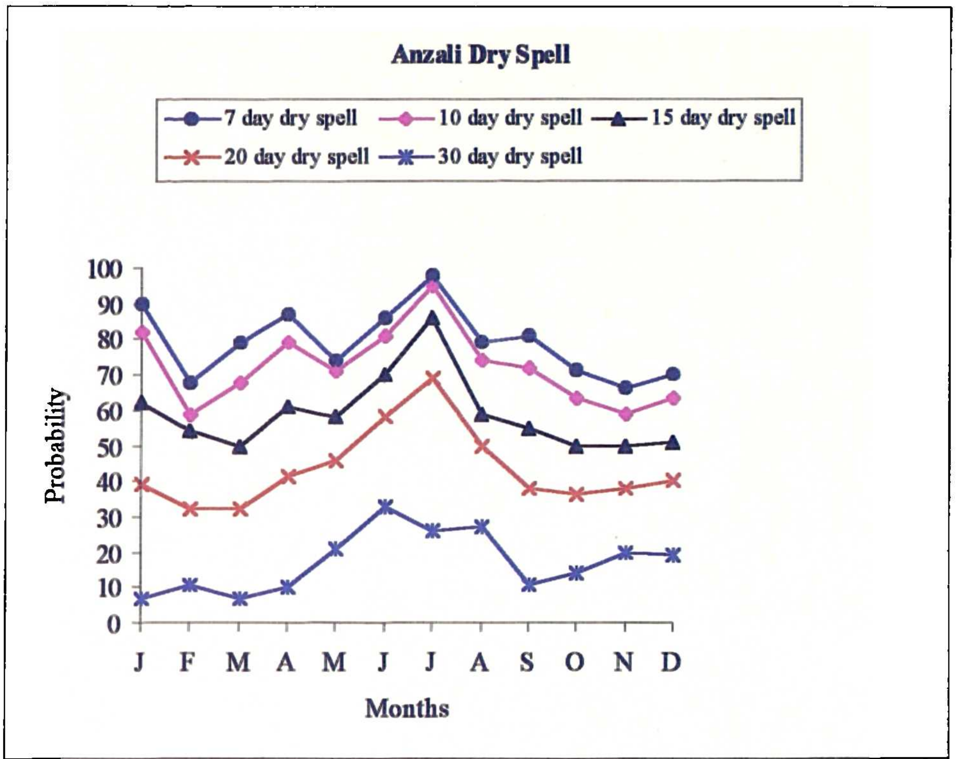
Months	Ramsar					Rasht				
	7	10	15	20	30	7	10	15	20	30
Jan.	87	89	72	50	9	99	96	62	43	2
Feb.	77	69	53	47	13	66	59	51	34	14
Mar.	81	73	59	47	11	76	67	50	33	10
Apr.	81	73	59	49	18	98	94	61	46	4
May	81	75	62	50	22	81	75	55	50	24
Jun.	89	84	72	52	27	96	93	65	66	25
Jul.	94	90	80	54	28	99	98	73	80	29
Aug.	86	81	69	51	28	96	91	62	57	16
Sep.	91	85	69	50	15	99	98	66	49	2
Oct.	85	77	59	48	11	81	72	51	38	11
Nov.	83	75	57	47	11	68	61	50	36	15
Dec.	93	86	69	50	11	78	70	51	39	14

Table 7.9-2 The percentage probability of Duration of dry spell days over the Southern Slope Stations.

Months	Ghazvin					Karaj					Semnan				
	7	10	15	20	30	7	10	15	20	30	7	10	15	20	30
Jan.	71	67	59	49	36	68	64	61	50	37	79	75	67	58	41
Feb.	66	62	53	53	31	77	71	59	47	23	85	79	69	57	33
Mar.	65	64	54	48	34	74	69	59	49	29	69	65	59	53	42
Apr.	68	64	56	50	35	72	68	59	51	35	73	69	63	55	43
May	60	57	53	50	43	74	70	63	56	43	69	66	61	55	46
Jun.	76	73	66	59	45	96	93	86	75	45	95	93	86	75	47
Jul.	80	77	70	63	49	88	84	77	68	49	92	88	81	72	49
Aug.	85	81	74	65	48	98	96	91	81	49	89	86	79	70	50
Sep.	99	98	94	84	46	99	99	99	95	48	99	99	95	86	47
Oct.	62	60	56	52	45	69	66	61	55	44	75	72	66	60	48
Nov.	62	59	55	50	43	72	69	62	55	43	74	71	65	58	45
Dec.	68	64	58	51	39	76	71	62	52	33	82	78	70	61	42

Table 7.9-2 (continue).

Months	Tehran					Veramin				
	7	10	15	20	30	7	10	15	20	30
Jan.	78	73	64	54	35	90	86	77	66	39
Feb.	79	72	60	49	24	98	95	85	65	18
Mar.	82	73	64	50	24	89	84	72	58	28
Apr.	78	73	62	50	27	84	80	70	59	38
May	74	69	60	51	34	79	75	67	57	39
Jun.	96	94	87	75	43	99	99	99	96	47
Jul.	97	95	89	79	50	99	99	99	99	55
Aug.	96	93	86	76	47	99	99	99	98	52
Sep.	99	99	96	88	45	99	99	99	99	45
Oct.	71	68	62	45	43	77	73	67	60	46
Nov.	69	65	57	50	35	76	72	64	55	38
Dec.	85	79	67	53	24	91	87	77	64	36



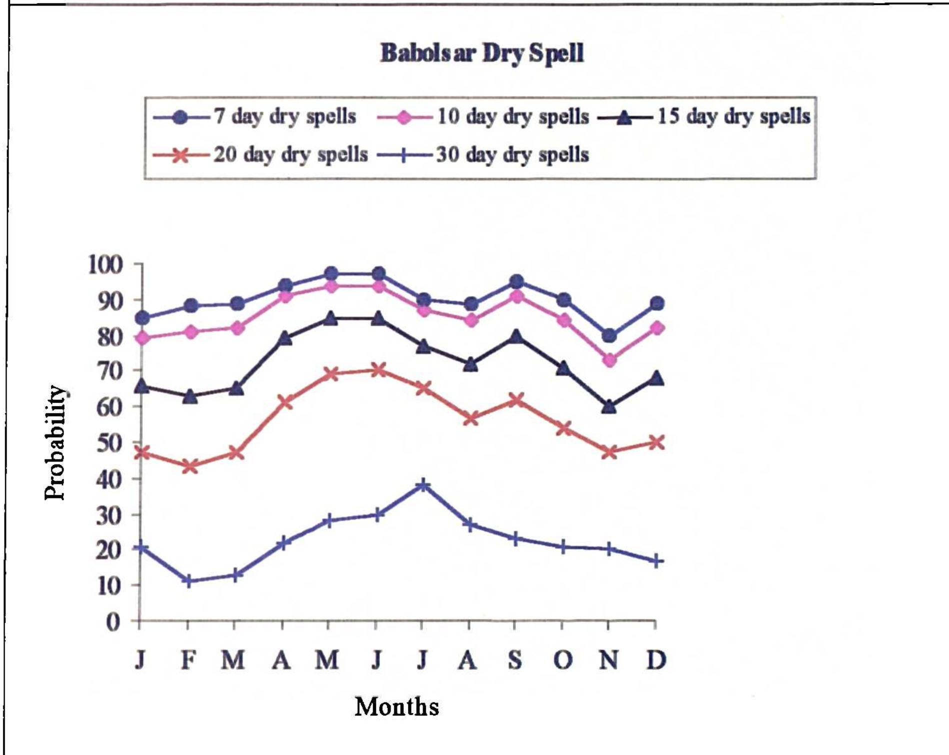


Figure 7.9-1 The percentage probability of dry spell days over the Central Elburz Stations

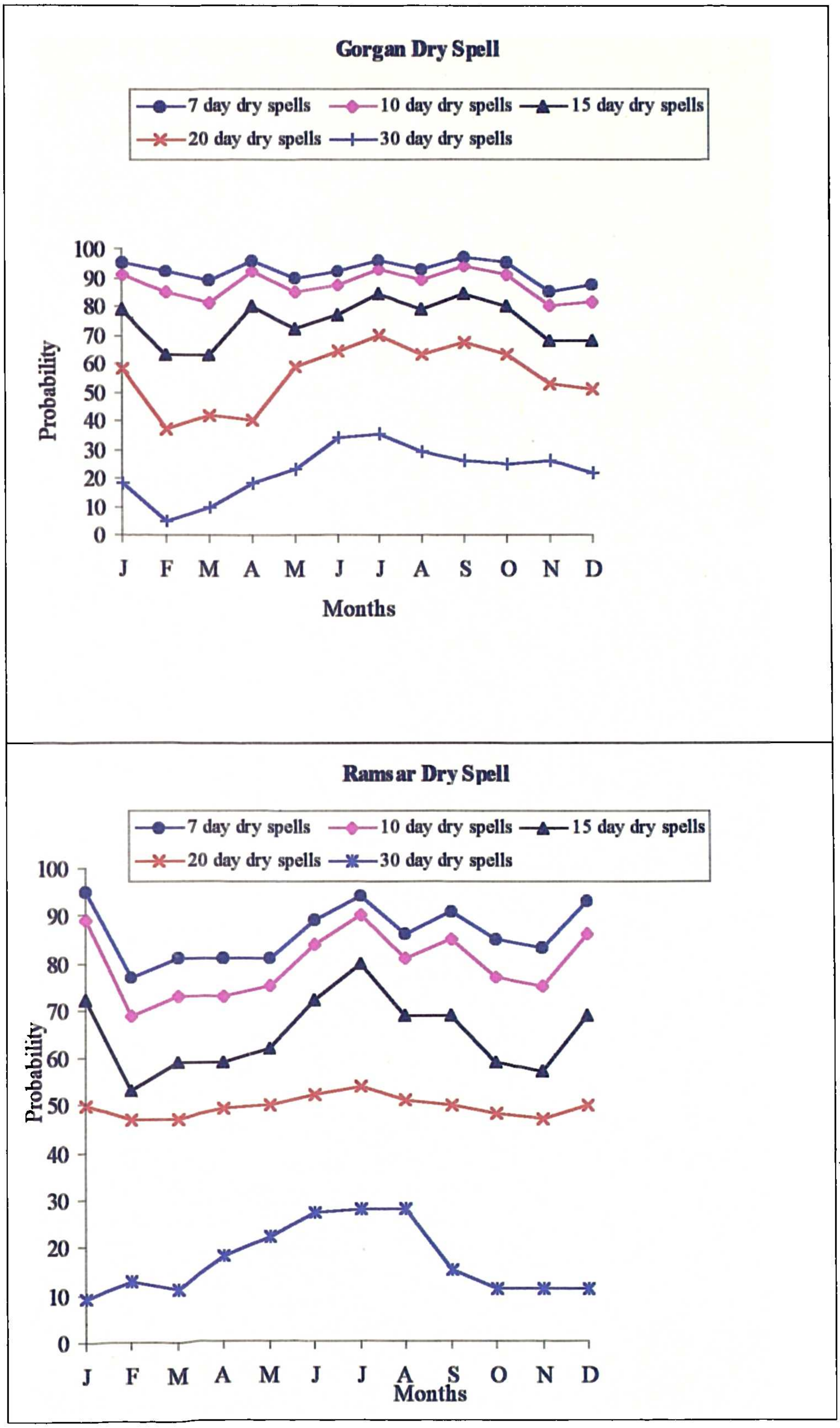


Figure 7.9-2 The percentage probability of dry spell days over the Central Elburz Stations

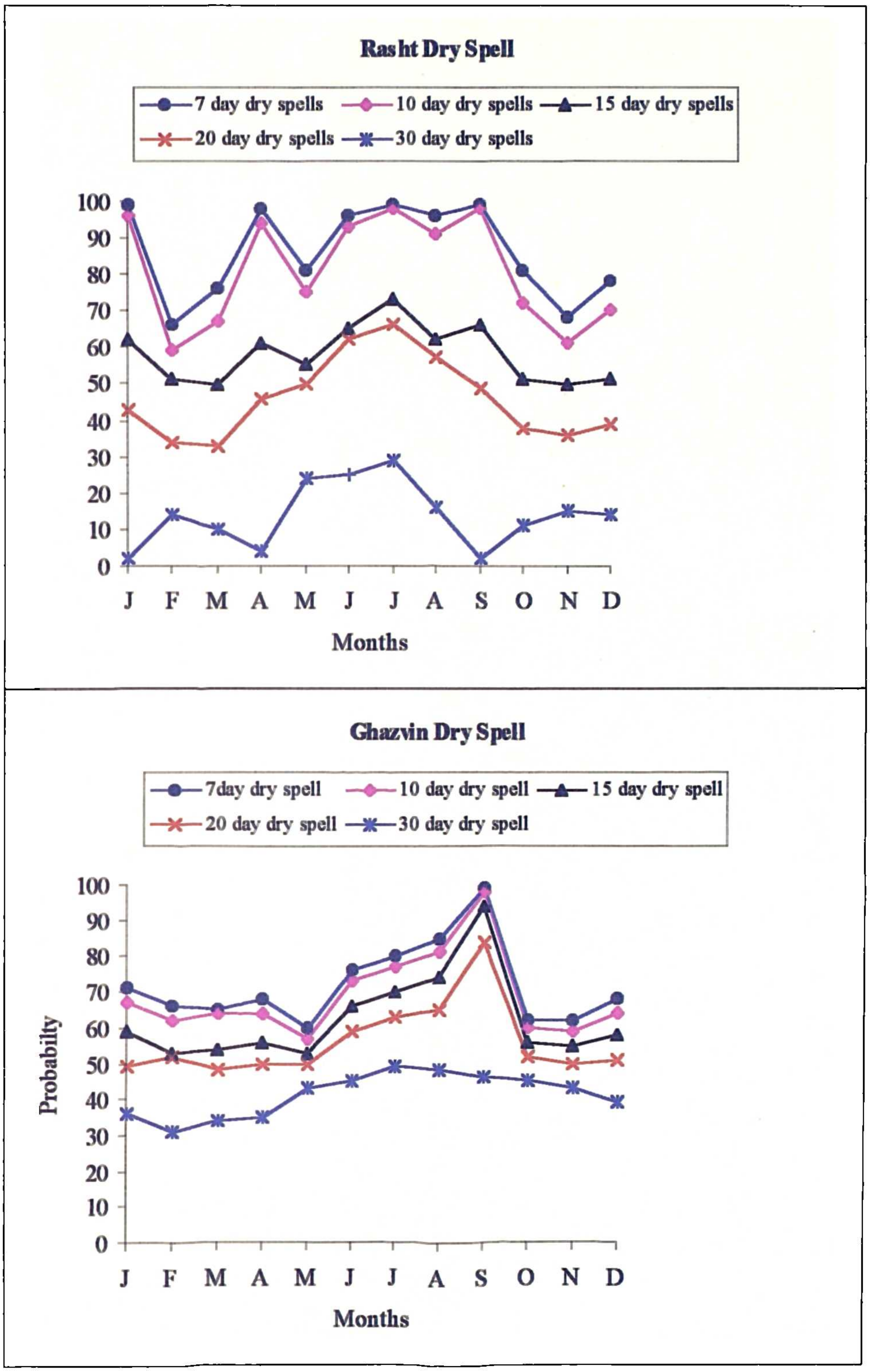
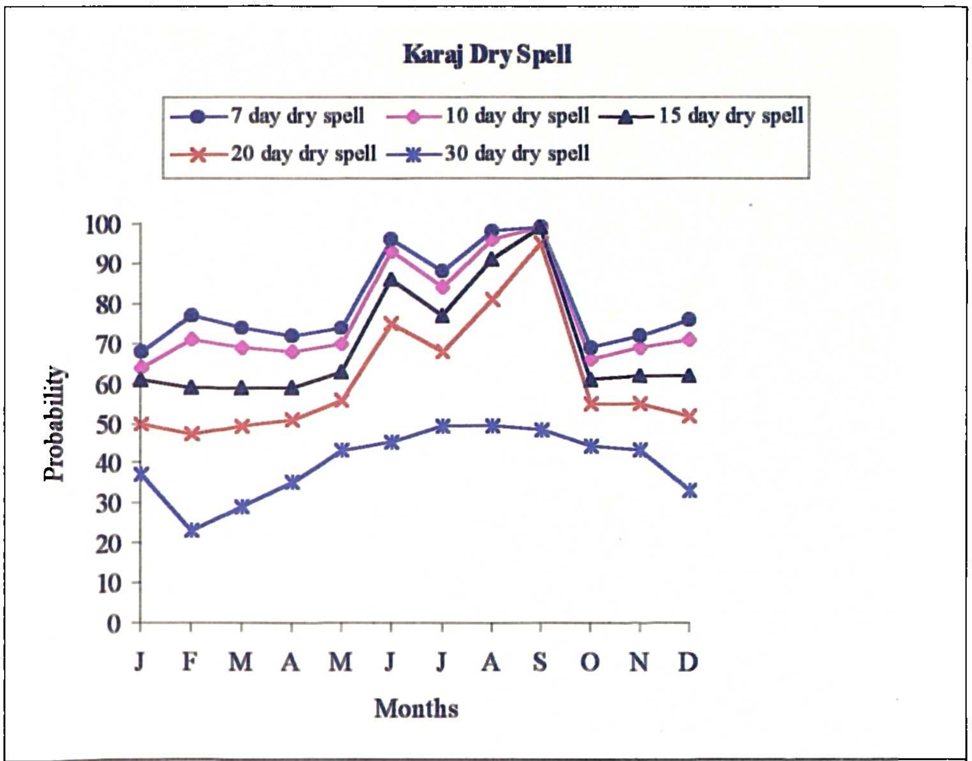


Figure 7.9-3 The percentage probability of dry spell days over the Central Elburz Stations



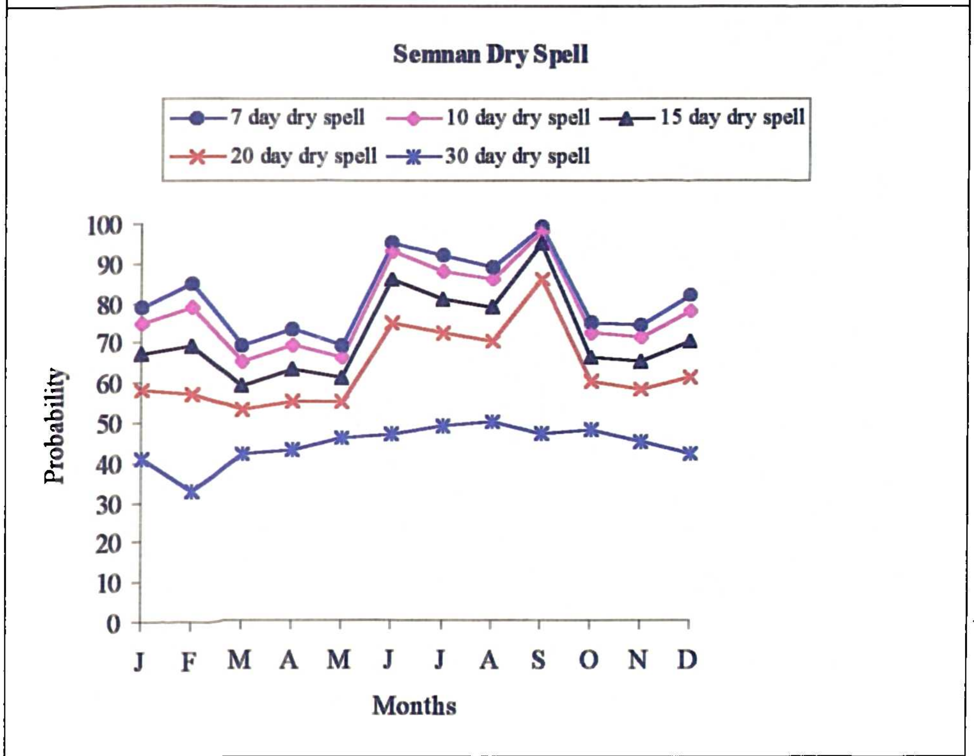
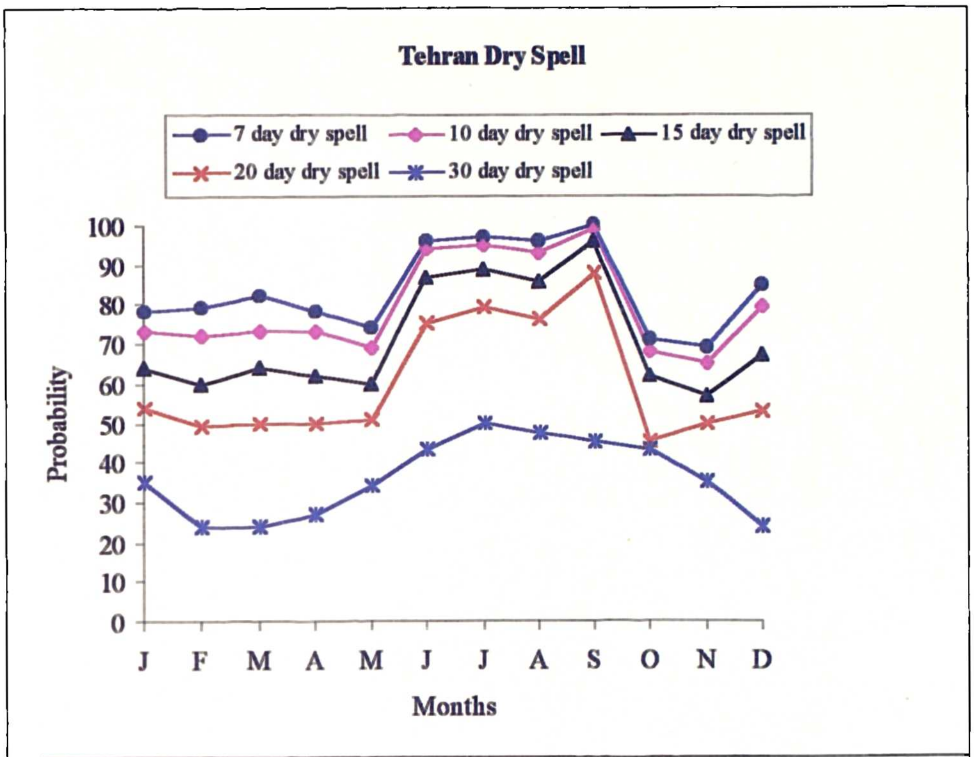


Figure 7.9-4 The percentage probability of dry spell days over the Central Elburz Stations



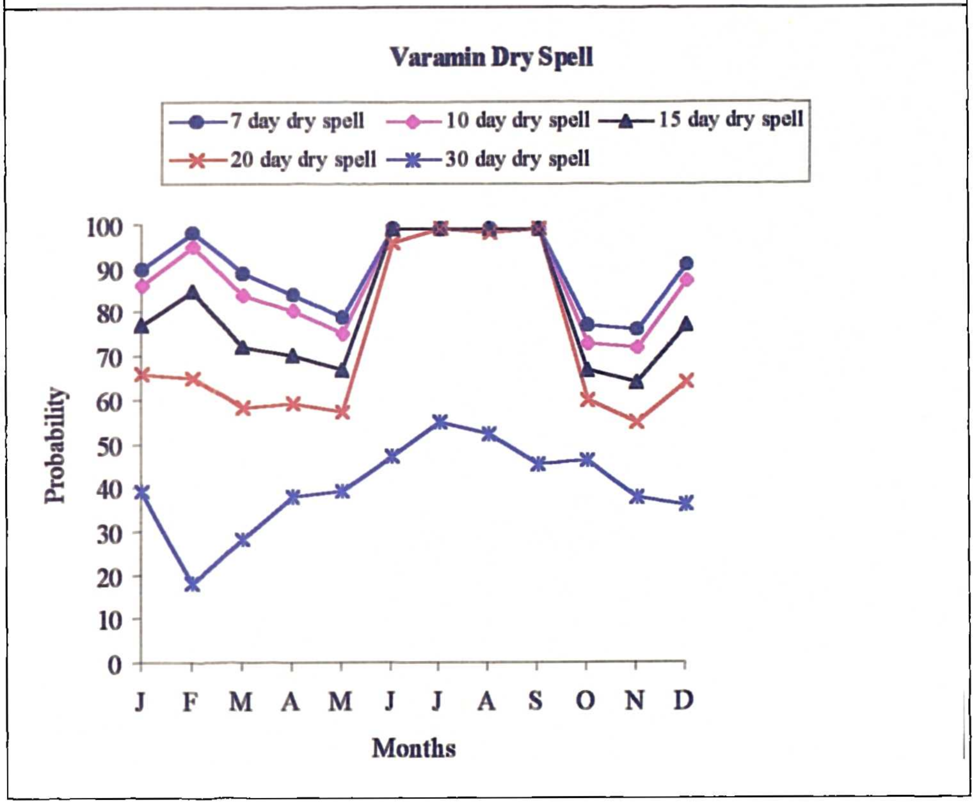


Figure 7.9-5 The percentage probability of dry spell days over the Central Elburz Stations.

8

8. Availability of Water for Plant Growth

So far this thesis has considered rainfall in an attempt to define the seasons in this area of Iran. However there is a need to consider plant growth. Throughout this region the maximum rainfall occurs in the winter months. The growing season is not entirely controlled by availability of moisture since temperature can fall below the minimum for growth in the winter months. For example, in most parts of Iran, especially the Central Elburz stations (southern slopes) December, January, February and early March temperatures fall below the minimum. During these months soil moisture accumulates and is available for plants when temperatures rise enough for them to recommence growth.

It is not the purpose of this study to determine the commencement of growth which would entail an analysis of daily temperature. The calculation of the beginning and end of the wet season is based on moisture and does not assume that this will be the growing season. However, calculation of the water need of a crop requires approximate dates for the planting and the growth cycle of the crop. For example, in the case of wheat it is planted in September but active growth does not occur until March-April. This is considered in the adoption of values of crop water needs.

The adoption of these values does take into account growth and traditional planting practices crop water needs are described in the next pages. As previously mentioned, wheat is planted in the end of Summer (September) because of falling temperature and the hope of rainfall soon after. There is not an exact date when planting commences over the Central Elburz stations. Furthermore planting dates are not the same for all parts of the Central Elburz stations and differ from one area to another by several days.

The effectiveness of rainfall for plant growth is dependent on a number of factors, the most important of which is the rate of evapotranspiration. Potential evaporation is a purely climatological concept and can either be directly measured using evaporation pans or estimated from meteorological variables using established formula. The rate of transpiration from a crop depends on the plant physiology as well as the atmosphere. The potential crop transpiration assumes that water is in constant supply. Actual transpiration of the crop is dependent on the supply of water and can be calculated by a water balance approach.

The aim of this part of the study is to examine each of these aspects of evapotranspiration and to make estimates using the available data in this region of Iran. The approach explains the variation in potential evapotranspiration and crop water requirement for two types of wheat and citrus crops over the two different parts of the Central Elburz stations. However, sparse networks and restricted meteorological measurements limit the options available. It is important to consider the accuracy of such estimates and the effect of using them to determine the periods of water availability for agriculture.

8.1 Water and plant growth

Plant growth is influenced by a wide range of physical factors including various climatic elements such as temperature, radiation, wind and humidity in many cases, water availability is a major control.

Water is an essential element in plant growth. Every process occurring in plants is affected by water. Nevertheless, no simple and regular relationship exists between water stress and the various aspects of plant function. The relationship changes with plant characteristics, stages of growth, soil and climatic conditions. Chang (1968) pointed out that water is:

1) the major constituent of physiologically active plant tissue;

2) a reagent in photosynthesis and in hydrolytic processes, such as starch digestion;

3) the solvent in which salts, sugar and other solutes move from cell to cell and organ to organ and;

4) an essential element for the maintenance of plant turgidity, necessary for cell enlargement and growth. In addition, water is needed for transpiration which though serving no direct, useful function in plant growth and development has several beneficial effects. This process is also necessary for the cooling of the leaves when these are exposed to the sun for long periods and therefore in danger of being damaged by excessively high temperatures (Nieuwolt 1982). Due to many functions, it is not surprising that lack of water or moisture stress, reduces the growth and development of plants.

About 40 years ago, considerable attention has been given to the problem of measuring or estimating the amount of water requirement by crops to increase the effectiveness and the productiveness of agricultural areas. Determining water use or requirements for different agricultural crops is of great significance, particularly in arid and semi-arid regions, for planning and developing agricultural schemes. Even in places where irrigation is possible, sound farm-management decisions depend on accurate estimates of irrigation need which can allow replenishment of soil moisture content at an early stage of depletion and before soil moisture deficit approaches a critical state (Siam1979). In the study of soil moisture-plant relationships it is necessary to consider the water used or required by crops or vegetation in a given area to be the total of the water used by the living plants in transpiration (or building of their tissues) that evaporated from the soil and from the rainfall intercepted by the plant leaves. Water is lost through both transpiration and evaporation processes.

Atmospheric elements whose influence on transpiration has been studied include solar radiation, air temperature, wind and atmospheric humidity. Transpiration and growth are both affected in the same way by variations in soil moisture, both increase with increase of available water in the root zone of the soil, to an optimum rate. Above the optimum both are less, presumably because of poor aeration of the soil, which results in a lack of oxygen to supply the roots and an excess of carbon dioxide. On the other hand, as water in the soil increases above the optimum for growth, direct evaporation from the soil surface also continues to increase.

The maintenance of maximum transpiration rate is a necessary condition for maximum growth. Thus in order to evaluate the climate in relation to the growth of crops it is necessary to estimate the rate of transpiration.

8.2 Evaporation and Evapotranspiration

Evaporation is, with precipitation, a principal element in the global water budget. Evaporation is one of the most important parameters in many scientific fields. Water vapour is the main source of many atmospheric activities. Changes in the global hydrological cycle will occur if there are changes in the magnitude and distribution of the evaporative sources of water vapour (Shuttleworth 1983).

Evaporation can be defined as the process by which a liquid is converted into a gaseous form. It involves the movement of individual water molecules from the surface of the earth into the atmosphere, a process occurring whenever there is a water pressure gradient from the surface to the air (Briggs and Smithson 1992).

The study of evaporation is important not only to prevent the loss of water in drought but also to manage the use of water by plants. Evaporation is very important in arid regions due to the limited water available and extremely high rates of potential evaporation, it is also an important parameter in wet areas it is necessary to investigate the water balance. In many countries the study of evaporation has been a neglected part of climatology. It was only in the 1930's that climatologists began to show an interest in the subject. An important development was the publication of Thornthwaite's articles (Thornthwaite, 1948a and 1948b) on water balance' (Nieuwolt 1965). Evaporation is an important factor in hydrology and climatology as well as in such diverse fields as agriculture, forestry and reservoir management. Its measurement or estimation has therefore attracted the attention of scientists from various disciplines (Ayoade 1976). Jensen, *et al* (1990) mentioned evaporation is used to describe water loss from water and bare ground surfaces while evapotranspiration is used for water loss from vegetated surfaces where transpiration from plants is of greater importance. Transpiration is a process through which water in the plant transfers to vapour in the atmosphere and this is similar to evaporation and transpiration are complex processes and these difficulties are encountered in attempts to measure or estimate these parameters. The combined effects of evaporation processes from all surfaces and the transpiration of plants are often called evapotranspiration, which indicates the total flow of water vapour into the atmosphere.

Burman and pochop (1994) defined Evapotranspiration is the combined process of both evaporation from soil and plant surfaces and transpiration through plant surfaces. Evapotranspiration is a physical process yet since it is subject to biological control, it must be studied by methods unfamiliar to the meteorologist. Information concerning evapotranspiration has come chiefly not from the meteorologist but from the biologist. For this reason it is necessary to make use of the literature and apply the methods of plant physiology. Nevertheless, evapotranspiration represents the return flow of water to the atmosphere and is thus an important meteorological process (Thornthwaite 1948).

As indicated previously on vegetated surface where transpiration is an important component of water loss the term evapotranspiration is used. However, there is no difference in the physical process of evaporation from a water surface and from plants. Evapotranspiration involves the following four sequential but distinct processes:

a) movement of water within the soil towards the ground surface or zone of absorption around the roots of plants,

b) transpiration,

c) vaporization of the water at the soil or plant surface or the stomata of leaves,

d) removal and transport of the evaporated water, now in gaseous form, into the atmosphere.

Evapotranspiration is controlled by several conditions:

1) the capacity of the air to take up more water vapour, in this case, the capacity of the air to retain water vapour increases rapidly with temperature. Usually warm tropical air masses can take up more water vapour than cold air mass.

2) the amount of energy available for the latent heat used in the processes of evaporation and transpiration. The energy for evapotranspiration is mainly provided by solar radiation, which is available in the largest quantities in the tropics and subtropics;

3) the degree of turbulence of the lower parts of the atmosphere, necessary to replace the saturated air layers close the earth's surface by unsaturated air from higher levels. Evaporation is a diffusive process, partly turbulent. The turbulent process is the dominant mechanism, except in the thin layer near the evaporation surface. According to the theory of turbulence the upward flow of water vapour is equal to the product of the vertical gradient of vapour pressure and the rate of mixing (Chang 1968). However, the rate of mixing does not depend upon the wind speed at a specific height, but depends upon the rate of change of the wind speed with height.

Turbulence is caused by different winds or by convectional currents. So the major mechanism for replacing the surface layer of air is wind which creates the turbulence responsible for moving air away from the water surface. Furthermore, the coefficient of turbulent transfer of air is not a constant. It varies from time to time and from place to place. It even varies with height at a given time and place. Thus three conditions are necessary for continuing evaporation from a free water surface:

i) energy;

ii) the difference in vapour pressure between the water surface and the atmosphere, and,

iii) the exchange of surface air by air capable of holding more water vapour. Ayoade (1988) suggests that the evapotranspiration depends on four major factors:

(i) solar radiation to supply the energy to vaporise the water,

(ii) ability of the air to remove the vapour which is a function of wind speed and air humidity,

(iii) vegetation characteristics especially its albedo, its coverage of the ground and depth of the root system,

(iv) soil characteristics especially the amount of moisture available in the root zone.

The later 2 factors introduced specific features of plants and soil which have to be considered in relation to the study region. Because of the composite of the soil- plant-atmosphere system it is necessary to examine:

1) potential evapotranspiration which a purely climatological parameters

2) crop potential evapotranspiration or crop water requirement.

8.3 The Concept of Potential Evapotranspiration

The description and discussion of evaporation in section 8.2 illustrated the complexity of that process in respect of evaporation from a vegetation covered surface. In particular, transpiration is dependent upon a sequence of water moving processes. For example, water at a point in the soil profile moves under the influence of a moisture gradient towards the root and then is absorbed and subsequently transferred through the plant stem system by the various resistances imposed to the leaves. It is finally vaporized in the stomatal cavities before passing through the stomatal apertures to the atmosphere. Thus soil, plant and atmosphere form parts of a continuous flow path of varying resistance in which water moves at varying rates. The full understanding and representation of evaporation from vegetated surfaces have proved elusive, and hydrologists and climatologist have resorted to stratagems of simplification in order to derive numerical values of evaporation for use in hydrological analysis and modelling. The most important simplification has undoubtedly been the development of the concept of potential evapotranspiration.

The concept of potential evapotranspiration was introduced by Thornthwaite (1948) in the context of his classification of climate. He based this on the assumption that there is a distinction, between the amount of water that actually transpires and evaporates and that which would transpire and evaporate if it were available, when water supply increases, as in a desert irrigation project, evaporation rises to a maximum that depends only on the climate. This we may call potential evapotranspiration, distinct from actual evapotranspiration (Thornthwaite 1948). So Thornthwaite (1948) defined potential evapotranspiration as the combined loss of water by evaporation from water surfaces, soil and transpiration by vegetation under conditions of ultimate or plentiful water supply. Potential evapotranspiration is the rate at which water would be transferred from wet soil and plant surface to the atmosphere when there is no restriction of water (Jensen, *et al* 1990). Consequently potential evapotranspiration represents the upper limit of evapotranspiration that occurs with a well watered agricultural crop that has an aerodynamically rough surface such as alfalfa with 30-50 cm of top growth, it depends on the existence of types of data and the aims of researchers, there are several methods of determining or estimating potential evapotranspiration. Penman (1956) defined E_0 as the potential evapotranspiration from an open water surface. His definition of the amount of water transpired in unit time by a short green crop, completely shading the ground of uniform height and not short of water is closely related to E_0 by considering the albedo of the crop. However, Chang (1964) considers this definition, though generally accepted, suffers from a lack of precision in at least two counts. First, the "short green crop" is not specified. Penman argues that when the cover is complete, the potential evapotranspiration is determined primarily by weather and not affected by the plant species provided that they have the same albedo. The second and more serious flaw lies in the fact that Penman's definition does not spell out the size of the field and conditions in the surrounding areas. In other words, no provision is made for the effect of advection energy. Shuttleworth (1983) defined potential evapotranspiration as the maximum quantity of water capable of being lost as water vapour, in a given climate, by a continuous, extensive stretch of vegetation covering the whole ground when the soil is kept saturated. This concept of maximum amount of water loss from a permanently moist surface is termed potential evapotranspiration (PE). Therefore potential evapotranspiration or using Penman's concept evaporation from an open water surface can be estimated from meteorological variables.

The concept of potential evapotranspiration has been used by many agricultural and hydrological researchers Jones (1981), Granger (1989), Ward and Robinson (1990), Parlange and Katul (1992), Brisson and Seguin (1992), Burman and Pochop (1994) and Shaw (1994).

Different formulae for estimating potential evapotranspiration have been derived, but the most widely used ones are those Thornthwaite (1948) and Penman (1948). Although the concept of potential evapotranspiration is in several respects theoretical, it has some practical usefulness. It can be used to estimate the water need of crops. Thornthwaite has been widely used more than others because it requires very limited meteorological data. It expresses PE simply as a function of mean air temperature and day length, these quantities are independent of the rate of evaporation, that it is applicable over a wide range of climatological conditions. It is an empirical formula relating temperature to potential evapotranspiration with the following adjustment:

$$\text{PE (mm/month)} = 16\left(\frac{10T}{I}\right)^{a} \quad \text{where}$$

T = mean monthly temperature (°C);

a = an empirical function of I;

I= the annual heat index, is the sum of twelve monthly heat indices;

$$I = \sum_{1}^{12} \left(\frac{T}{5}\right)^{1.514}$$

However, it can not be used effectively outside the Southern States of USA where it was developed from empirical studies. Nevertheless Thornthwaite used it to calculate the annual water balance of the world including the Middle East. It is in error in arid countries where radiation and temperature are not closely related. The Thornthwaite approach has provided a convenient and easily applicable method whose proven weaknesses have given it some superiority over other less well tried techniques. In areas like British isles, where advection effects resulting from frequent air mass changes lead to frequent rapid changes in mean air temperature and humidity, it is likely that the Thornthwaite approach will be unsuccessful (Ward and Robinson 1990).

Chang (1968) is critical of all empirical formula and the simple energy budget approach does not make sufficient allowance for the influence of advection; hence they must be modified when used to estimate the potential maximum evapotranspiration in arid climates.

The Penman combination equation for computing potential evapotranspiration is one which is theoretically sound and which has had widespread application when sufficient data are available. His equation is based upon reasonable physical principles such as the energy budget and the aerodynamic approaches thus, should not be regarded as an empirical formula. He expressed PE as a function of available radiant energy (R_N) and a term (E_a) combination saturation deficit and wind speed.

$$R_N = 0.75S - L_N \text{ where}$$

$0.75S$ = solar radiation absorbed by a grass surface;

L_N = net long-wave radiation from surface.

$$E_a = f\,(u)(e_s - e) \text{ where}$$

$f(u) = 0.35(1+0.01u)$ for short grass;

u = wind speed at 2 meters (miles/day);

e_s = saturation vapour pressure at mean air temperature and humidity;

e = actual vapour pressure (mm mercury) at mean air temperature.

Ayode (1976) concluded in his study for estimating potential evaporation values over Nigeria the Penman's method is slightly better than Thornthwaite's.

Thornthwaite's method is considered as inappropriate for this study for the following reasons:

1) estimate of potential evapotranspiration is in error especially in tropical and arid climates.

2) it is based on an annual regime.

3) it is only of general climatological interest and is not specific to agricultural crops.

Penman E_0 (potential evapotranspiration) is an accurate and widely used method in different parts of world, especially in recent years.

Reasons for using Penman E_0 (potential evapotranspiration) are:

1) physical formula combines energy and turbulent transfer of water vapour.

2) it has proved to be accurate in a general variety of climates including the tropic and arid climates.

3) it can be used with a crop coefficient to estimate crop water need.

Potential evapotranspiration is itself a climatic parameters, since it reflects the combined effects of a number of climatic parameter such as radiation, temperature, humidity and wind speed. For this reason it has been used in the derivation of climatic indices for delimiting climatic boundaries and classifying climates by many authors e.g.Ayoade (1976) indicated the relationship between potential evapotranspiration and rainfall can be used to define drought condition and delimit arid areas as well as the effectiveness of precipitation at a place.

8.4 Determining and Estimating Evapotranspiration in The Central Elburz

The data which is necessary for evapotranspiration studies is usually obtained by two methods:

1) the measurement of evapotranspiration using specialist equipment,

2) estimation using equations incorporating meteorological variables.

The method chosen depends on the existence and availability of types of data and the aim of researchers. Various empirical formulae have been suggested for the estimation of potential evapotranspiration by different authors in different parts of the world Thornthwaite (1944, 1948, 1954), Penman (1948, 1949, 1956 and 1963) Blaney (1954) Tanner (1960, 1968) Ward (1967, 1971) etc. Potential evapotranspiration has not previously been done for this part of Iran. Thus for estimating evapotranspiration in the Central Elburz stations only empirical methods can be used. The only possibility of estimating in this area of Iran is provided by temperature based methods of the Blaney-Criddle and pan evaporation. Data is only available for estimating monthly by Blaney-Criddle and also pan evaporation data is available, thus this measure of evaporation is also considered. Since the monthly Potential evapotranspiration will be estimated for each stations by the Blaney-Criddle and pan evaporation methods.

8.5 Measurement of Evapotranspiration by Pans

There are many kinds of pans in use, varying in dimensions, materials and conditions of exposure. Some are placed above ground, other are sunk below ground. Several methods of measuring evapotranspiration by pan have been used in different parts of world; Penman (1948), Chang (1964), Nieuwolt (1965), Ayoade (1978), Brutsaert (1982), Shuttleworth (1983), Doorenbos and Pruitt (1984), Sarpong (1986), Jafarpour (1978, 1986 and 1987), Doorenbos, and Kassem (1986). Some techniques indicate only potential evapotranspiration rates. While others measure actual evapotranspiration as well but this may or may not be at the potential rate. Also evaporation pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from a specific open water surface (Doorenbos, and Pruitt 1984).

Evaporation pans which are in common use are :

1) the class A pan of the USA Weather Bureau,

2) the Colorado Sunken Pan and

3) the GGI- 3000 Pan.

Only the class A pan is available in Iran. Dunne and Leopold (1978) conclude Evaporation pans, such as the class A pan, probably provide the best method of obtaining an index of potential evapotranspiration. However it is more difficult to use it to give accurate amounts of water evaporation.

8.5.1 The Class A pan Evaporation

This pan is the official evaporation measurement instrument in the United States but most countries use it in their meteorological stations network. The Class A Pan evaporation is circular, 121 cm (46.4 inches) in diameter and 25.5 cm (10 inches) deep. It is made of galvanised iron (22 gauge) or monel metal (0.8 mm). The pan is mounted on a wooden open frame platform with its bottom 15 cm above ground level. The soil is built up to within 5 cm of the bottom of the pan. It is filled with water 5 cm below the rim and water level should not drop to more than 7.5 cm below the rim. Also a small cylinder standing in the centre of the pan is used to support a hook gauge for precise measurements of water level. A three-cup anemometer for measuring wind speed is attached to the front of the pan. The Iranian Meteorological services have adopted the use of the class A pan as the standard instrument for measuring evaporation in the country in accordance with recommendation by the World Meteorological Organization (W.M.O) as the standard for evaporation measurement.

The general effect of the various factors is to make pan evaporation rates usually greater than that from a large open water surface. A correction factor (pan coefficient) must be used to estimate open water surface evaporation but unfortunately these coefficients are not constant for a specific site, tending to show a seasonal variation and to be affected by exposure. Also ratios between evaporation from different pan types are not constant and consequently comparisons using dissimilar types are dangerous. Most of the above authors mentioned have not considered the pan coefficient, some of them e.g. Jafarpour (1978, 1987) only compared rainfall and pan evaporation. Metochis and Orphnos (1997) defined Class A Pan evaporation provides an accurate estimate of the water requirement. However, Doorenbos and Pruit (1984) explained the Pan evaporation method can be graded next (after the Penman modified method) with possible error of 15 percent depending on location of the pan.

Chiew *et al* (1995) in their studies concluded that there is a satisfactory correlation between class A pan and Penman- Monteith ET0 for evaporation. They regonized pan data is useful only if an accurate pan coefficient is used to relate the pan data to Penman- Montieth ET0.

Data required for potential evapotranspiration by pan estimation are pan evaporation (E pan in mm/day and period of time), estimated values of mean relative humidity and mean windrun (U in Km/day at 2 m height) and information on whether the pan is surrounded by a cropped or dry fallow area.

Reference evapotranspiration of potential (**ETo**) representing the mean value in mm/day or a special time period over the period considered may be obtained from pan evaporation by the following Equation:

ETo = k pan . Epan where,

ETo = Reference evapotranspiration which is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. As previously mentioned many methods such as Thornthwaite, Penman, Blaney- Criddle and Pan Evaporation, are modified to calculate **ETo** based on meteorological data available for a special time period.

Epan = evaporation in mm for an unscreened class A evaporation pan;

k pan = pan coefficient (with regard especial Tables for Class A Pan for different ground cover and levels of mean relative humidity and windrun). These tables have been provided by FAO (1984-1986). Since pan data is being used to estimate reference crop evapotranspiration, the magnitude of the pan coefficient will be dependent upon whether grass reference ET0 is being sought. FAO (1984) as the international organizations gave pan coefficient to estimate grass reference. Their coefficient are for Class A and considered different ground covers.

Evaporation from the Class A Pan was recorded monthly and was converted to potential evapotranspiration using a coefficient which was determined and described by FAO (1984-1986). The evaporation Pans at southern slope stations are placed in short green cropped area where humidity is medium (40 to 70%) and it is high (>70%) for the coastal area stations. Based on FAO (1984 and 1986) the figures 0.8 for coastal area stations (Anzali, Babolsar and Gorgan) and 0.75 for southern slopes stations have been adopted in this study. The results of this method has been presented by Table 8.5-2 and Figures 8.5-1 to 8.5- 6.

Concerning Table 8.5-2 as mentioned in foregoing pages different air masses invade during the autumn and winter months across Iran. They meet together and form frontal systems over Iran resulting the intensive cooling air and rain or snow throughout the country. Some of these air masses are characterised by extremely cold air and may be stay until the end of May. As a result in the most parts of Iran January, February and March (in some years December and April) temperatures fall below the minimum. Also during these months evaporation values become very small or approximately below minimum.

Evaporation data from class A pan were obtained for the period 1982-87 for Anzali, Babolsar, Gorgan, Ghazvin, Karaj and Seman stations of the coastal and southern slopes of the Central Elburz. These have shown in the Table 8.5-1.

Table 8.5-1 Stations used in the analysis for the period 1982 to 1987.

Stations	Altitude (m)	Latitude (°N)	Longitude (°E)	No of years
Anzali	- 26	37.28	49. 28	1984-87
Babolsar	- 21	36.43	52. 39	1982-87
Gorgan	105	36.51	54. 16	1984-87
Ghazvin	1304	36. 15	50	1982-87
Karaj	1321	35. 48	51. 10	1982-87
Semnan	1138	35. 33	53. 23	1984-87

An indication of the spatial variation in pan evaporation will be given by comparing evaporation values from stations located in the Central Elburz stations. The selecting and choosing these stations are because of two important economic crops:

1) prennial crops such as citrus in (Anzali and Babolsar stations), this area has capacity for developing orange trees as a result producing different types of orange to market and exporting to foreign countries.

2) cereal crops such as wheat in (Gorgan, Ghazvin, Karaj and Semnan stations). Wheat is predominant rained crop in the southern slopes of the Elburz. It grows slowly during the winter. The crop usually suffers water stress particularly during end of May-June when about 80% of the dry months is produced. It has been pointed out that the distribution of rainfall is the major factor affecting grain yield of wheat and the enough rainfall (above mean) during the pre-sowing and heading of flowering periods has positive effects.

Routine measurements of evaporation did not begin in this part of the Central Elburz until the 1980's. At present evaporation is measured at most synoptic weather stations and in a few agricultural research stations.

The objective of the present study is to determine first potential evapotranspiration and consequently water requirements for each crop.

8.5.2 Advantages of Evaporimeters

Chang (1968) considers that evaporimeters have the advantage of giving sufficient allowance to the advected energy in an arid climate. Another benefit of evaporimeters over various formulae is that they can be used to directly measure evapotranspiration throughout the life cycle of a crop. Also evaporimeters like Pan class A are inexpensive and easy to handle in the field.

8.5.3 Disadvantages of Evaporimeters

In contrast to a lake, the class A pan receives large quantities of energy from radiation and conduction through its base and sides. Evaporation from the pan, therefore will be larger than from a large body of water such as a lake under the same meteorological conditions. This is because evaporation pans are artificial bodies that create their own thermal and aerodynamic environment. Moreover, the differences between pan and lake will vary through the year because of seasonal differences in radiation, air temperature, wind and heat storage within the larger body of water. These instruments often indicate inflated values due to advection. Advection of energy from outside an area may greatly increase evaporative demand. In arid and semi arid regions, considerable energy may be advected from surrounding dry areas over irrigated zones or evaporation pan. Evaporation from the latter will then be much greater than if they were surrounded by moist conditions in a humid area.

Advection effects are not serious in a humid area, but in an arid area they can result in the pan seriously overestimating evaporation from a large water surface or large irrigated area (Jackson 1989).

Evaporation Pans also suffer from other inaccuracies due to the direct absorption of solar radiation or heat from the ground. However, the effect of regional advection of heat or the oasis effect should be included in the term of seasonal potential evaporation because most irrigation projects and most farm fields are subjected to advection conditions during parts of the growing season. This is due to the oasis effect caused by the relatively small evaporating surface. For irrigation fields, pan evaporation may accurately represent evapotranspiration. Saturated air layers over the pan are very frequency replaced by relatively dry air from the surrounding areas where normally no water is available for evaporation. Over large water bodies such as lakes or over densely vegetated areas the replacement air layers come mainly from other parts of the evaporating or transporting surface. A coefficient that varies through the year must therefore be applied to measurements of pan evaporation in order to estimate water loss from a lake. These figures from evaporation pans are often corrected by a factor around 0.7 to make them comparable to evaporation data from lakes and reservoir (Nieuwolt 1982). Thus FAO (1984 and 1986) uses stabilised pan coefficient (K pan) for correcting evaporation pans. Unfortunately in spite of the need to convert pan data researchers such as Jafarpour (1978, 1986 and 1987), and Allaei (1994) have not used any factor to correct evaporation pan data. As already mentioned in this study pan coefficient (k pan) figures have been used.

Table 8.5-2 Monthly Potential Evaporation (mm) by Pan Method over the Central Elburz selected stations*.

Stations	Years	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Anzali	1984	5	4.5	4.5	4.6	12.3	54.1	83.4	53.2	46	29.2	15	8.4
	1985	3.8	4.6	4.2	4.3	67.4	81	60.6	64.5	49.2	26.5	21.5	11
	1986	12	4.6	4.3	32.3	34.6	56.5	90.6	84.6	59.7	19.2	11.8	1
	1987	4.3	5.7	4.1	30.8	57.4	76.8	76.3	54.1	29.3	13.3	18.1	18
Babolsar	1982	4.3	4.6	5.4	7.5	73.9	108.3	123.3	100.3	82.6	4.1	3.3	4.5
	1983	4.2	4.5	5.3	6.2	106.6	97.5	145.6	120.9	59.4	54.2	13.9	4.3
	1984	4.3	4.8	5.0	7.4	43.9	49.5	120.8	71.6	61.7	40.8	16.9	4.3
	1985	4.3	4.8	5.2	7.6	89.8	98.1	88.1	95.2	52	29.2	10.5	5
	1986	4.5	4.8	5.1	7.3	59.2	86.1	89.6	92.5	72.5	37.8	30.1	5.4
	1987	4.5	4.8	5.1	7.3	66.3	100.7	109.4	80.6	46.1	30.6	14.0	5.2
Gorgan	1984	4.6	4.3	5.5	7.9	43.2	99.0	121.3	64.7	76.1	55.3	33.4	5
	1985	4.2	4.9	5.2	7.9	29.4	35.6	37.5	118.4	100	59.7	10.6	4.4
	1986	4.5	5.3	5.7	7.5	52.1	153.9	133.1	133.2	110.7	57.4	30.6	4.2
	1987	4.6	4.9	5.6	7.0	80.5	120.5	120.8	99.2	85.9	41.7	22.7	4.5
Ghazvin	1982	11.4	3.6	48.9	71.3	78.6	143.5	170.1	139.4	111.2	41.3	23.7	3.3
	1983	3.8	3.3	62.8	60.7	65.8	114	164.2	134.4	85.7	56.2	39.2	12
	1984	3.4	3.3	49.7	62.4	57.8	132.6	185.7	154.6	102	54.3	25.9	3
	1985	3.9	4.5	4.5	60.3	115.1	124	158.8	128.6	129.3	74.8	32.7	7.4
	1986	3.4	4.1	4.5	22.7	87.7	155.1	183.8	158.1	114.3	65.7	27.7	3.5
	1987	3.7	4.4	4.9	47.1	95.5	123.4	145	154.1	96.6	48.8	28	3
Karaj	1982	3.4	3.6	4.9	95.1	119.8	179.4	189.4	172	130	59.1	8.3	3.4
	1983	3.7	3.4	4.6	51.8	89.5	145.9	193.7	169.3	116.3	108.6	42.8	3.5
	1984	3.4	3.3	5.4	97.1	103	152.7	168	161.3	118.8	73.3	35.4	3.3
	1985	3.2	4	4.6	43.5	60.3	83.7	97	75.7	68.3	42.7	21.2	2.5
	1986	3.6	4.2	4.6	69.6	115.1	170.5	205.4	178.2	146.2	96.2	39.4	3.2
	1987	3.8	4.4	5.1	85.9	114.7	187.5	202.1	197.5	129	55.5	41.8	3.7
Semnan	1984	3.9	3.9	6	102.	123.6	184	209.8	189.3	130.9	64.3	24.8	3.4
	1985	3.7	4.4	5.3	127	154.8	185.9	194.5	150.1	123.7	76.7	36.9	2.5
	1986	4	4.9	36.8	71.5	141.6	175.9	186.6	168.1	135.9	91.7	36.2	2.5
	1987	4.1	4.7	16.5	92.9	126.6	194.8	208.3	204.8	143.8	64.5	42.2	3.9

* pan has been corrected by K = pan coefficient FAO (1984-1986).

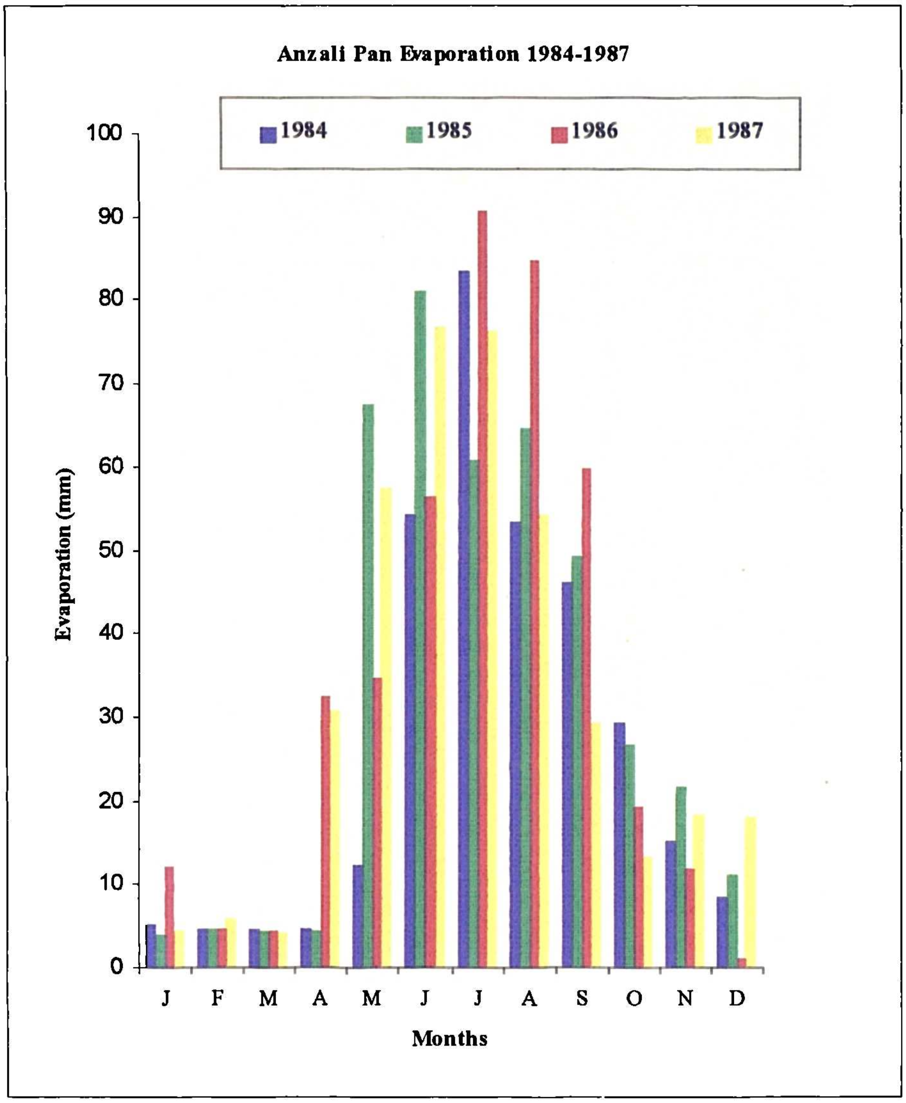


Figure 8.5-1 Monthly potential evaporation by Pan at the Central Elburz stations.

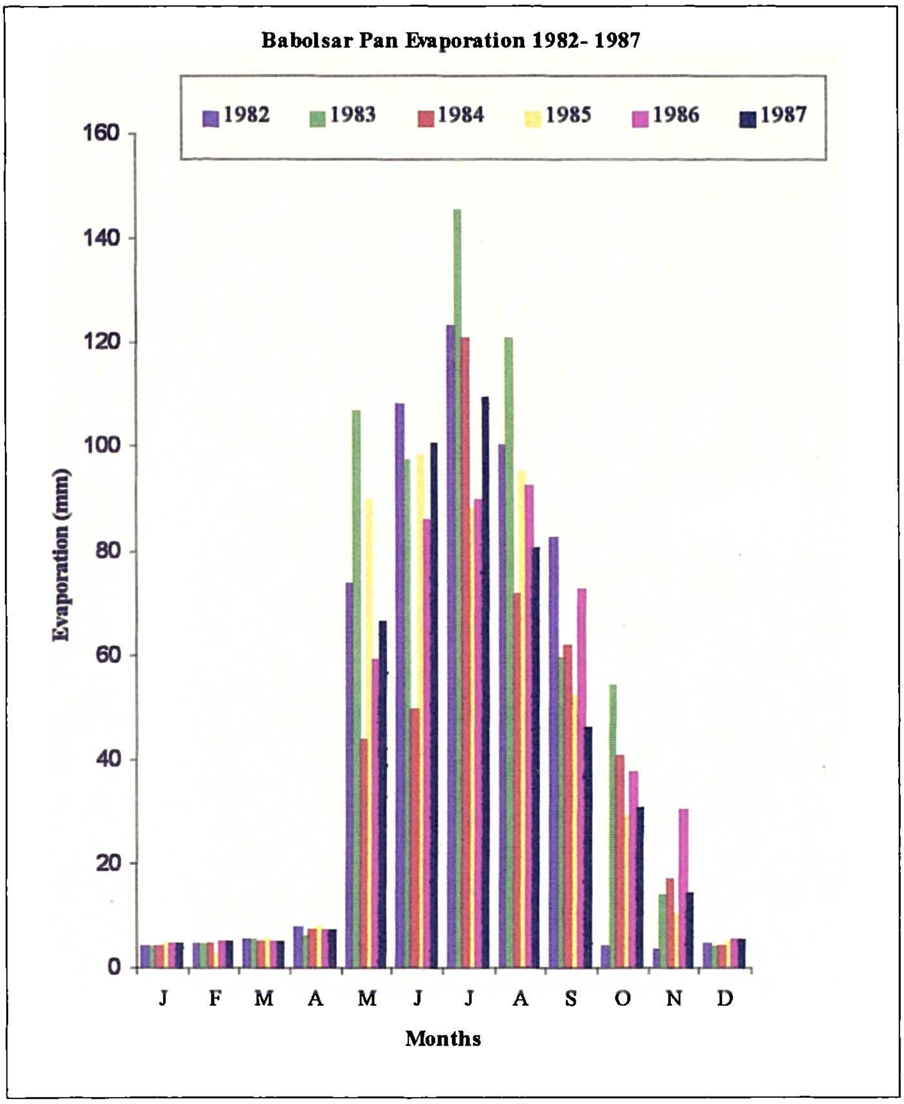


Figure 8.5-2 Monthly potential evaporation by Pan at the Central Elburz stations.

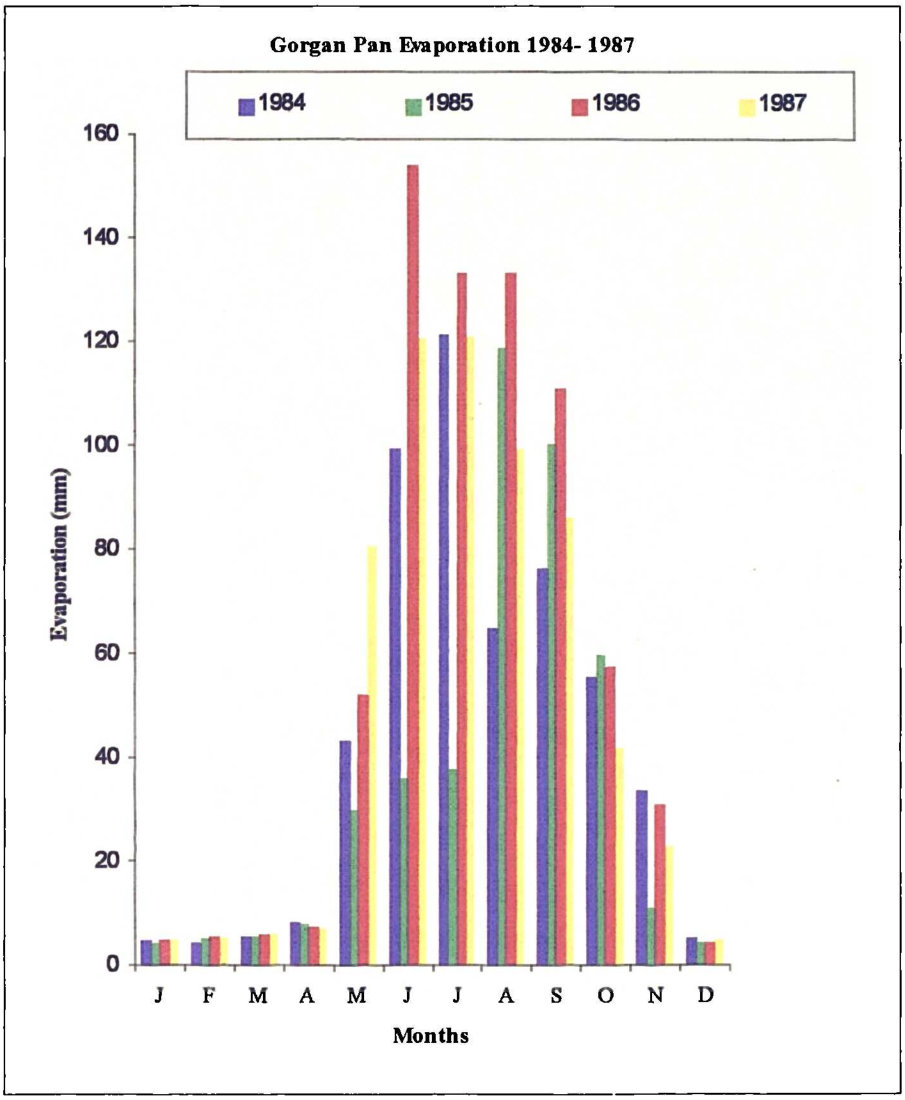


Figure 8.5-3 Monthly potential evaporation by Pan at the Central Elburz stations.

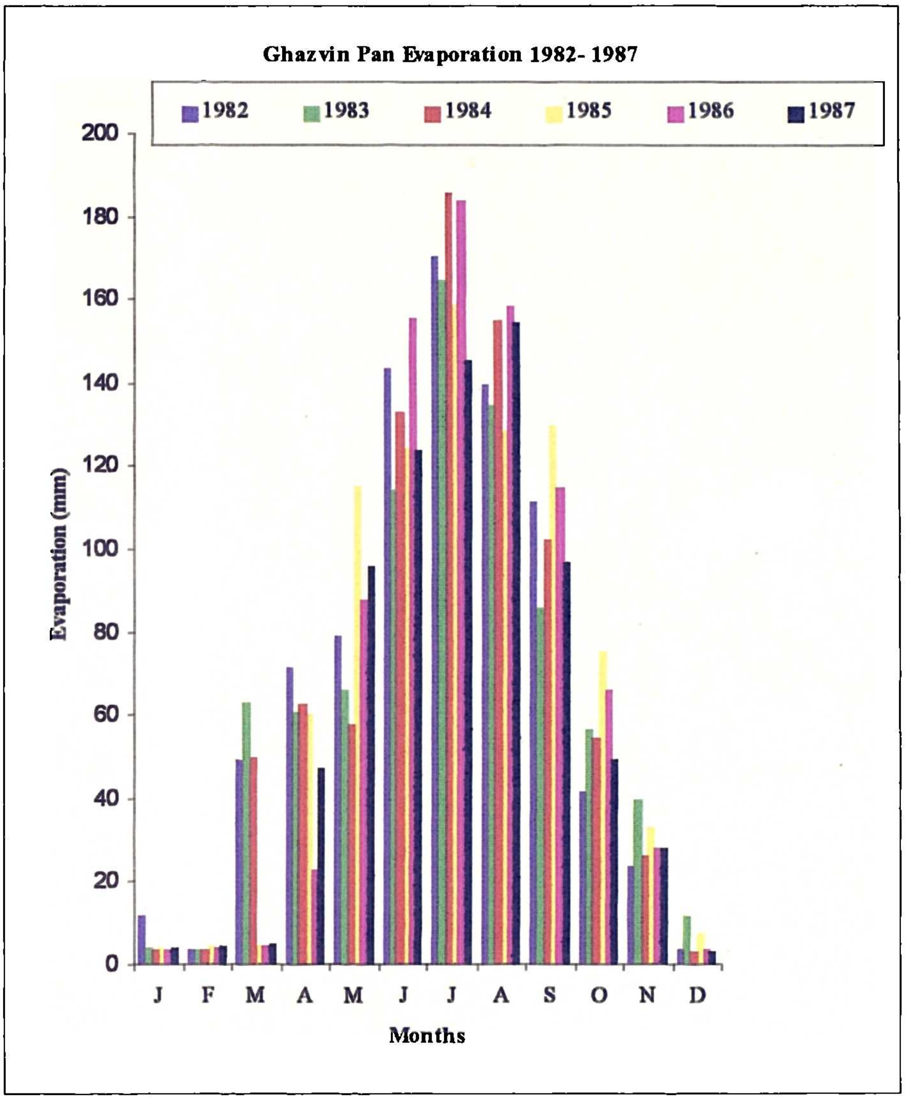


Figure 8.5-4 Monthly potential evaporation by Pan at the Central Elburz stations.

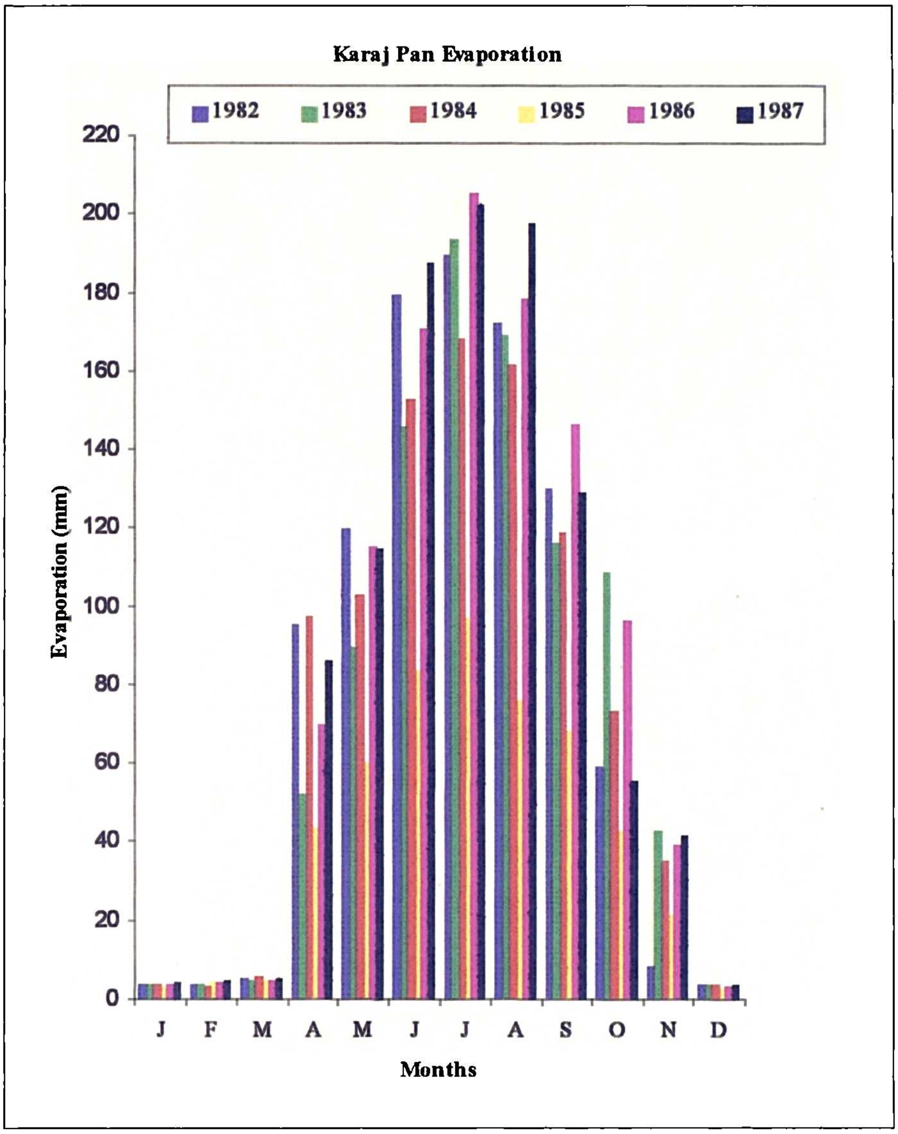


Figure 8.5-5 Monthly potential evaporation by Pan at the Central Elburz stations.

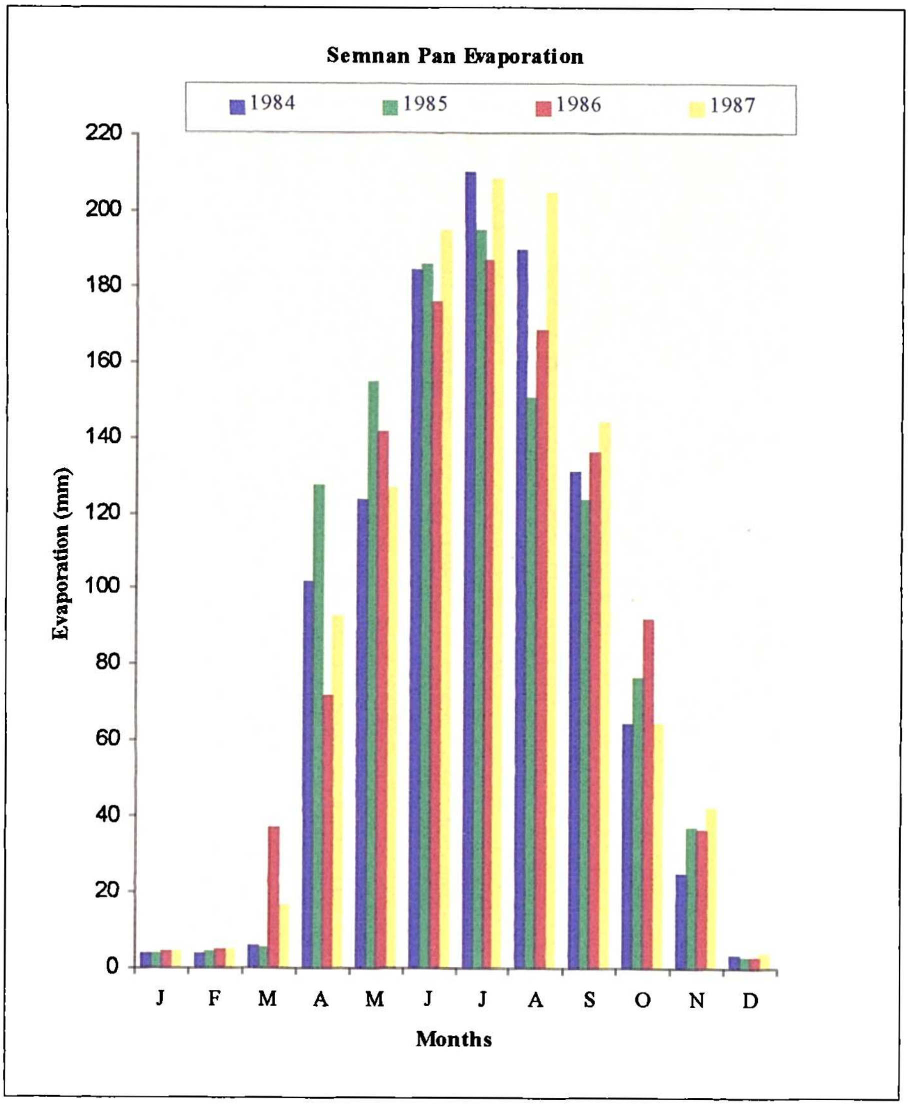


Figure 8.5-6 Monthly potential evaporation by Pan at the Central Elburz stations.

8.6 Analysis of Pan Evaporation over the Central Elburz Stations

Evaporation is, with precipitation, a principal element in the global water budget. Evaporation is a complicated process and has a major role and an important factor in hydrology and climatology as well as in such diverse fields as agriculture, forestry and reservoir management and other related disciplines. Determination of evaporation is also a problematic and difficult task. Different methods are used to determine evaporation depends on application and available data. Its measurement or estimation has therefore attracted the attention of scientists from various disciplines.

Table 8.5-2 and Figures 8.5-1 to 8.5-6 show clearly the seasonal regime of evaporation in the Central Elburz for the period 1982 to 1987 based on class A pan evaporation, corrected by the appropriate coefficient. Recordings are made at 6 stations including southern slope and coastal area stations over the Central Elburz. It has been possible to calculate reasonably reliable averages of the evaporation for each month by Pan evaporation. This was considered too narrow a basis for the rather extensive extrapolation of evaporation for the region from Anzali, Babolsar, Gorgan, Ghazvin, Karj and Semnan stations. Both table and figures show the seasonal march of the measured evaporation obtained from the class A pan. The highest evaporation amounts are recorded towards the end of dry season, namely in July and August. Evapotranspiration goes up dramatically before the heading of winter crops just at the time when they are required irrigation. At this time water deficit for unirrigated agriculture usually reduces crop production. Usually with the beginning of the summer season the evapotranspiration amount considerably increases and it limits the development of summer crops especially in the southern slopes area. In this situation with the start of the summer season a water deficit occurs for all of summer season months. The water balance assessment in the following chapters considers this more thoroughly.

The cultivated southern slopes area have an annual potential evaporation of approximately 1000 mm. The lowest values are recorded in the middle of the wet season namely in December and March, when there is a considerable increase in cloud amounts and consequently a decrease in the rate of solar radiation received at the ground surface. Also winter is wet due to the existence of different air masses such as cP, mP and mT. There is a water surplus during the winter season and a lowering of the water deficit.

The amounts of evaporation over the Central Elburz stations vary both spatially and through time. The stations analysed in this study based on their evaporation results and climatological aspect can be divided into two types:

a) coastal stations; in this area the amount of evaporation is less than the rainfall especially in the south west of the Caspian Sea but it is more than the rainfall in the east. Distance from the sea and the effects of air masses and the wind circulation from central Asia may be the reasons for higher evaporation witnessed to the west and south west of the Caspian Sea.

b) southern slope stations; the amounts of evaporation are similar for three stations (Ghazvin, Karaj and Semnan Stations). Monthly evaporation values for all three stations are higher than coastal area stations. The values of evaporation are in some cases several times larger than the mean annual rainfall. The large difference between the south and the north of the Central Elburz in measured evaporation values may be because of the effects of advected energy during the dry season. Since the dry season is longer in the southern slope stations than in the northern of the Central Elburz, the seasonal variations in measured evaporation values in the southern slope stations are also greater than coastal area stations. A general feature is that the potential evaporation computed decreases when the rainfall increases. This is caused by the higher relative humidity, lower temperature and more cloudiness during times of rain as compared with the dry period. However the variation of evaporation is much smaller than that of precipitation (Nieuwolt 1965). In all months there is a general and rapid increase of evaporation with the increased distance from the coast; this may be due to the combined effects of succeeding factors as follows:

1) Convection is strong over the land especially during warmer times of the day when most of the evaporation takes place and is almost absent over the sea during that time. This increases radiation and reduces cloudiness over the land.

2) wind speeds tend to be higher near the land stations than over the coastal stations. The local wind 120 days (Iranian Name of Bade 120 Rouzeh Sistan) which blows from the Afghanistan border mountains during June to end of September coincides with higher evaporation.

In contrast with Blackie *et al* (1993) in their evaporation studies in an area in Scotland with 600 m altitude concluded that the value of evaporation from high altitudes was more that low altitude. It is not true with our analysis especially in southern slope stations which their evaporation amounts decrease with elevation. In southern slope stations high rates of evapotranspiration influence agriculture, and farmers have been forced to adapt to the conditions using irrigation by Quanat or by growing drought-resistant crops. Thus excessive evapotranspiration, like deficiency of rainfall is accountable for the drought and hardship in many arid areas.

8.7 The Blaney- Criddle Method

Many factors operate singly, or in combination, to influence the amount of water consumed by plants. The effects of these factors are not necessarily constant but may fluctuate from year to year as well as from place to place. Some include the human factor, but others are related to physical influences and the environment. The factors included in climate that particularly affect consumptive use are rainfall, temperature, humidity, wind movement and length of growing season. Since all the formulae for estimating potential evapotranspiration presuppose a complete cover of actively growing vegetation, they will over estimate actual evapotranspiration under normal irrigation practice either when the crop is young or during the period of ripening (Chang 1968).

Various methods have been used by agricultural engineers to determine consumptive use of water by agricultural crops and natural vegetation under field conditions. Primarily the choice of method must be based on the type of climatic data available and on the accuracy required in determining water needs. Nevertheless many formula incorporate a general factor or crop coefficient to estimate potential evapotranspiration for a specific crop.

As previously mentioned evapotranspiration is a very complex phenomenon, as evidenced by the wide variety of formulas, mostly empirical, used to estimate. These formulas range from simple equations expressing Et as a function of temperature alone to models requiring more extensive data. The formula developed by Blaney-Criddle is an example of formula termed temperature based models. The Penman (1948) formula is an example of extensive data. However, the temperature methods popular with the engineers such as Blaney- Criddle's and Thornthwaite's methods have been used widely.

A practising hydrologist is faced with making do available climatic data. The method is selected to estimate water requirement depends on types of data availability, aim of the researcher and time required for the study. In the case of the Central Elburz stations it is only possible to use empirical methods based on temperature data. A major reason for using temperature based methods is the unavailability of the meteorological data necessary for the utilisation of the more and precise methods. In this regard the Blaney- Criddle is the preferred formula for this region, and has been adopted for this study. The Blaney- Criddle method is suggested for areas where available climatic data cover only monthly air temperature data and therefore adequate for applications where only long term ET0 estimates are required. Since the Blaney-Criddle formula relates to transpiration it has been widely used for agriculture especially irrigated agriculture and is thus a suitable measure of crop transpiration especially in the arid and semi-arid area.

The Blaney- Criddle method is distinguished by the many definitions and the amount of discussion which has been held by different investigators. Burman and Pochop (1994) explain that the Blaney- Criddle method was introduced in 1942 and became popular in the 1950's. Because of its simplicity and the requirement of only air temperature measurement, the Blaney- Criddle method became very popular in practical situations and remains widely used. Also the Blaney- Criddle method represents established practice over many years and can provide very useful long term estimates. The Blaney-Criddle formula was developed for estimating consumptive use of irrigated crops in the western United States. It is based on the same assumption as Thornthwaite's methods and also uses temperature and day length as the major independent variables. The Blaney-Criddle method is now more widely applied in agricultural development work more than Thornthwaite's methods outside of the western United States (Dunne and Leopold 1978). According to Jensen (1973) the Blaney- Criddle procedure for estimating evaporation is well known in the western United States and is used extensively throughout the world. However, the empirical nature of the formula can provide some errors for areas which their climates are not similar to the western United States. Moreover, it may be tend to underestimate in areas more arid than the western United State and overestimate in areas less than it.

The Blaney- Criddle method is well known and is used to estimate the crop water requirements for vegetables, cereals and prennial crops of the study area of western

Saudi Arabi (Abu Rizaizia and Al- Osaimy 1996). Also some investigators have discussed advantages, and disadvantages of the Blaney-Criddle model and have compared to other potential evapotranspiration methods.
The Blaney-Criddle method has been developed for estimating monthly and seasonal values of evapotranspiration. It can give rough mean values for practical purposes and should be used as a rough guide (WMO, 1966). Chang (1968) indicated the Blaney-Criddle formula is the most widely used procedure for indirectly estimating evapotranspiration in the semi-arid lands of the western United States , it suffers from similar to those Thornthwaite's methods. However, Chang (1968) reported that the method checked very closely with the water needs of native hay in the area of Wyoming. Chiew *et al.* (1995) and Duru (1984) in their studies in Australia and Nigeria reported the Blaney- Criddle method which uses only temperature date gives similar monthly Eto estimates as Penman and Penman- Montith is therefore adequate for applications where long term Eto estimates are required. Moreover, FAO (Doorenbos and Pruitt 1984) reported the Penman method gives the best results with the minimum possible error of plus or minus 10 percent in summer and up to 20 percent under low evaporative conditions and the Blaney- Criddle method should only be applied for periods of one month or longer winter conditions an over and under prediction of up to 25 percent has been noted.

Blaney and Morin (1942) derived an empirical formula to relate evaporation to temperature, relative humidity and length of day time hours based on measurements in New Mexico and Texas (Chang 1968). The relation was of the form:

$$U=KTp\,(114-h) \qquad \textbf{Equation no. 1}$$

where;

U = the monthly consumptive use in inches,

K = is a crop coefficient,

T = is the mean monthly temperature in F.,

p = is the monthly percentage of daytime hours in the year and

h = is the mean monthly relative humidity.

A lack of humidity data led to the Blaney- Criddle method which relates the consumptive use to day length and temperature. Thus the equation was later simplified by Blaney and Criddle (1950) by dropping the humidity term. This makes the formula more useful in areas with limited meteorological data. Thus it takes the following form:

$$U = KTp \qquad \textbf{Equation no. 2}$$

The Blaney- Criddle formula has been changed in 1951 and 1962 for determining consumptive use and irrigation requirement of different crops for the main agricultural regions of Israel. Also according to Blaney- Criddle this formula estimates less water use than the previous formula. The Blaney- Criddle formula was adapted for use in Israel as follows:

$$U = KP/100\ (45.7\ T + 813) \qquad \textbf{Equation no. 3}$$

where;

U = Monthly consumptive use (evaporation) in millimetres;

K = is the monthly empirical coefficient, it is varied from month to month;

P = describes the monthly percentage of annual day time hours and

T = refers to the mean monthly temperature in degrees centigrade.

Jafarpour (1978, 1986 and 1987) has adapted this formula for some western and south eastern stations parts of Iran.

Baybordi (1976) considered the Blaney- Criddle formula is useful for estimating potential evapotranspiration in Iran.

The Blaney- Criddle method has been used successfully for estimating potential evaporation of Dezful station in south west of Iran (Hashemi and Habibian 1979). However Jafarpour has not considered the effect of stages of growth on seasonal crop coefficients nor the effect of different crop types. According to Kaviani (1988) the Blaney-Criddle Formula has been used in many arid areas, it has advantages in Iraq with the following adjustment:

$$E = K.F = \Sigma K.f \qquad \textbf{Equation no. 4}$$

where;

E = Potential Evapotranspiration value in inches

K = Empirical crop coefficient that varies with crop types (it differs with stage of growth of seasonal crops);

f = (T. P)/100;

T = the mean monthly temperature in F and

P = the monthly percentage of daytime hours in the year.

According to FAO (Doorenbos and Pruitt 1984) the original Blaney-Criddle equation involves the calculation of the consumptive use factor (**f**) from mean temperature (**T**) percentage (**P**) of total annual daylight hours occurring during the period being considered. An empirically determined consumptive use crop coefficient (**K**) is then applied to establish the consumptive water requirements (**CU**).

$$CU = K.f = K(P.T/100) \qquad \textbf{Equation no.5}$$

with **T** in degrees Fahrenheit.

CU is defined as the amount of water required to meet the potential evapotranspiration needs of vegetative areas. The effect of climate on crop water requirements is however insufficiently defined by temperature and day length and crop water requirements can vary widely between areas despite similar values of **T** and **P**.

The most recent statement of the Blaney-Criddle Formula is the modification used by the U.S. Soil Conservation Services (1970):

$$Et = (0.142Ta + 1.095)(Ta + 17.8)kd \qquad \textbf{Equation no.6}$$

where,

E*t* = Potential evaporation (cm/mo)

T*a* = average air temperature (°C). When T*a* is less than 3 °C, the first term in parenthesises set equal to 1.38.

k = empirical crop factor that various with crop type and stage of growth. For perennial crops the coefficient is given for each month. For annual crops the coefficient is tabulated for various percentages of the growing season.

d = the monthly fraction of annual hours of daylight which is determined by latitude.

The Blaney-Criddle method is suitable for calculating individual months in this study. Since for a given location climatic conditions and consequently **U** (potential evaporation) may vary greatly from year to year, it is preferable be calculate **U** for each calendar month and for each year of record rather than by using mean monthly temperatures based on several year's records, because of changing climatic conditions for each month or periods from year to year. In this regard our analysing is based on individual monthly for each year. In this study K as crop factor has been used for stages of growth of wheat (Gorgan, Ghazvin, Karaj and Semnan Stations) and citrus trees (Anzali and Babolsar stations).

The Blaney- Criddle formula used in Israel has been adapted for this study with the following adjustment:

$$\mathbf{U = KP/100\,(45.7\,T + 813)}$$

The reasons for choosing this equation are:

I) For example, it has been used in the Middle East (in Israel 1962) for the first time.

II) Some authors such as Jafarpour (1978, 1986 and 1987) has used this Blaney-Criddle formula for estimating potential evapotranspiration for some stations in western parts of Iran.

III) The equation has been recommended by the Ministry of Power (1992) to estimate water loss Iran.

There are differences between the Blaney- Criddle for potential evapotranspiration and crop potential evapotranspiration. Unfortunately some investigators did not distinguish between them. In this study the Blaney- Criddle formula has been calculated for potential evapotranspiration and consequently the crop water requirements (in crop water requirement section) over Anzali, Babosar, Gorgan, Ghazvin, Karaj and Semnan stations. The results of potential evapotranspiration calculated by the Blaney- Criddle method have been demonstrated in Table 8.7-1 to Table 8.7-12. Also these results have been compared with potential evapotranspiration calculated by the pan in Figure 8.7-1 to Figure 8.7-12. Figures 8.7-1 to 8.7-12 show that the amounts of potential evapotranspiration estimated by Blaney- Criddle method are more at Anzali, Babolsar and Gorgan (coastal area) but lower than pan for Ghazvin, Karaj and Semnan (southern slopes) stations. As previously mentioned there was difference between the coastal area and southern slopes from the point of view of rainfall. Also these figures indicate two different potential evapotranspiration regimes in the coastal and southern slopes of the Central Elburz. The values of potential evapotranspiration estimated by the Pan method are more than that indicated by the Blaney- Criddle method from the May to the September period. However, in the other months (except January, February and March) they appear closer in Ghazvin, Karaj and Semnan (southern slopes) stations. Thus, the critical difference between Blaney-Criddle method and Pan Evaporation occurs during cold months. Those months are minimum in potential evaporation by pan they have a high values in the Blaney-Criddle method.

Table 8.7-1 Monthly Potential Evaporation (mm) by Blaney- Criddle over the Central Elburz selected stations.

Stations	Years	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	1984	34.8	19.9	39.3	64.2	88	112.7	135	115.4	97.4	72	51.8	26.7
	1985	27.2	28.9	28.3	64.2	101.5	124	126.2	119.3	97.4	69.8	52.4	35.2
	1986	34.5	28.6	34.4	67.1	94.3	115.4	127.6	120.2	98.9	73.4	46.6	35
	1987	41.1	32.3	37.4	54	93.4	116.8	125	116.7	89.7	59.8	46.6	38.3
Babolsar	1982	32.7	30	43.2	73.2	96.5	114.1	130.4	116.3	101.3	69.5	44	32.
	1983	30.1	35	46.6	71.2	104.5	118.6	134.1	121.5	95.3	72.7	55.9	39.2
	1984	32.7	33.8	36.3	70	103.1	123.1	126.3	119.8	100.9	72	53.4	39.2
	1985	32.7	33.8	36.3	70	103.1	123.1	126.3	119.8	100.9	72	53.4	39.2
	1986	37.5	34.4	37.5	69.2	96	119	132.3	124.1	104	79	50.5	35.8
	1987	37.5	34.4	37.5	69.2	96	119	132.3	124.1	104	79	50.5	35.7
Gorgan	1984	38.1	25.6	46.2	75.6	90.6	113.2	137.3	121.1	100.9	72.7	53.4	25.2
	1985	30.8	35.7	40.5	74.8	109	125.8	129.5	123.6	104.4	72.4	54	37.3
	1986	36.2	35	37.8	72.4	102.7	124.9	134.1	127.1	104.7	78.5	46.7	33.6
	1987	39.1	36	47.4	63.5	103.1	127.1	132.3	127.1	96.8	63.7	48.3	39.8
Ghazvin	1982	13.8	14	26.8	72	91.07	110.5	125.9	110.8	89.5	54.8	24.3	20.5
	1983	22.5	9.38	27.9	55.8	88.38	109.6	130	120.6	88.4	61.6	41.7	19
	1984	16.4	8.44	40.9	61.5	73.58	110.1	130.4	118.5	88.7	59	35	19.6
	1985	9.09	18.4	26	63.1	92.86	116.8	126.8	111.2	94.5	61	40.4	20.5
	1986	16.1	21.6	26	59	81.21	106.9	131.4	114.6	91	67	31.2	11.5
	1987	21.2	26.6	34	57.8	95.55	116.8	124.5	117.6	88.4	48.7	37.2	20.9
Karaj	1982	15.1	13.1	29.8	72.8	93.3	110.5	126.3	110.8	90	54.8	23.6	17.8
	1983	21.5	11	28.7	56.6	90.6	112	133.2	120.6	89.1	62.7	42.3	19.6
	1984	15.8	8.5	42.8	63.9	76.72	111	130.9	121.5	93	60.2	37.5	17.5
	1985	11.3	20.3	28.7	67.9	97.79	118.1	127.2	112	97.2	64	41.3	22.7
	1986	19.3	24.7	27.5	61.5	84.79	111.4	133.2	117.6	94.5	71.3	33.1	14
	1987	23.7	27.8	37.8	61.5	99.59	120.4	127.7	121.5	90.7	50.5	40	23.7
Semnan	1984	23.4	18.1	54.6	82.1	97.8	138.4	150.1	146.4	107	70.2	45.5	14.3
	1985	19.3	27.8	42	84.9	115.7	146	156.5	126.6	111.2	74.9	49.9	29.2
	1986	25	30	38.6	78.9	111.2	133.4	151	128.8	105.5	83.5	41.7	19
	1987	27.6	32.9	50.4	79.3	119.7	140.6	146.4	140	107.4	63	49	29

Table 8.7-2 Anzali Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method.

Years	Months	Mean T °C	P	PEo
1984	Jan	8.5	6.87	34.82
	Feb	3.8	6.79	19.92
	Mar	8.2	8.34	39.38
	Apr	13.8	8.90	64.26
	May	17.6	9.92	87.92
	Jun	23	9.95	112.71
	July	27.5	10.10	135.06
	Aug	24.8	9.47	115.46
	Sep	23.3	8.38	97.36
	Oct	17.9	7.8	71.94
	Nov	14	6.82	51.76
	Dec	6.1	6.66	26.70
1985	Jan	6.1	6.87	27.28
	Feb	6.7	6.79	28.92
	Mar	5.3	8.34	28.33
	Apr	13.8	8.90	64.26
	May	20.6	9.92	101.52
	Jun	25.5	9.95	124.08
	July	25.6	10.10	126.29
	Aug	25.7	9.47	119.35
	Sep	23.3	8.38	97.36
	Oct	17.3	7.8	69.80
	Nov	14.2	6.82	52.39
	Dec	8.9	6.66	35.22

Table 8.7-3 Anzali Potential Evapotranspiration (mm) estimation by Blaney-Criddle method (con).

Years	Months	Mean T °C	P	PEo
1986	Jan	8.4	6.87	34.50
	Feb	6.6	6.79	28.61
	Mar	6.9	8.34	34.43
	Apr	14.5	8.9	67.11
	May	19	9.92	94.27
	Jun	23.6	9.95	115.44
	July	25.9	10.1	127.68
	Aug	25.9	9.47	120.22
	Sep	23.7	8.38	98.89
	Oct	18.3	7.8	73.36
	Nov	12.2	6.82	46.15
	Dec	8.8	6.66	34.91
1987	Jan	10.5	6.87	41.10
	Feb	7.8	6.79	32.33
	Mar	7.7	8.34	37.48
	Apr	11.3	8.9	54.09
	May	18.8	9.92	93.36
	Jun	23.9	9.95	116.81
	July	25.3	10.1	124.91
	Aug	25.1	9.47	116.76
	Sep	21.3	8.38	89.70
	Oct	14.5	7.8	59.82
	Nov	12.2	6.82	46.15
	Dec	9.9	6.66	38.26

Table 8.7-4 Babolsar Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method.

Years	Months	Mean T °C	P	PEo
1982	Jan	7.7	6.99	32.73
	Feb	7	6.86	30.08
	Mar	9.2	8.35	43.24
	Apr	16.1	8.85	73.25
	May	19.7	9.81	96.45
	Jun	23.6	9.83	114.15
	July	26.8	9.99	130.48
	Aug	25.2	9.40	116.38
	Sep	24.4	8.36	101.35
	Oct	17.1	7.85	69.48
	Nov	11.3	6.92	43.87
	Dec	7.7	6.79	32.02
1983	Jan	6.9	6.99	30.17
	Feb	8.6	6.86	35.09
	Mar	10.1	8.35	46.67
	Apr	15.6	8.85	71.22
	May	21.5	9.81	104.52
	Jun	24.6	9.83	118.64
	July	27.6	9.99	134.14
	Aug	26.4	9.40	121.54
	Sep	22.8	8.36	95.24
	Oct	18	7.85	72.70
	Nov	15.1	6.92	55.88
	Dec	10	6.79	39.16
1984	Jan	7.7	6.99	32.73
	Feb	8.2	6.86	33.84
	Mar	7.4	8.35	36.37
	Apr	15.3	8.85	70.01
	May	21.2	9.81	103.17
	Jun	25.6	9.83	123.13
	July	25.9	9.99	126.37
	Aug	26	9.40	119.82
	Sep	24.3	8.36	100.97
	Oct	17.8	7.85	71.99
	Nov	14.3	6.92	53.35
	Dec	10	6.79	39.16

Table 8.7-5 Babolsar Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method (con).

Years	Months	Mean T °C	P	PEo
1985	Jan	7.7	6.99	32.73
	Feb	8.2	6.86	33.84
	Mar	7.4	8.35	36.37
	Apr	15.3	8.85	70.01
	May	21.2	9.81	103.17
	Jun	25.6	9.83	123.13
	July	25.9	9.99	126.37
	Aug	26	9.40	119.82
	Sep	24.3	8.36	100.97
	Oct	17.8	7.85	71.99
	Nov	14.3	6.92	53.35
	Dec	10	6.79	39.16
1986	Jan	9.2	6.99	37.52
	Feb	8.4	6.86	34.46
	Mar	7.7	8.35	37.51
	Apr	15.1	8.85	69.20
	May	19.6	9.81	96.00
	Jun	24.7	9.83	119.09
	July	27.2	9.99	132.31
	Aug	27	9.40	124.12
	Sep	25.1	8.36	104.03
	Oct	19.5	7.85	78.09
	Nov	13.4	6.92	50.51
	Dec	8.9	6.79	35.75
1987	Jan	9.2	6.99	37.52
	Feb	8.4	6.86	34.46
	Mar	7.7	8.35	37.51
	Apr	15.1	8.85	69.20
	May	19.6	9.81	96.00
	Jun	24.7	9.83	119.09
	July	27.2	9.99	132.31
	Aug	27	9.40	124.12
	Sep	25.1	8.36	104.03
	Oct	19.5	7.85	78.09
	Nov	13.4	6.92	50.51
	Dec	8.9	6.79	35.75

Table 8.7-6 Gorgan Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method.

Years	Months	Mean T °C	P	PEo
1984	Jan	9.4	6.99	38.16
	Feb	5.6	6.86	25.69
	Mar	10	8.35	46.29
	Apr	16.7	8.85	75.67
	May	18.4	9.81	90.62
	Jun	23.4	9.83	113.25
	July	28.3	9.99	137.33
	Aug	26.3	9.40	121.11
	Sep	24.3	8.36	100.97
	Oct	18	7.85	72.70
	Nov	14.3	6.92	53.35
	Dec	5.5	6.79	25.20
1985	Jan	7.1	6.99	30.81
	Feb	8.8	6.86	35.72
	Mar	8.5	8.35	40.57
	Apr	16.5	8.85	74.86
	May	22.5	9.81	109.00
	Jun	26.2	9.83	125.83
	July	26.6	9.99	129.57
	Aug	26.9	9.40	123.69
	Sep	25.2	8.36	104.41
	Oct	17.9	7.85	72.35
	Nov	14.5	6.92	53.99
	Dec	9.4	6.79	37.30
1986	Jan	8.8	6.99	36.24
	Feb	8.6	6.86	35.09
	Mar	7.8	8.35	37.89
	Apr	15.9	8.85	72.44
	May	21.1	9.81	102.72
	Jun	26	9.83	124.93
	July	27.6	9.99	134.14
	Aug	27.7	9.40	127.12
	Sep	25.3	8.36	104.79
	Oct	19.6	7.85	78.44
	Nov	12.2	6.92	46.71
	Dec	8.2	6.79	33.57
1987	Jan	9.7	6.99	39.12
	Feb	8.9	6.86	36.03
	Mar	10.3	8.35	47.43
	Apr	13.7	8.85	63.54
	May	21.2	9.81	103.17
	Jun	26.5	9.83	127.18
	July	27.2	9.99	132.31
	Aug	27.7	9.40	127.12
	Sep	23.2	8.36	96.77
	Oct	15.5	7.85	63.74
	Nov	12.7	6.92	48.29
	Dec	10.2	6.79	39.78

Table 8.7-7 Ghazvin Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method.

Years	Months	Mean T °C	P	PEo
1982	Jan	1.8	6.99	13.88
	Feb	1.9	6.86	14.09
	Mar	4.9	8.35	26.83
	Apr	15.8	8.85	72.03
	May	18.5	9.81	91.07
	Jun	22.8	9.83	110.55
	July	25.8	9.99	125.92
	Aug	23.9	9.40	110.80
	Sep	21.3	8.36	89.51
	Oct	13	7.85	54.77
	Nov	5.1	6.92	24.26
	Dec	4	6.79	20.54
1983	Jan	4.5	6.99	22.50
	Feb	0.4	6.86	9.38
	Mar	5.2	8.35	27.97
	Apr	11.8	8.85	55.85
	May	17.9	9.81	88.38
	Jun	22.6	9.83	109.66
	July	26.7	9.99	130.03
	Aug	26.2	9.40	120.68
	Sep	21	8.36	88.36
	Oct	14.9	7.85	61.58
	Nov	10.6	6.92	41.65
	Dec	3.5	6.79	18.99
1984	Jan	2.6	6.99	16.44
	Feb	0.1	6.86	8.44
	Mar	8.6	8.35	40.95
	Apr	13.2	8.85	61.52
	May	14.6	9.81	73.58
	Jun	22.7	9.83	110.11
	July	26.8	9.99	130.48
	Aug	25.7	9.40	118.53
	Sep	21.1	8.36	88.74
	Oct	14.2	7.85	59.07
	Nov	8.5	6.92	35.01
	Dec	3.7	6.79	19.61

Table 8.7-8 Ghazvin Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method(con).

Years	Months	Mean T °C	P	PEo
1985	Jan	0.3	6.99	9.09
	Feb	3.3	6.86	18.48
	Mar	4.7	8.35	26.06
	Apr	13.6	8.85	63.13
	May	18.9	9.81	92.86
	Jun	24.2	9.83	116.84
	July	26	9.99	126.83
	Aug	24	9.40	111.23
	Sep	22.6	8.36	94.47
	Oct	14.8	7.85	61.22
	Nov	10.2	6.92	40.39
	Dec	4	6.79	20.54
1986	Jan	2.5	6.99	16.12
	Feb	4.3	6.86	21.61
	Mar	4.7	8.35	26.06
	Apr	12.6	8.85	59.09
	May	16.3	9.81	81.21
	Jun	22	9.83	106.96
	July	27	9.99	131.40
	Aug	24.8	9.40	114.67
	Sep	21.7	8.36	91.04
	Oct	16.4	7.85	66.96
	Nov	7.3	6.92	31.22
	Dec	1.1	6.79	11.54
1987	Jan	4.1	6.99	21.23
	Feb	5.9	6.86	26.63
	Mar	6.8	8.35	34.08
	Apr	12.3	8.85	57.88
	May	19.5	9.81	95.55
	Jun	24.2	9.83	116.84
	July	25.5	9.99	124.55
	Aug	25.5	9.40	117.67
	Sep	21	8.36	88.36
	Oct	11.3	7.85	48.67
	Nov	9.2	6.92	37.22
	Dec	4.1	6.79	20.85

Table 8.7-9 Karaj Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method.

Years	Months	Mean T °C	P	PEo
1982	Jan	2.2	6.99	15.16
	Feb	1.6	6.86	13.15
	Mar	5.7	8.35	29.88
	Apr	16	8.85	72.84
	May	19	9.81	93.31
	Jun	22.8	9.83	110.55
	July	25.9	9.99	126.37
	Aug	23.9	9.40	110.80
	Sep	21.4	8.36	89.89
	Oct	13	7.85	54.77
	Nov	4.9	6.92	23.63
	Dec	3.1	6.79	17.75
1983	Jan	4.2	6.99	21.55
	Feb	0.9	6.86	10.95
	Mar	5.4	8.35	28.74
	Apr	12	8.85	56.66
	May	18.4	9.81	90.62
	Jun	23.1	9.83	111.90
	July	27.4	9.99	133.22
	Aug	26.2	9.40	120.68
	Sep	21.2	8.36	89.13
	Oct	15.2	7.85	62.66
	Nov	10.8	6.92	42.28
	Dec	3.7	6.79	19.61
1984	Jan	2.4	6.99	15.80
	Feb	0.1	6.86	8.44
	Mar	9.1	8.35	42.86
	Apr	13.8	8.85	63.94
	May	15.3	9.81	76.72
	Jun	22.9	9.83	111.00
	July	26.9	9.99	130.94
	Aug	26.4	9.40	121.54
	Sep	22	8.36	92.18
	Oct	14.5	7.85	60.15
	Nov	9.3	6.92	37.54
	Dec	3	6.79	17.44

Table 8.7-10 Karaj Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method(con).

Years	Months	Mean T °C	P	PEo
1985	Jan	1	6.99	11.32
	Feb	3.9	6.86	20.36
	Mar	5.4	8.35	28.74
	Apr	14.8	8.85	67.99
	May	20	9.81	97.79
	Jun	24.5	9.83	118.19
	July	26.1	9.99	127.29
	Aug	24.2	9.40	112.09
	Sep	23.3	8.36	97.15
	Oct	15.6	7.85	64.09
	Nov	10.5	6.92	41.34
	Dec	4.7	6.79	22.71
1986	Jan	3.5	6.99	19.31
	Feb	5.3	6.86	24.75
	Mar	5.1	8.35	27.59
	Apr	13.2	8.85	61.52
	May	17.1	9.81	84.79
	Jun	23	9.83	111.45
	July	27.4	9.99	133.22
	Aug	25.5	9.40	117.67
	Sep	22.6	8.36	94.47
	Oct	17.6	7.85	71.27
	Nov	7.9	6.92	33.11
	Dec	1.9	6.79	14.03
1987	Jan	4.9	6.99	23.78
	Feb	6.3	6.86	27.88
	Mar	7.8	8.35	37.89
	Apr	13.2	8.85	61.52
	May	20.4	9.81	99.59
	Jun	25	9.83	120.44
	July	26.2	9.99	127.74
	Aug	26.4	9.40	121.54
	Sep	21.6	8.36	90.65
	Oct	11.8	7.85	50.46
	Nov	10.1	6.92	40.07
	Dec	5	6.79	23.65

Table 8.7-11 Semnan Potential Evapotranspiration (mm) Estimation by Blaney-Criddle method.

Years	Months	Mean T °C	P	PEo
1984	Jan	4.8	6.99	23.46
	Feb	3.2	6.86	18.16
	Mar	12.2	8.35	54.68
	Apr	18.3	8.85	82.14
	May	20	9.81	97.79
	Jun	29	9.83	138.41
	July	31.1	9.99	150.11
	Aug	32.2	9.40	146.45
	Sep	25.9	8.36	107.08
	Oct	17.3	7.85	70.19
	Nov	11.8	6.92	45.45
	Dec	2	6.79	14.34
1985	Jan	3.5	6.99	19.31
	Feb	6.3	6.86	27.88
	Mar	8.9	8.35	42.09
	Apr	19	8.85	84.97
	May	24	9.81	115.73
	Jun	30.7	9.83	146.04
	July	32.5	9.99	156.51
	Aug	27.6	9.40	126.69
	Sep	27	8.36	111.28
	Oct	18.6	7.85	74.86
	Nov	13.2	6.92	49.87
	Dec	6.8	6.79	29.23

Table 8.7-12 Semnan Potential Evapotranspiration (mm) estimation by Blaney-Criddle method(con).

Years	Months	Mean T °C	P	PEo
1986	Jan	5.3	6.99	25.06
	Feb	7	6.86	30.08
	Mar	8	8.35	38.66
	Apr	17.5	8.85	78.91
	May	23	9.81	111.24
	Jun	27.9	9.83	133.47
	July	31.3	9.99	151.03
	Aug	28.1	9.40	128.84
	Sep	25.5	8.36	105.55
	Oct	21	7.85	83.47
	Nov	10.6	6.92	41.65
	Dec	3.5	6.79	18.99
1987	Jan	6.1	6.99	27.62
	Feb	7.9	6.86	32.90
	Mar	11.1	8.35	50.49
	Apr	17.6	8.85	79.31
	May	24.9	9.81	119.76
	Jun	29.5	9.83	140.65
	July	30.3	9.99	146.46
	Aug	30.7	9.40	140.01
	Sep	26	8.36	107.46
	Oct	15.3	7.85	63.02
	Nov	12.9	6.92	48.93
	Dec	6.7	6.79	28.92

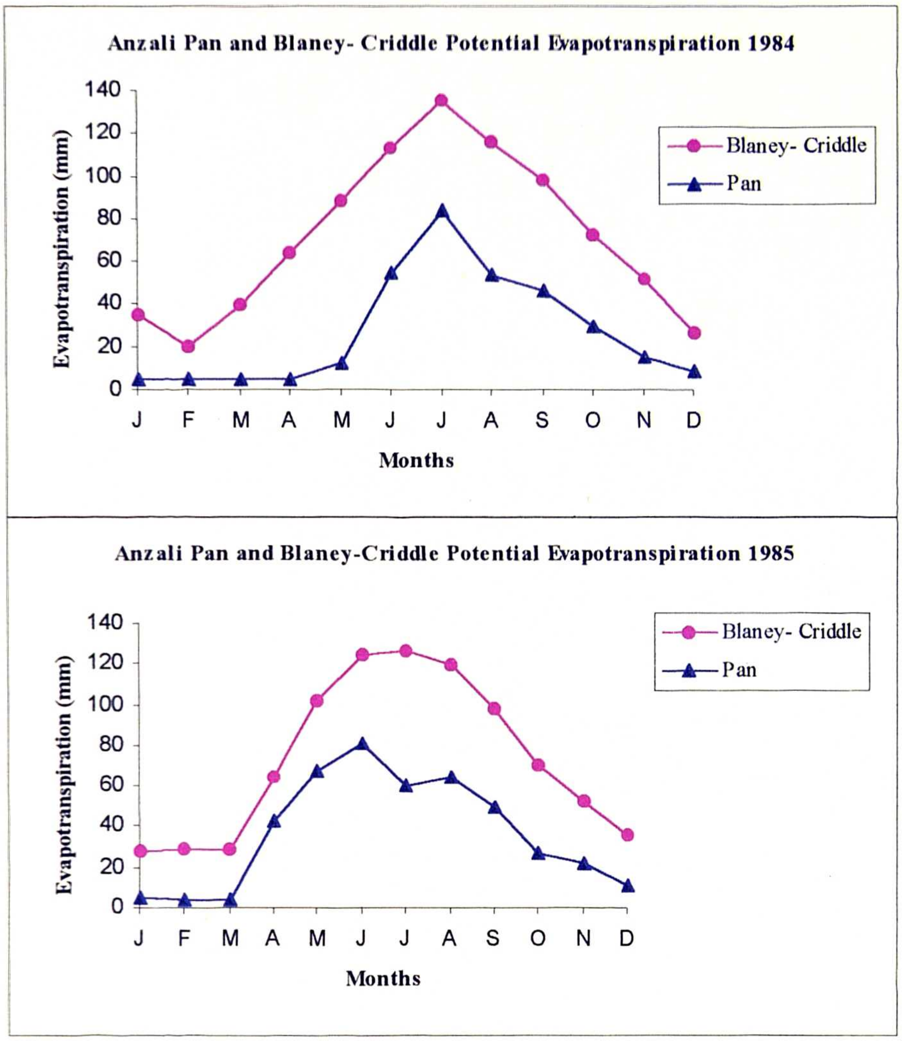
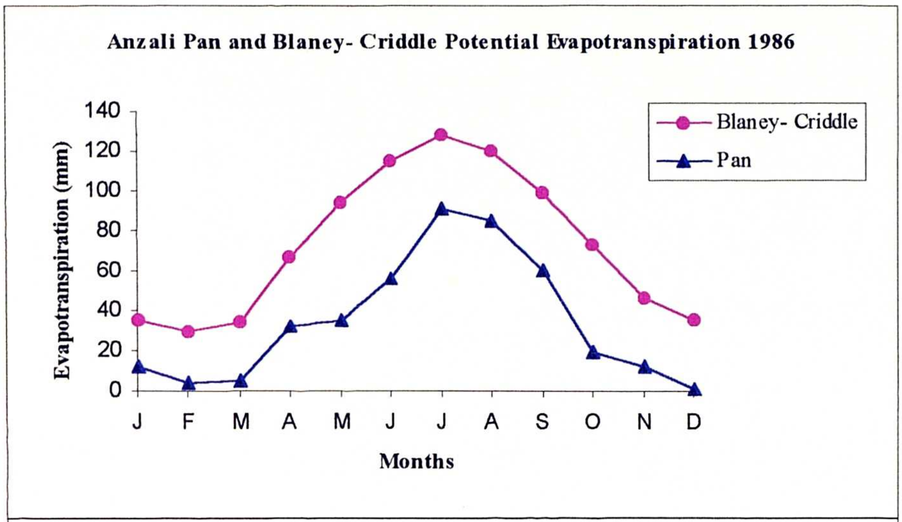


Figure 8.7-1 Comparison between Pan and Blaney-Criddle over Anzali Station.



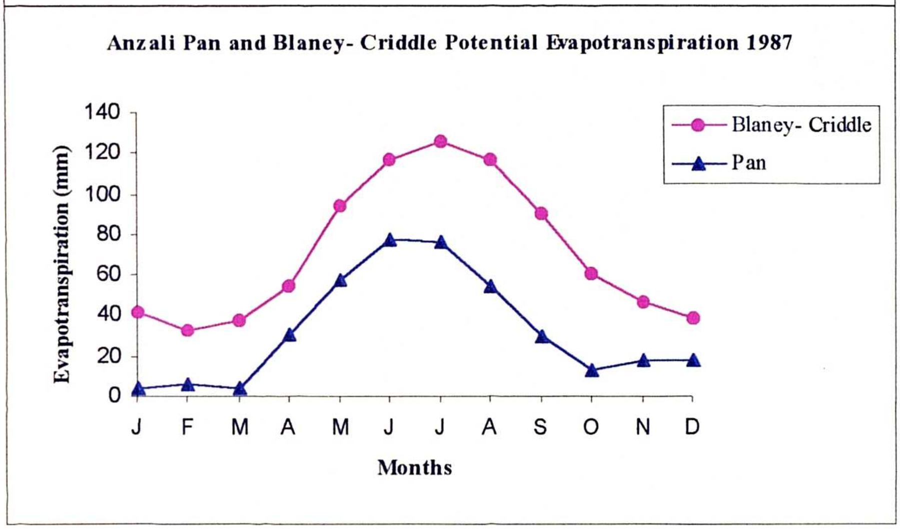


Figure 8.7-2 Comparison between Pan and Blaney-Criddle over Anzali Station

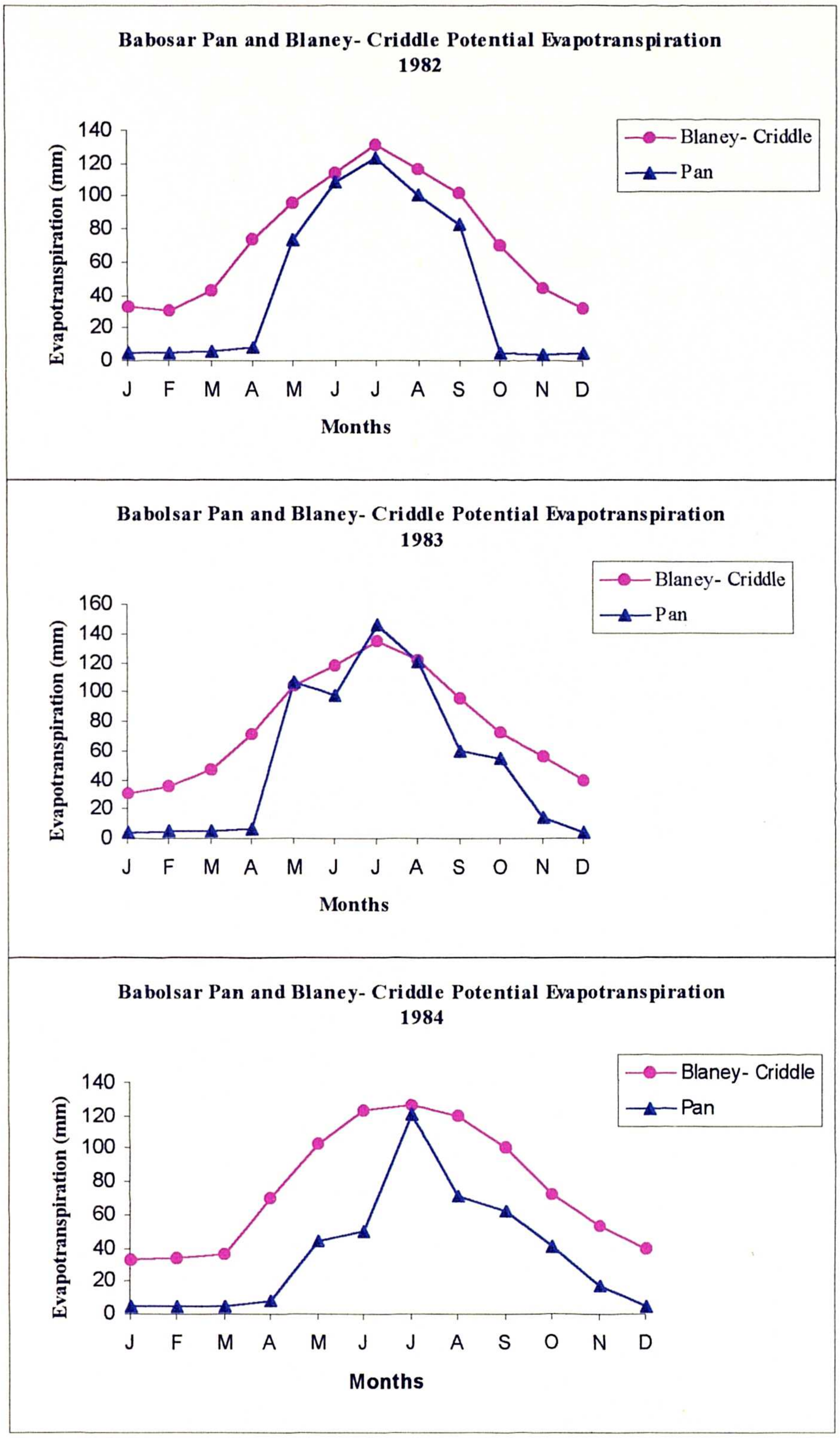


Figure 8.7-3 Comparison between Pan and Blaney-Criddle over Babolsar Station.

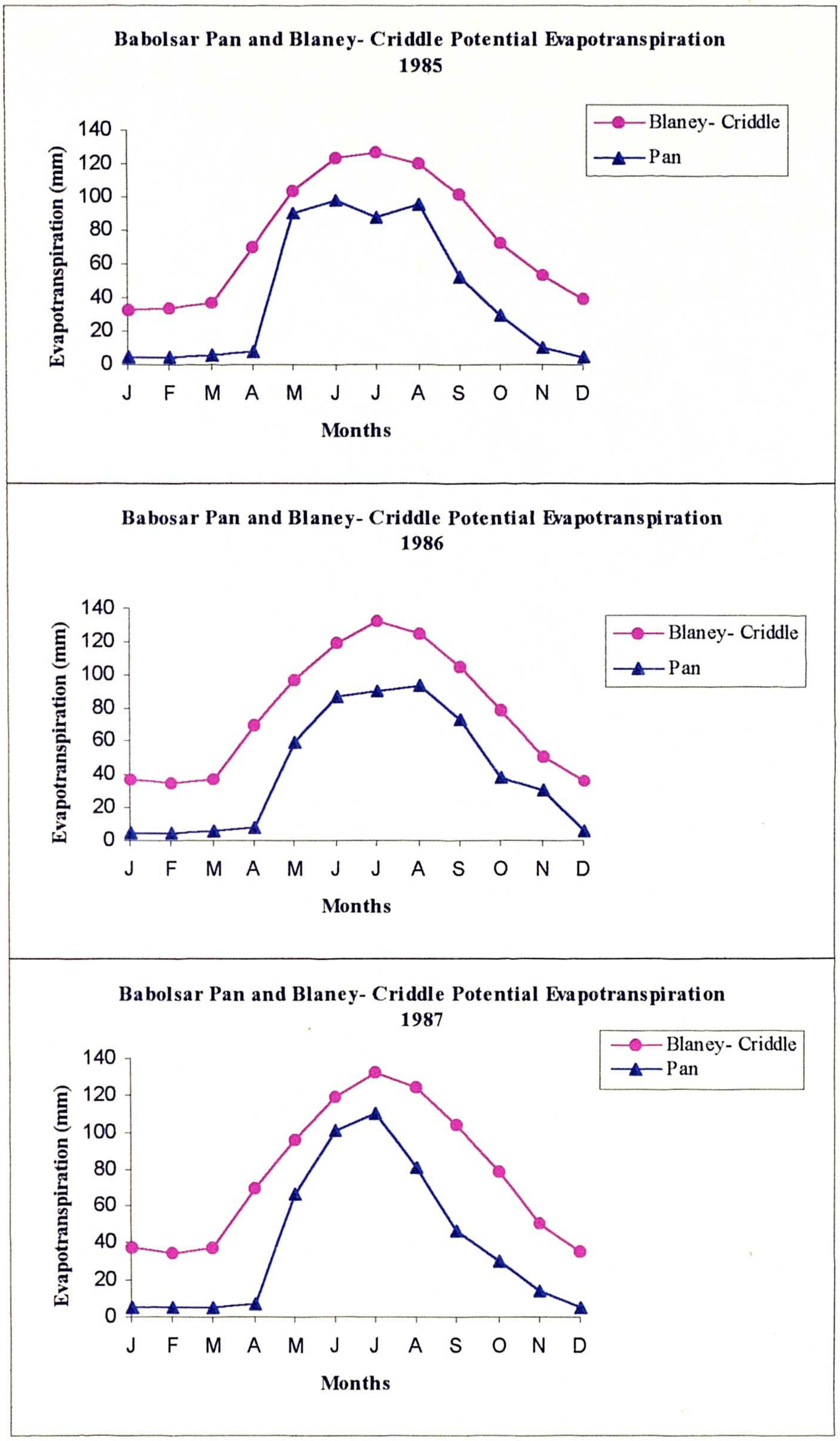


Figure 8.7-4 Comparison between Pan and Blaney-Criddle over Babolsar Station.

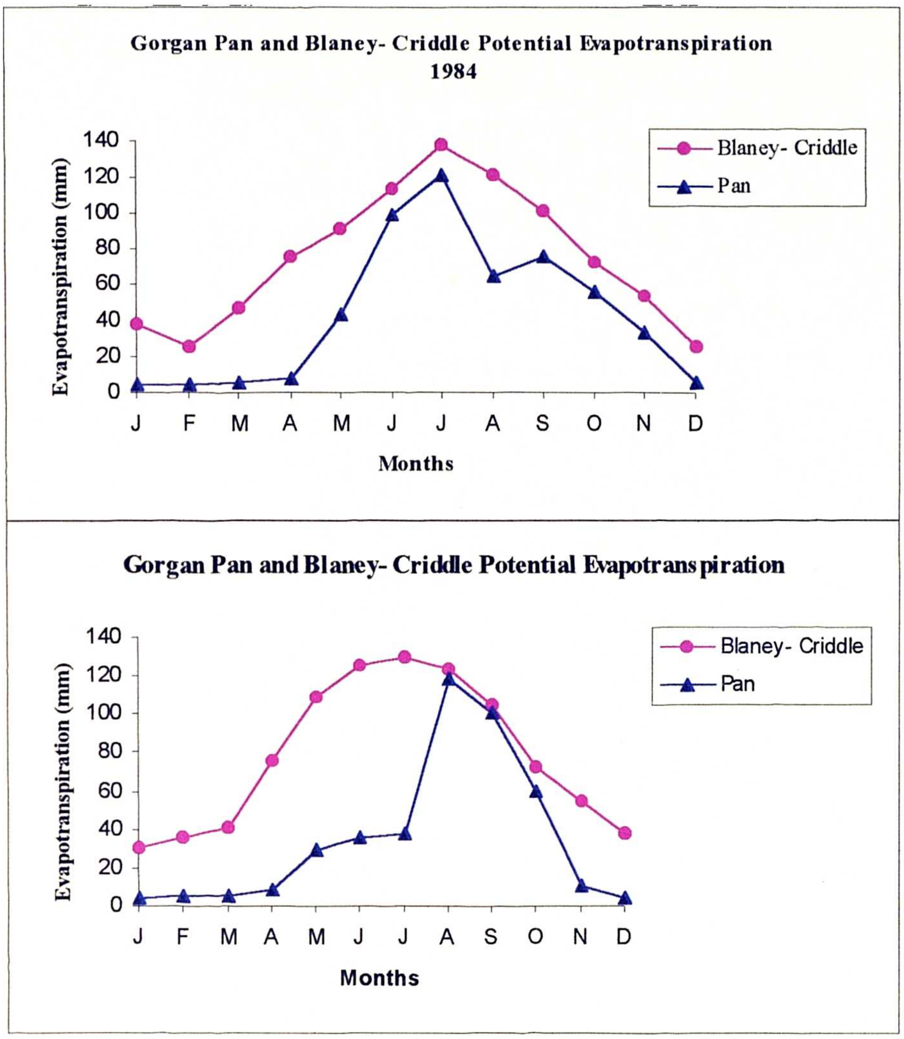


Figure 8.7-5 Comparison between Pan and Blaney-Criddle over Gorgan Station.

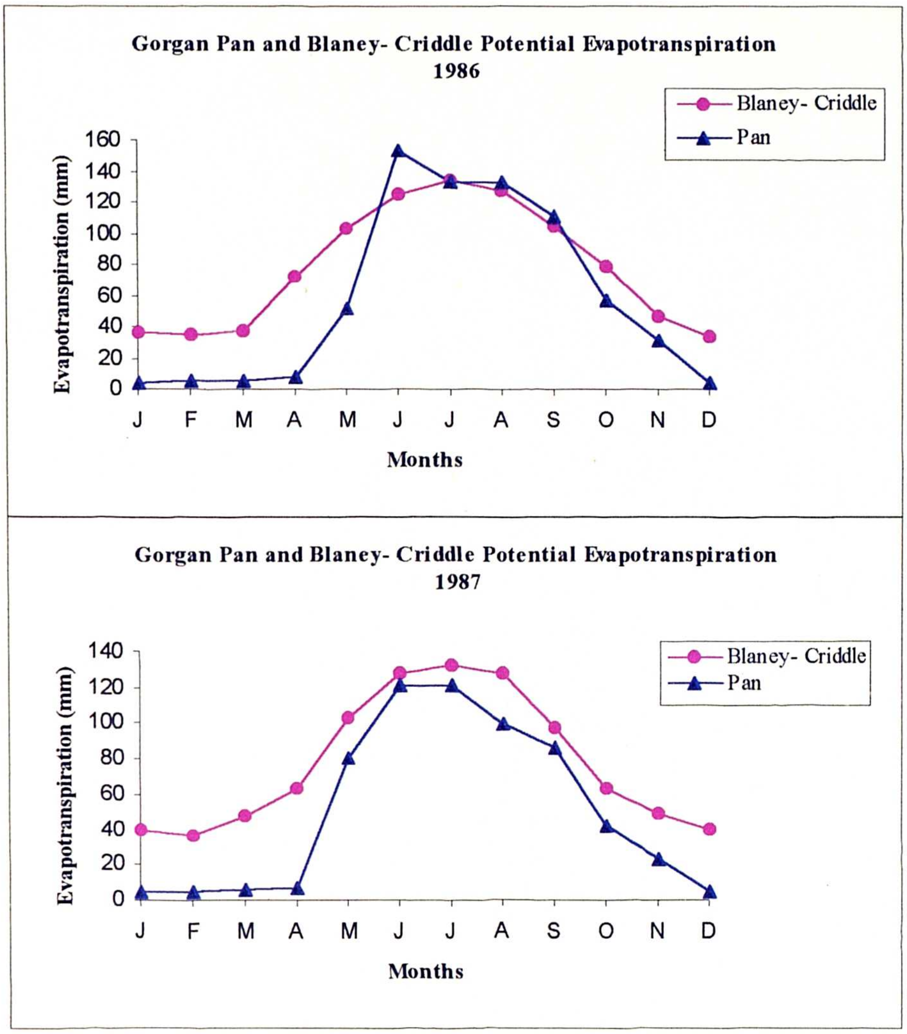


Figure 8.7-6 Comparison between Pan and Blaney-Criddle over Gorgan Station.

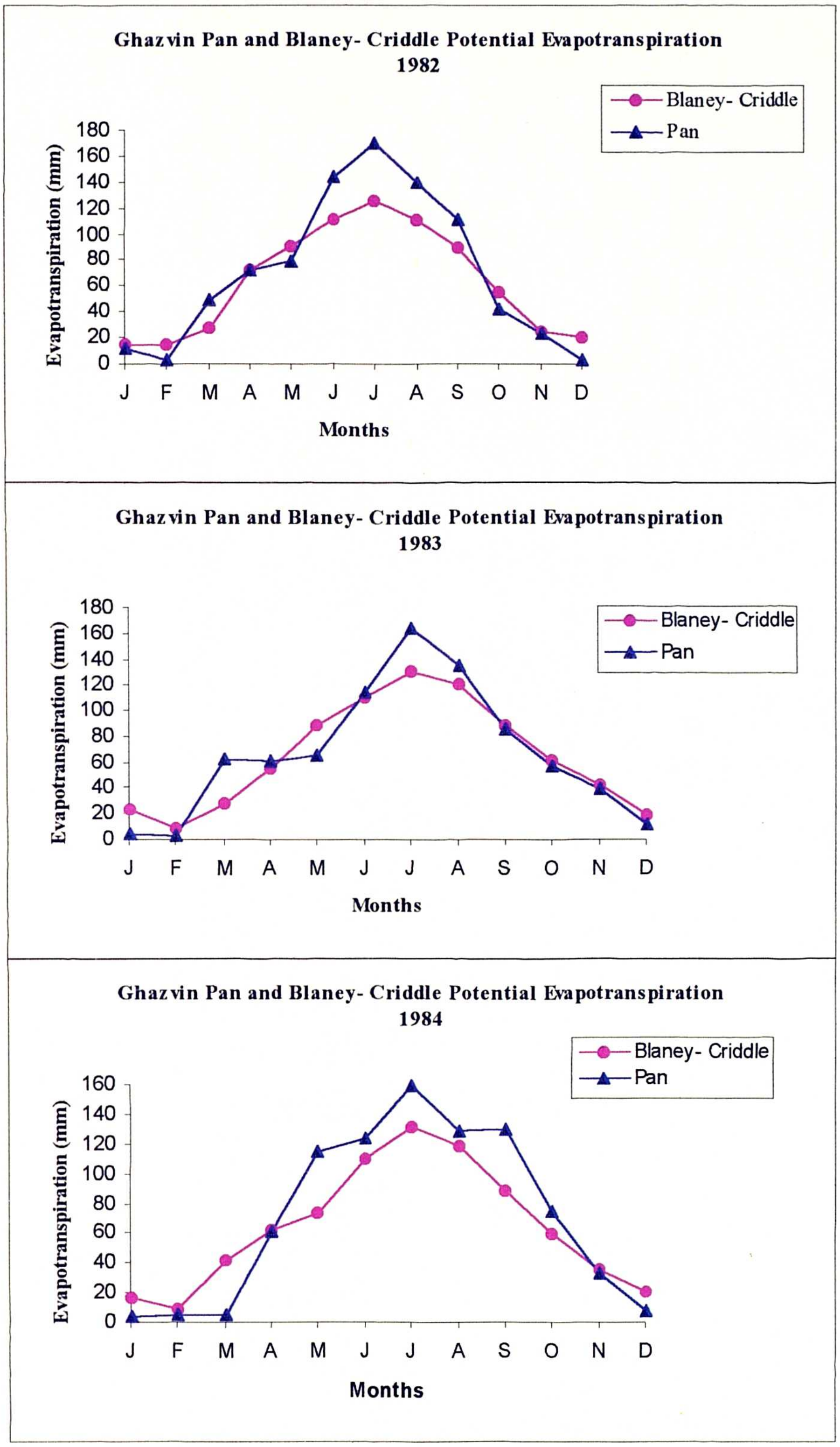


Figure 8.7-7 Comparison between Pan and Blaney-Criddle over Ghazvin Station.

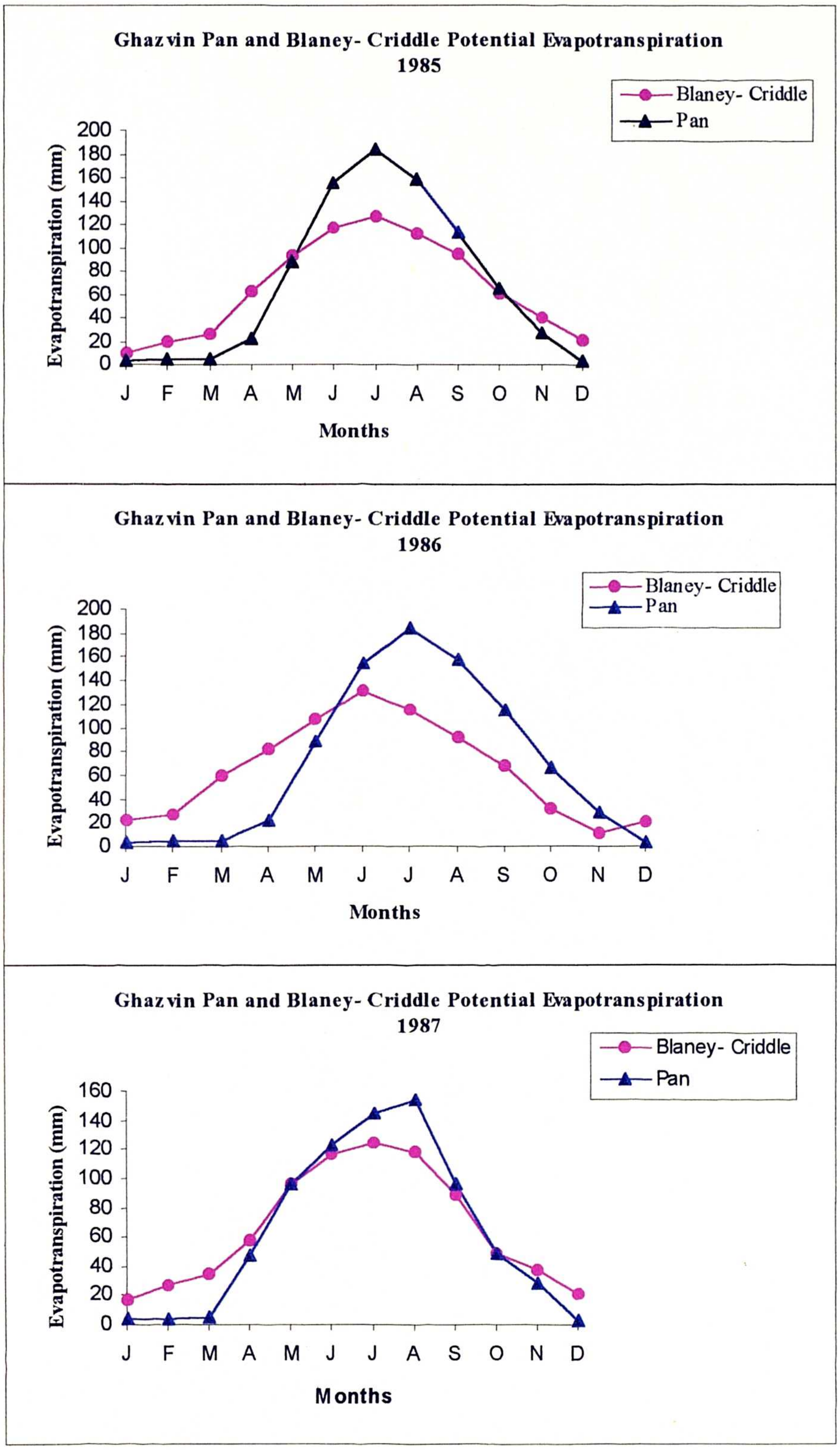


Figure 8.7-8 Comparison between Pan and Blaney-Criddle over Ghazvin Station.

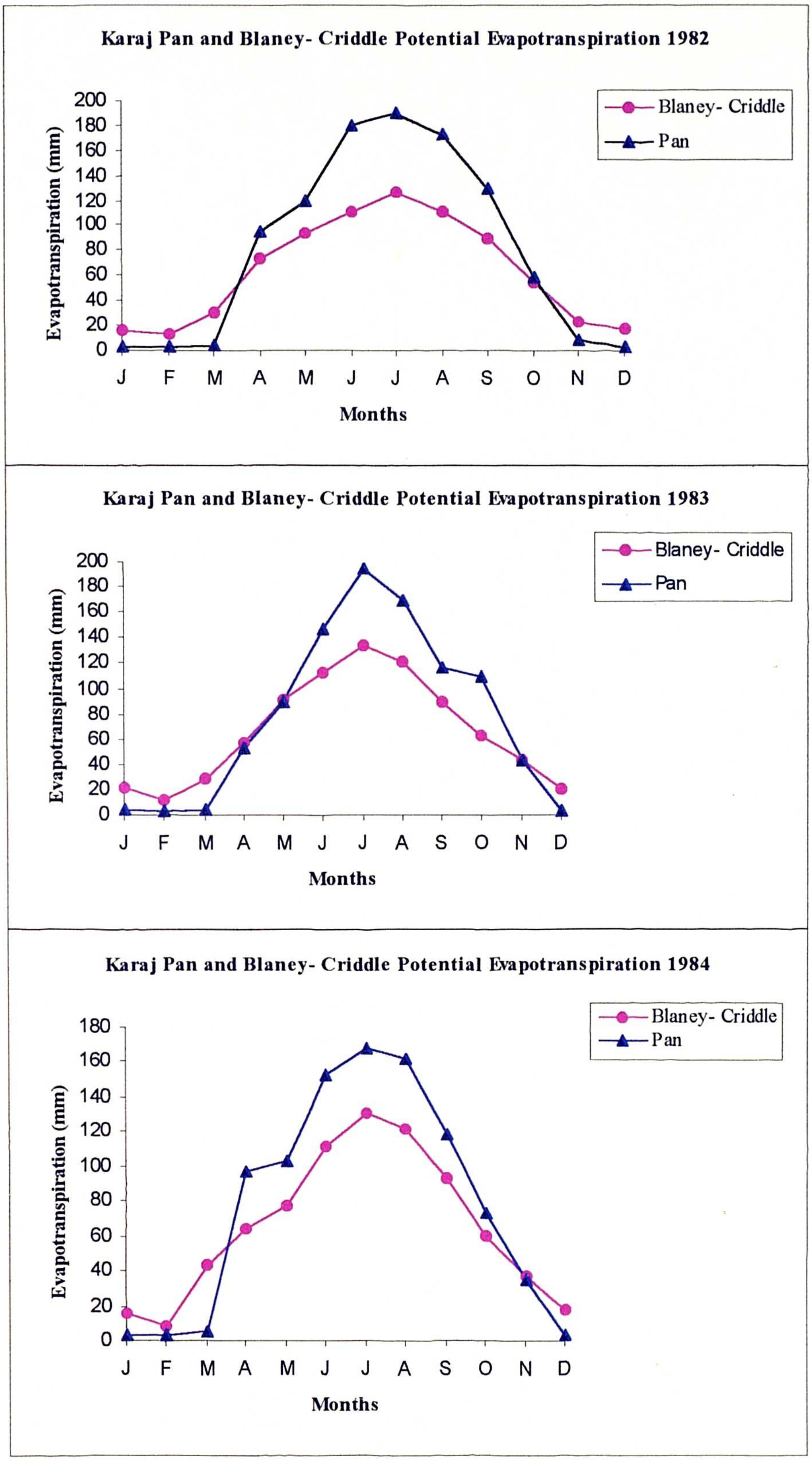


Figure 8.7-9 Comparison between Pan and Blaney-Criddle over Karaj Station.

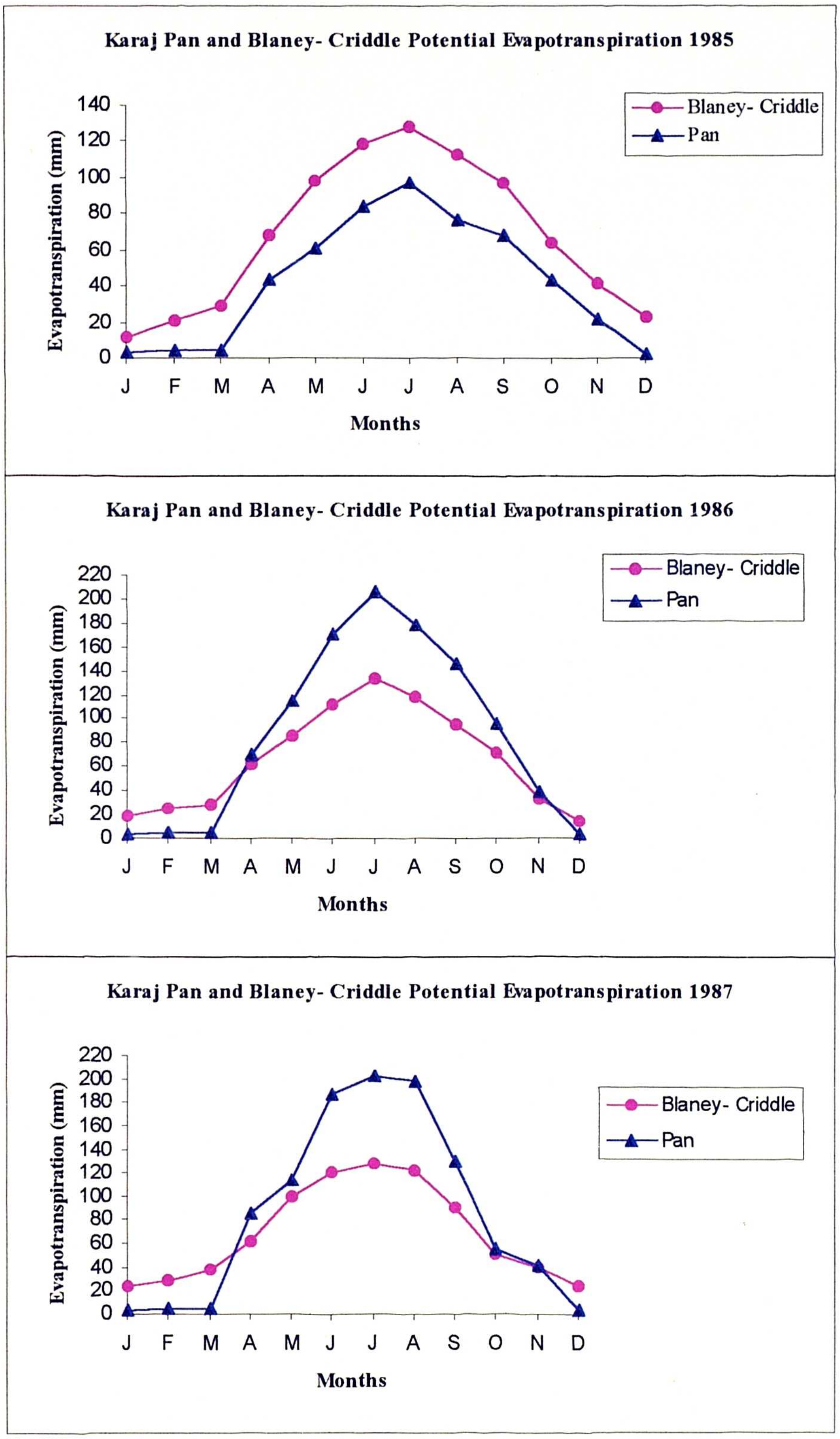


Figure 8.7-10 Comparison between Pan and Blaney-Criddle over Karaj Station.

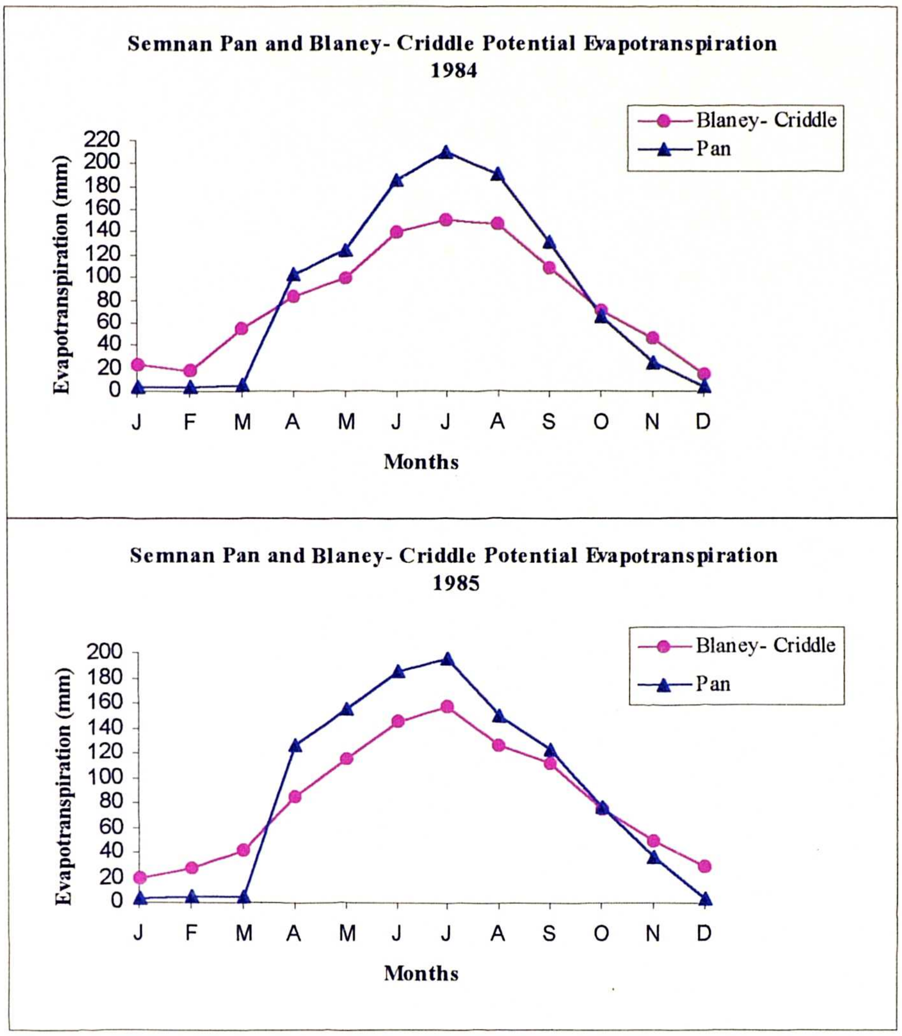


Figure 8.7-11 Comparison between Pan and Blaney-Criddle over Semnan Station.

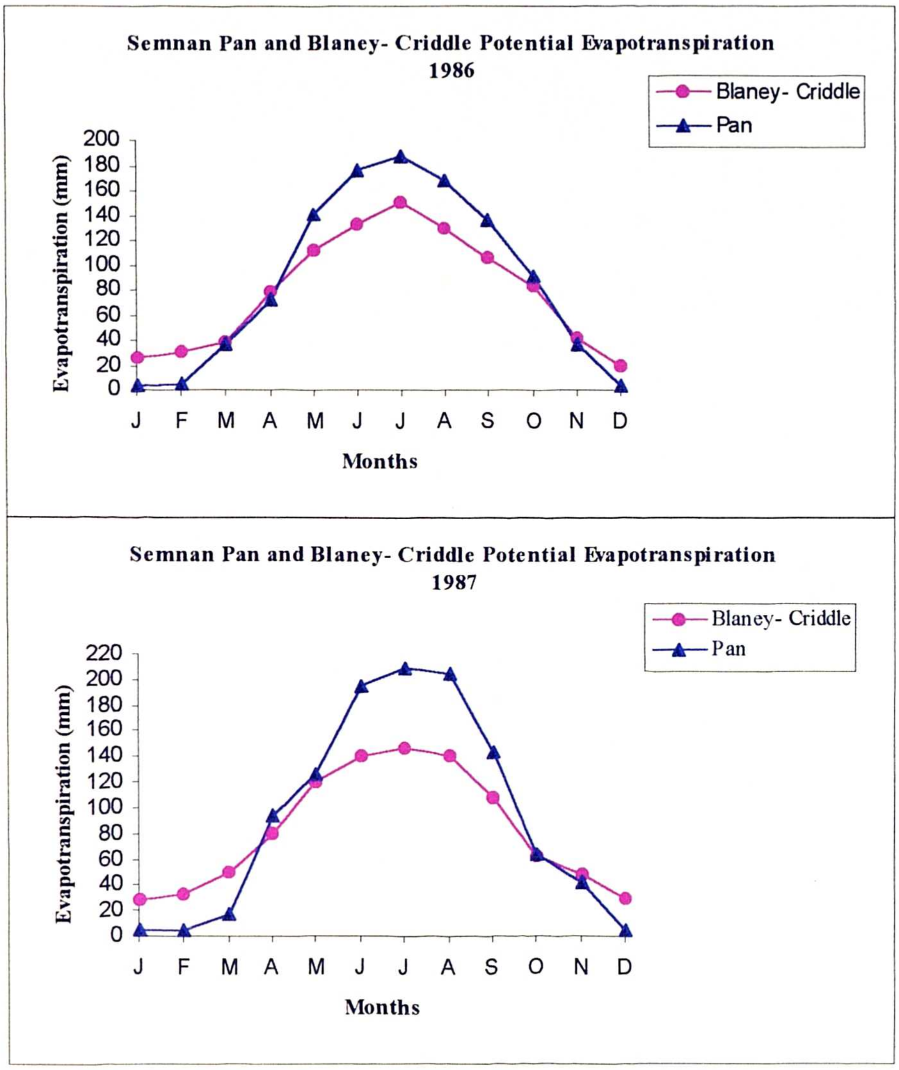


Figure 8.7-12 Comparison between Pan and Blaney-Criddle over Semnan Station.

8.8 Relationship between Pan and the Blaney- Criddle over the Central Elburz Stations

The linear regression is commonly used to describe the association between two variables. In this study the Pan method and the Blaney- Criddle method have been regressed for their closeness over the Central Elburz stations in the following ways:

1) regression between pan and the Blaney- Criddle method for each station for all years.

2) regression between pan and the Blaney-Criddle method for each stations for seasons separately.

3) regression between pan and the Blaney-Criddle method at the coastal area and southern slope stations.

The basis of this regression analysis is to establish whether or not any of the stations have close similarities and also to find regional differences. Thus R^2 provides an indication of the closeness of the data point to the line of best fit. A value of R^2 close to unity indicates a high degree of relationship between two variables. The values of R^2 is always between 0 and 1.

The analysis results for the Central Elburz stations are illustrated in Figures 8.8-1 to 8.8-2. Figures 8.8-1 to 8.8-2 indicate that all stations have high correlation as follows:

1) stations whose R^2 values are between 0.73 and 0.86 (coastal stations: Anzali, Babolsar and Gorgan).

2) stations whose R^2 values are between 0.93 and 0.97 (southern slope stations: Ghazvin, Karaj and Semnan).

Regarding Figures 8.8-3 to 8.8-8 the values of R^2 for four seasons in all stations except during winter at Anzali and summer at Gorgan generally are significant. However, the values of R^2 in southern slope stations are greater than the coastal area stations.

Figures 8.8-9 to 8.8-10 have been produced by grouping data from the Central Elburz stations. These graphs demonstrate that the values of R^2 differ between 0.77 to 92 from the coastal area and southern slope stations. In every aspect it can be concluded from the basis of regression analysis, there is a closer relationship between pan and Blaney- Criddle in southern slopes than coastal area stations. Also southern slope stations have close fit to each other.

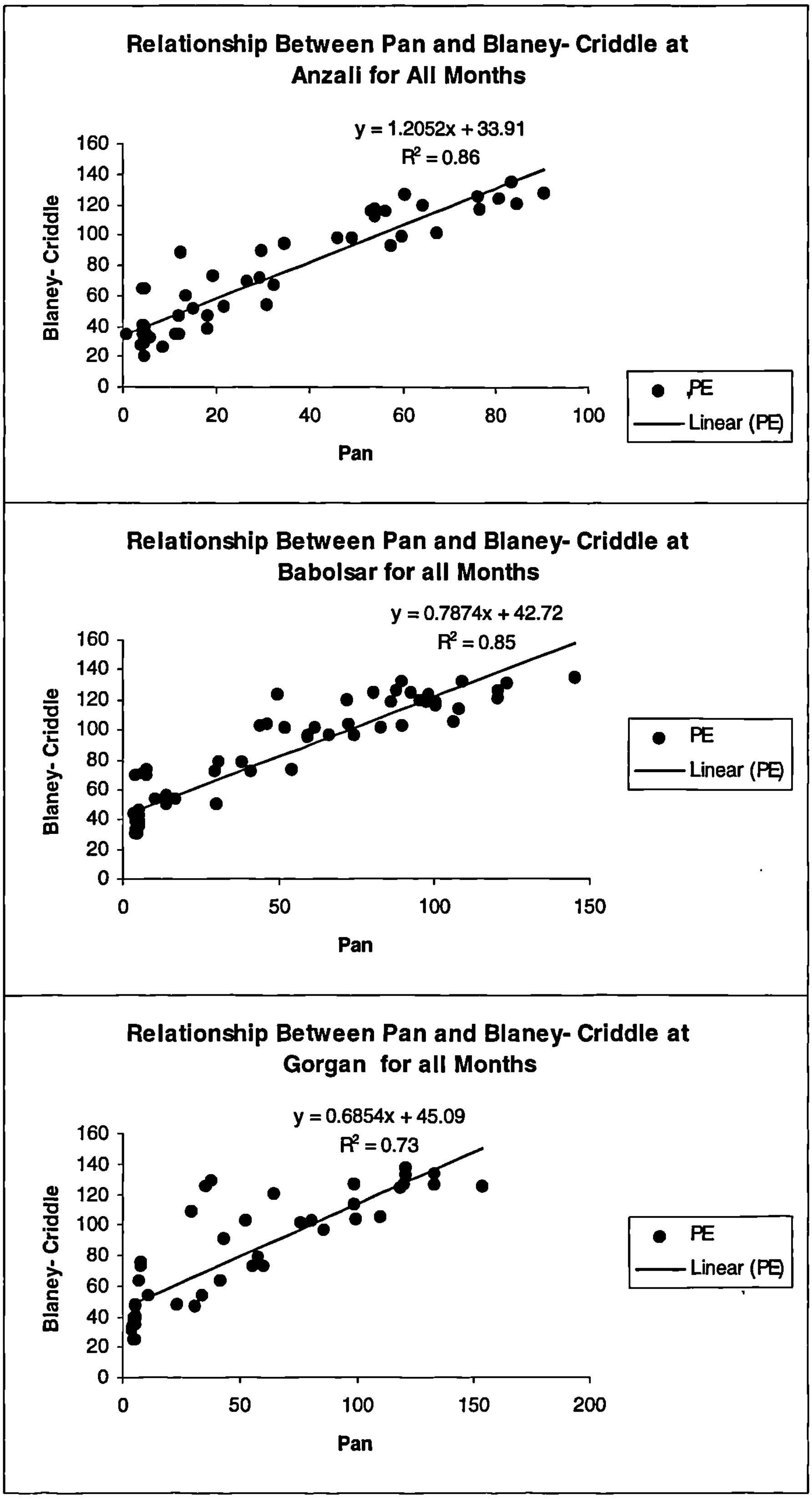


Figure 8.8-1 Relationship Between Pan and the Blaney- Criddle method for individual Stations.

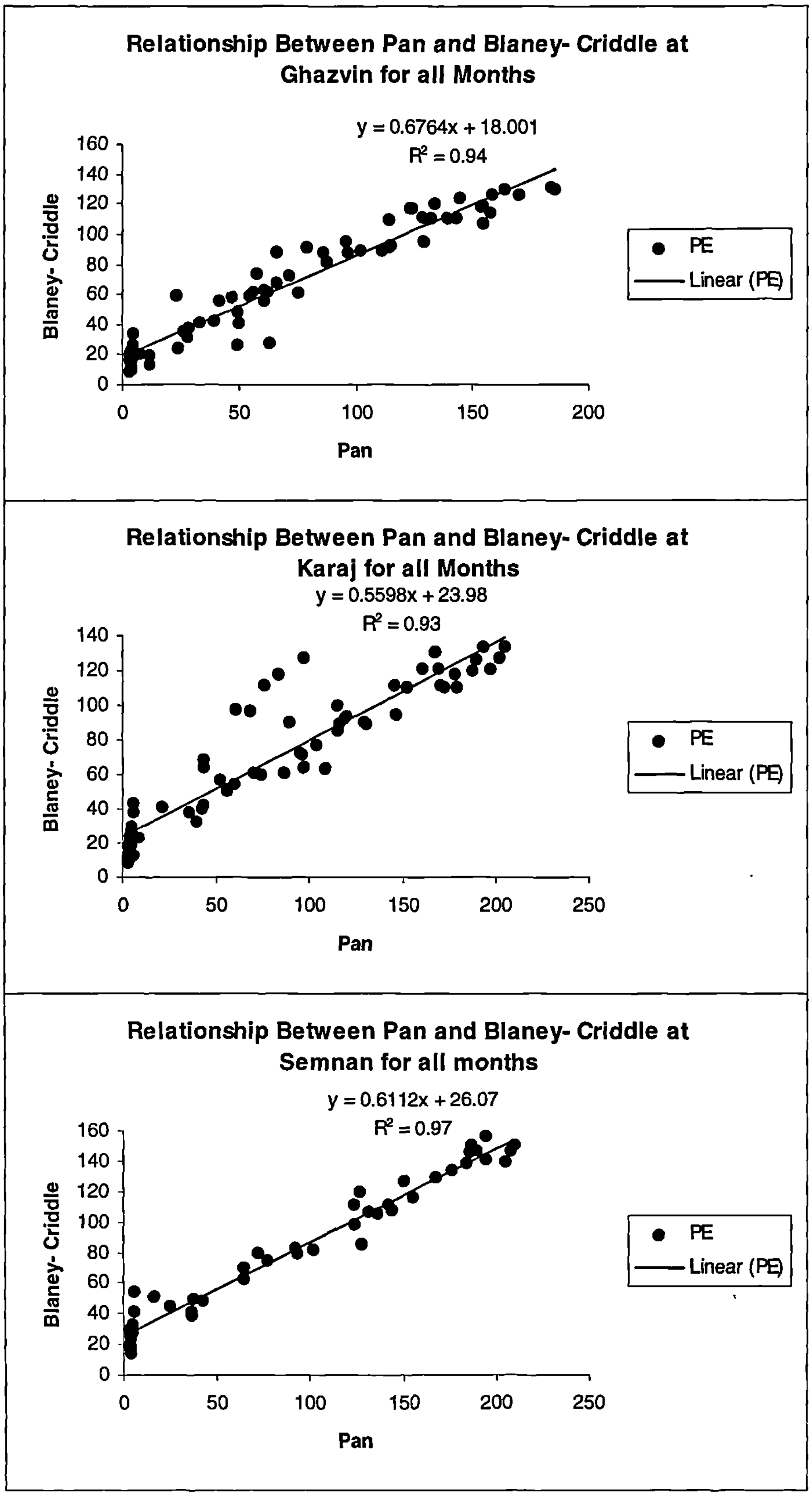


Figure 8.8-2 Relationship Between Pan and the Blaney- Criddle method for individual Stations.

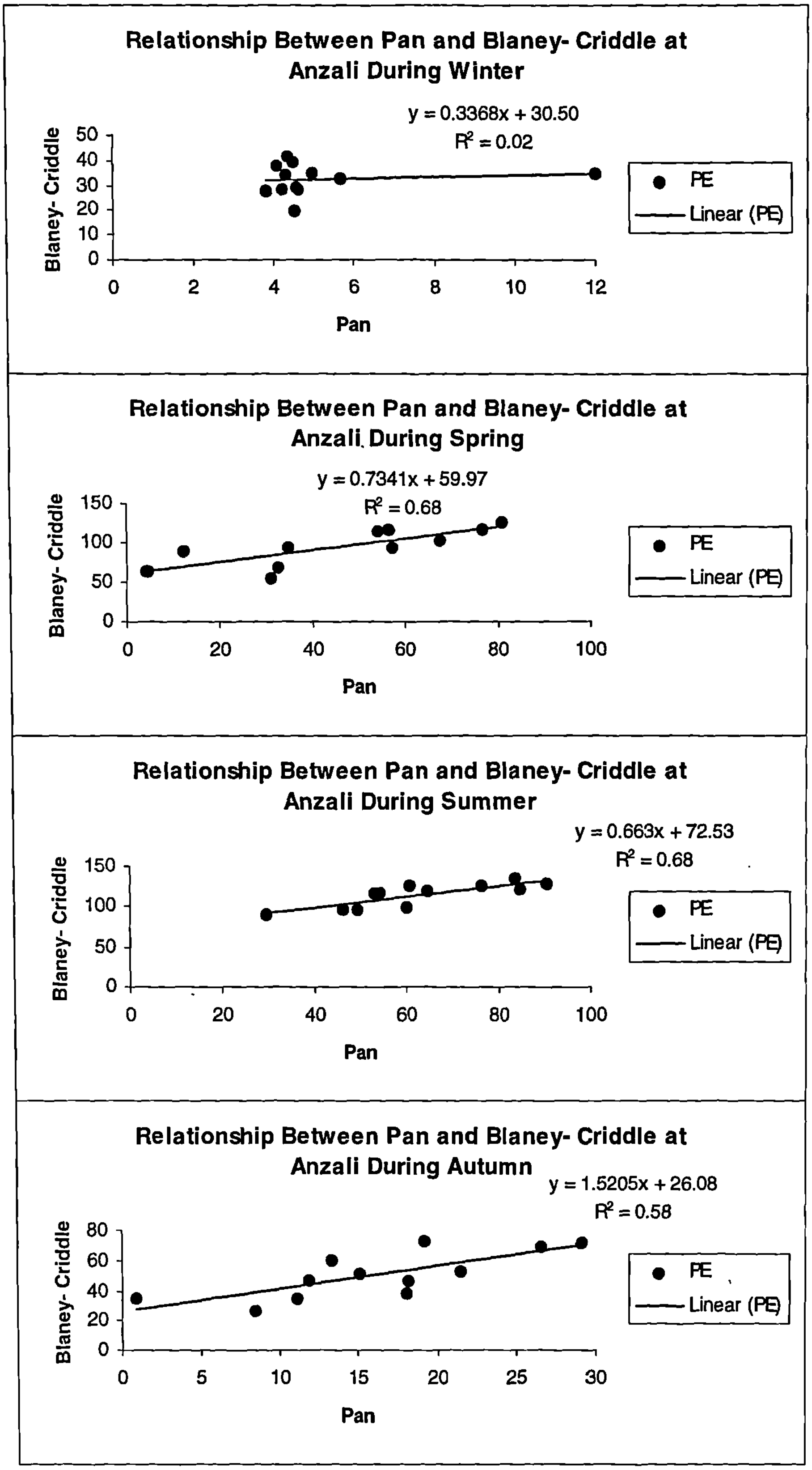


Figure 8.8-3 Relationship Between Pan and the Blaney- Criddle method for Seasons at Anzali Station.

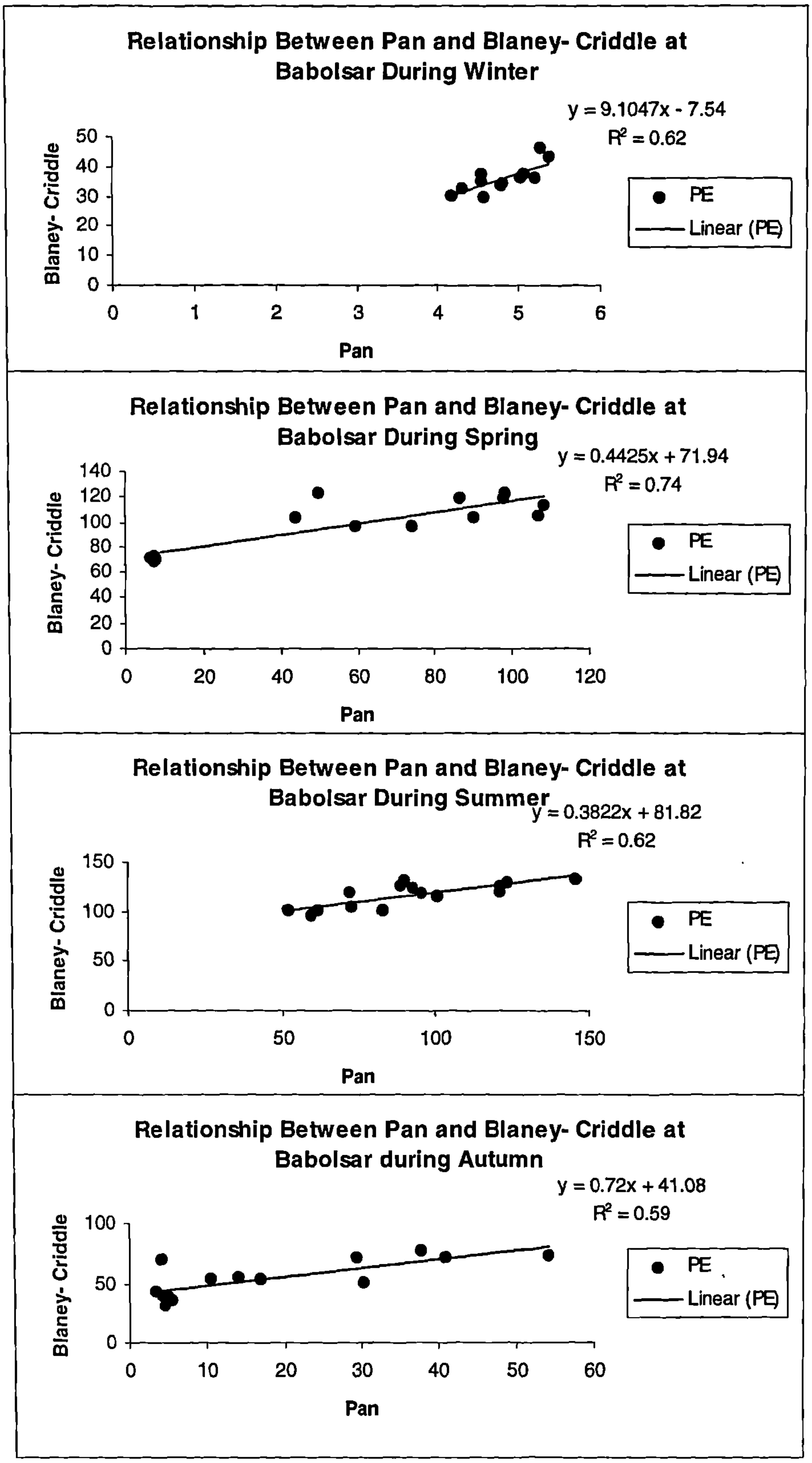


Figure 8.8-4 Relationship Between Pan and the Blaney- Criddle method for Seasons at Babolsar Station.

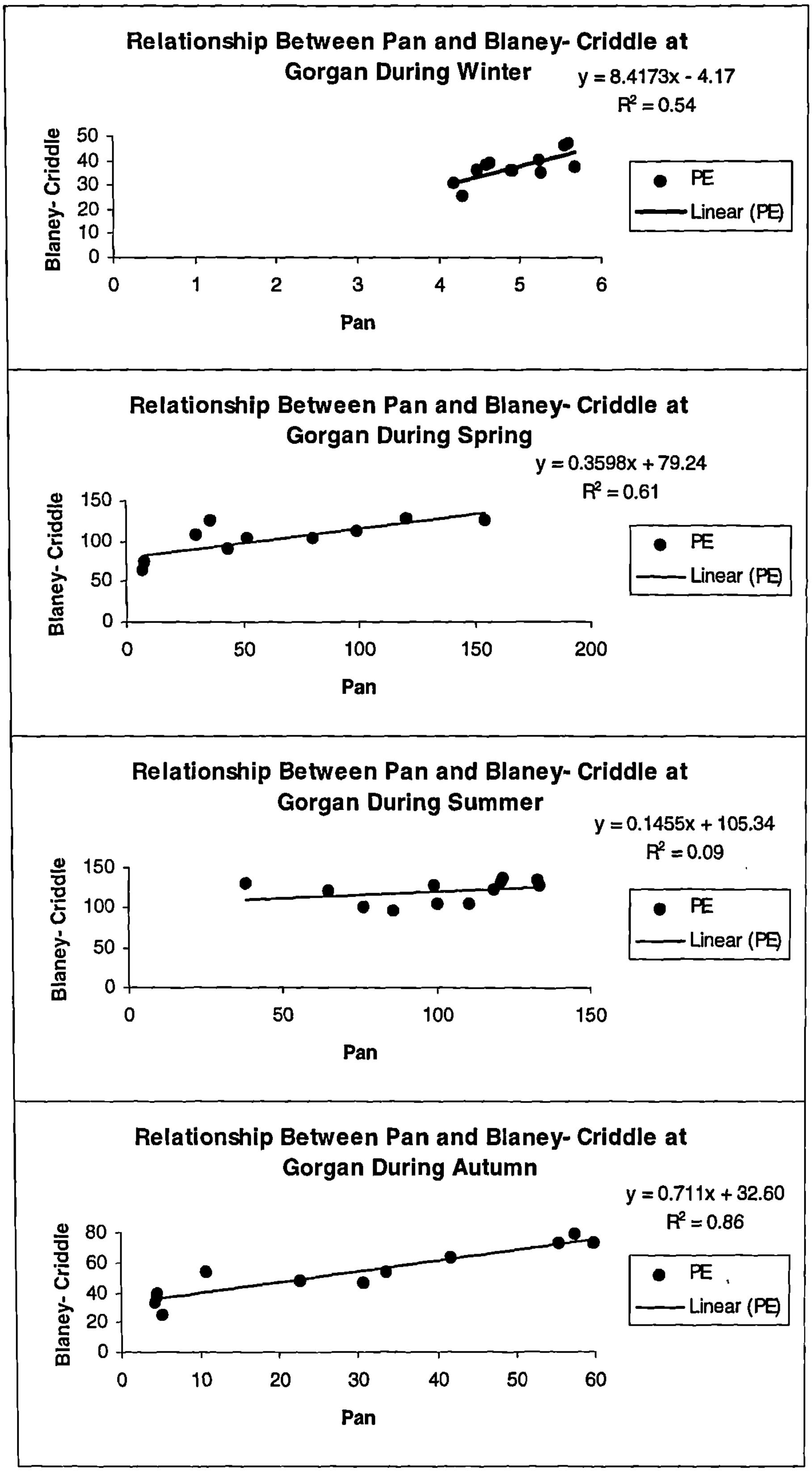


Figure 8.8-5 Relationship Between Pan and the Blaney- Criddle method for Seasons at Gorgan Station.

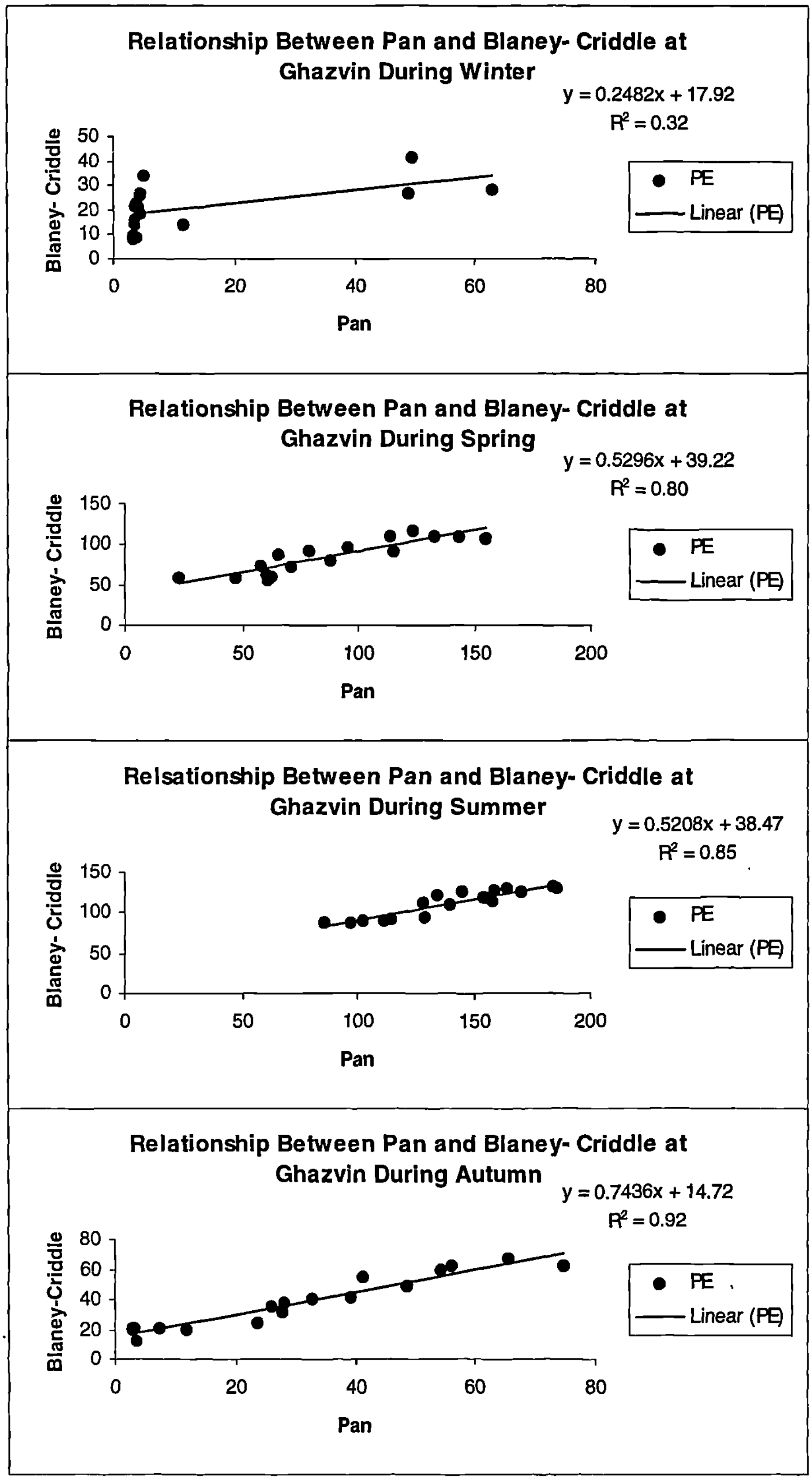


Figure 8.8-6 Relationship Between Pan and the Blaney- Criddle method for Seasons at Ghazvin Station.

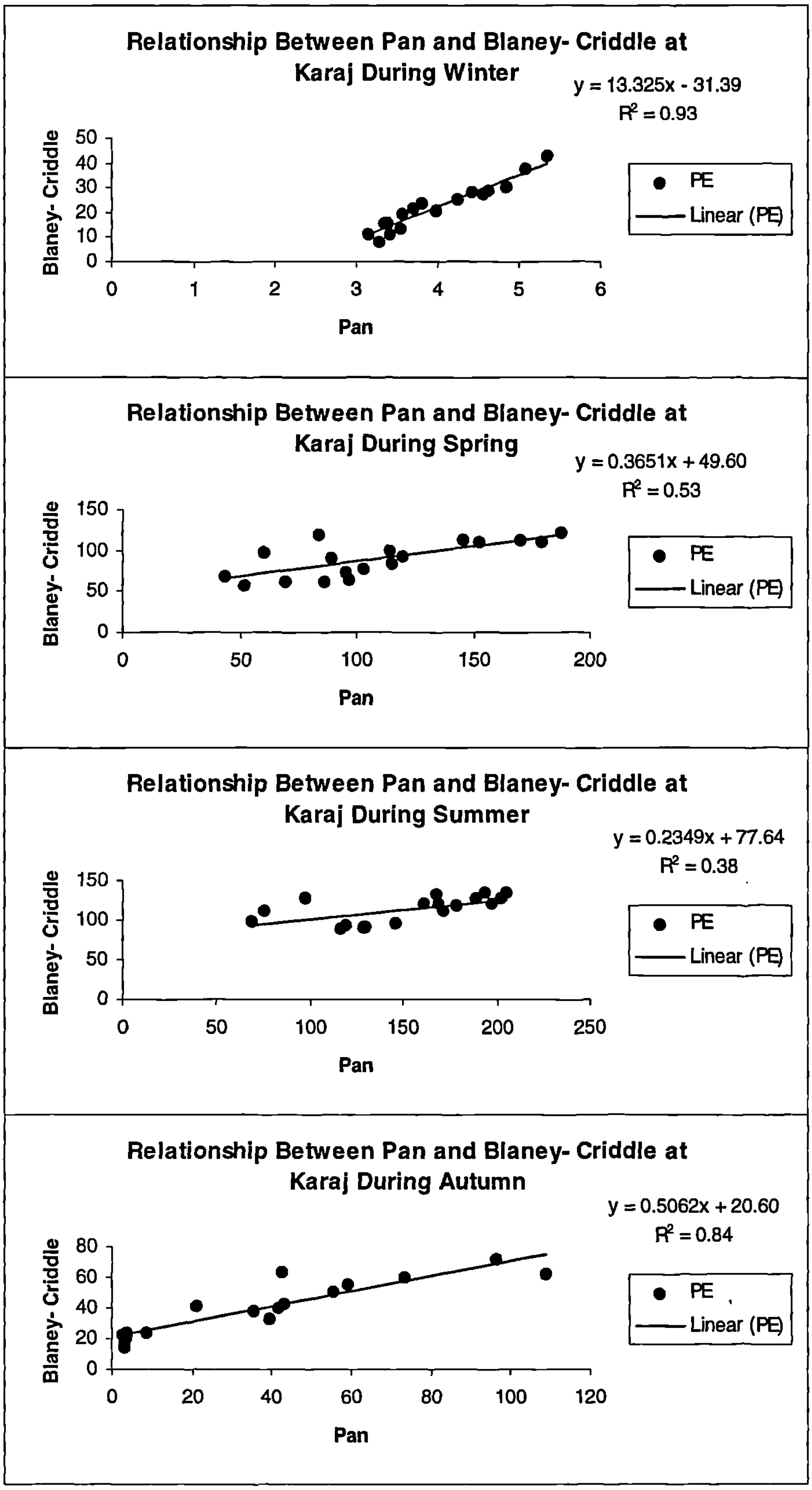


Figure 8.8-7 Relationship Between Pan and the Blaney- Criddle method for Seasons at Karaj Station.

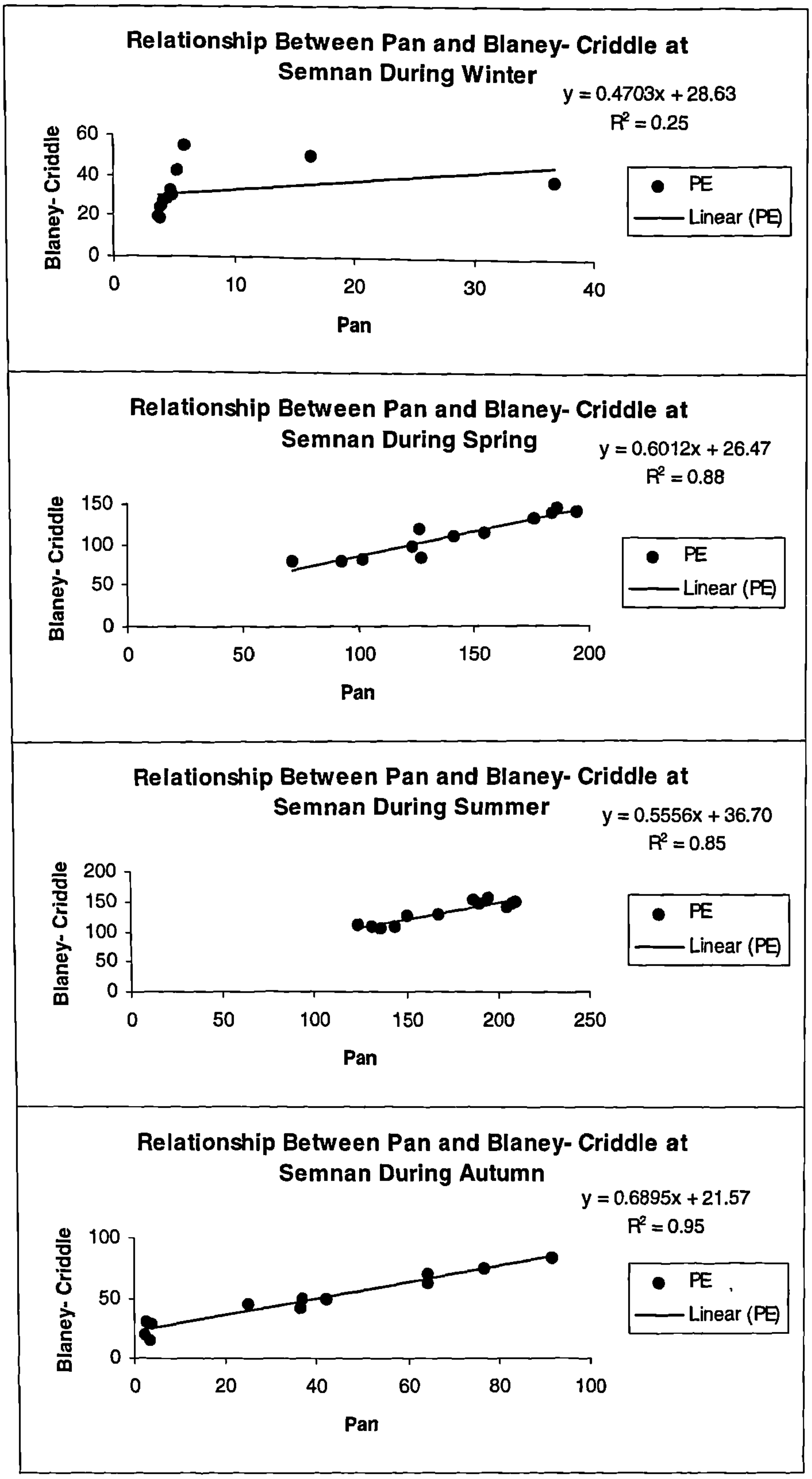


Figure 8.8-8 Relationship Between Pan and the Blaney- Criddle method for Seasons at Semnan Station.

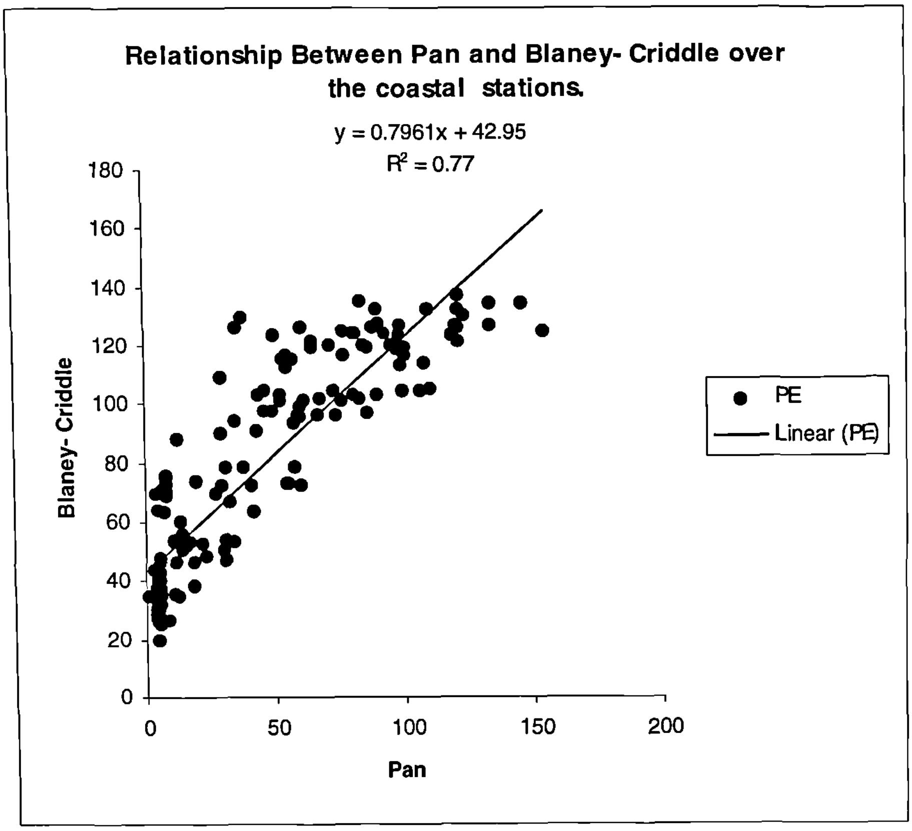


Figure 8.8-9 Relationship Between Pan and the Blaney- Criddle method over the Coastal Stations.

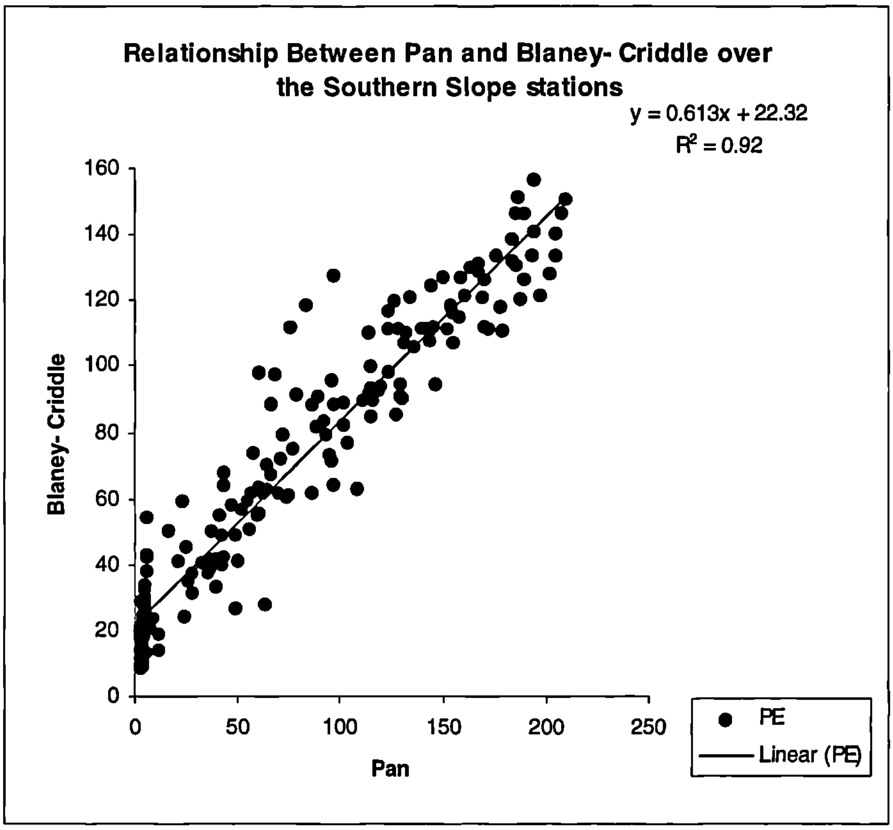


Figure 8.8-10 Relationship Between Pan and the Blaney- Criddle method over the Southern Slope Stations.

8.9 Assessment of Pan and Blaney- Criddle Methods for Potential Evapotranspiration

As has been explained in previous sections, Pan evaporation is likely to be overestimated for determining potential evapotranspiration in respect of lake evaporation due to advection and this effect will be greater in dry areas (southern slopes) or in dry seasons. The overestimation has been corrected using factor 0.8 for coastal stations and 0.75 for southern slopes based upon general recommendation by FAO (1984 and 1986). In areas where climate data are not available, the FAO tables can be used to guide the selection of appropriate pan coefficient values (Chiew *et al.* 1995). Equally the Blaney-Criddle formula selected for this study uses for air temperature and evaporation which was derived empirically in USA. Considering the climatic conditions and especially the seasonal regime, the western areas of USA are similar in many respects to the climate of Iran. Nevertheless the estimates of potential evapotranspiration derived from the Blaney- Criddle formula (equation 3) for the study of the Central Elburz stations.

Monthly analyses results over the Central Elburz stations show the large amount water need for each station. The calculations for Blaney- Criddle potential evaporation over the Central Elburz stations show variation from station to station and month to month. There are differences between coastal area and southern slope stations with regards potential evaporation point of view. The results of potential evapotranspiration calculated by the Blaney-Criddle method have been demonstrated in Table 8.7-1 to 8.7-12. Also these results have been compared with potential evapotranspiration calculated by the pan in Figures 8.7-1 to 8.7-12. The amounts of potential evapotranspiration estimated by the Blaney- Criddle method are more at Anzali, Babolsar and Gorgan (coastal area) but lower than pan for Ghazvin, Karaj and Semnan (southern slopes) stations. The values of potential evapotranspiration estimated by the Pan method are more than that indicated by the Blaney- Criddle method from the May to the September period. However, in the other months (except January, February and March) they appear closer in Ghazvin, Karaj and Semnan (southern slopes) stations. Thus, the critical difference between Blaney- Criddle method and pan evaporation occurs during cold months. Those months are at minimum in potential evaporation by pan they have a high values in the Blaney-Criddle method but the rhythm of water needs in different seasons calculated by both methods is similar. The results from both methods of analysis agree with the peak of water requirement of the crops in these areas. Considering Tables 8.7-1 to 8.7-12 and Figures 8.7-1 to 8.7-12, it seems the Blaney- Criddle it is not a useful method for the coastal area stations due to high errors and affecting by the sea temperature having little response to seasonal change in radiation. In the southern slope stations where the area is more similar to original climate derived the Blaney- Criddle this method is suitable for dry period but it is in error during cold weather that the crop does not need water. Therefore there is 2 main conclusions from this study where ET0 values estimated using the Blaney-Criddle and pan evaporation method for the 6 Central Elburz locations with a different climate conditions are compared. The Blaney-Criddle estimating being consistently higher than Pan method over the coastal stations. But it is less or close in the southern slope stations. Also regression analysis found, there is a relationship between pan and Blaney- Criddle but there is a stronger correlation between pan and Blaney- Criddle in the southern slope than the coastal area stations. It is recommended pan evaporation for the coastal area stations and in southern slopes stations both pan and Blaney- Criddle are useful. But exception the cold months (however in these months there is available enough water for plants) the Blaney-Criddle method is preferred as is previously mentioned the Blaney-Criddle method developed in arid area and can provide good estimates of the values in an arid area.

8.10 Crop Water Requirement

Large increases in irrigated area in unit production and in improved management of rain-fed agriculture will be required. Unless such improvements, it will be difficult to produce the food and fruit required for increasing in region and consequently exporting to other countries. Availability of water and efficiency of its economic use are dominant factors controlling or limiting crop production. A better understanding of water requirement can therefore result in large benefits.

As previous mentioned many factors operate singly or in combination to influence the amount of water required by plants. Their effects are not necessarily constant but may differ with locality and fluctuate from time to time. The more important influences are climate and plant growth characteristics.

It is essential that the water requirements of crops be known in irrigation planning and in soil conservation as well as for individual farms (Soil Conservation Service 1970).

Determining the amount of water requirement crops for different agricultural crops is great importance component for planning in irrigation and agricultural water research management and development, particularly in arid and semi-arid regions such as Iran. In this regard the water requirements of crops can not be discussed without considering the type of crop, and various stages of plant growth. Water requirements for wheat and citrus and their different stages of growth over the Central Elburz stations for each year during 1982 to 1987 by the Blaney- Criddle and Pan methods will be calculated in next pages. In areas for which few or no measurements of water need are available, it is usually necessary to estimate water need of crops from climatological data. The water need for this study has been estimated by the Blaney-Criddle and Pan method which is the best possible formula considering the limited data available in this region.

It is the aim of the present study to determine the pattern of water requirements of crops of wheat, and citrus since which they are the most important cereal and fruit cultivated staple food crops throughout the Central Elburz areas.

Crop water requirements are defined here as the depth of water needed to meet the water loss through evapotranspiration (ET crop) of a disease-free crop, growing in large fields under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment (Doorenbos *et al* 1984). For a given climate crop and crop development stage the maximum evapotranspiration (ET crop) in a period considered is:

$$ET = kc.\ ET0 \quad \text{Where,}$$

ET is maximum evapotranspiration or crop water use,

kc is crop coefficient and

ET0 is reference evapotranspiration. It is calculated by the different methods previously described.

ET crop is the sum of transpiration by the crop and evaporation from the soil surface. Evaporation is important following sowing and during the early growing period may be considerable especially when the soil surface is continually wet from irrigation and rain.

Plant transpiration will be low at emergence of seedling and increases with plant growth to reach a maximum when full ground cover is reached. Maximum evapotranspiration ET (crop) refers to conditions when water is adequate for unrestricted growth and development. Also ET (crop) represents the rate of the maximum evapotranspiration of a healthy crop grown in large fields under optimum agronomic and irrigation management. The level of (ET) has been shown to be related to the evaporative demands of air. The evaporative demand can be expressed as the reference evapotranspiration (ET0) which when calculated predicts the effect of climate on the level of crop evapotranspiration. Therefore to determine ET (crop) several stages are recommended:

a) the effect of climate on crop water requirements is given by the reference evapotranspiration (ET0) which is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (FAO 1984). In this study ET0 for the Central Elburz stations has been calculated by the Blaney-Criddle equation and Pan evaporation measurements.

b) the effect of the crop characteristic on crop water requirements is given by the reference crop coefficient (kc) which presents the relationship between reference (ET0) and crop evapotranspiration (ET crop) when water supply fully meets the water requirements of the crop or:

ET crop = **kc.ET0**. So a crop coefficient is the ratio of reference potential evapotranspiration (ET0) and crop evapotranspiration (ET crop) from a specific crop or plant at a specific time. Crop coefficient is changed with the stages of crop growing.

c) the effects of local conditions and agricultural practices on crop water requirements includes the local effect of variations in climate over time, distance from the sea and altitude, size of fields, advection, soil water availability, irrigation, cultivation methods and practices. However, local field data to determine local crop coefficient are not available for this part of Iran.

8.11 Crop Coefficient k (kc)

As previously explained empirically-determined crop coefficient (kc) can be used to relate (ET0) and maximum crop evapotranspiration (ET crop) when water supply fully meets the water requirements of the crop or **ET** (crop) = **kc. ET0**.

Taha *et al* (1982) defined the crop coefficient (kc) which is a coefficient relating potential to actual evapotranspiration mainly depends on ground cover and canopy roughness. James and wright (1982) explained crop coefficient can be used to estimate actual water use for a particular crop from estimates or measurement of a potential or reference ET.

In selecting the appropriate (kc) value for each period or month in the growing season for a given crop the rate of crop development must be considered. The values of (kc) varies with the crop, its stage of growth, growing season and the prevailing weather conditions. The crop coefficient (k) by Blaney-Criddle method has been modified to crop coefficient (kc) by FAO (1984, 1986).

In Iran a crop can be sown in autumn, winter, spring and summer thus the crop coefficient will vary and depend on location and crop. As previuosly mentioned in the case of wheat it is planted mid-September because of falling temperature and the hope of rainfall soon herein after but active growth does not occur until March- April. Harvesting time is during end of June to August, depends on growing season (growing season date is arbitrary) and differs from year to year. However, planting dates are not the same and differ from one area to another by several days for all stations. Crop coefficient (kc) for given stages of crop development for selected crops and in different climatic conditions are presented in special tables by Doorenbos and Kassem (1986). These have been used because of the lack of local data in the Central Elburz.

For all of crops the (kc) values increase from a low amount at time of crop emergence to a maximum amount during the period when the crop reaches full development and declines as the crop matures. Thus information required on crop coefficient (kc) are:

a) the date of sowing

b) the length of the total growing season;

c) the duration of initial stage (germination to 10 percent ground cover);

d) the duration of crop development stage (from 10 percent to 80 percent ground cover);

e) the duration of the mid-season stage (from 80 percent ground cover to start of ripening);

f) the duration of the late season stage (from start of ripening to harvest). Therefore the crop growing season is divided into four stages as follow:

1) initial stage: germination and early growth when the soil surface is not or is hardly covered by the crop (ground cover 10%);

2) crop development stage: from end of initial stage to attainment of effective full ground cover (ground cover between 70 and 80%);

3) mid season stage: from attainment of effective full ground cover to time of start of maturing as indicated by discolouring of leaves or leaves falling off. For some crops this may extend to very near harvest unless irrigation is not applied at late season and reduction in (ET crop) is induced;

4) late season stage: from end of mid-season stage until full maturity or harvest.

The value of the crop coefficient (kc) varies with the development stages of the select crops. General information on crop development stages (growing season of crops) is given for different crops in FAO by Doorenbos and Pruitt (1984), Doorenbos and Kassem (1986). However, these general figures have been provided by FAO for the Middle East countries such as Lebanon and have been considered suitable for other Middle East countries. In this study values of kc has been derived from the above references for each month of growth, for citrus in coastal area stations (Anzali and Babolsar) for wheat crop (Gorgan, Ghazvin, Karaj and Semnan stations). The crop coefficient (kc) ranged from 0.2 at the beginning of the growing season (September) and increased with the development of the crop to reach a maximum value of 1.1 (May) when the crop was fully grown for wheat and for citrus is 0.45 to 0.55. As previously mentioned crop water requirements of wheat and citrus have been determined by two different methods of the Blaney- Criddle and Pan. The results of calculations demonstrated in Table 8.11-1 to Table 8.11-13. Table 8.11-1 to Table 8.11-13 and Figures 8.11-1 to 8.11-12 indicate that the values of crop potential evapotranspiration estimated by the Blaney-Criddle method are high at the Anzali, Babolsar (Coastal area) stations but lower than the Pan evaporation method (with the exception of some years) for the Ghazvin, Karaj, Semnan (southern slopes) and Gorgan stations. However, the values are very close in these southern slope stations. Also the results of both methods have been compared in Figures 8.11-1 to 8.11-12. Regarding to previous sections, it was recommended both Blaney- Criddle and Pan methods are useful for the southern slope stations due to their local conditions with the applications of these methods. In this regard the analysis results indicate that the values of both method are closer in southern slope than coastal area stations. Also the calculations for both Blaney- Criddle and Pan methods show variation from one station to another. Consequently the values of crop water requirements are different for the stages of crop growth. The rhythm of crop water requirements are different in the coastal and southern slope stations. The peak water requirement of the crops at Gorgan, Ghavin, Karaj and Semnan stations is during May but at Anzali and Babolsar is July. This is due to differences in the types of crops, the methods of estimating, the amount of the temperature during the season of crop cultivation.

Table 8.11-1 Monthly Crop Potential Evapotranspiration (Et crop) by the Blaney Criddle over the Central Elburz Stations.

Stations	Years	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	1984	22.8	14.6	23.8	36.2	48.0	55.2	65.3	56.4	48.3	36.8	30.0	17.4
	1985	18.7	19.6	18.2	36.2	54.8	60.3	61.3	58.2	48.3	35.9	30.3	21.7
	1986	22.6	19.4	21.3	37.6	51.2	56.4	61.9	58.6	49.0	37.5	27.1	21.5
	1987	26.3	21.4	22.8	31.1	50.7	57.0	60.7	57.0	44.8	31.4	27.1	23.2
Babolsar	1982	18.0	16.5	21.6	36.6	48.2	51.4	58.7	52.4	45.6	31.3	21.9	16.0
	1983	16.6	19.3	23.3	35.6	52.3	53.4	60.4	54.7	42.9	32.7	27.9	19.6
	1984	18.0	18.6	18.2	35.0	51.6	55.4	56.9	53.9	45.4	32.4	26.7	19.6
	1985	18.0	18.6	18.2	35.0	51.6	55.4	56.9	53.9	45.4	32.4	26.7	19.6
	1986	20.6	19.0	18.8	34.6	48.0	53.6	59.5	55.9	46.8	35.1	25.3	17.9
	1987	20.6	19.0	18.8	34.6	48.0	53.6	59.5	55.9	46.8	35.1	25.3	17.9
Gorgan	1984	7.6	5.1	13.9	60.5	99.7	22.7	27.5	24.2	20.2	21.8	16.0	5.0
	1985	6.2	7.1	12.2	59.9	120	25.2	25.9	24.7	20.9	21.7	16.2	7.5
	1986	7.3	7.0	11.4	58.0	113	25.0	26.8	25.4	21.0	23.5	14.0	6.7
	1987	7.8	7.2	14.2	50.8	114	25.4	26.5	25.4	19.4	19.1	14.5	8.0
Ghazvin	1982	2.8	2.8	8.1	57.6	100	22.1	25.2	22.2	17.9	16.4	7.3	4.1
	1983	4.5	1.9	8.4	44.7	97.2	21.9	26.0	24.1	17.7	18.5	12.5	3.8
	1984	3.3	1.7	12.3	49.2	80.9	22.0	26.1	23.7	17.8	17.7	10.5	3.9
	1985	1.8	3.7	7.8	50.5	102	23.4	25.4	22.3	18.9	18.4	12.1	4.1
	1986	3.2	4.3	7.8	47.3	89.3	21.4	26.2	22.9	18.2	20.1	9.4	2.3
	1987	4.3	5.3	10.2	46.3	105	23.4	24.9	23.5	17.7	14.6	11.2	4.2
Karaj	1982	3.0	2.6	9.0	58.3	103	22.1	25.3	22.2	18.0	16.4	7.1	3.6
	1983	4.3	2.2	8.6	45.3	99.7	22.4	26.6	24.1	17.8	18.8	12.7	3.9
	1984	3.2	1.7	12.9	51.2	84.4	22.2	26.2	24.3	18.4	18.0	11.3	3.5
	1985	2.3	4.1	8.6	54.4	108	23.6	25.5	22.4	19.4	19.2	12.4	4.5
	1986	3.9	5.0	8.3	49.2	93.3	22.3	26.6	23.5	18.9	21.4	9.9	2.8
	1987	4.8	5.6	11.4	49.2	110	24.1	25.5	24.3	18.1	15.1	12.0	4.7
Semnan	1984	4.7	3.6	16.4	65.7	108	27.7	30.0	29.3	21.4	21.1	13.6	2.9
	1985	3.9	5.6	12.6	68.0	127	29.2	31.3	25.3	22.3	22.5	15.0	5.9
	1986	5.0	6.0	11.6	63.1	122	26.7	30.2	25.8	21.1	25.0	12.5	3.8
	1987	5.5	6.6	15.2	63.5	132	28.1	29.3	28.0	21.5	18.9	14.7	5.8

Table 8.11-2 Monthly Crop Potential Evapotranspiration (Et crop) by Pan Method over the Central Elburz Stations.

Stations	Years	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	1984	2.7	2.5	2.2	2.3	6.1	24.3	37.5	23.9	20.7	13.1	7.5	4.2
	1985	2.1	2.5	2.1	21.0	33.7	36.4	27.2	29.0	22.1	11.9	10.8	5.5
	1986	6.6	2.5	2.2	16.2	17.3	25.4	40.7	38.0	26.9	8.6	5.9	0.5
	1987	2.4	3.1	2.0	15.4	28.7	34.5	34.3	24.3	13.2	6.0	9.1	9.0
Babolsar	1982	2.4	2.5	2.7	3.8	36.9	48.7	55.4	45.1	37.2	1.9	1.6	2.2
	1983	2.3	2.5	2.6	3.1	53.3	43.9	65.5	54.4	26.7	24.4	6.9	2.2
	1984	2.4	2.6	2.5	3.7	22.0	22.3	54.4	32.2	27.7	18.4	8.4	2.2
	1985	2.4	2.6	2.6	3.8	44.9	44.1	39.7	42.8	23.4	13.2	5.2	2.5
	1986	2.5	2.7	2.5	3.7	29.6	38.7	40.3	41.6	32.6	17.0	15.1	2.7
	1987	2.5	2.7	2.5	3.7	33.2	45.3	49.2	36.3	20.7	13.8	7.0	2.6
Gorgan	1984	0.9	0.9	1.7	6.3	47.5	19.8	24.3	12.9	15.2	16.6	10.0	1.0
	1985	0.8	1.0	1.6	6.3	32.4	7.1	7.5	23.7	20.0	17.9	3.2	0.9
	1986	0.9	1.1	1.7	6.0	57.3	30.8	26.6	26.6	22.1	17.2	9.2	0.8
	1987	0.9	1.0	1.7	5.6	88.6	24.1	24.2	19.8	17.2	12.5	6.8	0.9
Ghazvin	1982	2.3	0.7	14.7	57.0	86.5	28.7	34.0	27.9	22.2	12.4	7.1	0.7
	1983	0.8	0.7	18.8	48.6	72.4	22.8	32.8	26.9	17.2	16.9	11.8	2.3
	1984	0.7	0.7	14.9	49.9	63.6	26.5	37.2	30.9	20.4	16.3	7.8	0.6
	1985	0.8	0.9	1.4	48.2	126.6	24.8	31.8	25.7	25.9	22.5	9.8	1.5
	1986	0.7	0.8	1.3	18.2	96.5	31.0	36.8	31.6	22.9	19.7	8.3	0.7
	1987	0.7	0.9	1.5	37.7	105.0	24.7	29.0	30.8	19.3	14.6	8.4	0.6
Karaj	1982	0.7	0.7	1.5	76.1	131.8	35.9	37.9	34.4	26.0	17.7	2.5	0.7
	1983	0.7	0.7	1.4	41.4	98.4	29.2	38.8	33.9	23.3	32.6	12.9	0.7
	1984	0.7	0.7	1.6	77.7	113.3	30.5	33.6	32.3	23.8	22.0	10.6	0.7
	1985	0.6	0.8	1.4	34.8	66.4	16.7	19.4	15.2	13.7	12.8	6.4	0.5
	1986	0.7	0.9	1.4	55.7	126.6	34.1	41.0	35.7	29.2	28.9	11.8	0.6
	1987	0.8	0.9	1.5	68.7	126.8	37.5	40.4	39.5	25.8	16.7	12.5	0.7
Semnan	1984	0.8	0.8	1.8	81.6	136.0	36.8	42.0	37.9	26.2	19.3	7.5	0.7
	1985	0.7	0.9	1.6	101.6	170.3	37.2	38.9	30.0	24.7	23.0	11.1	0.5
	1986	0.8	1.0	11.0	57.2	155.8	35.2	37.3	33.6	27.2	27.5	10.9	0.5
	1987	0.8	0.9	5.0	74.3	139	39.0	41.7	41.0	28.8	19.4	12.7	0.8

Table 8.11-3 Anzali Crop Potential Evapotranspiration (Et crop) for citrus by the Blaney-Criddle method.

Years	Months	K	ET0	ET
1984	Jan	0.55	34.81	22.80
	Feb	0.55	19.92	14.61
	Mar	0.5	39.38	23.75
	Apr	0.5	64.25	36.19
	May	0.5	87.91	48.02
	June	0.45	112.71	55.19
	July	0.45	135.06	65.24
	Aug	0.45	115.45	56.42
	Sep	0.45	97.36	48.28
	Oct	0.45	71.93	36.84
	Nov	0.5	51.76	29.94
	Dec	0.5	26.69	17.41
1985	Jan	0.55	27.28	18.66
	Feb	0.55	28.92	19.56
	Mar	0.5	28.33	18.23
	Apr	0.5	64.25	36.19
	May	0.5	101.51	54.82
	June	0.45	124.08	60.30
	July	0.45	126.29	61.30
	Aug	0.45	119.35	58.18
	Sep	0.45	97.36	48.28
	Oct	0.45	69.79	35.88
	Nov	0.5	52.38	30.25
	Dec	0.5	35.21	21.67

Table 8.11-4 Anzali Crop Potential Evapotranspiration (Et crop) for citrus by the Blaney-Criddle method (con).

Years	Months	K	ETO	ET
1986	Jan	0.55	34.5	22.63
	Feb	0.55	28.61	19.39
	Mar	0.5	34.42	21.27
	Apr	0.5	67.1	37.61
	May	0.5	94.26	51.19
	June	0.45	115.44	56.42
	July	0.45	127.67	61.92
	Aug	0.45	120.21	58.57
	Sep	0.45	98.89	48.97
	Oct	0.45	73.36	37.48
	Nov	0.5	46.15	27.14
	Dec	0.5	34.91	21.52
1987	Jan	0.55	41.09	26.26
	Feb	0.55	32.33	21.44
	Mar	0.5	37.47	22.80
	Apr	0.5	54.09	31.11
	May	0.5	93.35	50.74
	June	0.45	116.80	57.03
	July	0.45	124.90	60.67
	Aug	0.45	116.75	57.01
	Sep	0.45	89.70	44.83
	Oct	0.45	59.81	31.38
	Nov	0.5	46.15	27.14
	Dec	0.5	38.26	23.19

Table 8.11-5 Babolsar crop Potential Evapotranspiration (Et crop) for citrus estimated by the Blaney-Criddle method.

Years	Months	K	ETO	Et
1982	Jan	0.55	32.73	18.00
	Feb	0.55	30.08	16.54
	Mar	0.5	43.24	21.62
	Apr	0.5	73.25	36.62
	May	0.5	96.45	48.22
	June	0.45	114.15	51.37
	July	0.45	130.48	58.72
	Aug	0.45	116.38	52.37
	Sep	0.45	101.35	45.61
	Oct	0.45	69.48	31.26
	Nov	0.5	43.87	21.93
	Dec	0.5	32.02	16.01
1983	Jan	0.55	30.17	16.59
	Feb	0.55	35.09	19.30
	Mar	0.5	46.67	23.34
	Apr	0.5	71.22	35.61
	May	0.5	104.52	52.26
	Jun	0.45	118.64	53.39
	July	0.45	134.14	60.36
	Aug	0.45	121.54	54.69
	Sep	0.45	95.24	42.86
	Oct	0.45	72.70	32.72
	Nov	0.5	55.88	27.94
	Dec	0.5	39.16	19.58
1984	Jan	0.55	32.73	18.00
	Feb	0.55	33.84	18.61
	Mar	0.5	36.37	18.18
	Apr	0.5	70.01	35.01
	May	0.5	103.17	51.59
	June	0.45	123.13	55.41
	July	0.45	126.37	56.87
	Aug	0.45	119.82	53.92
	Sep	0.45	100.97	45.44
	Oct	0.45	71.99	32.39
	Nov	0.5	53.35	26.68
	Dec	0.5	39.16	19.58

Table 8.11-6 Babolsar Crop Potential Evapotranspiration (Et crop) for citrus estimated by the Blaney-Criddle method (co).

Years	Months	K	ETO	Et
1985	Jan	0.55	32.73	18.00
	Feb	0.55	33.84	18.61
	Mar	0.5	36.37	18.18
	Apr	0.5	70.01	35.01
	May	0.5	103.17	51.59
	June	0.45	123.13	55.41
	July	0.45	126.37	56.87
	Aug	0.45	119.82	53.92
	Sep	0.45	100.97	45.44
	Oct	0.45	71.99	32.39
	Nov	0.5	53.35	26.68
	Dec	0.5	39.16	19.58
1986	Jan	0.55	37.52	20.64
	Feb	0.55	34.46	18.96
	Mar	0.5	37.51	18.76
	Apr	0.5	69.20	34.60
	May	0.5	96.00	48.00
	June	0.45	119.09	53.59
	July	0.45	132.31	59.54
	Aug	0.45	124.12	55.85
	Sep	0.45	104.03	46.81
	Oct	0.45	78.09	35.14
	Nov	0.5	50.51	25.25
	Dec	0.5	35.75	17.87
1987	Jan	0.55	37.52	20.64
	Feb	0.55	34.46	18.96
	Mar	0.5	37.51	18.76
	Apr	0.5	69.20	34.60
	May	0.5	96.00	48.00
	June	0.45	119.09	53.59
	July	0.45	132.31	59.54
	Aug	0.45	124.12	55.85
	Sep	0.45	104.03	46.81
	Oct	0.45	78.09	35.14
	Nov	0.5	50.51	25.25
	Dec	0.5	35.75	17.87

Table 8.11-7 Gorgan Crop Potential Evapotranspiration (Et crop) for wheat estimated by the Blaney-Criddle method

Years	Months	K	ETO	Et
1984	Jan	0.2	38.16	7.63
	Feb	0.2	25.69	5.14
	Mar	0.3	46.29	13.89
	Apr	0.8	75.67	60.54
	May	1.1	90.62	99.68
	Jun	0.2	113.25	22.65
	July	0.2	137.33	27.47
	Aug	0.2	121.11	24.22
	Sep	0.2	100.97	20.19
	Oct	0.3	72.70	21.81
	Nov	0.3	53.35	16.01
	Dec	0.2	25.20	5.04
1985	Jan	0.2	30.81	6.16
	Feb	0.2	35.72	7.14
	Mar	0.3	40.57	12.17
	Apr	0.8	74.86	59.89
	May	1.1	109.00	119.90
	June	0.2	125.83	25.17
	July	0.2	129.57	25.91
	Aug	0.2	123.69	24.74
	Sep	0.2	104.41	20.88
	Oct	0.3	72.35	21.70
	Nov	0.3	53.99	16.20
	Dec	0.2	37.30	7.46
1986	Jan	0.2	36.24	7.25
	Feb	0.2	35.09	7.02
	Mar	0.3	37.89	11.37
	Apr	0.8	72.44	57.95
	May	1.1	102.72	113.00
	June	0.2	124.93	24.99
	July	0.2	134.14	26.83
	Aug	0.2	127.12	25.42
	Sep	0.2	104.79	20.96
	Oct	0.3	78.44	23.53
	Nov	0.3	46.71	14.01
	Dec	0.2	33.57	6.71
1987	Jan	0.2	39.12	7.82
	Feb	0.2	36.03	7.21
	Mar	0.3	47.43	14.23
	Apr	0.8	63.54	50.83
	May	1.1	103.17	113.49
	June	0.2	127.18	25.44
	July	0.2	132.31	26.46
	Aug	0.2	127.12	25.42
	Sep	0.2	96.77	19.35
	Oct	0.3	63.74	19.12
	Nov	0.3	48.29	14.49
	Dec	0.2	39.78	7.96

Table 8.11-8 Ghazvin Crop Potential Evapotranspiration (Et crop) for wheat estimated by the Blaney-Criddle method.

Years	Months	K	ET0	Et
1982	Jan	0.2	13.88	2.78
	Feb	0.2	14.09	2.82
	Mar	0.3	26.83	8.05
	Apr	0.8	72.03	57.63
	May	1.1	91.07	100.18
	June	0.2	110.55	22.11
	July	0.2	125.92	25.18
	Aug	0.2	110.80	22.16
	Sep	0.2	89.51	17.90
	Oct	0.3	54.77	16.43
	Nov	0.3	24.26	7.28
	Dec	0.2	20.54	4.11
1983	Jan	0.2	22.50	4.50
	Feb	0.2	9.38	1.88
	Mar	0.3	27.97	8.39
	Apr	0.8	55.85	44.68
	May	1.1	88.38	97.22
	June	0.2	109.66	21.93
	July	0.2	130.03	26.01
	Aug	0.2	120.68	24.14
	Sep	0.2	88.36	17.67
	Oct	0.3	61.58	18.47
	Nov	0.3	41.65	12.50
	Dec	0.2	18.99	3.80
1984	Jan	0.2	16.44	3.29
	Feb	0.2	8.44	1.69
	Mar	0.3	40.95	12.28
	Apr	0.8	61.52	49.21
	May	1.1	73.58	80.94
	June	0.2	110.11	22.02
	July	0.2	130.48	26.10
	Aug	0.2	118.53	23.71
	Sep	0.2	88.74	17.75
	Oct	0.3	59.07	17.72
	Nov	0.3	35.01	10.50
	Dec	0.2	19.61	3.92

Table 8.11-9 Ghazvin Crop Potential Evapotranspiration (Et crop) for wheat estimated by the Blaney-Criddle method (co).

Years	Months	K	ET0	Et
1985	Jan	0.2	9.09	1.82
	Feb	0.2	18.48	3.70
	Mar	0.3	26.06	7.82
	Apr	0.8	63.13	50.51
	May	1.1	92.86	102.15
	June	0.2	116.84	23.37
	July	0.2	126.83	25.37
	Aug	0.2	111.23	22.25
	Sep	0.2	94.47	18.89
	Oct	0.3	61.22	18.37
	Nov	0.3	40.39	12.12
	Dec	0.2	20.54	4.11
1986	Jan	0.2	16.12	3.22
	Feb	0.2	21.61	4.32
	Mar	0.3	26.06	7.82
	Apr	0.8	59.09	47.27
	May	1.1	81.21	89.33
	June	0.2	106.96	21.39
	July	0.2	131.40	26.28
	Aug	0.2	114.67	22.93
	Sep	0.2	91.04	18.21
	Oct	0.3	66.96	20.09
	Nov	0.3	31.22	9.36
	Dec	0.2	11.54	2.31
1987	Jan	0.2	21.23	4.25
	Feb	0.2	26.63	5.33
	Mar	0.3	34.08	10.22
	Apr	0.8	57.88	46.30
	May	1.1	95 55	105.11
	June	0.2	116.84	23.37
	July	0.2	124.55	24.91
	Aug	0.2	117.67	23.53
	Sep	0.2	88.36	17.67
	Oct	0.3	48.67	14.60
	Nov	0.3	37.22	11.17
	Dec	0.2	20.85	4.17

Table 8.11-10 Karaj Crop Potential Evapotranspiration (Et crop) for wheat estimated by the Blaney-Criddle method.

Years	Months	K	ET0	Et
1982	Jan	0.2	15.16	3.03
	Feb	0.2	13.15	2.63
	Mar	0.3	29.88	8.96
	Apr	0.8	72.84	58.27
	May	1.1	93.31	102.64
	June	0.2	110.55	22.11
	July	0.2	126.37	25.27
	Aug	0.2	110.80	22.16
	Sep	0.2	89.89	17.98
	Oct	0.3	54.77	16.43
	Nov	0.3	23.63	7.09
	Dec	0.2	17.75	3.55
1983	Jan	0.2	21.55	4.31
	Feb	0.2	10.95	2.19
	Mar	0.3	28.74	8.62
	Apr	0.8	56.66	45.33
	May	1.1	90.62	99.68
	June	0.2	111.90	22.38
	July	0.2	133.22	26.64
	Aug	0.2	120.68	24.14
	Sep	0.2	89.13	17.83
	Oct	0.3	62.66	18.80
	Nov	0.3	42.28	12.69
	Dec	0.2	19.61	3.92
1984	Jan	0.2	15.80	3.16
	Feb	0.2	8.44	1.69
	Mar	0.3	42.86	12.86
	Apr	0.8	63.94	51.15
	May	1.1	76.72	84.39
	June	0.2	111.00	22.20
	July	0.2	130.94	26.19
	Aug	0.2	121.54	24.31
	Sep	0.2	92.18	18.44
	Oct	0.3	60.15	18.04
	Nov	0.3	37.54	11.26
	Dec	0.2	17.44	3.49

Table 8.11-11 Karaj Crop Potential Evapotranspiration (Et crop) for wheat estimated by the Blaney-Criddle method (co).

Years	Months	K	ETO	Et
	Jan	0.2	11.32	2.26
	Feb	0.2	20.36	4.07
	Mar	0.3	28.74	8.62
	Apr	0.8	67.99	54.39
1985	May	1.1	97.79	107.57
	June	0.2	118.19	23.64
	July	0.2	127.29	25.46
	Aug	0.2	112.09	22.42
	Sep	0.2	97.15	19.43
	Oct	0.3	64.09	19.23
	Nov	0.3	41.34	12.40
	Dec	0.2	22.71	4.54
	Jan	0.2	19.31	3.86
	Feb	0.2	24.75	4.95
	Mar	0.3	27.59	8.28
1986	Apr	0.8	61.52	49.21
	May	1.1	84.79	93.27
	June	0.2	111.45	22.29
	July	0.2	133.22	26.64
	Aug	0.2	117.67	23.53
	Sep	0.2	94.47	18.89
	Oct	0.3	71.27	21.38
	Nov	0.3	33.11	9.93
	Dec	0.2	14.03	2.81
	Jan	0.2	23.78	4.76
	Feb	0.2	27.88	5.58
1987	Mar	0.3	37.89	11.37
	Apr	0.8	61.52	49.21
	May	1.1	99.59	109.55
	Jun	0.2	120.44	24.09
	July	0.2	127.74	25.55
	Aug	0.2	121.54	24.31
	Sep	0.2	90.65	18.13
	Oct	0.3	50.46	15.14
	Nov	0.3	40.07	12.02
	Dec	0.2	23.65	4.73

Table 8.11-12 Semnan Crop Potential Evapotranspiration (Et crop) for wheat estimated by the Blaney-Criddle method.

Years	Months	K	ETO	Et
1984	Jan	0.2	23.46	4.69
	Feb	0.2	18.16	3.63
	Mar	0.3	54.68	16.41
	Apr	0.8	82.14	65.71
	May	1.1	97.79	107.57
	June	0.2	138.41	27.68
	July	0.2	150.11	30.02
	Aug	0.2	146.45	29.29
	Sep	0.2	107.08	21.42
	Oct	0.3	70.19	21.06
	Nov	0.3	45.45	13.63
	Dec	0.2	14.34	2.87
1985	Jan	0.2	19.31	3.86
	Feb	0.2	27.88	5.58
	Mar	0.3	42.09	12.63
	Apr	0.8	84.97	67.98
	May	1.1	115.73	127.30
	June	0.2	146.04	29.21
	July	0.2	156.51	31.30
	Aug	0.2	126.69	25.34
	Sep	0.2	111.28	22.26
	Oct	0.3	74.86	22.46
	Nov	0.3	49.87	14.96
	Dec	0.2	29.23	5.85

Table 8.11-13 Semnan Crop Potential Evapotranspiration (Et crop) for wheat estimated by the Blaney-Criddle method (co).

Years	Months	K	ETO	Et
1986	Jan	0.2	25.06	5.01
	Feb	0.2	30.08	6.02
	Mar	0.3	38.66	11.60
	Apr	0.8	78.91	63.13
	May	1.1	111.24	122.37
	June	0.2	133.47	26.69
	July	0.2	151.03	30.21
	Aug	0.2	128.84	25.77
	Sep	0.2	105.55	21.11
	Oct	0.3	83.47	25.04
	Nov	0.3	41.65	12.50
	Dec	0.2	18.99	3.80
1987	Jan	0.2	27.62	5.52
	Feb	0.2	32.90	6.58
	Mar	0.3	50.49	15.15
	Apr	0.8	79.31	63.45
	May	1.1	119.76	131.74
	Jun	0.2	140.65	28.13
	July	0.2	146.46	29.29
	Aug	0.2	140.01	28.00
	Sep	0.2	107.46	21.49
	Oct	0.3	63.02	18.91
	Nov	0.3	48.93	14.68
	Dec	0.2	28.92	5.78

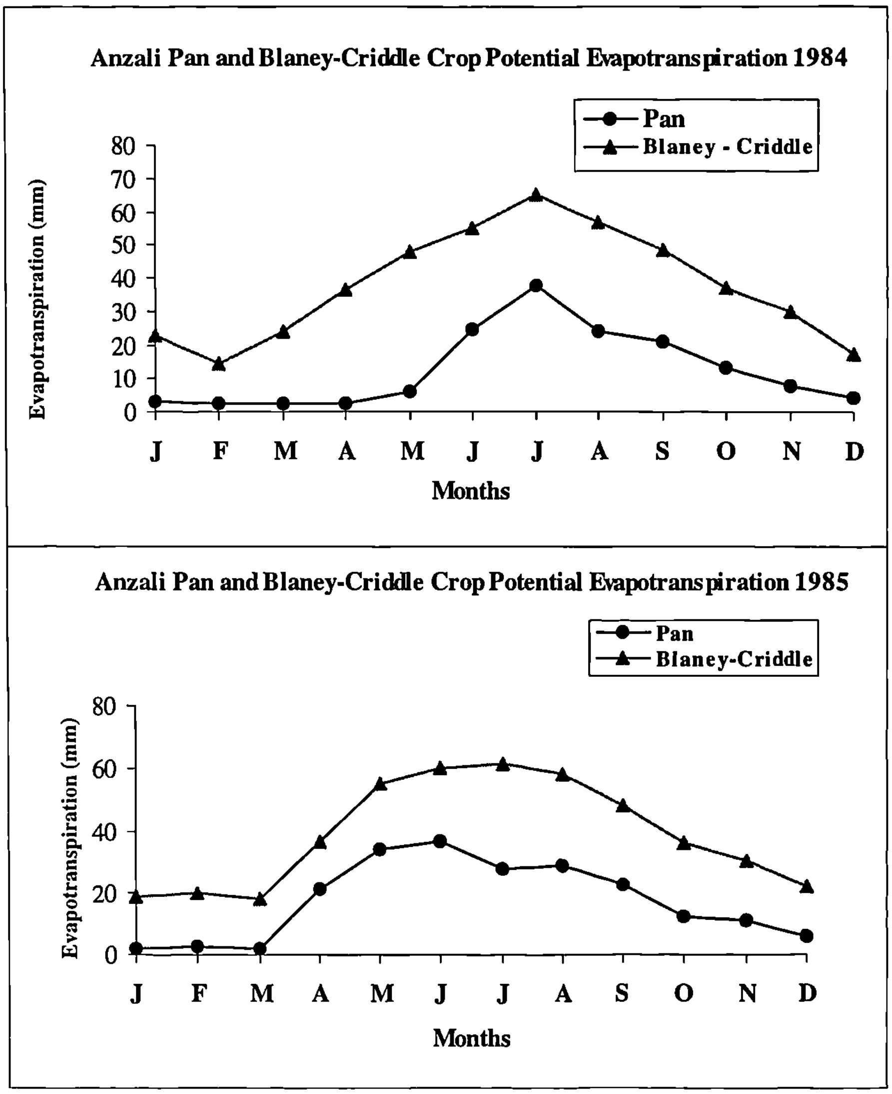


Figure 8.11-1 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Anzali Station.

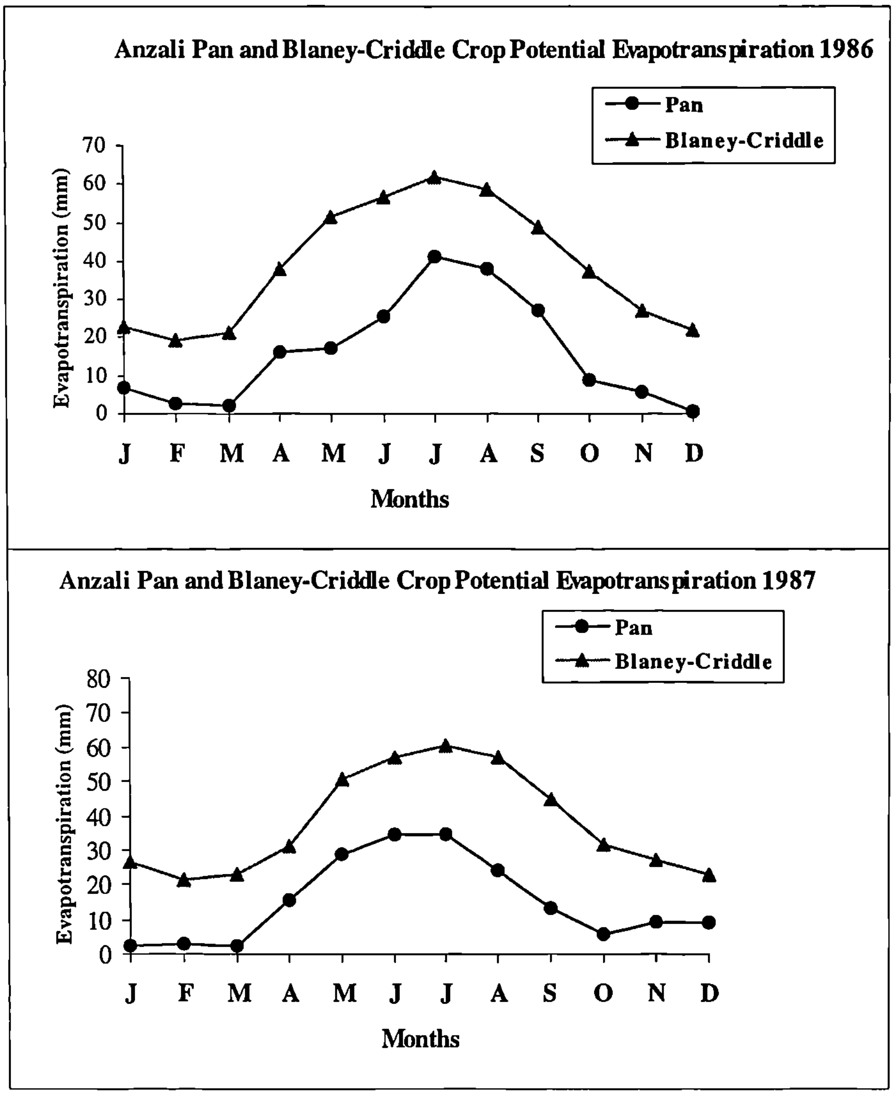


Figure 8.11-2 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Anzali Station.

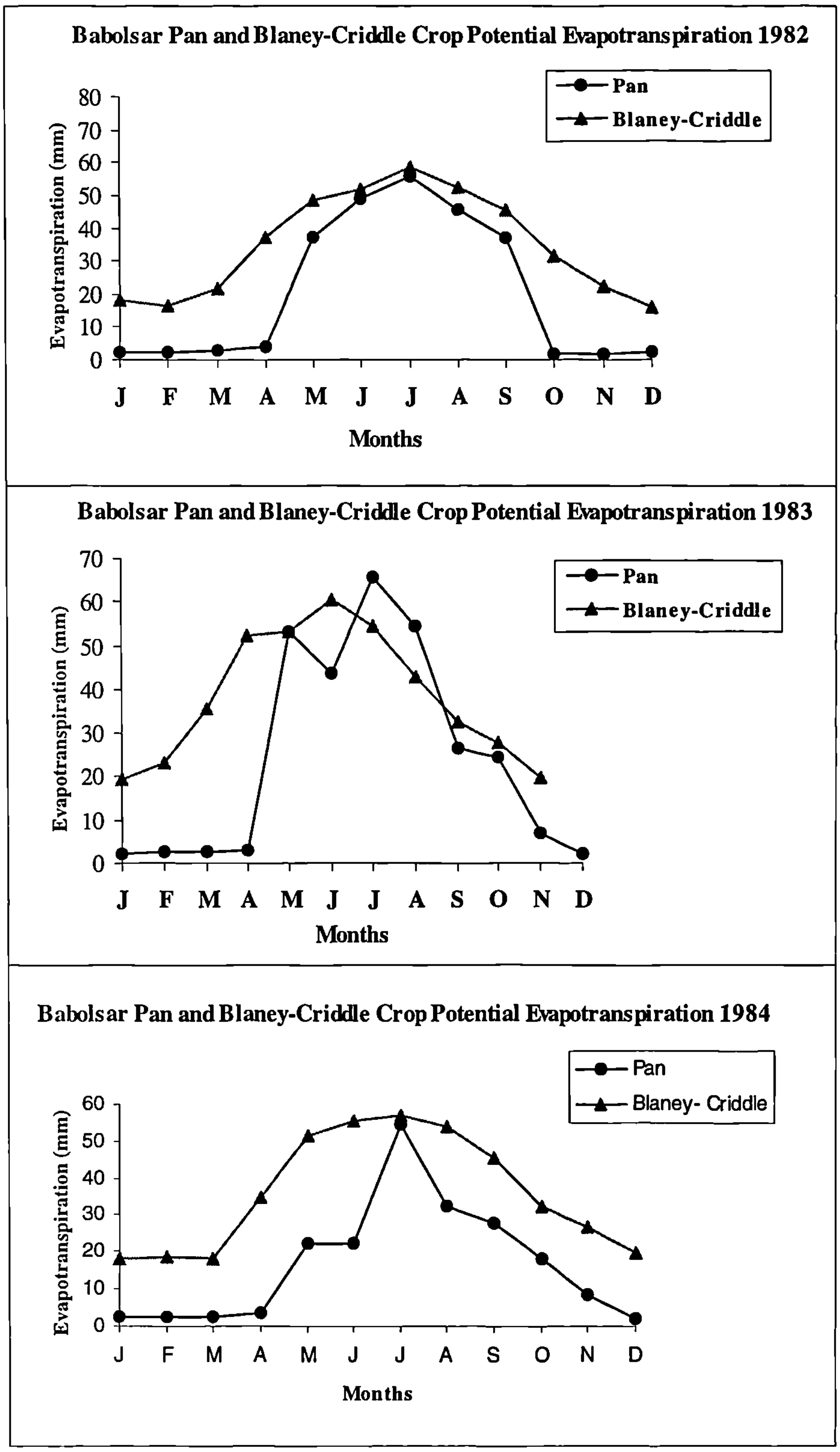


Figure 8.11-3 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Babolsar Station.

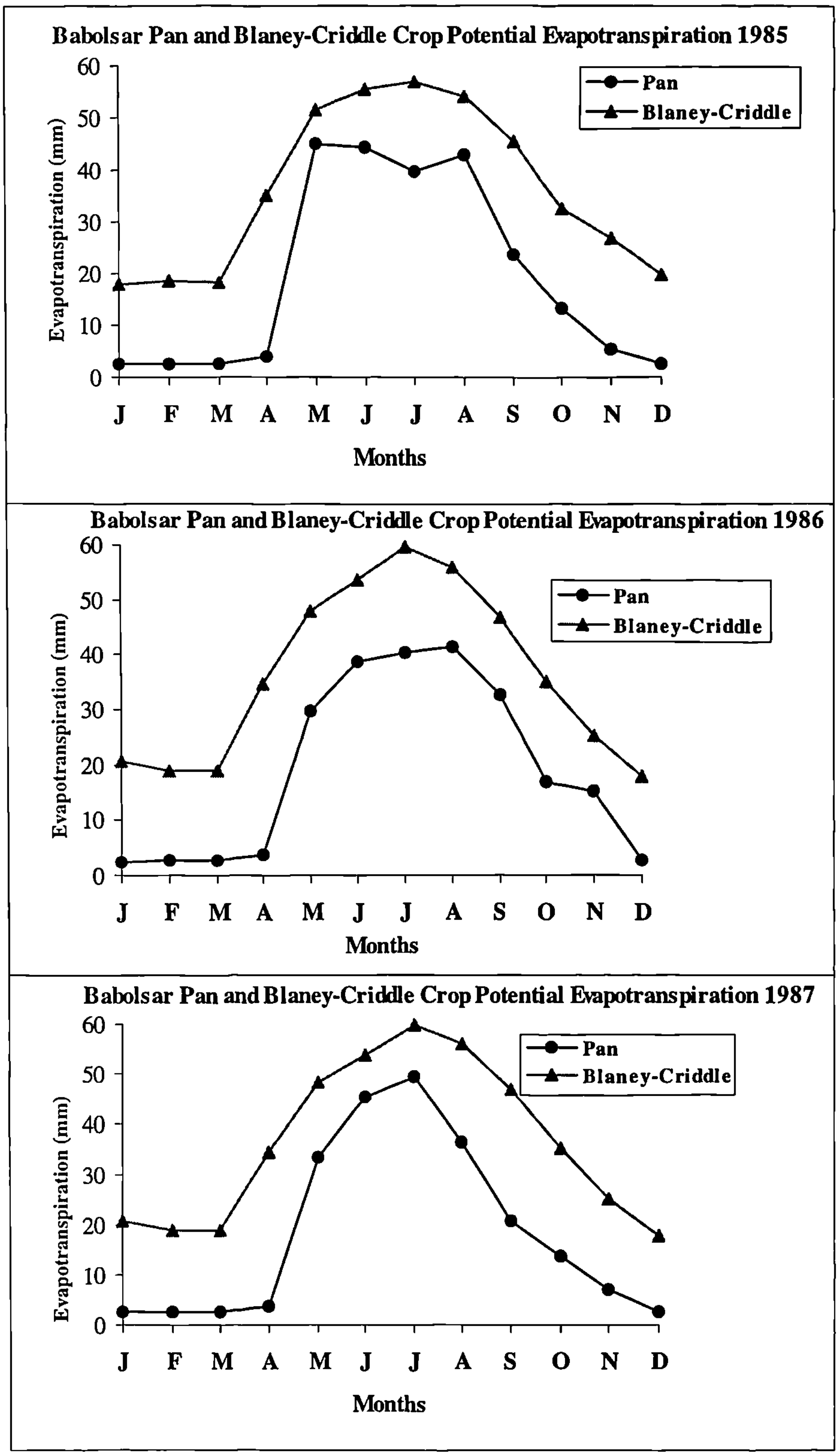


Figure 8.11-4 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Babolsar Station.

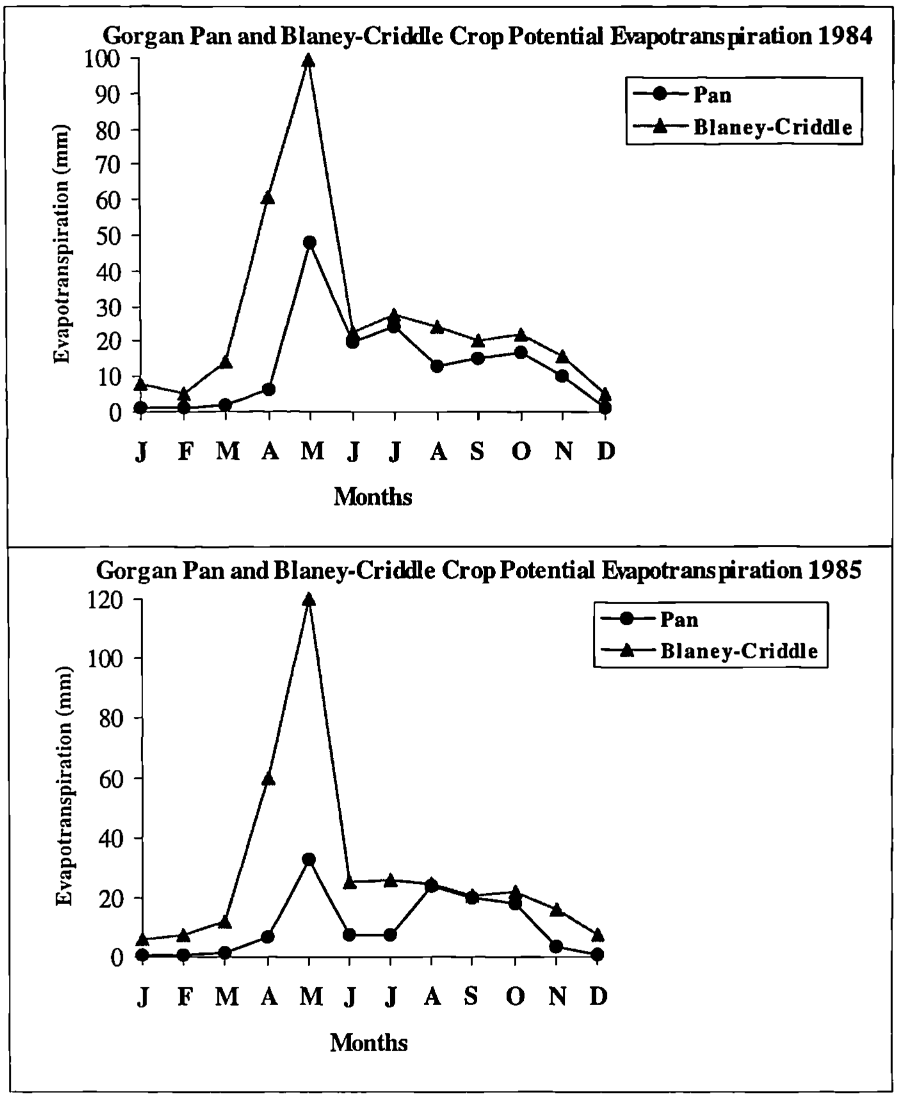


Figure 8.11-5 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Gorgan Station.

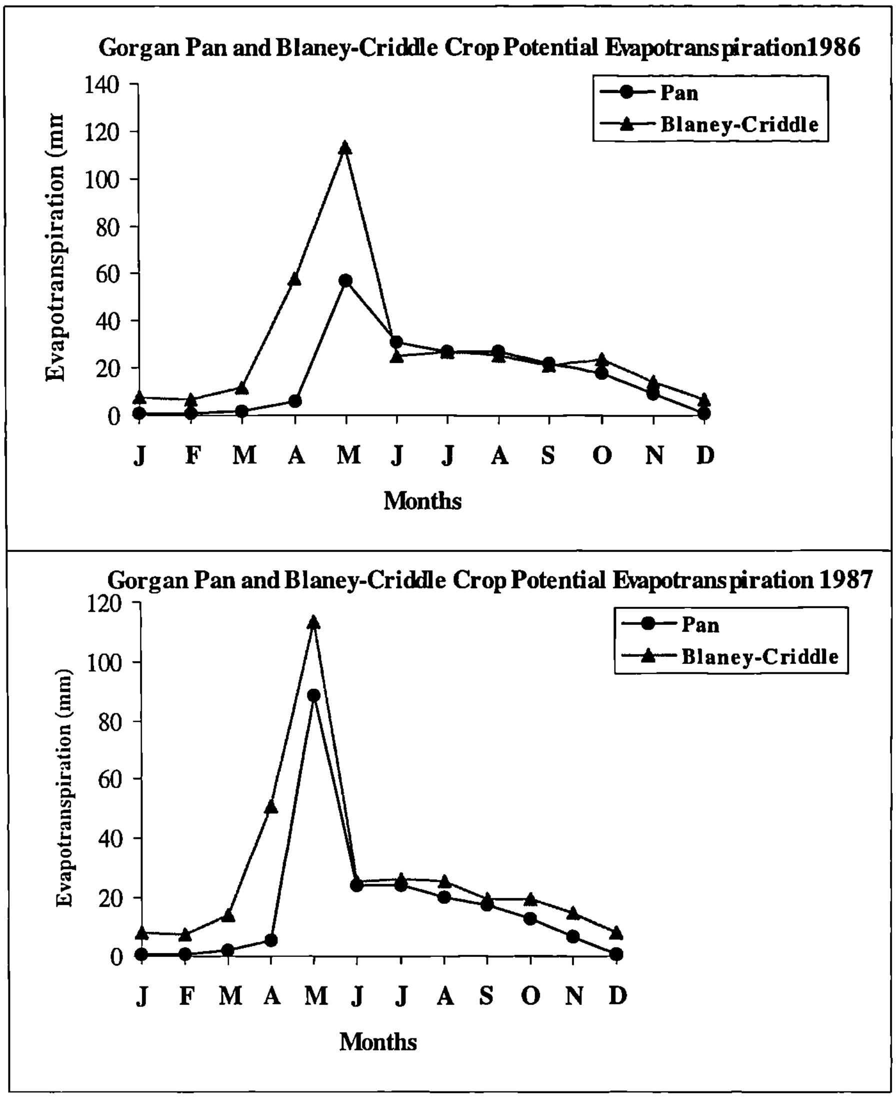


Figure 8.11-6 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Gorgan Station.

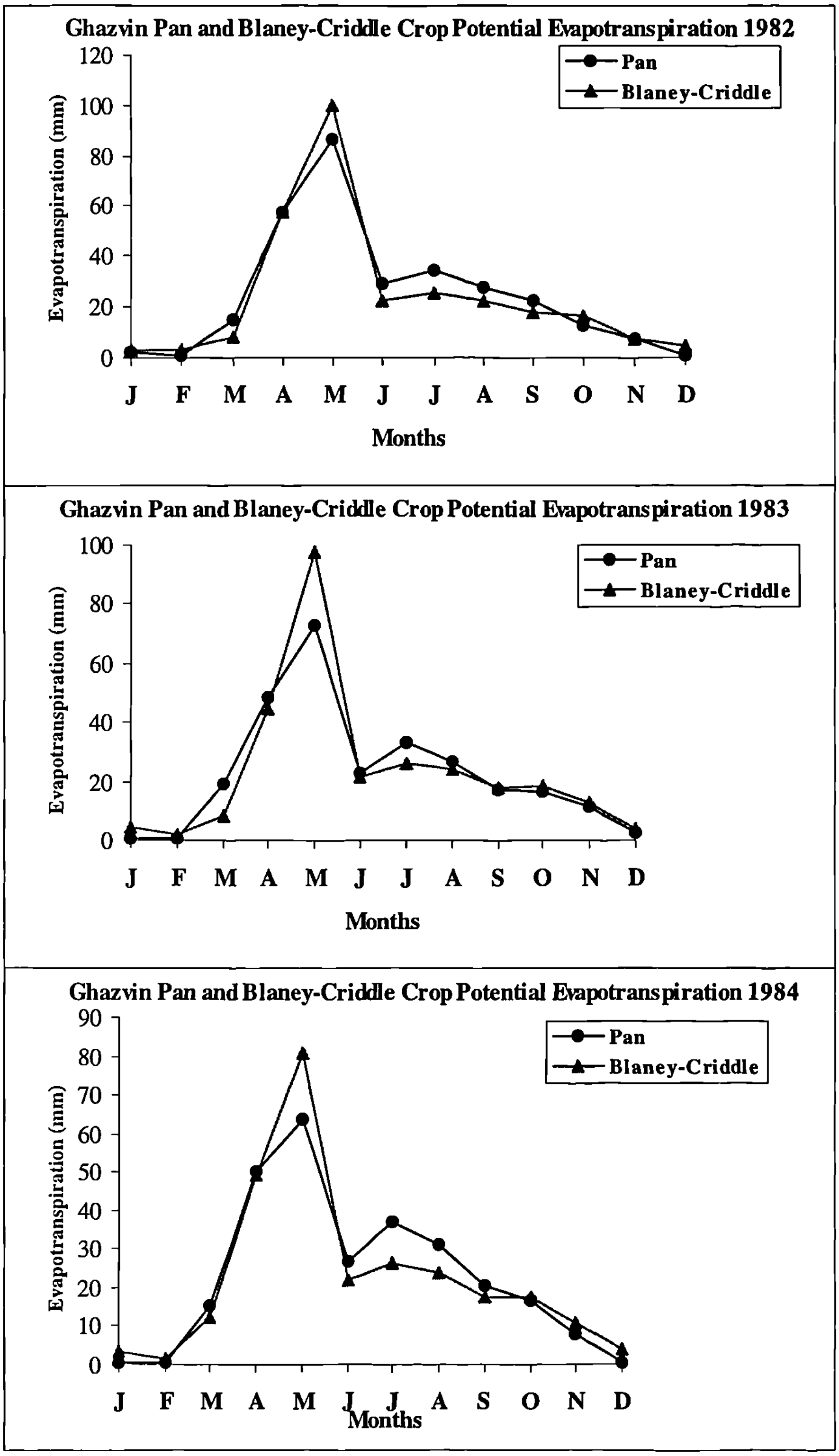


Figure 8.11-7 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Ghazvin Station.

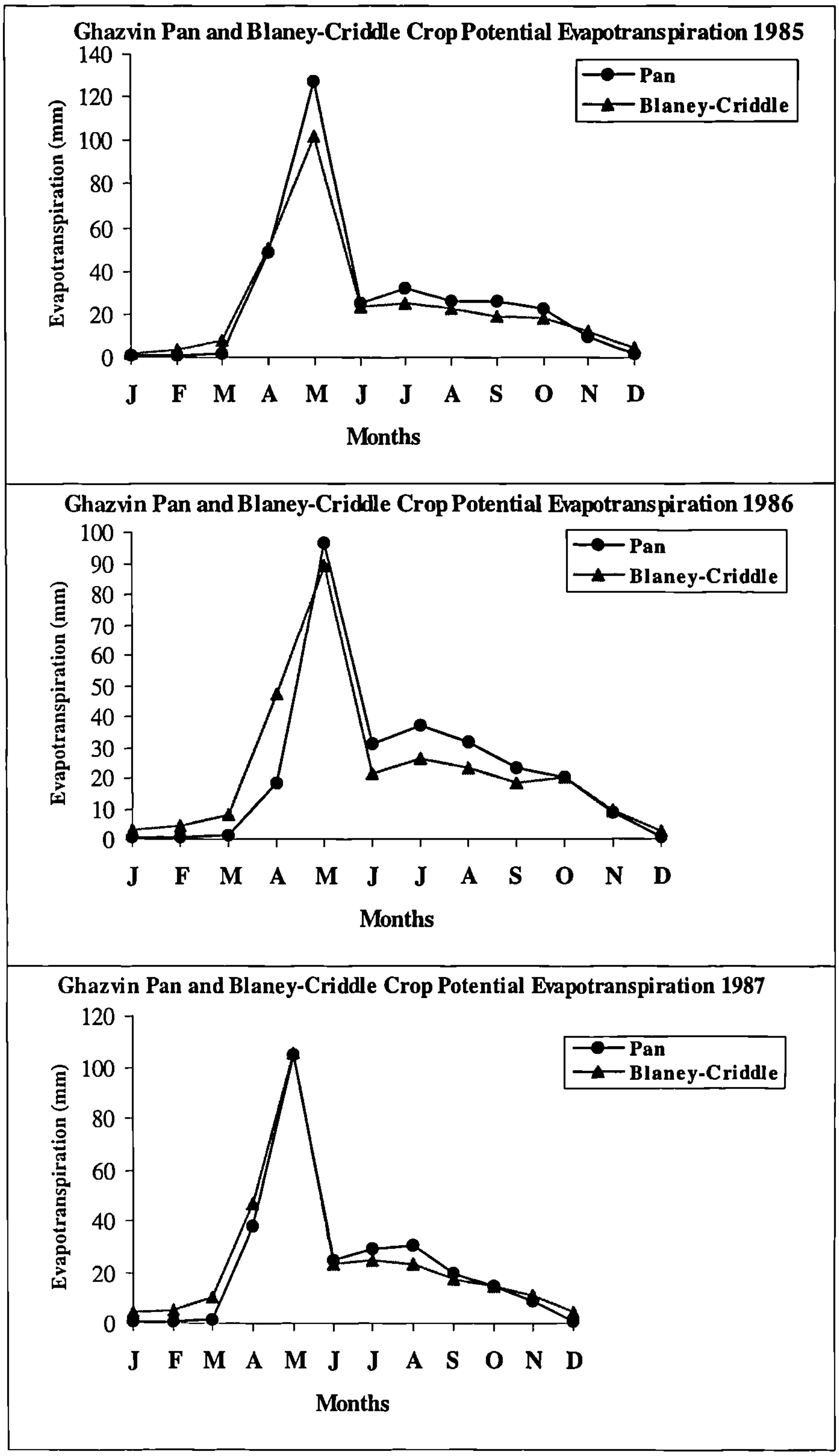


Figure 8.11-8 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Ghazvin Station.

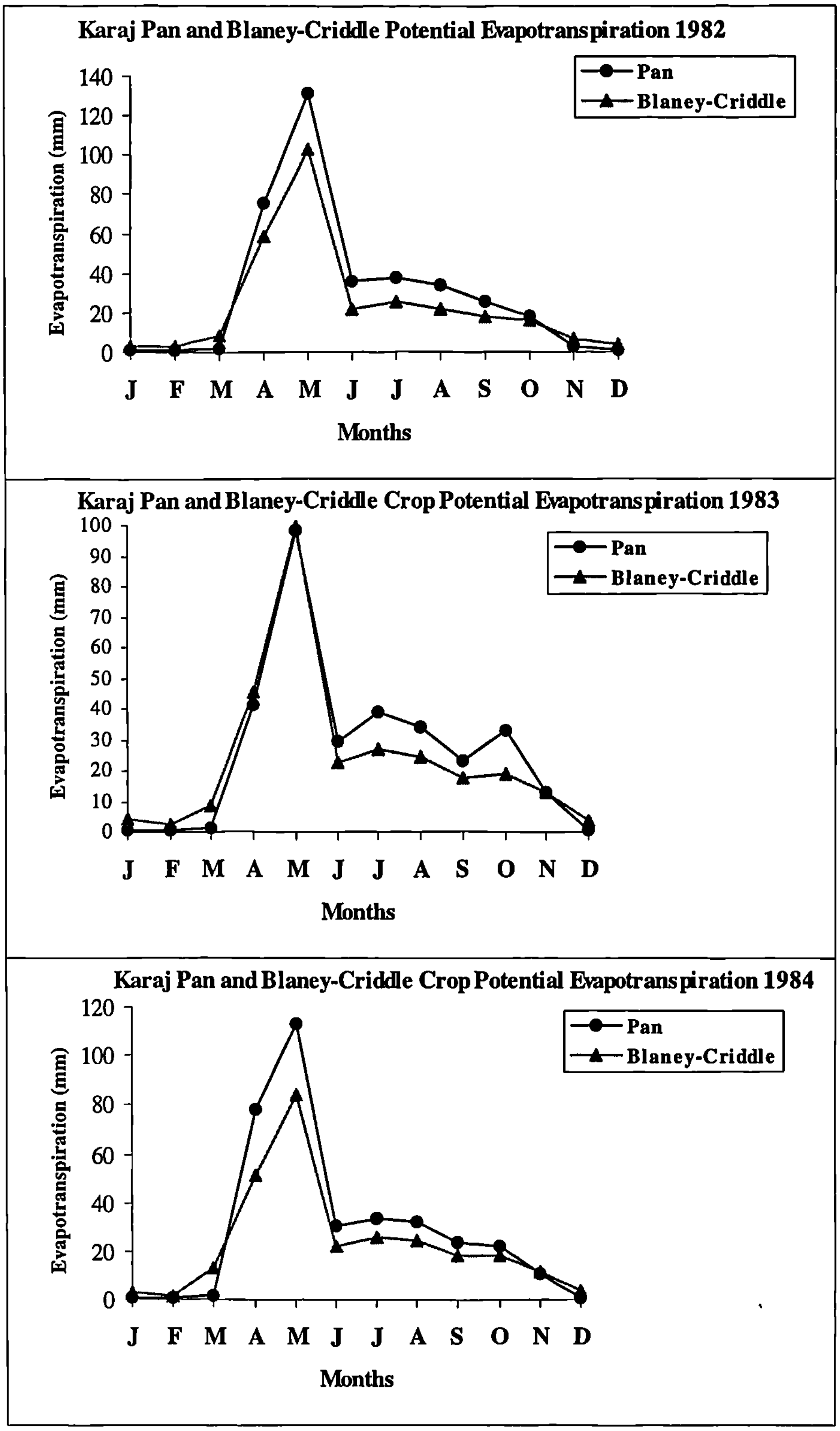


Figure 8.11-9 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Karaj Station.

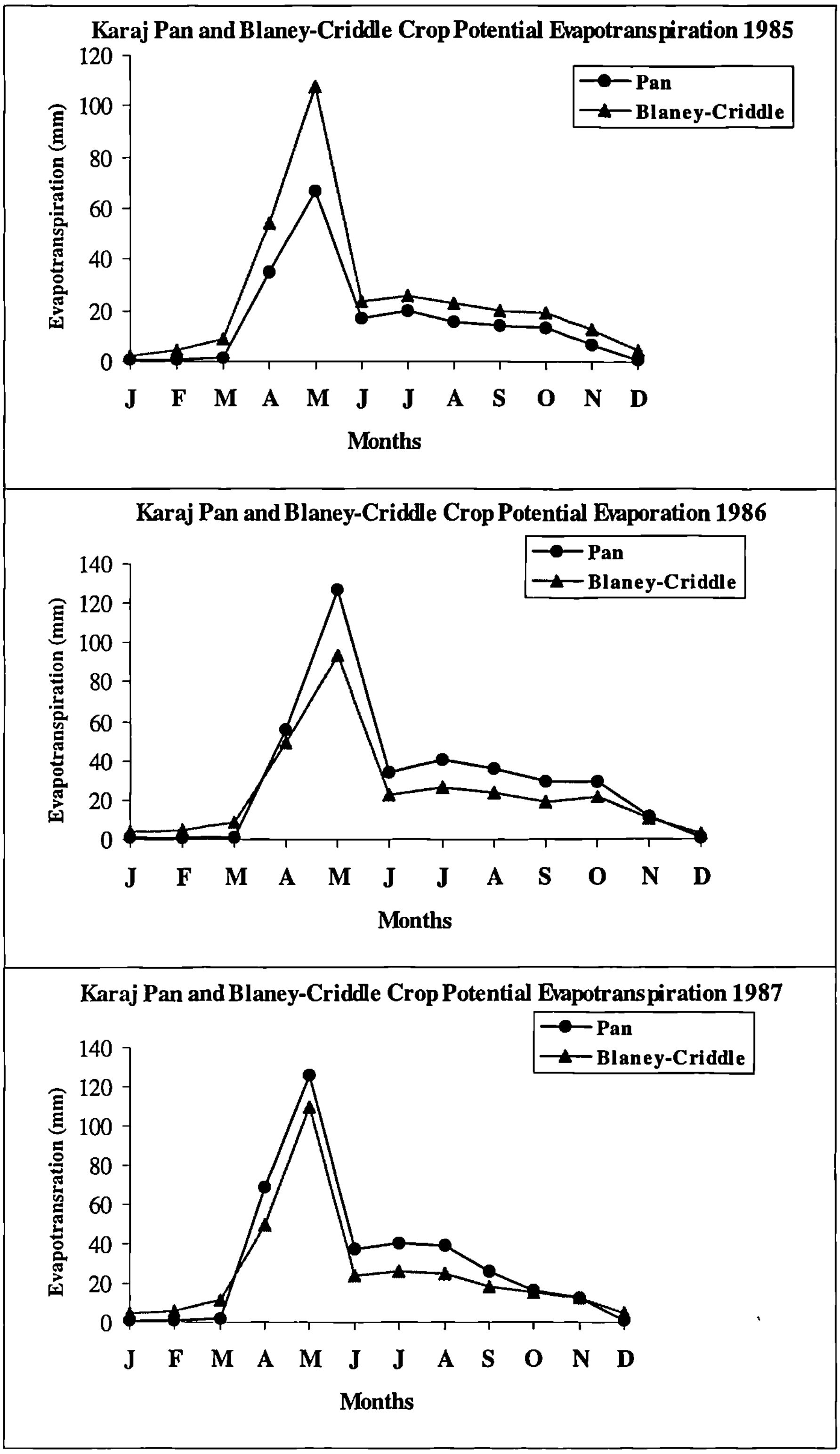


Figure 8.11-10 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Karaj Station.

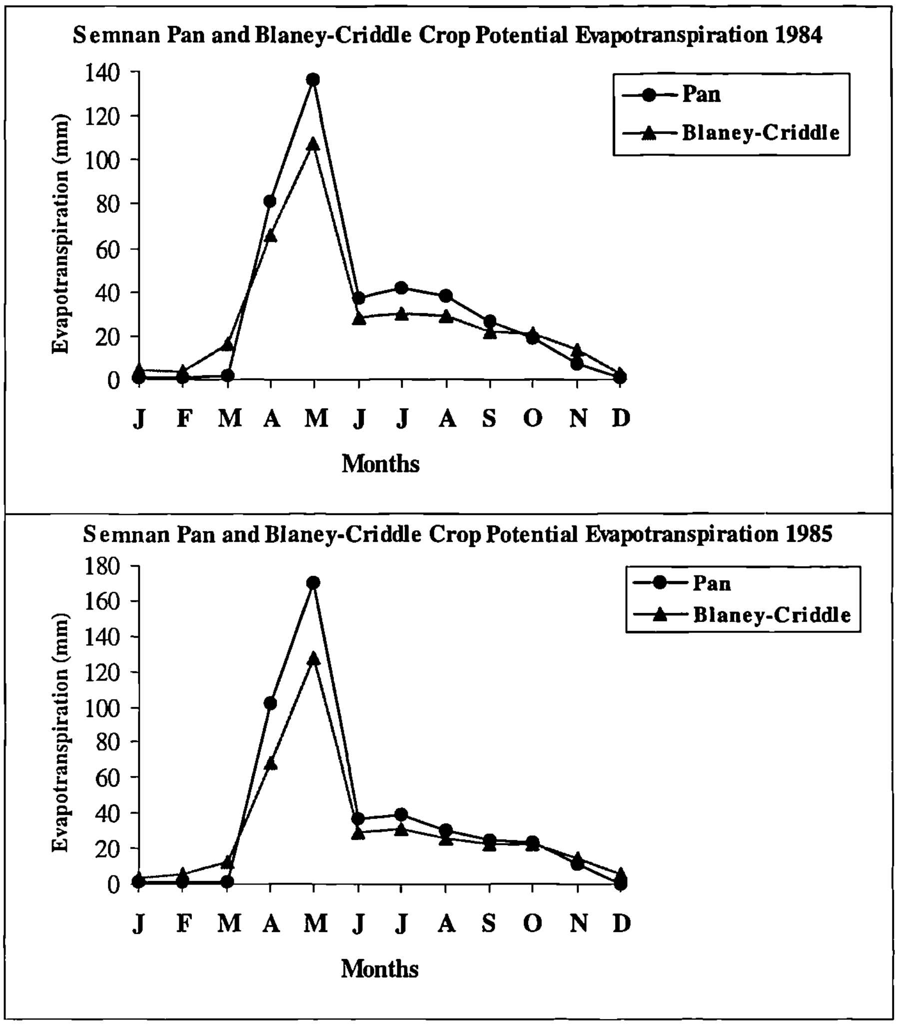


Figure 8.11-11 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Semnan Station.

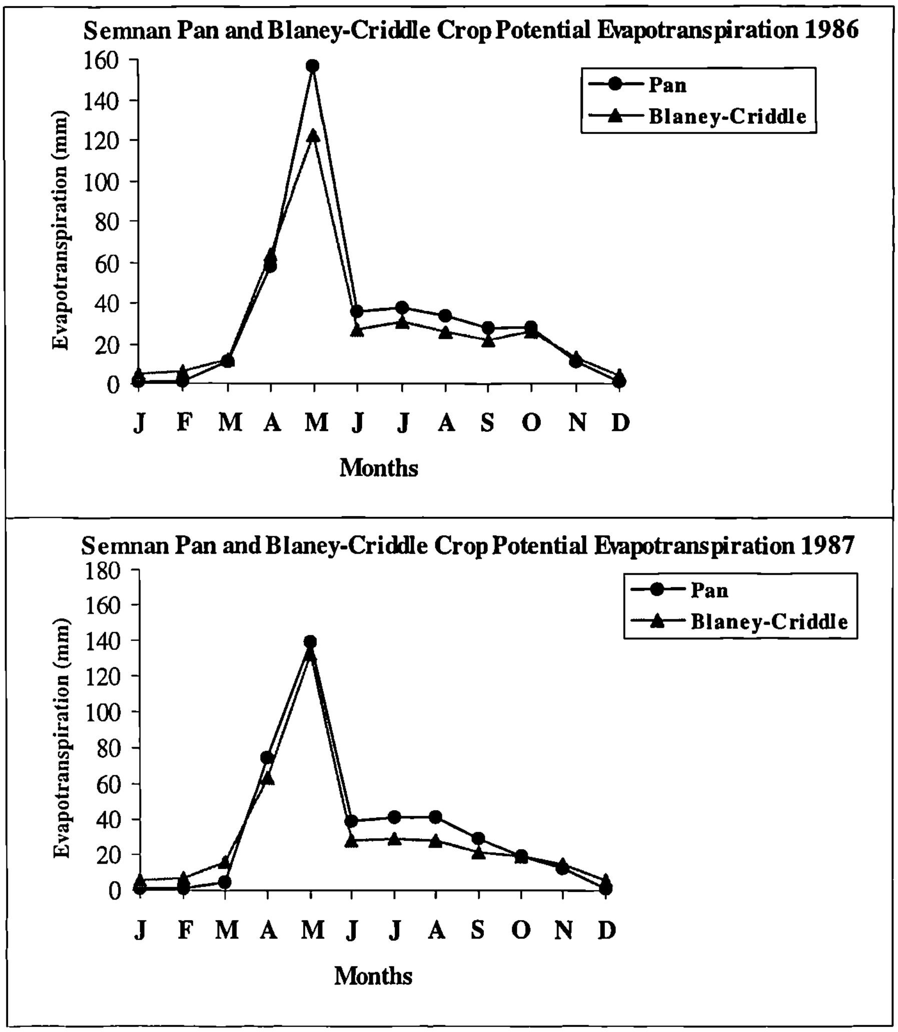


Figure 8.11-12 Comparison between Pan and Blaney- Criddle Crop Potential Evapotranspiration over Semnan Station.

8.12 Assessment of Pan and Blaney- Criddle Methods for Crop Water Requirement.

Meteorological data for selected stations in the Central Elburz stations of Iran were used to estimate the potential evapotranspiration (PE0) and water requirements of crops (Et crop) for two different types of crops (wheat and citrus) by using two well known Blaney- Criddle and Pan evaporation methods. The choice of these methods was based on the theoretical background related to availability of data. Data analysis showed that the potential evapotranspiration (PE0) and water requirements of crops (Et crop) varies from one location to another because of differences in the types of crops, the methods of estimating, the amount of rainfall, and the amount of the temperature during the season of cultivation.

Providing information for crop water need and planning irrigation systems peak water requirement of wheat and citrus crop were determined over the Central Elburz stations. The estimates of crop potential evapotranspiration derived from the Blaney-Criddle formula (equation 3) and pan evaporation. An important consideration in this equation is this **K**(Kc) factor which converts potential evapotranspiration into values of potential crop transpiration or crop water requirements for the different growth periods. For wheat and other annual crops grown in a single season this factor various with time after planting. On the other hand evergreen citrus have a relatively constant **K** (Kc) factor throughout the year, though there may be differences between mature and immature trees. This **K**(Kc) factor can also be applied to pan evaporation to give a comparable potential crop transpiration estimate.

Pan evaporation and the Blaney- Criddle equation adjusted for crop and season can be considered an accurate estimate of potential crop transpiration. It is useful however to compare these results. Comparison is made of potential evapotranspiration between pan and Blaney- Criddle for all months of the year. Also comparison is made of the crop water requirements of wheat for the growing season and citrus throughout the year.

Tables 8.11-1 to 8.11-13 and Figures 8.11-1 to 8.11-12 demonstrate values of monthly and seasonal water crop requirement currently proposed by the Blaney- Criddle formula and Pan Evaporation for most irrigated crops. These tables and graphs have been used for wheat at Gorgan, Ghazvin, Karaj and Semnan stations and citrus at Anzali and Babolsar stations. It will be noted that the peak water requirement month is July in coastal area stations while it is May in the Gorgan and the southern slope stations. The range in the values of these coefficients has been shown in Table 8.11-1 to Table 8.11-13 and Figures 8.11-1 to 8.11-12. The calculations for Blaney- Criddle and pan crop potential evaporation over the Central Elburz stations show variation over space and in time. Based on analysis the Pan evaporation method is suggested for coastal stations. The results of both pan and Blaney- Criddle method for southern slope stations are close. However, the Blaney- Criddle method is recommended in this case as the resulting amount for water requirements is less than pan method for the southern slope stations.

9

9. The Seasonal Water Balance

In the previous chapter evaporation, evapotranspiration, Potential evapotranspiration and the different methods of determining or estimating Potential evapotranspiration were discussed. This is important in assessing the water balance. The idea of the water balance enunciated in Thornthwaite's (1948) classification of climate is not new. It is no more than a universal mathematical statement of the hydrological cycle over an area. Thornthwaite's principal contribution lies in the ingenious methods he devised for calculating approximately several parameters that are not often or widely measured requiring only some simple and reasonable assumptions. However, Thornthwaite's classifications of climate uses mean figures. For the purpose of this study we need to evaluate the seasonal pattern over a number of years.

Evaporation of water in the natural environment, be it from free water surfaces or from land surfaces covered by vegetation, is one of the main phases of the hydrological cycle (Brutsaert 1982). This hydrological, or water cycle consists of the continual movement of water from the atmosphere to the earth's surface by rainfall, whence it runs off to rivers, lakes and to the seas, either through infiltrated underground seepage or directly as surface flow. However, this concept has little value as a working hypothesis for the hydrologist concerned with a detailed, quantitative study of water occurrence distribution and movement in a specific area (Ward and Robinson 1990). The vagueness of the interminable hydrological cycle must be replaced by a more direct approach to the water balance concept. However, the concept of the water balance implicit in Thornthwaite's classification of climates has been separately developed and extended, and is now an important technique in its own right (Ward 1967). A comprehensive understanding of the hydrological cycle includes many subject areas but attention to the extensive range of disciplines of interest to the climatologist is not realistic. We must surely focus on those aspects of the water balance that are directly relevant to climate. Other disciplines including can benefit from such climatological analysis of the water balance. From a climatological point of view the water balance must be considered in relation to the growth of agricultural crops for this is an important evaluation of the seasons. Also it is necessary to consider the probably of seasonal water availability. This differs from Thornthwaite's generalised water balances which describe the average water balance to distinguish between regions.

9.1 The Water Balance Concept

The relations between rainfall and the water requirements of crops are often illustrated by the water balance, which can be based on actual data for days, weeks, months, or on monthly means (Thornthwaite 1948). The time interval depends on the aim of the study of the water balance. For example, for day to day agricultural operation, the daily water balance is considered preferable. Nevertheless weekly computation can give essentially similar results. For long term water balance planning, the monthly computation may be satisfactory. In the previous pages we noted that the amounts of evaporation and evapotranspiration were partly controlled by water availability which, over most land surfaces at least, is largely controlled by rainfall.

The difference between precipitation and evaporation in any area can loosely be called the water balance of the area. The concept of the water balance is of most immediate interest over land areas, since any excess of precipitation over evaporation represents water that runs off the surface or is stored in the soil or lakes. It therefore represents the water that can be used by mankind (Sellers and Robinson 1989).

The manner in which we define the water balance and the use to which the concept can be put depends greatly on the space and time scales of interest. The most exact definition is necessary for the smallest scales where the local water balance of a land area has several applications especially in agriculture. On a regional scale the land surface water balance has an important impact on the distribution of the natural vegetation.

The term water balance was used by Thornthwaite to refer to the balance between the income of water from rainfall and the outflow of water by evapotranspiration, ground water recharge, and stream flow. The budget can be computed for a soil profile or for a whole drainage basin. The most obvious use of the water balance is for a basic description of the hydrology of a place or region. The present study has two aims:

1) to describe and evaluate the seasonal pattern already defined by the study of rainfall alone. The water balance is therefore used to define of the limits of water availability and to consider the probability of limit and duration of these seasons.

2) at a regional scale the analysis of the monthly pattern of the water balance can provide a classification of the seasonal climates of this area of Iran. Thus the aim of water balance study in this part is to determine the probability of potential water deficits to provide an assessment of wet and dry season.

9.2 Application of Water Balance to Agriculture

Calculation of the water budget entails the consideration of the main components of the water economy of a place, water supply (rainfall), water need (potential evapotranspiration) and storage through a book-keeping procedure. The water availability conditions of that place can be ascertained in terms of water deficit or water surplus (Sirinanda 1984).

The power of the water balance technique in planning is obvious. Usually graphs can be drawn of the annual extreme water deficit or surplus or of the total annual irrigation need or runoff. Also the water balance is used to define the seasonal and geographical pattern of water supply and irrigation demand at an early stage in planning for the

development of water resources. The results of calculation of water balance in every area indicate a great deal of information on the hydrology of that area.
Besides showing the seasonal pattern of rainfall, evapotranspiration and run off, the water balance indicates the times of moisture deficit, soil moisture recharge and moisture surplus. The moisture deficit indicates that the plants are under some stress and if the cover is a valuable crop the calculation will indicate the timing and magnitude of irrigation necessary to remove the stress. Thus the water balance is valuable for understanding the ecology, agronomy and economics of growing crops. The water balance is used for computing seasonal and the geographic pattern of irrigation demand, soil moisture stresses for both crops and natural vegetation and the prediction of streamflow and water table elevation.

In water balances, the water requirements of crops are often indicated by potential evapotranspiration which is the amount that would evaporate from an open water surface under prevailing conditions. Its amount is obtained from evaporation pans or is estimated from other meteorological data by different methods. However this can over estimate the requirements of crops which transpire at the potential rate (or Penman E_0) for only a limited time during growth.

The water balance of an area depends on meteorological factors influencing rainfall and evaporative loss from plants and the soil as well as other factors influencing surface and subsurface water movement, soil infiltration, percolation, water storage capacity characteristics, crop species and the development stage of the crop.

The water balance concept fundamentally considers rainfall as income and potential evapotranspiration as output consequently if the balance shows a water surplus this can be considered as surface run-off or an addition to groundwater. The balance therefore constitutes the effectual moisture resource of a given area. In the various water budgeting procedures the concept is extended to include the soil as a kind of reserve to which the plants can turn in times of water stress. When this concept is mathematically expressed, it is known as the hydrological formula or the water balance equation and is of the general form;

$$P = E + R + \Delta s$$

where;

P = Precipitation or rainfall,

E = Evapotranspiration,

R = Run -off, and

Δs = Change in storage.

Chang (1966) used a water balance equation of the soil plant system down to the rooting depth. The same basic equation used but leaching components (S_L) is specified. Thus the equation is:

$$P = E + R + \Delta s + S_L$$

This can have importantce in managing salinity in irrigation agriculture. Hanna (1975) has used the same water balance equation to calculate potential water deficit for the assess of the wet and dry seasons in Uganda.

By comparing rainfall and potential evapotranspiration on a monthly basis it is possible to make quantitative estimates of water balances. This study uses estimation of crop potential evapotranspiration the value of these estimates to this study is their use in estimating water supply for specific crops.

Soil water content is an important parameter in many models presently used in agriculture, forestry and hydrology. Soil moisture plays an important role not only in plant growth, development and yields, but also in farm operations such as planting, cultivation, harvesting and irrigation. The accuracy of estimating of soil moisture storage depends on the intended use of these data. The following analysis of the water balance can be used for other purposes by varying the crop factor in potential evapotranspiration.

The water balance is sensitive to the rooting ability of the plant which is partly controlled by physical conditions and partly by habit. The depth of penetration of roots determines the soil- water reservoir available to plants. It is therefore possible to determine the available water capacities for each type of crop (Hanna 1975). In summary according to Jackson (1989) some of the major applications of water balance studies are as follows:

1) To provide a general overview of the water conditions in area.

2) To form part of a model for investigating rainfall- run off relationships and streamflow prediction from climatic data.

3) To assess the suitability of an area for a particular crop and vice versa. Related to this is the assessment of favourable planting and harvesting dates.

4) To assess irrigation requirement- both quantity and interval.

5) To examine water- yield relationships.

6) To assess water use by a particular vegetation or crop type.

The following analysis can be used for some of these applications.

9.3 Water Balance Analysis

Although it is possible to use rainfall to define seasonal water supply crops conditions affecting the availability of water for plant growth are likely to be of greater practical interest for the irrigation planner as well as the management of rain grown agriculture. In this respect the water balance approach using rainfall, evapotranspiration and soil characteristics provides a more realistic evaluation of the availability of water to crop growth. Most water balance studies discussed are of considerable value in delimiting seasonal conditions, growing periods, time of deficit and surplus. Simple analyses based on average monthly data are usual for agroclimatic classification but are limited for practical agriculture operations. Also water balance diagrams providing information as to the period of moisture deficit and surplus, illustrate aspects of the hydrological cycle not immediately revealed by streamflow and rainfall data.

Water balance analysis not only provides insight into the factors of evapotranspiration, soil moisture and precipitation that directly affect crop growth but has practical value in computing crop water needs and irrigation diversion requirements during periods of moisture deficit. However, the use of water balance analysis in this manner needs for accurate data on both soil characteristics and evapotranspiration rates (Manner 1969). This is considered in the following discussion.

9.4 Potential Water Deficit in the Central Elburz Stations

The calculation of the water balance produces, for a selected time interval, the water balance for crop growth and the available soil moisture can be estimated for each time interval. If this is less than the water requirement of the crop to enable it to transpire at the potential rate then there is a deficit. Thus the difference between AE (actual evapotranspiration) and PE (potential evapotranspiration) is termed the potential water deficit. To quantify this potential water deficit we need to estimate the crop water need and the available water capacity of the soil.

Before describing and explaining the analyses of the results of potential water deficit in the Central Elburz stations first we have to define the some terms of the water balance.

9.5 Storage Capacity Concept (Available Water Capacity)

Rainfall in excess of evapotranspiration will infiltrate into the soil and add to the storage. This storage can only be used if it can be reached by the plant's roots. The water which can be held within the root zone and withdrawn by the suction of the roots is termed available water capacity (Hanna 1975). Available water capacity has an upper limit which is called field capacity and a lower limit defined as permanent wilting point. When a soil has been saturated by water, and allowed to drain under gravity until no more water moves downward, the soil is said to be at field capacity (Strahler 1992). The field capacity is defined as the amount of water held in soil after excess gravitational water has drained away and the rate of downward movement of water has materially decreased, which usually takes place within 2 or 3 days after rain or irrigation in pervious soils of uniform structure and texture. In a similar context, Siam (1979) defined the field capacity as an amount of water remaining in well-drained soil when the velocity of downward flow into unsaturated soil has become infinitely small. For practical agricultural purposes, the storage capacity of a soil should be determined in the field. Therefore the rooting capacity of the plant that is partly controlled by physical conditions of the soil and by the habit of the plant must be considered. Soil conditions are soil texture, type of soil, soil structure, organic matter content, uniformity determine the capacity within the depth of the soil layer occupied by the root seplin. Thus it is not a constant but can vary between sites. For example, sandy soil has a very small storage capacity and clay soil has a large capacity. 'It can vary from just a few millimetres on a shallow sand to well over 400 mm on a deep well-aerated silt loam' (Thornthwaite and Mather1955).

In his study of global water balance, Thornthwaite (1948) assumed a storage capacity of ten centimetres for a normal soil, which he subsequently raised to 40 centimetres (Thornthwaite and Mather1955). Such standard values are at the best crude and can only be relevant to large scale studies. But local soil and crop must be considered in small area studies. Thus it is important to attempt to quantify available water capacity for the specific area

In low- rainfall areas, permeable soils accentuate aridity for shallow-rooted grasses since water penetrates to lower levels (Jackson1989). Thus water will percolate beyond the root zone and not contribute to the available reservoir of soil water.
In dry areas of the Central Elburz stations rainfall totals are low water does not penetrate deeply enough to make any difference in availability water capacity between soils. Jafarpour (1978) suggested that in dry and semi-dry areas of Iran 100 mm may be the maximum for shallow rooting field crops. Also Mahdavi (1987) has used 100 mm available water capacity for the Central Iran. In this study, therefore, the water balance is based upon available water capacity of 100 mm.

9.6 Actual Evapotranspiration

In order for the relationship between rainfall and evapotranspiration to be understood two aspects of evapotranspiration, potential and actual evapotranspiration should be calculated. In previous pages we defined and discussed the concept of the potential evapotranspiration. Actual evapotranspiration is equal to the potential evapotranspiration rate so long as a vegetation covering the ground has enough water to meet its requirement. However, if the requirement of water to the plant is limited the actual evapotranspiration will fall below the potential evapotranspiration amount. Thus when soil moisture is plentiful, the evapotranspiration rate is maintained at the potential rate, determined largely by the prevailing weather conditions but as the soil dries out actual evapotranspiration will fall below the potential rate (Chang 1964). Actual evapotranspiration which is the true or real rate of water- vapour return to the from the ground and its plant cover (Strahler 1992).

9.7 Methods of Calculating Actual Evapotranspiration

The rate of actual evapotranspiration is controlled not only by the prevailing climatic conditions expressed by potential evapotranspiration but also by non climatic factors like soil and plant characteristics such as available water capacity and crop potential evapotranspiration. Amounts of actual evapotranspiration over a given locality can be measured using different methods. Hanna (1975) has used one method of actual evapotranspiration in Uganda suitable for sugar cane agriculture. His method for calculation of actual evapotranspiration is based on:

a) If total water equal PE

AE = PE

b) If total water is less than PE

AE = P + S.M. (accumulated). Where;

PE = Potential Evapotranspiration,

AE = Actual Evapotranspiration

P = Rainfall and

S.M.= Soil moisture accumulation

This method assumes that the rate of AE does not change throughout the range of available water. Siam (1979) assumed the relationship of AE to soil water availability as being consistent until permanent wilting point is reached. However, Thorntwaite assumes that the rate of AE will decline with decreasing soil moisture and computed tables for calculation of AE. More recent research has suggested that AE does not decline until a proportion of soil water capacity (about 80 percent) is reached.

In the following analysis the rate of AE is considered consistent throughout the range of available soil water. Thus AE ceases abruptly when zero available soil water is reached and plants are at permanent wilting point. Thus from the former discussion it is seen and understood that:

a) Potential evapotranspiration (E_0) depends on weather factors and does not take into account plant factors.

b) Under any given conditions, water needs of a crop depend on the evaporative demand; this is considered as crop potential evapotranspiration (E_t).

c) Actual evapotranspiration depends on weather factors as expressed by potential evapotranspiration and soil water availability and plant cover, which determines crop potential evapotranspiration (E_t).

d) Actual evapotranspiration is equal to potential evapotranspiration for full canopy cover and adequate soil moisture.

9.8 Meteorological Data and Method

The data used in this study for the calculation of the water balance and the potential water deficit over the central Elburz stations are the monthly series of the rainfall records and the monthly potential evapotranspiration. Rainfall records have been published by the Iranian Meteorological Department. Also the monthly potential evapotranspiration estimated by the author using the Blanney- Criddle method and Pan evaporation method for the period of the 1982 to 1987. Thus this study attempts by a computer analysis of the water balance over a period of 30 years data to evaluate the potential water deficit. Six stations in two different types of climatic conditions are been used as follows:

a) Coastal area stations including Anzali, Babolsar and Gorgan stations,

b) Southern slope stations include Ghazvin, Karaj and Semnan stations.

For these Central Elburz stations there is a long period of rainfall data but there is no equivalant Potential Evapotranspiration data. In the present study, it has been thought reasonable to apply the average monthly evaporation based upon the existing data to all years. In this regard the Thornthwaite (1948), Thornthwaite and Mather (1955) used average rainfall and average potential evapotranspiration. However, Hanna (1975) used the average potential evapotranspiration and actual rainfall data for the water balance for calculating water deficit and determining of wet months over Uganda. This has been adapted for this study for water potential evapotranspiration and estimating of the monthly potential water deficit over the Central Elburz stations of Iran based on a period of 6 years average potential evapotranspiration and actual rainfall data for 30 years. First the water balance method has been estimated by monthly rainfall and the potential evapotranspiration for each individual month and year, the results are shown in Tables 9-1 to 9-14. Secondly it was computed using the arithmetic average potential evapotranspiration for each month together with individual monthly rainfall and results are demonstrated in Tables 9-15 to 9-16. Also to justify this potential water deficit it must estimate the error involved in using the mean potential evapotranspiration. In this regard it has been done this by calculations:

a) potential water deficit from actual potential evapotranspiration for each individual month with the same period of rainfall (Tables 9-13 to 9- 14)

b) potential water deficit from mean potential evapotranspiration and 5 years of rainfall (Table 9-17). The difference between these results gives the magnitude of the error involve, this is shown in Table (9- 18). Regarding the Table 9- 18 the magnitude of the error is zero in most months but in some of them it is very small. Thus the effect of any deviation of actual evaporation from these mean values is small compared with the influence of rainfall variability on the water balance.

9.9 Potential Water Deficit Concepts

With regard to the previous pages when the rainfall and soil moisture storage together are greater than the potential evapotranspiration the actual evapotranspiration equals the potential evapotranspiration since there is enough moisture in the soil so that evapotranspiration can be proceed unhindered. For months where the rainfall and soil moisture storage is less than the potential evapotranspiration, the actual evapotranspiration equals the sum of the rainfall and any moisture stored in the ground.

Every farmer, agriculture management and agronomist know that weather and climate are both very significant factors in crop production. They also may understand which water deficit in summer season is a major stay to peak crop. Irrigation is the solution to this problem but actual irrigation involves more than installing equipment and turning on the water. If farmer, agriculturist management and agronomist proposes to supply supplementary water to his crops, he should have some practical means of determining how much water to use and when it is required. It is normal for them to pay attention the plants for signs of water deficiency as a basis for providing water.

According to Strahler (1992) the actual evapotranspiration is water use and the potential evapotranspiration is named water need. The word need signifies the quantity of soil water needed if plant growth is to be maximized for the given conditions of solar radiation and air temperature and the available supply of nutrients. Thus any deficiency in water use will reduce crop yields.

It can be considered as the quantity of water that must be furnished by irrigation to achieve maximum crop growth within an agricultural system. The frequency of months with potential water deficit depends on the rainfall pattern, the moisture characteristics of the soil, the rooting depth and the evapotranspiration value. The amount of deficit is quite sensitive to a change in the moisture storage capacity of the soil. It is therefore impossible to be precise in the water balance without considering a particular land use or crop. Each plant type bears an individual relationship to the potential evapotranspiration and thus the seasonal demands for water depend on land use (Hanna 1974).

The amount by which the actual and potential evapotranspiration differ in any months is called potential water deficit. The potential water deficit indicates that the plants are under some stress and if the crop justifies the cost the calculations would indicate the timing and magnitude of irrigation necessary to remove the stress.

9.10 Potential Water Deficits over the Central Elburz stations

In Iran particularly dry areas have high rates of evapotranspiration and uncertainty of rainfall which combine to make water the most important single control over agriculture and explains the considerable interest in rainfall and in methods of conserving soil water. Few researches have been concerned with the amount of annual rainfall but none have considered monthly rainfall, crop requirement to evaluate growing season conditions. The employment of the water balance method in the climatological investigation in the Central Elburz stations is an advance on previous studies. The lack of any literature on this area of study means that this work has to be discussed in the contest of research done elsewhere in comparable climates. The average monthly pattern of the climatic water balance, rainfall, potential evapotranspiration and taking into consideration soil moisture characteristics shown in tables and figures. The composite potential water deficit at the selected stations of the Central Elburz suggest certain spatial patterns that merit identification in terms of seasonal moisture regime.

Reference to previous discussion about Potential water deficit calculation, the results of the potential water deficit analysis of the Central Elburz stations has been demonstrated in Tables 9-1 to 9-16 and Figure 9-1 to 9-2. A 30 years of actual monthly rainfall and mean potential evapotranspiration have been used to calculate average potential water deficit. The monthly rates of available soil water in storage are calculated by accumulating the changes in storage brought about by the difference between rainfall and potential evapotranspiration up to the maximum available water capacity of 100 mm. Water surplus over this maximum will be run off in that month. Water storage in the soil can supplement rainfall and thus reduces the potential water deficit and can accumulate over a long wet period to give a subsistential benefit. In this study water balances derived from individual and average monthly are presented to emphasize the differences between the average year and water balance assessment based on many years. The calculation of the average balance assumes a continuity from month to month. In regard to this, it has been chosen to adapt method of water balance analysis. In this method, the water balance has been calculated continuously. First from January 1982 to December 1987 potential water deficits have been estimated for each of the twelve months of the year by a period of 5 years actual potential evapotranspiration and rainfall. The results of this calculations are given in Tables 9-1 to 9-12. Also the averages for six stations of the Central Elburz based on all years has been demonstrated in Table 9-13 and 9-14. Secondly from January 1958 to December 1987 potential water deficits have been estimated for each of the twelve months of the year by average potenial evapotranspiration and actual rainfall for each month. The results of this calculations are given in Tables 9-15 to 9-16. Generally in the case of all stations the results of the potential water deficit averaged over all years and the potential water deficit based on each individual years are nearly close.

9.11 Seasonal Moisture Regime

Regarding to Tables 9-1 to 9-16 and Figures 9-1 to 9- 2, in the case of Anzali except May, June, July and August the monthly potential water deficit average for other moths are zero. Also Babolsar station has similar situation as Anzali except September. Amount of potential water deficit at Gorgan station is more than zero for June, July August, September and October. For Ghazvin, the values of January, February, March, and December average months are at zero point but other months are more. Karaj station demonstrates that the values of January, February, March, and December average months are nearly zero the others are more than zero. In the case of Semnan the amounts of average months for all months are more than zero.

In summary several types of water balances can be recognized in the Central Elburz Stations:

a) Anzali type, where a water surplus prevails throughout the year. Average rainfall always exceeds the average potential evaporation. The rainfall shows a very relatively variation during the year. As it was previously explained the maximum occurs in the months of Autumn, but there is no clear minimum period.

b) East coast type, as exemplified by Babolsar and Gorgan. There is a large of water surplus in the period of October- April at Babolsar and November to May at Gorgan, but a moisture deficit between June and September-October which is caused by lower rainfall as well as increased evaporation.

c) Southern slope types, this type of water balance can be divided to two types of water balance:

1) Ghazvin and Karaj type, the months of April to November indicate moisture deficit water but from December to April there is water surplus at Ghazvin. Karaj type the months of April to November indicate moisture deficit but December to March is nearly water surplus.

2) Semnan type, there is no approximately moisture surplus in this station because of locating inland, closure to the Great Kavir (Great Desert of Iran) and distance of water resources (regarding chapter 3) where a water deficit prevails throughout the year. Average rainfall always is less than average potential evaporation. In this regard Semnan type water balance indicates a drought that it will be discussed in next pages.

A general features of following tables and figures is that the potential evaporation computed decreases when the rainfall goes up. This is due to by the higher relative humidity, lower temperatures and more cloudiness during times of rain as compared with dry periods. As a result those locations they have more rainfall than potential evaporation, the water deficit and potential water deficit are less. During summer when there is no Mediterranean air mass and area is under influence of subsidence potential water deficit is at high record in southern slope stations.

In summary the coastal area stations where a water surplus prevails throughout the year due to closer to the Caspian Sea and local conditions the water deficit is less. The rhythm of moisture deficit and surplus are similar for coastal stations but it differ from one station to another at southern slope stations.

Table 9-1 Anzali Monthly Water Balance using by Pan Evapotranspiration 1984-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1984	J	120.63	4.98	115.65	100	15.65	4.98	0
	F	215.75	4.5	211.25	100	111.25	4.5	0
	M	76.09	4.48	71.61	100	71.61	4.48	0
	A	34.35	4.62	29.73	100	29.73	4.62	0
	M	63.56	12.28	51.28	100	51.28	12.28	0
	J	8.3	54.09	-45.79	54.21		54.09	0
	J	3.12	83.4	-80.28			57.43	25.97
	A	162.01	53.2	108.81	100	8.81	53.2	0
	S	58.21	46	12.21	100	12.21	46	0
	O	357.7	29.15	328.55	100	328.55	29.15	0
	N	473	15.04	457.96	100	457.96	15.04	0
	D	361.15	8.39	352.76	100	352.76	8.39	0
1985	J	104.11	3.79	100.32	100	100.32	3.79	0
	F	113.22	4.57	108.65	100	108.65	4.57	0
	M	153.8	4.2	149.6	100	149.6	4.2	0
	A	16.24	4.31	11.93	100	11.93	4.31	0
	M	10.32	67.4	-57.08	42.92		53.24	14.16
	J	10.04	80.99	-70.95			10.04	70.95
	J	55.71	60.61	-4.9			55.71	4.9
	A	17.92	64.48	-46.56			17.92	46.56
	S	241.53	49.2	192.33	100	92.33	49.2	0
	O	548.43	26.52	521.91	100	521.91	26.52	0
	N	251.02	21.51	229.51	100	229.51	21.51	0
	D	274.3	11.04	263.26	100	263.26	11.04	0

Table 9-2 Anzali Monthly Water Balance using by Pan Evapotranspiration 1984-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1986	J	152.1	12	140.1	100	140.1	12	0
	F	86.8	4.61	82.19	100	82.19	4.61	0
	M	111.71	4.29	107.42	100	107.42	4.29	0
	A	22.04	32.3	-10.26	89.74		32.3	0
	M	52.21	34.59	17.62	100	7.36	34.59	0
	J	191.34	56.47	134.87	100	134.87	56.47	0
	J	8.74	90.56	-81.82	18.18		26.92	63.64
	A	58.02	84.6	-26.58			58.02	26.58
	S	206.73	59.74	146.99	100	46.99	59.74	0
	O	231.03	19.16	211.87	100	211.87	19.16	0
	N	513.08	11.83	501.25	100	501.25	11.83	0
	D	464.8	0.91	463.89	100	463.89	0.91	0
1987	J	47.71	4.34	43.37	100	43.37	4.34	0
	F	110.54	5.68	104.86	100	104.86	5.68	0
	M	91.35	4.06	87.29	100	87.29	4.06	0
	A	43.35	30.8	12.55	100	12.55	30.8	0
	M	6.32	57.35	-51.03	48.97		55.29	2.06
	J	0.11	76.75	-76.64			0.11	76.64
	J	48.7	76.32	-27.62			48.7	27.62
	A	308.03	54.09	253.94	100	153.94	54.09	0
	S	172.3	29.33	142.97	100	42.97	29.33	0
	O	564.3	13.29	551.01	100	451.01	13.29	0
	N	167.41	18.12	149.29	100	49.29	18.12	0
	D	194.5	18.09	176.41	100	76.41	18.09	0

Table 9-3 Babolsar Monthly Water Balance using by Pan Evapotranspiration 1982-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1982	J	202.41	4.29	198.12	100	98.12	4.29	0
	F	116.6	4.55	112.05	100	112.05	4.55	0
	M	80.33	5.37	74.96	100	74.96	5.37	0
	A	3.07	7.52	-4.45	95.55		7.52	0
	M	51.66	73.86	-22.2	73.35		73.86	0
	J	28.81	108.3	-79.49			28.81	79.49
	J	19.62	123.3	-103.68			19.62	103.68
	A	66.62	100.3	-33.68			66.62	33.68
	S	34.22	82.56	-48.34			34.22	48.34
	O	92.02	4.128	87.892	87.89		4.128	0
	N	269.42	3.29	266.13	100	254.02	3.29	0
	D	41.01	4.46	36.55	100	36.55	4.46	0
1983	J	133.04	4.17	128.87	100	128.87	4.17	0
	F	12.8	4.53	8.27	100	8.27	4.53	0
	M	91.51	5.25	86.26	100	86.26	5.25	0
	A	19.7	6.19	13.51	100	13.51	6.19	0
	M	23.01	106.6	-83.59	16.41		39.42	67.18
	J	28.81	97.5	-68.69			28.81	68.69
	J	6	145.6	-139.6			6	139.6
	A	140.71	120.9	19.81	19.81		120.9	0
	S	62.95	59.4	3.55	23.36		59.4	0
	O	67.64	54.2	13.44	36.8		54.2	0
	N	56.01	13.88	42.13	78.93		13.88	0
	D	151.34	4.29	147.05	100	125.98	4.29	0
1984	J	81.9	4.29	77.61	100	77.61	4.29	0
	F	66.91	4.77	62.14	100	62.14	4.77	0
	M	39.86	5.01	34.85	100	34.85	5.01	0
	A	6.82	7.35	-0.53	99.47		7.35	0
	M	20.11	43.89	-23.78	75.69		43.89	0
	J	25.61	49.52	-23.91	51.78		49.52	0
	J	4.9	120.8	-115.9			4.9	115.9
	A	111.83	71.6	40.23	40.23		71.6	0
	S	8.03	61.65	-53.62			8.03	53.62
	O	268.12	40.78	227.34	100	127.34	40.78	0
	N	138.44	16.88	121.56	100	121.56	16.88	0
	D	226.51	4.29	222.22	100	222.22	4.29	0

Table 9-4 Babolsar Monthly Water Balance using by Pan Evapotranspiration 1982-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1985	J	47.13	4.29	42.84	100	42.84	4.29	0
	F	130.3	4.77	125.53	100	125.53	4.77	0
	M	71.36	5.2	66.16	100	66.16	5.2	0
	A	6.71	7.6	-0.89	99.11		7.6	0
	M	3.6	89.84	-86.24	12.87		16.47	73.37
	J	6.01	98.05	-92.04			12.88	85.17
	J	10.11	88.14	-78.03			10.11	78.03
	A	73	95.21	-22.21			73	22.21
	S	20.4	52	-31.6			20.4	31.6
	O	206.2	29.24	176.96	100	76.96	29.24	0
	N	42.5	10.46	32.04	100	32.04	10.46	0
	D	92.42	4.98	87.44	100	87.44	4.98	0
1986	J	85	4.54	80.46	100	80.46	4.54	0
	F	64.12	4.81	59.31	100	59.31	4.81	0
	M	90.5	5.07	85.43	100	85.43	5.07	0
	A	11.64	7.3	4.34	100	4.34	7.3	0
	M	2.05	59.22	-57.17	42.83		44.88	14.34
	J	24.11	86.08	-61.97			24.11	61.97
	J	16.01	89.64	-73.63			16.01	73.63
	A	12	92.48	-80.48			12	80.48
	S	106.41	72.52	33.89	33.89		72.52	0
	O	126.21	37.77	88.44	100	22.33	37.77	0
	N	324.6	30.13	294.47	100	294.47	30.13	0
	D	133.9	5.37	128.53	100	128.53	5.37	0
1987	J	15.51	4.54	10.97	100	10.97	4.54	0
	F	67.1	4.81	62.29	100	62.29	4.81	0
	M	64.97	5.07	59.9	100	59.9	5.07	0
	A	43.31	7.3	36.01	100	36.01	7.3	0
	M	3.4	66.31	-62.91	37 09		40.49	25.82
	J	1.01	100.7	-99.69			1.01	99.69
	J	11.61	109.4	-97.79			11.61	97.79
	A	202.74	80.59	122.15	100	22.15	80.59	0
	S	41.5	46.06	-4.56	95.44		46.06	0
	O	369.01	30.64	338.37	100	333.81	30.64	0
	N	77.9	14.03	63.87	100	63.87	14.03	0
	D	181.81	5.18	176.63	100	176.63	5.18	0

Table 9-5 Gorgan Monthly Water Balance using by Pan Evapotranspiration 1984-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1984	J	33.9	4.58	29.32	29.32		4.58	0
	F	62.2	4.29	57.91	87.23		4.29	0
	M	53.72	5.53	48.19	100	35.42	5.53	0
	A	34.7	7.92	26.78	100	26.78	7.92	0
	M	98.6	43.2	55.4	100	55.4	43.2	0
	J	31.31	99.04	-67.73	32.27		63.58	35.46
	J	3.7	121.3	-117.6			3.7	117.6
	A	44.4	64.66	-20.26			44.4	20.26
	S	2.6	76.06	-73.46			2.6	73.46
	O	68.2	55.28	12.92	12.92		55.28	0
	N	78.5	33.37	45.13	58.05		33.37	0
	D	48.9	5.04	43.86	100	1.91	5.04	0
1985	J	48.2	4.19	44.01	100	44.01	4.19	0
	F	100.6	4.88	95.72	100	95.72	4.88	0
	M	32.3	5.23	27.07	100	27.07	5.23	0
	A	29.8	7.88	21.92	100	21.92	7.88	0
	M	5	29.44	-24.44	75.56		29.44	0
	J	13.4	35.63	-22.23	53.33		35.63	0
	J	3.6	37.54	-33.94	19.39		22.99	14.55
	A	36.4	118.4	-82			36.4	82
	S	26.2	99.97	-73.77			26.2	73.77
	O	62.9	59.68	3.22	3.22		59.68	0
	N	15.1	10.6	4.5	7.72		10.6	0
	D	55.9	4.37	51.53	59.25		4.37	0

Table 9-6 Gorgan Monthly Water Balance using by Pan Evapotranspiration1982-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1986	J	39	4.47	34.53	93.78		4.47	0
	F	78	5.25	72.75	100	66.53	5.25	0
	M	46.2	5.68	40.52	100	40.52	5.68	0
	A	31.8	7.48	24.32	100	24.32	7.48	0
	M	15.02	52.06	-37.04	62.95		52.06	0
	J	3.12	153.9	-150.78			3.12	150.78
	J	14	133.1	-119.1			14	119.1
	A	14	133.2	-119.2			14	119.2
	S	63	110.7	-47.7			63	47.7
	O	19.2	57.35	-38.15			19.2	38.15
	N	86.1	30.59	55.51	55.51		30.59	0
	D	66.9	4.2	62.7	100	18.21	4.2	0
1987	J	49.6	4.63	44.97	100	44.97	4.63	0
	F	67.1	4.9	62.2	100	62.2	4.9	0
	M	116.2	5.59	110.61	100	110.61	5.59	0
	A	60.51	6.99	53.52	100	53.52	6.99	0
	M	33.1	80.52	-47.42	52.58		80.52	0
	J	2.1	120.5	-118.4			2.1	118.4
	J	24.1	120.8	-96.7			24.1	96.7
	A	46.4	99.22	-52.82			46.4	52.82
	S	39.5	85.9	-46.4			39.5	46.4
	O	95.91	41.71	54.2	54.2		41.71	0
	N	27.9	22.65	5.25	59.45		22.65	0
	D	48	4.5	43.5	100	2.95	4.5	0

Table 9-7 Ghazvin Monthly Water Balance using by Blaney-Criddle method 1982-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1982	J	58.92	13.8	45.12	45.12		13.8	0
	F	104.64	14	90.64	100	35.76	14	0
	M	56.01	26.8	29.21	100	29.21	26.8	0
	A	28.25	72	-43.75	56.25		72	0
	M	39.69	91.07	-51.38	4.87		44.52	46.55
	J	13.43	110.5	-97.07			13.43	97.07
	J	1.73	125.9	-124.17			1.73	124.17
	A	0	110.8	-110.8			0	110.8
	S	1.01	89.51	-88.5			1.01	88.5
	O	57.96	54.77	3.19	3.19		54.77	0
	N	62.74	24.26	38.48	41.57		24.26	0
	D	72.51	20.54	51.97	93.64		20.54	0
1983	J	29.94	22.5	7.44	100	1.08	22.5	0
	F	30.6	9.38	21.22	100	21.22	9.38	0
	M	38.03	27.9	10.13	100	10.13	27.9	0
	A	33.22	55.8	-22.58	77.42		55.8	0
	M	47.04	88.38	-41.34	36.08		83.15	5.23
	J	9.54	109.6	-100.06			9.54	100.06
	J	0	130	-130			0	130
	A	0	120.6	-120.6			0	120.6
	S	2.02	88.36	-86.34			2.02	86.34
	O	0	61.58	-61.58			0	61.58
	N	57.04	41.65	15.39	15.39		41.65	0
	D	32.65	18.99	13.66	29.08		18.99	0
1984	J	26.31	16.4	9.91	38.96		16.4	0
	F	24.76	8.44	16.32	55.28		8.44	0
	M	106.66	40.9	65.76	100	21.04	40.9	0
	A	56.64	61.5	-4.86	95.14		61.5	0
	M	47.71	73.58	-25.87	69.27		73.58	0
	J	0	110.1	-110.1			0	110 1
	J	0.11	130.4	-130.29			0.11	130.29
	A	2.92	118.5	-115.58			2.92	115.58
	S	0.1	88.74	-88.64			0.1	88.64
	O	37.51	59.07	-21.56			37.51	21.56
	N	61.03	35.01	26.02	26.02		35.01	0
	D	76.54	19.61	56.93	82.95		19.61	0

Table 9-8 Ghazvin Monthly Water Balance using by Blaney-Criddle method 1982-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1985	J	57.12	9.09	48.03	100	30.98	9.09	0
	F	47.13	18.4	28.73	100	28.73	18.4	0
	M	24.11	26	-1.89	98.11		26	0
	A	19.26	63.1	-43.84	54.27		63.1	0
	M	4.55	92.86	-88.31			4.55	88.31
	J	0.44	116.8	-116.36			0.44	116.36
	J	0	126.8	-126.8			0	126.8
	A	7.31	111.2	-103.89			7.31	103.89
	S	0	94.47	-94.47			0	94.47
	O	3.91	61.22	-57.31			3.91	57.31
	N	34.92	40.39	-5.47			34.92	5.47
	D	49.61	20.54	29.07	29.07		20.54	0
1986	J	16.82	16.1	0.72	29.79		16.1	0
	F	27.55	21.6	5.95	35.74		21.6	0
	M	32.94	26	6.94	42.68		26	0
	A	41.76	59	-17.24	25.44		59	0
	M	39.88	81.21	-41.33			39.88	41.33
	J	10.72	106.9	-96.18			10.72	96.18
	J	0.02	131.4	-131.38			0.02	131.38
	A	5.03	114.6	-109.57			5.03	109.57
	S	0.11	91.04	-90.93			0.11	90.93
	O	27.42	66.96	-39.54			27.42	39.54
	N	67.36	31.22	36.14	36.14		31.22	0
	D	29.2	11.54	17.66	53.8		11.54	0
1987	J	9.71	21.2	-11.49	42.31		21.2	0
	F	25.72	26.6	-0.88	41.43		26.6	0
	M	120.53	34	86.53	100	27.96	34	0
	A	44.42	57.8	-13.38	86.62		57.8	0
	M	24.4	95.55	-71.15	15.47		39.87	55.68
	J	2	116.8	-114.8			2	114.8
	J	5.51	124.5	-118.99			5.51	118.99
	A	0.82	117.6	-116.78			0.82	116.78
	S	0.33	88.36	-88.03			0.33	88.03
	O	109.62	48.67	60.95	60.95		48.67	0
	N	17.92	37.22	-19.3	41.65		37.22	0
	D	45.85	20.85	25	66.65		20.85	0

Table 9-9 Karaj Monthly Water Balance using by Blaney-Criddle method 1982-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1982	J	31	15.1	15.9	15.9		15.1	0
	F	42.1	13.1	29	44.9		13.1	0
	M	38.9	29.8	9.1	54		29.8	0
	A	11.6	72.8	-61.2			11.6	61.2
	M	25.7	93.31	-67.61			25.7	67.61
	J	2	110.5	-108.5			2	108.5
	J	0	126.3	-126.3			0	126.3
	A	0	110.8	-110.8			0	110.8
	S	0	89.89	-89.89			0	89.89
	O	98.8	54.77	44.03	44.03		54.77	0
	N	54.7	23.63	31.07	75.1		23.63	0
	D	59.4	17.75	41.65	100	16.75	17.75	0
1983	J	19	21.5	-2.5	97.5		21.5	0
	F	14.3	10.9	3.4	100	0.9	10.9	0
	M	37.4	28.7	8.7	100	8.7	28.7	0
	A	43.9	56.6	-12.7	87.3		56.6	0
	M	27.1	90.62	-63.52	23.78		50.88	39.74
	J	13.2	111.9	-98.7			13.2	98.7
	J	0	133.2	-133.2			0	133.2
	A	0	120.6	-120.6			0	120.6
	S	6.6	89.13	-82.53			6.6	82.53
	O	0.4	62.66	-62.26			0.4	62.26
	N	26.3	42.28	-15.98			26.3	15.98
	D	61.3	19.61	41.69	41.69		19.61	0
1984	J	21.8	15.8	6	47.69		15.8	0
	F	19.7	8.44	11.26	58.95		8.44	0
	M	54.7	42.8	11.9	70.85		42.8	0
	A	17.3	63.9	-46.6	24.25		41.55	22.35
	M	41.4	76.72	-35.32			41.4	35.32
	J	0	111	-111			0	111
	J	0	130.9	-130.9			0	130.9
	A	0	121.5	-121.5			0	121.5
	S	0	92.18	-92.18			0	92.18
	O	10.4	60.15	-49.75			10.4	49.75
	N	54.6	37.54	17.06	17.06		37.54	0
	D	57.5	17.44	40.06	57.12		17.44	0

Table 9-10 Karaj Monthly Water Balance using by Blaney-Criddle method 1982-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1985	J	70.3	11.3	59	100	16.12	11.3	0
	F	35	20.3	14.7	100	14.7	20.3	0
	M	17.7	28.7	-11	89		28.7	0
	A	0	67.9	-67.9	21.1		21.1	46.8
	M	0.3	97.79	-97.49			0.3	97.49
	J	0	118.1	-118.1			0	118.1
	J	0	127.2	-127.2			0	127.2
	A	0.5	112	-111.5			0.5	111.5
	S	0	97.15	-97.15			0	97.15
	O	1	64.09	-63.09			1	63.09
	N	28.5	41.34	-12.84			28.5	12.84
	D	45.2	22.71	22.49	22.49		22.71	0
1986	J	3.5	19.3	-15.8	6.69		10.19	9.11
	F	15.6	24.7	-9.1			15.6	9.1
	M	46.5	27.5	19	19		27.5	0
	A	58.3	61.5	-3.2	15.8		61.5	0
	M	60.2	84.79	-24.59			60.2	24.59
	J	2.7	111.4	-108.7			2.7	108.7
	J	0	133.2	-133.2			0	133.2
	A	1.3	117.6	-116.3			1.3	116.3
	S	0	94.47	-94.47			0	94.47
	O	6.9	71.27	-64.37			6.9	64.37
	N	39.3	33.11	6.19	6.19		33.11	0
	D	31	14.03	16.97	23.16		14.03	0
1987	J	4.8	23.7	-18.9	4.26		9.06	14.64
	F	45.2	27.8	17.4	21.66		27.8	0
	M	93.8	37.8	56	77.66		37.8	0
	A	25.7	61.5	-35.8	41.86		61.5	0
	M	19.3	99.59	-80.29			19.3	80.29
	J	1	120.4	-119.4			1	119.4
	J	4.1	127.7	-123.6			4.1	123.6
	A	0	121.5	-121.5			0	121.5
	S	0.2	90.65	-90.45			0.2	90.45
	O	97.4	50.46	46.94	46.9		50.46	0
	N	8.4	40.07	-31.67	15.23		23.63	16.44
	D	34.5	23.65	10.85	10.85		23.65	0

Table 9-11 Semnan Monthly Water Balance using by Blaney-Criddle method 1984-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1984	J	10.21	23.4	-13.19			10.21	13.19
	F	5.22	18.1	-12.88			5.22	12.88
	M	32.35	54.6	-22.25			32.35	22.25
	A	16.41	82.1	-65.69			16.41	65.69
	M	38.23	97.79	-59.56			38.23	59.56
	J	3.02	138.4	-135.38			3.02	135.38
	J	0	150.1	-150.1			0	150.1
	A	0	146.4	-146.4			0	146.4
	S	0.1	107	-106.9			0.1	106.9
	O	2	70.19	-68.19			2	68.19
	N	16.01	45.45	-29.44			16.01	29.44
	D	12.92	14.34	-1.42			12.92	1.42
1985	J	47.51	19.3	28.21			19.3	0
	F	24.61	27.8	-3.19			24.61	3.19
	M	2.58	42	-39.42			2.58	39.42
	A	7.2	84.9	-77.7			7.2	77.7
	M	0.6	115.7	-115.1			0.6	115.1
	J	2	146	-144			2	144
	J	0	156.5	-156.5			0	156.5
	A	21	126.6	-105.6			21	105.6
	S	0	111.2	-111.2			0	111.2
	O	1.1	74.86	-73.76			1.1	73.76
	N	3.03	49.87	-46.84			3.03	46.84
	D	4.52	29.23	-24.71			4.52	24.71

Table 9-12 Semnan Monthly Water Balance using by Blaney-Criddle method 1984-1987.

Years	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
1986	J	0.92	25	-24.08			0.92	24.08
	F	14.81	30	-15.19			14.81	15.19
	M	16.5	38.6	-22.1			16.5	22.1
	A	26.62	78.9	-52.28			26.62	52.28
	M	15.72	111.2	-95.48			15.72	95.48
	J	0.82	133.4	-132.58			0.82	132.58
	J	4.6	151	-146.4			4.6	146.4
	A	41	128.8	-87.8			41	87.8
	S	0.01	105.5	-105.49			0.01	105.49
	O	0.6	83.47	-82.87			0.6	82.87
	N	37.83	41.65	-3.82			37.83	3.82
	D	36.22	18.99	17.23	17.23		18.99	0
1987	J	2.62	27.6	-24.98			2.62	24.98
	F	8.51	32.9	-24.39			8.51	24.39
	M	47.93	50.4	-2.47			47.93	2.47
	A	1.22	79.3	-78.08			1.22	78.08
	M	15.73	119.7	-103.97			15.73	103.97
	J	0	140.6	-140.6			0	140.6
	J	10.63	146.4	-135.77			10.63	135.77
	A	0.21	140	-139.79			0.21	139.79
	S	5.01	107.4	-102.39			5.01	102.39
	O	24.27	63.02	-38.75			24.27	38.75
	N	0.01	48.93	-48.92			0.01	48.92
	D	26.31	28.92	-2.61			26.31	2.61

Table 9-13 Average Potential water deficit over the Central Elburz 1982-1987.

Stations	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
	J	106.1	6.3	99.9	100	74.9	6.3	0
	F	131.6	4.8	126.7	100	101.7	4.8	0
	M	108.2	4.3	104.0	100	104.0	4.3	0
	A	29.0	18.0	11.0	97.4	18.1	18.0	0
	M	33.1	42.9	-9.8	73.0	29.3	38.9	4.1
Anzali	J	52.4	67.1	-14.6	77.1	134.9	30.2	36.9
	J	29.1	77.7	-48.7	18.2		33.6	44.1
	A	136.5	64.1	72.4	100	81.4	45.8	18.3
	S	169.7	46.1	123.6	100	48.6	46.1	0
	O	425.4	22.0	403.3	100	378.3	22.0	0
	N	351.1	16.6	334.5	100	309.5	16.6	0
	D	323.7	9.6	314.1	100	289.1	9.6	0
	J	94.2	4.4	89.8	100	73.1	4.4	0
	F	76.3	4.7	71.6	100	71.6	4.7	0
	M	73.1	5.2	67.9	100	67.9	5.2	0
	A	15.2	7.2	8.0	99.02	18.0	7.2	0
	M	17.3	73.3	-56.0	43.04		43.2	30.1
Babolsar	J	19.1	90.0	-71.0	51.78		23.0	67.0
	J	11.4	112.8	-101.4			11.4	101.4
	A	101.2	93.5	7.6	53.34	22.15	70.8	22.7
	S	45.6	62.4	-16.8	50.9		40.1	22.3
	O	188.2	32.8	155.4	87.45	140.1	32.8	0
	N	151.5	14.8	136.7	96.45	153.2	14.8	0
	D	137.8	4.8	133.1	100	129.6	4.8	0
	J	42.7	4.5	38.2	80.8	44.5	4.5	0
	F	77.0	4.8	72.1	96.8	74.8	4.8	0
	M	62.1	5.5	56.6	100	53.4	5.5	0
	A	39.2	7.6	31.6	100	31.6	7.6	0
	M	37.9	51.3	-13.4	72.8	55.4	51.3	0
Gorgan	J	12.5	102.3	-89.8	42.8		26.1	76.2
	J	11.4	103.2	-91.8	19.4		16.2	87.0
	A	35.3	103.9	-68.6			35.3	68.6
	S	32.8	93.2	-60.3			32.8	60.3
	O	61.6	53.5	8.0	23.4		44.0	9.5
	N	51.9	24.3	27.6	45.2		24.3	0
	D	54.9	4.5	50.4	89.8	7.7	4.5	0

Table 9-14 Average Potential water deficit over the Central Elburz1982-1987.

Stations	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
Ghazvin	J	33.14	16.5	16.6	59.36	5.34	16.52	0
	F	43.40	16.4	27.0	72.08	14.28	16.40	0
	M	63.05	30.3	32.8	90.13	14.96	30.27	0
	A	37.26	61.5	-24.3	65.86		61.53	0
	M	33.88	87.1	-53.2	31.42		47.59	39.52
	J	6.02	111.8	-105.8			6.02	105.76
	J	1.23	128.2	-126.9			1.23	126.94
	A	2.68	115.6	-112.9			2.68	112.87
	S	0.60	90.1	-89.5			0.60	89.49
	O	39.40	58.7	-19.3	32.07		28.71	30.00
	N	50.17	35.0	15.2	32.15		34.05	0.91
	D	51.06	18.7	32.4	59.20		18.68	0
Karaj	J	25.07	17.78	7.3	45.3	2.68	13.83	2.4
	F	28.65	17.54	11.1	65.1	2.6	16.02	1.5
	M	48.17	32.55	15.6	68.4	1.45	32.55	0
	A	26.13	64.03	-37.9	38.1		42.31	21.7
	M	29.00	90.47	-61.5	23.8		32.96	57.5
	J	3.15	113.9	-110.7			3.15	110.7
	J	0.68	129.8	-129.1			0.68	129.1
	A	0.30	117.3	-117.0			0.30	117.0
	S	1.13	92.25	-91.1			1.13	91.1
	O	35.82	60.57	-24.8	45.5		20.66	39.9
	N	35.30	36.33	-1.0	28.4		28.79	7.5
	D	48.15	19.20	29.0	45.1		19.20	0
Semnan	J	15.3	23.8	-8.5			8.3	15.6
	F	13.3	27.2	-13.9			13.3	13.9
	M	24.8	46.4	-21.6			24.8	21.6
	A	12.9	81.3	-68.4			12.9	68.4
	M	17.6	111.1	-93.5			17.6	93.5
	J	1.5	139.6	-138.1			1.5	138.1
	J	3.8	151.0	-147.2			3.8	147.2
	A	15.6	135.5	-119.9			15.6	119.9
	S	1.3	107.8	-106.5			1.3	106.5
	O	7.0	72.9	-65.9			7.0	65.9
	N	14.2	46.5	-32.3			14.2	32.3
	D	20.0	22.9	-2.9	4.37		15.7	7.2

Table 9-15 Average Potential water deficit over the Central Elburz 1958-1987.

Stations	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
Anzali	J	174.5	6.3	168.2	98.6	166.2	6.3	0
	F	135.1	4.8	130.3	100	135.3	4.8	0
	M	111.2	4.3	106.9	100	103.7	4.3	0
	A	55.2	18	37.2	99.2	48.2	18.0	0
	M	46.6	42.9	3.7	87.7	103.6	42.4	0.5
	J	54.6	67.1	-12.5	70	122.0	58.5	8.6
	J	51.4	77.7	-29.1	55.1	175.6	50.8	26.9
	A	126	64.1	59.2	83.3	116.7	53.4	10.7
	S	233.5	46.1	187.4	95.6	155.7	46.1	0
	O	346	22	324	99.3	294.3	22.0	0
	N	287.7	16.6	271.1	100	247.6	16.6	0
	D	214.4	9.6	204.8	100	175.4	9.6	0
Babolsar	J	88.4	4.4	81.3	97.5	82.6	4.4	0
	F	70.3	4.7	68.3	98.8	66.5	4.7	0
	M	61.7	5.2	53.6	99.9	57.4	5.2	0
	A	32.2	7.2	22.4	99.6	29.1	7.2	0
	M	19.0	73.3	-54.5	45.1	10.7	43.5	28.3
	J	22.0	90.0	-66.9	35.7		24.2	64.8
	J	25.6	112.8	-87.7	16.6		24.5	89.9
	A	56.7	93.5	-32.6	58.4	22.2	48.2	44.4
	S	77.5	62.4	13.5	55.8	44.5	47.9	16
	O	158.1	32.8	125.9	87.3	103.9	32.6	0.2
	N	130.8	14.8	119.8	99	108.7	14.8	0
	D	128.2	4.8	121.7	100	119.1	4.8	0
Gorgan	J	62.8	4.5	59.6	94.7	51.1	4.5	0
	F	64.2	4.8	58.8	99.1	78.7	4.8	0
	M	82.6	5.5	77.3	100.0	58.1	5.5	0
	A	54.0	7.6	47.0	100.0	49.7	7.6	0
	M	48.3	51.3	-0.2	85.8	56.2	50.2	0
	J	36.1	102.3	-61.4	38.7	57.8	48.4	51
	J	26.1	103.2	-74.9	40.3	25.2	26.1	75
	A	29.8	103.9	-73.2	19.2	54.3	30.5	73
	S	39.8	93.2	-53.9	12.0	50.4	38.9	54
	O	80.8	53.5	28.7	41.7	62.2	46.5	7
	N	73.5	24.3	49.5	65.0	70.7	24.1	0
	D	64.6	4.5	60.6	92.1	45.0	4.5	0

Table 9-16 Average Potential water deficit over the Central Elburz 1958-1987 (con).

Stations	Months	P	PE	ΔS	Acc.S.W	R	AE	P.W.D
Ghazvin	J	42	17	25	53	27.49	16	0
	F	36	16	19	67	27.78	16	0
	M	53	30	23	73	39.42	30	0
	A	43	62	-19	59	9.55	54	8
	M	36	87	-51	36		40	47
	J	6	112	-106	0		6	106
	J	3	128	-125	0		3	125
	A	2	116	-114	0		2	114
	S	1	90	-89	0		1	89
	O	21	59	-38	23		18	40
	N	29	35	-6	30		20	15
	D	44	19	25	42	8.45	17	1
Karaj	J	30.41	17.78	12.63	39.13	16.12	15.96	1.83
	F	25.68	17.54	8.14	53.25	7.8	15.73	1.81
	M	38.14	32.55	5.59	53.06	14.36	29.50	3.05
	A	34.99	64.03	-29.04	34.64		41.47	22.56
	M	22.95	90.47	-67.52	9.59		24.03	66.44
	J	3.95	113.9	-109.95	0		3.95	109.95
	J	1.64	129.8	-128.15	0		1.64	128.15
	A	1.17	117.3	-116.14	0		1.17	116.14
	S	0.97	92.25	-91.28	0		0.97	91.28
	O	15.87	60.57	-44.70	45.94		12.84	47.73
	N	21.03	36.33	-15.30	19.67		18.33	18.00
	D	33.12	19.20	13.92	30.86	16.75	16.63	2.57
Semnan	J	20.5	23.8	-3.3	6.7		13.7	10.1
	F	17.5	27.2	-9.7	3.6		16.6	10.6
	M	20.7	46.4	-25.7			20.9	25.5
	A	14.5	81.3	-66.8			14.5	66.8
	M	15.2	111.1	-95.9			15.2	95.9
	J	2.8	139.6	-136.8			2.8	136.8
	J	1.2	151.0	-149.8			1.2	149.8
	A	3.6	135.5	-131.9			3.6	131.9
	S	1.5	107.8	-106.3			1.5	106.3
	O	6.4	72.9	-66.5			6.4	66.5
	N	8.3	46.5	-38.2			8.3	38.2
	D	16.9	22.9	-6.0	3		12.9	10.0

Table 9-17 Average Potential water deficit for PE and 5 years rainfall over the Central Elburz

	Stations					
Months	Anzali	Babolsar	Gorgan	Ghazvin	Karaj	Semnan
J	0	0	0	0	4.5	14.4
F	0	0	0	0	0	13.3
M	0	0	0	0	0	21.9
A	0	0	0	0	19.7	68.4
M	0	21.4	0	38.2	58.8	93.5
J	21.2	68.8	82.6	105.8	110.8	138.1
J	31.4	101.4	91.9	127	129.1	147.2
A	11.5	21.5	68.6	112.9	117	119.9
S	0	20.8	60.4	89.5	91.1	106.5
O	0	0	8.6	27.8	37.3	65.9
N	0	0	2.3	0	3	32.3
D	0	0	0	0	0	7.1

Table 9-18 Deviation Average Potential water deficit PE and 5 years rainfall from the actual PE and rainfall over the Central Elburz

	Stations					
Months	Anzali	Babolsar	Gorgan	Ghazvin	Karaj	Semnan
J	0	0	0	0	2.1	-1.2
F	0	0	0	0	-1.5	-0.6
M	0	0	0	0	0	0.3
A	0	0	0	0	-2	0
M	-4.1	-8.7	0	-1.32	1.3	0
J	-15.7	1.8	6.4	0.04	0.1	0
J	-12.7	0.025	4.9	0.06	0	0
A	-6.7	-1.2	0	0.03	0	0
S	0	-1.5	0.1	0.01	0	0
O	0	0	-0.9	-2.2	-2.6	0
N	0	0	2.3	-0.91	-4.5	0
D	0	0	0	0	0	-0.1

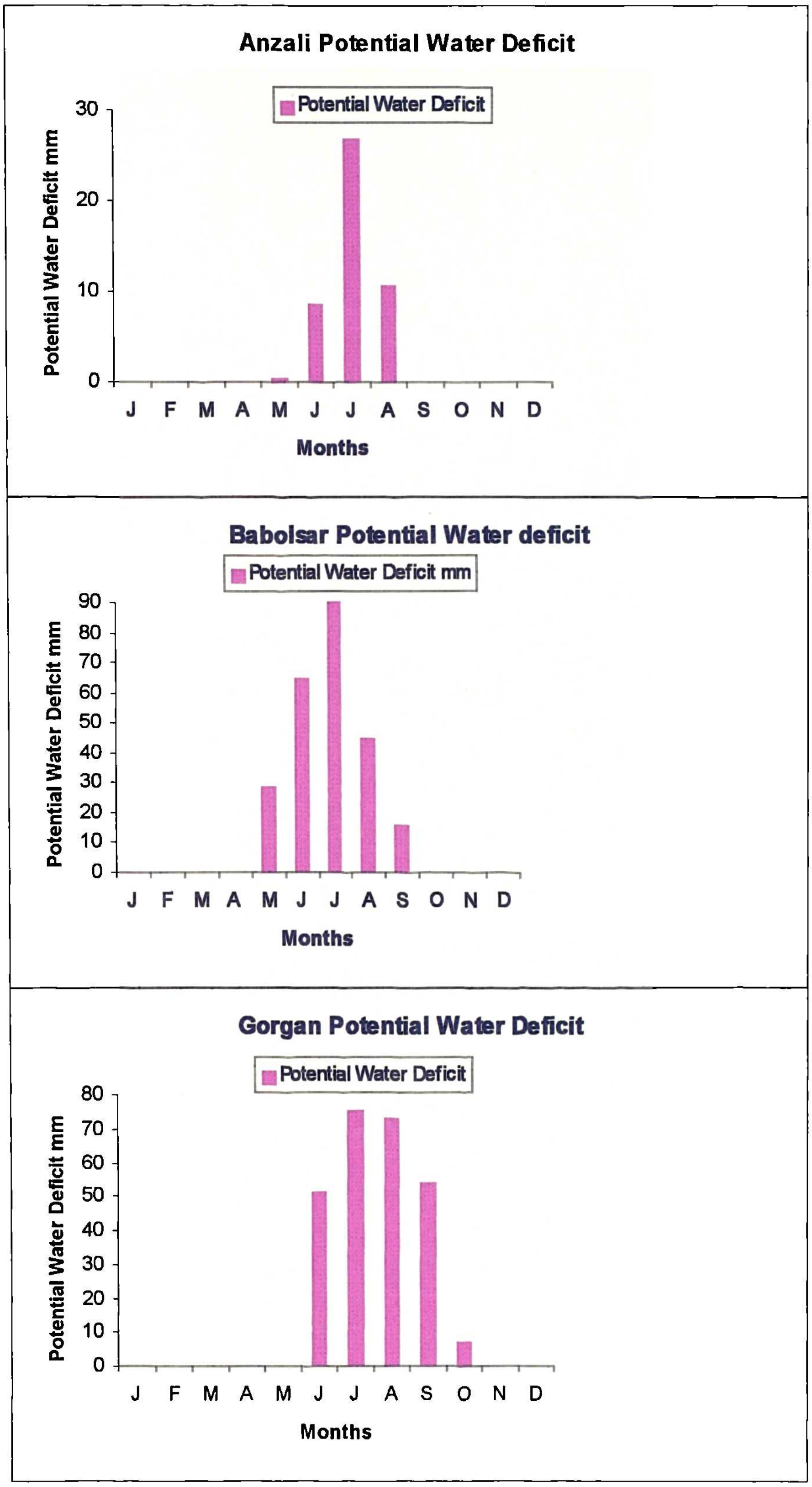


Figure 9-1 Average Potential Water Deficit over the Coastal Area Stations 1958-1987.

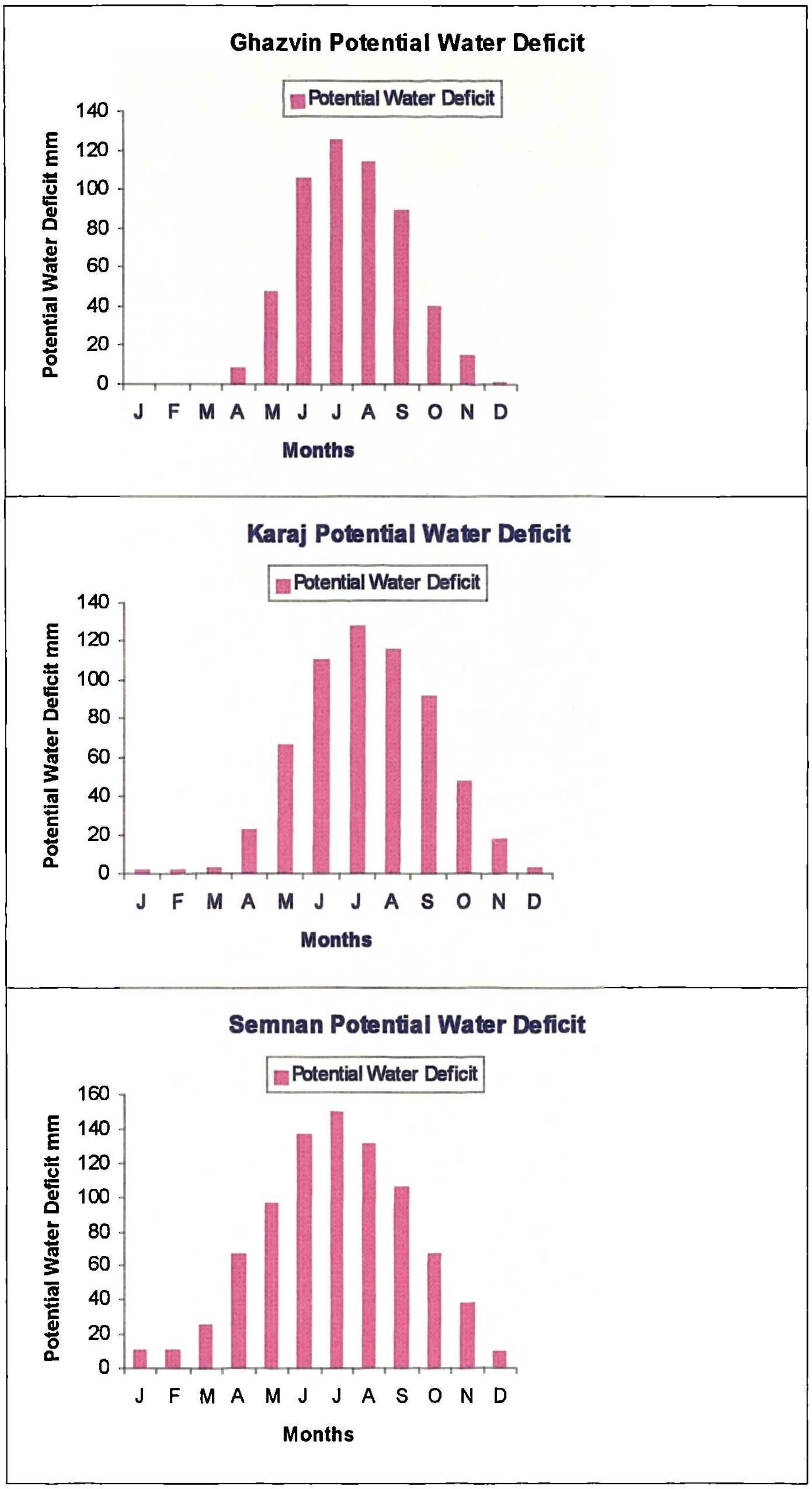


Figure 9-2 Average Potential Water Deficit over the Southern Slope Stations 1958-1987.

9.12 Probability of Potential Water Deficit and Determination of Wet and Dry Months

The wet season and the wet month in water balance will often be different from the definition by rainfall alone. Since it describes the soil water condition from an agricultural viewpoint, it is a more valuable assessment.

A month can be considered wet if rainfall and soil water satisfies potential evapotranspiration which means no potential water deficit (Hanna 1975). Because of the highly variable rainfall in Iran, there is a need to consider the chance of adequate soil moisture being realized for agricultural planning of this area. The monthly potential water deficits is provided the basis for calculation the upper and lower limit for probability estimate. In this regard probability of potential water deficit for each month for a long term (30 years) has been calculated. The analysis results for the Central Elburz stations have been shown in Tables 9-19 to 9-20 and Figures 9-3 to 9-4.

Regarding to Tables 9-19 to 9-20 and Figures 9-3 to 9-4 the wet months for Anzali are September to April, it differs at Babosar from October to April. In Gorgan the wet months are during November to May. However, there is no exact lower limit at zero point in the southern slope stations but some of months are near zero. Thus it can be said the period of November to April is nearly wet at Ghazvin, Karaj and Semnan stations. Therefore analysis showed two different wet and dry areas. The southern slope stations must be carefully considered in any agricultural planning. As previously pointed out there are differences between rainy season on the coastal area and the southern slop stations over the Central Elburz. Also it is proven by this analysis and it can be said that the coastal area and the southern slope stations have two different regimes.

Referring back to chapter 3 (Seasonal Rainfall Pattern) about wet months and chapter 7 about timing of rainfall based on monthly and daily rainfall alone, these are similar with wet months estimated by water balance method on coastal area stations. However, the length of wet months based on water balance is short or does not exist for southern slope stations. But it occurs during the timing of rainfall and wet months previously have been defined by rainfall alone.

The wet months have the general consequence of lowering deficits while they are higher during the dry months. In wetter months distributions are normal while dry months are skewed. If the lower limit is more than zero the month is considered dry. The severity of the drought depends on the value of the lower limit. In this regard the coastal area stations of the Central Elburz have about 8 months lower limit as zero. Thus it is obvious there is a few drought months (about May to October) in this part of Iran. But the southern slope stations with long persistent dry season and high monthly deficits is also characterised by a short wet season. Since the southern slope stations have a long period drought from April to November. The reasons of drought in this part of the Central Elburz it may be high continentality, proximity of desert area and distance from the sea (regarding to chapter 3). Every knows that drought makes farming difficult or impossible in the semi arid and arid regions of world. Thornthwaite and Mather (1955) distinguish four kinds of drought as follows:

1) Permanent, it is characteristic of driest climates, in this type of drought agriculture is impossible except by irrigation

2) Seasonal, where is found in the climates that have well defined wet and dry seasons exist. For successful agriculture planting dates must be adjusted so that the crop develops during the rainy season. Therefore crop must be irrigated during the dry season such as the southern slope stations of the Central Elburz.

3) Contingent, because of rainfall variability and

4) Invisible, can occur in any area but most common in regions even when there is rain on every day.

If rain does not meet evaporative needs, a borderline water deficiency exists which limits growth and yield (Jackson 1989). In consideration of these different conditions, the role of irrigation will be vary. According to Strahler (1992) a dry climate is one in which the total annual soil water shortage (potential water deficit) is 15 cm or more, while at the same time there is no water surplus. A wet climate is one in which the soil water shortage (potential water deficit) is less than 15 cm (There is no requirement that a moist climate must show a water surplus). Based on above definitions the southern slope stations such as Semnan are dry climate.

Table 9-19 90 % Probability of Monthly Potential Water Deficit (1958-1987) 100- A.W.

Stations	Factors	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	Average	0	0	0	0	0.5	8.6	26.9	10.7	0	0	0	0
	Stdev σ	0	0	0	0	2.6	20.3	29.2	18.8	0	0	0	0
	1.6449 σ	0	0	0	0	4.3	33.5	48.0	30.9	0	0	0	0
Babolsar	Average	0	0	0	0	28.3	64.8	89.9	44.4	16.0	0.2	0	0
	Stdevσ	0	0	0	0	24.6	25.6	31.8	29.9	19.1	0.8	0	0
	1.6449 σ	0	0	0	0	40.4	42.2	52.3	49.2	31.5	1.4	0	0
Gorgan	Average	0	0	0	0	0	51.4	75.4	72.5	53.9	7.3	0	0
	Stdev σ	0	0	0	0	0	38.2	30.3	23.9	20.6	13.5	0	0
	1.6449 σ	0	0	0	0	0	62.9	49.9	39.3	33.9	22.3	0	0
Ghazvin	Average	0.4	0.4	0.2	7.6	46.7	105.5	125.3	113.8	88.9	40.3	14.9	1.4
	Stdevσ	2.0	2.3	1.1	15.3	29.4	7.9	8.6	3.6	3.5	20.0	13.1	4.1
	1.6449σ	3.3	3.7	1.9	25.2	48.3	13.0	14.2	5.9	5.8	32.9	21.6	6.8
Karaj	Average	1.8	1.8	3.0	22.6	66.4	109.9	128.2	116.1	91.3	47.7	18.0	2.6
	Stdevσ	4.0	4.2	7.4	21.0	21.6	6.1	4.6	4.1	2.8	18.5	11.4	4.8
	1.6449 σ	6.6	6.9	12.2	34.5	35.6	10.0	7.6	6.7	4.5	30.4	18.7	7.9
Semnan	Average	10.1	10.6	25.5	66.8	95.9	136.8	149.8	131.9	106.3	66.5	38.2	10.0
	Stdevσ	8.8	8.5	14.3	10.1	15.0	3.9	3.7	11.4	3.2	10.9	11.2	8.2
	1.6449 σ	14.5	14.0	23.5	16.6	24.6	6.5	6.2	18.8	5.3	17.9	18.5	13.6

Table 9-20 Upper and Lower Limit of Monthly Water Deficit (1958-1987) 100- A.W.

Stations	Factors	J	F	M	A	M	J	J	A	S	O	N	D
Anzali	Average	0	0	0	0	0.5	8.6	26.9	10.7	0	0	0	0
	Upper	0	0	0	0	4.8	42.1	74.9	41.6	0	0	0	0
	Lower	0	0	0	0	3.7	24.9	21.2	20.1	0	0	0	0
Babolsar	Average	0	0	0	0	28.3	64.8	89.9	44.4	16.0	0.2	0	0
	Upper	0	0	0	0	68.7	107.0	142.2	93.6	47.5	1.5	0	0
	Lower	0	0	0	0	12.2	-22.7	-37.5	4.8	15.4	1.2	0	0
Gorgan	Average	0	0	0	0	0	51.4	75.4	72.5	53.9	7.3	0	0
	Upper	0	0	0	0	0	114.3	125.3	111.8	87.8	29.6	0	0
	Lower	0	0	0	0	0	11.5	-25.6	-33.2	-20.0	14.9	0	0
Ghazvin	Average	0.4	0.4	0.2	7.6	46.7	105.5	125.3	113.8	88.9	40.3	14.9	1.4
	Upper	3.6	4.2	2.1	32.7	95.1	118.5	139.5	119.7	94.7	73.2	36.5	8.2
	Lower	2.9	3.3	1.7	17.6	1.6	-92.6	-111.1	-107.9	-83.1	-7.4	6.7	5.4
Karaj	Average	1.8	1.8	3.0	22.6	66.4	109.9	128.2	116.1	91.3	47.7	18.0	2.6
	Upper	8.4	8.7	15.2	57.1	102.0	119.9	135.7	122.9	95.8	78.2	36.7	10.5
	Lower	4.7	5.1	9.2	12.0	-30.9	-100.0	-120.6	-109.4	-86.7	-17.3	0.7	5.3
Semnan	Average	10.1	10.6	25.5	66.8	95.9	136.8	149.8	131.9	106.3	66.5	38.2	10.0
	Upper	24.6	24.6	49.0	83.4	120.5	143.3	155.9	150.7	111.6	84.4	56.7	23.5
	Lower	4.4	3.4	-2.1	-50.3	-71.3	-130.3	-143.6	-113.1	-101.1	-48.7	-19.7	3.6

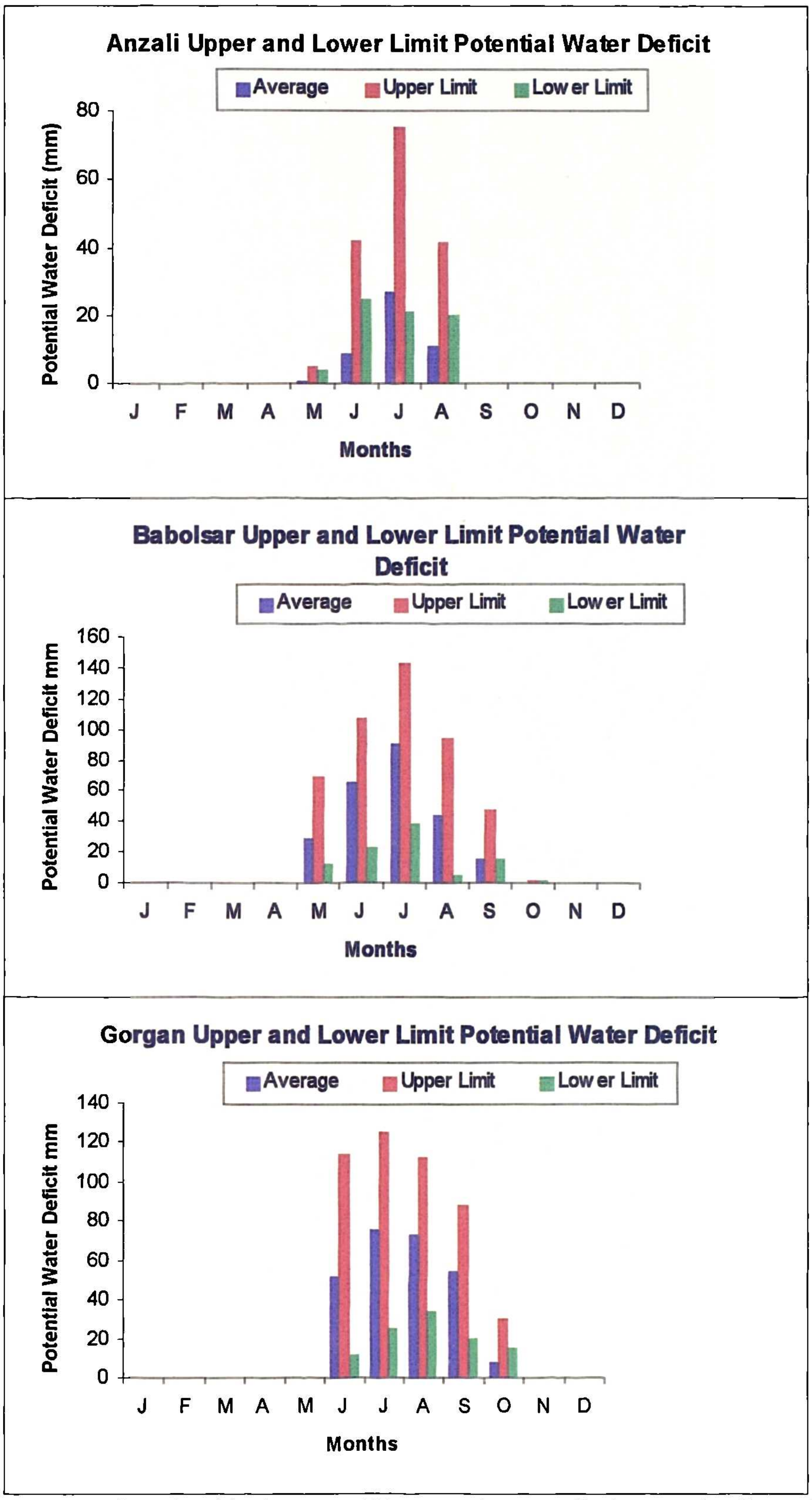


Figure 9-3 The Monthly Average, Upper and Lower limit over the Central Elburz Stations.

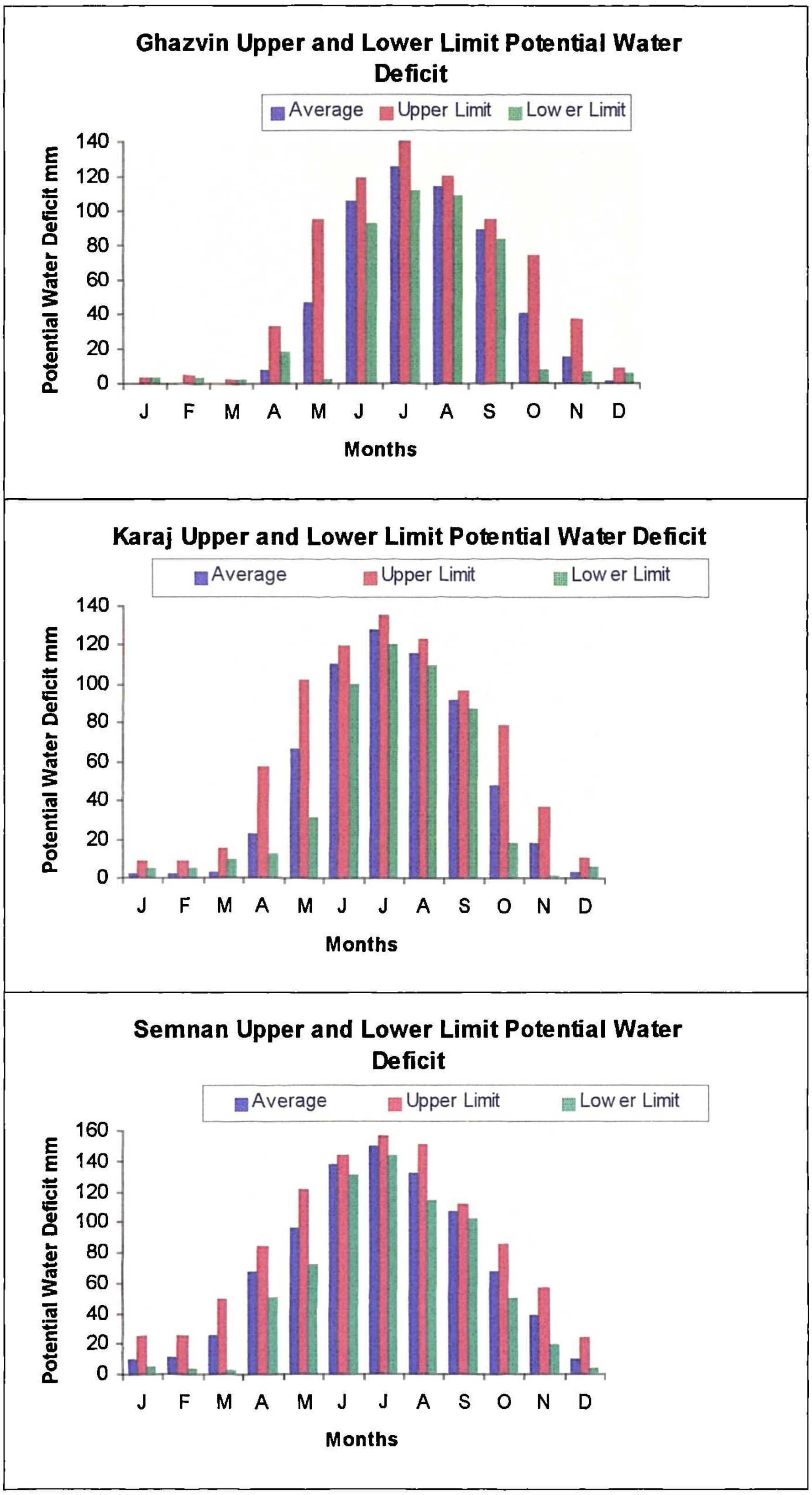


Figure 9-4 The Monthly Average, Upper and Lower limit over the Central Elburz Stations.

9.13 Summary and Conclusion

From a climatological point of view the water balance must be considered in relation to the growth of agricultural crops for this is an important evaluation of the seasons. Also it is necessary to consider the probably of seasonal water availability. By comparing rainfall and potential evapotranspiration on a monthly basis it is possible to make quantitative estimates of water balances. The difference between precipitation and evaporation in any area can loosely be called the water balance of the area.

The present aims of this study is to describe and evaluate the seasonal pattern already defined by the study of rainfall alone. The water balance is therefore used to define of the limits of water availability and to consider the probability of limit and duration of these seasons.

It is possible to use rainfall to define seasonal water supply crops, conditions affecting the availability of water for plant growth are likely to be of greater practical interest for the irrigation planner as well as the management of rain grown agriculture. In this respect the water balance approach using rainfall, evapotranspiration and soil characteristics provides a more realistic evaluation of the availability of water to crop growth.

The results of the potential water deficit averaged over all years and the potential water deficit based on each individual years showed similar values.
The analysis results recognized several types of water balances in the Central Elburz Stations:

a) Anzali type, where a water surplus prevails throughout the year. Average rainfall always exceeds the average potential evaporation. The rainfall shows a very relatively variation during the year. As it was previously explained the maximum occurs in the months of Autumn, but there is no clear minimum period.

b) East coast type, as exemplified by Babolsar and Gorgan. There is a large of water surplus in the period of October- April at Babolsar and November to May at Gorgan, but a moisture deficit between June and September-October which is caused by lower rainfall as well as increased evaporation.

c) Southern slope types, this type of water balance can be divided to two types of water balance:

1) Ghazvin and Karaj type, the months of April to November indicate moisture water deficit but from December to April there is water surplus at Ghazvin. Karaj type the months of April to November indicate moisture deficit but December to March is nearly water surplus.

2) Semnan type, there is no approximately moisture surplus in this station.

The coastal area stations where a water surplus prevails throughout the year the water deficit is less. The rhythm of moisture deficit and surplus are similar for coastal stations but it differs from one station to another at southern slope station.

The monthly potential water deficits is provided the basis for calculation the upper and lower limit for probability estimate. The analysis results of the Central Elburz stations showed that the wet months for Anzali are September to April, it differs at Babosar from October to April. In Gorgan the wet months are during November to May. However, there is no exact lower limit at zero point in the southern slope stations but some of months are near zero. Thus it can be said the period of November to April is nearly wet at Ghazvin, Karaj and Semnan stations. The analysis proved two different the coastal and southern slope seasonal regime.

The severity of the drought depends on the value of the lower limit. In this regard the coastal area stations of the Central Elburz have about 8 months lower limit as zero. Thus it is obvious there is a few drought months (about May to October) in this part of Iran. But the southern slope stations with long persistent dry season and high monthly deficits is also characterised by a short wet season. Since the southern slope stations have a long period drought from April to November.

10

10 Summary and Discussion

The area chosen for this study is the northern part of Iran surrounding the southern end of the Caspian Sea. It includes an important agricultural area based on rainfall and it merges into the semi arid zone with a well defined boundary. The effect of mountain barriers in creating boundaries is of particular important in this region. In this regard the Central Elburz mountains can be considered as the boundary between two regions, southern and northern. This has created an interesting physical boundary particularly from the point of view of rainfall. The distribution patterns of rainfall can be very useful in agricultural planning and management. An important aspect in the development of agriculture in the Central Elburz is the determination of the seasonal rainfall patterns. This study has been primarily concerned with the objective descriptions and climatic explanations of the distribution spatial and temporal patterns in the Central Elburz of the major components of the hydrologic equation namely rainfall and evapotranspiration. Thus this thesis should be considered as a contribution to the study of the seasonal rainfall regime of Iran and with direct value to agriculture in the region. However, there are many aspects which can be developed from this initial research in climatology in this region. The purpose of this thesis is to examine the pattern of rainfall especially in relation to the growing season both in time and spatially. The thesis describes the variation in the availability of moisture for growth throughout this region.

Rainfall data is available at 29 stations over periods ranging from 1957 to 1987 and these have been analysed using annual and monthly data. Daily rainfall is also available a sample of 10 stations have been analysed over a period of 10 years for using the timing of rain and seasonal patterns.

This region has not been the subject of detailed climatological research thus there is no basis for the development of previous ideas and the present work has to incorporate much descriptive analysis. Approaches to the analysis have to be based upon research in other parts of world, though an attempt has been made to restrict this largely to similar climates.

The first part of this study examines annual, monthly and seasonal rainfall over the region. In contrast with the claims of many authors, the highest rainfall coincides with higher elevations. In this analysis the maximum rainfall did not correspond with the highest parts of the Elburz, but occurs on the Caspian lowlands. Annual rainfall increases linearly with elevation in the southern slopes of the Central Elburz but decreases with elevation in the coastal area. The relationship between annual rainfall and altitude is significant in the southern slopes but results show it to be insignificant in the coastal area station.

The monthly and seasonal rainfall indicated two different categories of rainfall regimes over the Central Elburz stations as follows:

1) the Caspian coastal area rainfall regime comprises a first maximum in Autumn and a second maximum in winter while Spring is the driest season in coastal area.

2) the southern slope stations rainfall regime is characterized by a dry period of between 3 to 6 months, the winter is the wettest season, and rainfall occurs mostly in the cold period of the year.

Based on the monthly rainfall analysis the seasonal rainfall period is November-May for the southern Elburz but is September-December at the coastal area stations of the Central Elburz stations.

Rainfall analysis indicated that the rainfall origin of the southern and northern Elburz are different.

The Hierarchical Clustering technique was applied to classify the Central Elburz rainfall stations into a number of groups. The Hierarchical Clustering techniques by the Ward's method analysis was clearly suggested 3 homogeneous rainfall groups for the Central Elburz stations as follows:

1) Group A (including Anzali, Astara ,Havigh, Hashtpar, Shirgah, Lahijan, Rasht, Noushahr, Ramsar stations) covers the Caspian coastal area particularly its western part.

2) Group B (including Babolsar, Ghaemshar, Gorgan, Gonbad, Abali, Northern and Southern Kandavan stations), represents the two different areas including the higher altitudes and eastern coastal stations.

3) Group C (including Aminabad, Damghan, Dehsomeh, Garmsar, Ghazvin, Ghom Karaj, Semnan, Shahroud, Tehran, Takestan, and Varamin stations). This group reperesnts southern slope stations.

Before considering any analysis which could allow prediction on probability of future rainfall amounts, it is important to consider whether or not there trends. The result of trend analysis is that there is no consistent trend, few stations show positive trends, other negative trends and many are not significant. The cause of trends in studies elsewhere have been suggested as changes in global atmospheric process. Although this region may be affected by the westerly jet stream which various seasonally. The westerly jet stream can affect Iran and fluctuation in the seasonal rainfall could also be evident here. Also the start of the rainy season and indeed interruptions in the rains can be caused by jet streams activity and air masses as well as the strength of the Asian high pressure system. Therefore Jet streams and air masses vary in their strength and position both seasonally and from year to year. It is possible that rainfall data will show variations which could be linked to jet stream activity and length of air masses. There is not enough evidence of significant trends to postulate this for this region of Iran. Time series analysis were applied to the annual rainfall. The possible existence of trend has important implications for water resources, agriculture, rainfall probability and reliability estimate. The practical importance of trend, over the period considered and in the future if it continues, is difficult to assess. The over-all trend in a time series was examined in this study by the use of linear regression analysis and Mann- Kendal rank. A significant trend showed only 1o out of the all stations using regression analysis, and 9 out of the stations by Mann- Kendal rank. Thus the results of the trend analysis showed a weak statistically significant that some of the annual series examined indicated a form of fluctuation rather than any particular significant trend. Stations with a significant trend were 3 of these stations located on the coastal area (Gorgan, Gonbad, Shirgah), 5 stations located on the southern slopes (Damghan, Karaj, Semnan, Takestan and Tehran) and 2 stations were located in higher altitudes (Northern Kandavan, Southern Kandavan). In this study those stations have high rainfall variability, therefore refer to significance trends. Also persistence has been investigated because of its important information when considering water resources, rainfall probability and reliability for agricultural planning. Analyses results did not find any persistence and not provided a satisfactory basis significance for forecasting in the data series.

Variability and probability analysis have been used as description of the climate of this region. The amount rainfall for the year, season or month is no guide to the agricultural potential of an area, and a measure of rainfall variability is also required. As the rainfall of some parts of the Central Elburz is subject to marked seasonally, it was also necessary to determine the variability pattern of the rainfall distribution as well. Analyses of the variability pattern of annual rainfall over the central Elburz shows that rainfall variability increases in this region from north to south. Rainfall variability is much lower on the coastal area (where rainfall amounts are also high) than on the southern slope stations which the variability is high (where rainfall amounts are also low). The monthly rainfall distribution are positively skewed and the variability measurement often show coefficient of variation greater than 100% in the dry months especially in the southern slopes.

The monthly coefficient of variation patterns indicate that with lower value rainfall have relatively high coefficient of variation while months with higher rainfall have considerably lower coefficient of variation values. Months with the lowest mean rainfall such as May, June, July, August and September have a high variation coefficient while the wet months of October, November, December, January, February, March and April have a comparatively low coefficient of variation. Also the coastal area stations with higher monthly rainfall have considerably lower coefficient of variation values. The analysis of monthly variability rainfall is much more of a problem since some months are so highly skewed that variability analysis is inappropriate. However many agriculture studies use monthly data in this way and it is in any case preferable to use this rather than the arithmetic mean to describe rainfall in such months. Thus rainfall variability has been quantified by the coefficient of variation index and analysed in a similar way to that of rainfall distribution. The results of most stations have shown relationships between variability indices and rainfall amounts. In general rainfall variability was found to be the highest in the southern slope stations and the least in the coastal area.

Probability has a particular value in its application to agriculture. Annual rainfall is in most cases equivalent to seasonal total rainfall and in the case of wheat, planted in September and harvested in July is the total water available for growth. Rainfall probability and reliability would, therefore be of great value and relevance to the objective assessment of the agricultural potential in the Central Elburz of Iran. It was the aim and objective to make an assessment of the probability and reliability of receiving or exceeding critical annual rainfall amounts in the Central Elburz stations and to calculate probability and reliability tables and figures that may provide a basis for future planning of the water resources and agricultural potential in this area.

Reliability can be calculated in terms of the amount of rainfall that can be expected or exceeded at a given level of probability. In this study 90% probability is examined and this is related to the economy of agriculture units. Small farmers can not survive crop failure more than one in 10 years. In the case of the Central Elburz, 90% probability provides security in agriculture. Also 80 and 75 percent of probability have been adapted in this analysis. This spatial pattern of probability thus provides a map of agricultural potential. Almost all of the coastal area stations had more than 90% probability of exceeding the 240 mm annual rainfall. In the southern Elburz percentage probability of receiving 240 mm rainfall increases with altitude. In the Higher Altitude stations the percentage probability of 240 mm rainfall (for wheat crop) was more than 90%.

The 1000 mm rainfall minimum levels was selected for rice and citrus as being of most interest agriculturally, because in the Caspian coastal area stations annual totals of this order if well distributed in the rainy season appear sufficient to permit the adequate growth of rice. The highest values, more than 80% probability are found in the western stations of the Caspian Sea.

Cotton is cultivated intensively in the Gonbad and Gorgan distinct it is also grown in the some parts of the southern slopes. Because of its very great economic importance in different parts of Iran, the effects of water on cotton yields have received significant attention, particularly in terms of water requirements and irrigation. The highest values are found in the western stations of the Caspian Sea with amount of 100% probability of receiving 300 mm (water requirement for cotton) annual rainfall. However, the lower values are found in the eastern stations of the Caspian Sea where there is less than 92% of probability of receiving this critical rainfall.

The most important part of this thesis is the determination of seasonal patterns. Monthly analysis even though expressed wet month terms provides a course measure for the definition of seasons. Also examination of daily rainfall has been the focus of seasonal rainfall research elsewhere. In this study the timing of the rains and variation within the rainy season is analysed by daily rainfall. These provide a seasonal pattern rainfall for the region. Rainfall records are analysed to provide estimated percentage points of rainfall totals, variation in the start, duration and end of the rainfall season and the probability of dry spells within rainy season. Starting date of the rainy season found annually by searching the records for each year. In the coastal area in most years the rainy season starts between July and September but in some stations it can occur as late as October or November (Gorgan and Babolsar). In the southern slopes rainfall occurs in the Autumn months and also rainfall year is taken as October to June. Therefore the rainy season starts early in the coastal stations and progressively later in the southern slope stations. The months of August and September in most parts of the coastal area stations and months of October and November in most parts of the southern slope stations state of the Central Elburz signal the beginning of the rainy season. On the other hand the rainy season begins in the coastal areas stations in summer and, in the southern slope stations in Autumn.

In the coastal area stations the end of the rainy season begins in the first week of May (6 May) and in the third week of July (19 July). In the southern slope stations, the end of the rainy season starts between the first week of May (7 May) and the first week of July (7 July). So the end of rainy season differs for southern slopes stations and coastal area stations.

The length of rains differs from 204 to 340 days in the coastal area but ranges from 132 to 272 in the southern slopes. Also the results of relationship between start and duration of the rainy season indicate that early start of rains, relate to the longer duration of rainy season. In years when start rains are delayed the length of rainy season in many cases will be shorter.

In comparison with Wallen (1968), it was indicated that the start of the rains for the Middle East is usually in November or early December, and the end of the rainy season is May or even the middle of June. According to this present analysis this is true for the southern slope stations. But Wallen's results do not agree with the present analysis for the coastal area stations. Therefore the climatology of the coastal area differs with southern slopes.

Evaporation is a complicated process and has a major role and an important factor in hydrology and climatology as well as in such diverse fields as agriculture, forestry and reservoir management and other related disciplines. It has been possible to calculate reasonably reliable averages of the evaporation for each month by Pan evaporation for Anzali, Babolsar, Gorgan, Ghazvin, Karj and Semnan Stations.

Usually with the beginning of the summer season the evapotranspiration amount considerably increases and it limits the development of summer crops especially in the southern slopes. In this situation with the start of the summer season a water deficit occurs for all of summer season months. The amounts of evaporation over the Central Elburz stations vary both spatially and through time. The stations analysed were in two different area :

a) coastal stations; in this area the amount of evaporation is less than the rainfall especially in the south west of the Caspian but it is more than the rainfall in the east.

b) southern slope stations; the amounts of evaporation are similar for three stations (Ghazvin, Karaj and Semnan Stations). Monthly evaporation values for all three stations are higher than coastal area stations. The values of evaporation are in some cases several times larger than the annual rainfall.

The Blaney-Criddle formula selected for this study uses for air temperature and evaporation which was derived empirically in USA. Considering the climatic conditions and especially the seasonal regime, its western areas of USA are similar in many respects to the climate of Iran. Thus the estimates of potential evapotranspiration derived from the Blaney-Criddle formula for the studies of potential evapotranspiration over the Central Elburz. The calculations for Blaney-Criddle potential evaporation over the Central Elburz stations show variation from station to station and month to month. The amounts of potential evapotranspiration estimated by Blaney-Criddle method are more at Anzali, Babolsar and Gorgan (Coastal area) but lower than pan for Ghazvin, Karaj and Semnan (southern slopes) stations. The values of potential evapotranspiration estimated by the Pan method are greater than that indicated by the Blaney- Criddle method from the May to the

September period. However, in the other months (except January, February and March) they appear closer in Ghazvin, Karaj and Semnan (southern slopes) stations. The critical difference between Blaney-Criddle method and Pan evaporation occurs during cold months. Those months are at minimum in potential evaporation by Pan they have a high values in the Blaney-Criddle method but the rhythm of water needs in different seasons in both methods are similar. It will be noted that the peak water need month is July in the coastal area stations while it is on May in the southern slope stations. The results from both methods of analysis agree with the peak of water requirement of the crops in this area. The Blaney-Criddle is not a useful method for the coastal area stations due to high errors and affecting by the sea temperature having little response to seasonal change in radiation. In the southern slope stations where the area is more similar to original climate derived the Blaney-Criddle this method is suitable for dry period but it is in error during cold weather that the crop does not need water. The Blaney-Criddle estimating being consistently higher than Pan method over the coastal stations. But it is less or close in the southern slope stations. It is recommended pan evaporation for the coastal area stations and in southern slope stations both pan and Blaney-Criddle are useful. But exception the cold months (however in these months there is available enough water for plants) the Blaney-Criddle method is preferred as developed in arid areas and can provide good estimates of the values in an arid area. The Pan method and the Blaney- Criddle method have been regressed for their closeness, the regression analysis found, there is a relationship between Pan and Blaney- Criddle but there is a stronger correlation between Pan and Blaney- Criddle in the southern slope than the coastal area stations.

Rainfall alone can not determine the water availability for growth. Thus the water balance approach has been adapted. From a climatological point of view the water balance must be considered in relation to the growth of agricultural crops for this is an important evaluation of the seasons. The water balance approach provides the most rational method for agriculture since it considers the characteristics of plants in this area (wheat and citrus) and it examines effectiveness of rainfall. The adoption of probability analysis of potential water deficit provides a valuable explanation of water availability for crops growth in regions of variable rainfall. Also it is necessary to consider the probably of seasonal water availability. By comparing rainfall and potential evapotranspiration on a monthly basis it is possible to make quantitative estimates of water balances. The difference between rainfall and evaporation in any area can loosely be called the water balance of the area.

The aims of water balance study is to describe and evaluate the seasonal pattern already defined by the study of rainfall alone. The water balance is therefore used to define of the limits of water availability and to consider the probability of limit and duration of these seasons.

The Blaney-Criddle and Pan evaporation method have been used to estimate potential evaporation for wheat and citrus and compared to actual evapotranspiration to give potential water deficit. The potential water deficit have been estimated from monthly rainfall and monthly potential evaporation by Blaney-Criddle and Pan method. The results of potential water deficits have been shown that the use of the amount of the average potential evapotranspiration and individual monthly are similar values by two methods. The analysis of water balance recognized several types of water balances in the Central Elburz stations:

a) Anzali type, where a water surplus prevails throughout the year. Average rainfall always exceeds the average potential evaporation. The rainfall shows a very relatively variation during the year. As it was previously explained the maximum occurs in the months of Autumn, but there is no clear minimum period.

b) East coast type, as exemplified by Babolsar and Gorgan. There is a large of water surplus in the period of October- April at Babolsar and November to May at Gorgan, but a moisture deficit between June and September-October which is caused by lower rainfall as well as increased evaporation.

c) Southern slope type, this type of water balance can be divided into two types:

1) Ghazvin and Karaj type, the months of April to November indicate moisture water deficit but from December to April there is water surplus at Ghazvin. Karaj type the months of April to November indicate moisture deficit but December to March is nearly water surplus.

2) Semnan type, there is no approximately moisture surplus in this station.

The coastal area stations where a water surplus prevails throughout the year the water deficit is less. The rhythm of moisture deficit and surplus are similar for coastal stations but it differs from one station to another at southern slope stations.

The monthly potential water deficits is provided the basis for calculation the upper and lower limit for probability estimate. The analysis results of the Central Elburz stations showed that the wet months for Anzali are September to April, it differs at Babosar from October to April. In Gorgan the wet months are during November to May. However, there is no exact lower limit at zero point in the southern slope stations but some of months are near zero. Thus it can be said the period of November to April is nearly wet at Ghazvin, Karaj and Semnan stations. The analysis proved two different seasonal regimes including in the coastal with a long wet season (about 8 months) and southern slope by a short wet season.

The severity of the drought depends on the value of the lower limit. In this regard the coastal area stations of the Central Elburz have about 8 months lower limit as zero. Thus it is obvious there is a few drought months (about May to October) in this part of Iran. But the southern slope stations with long persistent dry season and high monthly deficits is also characterised by a short wet season. Since the southern slope stations have a long period drought from April to November.

In view of the experience gained from this study and summaries of the main results of the analysis together with the suggested profitable lines for future research are now outlined it can be suggested some of which the author intends to pursue in the future. The most important problem to be solved concerns the data available. The quality and quantity of the available data needs to be improved in order to allow more ambitious research. A synoptic approach to rainfall studies assumes an understanding of the dynamic climatology, where is not yet fully understood in the Central Elburz. Investigations of cilmatology will call for both surface and upper air data. The Penman method of estimating PE is theoretically the most sound and shown to be better than Thornthwaite, Blaney- Criddle and Pan methods in studies elsewhere. It is necessary develop meteorological stations to provide data Penman in this area for comprising with other methods. Water balance studies over the Central Elburz on a catchment basis are necessary. For the relationship between the different water balance components and the factors affect these relationships, it needs the instrumentation of catchments representative of the various soil, vegetation, physiographic regions. Thus the water balance can take account of soil condition which affect available water capacity.

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