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RAINFALL AND DROUGHT PATTERNS IN JORDAN

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CONTENTS

ABREVIATIONS

AAP	: Average annual precipitation
ADSD	: Average dry spell duration
ADSI	: Average dry spell index,
AWSD	: Average wet spell duration,
CSV	: Cumulative semivariogram
CVR	: Cumulative variances,
C °	: Temperature in Celsius,
D	: Dry spell,
DFD	: Drought frequency duration,
DFD 1, 2,..	: Drought frequency duration of one year, two years etc.
DT	: Drought duration,
INCD	: International Negotiating Committee of Convention to Combat Desertification,
JMD	: Jordan Meteorological Department,
LDSD	: Longest dry spell duration,
LMYD	: Largest multi-year drought,
MSL	: Mean sea level,
MWI	: Ministry of water and irrigation,
ND	: Number of droughts,
PVAR (i)	: Percentage of variances at harmonic number (i),
PCSV	: Point cumulative semivariogram,
PDI	: Palmer drought index,
SV	: Semivariogram,
SRDF	: Standard regional dependence function,
SPI	: Standardized precipitation index,
STDC	: Standard total cumulative index,
St.Dev.	: Standard deviation,
W	: Wet spell.

LIST OF SYMBOLS

A	: Amplitude
a_i	: Coefficient of cosine harmonic
b_i	: Coefficient of sine harmonic
i	: Harmonic number
K	: Frequency factor
m	: Rank of observation
$N_{(d)}$	: The total number of equally spaced observations
P_p	: Rainfall at site p; (subscript p), p also probability in other places
P_{p+d}	: Rainfall at site $p+d$, where d is distance between two sites
P_t	: Precipitation for a given time series
R_m	: Maximum distance
t	: Time of the year of maximum precipitation
T	: Total period of time series
T_r	: Return period
$W(r_{i,p})$	: Weighting factor between the station at site i and pivot station at site P that corresponds to distance $r_{i,p}$
V_i	: Variance of i-th harmonic,
V_m	: Maximum value of any regional variable
X	: Extreme event
X_t,	: Value of time series at time t
y	: Reduced variant with a probability function
y_n	: Mean reduced variant
Φ	: Phase angle
γ_d	: SV value at distance d
α.	: The weighting angle of SV samples
σ	: Standard deviation

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SUMMARY

The study of water resources such as rainfall is considered to be of great importance for Jordan. The great environmental challenge that Jordan faces today is the scarcity of water. Water resources in Jordan mainly depend on rainfall which is subject to great variability. Meanwhile, there is an observed population growth, so there is great demand for water. This study has the objective, to analyze the situation of water resources by studying rainfall temporally and spatially. For this purpose, scientific methodologies such as semivariogram and harmonic analysis methods are applied. The second objective of this work is to investigate the environmental and climatic impacts by studying dry and wet spells with their geographical distribution. This thesis is divided into six chapters. The first chapter is an introduction which describe the objectives of the study area and data. The second chapter presents a historical review of previous studies and a literature survey related to the investigated topics. Chapter three contains valuable information about Jordan in terms of the diversity of its climatic regions. The chapter also discusses the synoptical climatology of the weather patterns that affect Jordan in the main four seasons. Chapter four contains the main body of the study. It has three parts, the first part discuss the spatial analysis in each climatic region throughout the country by finding regressions which describe the spatial distribution of the rate change of rainfall in Jordan. All regressions show a decreasing of rainfall from north to the south and also from west to east. In the second part of this chapter, a geostatistical semivariogram model is applied. This method enable us to find the regional dependence function for any site. It measures the spatial homogeneity or heterogeneity of the rainfall as a regional variable. The method shows superiority in estimating rainfall throughout the country. Weak correlation exists between rainfall patterns in the west and east. The correlation and regional dependence between Amman and other sites in Jordan are determined. This method will be helpful in estimating rainfall in the desertic region where there is shortage of information. In part three of this chapter harmonic analysis techniques is used to analyze the precipitation climatology in Jordan. the amplitudes, phase angles and percentages of variances are determined. It is found that the first and second harmonics can describe more than 90 % of the total variances. In chapter five, drought as an environmental and climatic impact is introduced. Drought duration severity and frequency are determined throughout the country. It is found that Jordan mostly enjoys moderate drought. In chapter six, an important subject of hydro-meteorology is considered. The rainfall duration, intensity and frequency is determined as construting figures that can be applied in designing for water resources projects. The last section includes conclusions and fruitful recommendation.

ÜRDÜN'DEKİ YAĞIŞ VE KURAKLIK ŞEKİLLERİ

ÖZET

Su kaynaklarının incelenmesi Ürdün için büyük önem arzetmektdir. Bugün Ürdün'ün karşı karşıya kaldığı en büyük çevresel sıkıntı suyun yetersizliğidir. Ürdün'deki su kaynakları büyük değişiklikler gösteren yağış oranlarına bağlıdır. Bununla beraber nüfus oranındaki artışa paralel olarak suya olan ihtiyaç da önemli ölçüde artmaktadır. Bu çalışma, yağış oranını geçici süreyle ve yersel olarak analiz etmek suretiyle su kaynaklarının yerini bulmayı amaçlar. Bu amaçla, kullanılan bilimsel yöntemler iklimsel ve çevresel çalışmalar çerçevesinde Ürdün'de ilk kez uygulanmaktadır. Bu çalışmanın ikinci amacı; kuru ve yaş periyotları coğrafi dağılımlarıyla birlikte inceleyerek, çevresel ve iklimsel etkileri bulmaktır. Tez yedi bölüme ayrılmıştır. Birinci bölüm giriş kısmından oluşmaktadır. Bu bölüm, çalışmanın amaçlarını, çalışma alanının ve verilerinin tanımlarını içerir. İkinci bölüm, tezin konularıyla ilgili geçmiş çalışmaların ve literatürün incelenmesini içerir. Üçüncü bölüm, Ürdün'ün iklimsel bölgelerinin farklılıklarını içeren önemli bilgiler içerir. Diğer taraftan bu bölüm dört mevsim boyunca Ürdün'ü etkileyen sinoptik durumları inceler. Dördüncü bölüm, çalışmanın en önemli kısmını meydana getiriyor ve üç kısıma ayrılır. Birinci kısım ülke boyunca yer alan iklimsel bölgelernin yersel analizilerni; kuzeyden güneye ve batıdan doğuya doğru düşen değişken yağış oranı regresyon eğrileriyle incelenmektedir. Bütün regresyon eğrileri kuzeyden güneye ve batıdan doğuya düşen yağışın azaldığını göstermektedir. İkinci kısımda jeostatiksel semivaryogram model uygulanmıştır. Bu metot herhangi bir yer içeren bölgesel bağlılık fonksiyonunu bulmamızı sağlar. Bu bağlılık fonksiyonu yağışın yersel homojenliğini veya heterojenliğini bölgesel bir değişken olarak ölçer. Bu metotla Ürdün genelinde yapılan yağış tahminlerinde başarı oranı oldukça yüksektir. Batıda ve doğudaki yağış tarzları arasında zayıf bir korelasyon oluşur. Bundan hareketle bu çalışmada, Amman ve diğer bölgeler arasındaki korelasyon ve bölgesel bağlılık belirlenmektedir. Bu metot büyük bir bilgi eksikliğinin olduğu geniş çöl arazileri için yapılan yağış tahminlerine yardımcı olur. Birinci kısımda Ürdün'deki yağış iklimini analiz etmek için harmonik analiz teknikleri kullanılmıştır ve genlikler faz açıları ve varyans oranları belirlenmiştir. Birinci ve ikinci harmoniklerin toplam varyansın %90'ından fazlasını betimlediği bulunmuştur.

Beşinci bölümde çevresel ve iklimsel etki olarak kuraklık incelenmiştir. Kuraklık süresinin şiddeti ve frekansı ülke boyunca belirlenmiştir. Ürdün de çoğunlukla orta derecede kuraklık saptanmıştır. Altıncı bölümde hidrometeorolojinin su kaynakları ile ilgili önemli bir konusu ele alınmıştır. Su kaynaklarının tasarımında kullanılmak üzere yağış süresi, şiddeti ve frekansı grafiksel olarak belirlenmiştir. En son bölümde sonuçlar ve yeni tavsiyeler verilmiştir.

Chapter 1

Introduction

During the past century, the rapid development of the earth science has provided man new insights into the nature of his environment and into possible methods of modifying or controlling this environment. Among these sciences are hydrology and meteorology which deal with the distribution and movement of fresh water on the globe. However, meteorology is concerned with the atmosphere and the movement of water both as vapour and liquid in the air.

Earth, water and environmental sciences interact with the hydrological cycle. Actually, there is a potential value of meteorology in developing water resources, flood control and the studies regarding the impact of climate change on water resource. Beside, meteorological studies, the effect of the water scarcity appears in the environment , such as drought and desertification.

Jordan is one of the many countries today that faces various water problems accompanied by rapid population growth, urbanisation and industrialisation. This study is very important for Jordan which is expected to add new contribution and enlightening for the researchers and decision-makers by giving a new insight on rainfall as the main water resource by analysing the rainfall using different techniques. The climatic and environmental impact assessment of water resources will be discussed by analysing drought duration, frequency and severity. The study will add new effort to the environmental studies such as drought and desertification.

1.1 The Statement of the Problem

The of problem water scarcity is one of the critical challenges facing Jordan in this century due to the high rate of population growth and improving the standard of living. Jordan depends on groundwater resources as the first alternative and on the surface water as the second one.

The latter is subjected to high variability. In some years, average annual precipitation (AAP) is above normal, but it may be followed by several years of drought, this means that the AAP system is not durable. This rainfall patterns should be analyzed in order to understand the behavior and characteristics of such rainfall patterns. The side effect of scarcity of water resources on the environmental life in the form of drought and desertification is considered as important issues of environmental life in Jordan.

In general, the lack of water and the consequent climatic and environmental impacts constitute the main problems of this investigation. It is aiming to contribute to Jordan water issues debate by giving a clear picture upon the rainfall volume in the Kingdom and its spatial distribution. On the other hand, Jordan rainfall system is poorly known, especially in the desertic region. For this purpose, new techniques and climatic analysis need to be applied. These are semivariogram and harmonic analysis. The investigation using former techniques introduces new contribution in understanding the situation of water resources in terms of rainfall analysis. Consequently, there is a great concern about the impact of climate on water resources and environment. Countries are usually unprepared to cope with extreme climatic events, which affect human developments, but react through "crisis management", rather than through prerequisite planning. In this regard, this study can hopefully determine the climatic impacts on water resources and the environment by studying droughts in Jordan.

1.2 Objectives of the Investigation

The main objectives of this study can be summarised as the following:

1) To analyse the climate of Jordan in terms of precipitation as the main water resource in Jordan by new methods and to explain the synoptic situations of some weather patterns which affect Jordan during the year.

2) Using new techniques such as semivariogram for rainfall analysis to deal with rain as a regional variable which has dependent functions.
3) To analyze precipitation climatology using harmonic analysis providing us the annual, semi-annual periodicity of rainfall and the climatic amplitudes of rainfall of each site.
4) To study the spatial distribution and estimation of rainfall amounts in Jordan especially in the desertic regions by some correlation techniques, harmonic analysis and semivariogram approaches.
5) To provide new recommendations in the light of the results of this study.

1.3 Essential Facts

The following points will be considered as a set of essential problems assumed in the course of this study:

1) The scarcity of water resources is taken as an increasing problem of great concern where there is high rate of population growth.
2) There is appreciable amount of rainfall in the eastern and south-eastern parts of Jordan which represent more than 75% of the Kingdom's area. The rainfall volume and analysis are not clear in this part of Jordan, because of the lack of the studies and researches. In order to give the policy maker and the planner a clear idea about the volume of the amounts of rainfall at any point in this huge arid region, new techniques of objective and harmonic analysis will be applied. On the other hand, regional rainfall intensity, duration and frequency will be of great importance in designing structure of water resources projects.
3) Since the majority of the area lies in an arid region, the remaining part is exposed to the desertification. This climatic impact and its severity must be determined and analysed in terms of the rainfall by comparing the characteristics of the rainfall in deserts with high lands.
4) According to the result by Intergovernmental Panel on Climate Change (IPCC), there is a broad agreement that the climate change and greenhouse warming will

have major impacts on water resources, especially in the arid regions, (Frederic et al. 1997).

5) The assessment of climate change on water resources planning should play important role in semi-arid regions. For this reason, studying drought as an impact of water resources is necessary for Jordan. In the USA, there is an official criterion for water resources planning since 1930, (Frederic, et al. 1997).

1.4 The Importance of the Study

Why do we want to study water resources and the environmental and climatic impacts in Jordan? There are several factors that make this study very important, especially when meteorologists look at the interrelated subjects such as water resources, climate and environment from the meteorology point of view. The following factors force one to concentrate on such strategically important subject in such arid or semi-arid country like Jordan. There is continuous increase of demand on water resources due to the following reasons:

a) The natural growth rate of population in Jordan is 3.5 % per year which is considered high rate in comparison to international standard levels. This natural growth of population increases the demand for water in domestic, irrigation, and industrial sectors. For example, water supply in Jordan was 860 M m^3 in 1990 and the population was 3.3 million. However, the amount of water supply is 261 m3/year/capita. Finally, in the year 2020, the expected population will be 9.2 million, for the same amount of water supply, but the per capita use will decrease down to 93 m^3/ year /capita. The experts determined the minimum requirements for human needs as 125 m^3 / year (Bilen, 2000). The per capita domestic uses in Jordan are the least among the Middle East countries. It is 85 Lt./day, compared to the domestic uses in Europe of (250-350) Lit./day, to those of Israel of (280-300) Lt./day, to the Gulf states of (280-350) Lit./day, and to Iraq, Syria and Egypt of 130 Lt./day (Salameh and Banyan, 1993).

b) The political instability in the Middle East region mainly due to the Arab-Israeli conflict, and consequently, the waves of refugees towards Jordan

c) Improving the living standards, which consequently affect demand.

1.5 Data

For the effective execution of the study there are two sources of data available. These are,

1. Jordan Meteorological Department (JMD) data. This data is considered as the main data of the study where, 19 meteorological stations are chosen to give the best coverage of climatic regions of Jordan as shown Figure 1.1. The selection of these stations depends upon the basis of the quality and length of the period. Table 1.1 shows the locations and the elevation of these stations with respect to the mean sea level (MSL).

   The following data are available from JMD:

   - Monthly rainfall data,
   - Monthly minimum temperature,
   - Monthly maximum temperature,
   - Monthly mean temperature, and finally,
   - Location and elevation of the stations

2. The Ministry of Irrigation and Water, (MWI) data,

- Total annual rainfall data are recorded at 14 stations which are mostly located in the desertic region. In Figure 1.1 stations marked by name (identification code) are compiled by JMD (MWI) Table 1.2 shows their symbols as usually used by MWI, including the names and the locations. There are no enough JMD stations in this region. This is the main reason that the MWI stations are used here. This data is used in spatial analysis of rainfall in the desertic region for semivariogram technique.

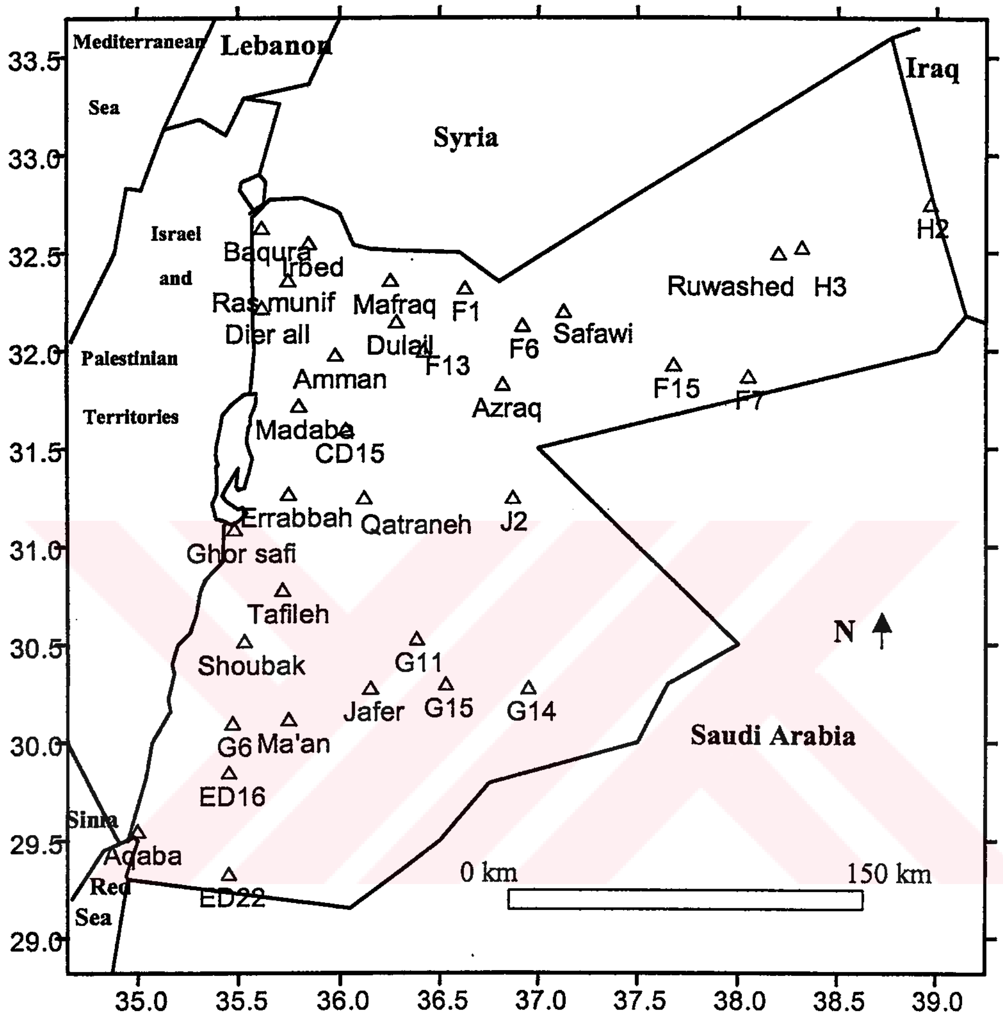

Figure 1.1: Stations of the studying area.

Table 1.1: The JMD stations location and elevations.

Station	St. No.	WMO No.	Latitude N °	Longitude E °	Elevation(m)
Amman	8	270	31.58	35.58	772
Azraq	9	288	31.49	36.49	521
Dulail	17	267	32.09	36.16	580
Safawi	6	260	32.12	37.07	672
Madaba	10	-	31.01	35.48	785
Dier alla	3	285	32.13	35.37	-224
Mafraq	5	265	32.21	36.15	686
Ras munif	4	257	32.21	35.45	1150
Rwashed	7	250	32.30	38.14	683
Irbed	2	255	32.33	35.51	616
Baqura	1	253	32.38	35.37	-170
Ghor safi	12	296	31.02	35.28	-350
Shoubak	15	300	30.31	35.53	1365
Jafer	14	305	30.16	36.09	865
Ma'an	13	341	30.10	35.45	1069
Tafileh	18	298	30.47	35.45	1200
Aqaba	16	340	29.33	35	51
Qatraneh	19	275	31.15	36.07	768
J. Univ.	20	274	32.02	35.88	980
Errabbah	11	292	31.27	35.75	920

Table 1.2: The codes, names and locations of MWI stations.

Station symbol	Station name and number		Latitude N	Longitude E	Elevation (m)
H 2	Trabeel	27	32.45	38.58	800
H 3	Kh.Um rujum	28	32.32	38.00	800
F 1	Um elqutain	34	32.19	36.38	986
F 6	Al-qraytain	21	32.08	36.55	800
F 13	Wadi salahib	23	32.00	36.25	700
F 15	Tlul elghar	31	31.56	37.21	750
F 7	Al wisad	22	31.52	38.03	750
CD 15	Dabah	34	31.36	36.03	750
J 2	El khrqah	29	31.15	36.52	635
G 11	Jabal qazumeh	24	31.43	37.00	640
G 15	Kabid	26	30.18	36.32	870
G 14	Inab	25	30.17	36.57	950
G 6	Qurain	30	30.06	35.28	1500
ED 16	Wadi ratma	32	29.51	35.27	900
ED 22	Wadi muwaqar	33	29.20	35.27	1000

Chapter 2

Literature review

The present study concentrates on water resources and the environmental and climatic impact assessments. For this purpose, different techniques are used in the rainfall analysis as a vital water resource in Jordan. The study uses spatial analysis of rainfall by a geostatistical semivariogram techniques and harmonic analysis. Drought, as an impact on water resources, is analyzed and the following literature may be considered as the infrastructure of our study.

2.1 The semivariogram

The semivariogram is a widely applied technique in geology and it is known as a geostatistical technique. Matheron (1963) used the term geostatistics in estimating ore deposit that are spatially distributed in an irregular manner. Since that time, geostatistics has become very well known and has been used in many fields of sciences. Journel and Huijbregts (1978), is an advanced reference text on the subject of mining geostatistics. It solves most of the mining engineering problems. The book includes some elements of geostatistics, definitions of regionalized variable and structure analysis of random variables. The book provides details on kriging estimation and illustrative example of case study.

Rendu (1978) presents the concepts of the semivariogram. The author provides examples of calculation procedures and mathematical representations of mining engineering and geology. Davis (1986) discusses the applicability of the semivariogram. He explains how natural phenomena may be treated as a regional variable. The book explains the difference between random and regional variables which have spatial arrangement, size, shape and time functions. On the other hand, the rate change of a regional variable along a specific orientation is defined, so that it is a measure of the degree of the spatial dependence among the sample. The author compares semivarigram with auto-correlation, so that semivariogram is considered as a mirror image of the auto-correlation for a stationary regionalized function.

Hevesi et al (1992), uses a multivariate geostatistical method for estimation rainfall in southern Nevada area. The study uses the geostatistical theory and semivariogram application. A cross validation procedure is used for estimation of rainfall. The maximum rainfall variability of the study area is determined, in addition to higher correlation between rainfall and elevation using this technique.

In a study of areal precipitation in mountainous region, Şen and Habib (1998), used the point cumulative semivariogram method in analyzing the rainfall. The authors used the data of south Nevada in the previous reference. The samples of point cumulative semivariogram are constructed for several stations. The samples show high regional variability. On the other hand, a correlation based on semivariogram samples is determined. For this purpose, the stations are classified according to the similarity among the samples. A contour map of the radius of influence around the study area is presented. The article demonstrates that the semivarigram is a good tool for assessing the regional dependence structure. The radius of influence shows high variability which reflects the heterogeneity of the region.

A semivariogram, as mentioned before, may be used in many branches of the natural sciences. A regional wind energy evaluation has been carried out in some parts of Turkey using semivariogram techniques (Şen and Şahin, 1998). The article uses the concepts of standard regional dependence function for estimation wind energy. The standard regional dependence functions express the regional weights of the site under investigation. The study shows successfulness in estimation wind potentials with an error not exceeding 12 % in the worst case. The article shows that the classical weighting function does not fit the actual data most of the time. For this reason, the study used weighting techniques developed by Şen (1989). This technique can be applied for a set of data distributed randomly i.e. not on the equi-distance biases.

A semivariogram model is used for the analysis of regional air pollution over Istanbul (Şen 1989). The article used the monthly data of sulfur dioxide concentration in 16 sites. The regional weighting function which is expressed as the regional dependence is calculated for sites to be estimated. The semivariogram, samples are constructed to show the spatial variation of the sulfur dioxide. The same model is used by Şen and Öztopal (2001) to measure the degree of the variability of air pollution in Istanbul with distance. For this purpose, a contour map of the region is constructed to depict the variation of sulfur dioxide. The article shows successfulness in exhibition of the dispersion of the pollution using semivariogram model. Tarawneh and Şahin (2002) have applied geostatistical semivariogram model to assess wind energy in Jordan, the model used for estimation wind potentials through out the country. Beside that standard regional dependence functions are determined for some areas.

2.2 Harmonic analysis

This analysis considers any time series as a sum of many simple time series, that have the form of regular sinusoidal of different amplitudes and wavelength. It is known as frequency analysis or Fourier analysis. Jean Fourier (1768-1830) provided the proof that any continuous single- valued function could be represented by a series of sinusoidal. This type of analysis is well known in electrical engineering and is used in the electrical signals; these electrical signals are considered as energy waves that change with time (Davis, 1986).

Panofsky and Brier (1958) introduced the time series analysis. The article assures the satisfaction of the harmonic analysis in exhibition of the properties of the time series, its variability, and periodicity. Besides, the behavior of the time series can be predicted. The article provides an illustrative example of the average hourly temperature in New York using harmonic analysis. The examples show the amplitudes and the time of maximum temperature.

An application of harmonic analysis is used by Scott and Shulman (1979), in an areal and temporal analysis of precipitation in the northeast of the United States. The article uses the annual precipitation data of 200 stations. The output of this analysis such as amplitudes, phase angles and the percentage of the variances are constructed in the form of contour maps. The investigation considered synoptic climatology of the study area in terms of harmonic analysis. The first harmonic, which is represented by one wave, or 1 year $^{-1}$ may be explained by the annual precipitation. The semi- annual and seasonal precipitation may be represented by the second and third harmonics. The first three harmonics account for the most of the variances of the original precipitation distribution of the studying area.

Kadıoğlu et al (1999), discussed the climatology of precipitation of Turkey in terms of harmonic analysis. The article uses the monthly averages for more than 200 stations. The amplitudes, phase angle percentage of variances are calculated for the study area. The result is shown in the form of contour maps. The article successfully explains the variation of the climate using these techniques. The annual, semi annual and seasonal precipitation are explained by the first, second and third harmonics. It is found that the first, second and third harmonics explain more than 90 % of the climatic variations in Turkey.

Tarawneh and Kadioğlu (2002) discussed precipitation climatology in Jordan. The first two harmonics contribute for about 90 % of the total variances. The phase angle charts show that maximum rainfall occurs in December and January.

2.3 Drought

Drought like many other natural phenomena such as flood, hurricanes and tornadoes, disrupts socioeconomic life. Drought literature is growing which explores society's ability to cope with natural hazardous. In the USA the adjustment of drought as a natural hazardous becomes possible.

Russel et al (1970) have framework on water supply management especially that is related to drought analysis. The article analyzes drought in terms of cost and losses, in addition to water demand, its relation to drought adjustment level was also discussed by providing practical examples from of municipal planning in Massachusetts. Previous studies in Jordan Aty (1976) showed the wet and dry spell cycles of precipitation in Jordan using probabilistic methodology. The article demonstrates that the Jordan's rainfall has high variability.

Şen (1998) proposed probabilistic formulation of spatio-temporal drought pattern. The study suggests that drought occurrence along time and space takes place randomly, and therefore, their scientific quantification is possible by probabilistic methods.

Wendland (1990) analyzed a case study of the 1988 drought in Illinois State. The article deals with several definitions of drought, such as hydrological, meteorological and agricultural drought. The study compares the monthly precipitation of 1988 as a percent of the mean 1951-1980. The response of soil moisture, river flow, lakes and reservoir and groundwater to the deficit of precipitation is calculated, taking into consideration the time response for each type.

Oguntoyinbo (1986) discusses drought prediction methods, such as statistical techniques, by finding correlation between rainfall cycles with sun spot cycles. The author exhibits examples of such correlation which shows that the climatic cycles have mutual forcing functions. The article discusses the time lagged tellecommections techniques. It depends on the correlation of the occurrence of some events in one area with other in another area, where the changes of some elements in one area precede the other one. An example is given by the article is the southern oscillation index and its relation with rainfall in many countries. The article also explains the contribution of the general circulation methods in drought analysis.

McKee et al (1993) proposed a well known standardized precipitation index (SPI) to monitor drought in the USA. The study explains the characteristics of this index and its applicability for testing some hydrological variables such as soil moisture and groundwater in any region. The article discusses the duration and frequency of drought and its relation to the time scale.

McKee et al (1995) compares between Palmer and SPI indices, and assures the applicability of the SPI index. Drought intensity is classified into four categories namely, extreme, severe, moderate and mild drought. The article uses SPI index for several time scales 3, 6, 12 and 24 months, so that it can be used if the drought appears in the short time scale and if the dry conditions persist, the index will develop in longer time scale.

Eljadid and Şen (1997) analyzed the wet and dry spells in Libya. The article shows the duration and frequency of dry and wet spell in north Libya. On the other hand, the droughts are analyzed for different truncation levels above and below the mean. The percentages of wet and dry spells are found for each truncation level. The out-come of this study shows the duration of dry spells in all stations which are longer than that of wet spells. Besides there are high differences between the quantities of wet and dry spells which imply that the available water in Libya is not sufficient to meet the long term water needs and requirements.

Iglesias (2001) discussed drought predictability in terms of climate change in the Mediterranean region. The author assures that the Mediterranean climate is relatively poorly known and understood, so that scientists and policy makers need information i.e. data and models. A correlation between the hydrological variables such as flow of the Nile River and El-Nino event, which is a recurring phenomenon of the warming surface of the tropical Pacific Ocean, suppressed upwelling of water along South America due to alteration of high and low pressure in the east and west of Pacific. The article confirms high rainfall amounts during El-Nino years.

Guttmann (1998) compares between Palmer and standardized precipitation drought indices. Depending on the similarity between the indexes in time scale, they may be used for different intervals of time according to the purpose of the study. On the other hand, Palmer index encounters some difficulties. These arise from the calculation of soil moisture and potential transpiration. Generally, the article assures that the Palmer index is not representing similar characteristics of all locations and therefore, it should not be used to compare conditions of different locations. In contrast, the standardized precipitation index is considered to be the same for all locations and easy for interpretation.

A study of drought analysis in the mountainous region in Jordan Tarawneh (1999) uses 30 years rainfall records. The intensity, duration and frequency of drought in the mountainous region are analyzed. The outcome of this article shows that Jordan enjoys moderate drought according to the drought categories classified by (Ikeda et. al 1980, Kemp 1991).

Drought intensity, duration and frequency in the desertic region using SPI index Tarawneh (1999) used 30 years records. The result of this study shows different behavior of drought in north desertic region from that in the southern desertic region.

In our study, 50 years records of rainfall data are used, and the classification of drought categories by (McKee, 1993). The length of the records in this study shows some differences in the results in comparison to former studies. For example, the maximum intensity of drought or duration found in some station by the former articles is not the same in our study. This makes this study more comprehensive because it includes the period of the former articles. On the other hand, contour charts depict the result of drought analysis in this study.

2.4 Rainfall intensity duration and frequency

Rainfall intensity, duration and frequency are hydro-meteorological concept. It is concerned with rainfall analysis depending upon observation of rainfall magnitude, duration and location. Determination of extreme values is often requested from hydrologists, especially in designing bridges, dams and culverts. These structures are subject to flooding and must be based upon the size of flood, so that its structure has to withstand during its estimated economic life. Statistical methods are particularly useful and wide-world used methods for estimation rainfall intensity, duration and frequency.

Frequency analysis of rainfall using different statistical methods is discussed by (Bruce and Clark, 1966). On the other hand, the concept of Gumbel distribution for estimation extremes and return periods are explained by providing examples. This text book is an important reference dealing with hydro-meteorological concepts.

A manual for estimation of probable maximum rainfall, WMO (1986), provides practical example in hydro-meteorological subjects. The article discusses the conceptual definitions of maximum rainfall. The article shows different model for estimation extreme values in different regions such as mid-latitudes and tropical regions.

Sivapalan and Blosch (1998) used a transformation aerial rainfall method to study the regional rainfall intensity, duration and frequency. The article presents a methodology for constructing catchment intensity duration frequency curves. The methods depend on spatial rainfall correlation function which can be determined by analyzing average rainfall intensity. The article represents an attempt to link current scientific theory of space-time rainfall field with design model.

Flood frequency distribution for correlated rainfall intensity and duration by Goel et al (2000) estimates probability distribution function of flood discharge for the catchment area with out measurements. This is considered one of the most common and important problems in hydrology. The study uses stochastic model to find correlation between rainfall intensity and duration. The study assumes storm intensity and duration to estimate stream flows.

Yue (2001) used Gumbel logistic model to analyze and find annual maximum storm peak in Japan. The study used daily rainfall records to demonstrate the applicability of this model. The article discusses the storm sequence in term of intensity and duration. It provides good information about the return periods and risk analysis. The model is verified by comparing the observed daily data with the empirical result of the model. It is found that it is suitable to represent the storm peak amount.

CHAPTER 3

Climate and Synoptic Climatology of Weather Patterns in Jordan

Jordan is a country that covers a land area of about 90,000 km^2 and, the population of Jordan is about 4.5 million. Since Jordan mainly depends on rainfall it is necessary to give a good picture of weather patterns that causes the rainfall because they reflect the dynamics of water resources, and consequently, the dry and wet spells. The climate of Jordan is influenced by the following factors.

3.1 Location

Jordan is located between 34. 59 – 39.18 °E and 29. 10 – 33. 22 °N (see Figure 1.1). This location is climatologically considered as transition location between the subtropics of hot and dry climate and the mid-latitudes frontal depression of cold winter season and relatively hot summer.

The belts of pressure systems on the earth surface oscillate in north and south directions. In the summer, the subtropical high-pressure belt is shifted to the north causing stable weather system. Such weather system is usually accompanied by downward motion, no cloud formations, and consequently, no precipitation.

In the winter, the subtropical high pressure belt moves to the south giving the opportunity to the frontal depressions to extend towards the south. The frontal depressions are associated with cold airmasses from the central Europe. These pressure systems are usually associated with rainfalls. When airmasses of polar origin are associated with the frontal depression, the precipitation will be in the form of snow.

In general, Jordan climatologically is considered as the area subtropics and frontal depression regions in winter. In general, Jordan enjoys the Mediterranean type of climate (Salameh and Bannayan, 1993).

3.2 Topography

Jordan has diverse mountainous terrain, landscape types and Jordan Valley, even though, it's areal size is small. Such varieties in topography and consequently, in climate are usually found only in large countries. In general, Jordan can be divided into three climatic regions based on equi-topographical features as in Figure 3.1. These climatic regions are

1) The Jordan Valley region (Ghor).

It is a part of the great valley that extends from southern Turkey territories through Lebanon and Syria to the salty depression of the Dead Sea, where it continues towards south to the Red Sea (Figure 3.1). Jordan Valley is the most fertile region, and it represents the food reservoir for the country. It starts with an altitude of 32 m below mean sea level (MSL) and decreases slowly to about 400 m again below MSL at the Dead Sea which is the lowest place on the earth's surface. Its width is 15 km in the north and about 30 km from the south. The adjacent region to the Jordan Valley is the mountainous regions so that, one can easily recognise the density of the contour of the elevation lines between the two regions (Figure 3.2). This region is several degrees warmer than the rest of the country because of its location in the lee side of the West Bank Mountains in which the westerly prevailing wind descends dry and hot air to this region. Temperature reaches 40 °C in summer and around 18 °C in winter (see Figures 3.3 and 3.4).

The maximum temperature in Jordan reaches its maximum in this region which is located along the western border of the Kingdom, to the east of Jordan Valley, the temperature decreases with height to reach its lowest value in the mountainous regions. Then it increases again in the desertic region along the eastern border (Figures 3.3 and 3.4). In this study, four stations, namely Baqura, Dier Alla, Ghor Safi and Aqaba are selected to represent the northern and southern parts of this region with the Dead Sea split in between (see Figures 1.1 and 3.1).

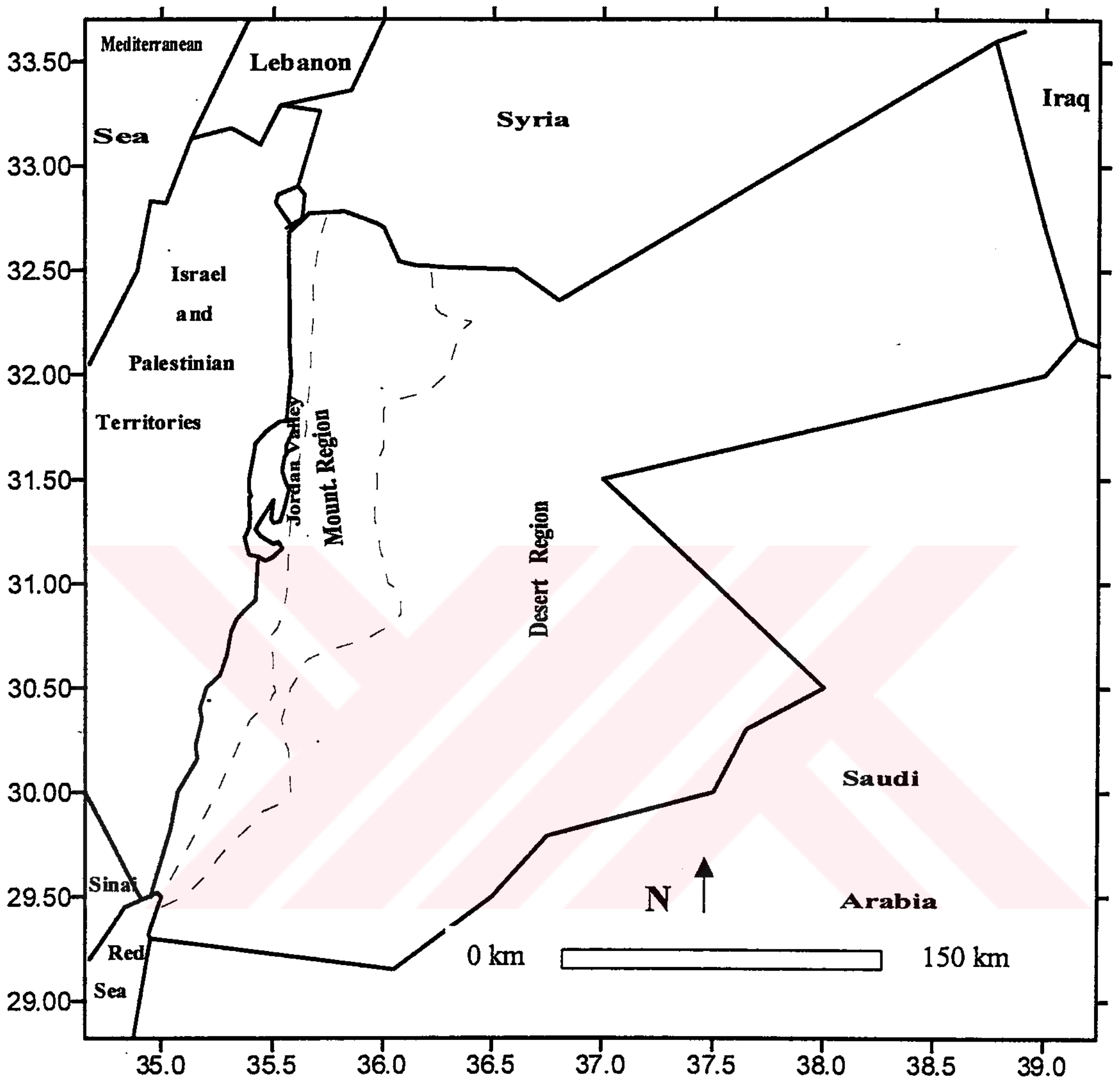

Figure 3.1: The climatic regions of Jordan.

The precipitation of this region is mainly in the northern part such as in Baqura and Dier Alla stations, due to its location near to the frontal depression belt, where Ghor Safi station south of the dead sea has AAP about 76 mm (Figure 3.5). The relations among AAP, elevations and north-south distance will be discussed in the next chapter.

2) High lands and marginal steeps (mountainous region).

This region is located to the east of Jordan Valley extending as a narrow strip area from north to the south, side by side to the Jordan Valley with an average width of around 30 km and length of some 300 km. Parts of this region are rugged and intersected by waddis or river beds. The majority of Jordanian population inhabits in this region. It is cold and wet in winter with temperature which sometimes reaches a few degrees below zero. It receives the highest rainfall in Jordan as shown in Figures 3.5. The peak of rainfall takes place during December to February period (see Figure 3.6) especially, in the northern part of this region, such as Ras Munif and Irbed, which are included in this study, while in summer it is hot and dry. In fact, in this region especially, the northern part is exposed to the frontal depressions which invade the east Mediterranean region mainly in winter season, such as Cyprus Low, so that the northern areas are considered as the principal track of these depressions. In addition to that, it is exposed directly to sea track over Mediterranean Sea which enhances and intensifies the rainfall averages over this area. The southern heights have medium amounts of rainfall, since it is not exposed directly to the frontal depression tracks as much as the northern heights. Besides, it is located to the east of the Sinai desert where the frontal depressions follow long land track loosing most of its humidity. The elevation of the mountain heights varies from 600-1500 m above MSL with temperature and rainfall variations accordingly.

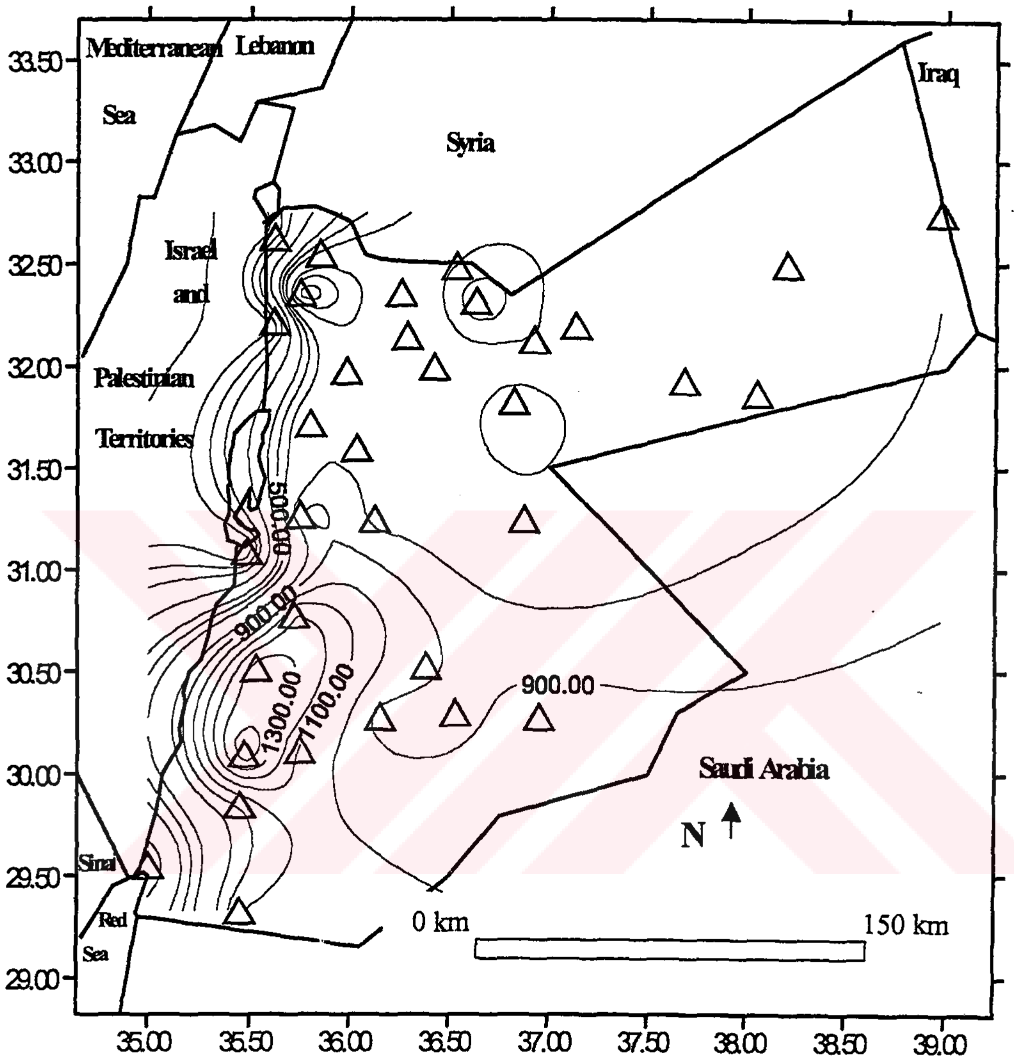

Figure 3.2: The elevations (m) of the stations from mean sea level.

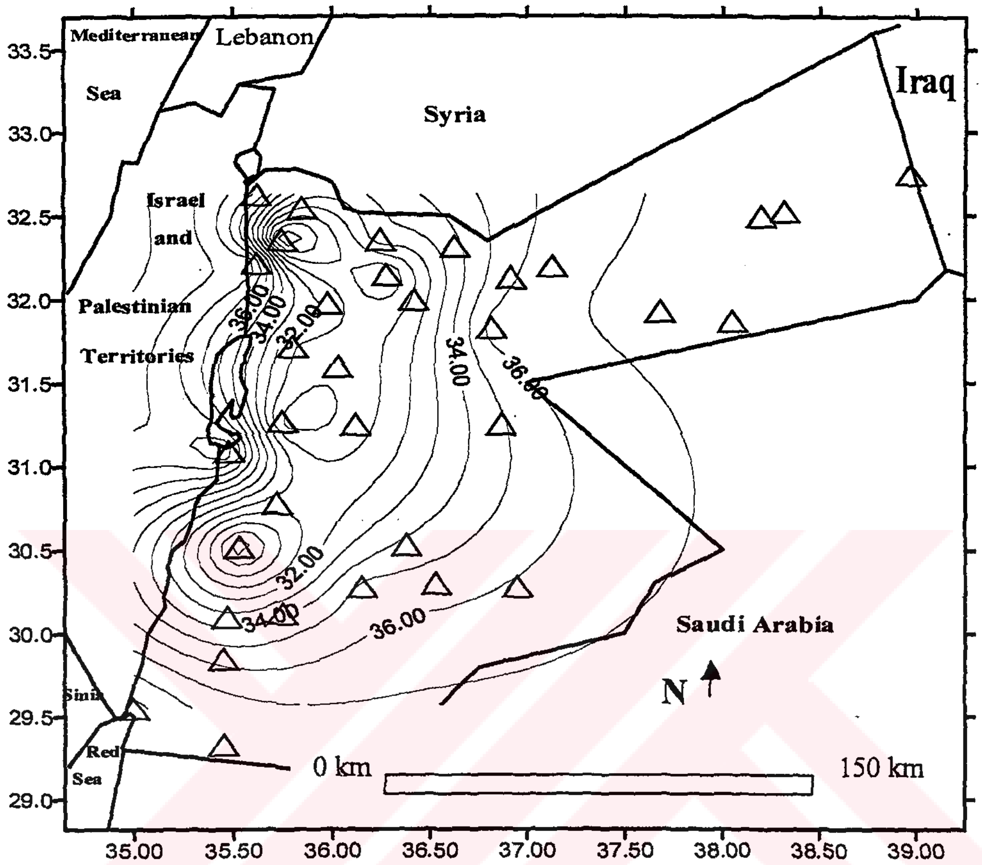

Figure 3.3: Maximum temperature (C °) in July in all regions of Jordan.

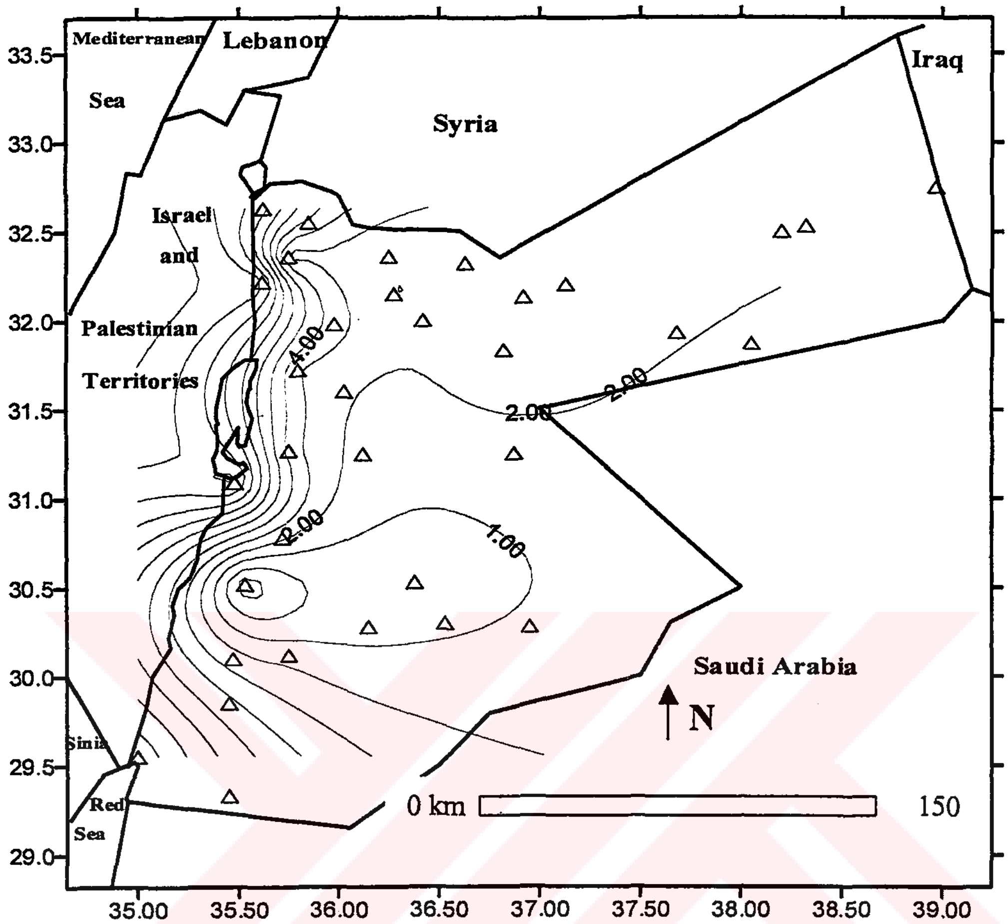

Figure 3.4: Minimum Temperature (C °) over Jordan in January.

3) The Desert or Eastern Semi-arid Region (Badia region)

This region occupies about 75% of the total area in Jordan. It extends from the north to south and southeast of Jordan. The aridity of the region is due to its location to the east of the two mountainous ridges, west bank in Palestinian and east bank in Jordanian territories where the westerly prevailing wind descends dry and hot in this region. The average rainfall in this region is less than 50 mm (Figure 3.5). In this study, several stations are included to represent this area such as; Jafer, Safawi, Mafraq, Dulail, Azraq and Ruwashed (see Figure 1.1).

3.3 The Synoptic Climatology and Seasonal Weather Patterns

Jordan is subjected to several weather patterns through the seasons of the year. As mentioned before, it is located between the subtropics belt in the south and frontal depression of mid-latitudes to the north, and consequently, the synoptic weather patterns change accordingly.

The synoptic weather patterns through out the year can be summarised as follows:

1) Winter Season

The winter is the principal season in Jordan for rainfall. The water year starts from early October to the late April (Figure 3.6). Jordan is usually affected by several air masses, such as the cold air masses of Siberian high-pressure origin.

The cyclogensis (cyclonic motion) takes place over the Mediterranean Sea when the flow of cold air from the Siberian high-pressure passes over the relatively warm water of the sea. The formation of Mediterranean Sea depressions such as the Cyprus Low invades East-Mediterranean countries causing decrease in temperature with rainfall that lasts usually 24 to 48 hours depending upon the deepening of the depression (see appendix A, Figure A.1).

Other types of depressions are formed when the Azores high-pressure moves to the northeast towards central Europe where there is stagnant cold air mass over the Alp Mountains. The presence of high pressure over central Europe lets the northwesterly cold flow to penetrate the Mediterranean Sea to form depressions which in turn, move to the east affecting Jordan. When the high pressure over central Europe moves towards the north, a northerly polar air affects the area by forming depressions over Turkey or over the Mediterranean Sea. These depressions are usually associated with snow fall over Jordan (Shehdeh, 1991).

Sometimes temperatures fall a few degrees below zero causing frost that causes damage to plants especially in the Jordan Valley region. This valley is considered as the reservoir of food for Jordan. The frost phenomena take place when the Siberian high pressure build up towards the south to cover all west Asian countries causing north easterly flow of cold air with clear skies which sometimes lasts for a week.

2) Spring Season.

During the spring season, the Siberian high pressure starts to weaken and moves northward, (Shehadeh, 1991). Besides the Mediterranean depressions take the northeast tracks towards east Europe. In spring season, the extension of Red Sea trough towards the north direction causes instability conditions especially in the desertic region, (see April rainfall in both Figures 3.6 and 3.7).. There are formations of huge convective clouds associated with thunderstorms and heavy showers, due to the warm and moist air at the earth's surface, in the presence of cold upper trough at 500 MB level a loft (Abandeh, 2000). The desertic regions satisfy these synoptical conditions.

The Khamasinic Depressions also affect Jordan and entire east Mediterranean area in the spring season. These depressions form when the temperature of the African desert starts to rise as a result of the perpendicularity of the sun on the north latitudes of the Northern Hemisphere. This leads to large temperature gradients between the two air masses over the desert and that over the Mediterranean Sea. These depressions form over the North African desert and follow land track holding huge amounts of dust with hot and dry conditions to the east Mediterranean countries. In the presence of cold upper trough and northerly flow, these depressions become cold giving showers of rain to clean dusty air of the areas (see appendix A, Figure A.2).

3) Summer Season

Jordan is usually hot, dry and no rainfall in summer season, where the maximum temperature reaches sometimes 40 C in some climatic regions (see Figure 3.3). In this season, the sun becomes perpendicular over the low latitudes of Northern Hemisphere. The difference in specific heat between the huge Indian continent and the Indian Ocean is the main reason of the formation of the thermal monsoon depression over Indian continent. This depression carries huge amount of moisture from the Indian Ocean causing floods over India and Bangladesh. In the contrast, the extension of the Indian monsoon through long land track over Iran and the Saudi Arabia desert causes heat waves in all west Asian countries. When the axis of this depression moves to the east, Azores high pressure moves to the east bringing north-westerly moderate weather condition with temperature averages around the normal (see appendix A. Figure A.3).

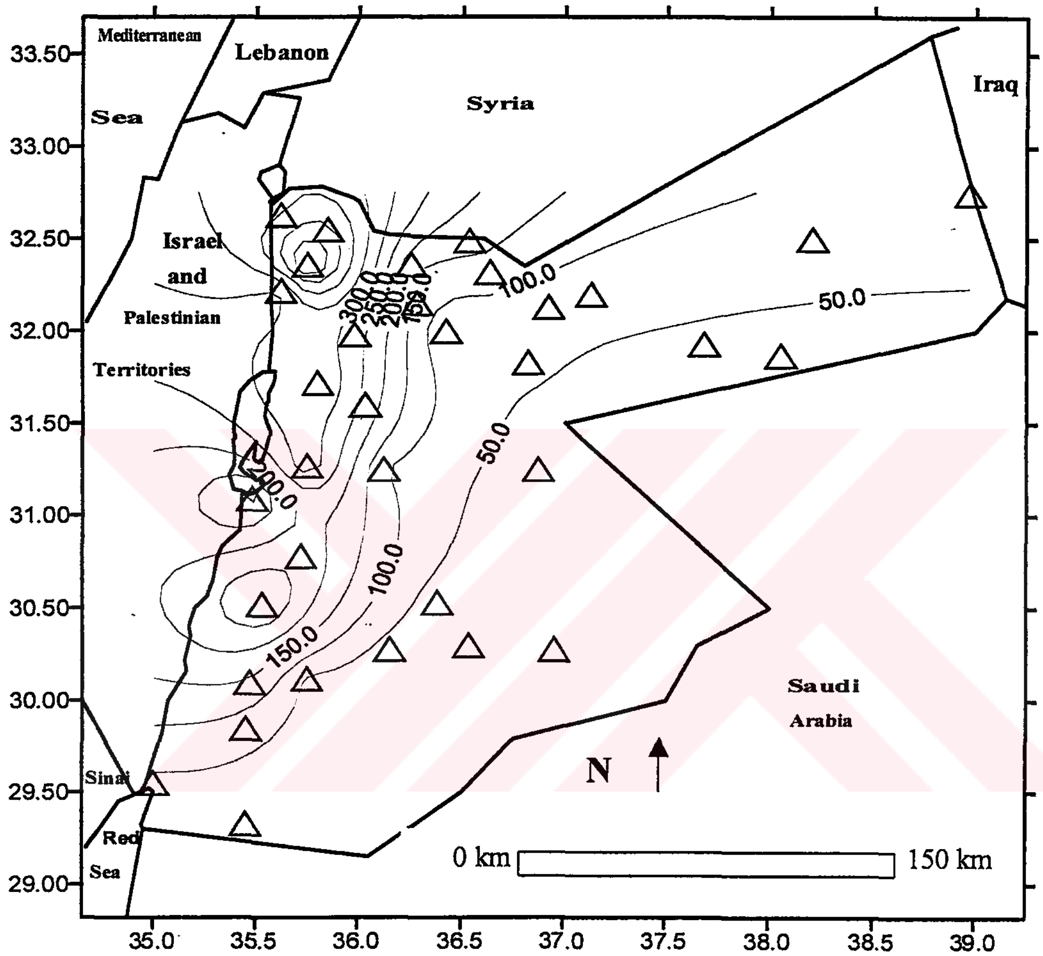

Figure 3.5: The average annual precipitation (mm) in Jordan.

4) Autumn Season

As the Indian monsoon starts gradually to disappear from the synoptic weather charts, the autumn season begins which is transition season between summer and winter. This season is characterised by the extension of the Red Sea trough which causes instability conditions in the desertic region (see appendix A, Figure A.4). This can be shown by October rainfall as presented in Figures 3.6 and 3.7. In this season, some early depressions affect Jordan which cause rainfall over Jordan in the early September, (Abendeh, 2000).

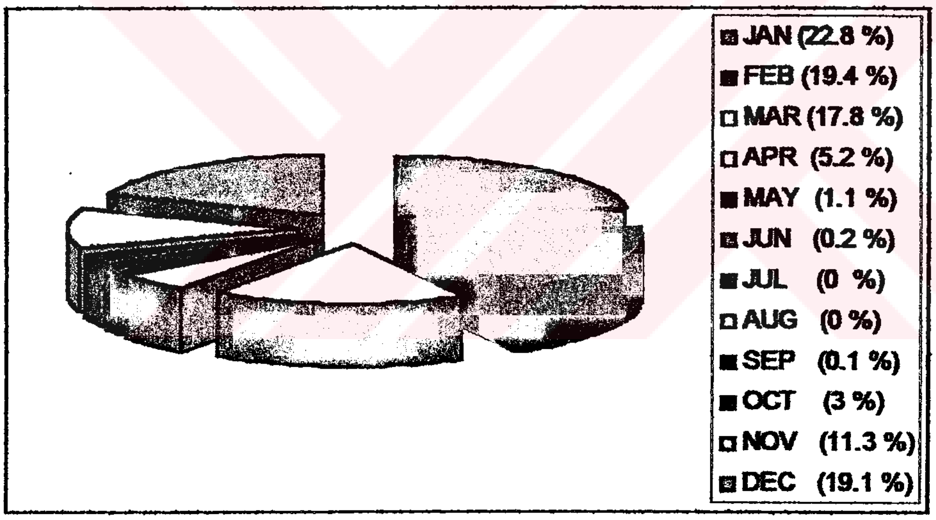

Figure 3.6 Monthly rainfall distributions at Ras- Munif station.

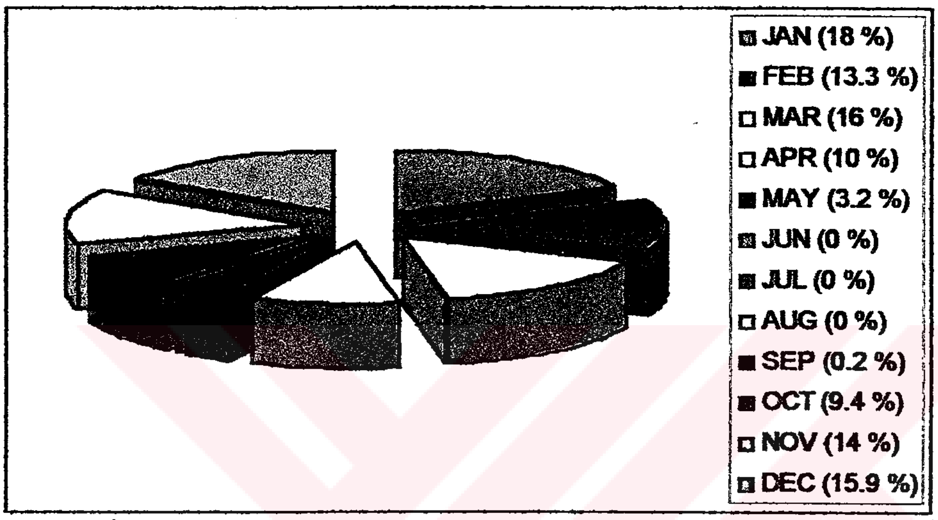

Figure 3.7 Monthly rainfall distributions in the desertic station (Jafer)

Chapter 4

Analysis of Rainfall in Jordan

4.1 Spatial distribution of Rainfall

Jordan has great variability of rainfall with respect to time and space. As mentioned before, the diversity in topography from west to the east and from north to the south is the reason behind the great spatial variability of the rainfall (Shehadeh 1976 and Ghanem 1997).

In order to explain the spatial variability of rainfall, let's see Figure 3.1 which shows the climatic regions of Jordan. The Jordan Valley and mountainous regions are narrow and extends from north to the south. In contrast, the desertic region has wide extensions to the east and south directions. For this reason, the spatial rainfall analysis in Jordan Valley and mountainous regions will be studied from north to the south direction. The desertic region will be analyzed, in general, and especially from west to the east.

On the other hand, the rainfall variability will be analyzed diagonally across the climatic regions, from northwest to the southeast.

4.1.1 Spatial distribution in Jordan Valley region, north-south direction

Jordan Valley is a narrow region that extends from north to the south between the two mountainous ridges of the west bank (west bank of Jordan River) and east (east bank of Jordan River) mountainous terrain in Jordan. The stations of this region are namely, Baqura, Deir alla, Ghor Safi and Aqaba (Table 4.1). In order to study the features of rainfall and the spatial analysis, the first station in the North West (Baqura) is taken as the origin from which the distances of the other stations are measured. Figures 4.1 and 4.2 exhibit how the rainfall decreases towards the south indicating the following facts:

a) The northern parts are closer to the tracks of the frontal depressions. Hence, one can easily note that, for example, at Baqura station No. 1 in Figure 4.2, in spite of its elevation –170 m below MSL, its AAP is 395 mm. This value is higher than 31 mm in Aqaba (station No. 16 Figure 4.2) of elevation 51 m above MSL. This example assures that high rates of precipitation are due to the north locations rather than due to the elevations. This is tantamount to saying that; the rainfall amounts increase at locations close to the tracks of the frontal depressions in the north of the country.

b) The prevailing wind in Jordan is westerly and has two main tracks, namely, sea and land tracks. The northern and central parts of the country are affected by the sea track where the southern parts are affected by land track across the Sinai desert (Met. Dept., 1988).

c) The exponential decrease in Figure 4.1 is the best model to fit the observed data. It represents the spatial variability of rainfall along the Jordan Valley region.

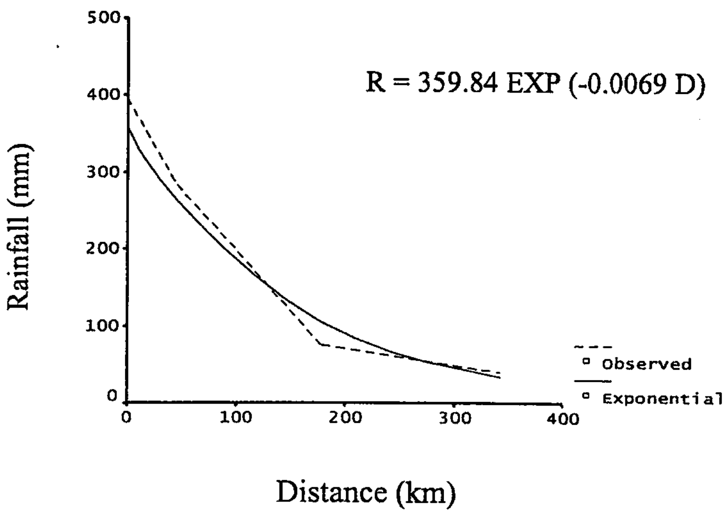

Figure 4.1: The rate change of rainfall in the south direction in the Jordan Valley, distances measured from Baqura.

This region is consider as the food reservoir for Jordan, especially in winter season, because, it is the hottest in the country in winter, so that it is considered suitable region

Table 4.1: Stations of the Jordan Valley and their AAP.

Station	Distance (km)	AAP (mm)
Baqura	0	396
Dier Alla	45	283
Ghor Safi	178	75
Aqaba	342	31

for planting vegetables in cold winter seasons. The spatial analysis and estimating the volume of rainfall, and consequently, the volume of water requirements for irrigation is very important in this relatively dry region.

4.1.2 Spatial rainfall distribution in the mountainous region, north-south

In this region, 9 stations are located approximately parallel to each other. The stations of this region are given the following numbers 2, 4, 8, 10, 34, 11, 18, 15 and 13 (see Figure 4.2, Table 1.1 and 1.2). Figure 4.2 shows the spatial distribution of rainfall with elevation. The following significant points result from the spatial distribution of the rainfall in this region:

a) In northern and central mountainous regions the height of the station plays an important role in determining the rainfall amounts. For example, in Figure 4.2 the distance between Irbed station No. 2 and Ras Munif No. 4 station is 18 km, the heights of these station are 616 m and 1150 m respectively, so that Ras Munif exceeds Irbed station by 120 mm.

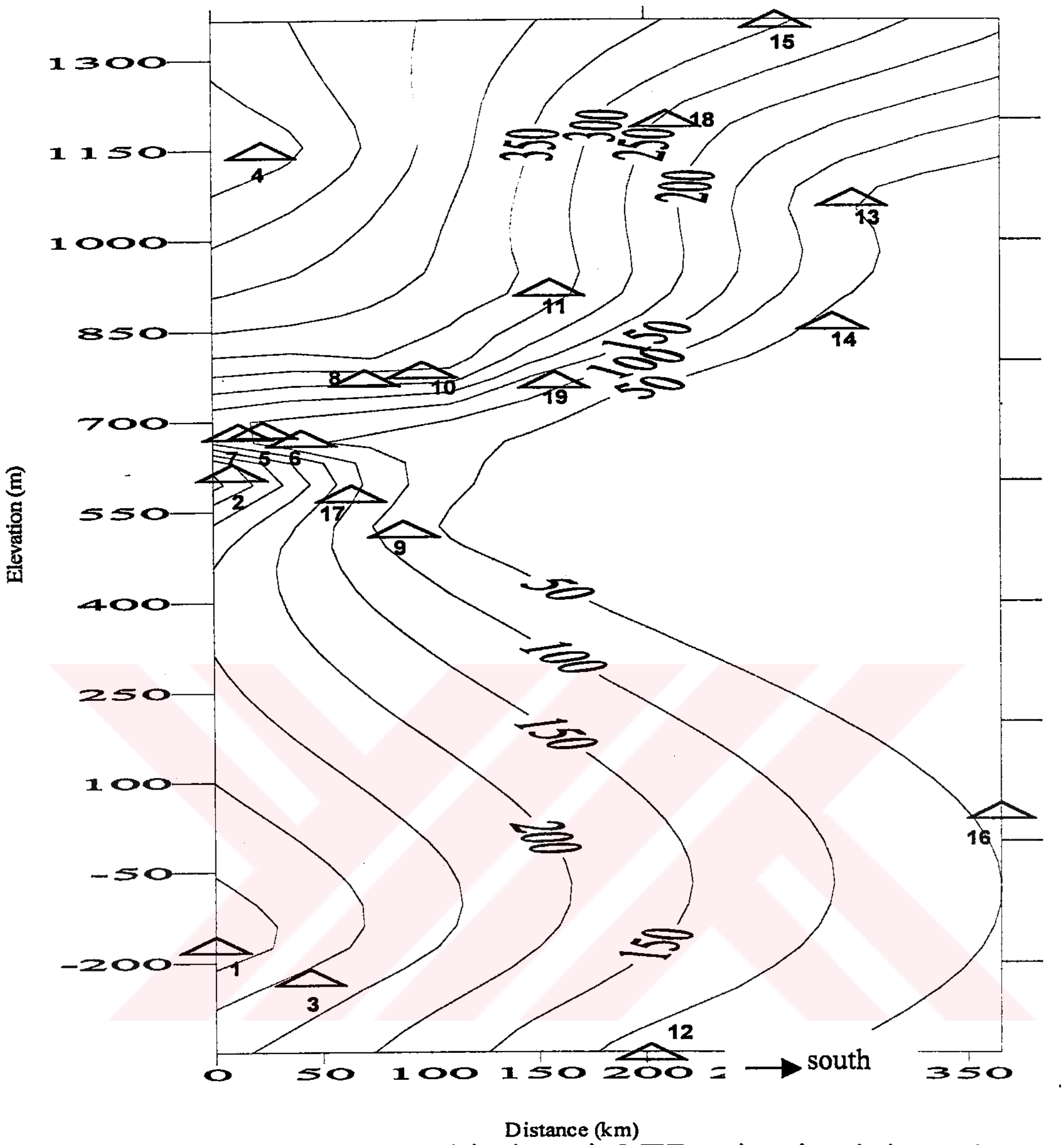

Figure 4.2: The amount of AAP (mm) in the main MET stations in relation to the elevation and locations of the station from the north, distances measured from Baqura.

b) The statement in (a) is not valid when one compares among the stations of the northern and southern mountains. In this case, the height factor should also be excluded. For example, in Figure 4.2, Irbed station No. 2 in the northern mountains has AAP of 462 mm and its elevation 616 m, while Madaba station No. 10 in the central mountains has AAP of 353 mm and its elevation is 785 m above MSL. The same

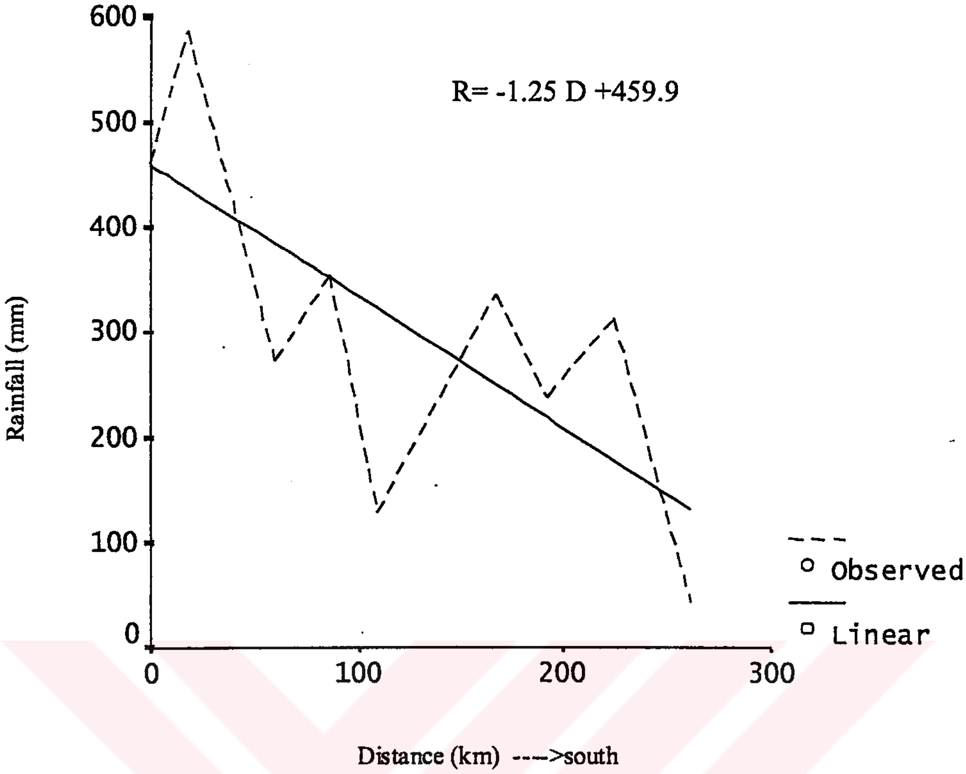

Figure 4.3: Directional southward change of rainfall in the mountainous region, distances measured from Irbed.

result is found by comparing the central and southern mountain stations, for example, Madaba station No. 10 in the central mountains in the former example and Ma'an station No. 13 of 43 mm and elevation 1069 m. The former examples show that the locations due to the north alignment play an important role in determining AAP. Figure 4.3 shows that AAP does not increase with elevation, instead, it depends on the locations in north or southwest or east of the Kingdom.

This may be attributed to two reasons. The first one is that the northern mountainous region is subject to sea tracks of moist air. Sometimes the lifting mechanism of moist air over these mountains leads to precipitation without any synoptically weather system. The second one is the tracks of the frontal depression that affect mainly the northern parts of Jordan.

Table 4.2: Mountainous region station distances with AAP.

Station	Distance (km)	Rainfall (mm)
Irbed	0	462
Ras Munif	18	587
Amman	60	272
Madaba	86	354
CD 15, Dhbah	109	128
Errabah	167	335
Tafileh	192	238
Shoubak	224	312
Ma'an	261	43

c) The location due to the east-west alignment affects the amount of AAP. For example Amman station and CD 15 Dhabh have the least AAP among other stations of the same region. They are located between the desert and mountainous regions, (see the longitudes of this station in Tables 1.1 and 1.2). This is due to their locations relatively in the lee side of the mountains.

4.1.3 Spatial rainfall distribution in the desert region (Badia region), east-west

Badia or desertic region is located in the eastern parts of Jordan behind two mountainous ridges.

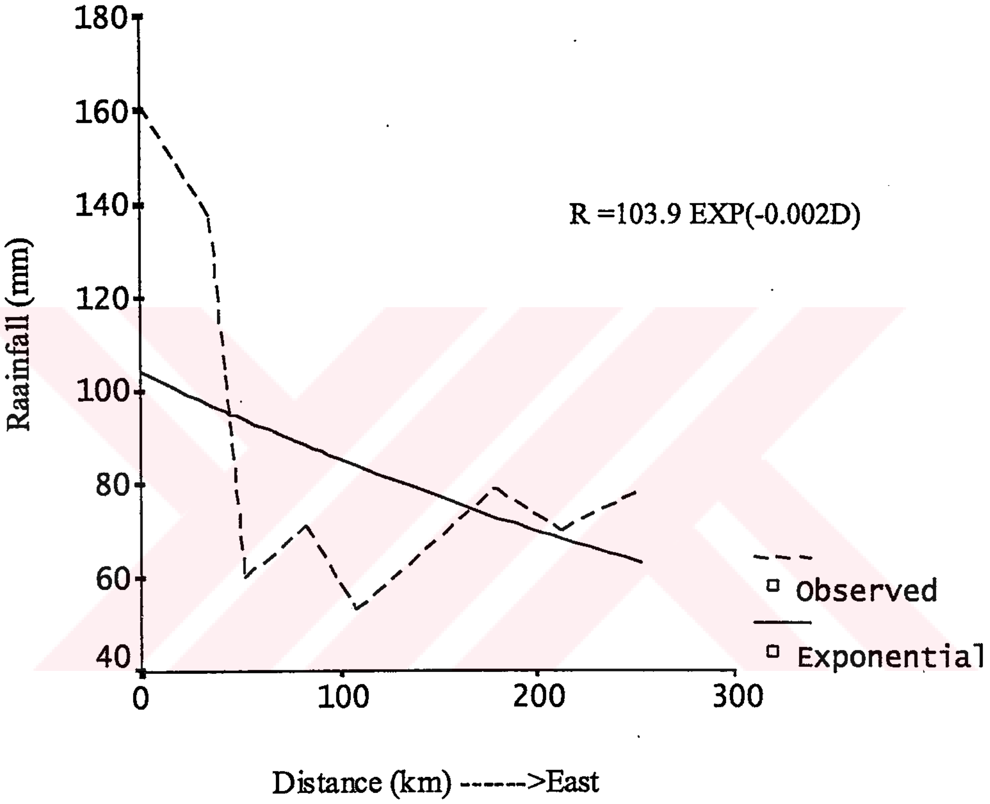

Figure 4.4: The rate change of rainfall in the desert due to eastward direction, distances measured from Mafraq.

In order to study the spatial variability of rainfall from west to east in the desertic region, stations of this region and their distances are measured from Mafraq as the origin, because it is the first station in the west of north desert or Badia region. Table 4.3 gives the directional eastward distances from Mafraq. The rainfall decreases from west to the east in this region, due to the location of this region in the lee side of the mountain ridges. Figure 4.4 show that the rainfall decreases exponentially from west to the east in the north desert. In order to have better understanding of the desertic rainfall, Figure 4.5 is adopted to shows the spatial distribution of rainfall in this region in relation to elevation and southward distance. One of the important results is that the elevation has no effect on the rainfall amount in the desertic region. Stations H3 No.(28) and H2 No. (27) Figure 4.5 have an elevation of about 800 m above MSL which is relatively high, but their AAP are 70 mm and 79 mm, respectively. This can be explained by the fact that, when winter storms penetrate the desertic region, they loose their intensities due to the dryness of the region, as the case in the H3 and H2 stations.

Table 4.3: North desert region station distances with AAP.

Station	Distance (km)	AAP (mm)
Mafraq	0	161
F1	35	137
Azraq	52	60
Safawi	82	71
F13	108	53
Ruwashed	179	79
H3	212	70
H2	253	79

Figure 4.5 assures that, even in the desertic region, the north locations have higher rainfall amounts. For example, station No. 29 has height less than stations (25, 24 and 26) as shown from the figure, but its AAP is higher than these stations. This confirms that, the northern desert areas receive more precipitation than the southern desert. This point must be taken into consideration in governmental planning, especially the reclamation projects of north Badia region.

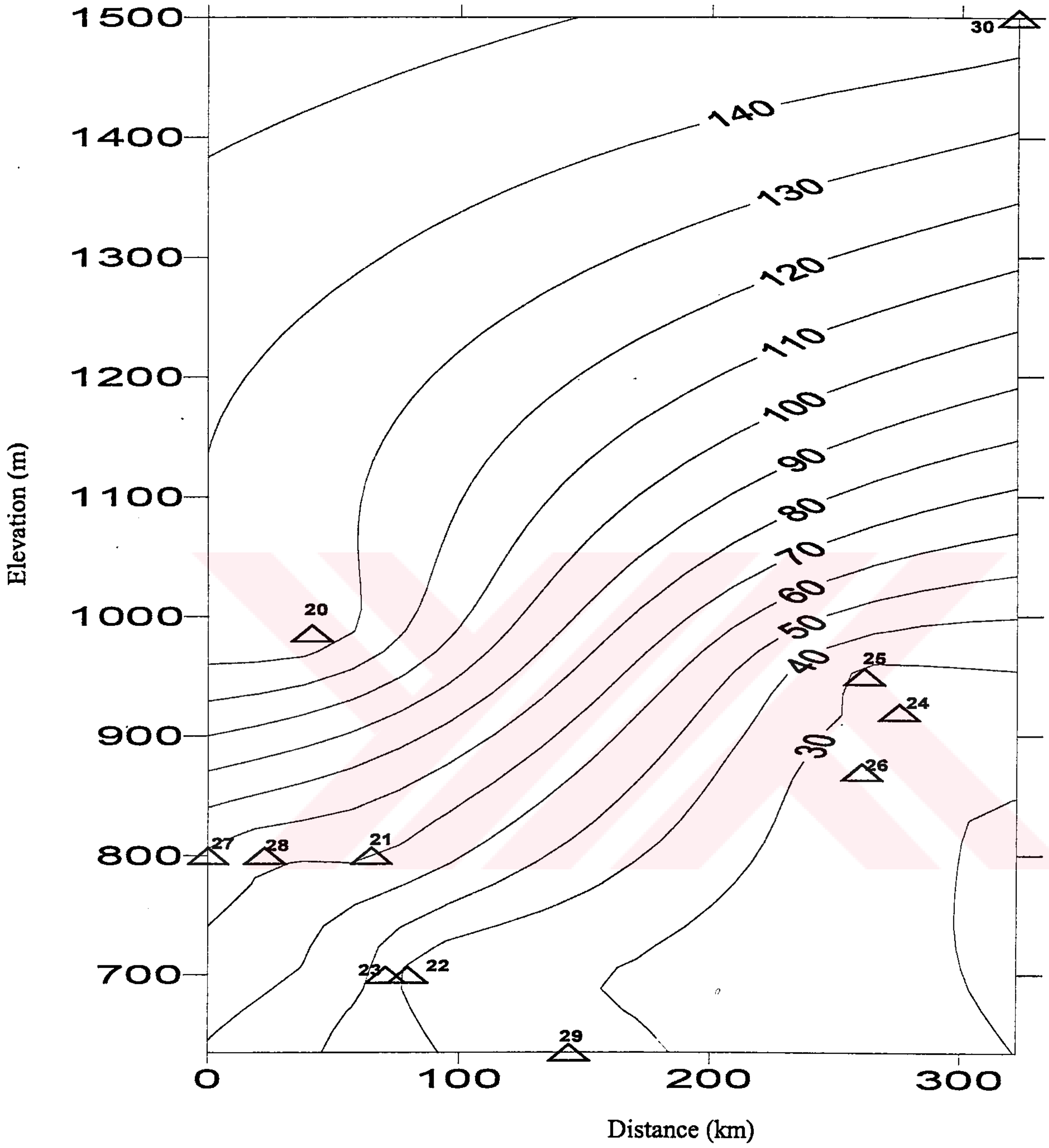

Figure 4.5: AAP (mm) of some desertic MWI station in relation to the elevations and location from northeast station No. 27, distances measured from Trabeel.

4.1.4 Spatial rainfall distribution across the climatic regions, northwest-southeast

In order to understand the spatial variability among the climatic regions, Baqura station is chosen to be the origin from which the southeast distances measurements. The following set of stations is taken across the climatic regions namely, Baqura, Irbed, Ras Munif, Amman, Dulail, CD15, Azraq, Qatraneh, J2, G11, G14 and G15. Figure 4.6 shows a decrease in of rainfall along the southeast direction. The outcome of this analysis assures what has been said about the effect of the elevation on rainfall amounts in the desertic regions, and the following example from Figure 4.2 supports this result. Baqura station No. (1) in Figure 4.2, is the first in the northwest with an elevation –170 m below MSL and AAP of 395 mm, whereas G14 station No.(25) has 950 m elevation above MSL with 26 mm AAP (see also Figure 4.5). The following main points may be concluded from the spatial analysis of rainfall in Jordan

1. The northern parts of Jordan receive the highest amount of rainfall, in comparison to the northern and southern stations of the same region; Table 4.4 shows some of the examples. This may be attributed to the high frequency of winter storms in the northern parts.

2. The eastern side stations have lower amounts of rainfall due to their locations in the lee side of the mountains. Even among the stations of one region the eastern stations, such as Amman (8) in the east of the mountainous region has annual rainfall of about 272 mm, where Madaba (10) station in the west within the same region has AAP of about 354 mm (Figure 4.2).

3. In the desertic region, there is shortage of information and the number of stations is not sufficient to cover the whole desrtic region. The spatial and regression analysis of rainfall in these areas will be useful for any water resources project, especially in the desert areas where there are a lot of agricultural projects such Mafraq and Disi areas.

4. The rate of decrease in rainfall along in the southeast direction is more than the rate of decrease in the south or east directions alone. This is because the southeast direction joins two factors that causing decrease in rainfall. These are the east

direction in the lee mountain side with the southward direction which lies way from the tracks of winter storms. Each eastward and southward direction has decreasing factor as, the same factors mentioned above.

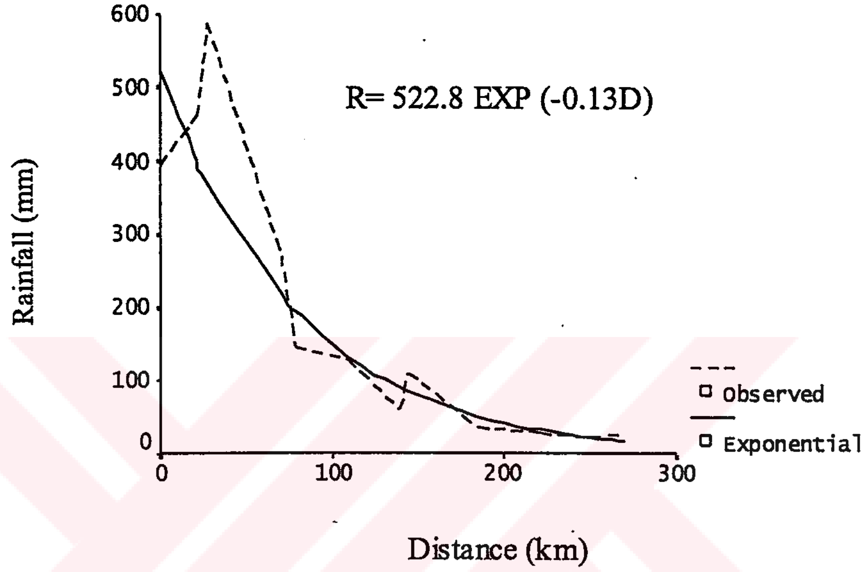

Figure 4.6: The change of rainfall across the climatic regions, distances measured from Baqura.

Table 4.4: Comparison between the northern and southern stations of the same regions.

Region	Location	Station	Rainfall amounts (mm)
Mountains	North	Irbed	462
		Ras munif	586
	South	Errabah	335
		Shoubak	312
Jordan Valley	North	Baqura	395
		Dier all	283
	South	Ghor safi	75
		Aqaba	31
Desert or Badia	North	Safawi	71
		H3	70
	South	Jafer	32
		G14	26

4.2 Precipitation Analysis Using Semivariogram Techniques

4.2.1 Definition

Jordan has divers' terrain and topography that cause temporal and spatial variability of rainfall. This variability of precipitation requires regional variability dependence in order to quantify the regional behaviour of the rainfall of the sites collectively under investigation. In this dissertation, semivariogram (SV) techniques will be used to analyse the precipitation in Jordan as a whole, especially in the analysis rainfall of in Badia or desert regions where there are shortages in the rainfall data. This method shows superiority in estimating any property, especially in the homogeneous topography such as the desert, so that it will help in estimating the missing values of the desert region which has problems in observing the rainfall.

This technique is called geostatistical technique and is widely used in mining engineering. Of course, it is different from statistical methods which are normally used for estimation. The statistical methods are restricted by a lot of assumptions. For example, the date should be linearly distributed and linearly related. Besides that, the covariance must be constant.

The rainfall analysis in the literature normally depends on the time series analysis or stochastic model of equal intervals, (Kadıoğlu et al, 1999; Scott et al, 1979). The spatial analysis of rainfall are desired for hydrological studies concerning site characteristics, such as water budget analysis, groundwater flow modelling and the characteristics of the current climate conditions (Hevesi et al, 1992). There are several methods for estimation of AAP such as Thiesen polygon and isohyetal methods (Bruce, 1962). However, the semivariogram is a technique developed to be used in the field of mining engineering, which is classified as a geo-statistical method. This method describes a phenomenon by a regionalized variable, that is characterised by the spatial distribution from one place to another and not purely random. The spatially correlated phenomena with irregular variation can be characterised in terms of spatial correlation such as variogram.

4.2.2 Theory of regionalized variable

A phenomenon is said to be a regionalized variable if it is spread in space and exhibits a certain structure, e.g. ore grade, temperature and rainfall etc. This theory was first applied in mining as mentioned before and its application extends to many earth sciences.

Consider two numerical values, say rainfall P_p at site p and P_{p+d} at site $p+d$ separated by distance d, then the variability between two quantities is characterized by the variogram function $2\gamma(p,d)$ which is defined as the expectation of random variable $[P_p + P_{p+d}]^2$ (Journel and Huijbregets, 1978) and can be written as follows

$$2\gamma(p,d) = E\left\{(P_p - P_{p+d})^2 \right\} \tag{4.1}$$

This variogram value $2\gamma(p,d)$ is function of both p location and distance d. An intrinsic hypothesis is introduced by the former authors. This hypothesis considers that the variogram function $2\gamma(p,d)$ depends only on the separation distance d, and not on the location p. In other words, hypothetically for any distance d, an increment P_{p+d} - P_p has zero expectation and the variance is independent of position,

$$E\lfloor P_{p+d} - P_p \rfloor = 0 \tag{4.2}$$

Then it is possible to estimate the variogram from the available data as the arithmetic mean of the square differences between two experimental measures $\lfloor P_{p+d}, P_p \rfloor$ at any two points separated by distance d, as introduced by Martheron (1963), as follows

$$2\gamma_d = \frac{1}{N_{(d)}} \sum_{p=1}^{N_{(d)}} (P_p - P_{p+d})^2 , \tag{4.3}$$

or as follows

$$\gamma_d = \frac{1}{2N_{(d)}} \sum_{p=1}^{N_{(d)}} (P_p - P_{p+d})^2 , \tag{4.4}$$

Where the SV value at distance d is γ_d, $N_{(d)}$ is the total number of equally spaced observations However, the distribution of any property is not measured on equally spaced basis. Şen (1989) developed the concept of cumulative semivariogram (CSV) where the summation of SV values change with irregularly spaced distances. Additionally, (point cumulative semivariogram) PCSV and (standard regional dependence function) SRDF are used later by Şen (1995) and Şen and Habib (1998).

The weightings of PCSV technique are related to distance between pivot and each site, in addition to the rainfall and the relationships between the sites. Logically, it is inversely related to distances, the smaller the distance the more the pivot site affected from the nearby stations. Supposing that the measurements at different sites are denoted by P_i, (i=1,2,3,.......,n) and the pivot site under the investigation with P_p, then it is possible to consider the following weighting average prediction formula as

$$P_P = \frac{\sum_{i=1}^{n} W(r_{i,P}) P_i}{\sum_{i=1}^{n} W(r_{i,P})} \tag{4.5}$$

Where $W(r_{i,p})$ is the weighting factor between the station at site i and pivot station at P that corresponds to distance $r_{i,p}$ and P_i is the rainfall value at site i. Figure 4.7 shows classic weighting functions used in the literature by different investigators. None of these functions represent the real event dependence. However, they are considered logically, as well as, geometrically in depicting and explaining the concept of spatial dependence in terms of distance. As it appears from this figure, the closest site to the pivot contributes by the highest weight, and the furthest ones by cooperatively the least weights. The discussion of weighting function in the literature can be abbreviated as the following:

1. The weighting function is considered as a good and practical approximation tool but cannot prove the morphological aspects that are related to the pivot site under

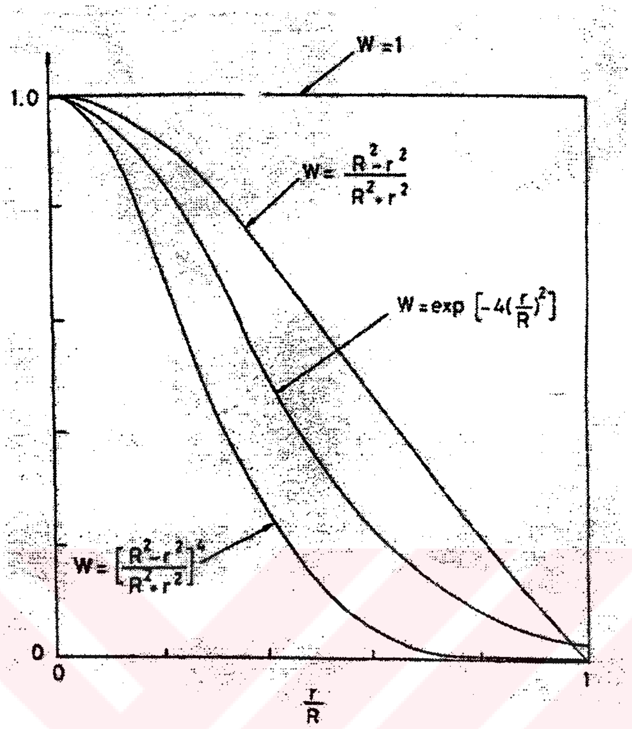

Figure 4.7: Classical weighting function.

investigation. It can be used with the concept of PCSV for interpretations and explanations. This helps to capture the physical meaning that might be the reason behind the behavior of the phenomenon.

2. It depends on the geometry and configuration of the measurements, which may reflect the natural regional variability of the phenomenon. Cressman (1959) used the following weighting function

$$W(r_{i,P}) = \begin{cases} \dfrac{R^2 - r_{i,P}^2}{R^2 + r_{i,P}^2} & for\ r_{i,P} \leq R \\ 0 & for\ r_{i,P} \geq R \end{cases} \qquad (4.6)$$

where, R is the radius of influence or maximum distance between the pivot and the furthest site in specific direction. In spite of its applicability in large scale and world wide validity, it is ineffective in small areas. Another form of weighting function is used by Thiebauxe and Pedder (1987) by extending the Cressman form with a little difference where an exponential parameter $\alpha = 4$ is adopted as

$$W(r_{i,P}) = \begin{cases} \left(\dfrac{R^2 - r_{i,P}^2}{R^2 + r_{i,P}^2} \right)^{\alpha} & for\ r_{i,P} \leq R \\ 0 & for\ r_{i,P} \geq R \end{cases} \tag{4.7}$$

Determination of α involves some difficulties in practical applications (Şen and Şahin 1998). The following form of weighting function is suggested by Sasaki, 1960, and Barnes, 1964.

$$W(r_{i,P}) = \exp\left[-4\left(\frac{r_{i,P}}{R} \right)^2 \right] \tag{4.8}$$

4.2.3 Standard Regional Dependence Function SRDF

The SRDF considers that any phenomenon has spatial variability recorded time-wise at each single station. In order to study such a phenomenon, the SRDF must be determined to depict the regional spatial variability of the phenomenon. Generally, the closer the station, the more the dependence.

In PCSV, a certain variable or phenomenon of a reference station or pivot site is chosen for prediction, proposing that the spatial behavior and regional effect from all sites may give a good idea about the degree of homogeneity from the records at all sites. The following steps are adopted in order to get a valuable sample PCSV for the pivot site:

1) Determine the distances between pivot and all other sites. If there are n sites, then the number of differences will be (n-1).

2) Calculate the half – squared differences of precipitation $(P_p - Pi)$ for (n-1) inter-distances. Herein, P_p and P_i show the rainfall amounts at pivot and other sites.

3) Plot the half squared – differences versus corresponding distances.

4) PCSV is the successive summations of half squared differences versus distances.

5) The same procedures can be applied by considering different pivot sites to construct the PCSV and hence, there is a distinctive PCSV sample for each site which corresponds to the classical autocorrelation function in time series analysis, for depicting the regional dependence.

6) The trigonometric SV can be adopted by plotting the ratio of PCSV (ratio of PCSV to its maximum value) versus the distance ratios (ratio of distances to the maximum

7) The angles express the correlation among the sites, the regional variability and the radius of influence.

In order to depict the regional dependence behavior of rainfall data, the classical correlation functions fail to cope with the situation. This is due to the fact that observation sites are irregularly distributed whereas the correlation coefficients require equal and regular time or space intervals. Therefore, it is necessary to develop a SRDF from the records at a set of irregularly situated sites. In this work, such a SRDF is suggested on the basis of PCSV along with the following steps.

1) Find the maximum PCSV value, V_m at the maximum distance, R_m.

2) Divide each PCSV value by the maximum value of V_m. This will result in dimensionless PCSV which assumes values between zero and one.

3) Subtract each dimensionless PCSV from one so that the maximum value will appear at zero distance whereas the least and zero value at the maximum distance. Such a graph is referred to as the standard regional dependence function SRDF.

4.2.4 Application for Jordan

In order to adopt a functional and regional dependence of rainfall phenomenon, a semivariogram technique is used to achieve the structural and spatial distribution of this process. The semivariogram assumes a relationship among the values of rainfall sample, which is a function of distance. For example, if the value P_i is samples with properties which functions are of point i then, a certain spatial structure exists in the sample distribution. Therefore, we are dealing with regionalized phenomenon, and P_i must be treated as regionalized variable (Rendu, 1978).

In order to achieve the spatial distribution of rainfall and its regional dependence, Amman, the "capital of Jordan" is taken as a pivot site due to its location relatively in the centre of Jordan from which one can go to any direction. Beside, its climatic characteristics do not represent the extremes of the Jordan climate in terms of rainfall or any other climatic elements. For example, it is located in the central mountainous region with AAP of 272 mm, in contrast to Ras Munif and Irbed stations which are located in the northern mountains with their AAP_S as 587 mm and 462 mm, respectively.

Eight semivariogram samples are constructed to analyze the regional variation climatic dependency and the spatial distribution of rainfall by finding the radius of influence around Amman. The major directions N, NE, E, SE,...and NW were considered to achieve the former objectives. Let us start from the N direction of Amman. Table 4.5 gives the stations in the north of Amman and their distances from Amman. Figure 4.8 represents the SV sample of the north Amman region which depicts the homogeneity of rainfall and the regional dependency among Amman and the sites in the north direction. The homogeneity of the sample is shown by α angles on the curve of (Figure 4.8). As α increases the regional dependency decreases. For example if, $\alpha = 0$ degree means that the site has the same regional dependency, and the phenomenon has the same regional characteristics as Amman, and vice versa. It should be noted that $\alpha = 90\ ^{o}$ is impossible, because it implies simply that the site has distance equal to zero from Amman which is Amman itself.

This homogeneity and high correlation appear from the curve in Figure 4.8 which goes steadily at first parallel to x-axis meaning that the change in α angle is very small and equal to 0.33 degree (the angle between the x axis and the line of the curve which is too small to appear in this figure). This small angle reflects the high correlation between Amman and the closest station from the north direction. The second station also has small angle about 34 degree and it has relatively high regional dependence with Amman (Table 4.5). The regional dependence of the second site is less than the previous site by comparison of the angles.

Table 4.5: Sites to north the Amman stations, (R_m maximum distance).

Station	AAP (mm)	Distance (r) (km)	PCSV	r/R_m	Contr-ibution	PCSV Ratio	SRDF	α^o
Amman	272	0	0	0	272	0	1	0.33
D. alla	284	27	72	.385	**283.36**	0.002	**0.99**	34
Mafraq	161	47	6232.5	.671	**129.61**	0.195	**0.81**	70
Irbed	462	61	24282.5	.871	**111.1**	0.759	**0.24**	62
Baqura	396	70	31970.5	1	**0**	1	**0**	
Total*	Amman to be estimated, its contribution and SRDF are not included in total				**524.07**		**2.04**	

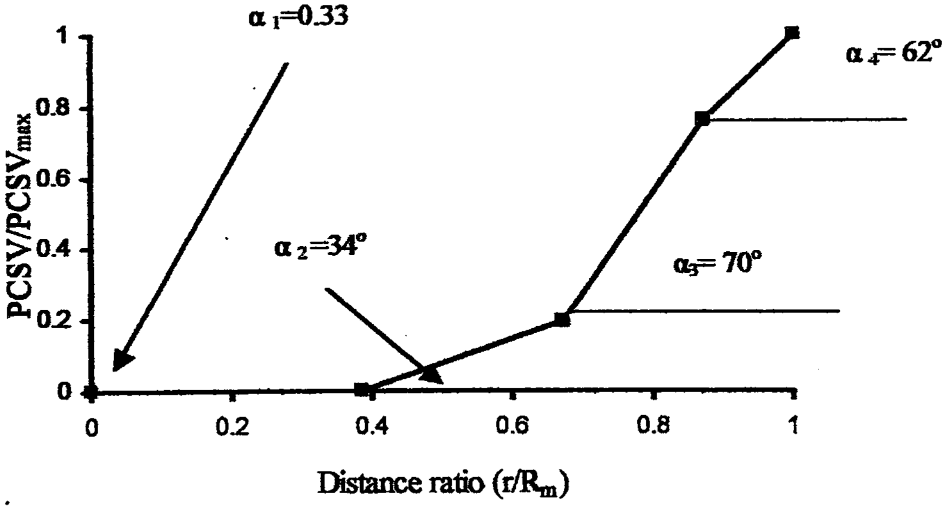

Figure 4.8 PCSV sample for the north direction.

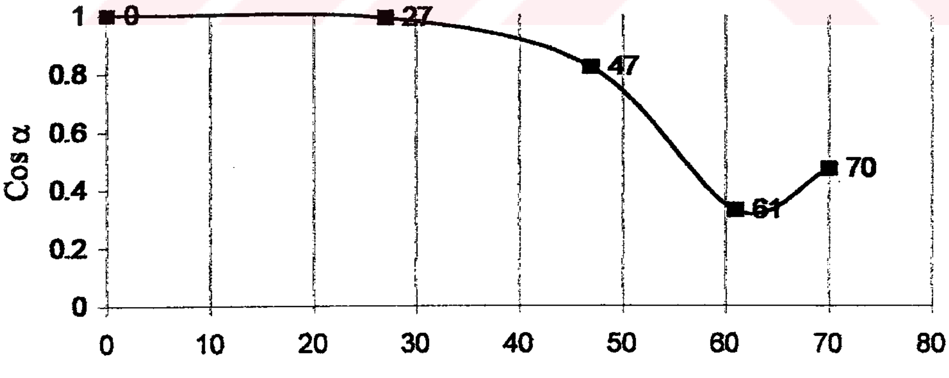

Figure 4.9 The radius of influence towards the north of Amman,distances measured from Amman.

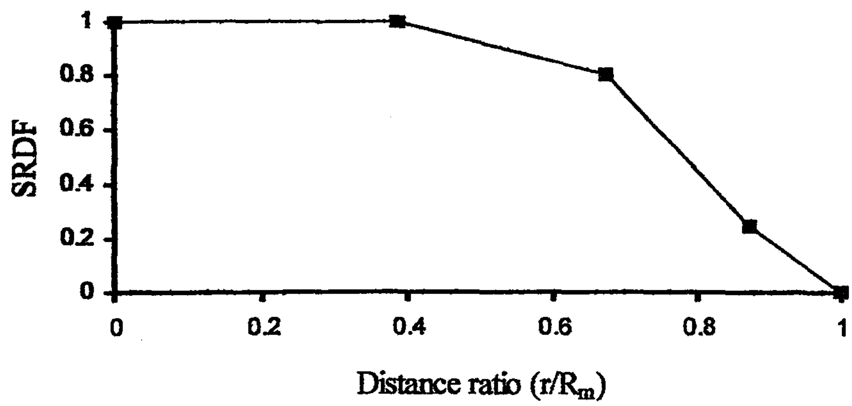

Figure 4.10: Directional SRDF of north Amman sample

The slope of the curve in Figure 4.8 increases where the third angle jumps to 70 degree which means that the regional dependence decreases and the corresponding distance to this angle has the weakest regional dependence at this site. This angle corresponding to the distance is called the radius of influence. Therefore, beyond this point no further dependence between the sites exists, even though if there are small angles to appear after this distance.

The radius of influence may be considered as a controversial subject, because it reaches to the maximum distance i.e., to the independence point where no more influence exists. Since, the rainfall data are not available and measured at close inter-distances; it is represented by the distance that corresponds to the largest angle or the lowest cosine of the correlation angles. The radius of influence may be represented in a satisfactory way, if sites are so close to each other. Şahin (2001) considered the radius of influence as the distance corresponding to the maximum α. Figure 4.9 shows that the radius of influence is 61 km corresponding to the minimum Cos α = 0.33 with (α =70 °). The figure also depicts the homogeneity of regional structure of the rainfall in the north of Amman.

It is found in this study that when the sample has inter-climatic stations; (the sample has stations from two or more climatic regions), the minimum angle of transfer from one climatic region to another is found as 55 ° between Amman in the mountainous region and Dulail in the desertic region. In the SE sample, the following angles are also observed between the climatic regions.

1) α = 61 ° between Errabah and Ghor Safi i.e. when one transfers from mountainous region to the Jordan valley region.

2) α = 57 ° between Madaba and Qatraneh, from mountainous region to the desertic region, and finally,

3) α = 70 ° between Mafraq and Irbed; from desertic region to the mountainous region.

From the correlation angles, one can easily identify the climatic regions where the large angles explain the transformation from one climatic region to another. The last station in Figure 4.9 is Baqura which has lower depencedency with Amman. It is out of the radius of influence. Besides, it is located in the furthest north of Jordan valley region which has differnent climatic charactaristics. The independency of this station assures the superiorty of SRDF technique in determining the regional structure of any regional phenomenon.

The SRDF in Figure 4.10 may also be used here for estimating the rainfall. Since each station has its regional dependence or (weight), one can easily estimate Amman from the weights of other sites as will be discussed in the next section. The SRDF in Figure 4.10 shows also how the furthest station has the lowest weighting, with SRDF almost equal to zero. The straightline reflects the great dependency and the homogeneity of the precipitation between Amman and the nothern stations of Jordan. This fact becomes very clear if one has a look at the chart of climatic regions of Jordan in Figure 1.1. It shows that the north of Amman belongs to the same climatic mountainous region. Besides, this figure indicates how the furthest station with distance ratio equal to 1 has the lowest regional dependence function equal to zero.

Let us now take the NE direction. The east or northeast directions are in the desert side, since Amman is located on the border of the desert so that any displacement to the east direction from Amman will be a part of the desert or the Badia region. The stations and their distances from Amman are given in Table 4.6. The PCSV sample in Figure 4.11 starts with angle of 47.7 ° which is higher than that of previous sample, since it represents the correlation between the Amman and the closest station; it is 0.33 ° in the N sample. The dependency and the homogeneity of the rainfall in the NE are lower than the previous sample. Amman represents the mountainous region while the other sites of the samples are located in the east of Amman in the desertic region. The curve increases gradually with larger slope in comparison to the slope of the previous sample of the north direction sample where the slope becomes larger at the final stages which express greater independency of the furthest sites in the depth of the desert. This show us that the northern area of Amman belongs to the same mountainous climatic region, where in the second sample, the climatic regions and the regional dependency are different. Figure 4.11 assures the regional independency, because of the low correlations among the desert and Amman stations in the mountainous regions. The radius of influence which is the distance that corresponds to the lowest cosine or (largest angle) is about 68 km in the NE as shown in Figure 4.12. This explains the effect of topography on the climate of Jordan, where the mountainous regions extend along the country from the north to the south and represent the border of rainfall, serving as an obstacle preventing the eastern regions from rainfall causing in a completely different climatic region after 68 km to the east of Amman.

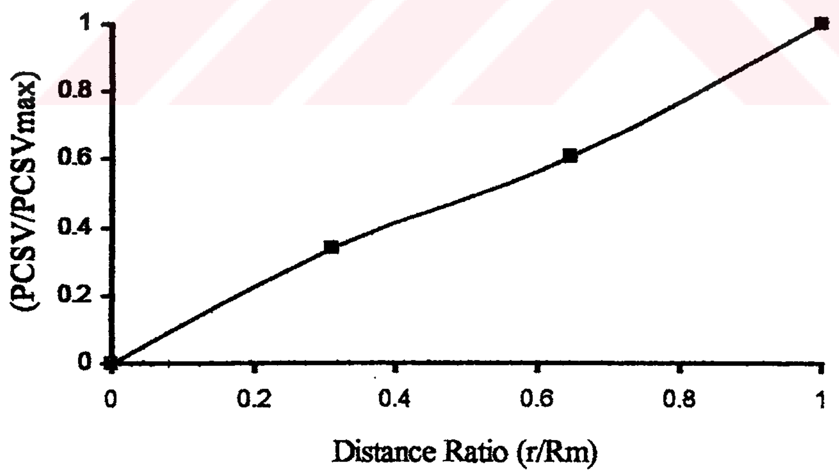

Figure 4.11: PCSV for north east of Amman sample.

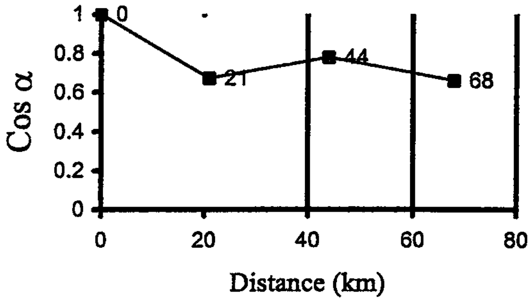

Figure 4.12: Radius f influence for norheast Amman, distances measured from Amman.

Since, the SV is considered as a geostatistical technique in which the spatial distribution can be identified regionally, this is tantamount to saying that the climatic regions may be identified by this technique. The eastern PCSV sample of the eastern direction will have no difference from the north-eastern sample,

Table 4.6: Sites of north-east Amman stations, (R_m is the maximum distance).

Station	AAP (mm)	Distance (r) (km)	PCSV	r/R_m	SRDF	Cont.	PCSV Ratio	α^o
Amman	272	0	0	0	1	272	0	47.7
Dulail	147	21	7812.5	0.31	**0.65**	**96.96**	0.34	38.4
Mafraq	161	44	13973	0.64	**0.39**	**62.98**	0.60	47.9
F1	138	68	22951	1	**0**	**0**	1	
Total ** (Amman to be estimated, its contribution and SRDF are not included in total					**1.04**	**159.94**		

because it is in the east direction is in the desertic region. The heterogeneity in the sample will be expected. The PCSV sample and the radius of influence are shown in the end of the study.

In order to assure the performance of this technique in determining the regional dependence and the homogeneity of rainfall phenomenon, let us take the southward direction which is also in mountainous region as Amman. One should expect homogeneity of this sample, since it is the southward extension of the mountainous region. There are six stations in the southward direction of Amman, as given in Table 4.7. The second station and last one namely Qatraneh and Ma'an, have the lowest AAP. The two stations are located relatively to the east of the mountainous region, and their elevations are above mean sea level with 768 m and 1069 m, respectively. These stations are classified as desertic in spite of their high elevations. The PCSV of the southern Amman in Figure 4.13 starts with small angle of about 27°, and then an abrupt

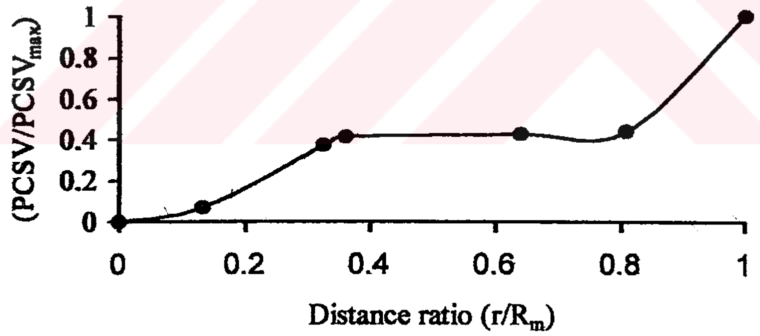

Figure 4.13: Directional PCSV for south Amman sample.

change occurs due to the Qatraneh station which has desertic properties. Later, the curve goes steady to explain the high regional correlations and homogeneity among the southern mountainous stations and Amman. These are called Mu'ab and Sharah mountains located relatively to the west, in contrast to Qatraneh and Ma'an stations. The last station in this figure is Ma'an which has also desertic properties as mentioned before. This station has another abrupt change in the curve which assures the regional independence of this station with the sample. In spite of the presence of the two stations of desertic properties in the mountainous region, the configuration of the mountainous stations is clearly depicted and identified by PCSV figure. The curve reflects the regional homogeneity of the rainfall and the high correlation among these stations. The radius of influence is found at Ma'an station. Figure 4.14 where the angle is 70.9 °. This angle is preceded by angles of 27.8 °, 57.8 °, 49.2 °, 2.4 ° and 5.3 ° (see Table 4.7) which reflect the homogeneity among the sites of the sample. The two stations can be identified visually from Figures 4.13 and 4.14. In the cases of Ma'an and Qatraneh stations, the lowest Cos α in Figure 4.14 refers to the former stations.

The regional dependence of rainfall appears from PCSV samples in all directions and radii of influence are given in Table 4.8. The other samples of E, SE, SW, W and NW directions are constructed see appendix B.

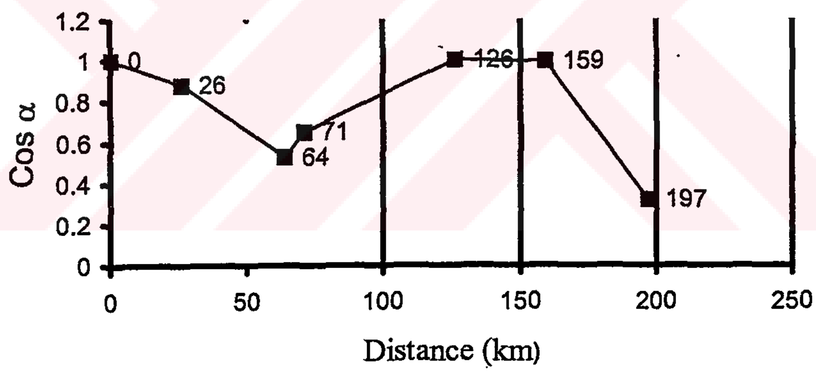

Figure 4.14: Radius of influence for southern Amman, distances measured from Amman

Table 4.7: Sites of south Amman stations, (R_m is maximum distance).

Station	AAP	PCSV	Distance Km	Dis. Ratio	SRDF	PCSV Ratio	Cont.	α^{o}
Amman	272	0	0	0	1	0	272	27.8
Madaba	355	3362	26	0.13	**0.93**	0.07	**329.31**	57.8
Qatrane	101	17982.5	64	0.32	**0.62**	0.37	**63.33**	49.2
Errabah	335	19967	71	0.36	**0.58**	0.41	**196.27**	2.45
Tafileh	238	20545	126	0.63	**0.57**	0.42	**136.59**	5.37
Shoubak	311	21305.5	159	0.80	**0.55**	0.44	**173.58**	70.9
Ma'an	40	48217.7	197	1	**0**	1	**0**	
Total** (Amman to be estimated its contribution and SRDF is not included in the total)					**3.25**		**899.08**	

4.2.5 Cross validation

The SV technique introduces very important concept in estimation of the rainfall using the trigonometric way or the SRDF methods. The estimation of rainfall or any missing values by adopting the SV can be achieved by calculating the angles which represent the weights of the sites. Şahin (2001) improved this technique in the calculations of wind energy. The average annual precipitation in Amman AAP_A can be found by rewriting equation (4.5) as follows:

$$AAP_A = \frac{P_1 Cos\alpha_1 + P_2 Cos\alpha_2 + ... + P_n Cos\alpha_n}{Cos\alpha_1 + Cos\alpha_2 + ... + Cos\alpha_n} , \qquad (4.9)$$

Where, P_s are the values of AAP and α is the correlation angle of the PCSV sample. The estimation of Amman AAP_A from the northern sample in Table 4.5 may be calculated by applying equation (4.5) in the form of equation (4.9) as

$$AAP_{A}= \frac{284 \cdot Cos(0.33) + 161.Cos(34) + 462.Cos(70) + 396.Cos(62)}{Cos(0.33) + Cos(34) + Cos(70) + Cos(62)} = 296.96 \text{ mm}$$

with the relative error of 8 %.

The cross validation can be applied using SRDF as weights multiplied by the rainfall of each site and dividing by the sum of the weights, by applying equation 4.5 directly, the summation of contributions is divided by total weights or SRDF. From Table 4.5 the summation of contributions are equal to 524.07; and summation of weights equal to 2.04, then AAP_A= 524.07 /2.04 = 256.89 mm with relative error of 5 %. Table 4.5 shows estimation for Amman, so its weight. (SRDF) is not included in the total of the contributions and weights.

The cross-validation method for the estimation by AAP reflects also the degree of the independency and regional correlations. In the case of all desert component directions, i.e. the east directions such as northeast sample, the estimated value is expected to have large error so that one may apply equation (4.5) and use Table 4.6, AAP =159.94/1.04 = 153.78 mm with an error of 43 %. Equation (4.9) is applied for the sample with an error 45 % which is given in Table 4.8. It reflects the independency of the rainfall phenomenon among the site under investigation. In the same way, the estimation of Amman AAP_A from the southern stations and using Table 4.7 and equation 4.5 leads to AAP_A = 899.08/3.25 = 276.86 mm with relative error of 1 %. Equation (4.9) yields for same sample AAP_A= 260.8 with an error of 4 % given in Table 4.8.

Different samples from all directions are calculated in the same way. Table 4.8 gives the result of cross validation method for estimations based on Amman AAP_A using different samples. In this table each sample represents a separate direction. The result reflects the heterogeneity of the rainfall regime between Amman and the eastern areas, which are the desertic region, of the north, central and southern desertic regions. Only the eastern parts have weak correlations. This can be seen from the errors between the estimated and measured values of the eastern samples.

Table 4.8: Results cross validation and the radius of influence.

Sample	Estimated AAP (mm)	Measured AAP (mm)	Error %	Radius of Influence
North	296.96	272	8	61
North-east	149.3	272	45	68
East	100.7	272	62	75
South-east	90	272	66	198
South	260.8	272	4	197
South-west	288.5	272	5	125
West	316.92	272	14	27
North-west	285	272	4	74

4. 3 Harmonic analysis of precipitation climatolgy

Precipitation as many meteorological elements is a list of values that varies with respect to time. The time interval in meteorological variables may extend from one second in the case of turbulence studies to thousands of years in climatology. One of the most important features in analysing the climatology of any region is to study, the precipitation and its periodicity of different harmonics in order to capture any physical interpretation related to the behaviour of the observed data. In this study, the amplitude of frequencies, phase angle and basic statistical parameters are calculated in order to depict the spatial periodicity of precipitation over Jordan. Precipitation records of 17 stations are chosen so that, all climatic regions of Jordan are represented.

4.3.1 Harmonic Analysis formulations

In this section study of the harmonic analysis will be discussed in order to analyze the parameters, namely, the amplitude (A) and phase angle (Φ) of a periodicity for which the data comprise only perfect sine curves of known period. (Panofsky and Breir, 1958) discussed the details of the harmonic analysis.

For a given precipitation time series P_t, t = 0, at origin X_t, can be written as sine signals as follow

$$P_t=\overline{P} + A_1 \mathrm{Sin}\left(\frac{2\Pi}{T}t+\Phi_1\right) + A_2 \mathrm{Sin}\left(\frac{4\Pi}{T}t+\Phi_2\right) + \ldots + A_n \mathrm{Sin}\left(\frac{2n\Pi}{T}t+\Phi_n\right) \quad (4.10)$$

where $\overline{P}$ is the arithmetic average of the original data series, the rest of the terms represent the first, second , ... nth harmonic analysis of the period T. Equation (4.10) can be rewritten in terms of sine and cosine function as:

$$P_t=\overline{P}+\sum_{i=1}^{n}\left[a_i Cos\frac{2\Pi}{T}it+b_i Sin\frac{2\Pi}{T}it\right] \quad (4.11)$$

where a_i and b_i are the components of i-th harmonic, the coefficient of i-th harmonic can be written as

$$a_i = \frac{2}{n}\sum_{t=0}^{n-1} p_t \ Cos\left(\frac{2\Pi}{12}it\right) \ i = 1,2,\ldots,\frac{N}{2} \tag{4.12}$$

and

$$b_i = \frac{2}{n}\sum_{t=0}^{n-1} p_t Sin\left(\frac{2\Pi}{12}it\right) \ i = 1,2,\ldots,\frac{N}{2} \tag{4.13}$$

Where p_t is the monthly mean precipitation in t-th month and n is the number the observation.

The amplitude can be written as

$$A_i = \sqrt{a_i^2 + b_i^2} \tag{4.14}$$

The phase angle of i-th harmonic as given by Duchon (1981) and Burroughs (1992) can be written as

$$\Phi_i = \arctan\left[\frac{b_i}{a_i}\right] \tag{4.15}$$

The date of the occurrence of the maximum for each harmonic can be written as

$$t_i = \left[\frac{T}{2\pi i}\right]\Phi_i \tag{4.16}$$

The variance of the harmonic as given by Jenkins et al (1980) can be written as

$$V_i = \frac{A_i^2}{2} \tag{4.17}$$

The first harmonic, generally, represents a single annual cycle of the observation (1/12) month^{-1} i.e, observation of one year can be expressed by one cycle with large amplitude in comparison to other harmonics. The second harmonic represents the tendency towards a semi-annual variation of precipitation, and the observed data is not similar to the represented form by harmonic analysis.

The third harmonic describes more details of the annual variation of precipitation, such as the seasonal variations or 4-month variations, so that, the third harmonic is an indicator of the different rainfall regime types (Kadıoğlu et al, 1999).

The phase angle charts indicate the displacements of the maximum along the time axis, which is represented by the time-axis, (0 = 0°, represents 15 December and the other months are represented every 30^0 and so on). The phase angle charts can express the precipitation regime and the boundaries. The ratio of the first and second harmonics may be considered as a good measure for describing the nature of precipitation and its variation.

4.3.2 Application to Jordan Precipitation Data

The harmonic analysis is the decomposition of the components as harmonics which explain the variations of the original data. It also gives the maximum and the minimum occurrence instances along the time axis. Tables 4.9, 4.10 and 4.11 give the contributions of each harmonic in three stations representing the climatic regions of Jordan, as Amman, Jafer and Baqura regions. The calculations of 1st to the 6th harmonics are given where, a_i and b_i are the coefficients of the harmonics, A_i, amplitudes, phase angle Φ_i, variance V_i percentages of variances **(PVAR)** and cumulative percentages of variances **(CVR)**. The first, second and third harmonics are quite enough to describe the variations of the data, because the first three harmonics have the majority of the variances. For example the variances of the first harmonic V_i in the three stations are given in Tables 4.9 - 4.11 as follows; 547.150, 4.97, and 1111.210 while their percentages; (variances of the first to the total variances) are 89.850, 92.882, and 90.98 respectively. Besides the second and third harmonics have small significant values. For example, the second harmonic in the former stations have the following percentages 9.654, 0.654 and 7.577 ;(see the former tables). It is clear that as the harmonic number increases the percentages decreases, for example, fourth harmonic 0.228, 1.685, and 0.327 in the former tables, the same result is found in the case of the 5th and 6th harmonics. For this reason, only the first two harmonic are considered, and those lower contributions are neglected from our discussion.

4.3.2.1 First harmonic

The first harmonic analysis as mentioned before represents the variation of one cycle, or one-year cycle (1/12) month $^{-1}$. Figure 4.15 depicts the observed data in Jafer station in the desertic region and its harmonics. Figures 4.16 and 4.17 depict the first, second, third and fourth harmonics of Deir Alla station in the north Jordan Valley and Shoubak station in the southern mountainous regions respectively. The first harmonic in the three figures is represented by one wave. It is a filtering wave so that, part of this wave goes below x-axis; (time or months) giving an impression of negative rainfall in summer months. The observed data in Figure 4.15 shows zero rainfall in summer months. It is clear from the former figures that the first harmonic is one wave that covers the whole period, where any small variations can not shown by the first harmonic. The first harmonic as shown from the former figures has the largest amplitude, so that winter season of maximum precipitation may be referred to the amplitude of the first harmonic (Scott and Shulman 1979). On the other hand, the first harmonic frequency of the first harmonic is (1/12) month $^{-1}$ where the second harmonic is (2/12) month $^{-1}$ which can explain more details.

The percentage of month to month variance by the first harmonic in Figure 4.18 explains the following:

1) The first harmonic explains the majority of the area within more than 90 % in the northern and southern parts and not less than 50 % in the eastern south -eastern part of the Kingdom.
2) The percentage of variance of the first harmonic decreases from west to the east, i.e. the closer to the Mediterranean Sea, the greater the variances which indicate the rainfall mechanism of the country.

3) The mountainous or high land regions in the north of Jordan have the highest percentage. This region is represented mainly by Ras Munif and Irbed stations, which have 90 % of the variance, also the southwest parts of the country where the highest mountainous terrain are found Table 1.1.

The highest percentage in these regions is due to the following:

a) It is high mountainous region especially Ras munif is 1150 m above MSL.
b) Its location is on the track of the frontal depressions zone.
c) The northern parts of Jordan generally, receive rainfall more than that of the southern parts. This is caused by the extension of depressions from Turkey through Syria, while the southern parts are affected by the Cyprus lows only.
d) The southwest mountain areas with 90 % of variance is explained which is represented by Shoubak. This region also represents a high mountainous area. It receives appreciable amounts of rainfall but not as much as that of the northern areas. In addition to the foregoing reasons in (b) and (c), the distribution of rainfall in Jordan depends on the type of the track of the westerly prevailing wind. The southern mountainous regions are usually affected by the land track across Sinai desert.

4) The southern Jordan Valley region shows a lower percentage in comparison to the northern stations. Figure 4.18 shows that Ghor Safi station near the Dead Sea has lower percentage than the northern stations of the Jordan Valley, such as Baqura and Deir Alla. On the other hand, Appendix C gives the percentages of the different harmonics for several stations. For Ghor Safi station the values of the third, fourth, fifth and sixth harmonics are higher than that of the northern stations such as Baqura station (see Table 4.11 and Appendix C). This reflects the difference in rainfall regime which arises from the winter storms that affect northern regions more than the southern regions as mentioned before, besides the altitude difference from mean sea level.
5) Desert Region is represented by 44-80 % of the percentages of variance explained by the first harmonic, except Rewashed station in the north-eastern shows value below 50 % in Figure 4.15. This low percentage leads to high percentages of the other harmonic, second and third etc. Appendix C gives the

percentages of first –sixth harmonics, 44.815 %, 10.632 %, 11.726 %, 8.308 %, 12.509 and 12.011 %, respectively. The higher percentages of the other harmonics in Rewashed station in the northeast reveal different rainfall regimes that can be measured by the second, third, etc harmonics. As mentioned before the higher harmonic numbers explain more details of the time series data.

Table 4.9: Calculations of the 1st to 6th harmonic for Amman station, where **i** number of harmonic, PVAR(i) percentages of variances, CVR cumulative variances

i	a_i	b_i	A_i	Φ_i	t	V_i	**PVAR(i)**	**CVR**
1	25.777	20.733	33.080	38.811	1.29	547.15	89.850	89.850
2	1.885	10.678	10.843	79.989	1.33	58.787	9.653	99.503
3	-0.988	-0.868	1.316	-89.680	-1	0.865	0.142	99.645
4	0.678	-1.521	1.666	-65.968	-0.55	1.387	0.228	99.873
5	-0.013	0.324	0.324	-89.719	-0.6	0.052	0.009	99.882
6	-1.200	0.000	1.200	-89.682	0.5	0.720	0.118	100.00

Table 4.10: Calculations of the 1st to 6th harmonic for Jafer statoin.

i	a_i	b_i	A_i	Φ_i	t	V_i	**PVAR(i)**	**CVR**
1	2.621	1.756	3.154	33.823	1.13	4.975	92.882	92.882
2	0.058	-0.258	0.265	-77.453	-1.29	0.035	0.654	93.536
3	0.245	-0.452	0.514	-61.523	0.68	0.132	2.465	96.001
4	-0.041	0.423	0.425	-89.699	-0.5	0.090	1.685	97.686
5	-0.131	0.463	0.481	-89.688	0.6	0.115	2.156	99.842
6	-0.130	0.000	0.130	-89.682	0.74	0.008	0.158	100.000

The amplitude of the first harmonic describes the natural variation in single cycle. Figure 4.19 shows the following:

The highest amplitudes are found in the northern regions reaching the highest value of 70 mm over Ras Munif station, 1150 m above MSL and decrease southward along the central and southern mountainous regions, where there are high mountainous such as, the Soubak station 1365 m above MSL as given in Table 1.1. The topographic type of rainfall is well depicted in this region, as shown in Figure 4.19, with an increase of amplitude values over the southern mountainous regions.

Table 4.11: Calculations of the 1st to 6th harmonic for Baqura station.

i	a_i	b_i	A_i	Φ_i	t	V_i	PVAR(i)	CVR
1	38.860	26.689	47.143	34.480	1.15	1111.210	90.984	90.984
2	7.083	11.615	13.604	58.626	0.68	92.533	7.577	98.561
3	3.503	-1.300	3.737	-20.359	-0.23	6.982	0.572	99.133
4	2.789	0.452	2.826	9.201	0.1	3.992	0.327	99.460
5	-.769	2.171	2.304	-89.687	-0.6	2.653	0.217	99.677
6	-2.810	.000	2.810	-89.682	-0.5	3.948	0.323	100.000

The precipitation distribution is highly depicted by the amplitude of the first harmonic charts. The mountainous region can be identified by this figure. The reason can be attributed to several winter storms such as Cyprus low that affects Jordan in winter season. The topography plays an important role in rainfall distribution over the climatic regions of Jordan, so that mountainous regions have the maximum amounts of rainfalls. In spite of the fact that the height of the southern mountainous regions is more than that of the northern mountainous region (see Table 1.1, elevation of Ras Munif and Soubak stations). The northern regions have more rainfall amounts because; they are subjected to the depressions that have direct sea tracks. Beside that, the northern regions have a good chance to catch any possible weather systems which are normally extended from Turkey towards Syria and Jordan. On the contrary, the southern regions are rarely affected by such weather systems. This explains why the northern mountainous regions have larger amplitudes than that of southern mountainous regions.

1) The amplitude of the first harmonic decreases from west to the east and south-east, which gives indications of decreasing rainfall regime towards the east and south-east region.

This explains the regime type of the desertic regions, in other words Figure 4.19 identifies the desertic region. The marginal amplitude line is of 20 mm where the east of this line desertic rainfall regime exists. The extensive amplitude lines between the northern mountainous and desertic regions in the north of the Kingdom. Figure 4.19 explains the large gradient between rainfall amounts over small distances not exceeding 30 km. On the other hand, the same figure depicts this gradient by looking at the rainfall amounts in two adjacent stations such as Wadi Dulail and Ras Munif in the north or Ma'an and Shoubak in the south. This is tantamount to saying that the climatic regions of Jordan are so close to each other.

2) The Jordan Valley region between Jordan to the east and West Bank has low amplitudes similar to the desertic regions. This can be shown by Ghor Safi station with 350 m below MSL in the south of the Dead Sea. It has amplitude less than 20 mm. The northern parts of this climatic region have good amounts of rainfall due to their locations to the north such as Baqura station with its elevation 170 m below MSL

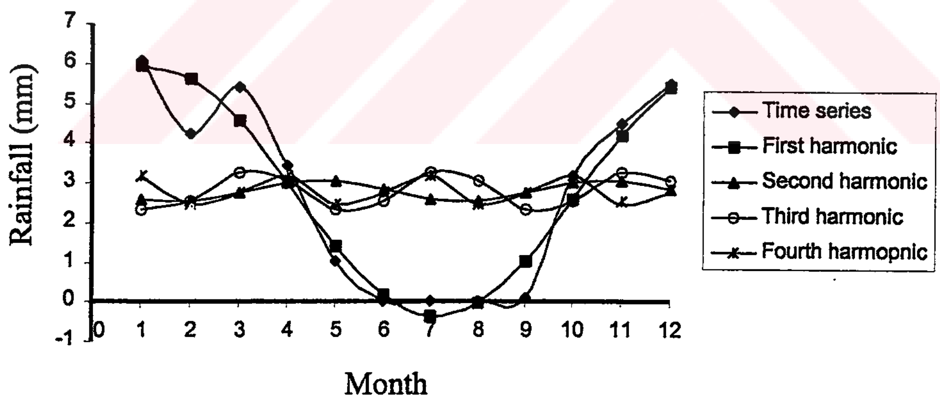

Figure 4.15: Jafer station, observed data and its 1^{st} - 4^{th} harmonics.

The stations of this region, namely, Dier Alla and Baqura have significant amplitudes higher than that of Ghor Safi due to its location in the north. In general, the northern part of Jordan Valley is more closed to the track of winter storms than Ghor Safi station. In addition to that Ghor Safi station is 350 m below MSL which is deeper than the stations in the northern part. The location of Jordan Valley lies to the east of

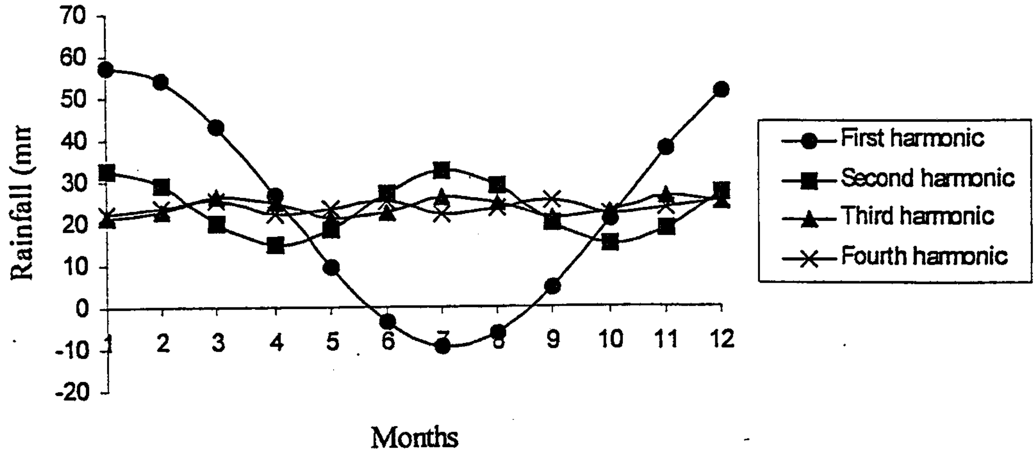

Figure 4.16: Deir all station, first fourth harmonics.

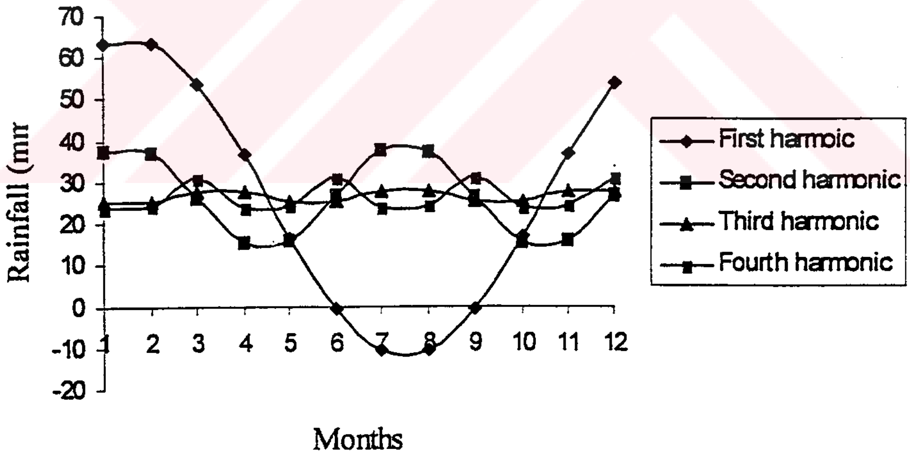

Figure 4.17: Shoubak station, first fourth harmonics.

mountain terrain in the West Bank of Israeli and Palestinian side. The chart of first harmonic amplitude reflects the actual distribution of rainfall of Jordan. The higher the amplitudes the higher amount of rainfall. The outcome result of the amplitude chart, is that Jordan may be divided according to amplitudes into the three rainfall regimes namely, mountainous, desertic and Jordan Valley regions.

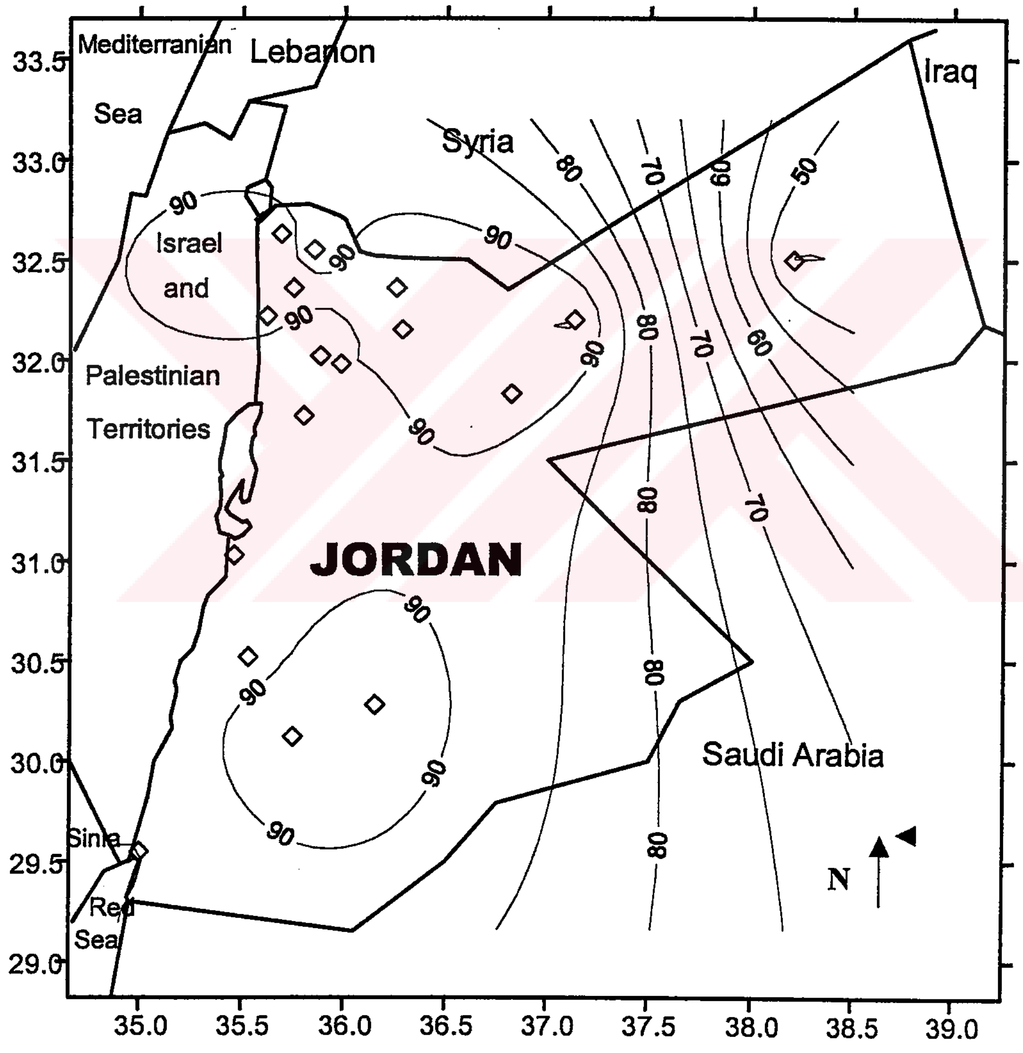

Figure 4.18: The percentages of variances of the first harmonic.

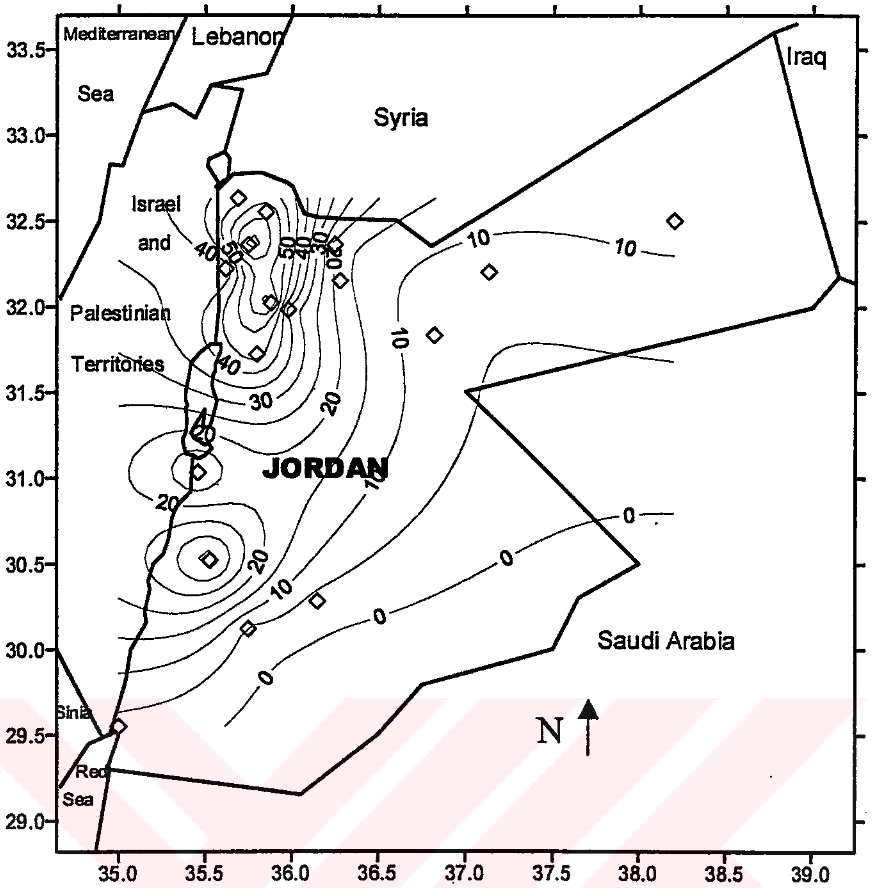

Figure 4.19: The amplitude (mm) of the first harmonic.

The phase angle chart in Figure 4.20 for the first harmonic shows the time of maximum occurrence of rainfall in January. This chart depicts and reflects also the type of precipitation regime, so that one can expect whether the type of rainfall is due the frontal depressions or the convective unstable cells of some clouds. The phase angle chart shows that the maximum rainfall in mountainous region occurs in January. The time of maximum occurrence of rainfall in the desertic regions in the south and south-eastern of the country and it varies between January and December. This can be attributed to some of deep depressions which affect sometimes large areas in the deep desert.

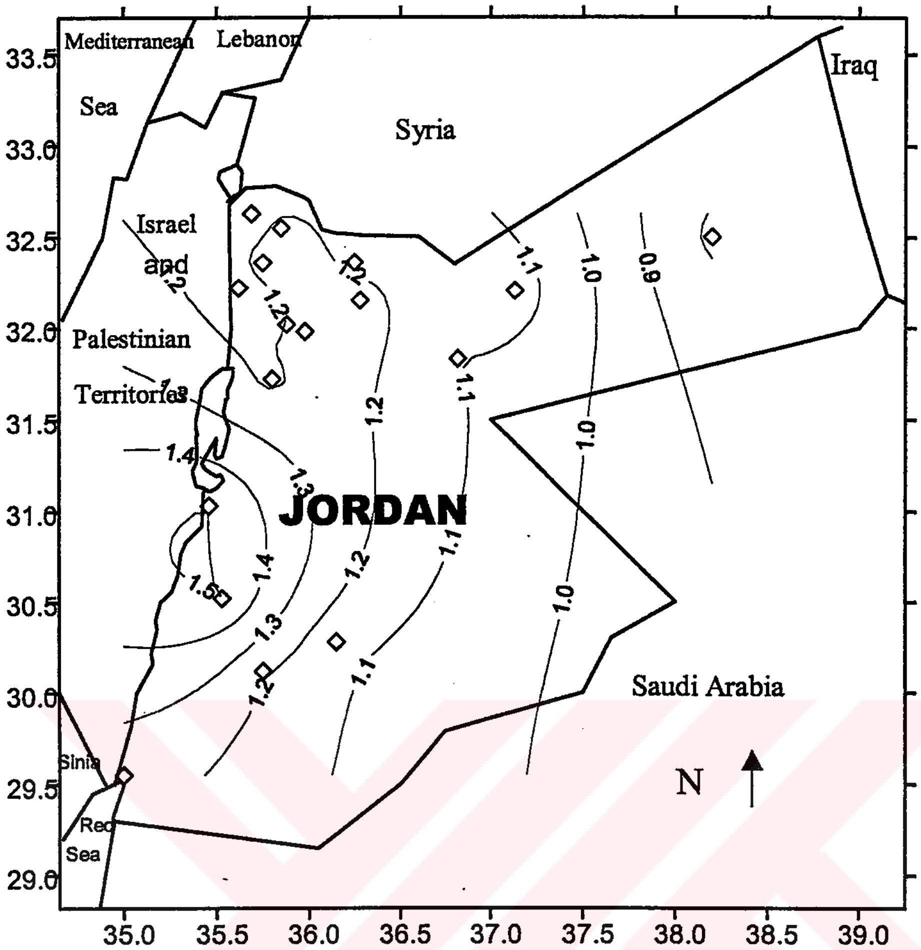

Figure 4.20: The phase angle of the first harmonic. Here 1 refers to 15 January, 2 for 15 February.

The phase angle of the first harmonic analysis reveals the time of maximum rainfall. All over the country, the time of maximum precipitation occurs around January. The desertic regions are not affected by all the weather systems that invade the east Mediterranean area during the winter. This can be explained by the backward shifting of the time axis towards December in the eastern regions. In southern heights and Jordan Valley, the maximum occurs between mid-januarys to February, as it appears in Ghor Safi and Shoubak stations. In general, Jordan has one principal rainy season that is winter, where January accounts as the highest rainfall month of all winter months.

4.3.2.2 Second harmonic

The second harmonic represents the spatial and temporal variation during semi-annual periods. As shown in Figures 4.16-4.17, it consists of two waves i.e., the frequency increases as mentioned before. For this reason, the semi-annual or seasonal rainfall such as convective types may be referred to second harmonic (Scott and Shulman, 1979). The percentage of variance of the second harmonic as plotted in Figure 4.21; (see also appendix c) reveals the following characteristics of the rainfall region:

1) The second harmonic is not effective as much as the first harmonic especially in the northern mountainous regions (see Figure 4.18)
2) The percentages of variances of the second harmonic increase from west to the east opposite to the percentages of the first harmonic, Rewashed station in the north-east of the Kingdom has 10 %. This explains the semi-annual rainfalls due the convective instability systems in transition season from spring and autumn.
3) The northern mountainous region such as Ras Munif station has lower percentage than that of desertic, southern and central mountainous regions. The reason is that the desert areas are affected by instable weather systems, which usually do not occur in winter season, but in late spring and early autumn. The instable weather systems require hot and moist air on the surface and cold air aloft mainly 500-mb level. The gradient between earth surface temperature and the upper air temperature plays a great role in intensifying such systems. This condition is not satisfied by the northern high mountain such as Ras Munif station. The source of moisture in transition seasons (spring and autumn) is available due to the extension of the Red Sea trough. For this reason, the desert area is considered as a trigger action of such weather system. On the contrary, in the mountain areas where the gradient between mountainous surface and its upper air temperatures is not as much as that of the desertic regions.

   In general, the percentages of the second harmonic are comparatively very low and not important as much as the first harmonic. This reflects that little rainfall is received through the semi-annual systems.

The amplitude of the second harmonicas as shown in Figure 4.22 is less important than that of the first harmonic. There are some similarities between the amplitudes of the first and the second harmonic charts in the northern and southern mountainous regions. These regions represent the highest amplitudes of the two harmonics. This emphasizes the uniqueness of the principal rainfall regime in semi-annual and annual basis.

The phase angle of the second harmonic in Figure 4.23 shows that the northern mountainous regions have maximum rainfall in January for the second harmonic, where the time lag decreases towards December in the eastern and towards November in the southern regions.

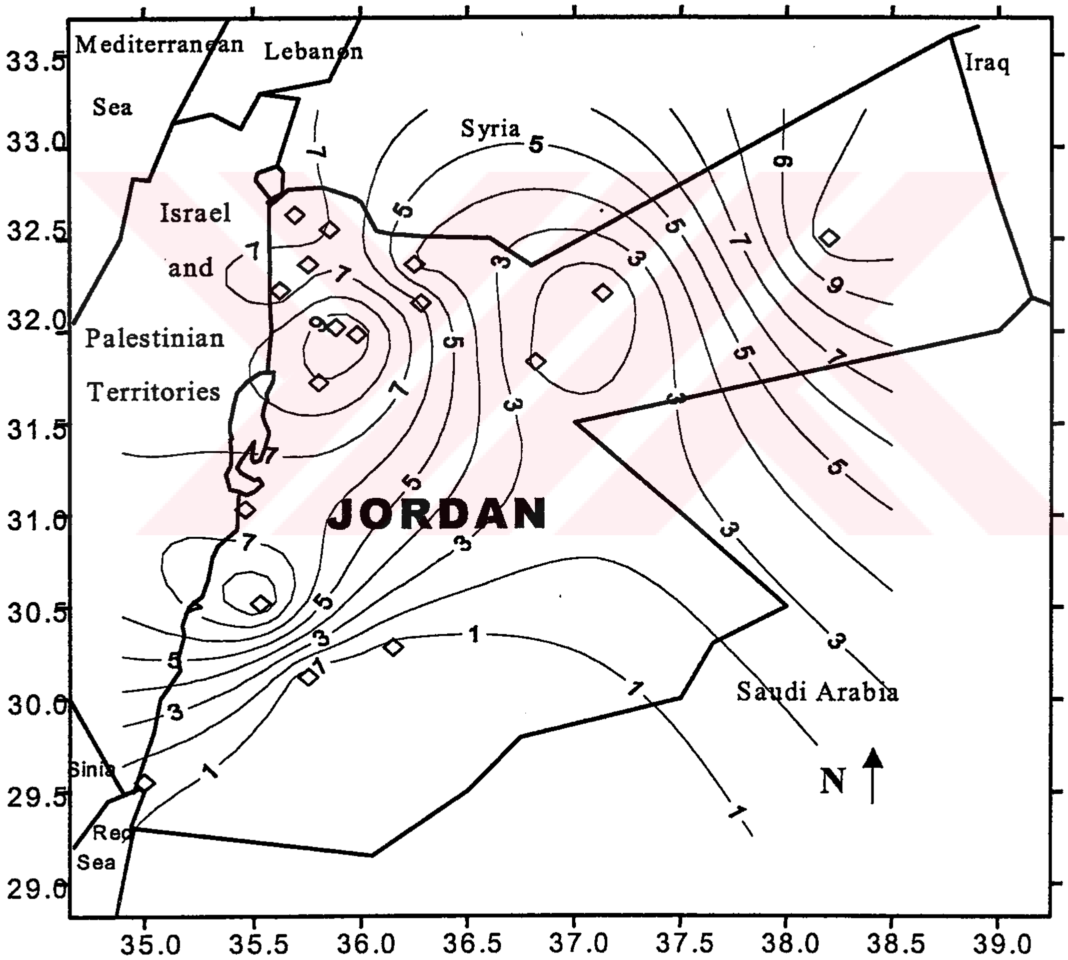

Figure 4.21: The percentage of variances of the second harmonic.

The overwhelming of the time lag means that, there is a shift of the time axis from December backward toward autumn which explains the activity of the convective rainfall type. The extension of the Red Sea trough associated with warm and moist air in the presence of cold upper trough at 500- mb level is the reason of this rainfall type.

The phase angle here again shows the seasonal variation, especially in the southern regions. The rainfall of transition season from autumn and spring is characterized by the desert rainfall which appears again in Ma'an and Jafer stations. Figure 4.33 depicts the important features of the autumn rainfall in the former stations.

4.3.3 Ratio

The ratio between the amplitudes of the second and first harmonics describes the weight of the semi-annual to the annual variations. The first harmonic amplitudes are generally higher than that of the second harmonic. Figure 4.24 emphasizes the relative importance of the first harmonic.

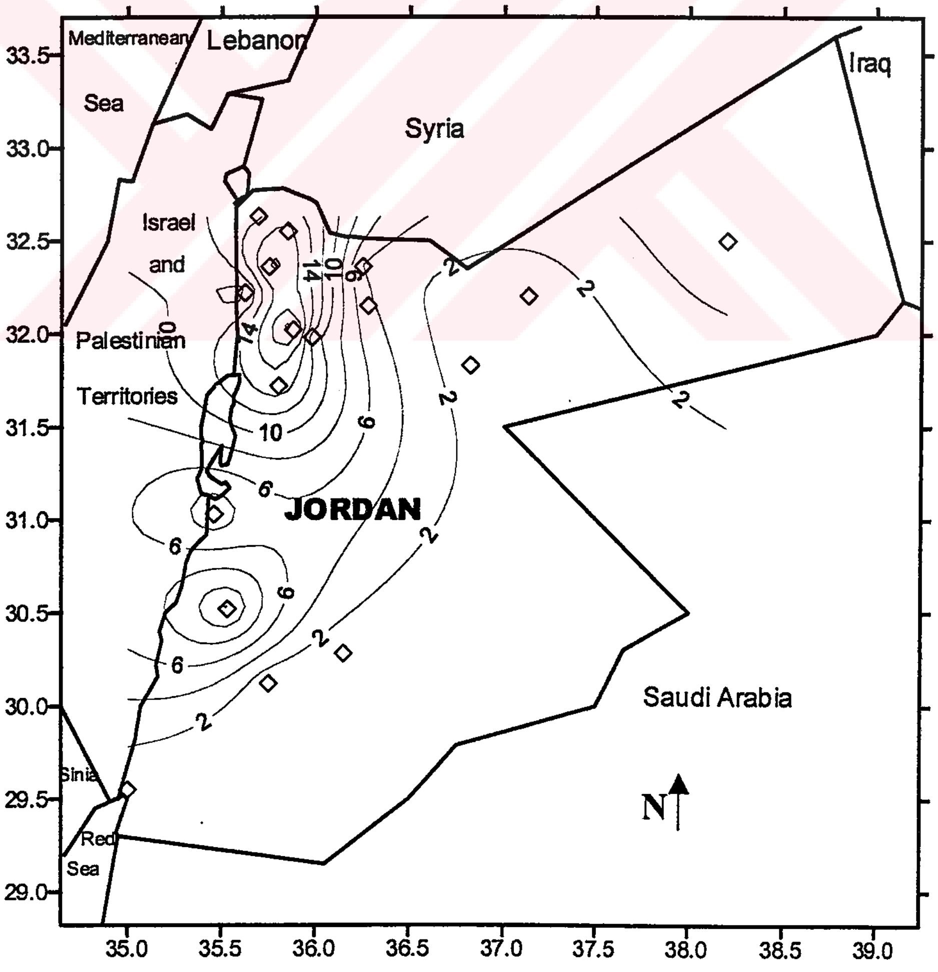

Figure 4.22: Amplitude (mm) of the second harmonic.

The desertic region in the north-east of the country, Rewashed station, reveals some important features compared with the semi-annual variations due to the convective rainfall which occurs in the transition season as mentioned before. This station has 0.5 as largest ratio in the region, (see Figure 4.24)

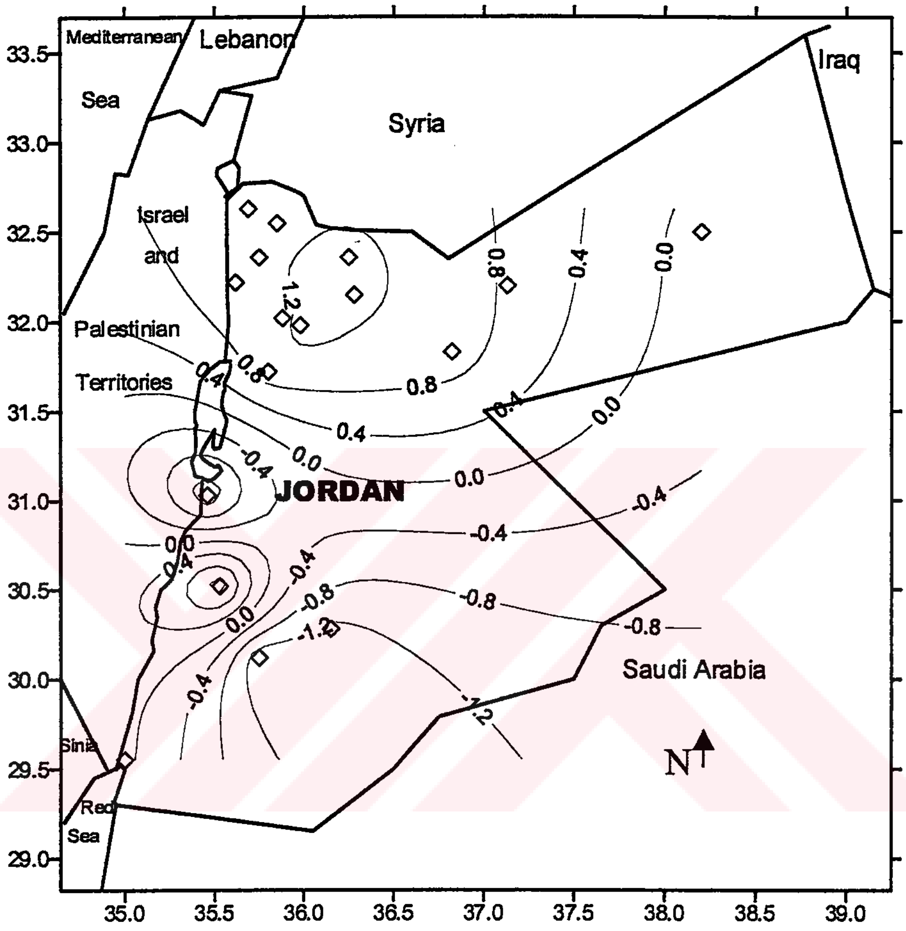

Figure 4.23: The phase angle of the second harmonic, Here 1 refers to 15 January, 2 for 15 February.

The low value of ratios through out the country is due to the dominant winter rainfall, which is explained by the amplitude of the first harmonic. The first harmonic has higher weight in comparison to the second harmonic. The higher values of ratios in the desert and Jordan Valley areas are due to the low values of the first harmonic amplitude.

The ratio chart in Figure 4.24 may express the variability of precipitation in same regions. For example, the desert areas have small differences between the amplitudes of first and second harmonics, which means there are no significant differences in rainfall amounts during the seasons. It has high ratio, because there is not regular rainfall season. The ratio chart may be considered as the coefficient of variability of rainfall and can be used in specifying the variability of the climate within the region.

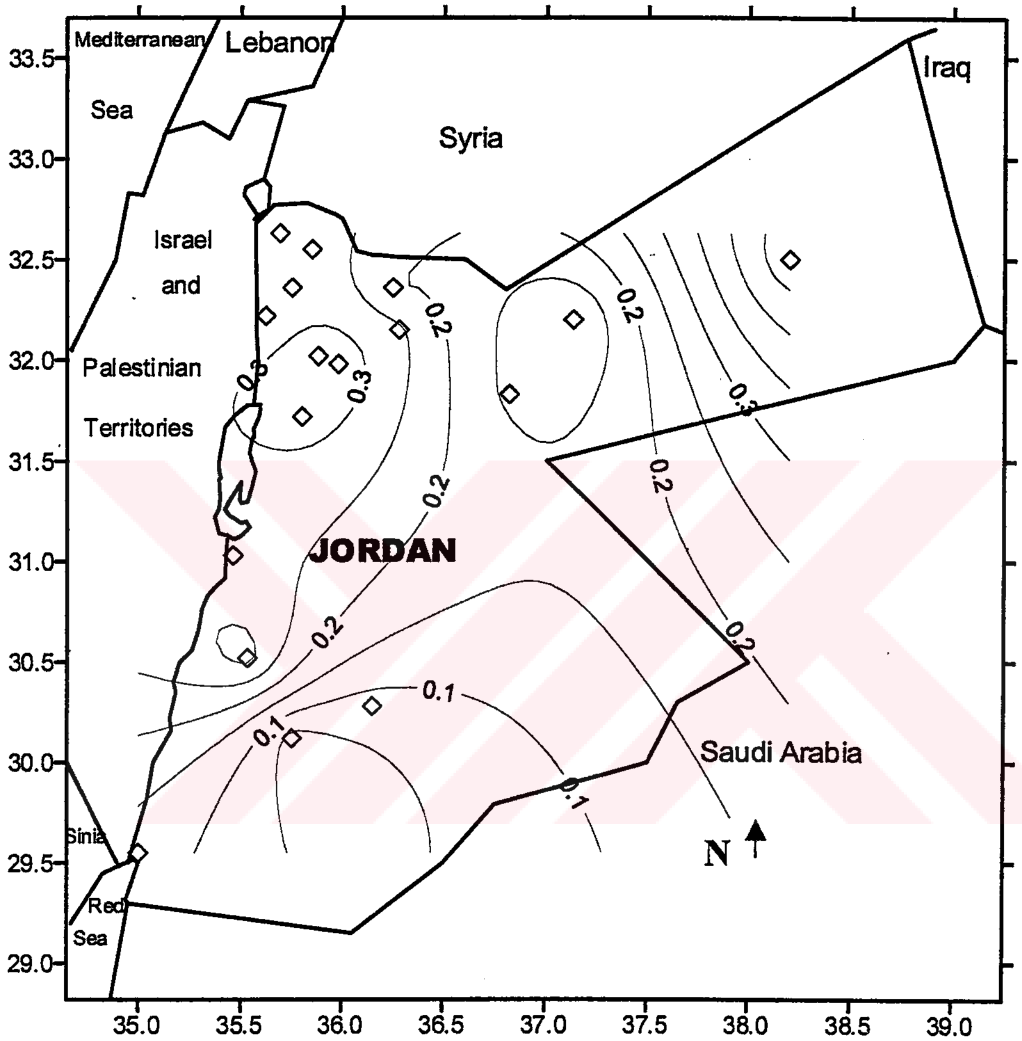

Figure 4.24: The ratio of the second to the first harmonic.

4.3.4 Coefficient of variation

In order to get a clear and representative analysis of the rainfall in Jordan, the coefficient of variations in Figure 4.25 is adopted in order for assessing the durability and stability of the rainfall regime in all the climatic regions of the Kingdom.

The coefficient of variation (CV) can be defined as the standard deviation (SD) divided by the arithmetic mean multiplied by 100. the calculated inter-annual CV_s

over the climatic regions are very high. This can be attributed to large SD values all over the country that reflects the high variability of the rainfall regime even in mountainous region, "the region of maximum rainfall". One should note that if the CV annual is considered the CV values over mountains should be less than of the mountainous areas. Figures 4.26 and 4.27 are the components of CV.

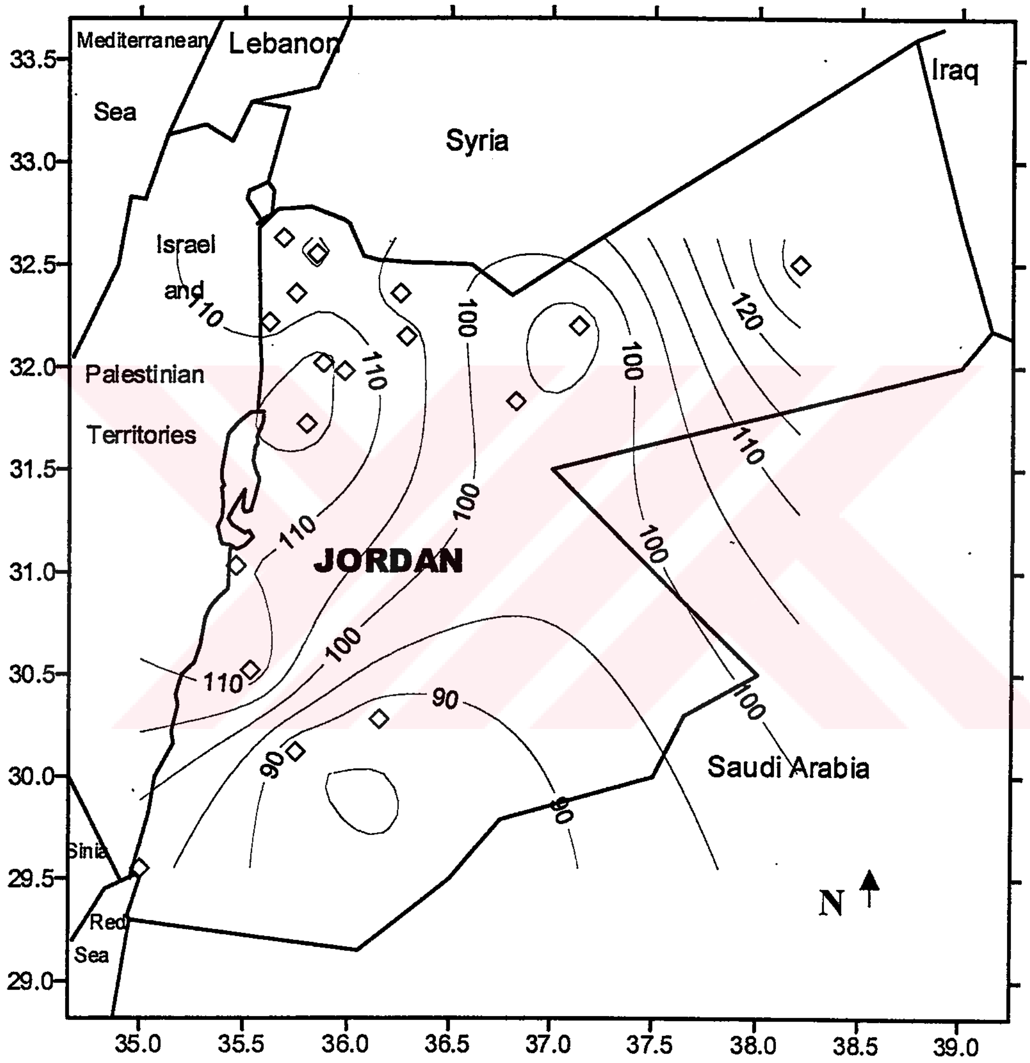

Figure 4.25: Spatial variation of the coefficient of variation.

The SD figure depicts the variations from the mean, where Figure 4.27 represents the inter-annual variations of monthly rainfall amounts. The SD is very high in mountainous region which emphasizes that the rainfall regime is not durable and stable. It is possible to interpret details of the precipitation climatology of Jordan in this study using harmonic analysis of precipitation records at meteorological stations scattered throughout Jordan. This technique helps in the identification of spatial precipitation patterns over Jordan.

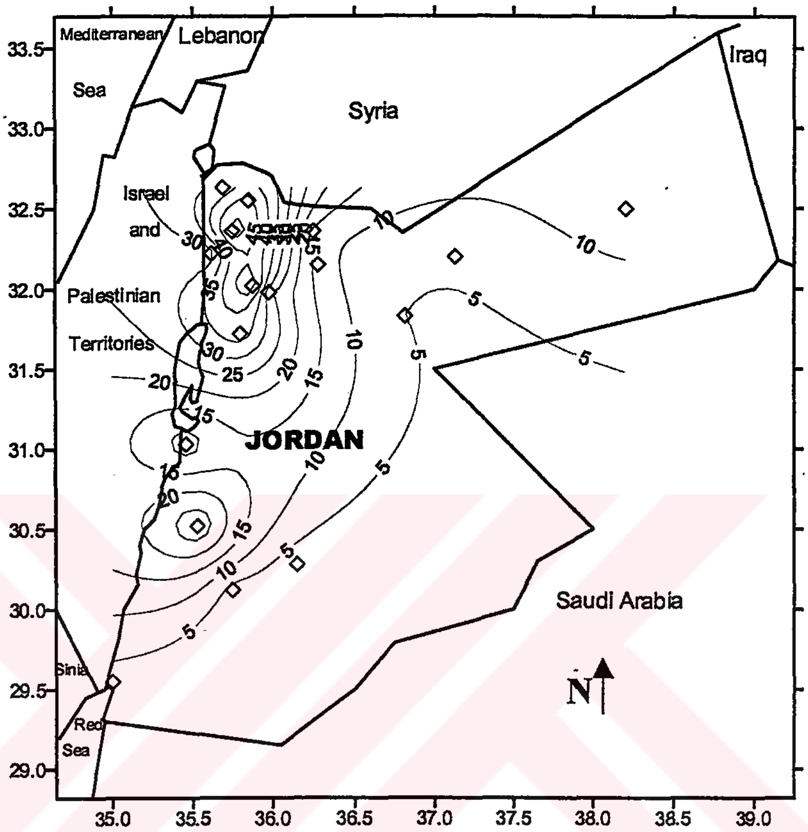

Figure 4.26: The standard deviation of inter-annual monthly rainfall.

Harmonic analysis technique also depicts the hidden characteristics of any climate data. In this study, all properties of precipitation climatology in Jordan are explained in terms of percentage of variances, amplitudes, phase angle and the ratio between first and second amplitudes. The result of all findings are shown in the form of contour charts Different climatic regions are in identified this study. The following conclusions can be drawn from the detailed harmonic analysis.

1. The first and second harmonics play dominant roles in expressing the regional climatology variation in Jordan. The first harmonic explains more than 60 % of the amplitude variations. Highest percentages are found in northern mountainous region which decrease gradually from the north to the south of Jordan. This explains the effect of frontal weather systems and the topographical effects.

2. Maximum (minimum) precipitation records appear during December or January (July or August).
3. The second harmonic shows an increasing trend in percentages from west to east reaching to highest values in the northeast Jordan which indicates the precipitation instability in this region.
4. The amplitudes of the first and second harmonic decrease from west to east and from north to south due to the tracks of the frontal depressions that affect east Mediterranean area.
5. The coefficient of variations is very high all over the country which confirms that the precipitation regime has high variability but not durable. This requires that Jordan should seek alternative water resources.

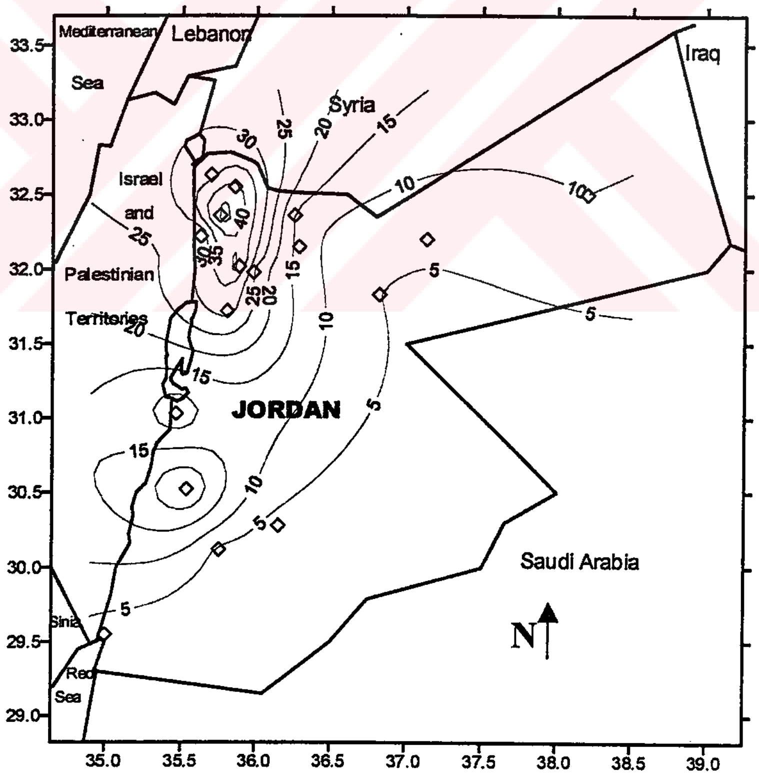

Figure 4.27: The inter-annual mean monthly rainfall.

Chapter 5

Drought analysis and assessment

5.1 Definition

Drought has been defined in several disciplines such as meteorological, agricultural and hydrological studies. There are numerous definitions of drought, while one definition may be applied to a given region, at the same time it cannot be extrapolated to other regions with different climate features. For example, in the USA drought conditions are said to occur when less than 2.55 mm of rainfall is recorded over 48 hours, where in Libya drought is occurred when cumulative annual rainfall is less than180 mm (Pe rarnaud, 1997). There are three classifications of drought:

1. Meteorological drought as the period during which monthly or annual rainfall is below normal.
2. Hydrological drought which is defined in terms of the effect of dry spells on surface or groundwater, where flow during this spells fails to meet the demand of a given water management system.
3. Agricultural drought may be defined in terms of the sensitivity of the crops at different stages to water requirements in terms of rainfall, irrigation, soil moisture content and evapotranspiration.

In general, drought as defined by the International Negotiating Committee of Convention to Combat Desertification (INCD), is the naturally occurring phenomenon that exists when rainfall is significantly below normal recorded levels, causing serious hydrological imbalance that adversely affect land resources production system (Dambe, 1997).

Drought has been studied by several methods and techniques. The real problem is that several kinds of information are needed to monitor droughts. The shortage of

rainfall causes a shortage in exploitable water resources, such as groundwater reservoir, soil moisture and stream flow. The significant deficit of these water resources on time scale varies from few weeks to several years. Drought monitoring would benefit from the information which indicates the status of rainfall, water supply and demand.
This led Mckee et. al. (1993) to propose the standardized precipitation index (SPI).
The drought intensity is defined by McKee et.al (1993) as shown in Table 5.1.

Table 5.1: Drought categories

SPI value	Drought category
0 to –0.99	Mild drought
-1 to –1.49	Moderate drought
-1.5 to –1.99	Severe drought
≤ -2	Extreme drought

The SPI may be defined as a coefficient of variation, or the difference from mean divided by standard deviation of the period of time. The drought occurs when the value of SPI assumes negative value and ends when it becomes positive.
Guttman (1998), compared between Palmer drought index (PDI) and SPI. The study explains the characteristics of each one. The PDI and its variations were designed to be standardized so that index values would have comparable meaning at all locations and times, other wise, comparison may lead to erroneous conclusion by users of PDI. On the other hand, the PDI calculations require observations based on the monthly water balance which involves soil moisture, evapotranspiration and runoff. The same study assumes that the SPI gives better representation of wetness and dryness than PDI.
On the other hand, Guttmann (1999) discussed the acceptance of the standardized precipitation index. The author recommended that the SPI could be used as the primary drought index because it is simple and invariant in its interpretation. It is also probabilistic so that it can be used in risk and decision analysis. The item strongly suggests the users to consider the SPI as an equal companion to the PDI.

In general, drought as a climatic phenomenon becomes more pressing in many fields, such as water management projects, agricultural planning, flood studies and industrial activities, especially, in arid regions.

5.2 Drought analysis and assessment in Jordan

Jordan as a semi-arid region has high variability of rainfall even in the mountains as shown in the chart of coefficient of variation in the previous chapter. Climate or rainfall variability is the major factor in the occurrence of drought (Oguntoyinbo, 1986).

The objective of drought analysis in Jordan is to be able to foretell and, if possible, avert any hardship that may be attendant on the eventual occurrence of such droughts. However, an accurate prediction of such drought occurrences is at present impossible. The prediction of periodicity of any climate phenomena can assume statistical approach in which a variable such as rainfall in the case of drought is statistically auto-predictable through knowledge of its past history (Ogontoyinbo, 1986).

Tarawneh (2000) used 30 years rainfall data for selected stations in Jordan in order to analyze drought. The study reveals the behavior of drought phenomena in different parts of the country.

In this study, 50 years seasonal rainfall (September-May) for 13 stations is used in drought analysis. The stations are selected on the basis of their long records. Fortunately, they are fairly distributed and cover the climatic regions of Jordan. For this purpose, SPI index is used to quantify precipitation deficit in terms of duration, severity and frequency. This index can be used for several time scale (McKee, 1995).

5.2.1 Drought duration

Water resources projects require long-term planning in terms of climatic and hydro-meteorological view points, especially in water requirements for irrigation and dam sizing. For this purpose, the analysis of duration of dry and wet spells is required.

The longest dry spell duration (LDSD) is 7 years in Jafer station No. 14 in the southern desert of Jordan, while it is 6 years in both Jordan University station No. 20 and Errabbah station No.11 in the central mountains. The minimum is one year in the northeast desert in Rewashed station No. 7. Figure 5.1 shows the LDSD for different locations in Jordan. This figure shows homogeneity of the LDSD in the central and southern mountains. This is clearly shown in the figure where Shoubak station No.15 in the southern mountains and Jordan University station No.20 in the central mountains. The average dry spell duration (ADSD) is different from LDSD. It is the number of drought years divided by the number of drought duration of different lengths. Figure 5.2 shows maximum ADSD in Shoubak station No. 15 in the southern mountainous area, where the ADSD is 2.3 years.

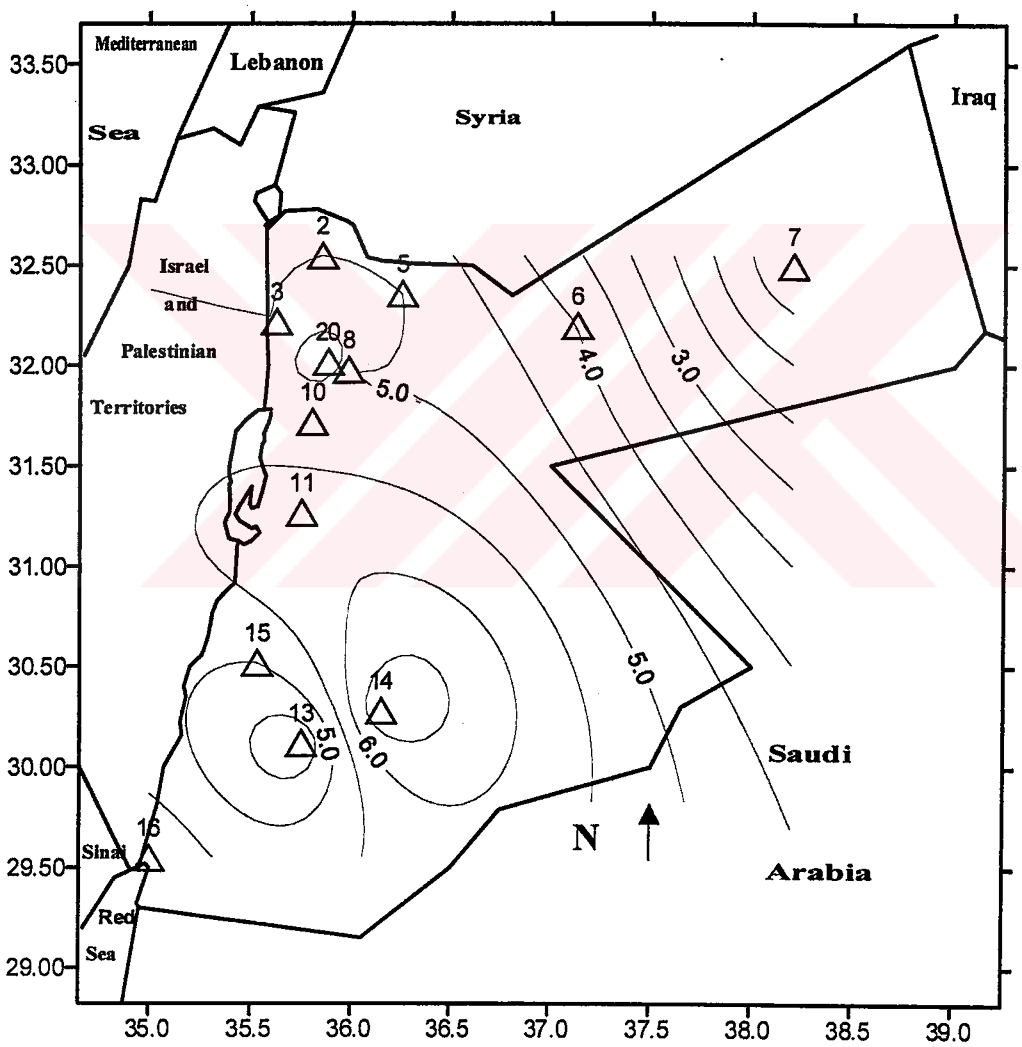

Figure 5.1: The largest dry spell duration in years, the numbers and names of the stations are given in Table 1.1

Station No. 3, Dier Alla, in the Jordan Valley region also has high value. Besides, there are high ADSDs in the central mountains such as in the Jordan University No.20 and Errabbah No. 11. Station No. 20 has high annual rainfall amounts so that it is an alert to be consider for planning in water resources of this area. On the other hand, the minimum is 1.5 year in the northeast in Rewashed station No.7.

The average wet spell duration (AWSD) may be defined as the number of wet years divided by the number of wet spells of different duration. The comparison between the averages of dry and wet spells is useful in determining the behavior of drought in each station. For example, in the previous example in Shoubak station, the average dry spells is 2.3 years while the wet spells is 1.5 year (Figure 5.3).

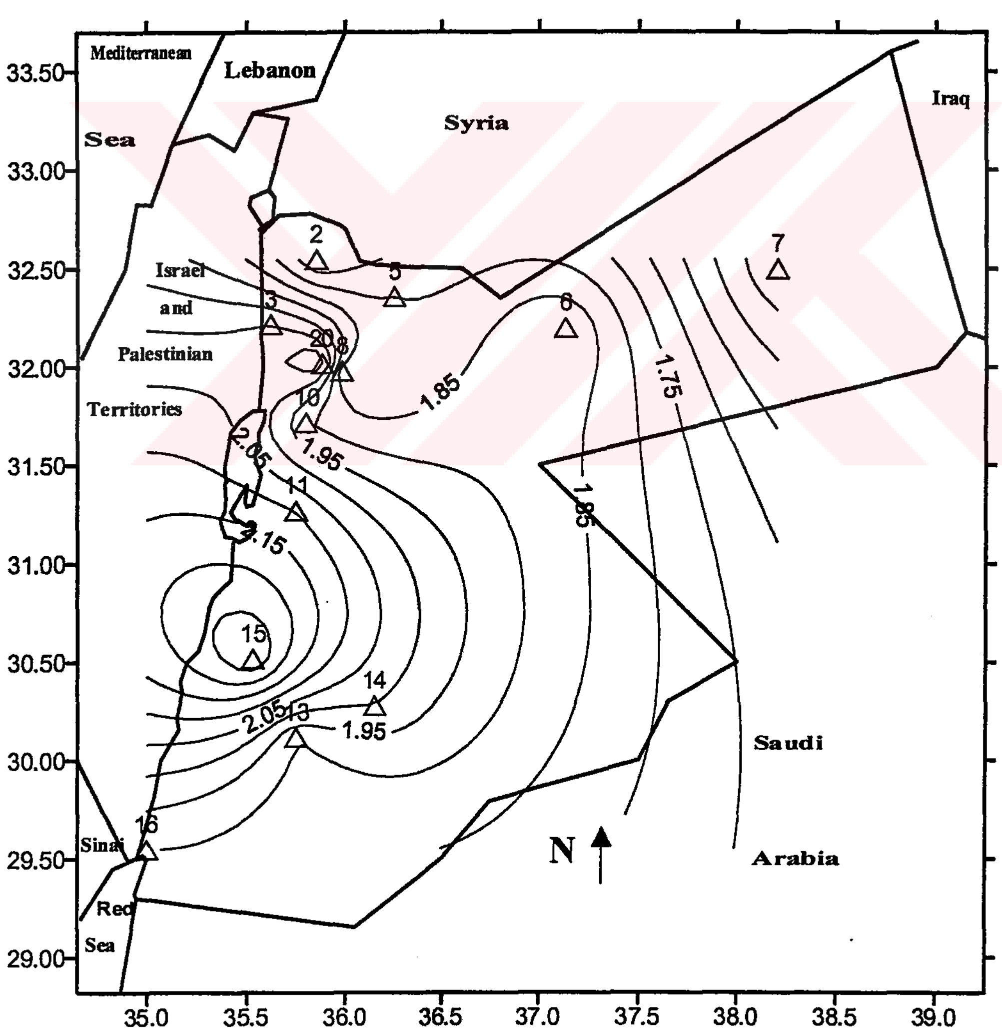

Figure 5.2: The average dry spell duration in years.

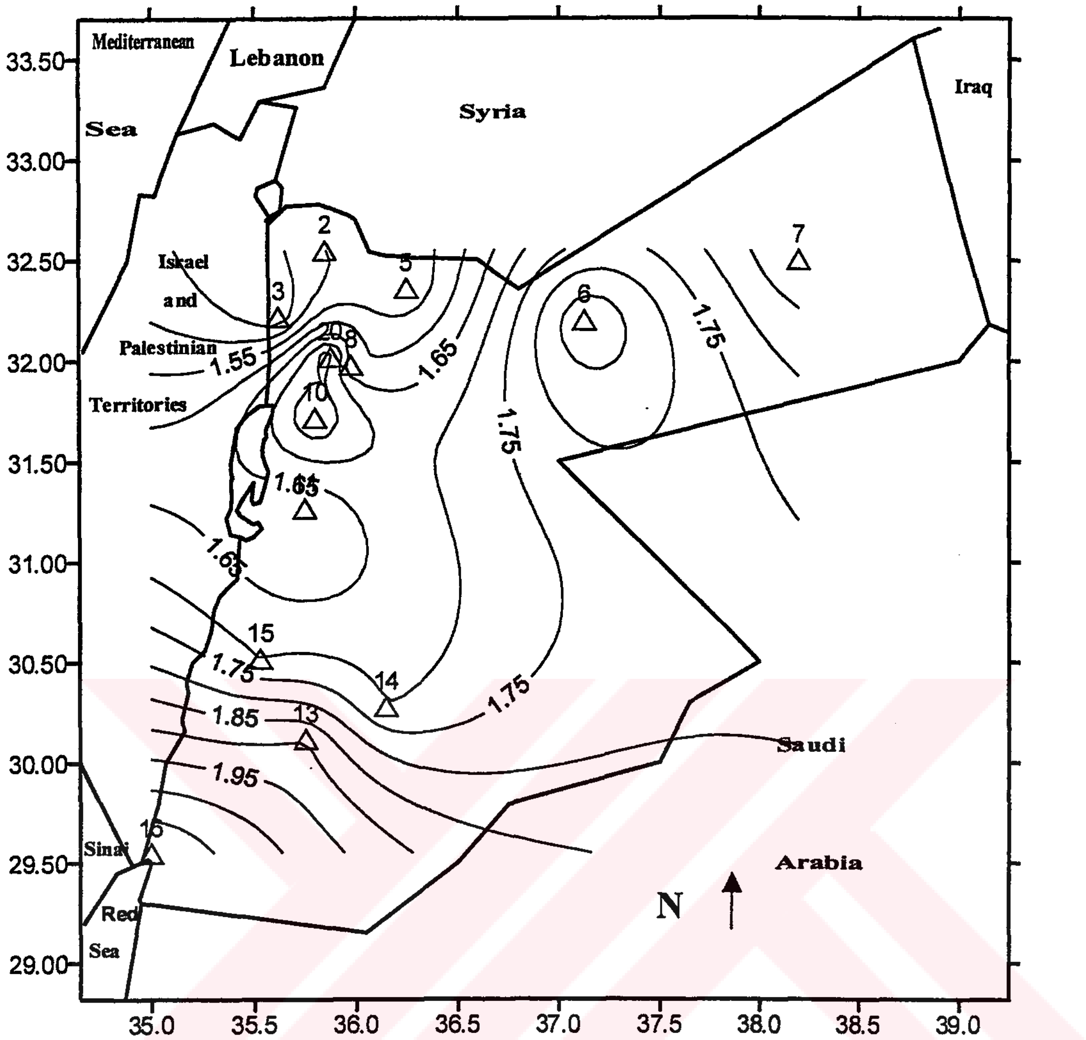

Figure 5.3: The average wet spell duration

This implies that the length of the continuos years below the average is larger than that of the above average. This result provides an important knowledge of the characteristics of the area to plan for water resources and irrigation projects.

The ADSD and AWSD are equal in Rewashed station; it is 1.5 year which means that the number of continuous years below average is equal to the number of the continuous years above the average.

Figure 5.3 shows kind of paradox because of high values of AWSD in some of the northern and southern desertic stations, such as Safawi station No. 6, Aqaba No.16, and Ma'an No. 13. This is logically right, since the data is standardized according to its mean and standard deviation. So that these station are relatively wet from the data distribution point of view but not in human sense. The AWSD may be considered as a description of the behavior of the time series around its mean rather than wetness in natural sense. In order to make this point more clear, Aqaba station has ADSD and AWSD values which are descriptions of the behavior of the data around its mean and quantified values to be compared with other sites in Jordan.

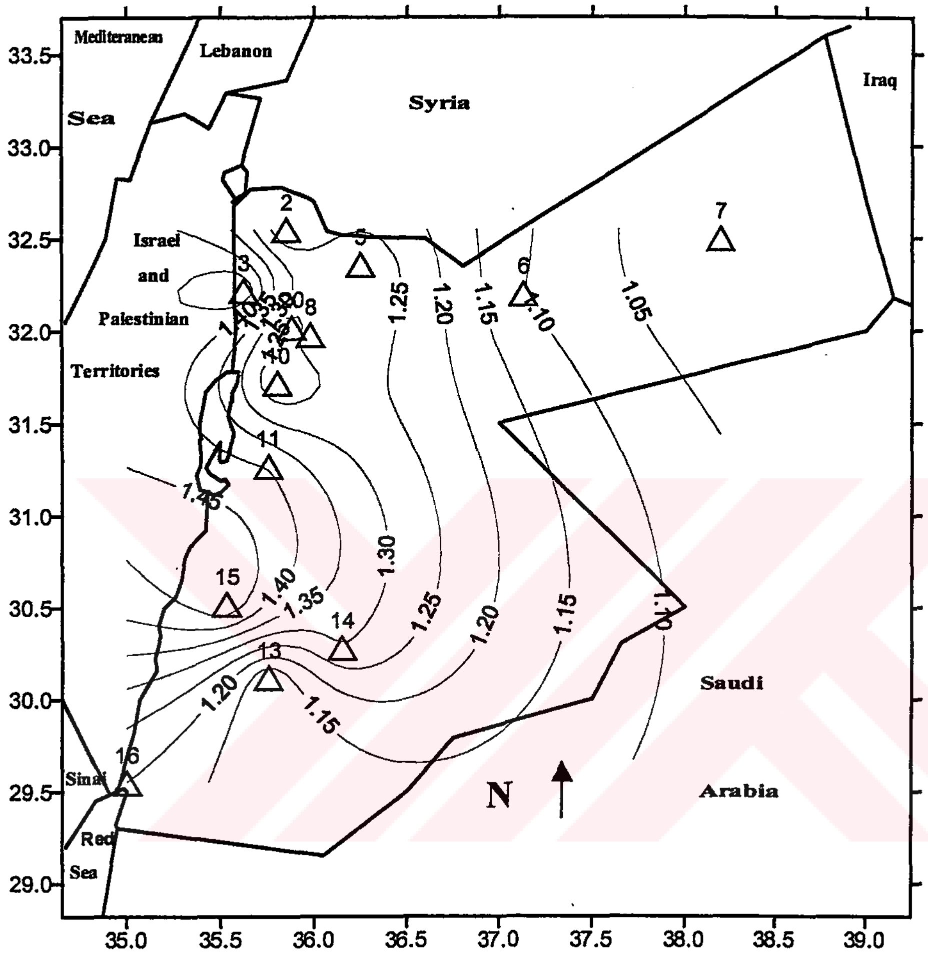

Figure 5.4: Dimensionless drought tendency in some stations of Jordan.

The former discussion of dry and wet spells leads us to the concept of drought tendency (DT), which is the ratio number of drought years to the number of wet years. It provides clear picture of the drought phenomenon besides the analysis of dry and wet durations. For example, rewashed station No. 7 has the same number of dry and wet years, so that its DT is one. This is also considered as good index to show the tendency of the data from its mean.

Figure 5.4 assures the results of the previous figures. For example, the southern mountainous station No. 15 and the Jordan Valley station No.3 have high DT and high ADSD as shown in Figure 5.2.

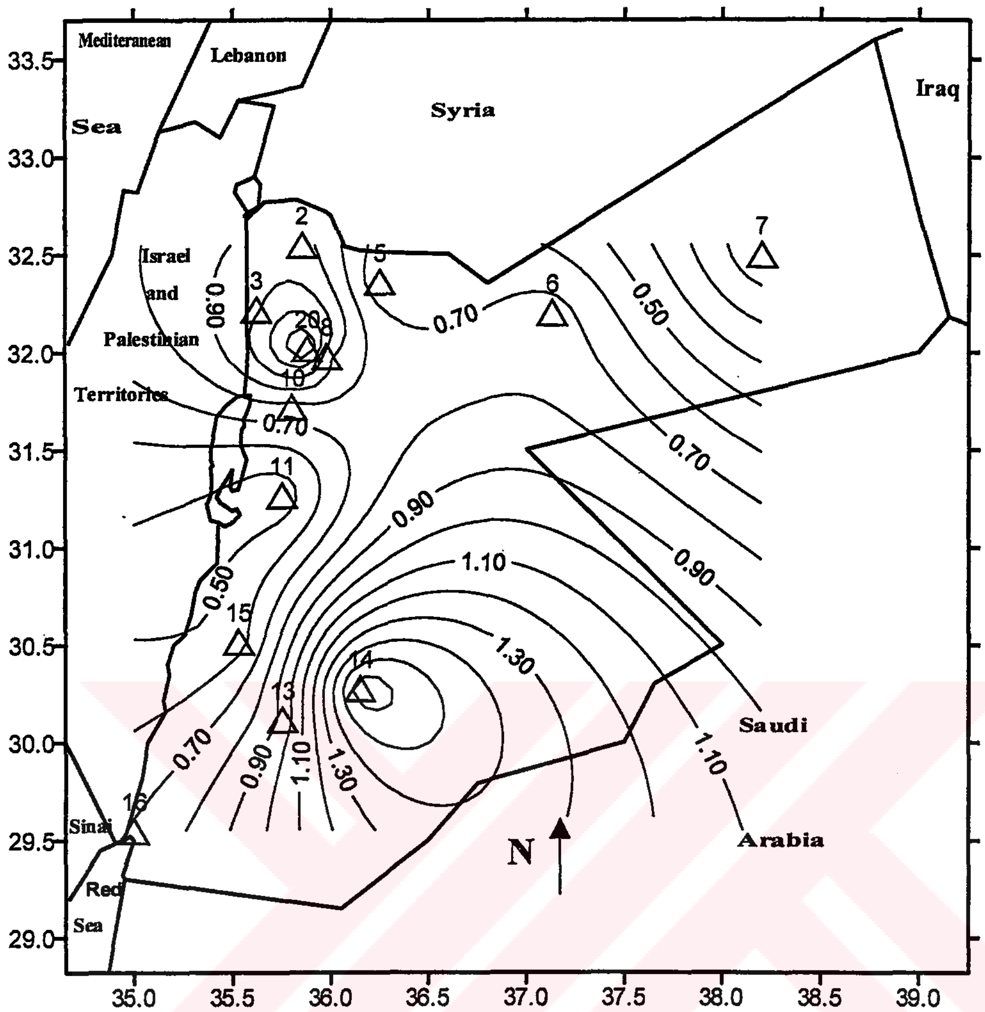

Figure 5.5: Skewness of the stations in the study area.

The duration of dry spells may be referred to the statistical property which is positive skewness. It expresses the occurrences or frequency distribution of the data which implies that the frequency distribution of the below-zero data is larger than that of the above zero. The positive skewnees occurs when the right-hand side extends towards extreme positive values of lower frequency. Figure 5.5 shows the skewness values of the some stations.

The skewness of the stations is always positive in all stations which assure that the higher frequency of the values occurs below the means. Figure 5.5 shows maximum positive as 1.68 in Jafer station No. 14 in the southern desertic region. It has the maximum LDSD as shown before. Jordan university station No.20 also has high positive skewness equal to 1.35, and it has high ADSD value as shown before. The minimum skewness is 0.11 in Rewashed station No. 7, with minimum LDSD.

5.2.2 Drought frequency duration

Drought frequency duration (DFD) is one of the important criteria in planning for water resources projects. It measures the probability of drought frequency. For example, high probability of five-year drought frequency (DRF5) implies sever extended drought which affects groundwater reservoir, soil moisture and ecosystem of that region.

The analysis of different drought periods frequency is adopted in contour charts in order to show the probability of different drought duration frequency. The drought frequency for one year and two years DFD1 and DED2 respectively has non-zero probability.

Figure 5.6 shows highest DRF1 in the northern mountains such as Irbed station No.2 and in the northeastern desertic areas in Rewashed station No. 7. Some of the central mountain stations, such as Amman No. 8 have high DFD1. Higher probability implies one-year drought, but lower probability indicates successive years of drought. The minimum probability of DFD1 is in the southern mountains of Shoubak area No. 15 and Ma'an No. 13. The minimum probability of one year drought gives the opportunity of higher probability of successive drought years in these areas.

The relative frequency of two years (DFD2) has also non-zero probability. In Figure 5.7, the probability of two-year successive drought occurrences is shown in all stations. The DFD2 has maximum value in the southern areas Ma'an station No. 13, where the minimum values are found in the northern and central mountains such as Amman No. 8 and Jordan University No. 20.

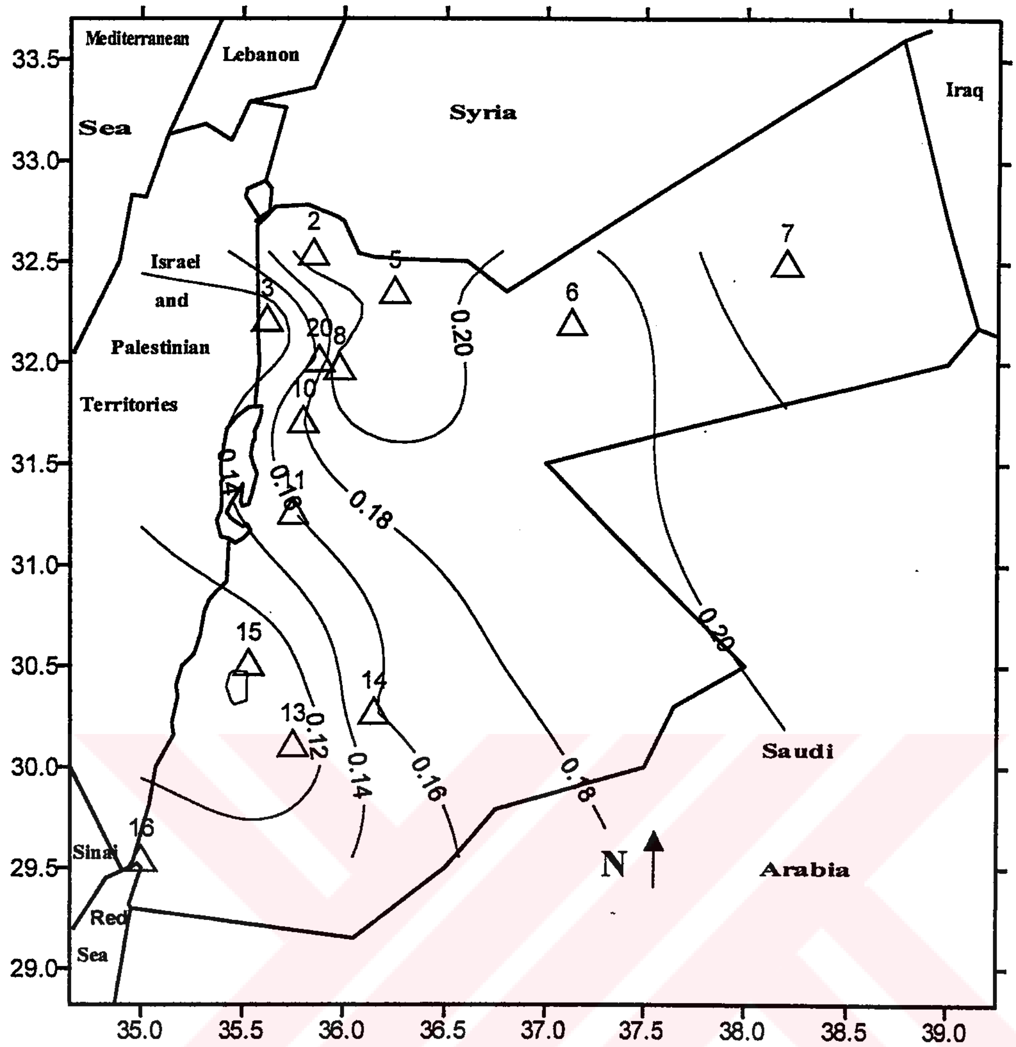

Figure 5.6: Drought relative frequency with one year, DFD1.

The DFD3 also occurs in all stations except in Rewashed in the northeast desertic region. Figure 5.8 shows maximum DFD3 values of in Safawi No.6 and Deir Alla No. 3, in Jordan Valley region.

It is very important to determine the relative frequency of drought for long period's i.e. more than one year or season in planning for water resources projects. These projects should be designed to withstand long period of droughts. It is not convenient to plan for one year or season. The relative frequency of four years (DFD4) is zero in the most stations except in some of the desertic areas and in two mountain stations, Madaba No. 10 in the central mountainous region and Shoubak No. 15 in the southern mountainous (Figure 5.9). The later station has high relatively DFD4.

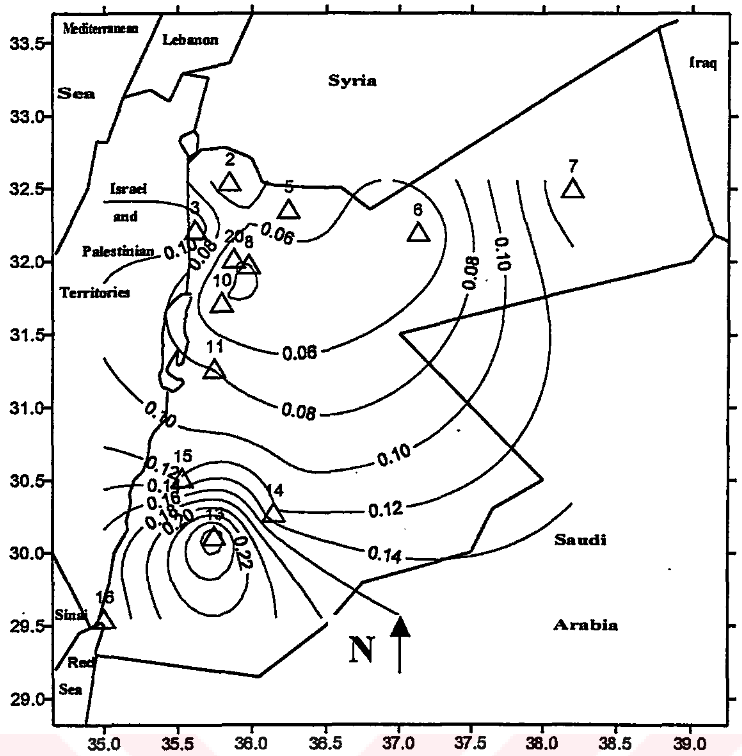

Figure 5.7: Drought frequency duration, DFD2.

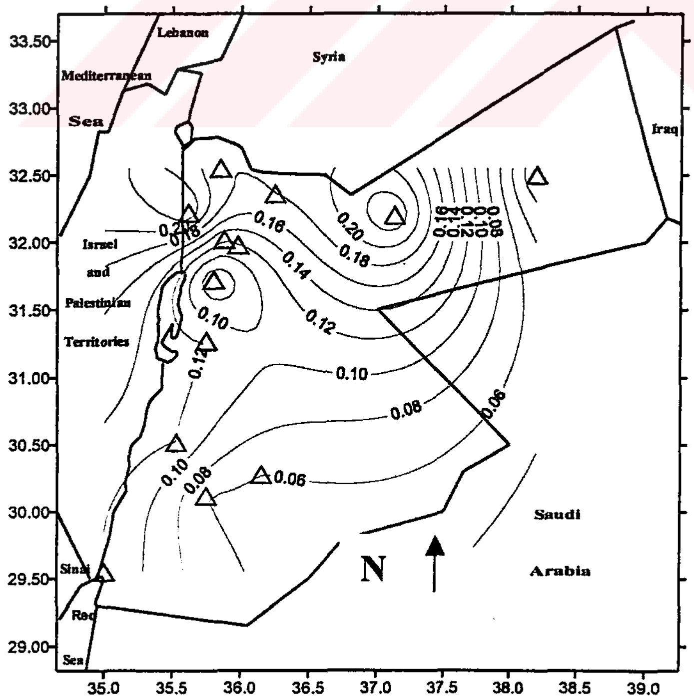

Figure 5.8: Drought frequency duration, DFD3.

This station has highest values of LDSD and DT. The analysis of drought explains the characteristics of the areas in which one can easily explore the stations that are subject to droughts.

One of the controversial results arises when RDF5 is probable in most of the mountainous stations such as stations Nos. 8, 11, 2, 15, 20, and 10). While it has zero probability in some of the desertic stations (No.14, 13, and 6). DFD5 in Figure 5.10 occurs at 9 stations, out of 13 with an equal probability of occurrence. The probability of RDF5 is very common for stations of Jordan. It occurs at 9 stations out of 13 stations.

The relative frequency of six-years (DFD6), i.e., six year successive drought occurs in three stations with equal probability. It occurs in stations No. 16, 11, and 20 once in 50 -year record. The later station No 20 has one of the highest total rainfall amounts in the northern mountainous region and higher probability of DFD6 (Figure 5.11).

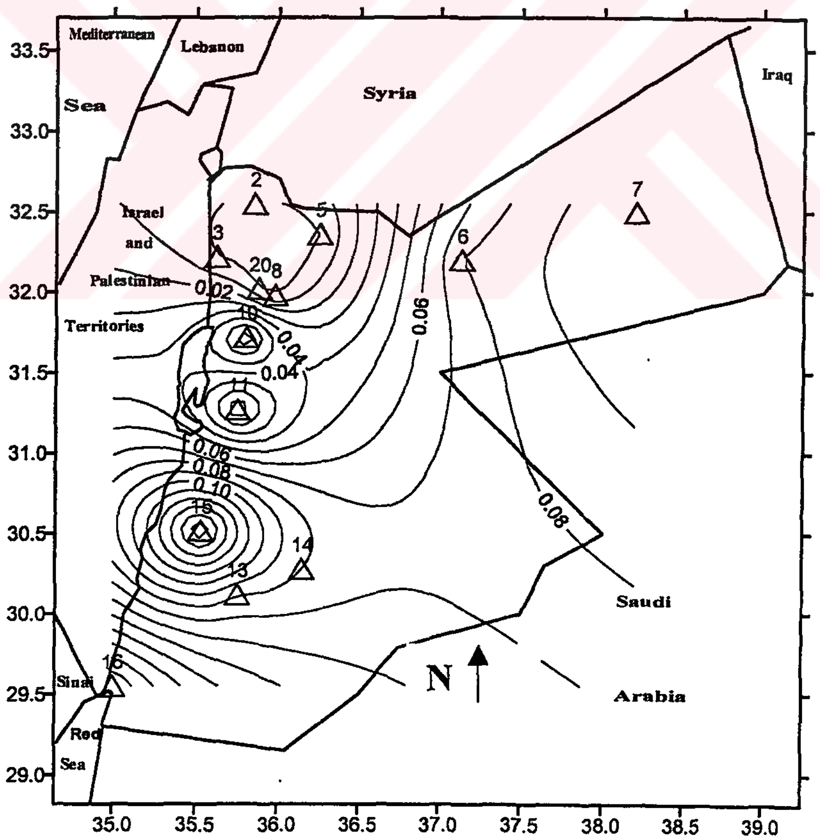

Figure 5.9: Drought frequency duration, DFD4.

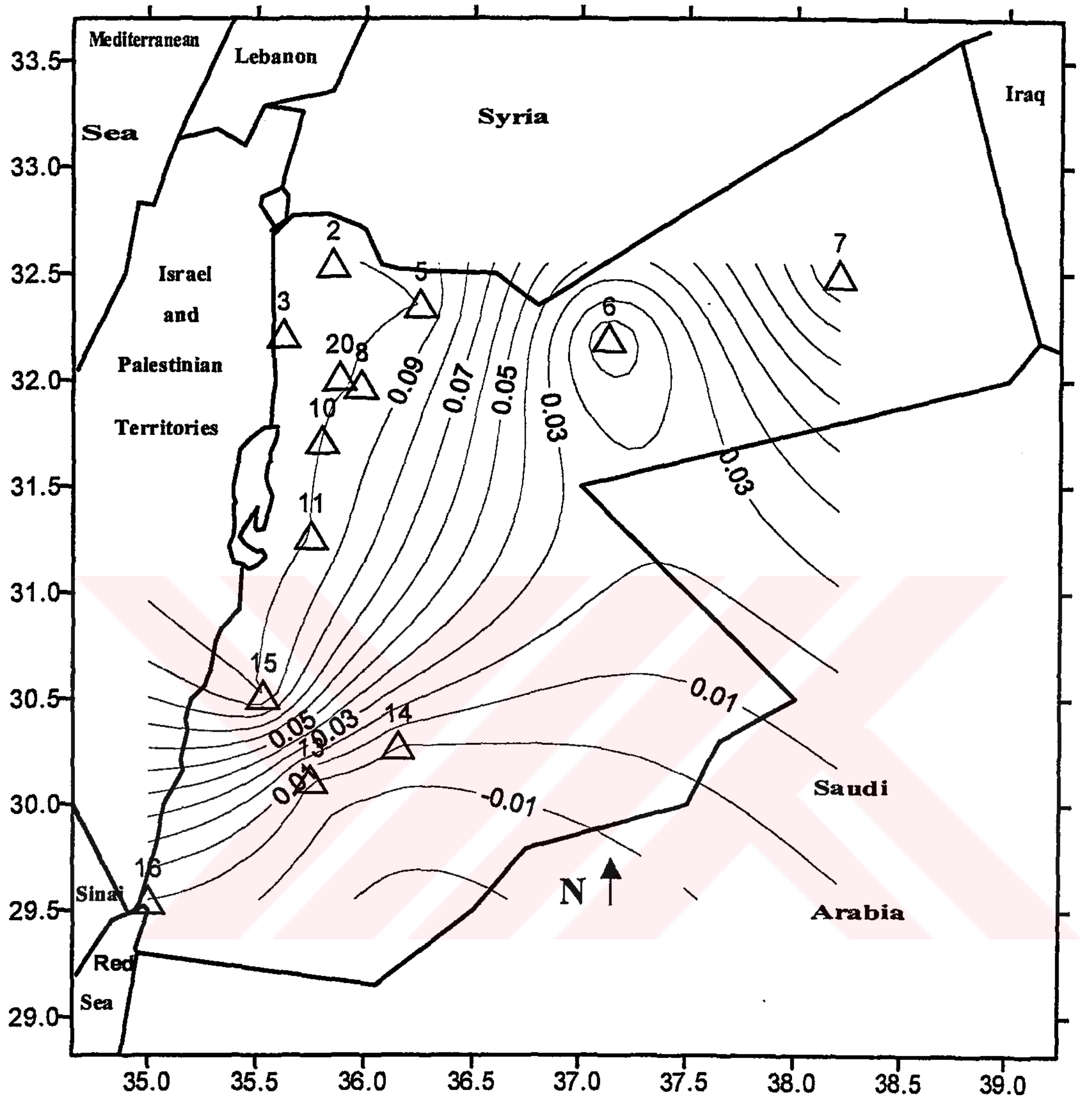

Figure 5.10: Drought frequency duration, DFD5.

On the other hand, it is one of the highest LDSD and ADSD. The central mountainous region has relatively moderate total rainfall amounts in addition to probability of DFD5 with higher values of LDSD and ADSD. These special cases should be taken into consideration in planning for water resources in these areas. The relative frequency with 7 years (DFD7) occurs once during the record period in Jafer station No. 14 in the southern desertic region.

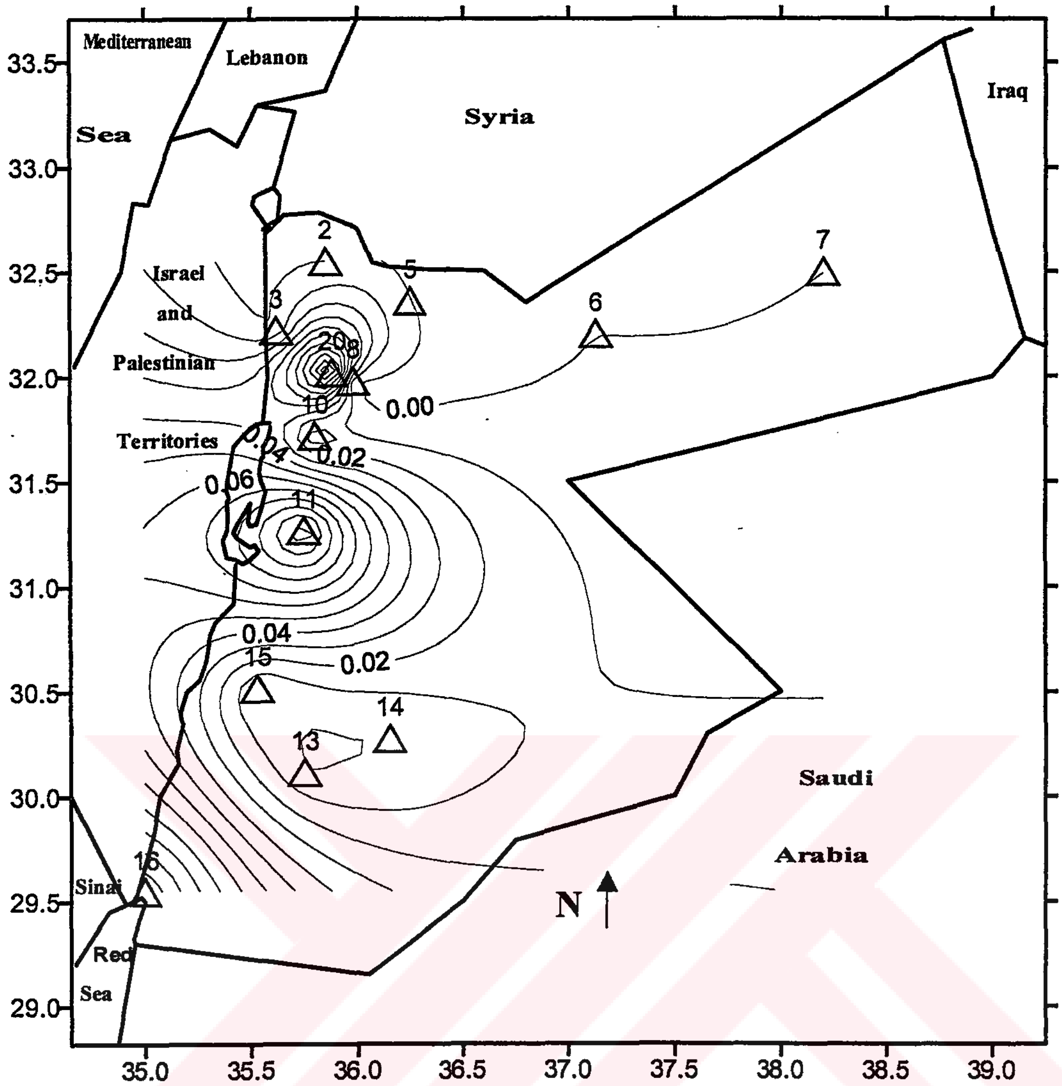

Figure 5.11: Drought frequency duration, DFD6.

5.2.3 Drought severity

The analyses of duration and frequency of drought refer to the occurrence of drought rather than to its intensity. In order to get clear picture of the analysis, the intensity of drought should be studied. It measures how far the rainfall is below the average. Several researches dealt with drought intensity using different indices, such as PDI as mentioned before. In the case of Jordan, the *SPI* index is more acceptable because PDI requires measured data on soil moisture, evapotranspiration and runoff which are not available for long records in Jordan (Tarawneh, 2000). The study uses 50 years of rainfall records for 13 stations. The proposed SPI index by McKee (1993) is used, beside the classification of drought as given in Table 5.1. Tarawneh (1999) uses another classification by (Kemp, 1991; Ikeda. 1980).

SPI index uses the rainfall data only, as the seasonal rainfall total from September to May. These data are used in analyzing drought intensity. The SPI index can be written as follows

$$SPI = \frac{Ra\inf all - averaage}{\sigma}, \qquad (5.1)$$

where σ is the standard deviation of the seasonal rainfall samples. Several quantities are derived from the calculations of SPI. In this study, the different quantities of drought intensity are adopted in the form of contour charts in order to allow comparison of different regions. The standard total cumulative drought (STCD) is calculated (see sample calculations at the end of this chapter) for 13 stations. It is the summation of SPI values through the records of 50 years. Figure 5.12 shows the variation of STCD in different regions. Actually, there are no big differences between the stations. Maximum values are found in the southern desertic areas and Aqaba station No. 16, where minimum values are in northern mountains such as Irbed station No. 2. The central and northeastern areas have moderate STCD values. This quantity contributes and helps in understanding the drought as a cumulative quantity in the record.

In order to classify the intensity of droughts in the stations of Jordan, the average dry spell index (ADSI) can be calculated by dividing STCD by the number of dry spells (ND) of different lengths. According to the criteria in Table 5.1, the following stations have severe droughts. Shoubak No. 15 and Madaba No.10, the value of ADSI is equal to 1.5. Figure 5.13 shows the dimensionless ADSI in the Kingdom. Aqaba station also has high value of 1.45 close to severe drought border. The rest of

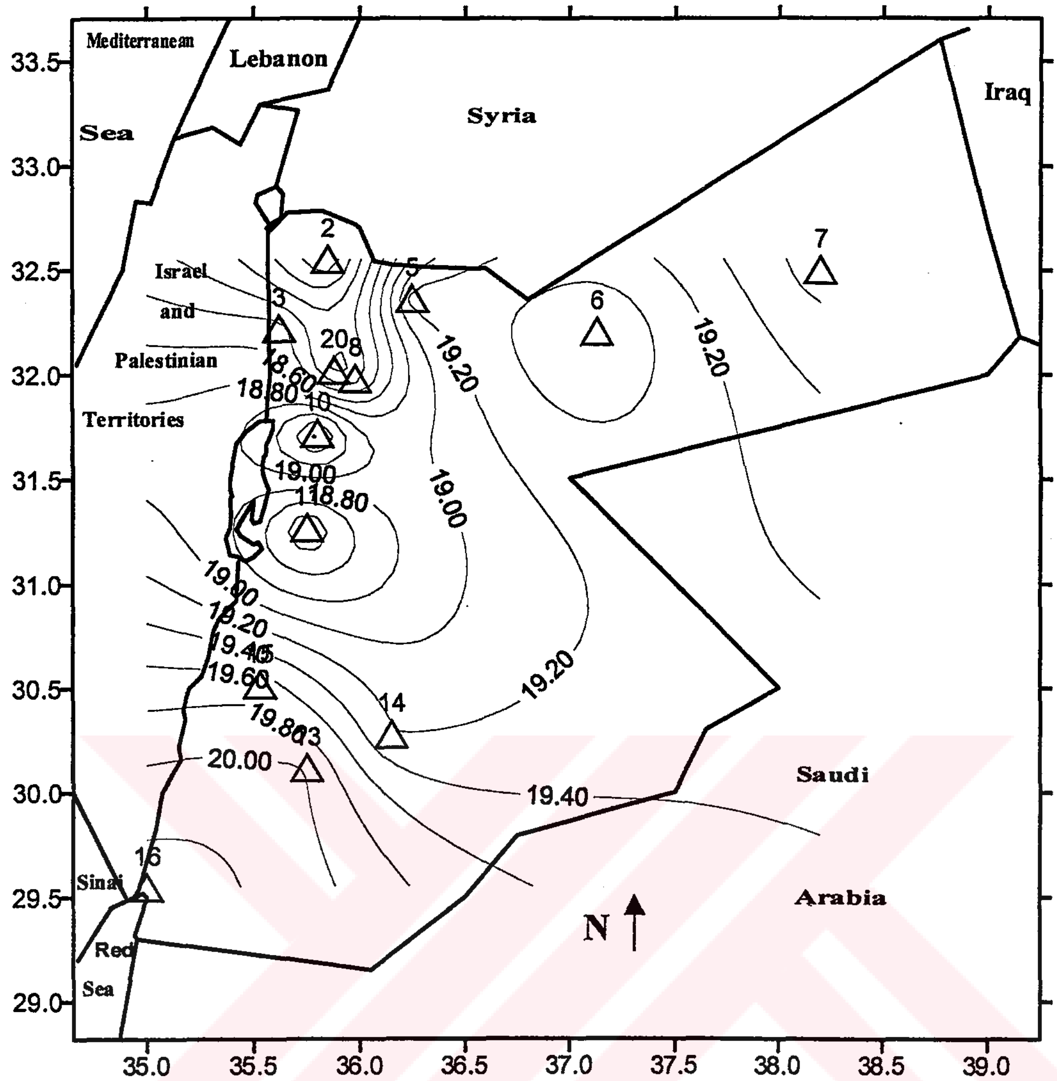

Figure 5.12: Dimensionless standard total cumulative drought.

the stations enjoy moderate droughts, with minimum ADSI in northern mountains such as Irbed No.2 and some central mountains areas, for instance, Amman No 8 station. The northeastern desertic region also enjoys moderate drought with lower ADSI values. During the calculations of different quantities of dry spell duration and its relative frequency, Rewashed station No. 7 is relatively considered as one of the best desertic station. It has minimum values of LDSD, ADSD, DT and skewness.

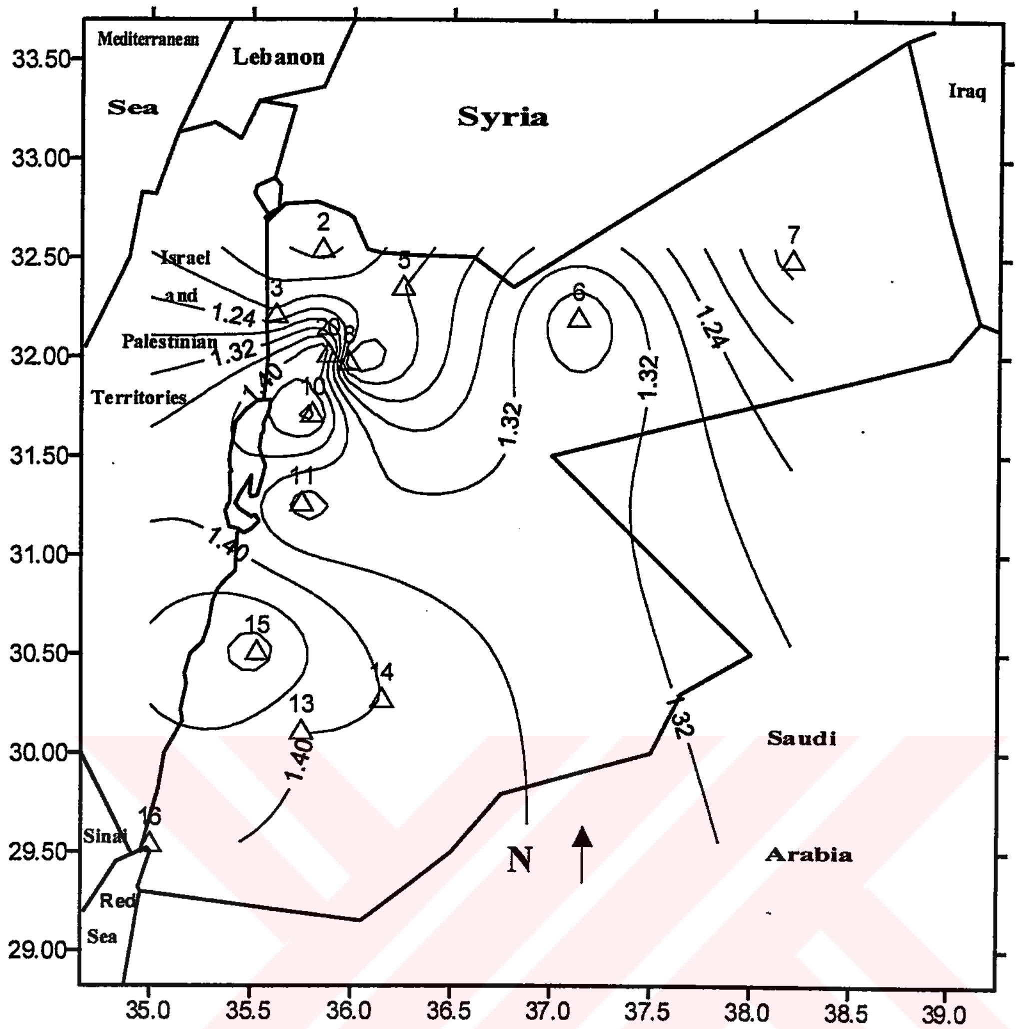

Figure 5.13: Dimensionless ADSI in some stations of Jordan.

This area should be given more prominence in terms of agricultural projects. This result will be of great importance for the Administration of the Reclamation of Jordanian Badia Program. Table 5.2 gives the values of absolute ADSI in some stations, and the type of drought in each station. In calculating the average of all stations, Jordan may be classified as moderate drought region as given in Table 5.2.

Table 5.2: Average dry spell index (ADSI) and drought types.

Station	ADSI	Type of drought
Amman	1.1	Moderate
Aqaba	1.45	"
Dier Alla	1.2	"
Errabbah	1.3	"
Irbed	1.1	"
Jafer	1.37	"
Mafraq	1.2	"
Ma'an	1.4	"
Ruwashed	1.1	"
Safawi	1.4	"
Shaoubak	1.5	Severe
Jordan University	1.37	Moderate
Madaba	1.5	Severe
Average Drought	1.3	Moderate

In order to find the extreme of single year dry spell intensity, the largest single year intensity (LSYI) is calculated for each station. This quantity is useful for the short-term planning, especially, for irrigation and agricultural projects so that it is valuable in determining the type of plant, where some plants cannot withstand in such extreme circumstances. Most of the stations in Jordan have extremes exceeding the limit of moderate to severe droughts except two stations in the southern Jordan which are Jafer No. 14 and Aqaba No.16. Figure 5.14 shows the variations of extremes of dry spells intensity, where the northeastern areas have the largest extremes. In the central and northern mountain areas, there are similarities in the extremes, where the lines between central and northern areas are parallel, so that they show some homogeneity in the extremes.

On the other hand, the largest multi-year drought (LMYD) has more alarming indicator. It is the summation of *SPI* of successive years. The LMYD expresses how rainfall falls far below the average, during successive long periods. Figure 5.15 shows the variation of LMYD in Jordan.

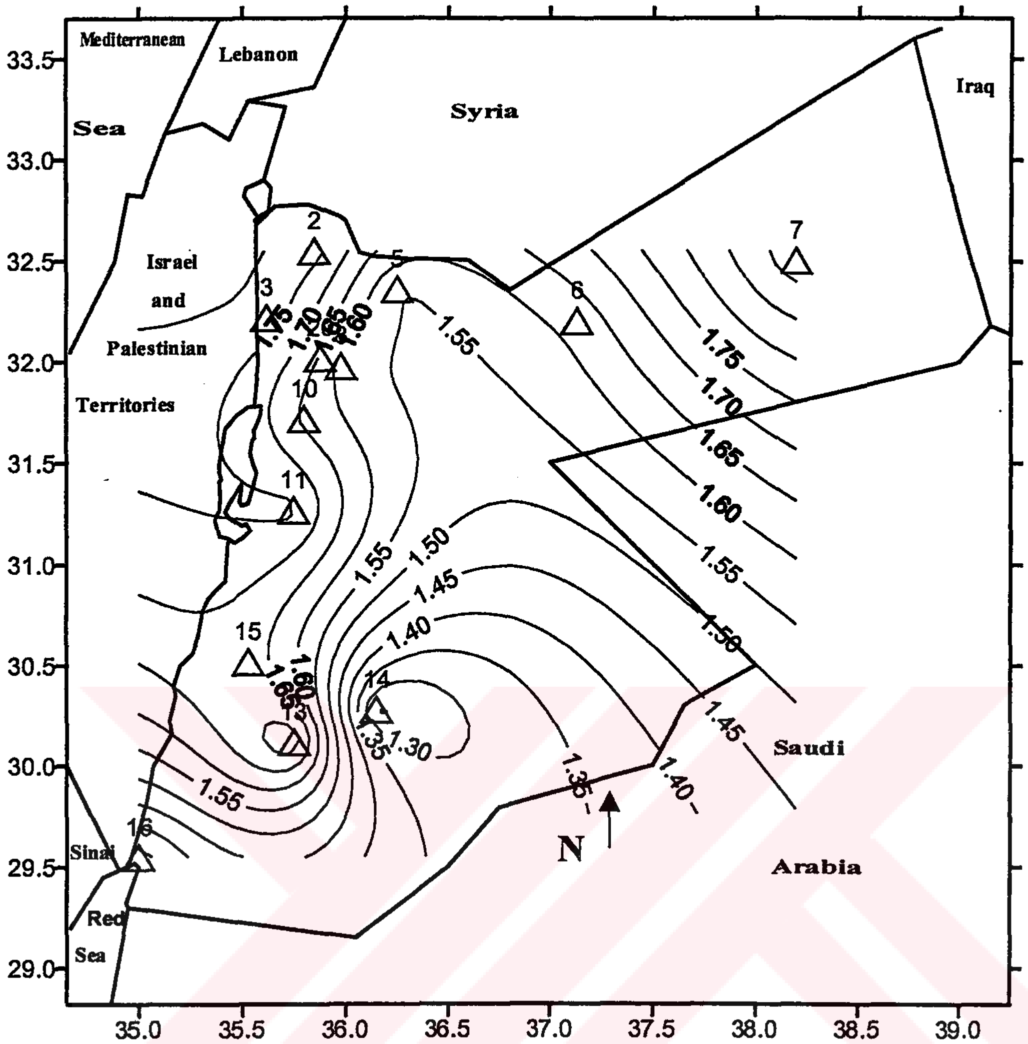

Figure 5.14: Dimensionless largest single year drought LSYD.

The area which extends from Errabbah station No. 11 in the central mountains to the Jafer station No. 14 in the southeastern desertic region has maximum LMYD. Ma'an station No. 13, which is 50 km to the west of Jafer station, has lower LMYD value in spite of its desertic climate. The extensive lines between the two station show relatively large gradient between them. The southern station Aqaba No. 16 also has high LMYD values. Station No. 20 is a special case in the central mountains. It is 20 km west of Amman station No. 8, with high LMYD while the northern and northeastern areas have lower values.

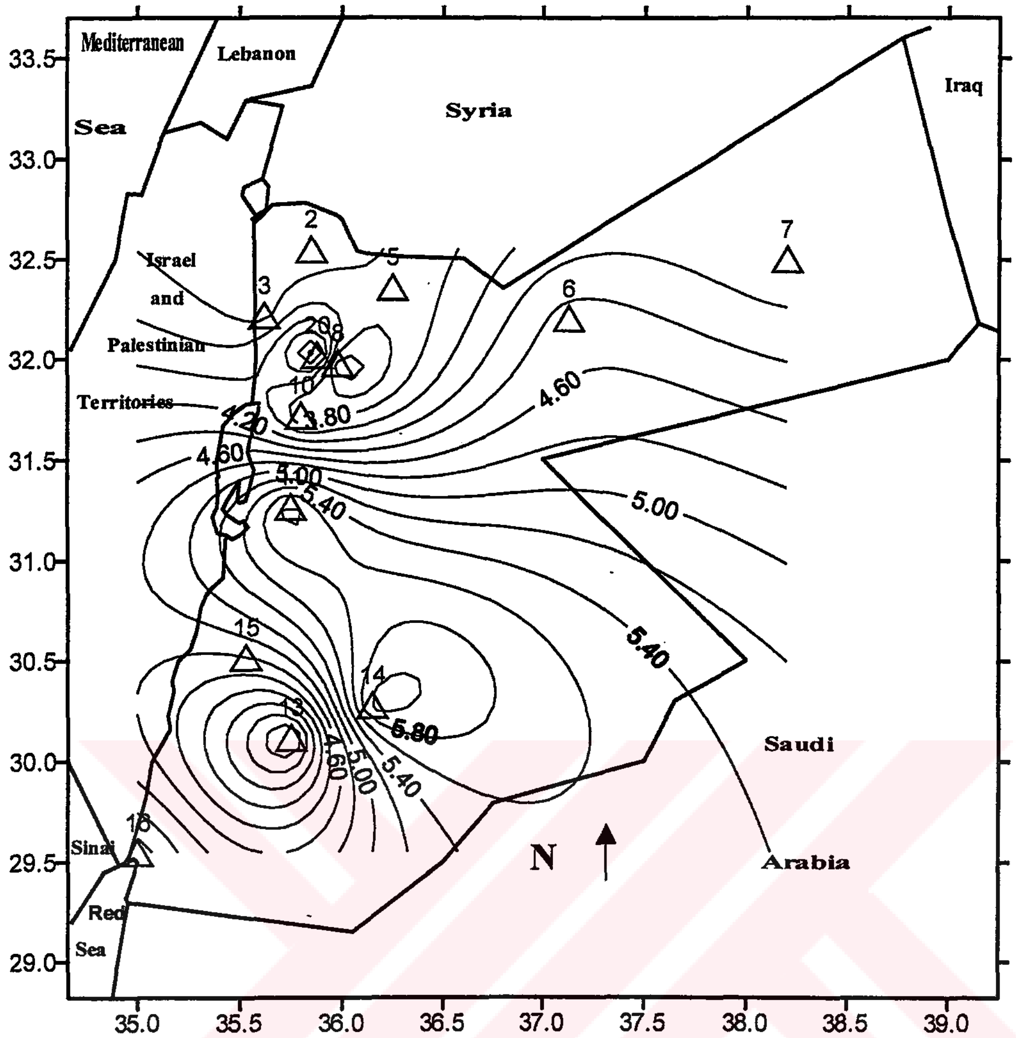

Figure 5.15: Directional largest multi-year drought LMYD.

Table 5.3: Dry and wet spell calculations for Jordan University station.

Season	Rainfall	SPI	State	DSD	CDS
50/51	264	-1.28748	D	1	1,28748
51/52	637	1.013572	W		
52/53	503	0.186921	W		
53/54	509	0.22393	W		
54/55	249	-1.38001	D	1	1,38001
55/56	509	0.223935	W		
56/57	568	0.584824	W		
57/58	321	-0.93275	D		4,80197
58/59	356	-0.72116	D		
59/60	205	-1.6520	D		
60/61	402	-0.43800	D		
61/62	404	0.-42319	D		
62/63	370	-0.63479	D	6	
63/64	605	0.818630	W		
64/65	476	0.021591	W		
65/66	272	-1.23874	D	1	1,23874
66/67	676	1.254164	W		
67/68	410	-0.38741	D	1	0,387415
68/69	627	0.950030	W		
69/70	377	-0.58914	D	1	0,589143
70/71	582	0.674892	W		
71/72	482	0.058605	W		
72/73	321	-0.93399	D	1	0,933991
73/74	719	1.516965	W		
74/75	403	-0.43121	D		2,60025
75/76	346	-0.77914	D		
76/77	441	-0.19555	D		
77/78	464	-0.05243	D		
78/79	288	-1.14189	D	5	

79/80	756	1.746453	W		
80/81	530	0.356570	W		
81/82	460	-0.07773	D	1	2,60025
82/83	678	1.267736	W		
83/84	488	0.091301	W		
84/85	461	-0.07032	D		1,04874
85/86	314	-0.97840	D	2	
86/87	550	0.474398	W		
87/88	666	1.192474	W		
88/89	432	-0.25046	D		0,646514
89/90	430	-0.26156	D		
90/91	451	-0.13448	D	3	
91/92	1128	4.040716	W		
92/93	559	0.533004	W		
93/94	381	-0.56755	D	1	0,567551
94/95	544	0.436767	W		
95/96	412	-0.37384	D	1	0,373843
96/97	587	0.707587	W		
97/98	438	-0.21159	D		2,43122
98/99	234	-1.47193	D		
99/00	352	-0.74768	D	3	

5.4 Sample of calculations of Jordan University station

1) Drought duration

AAP = 472.73 mm, Standard deviation =162.1 mm

D =28 years, W = 22 years,

$$DT = \frac{\sum D}{\sum W} = \frac{28}{22} = 1.27$$

LDSD = 6 year, ND = 14

$$ADSD = \frac{1+1+6+1+1+1+1+5+1+2+3+1+1+3}{14} = 2$$

$$AWSD = \frac{22}{13} = 1.69 \text{ year}$$

2) Drought frequency duration

$$DFD1 = \frac{9 \times 1}{50} = 0.18, \qquad DFD2 = \frac{1 \times 2}{50} = 0.04$$

$$DFD3 = \frac{2 \times 3}{50} = 0.12, \qquad DFD4 = 0$$

$$DFD5 = \frac{1 \times 5}{50} = 0.1, \qquad DFD6 = \frac{1 \times 6}{50} = 0.12$$

3) Drought severity

STCD =18.36

$$ADSI = \frac{STCD}{ND} = \frac{18.36}{14} = 1.31$$

LSYD = 1.65 year, LMYD = 4.8 years

Chapter 6

Regional rainfall intensity, duration and frequency

Natural extremes such as floods and droughts accompanied mankind through his entire history, witnesses to the destructive effects of floods and negative consequences of droughts, the seven lean years of Egypt, and several examples in Qur'an. In the present the result of the current extreme drought in the Sahel or recent catastrophic flood in Bengladesh and Sudan are illustrative examples. Studeis dealing with rainfall intensity, duration and frequency rank at the top of the list of hydrological topics worldwide (Starosolszky and Melder, 1989).

6.1 The needs for quantifying rainfall

An engineering design always takes into account the extreme situations. For example, when a highway bridges is built, it must be able to pass the design discharge of specific magnitude without being flooded during its lifetime. The same is held when a dam is built, drainage structure should withstand with extremes similar to a construction of a building, that it must withstand design wind loads of the highest magnitudes.

Generally, a design for extreme events is required for water resources projects, because there is always some chance (risk) that this design event will be exceeded during the intended useful life of the project. This raises question of how large or small should that risk be quantified. This similar concept can be answered using probability.

6.2 Return periods

In order to understand the concept of return periods, the following simple rules of probability should be taken into consideration. The probability of an event (E) is neither negative nor more than one.

$$0 \le P(E) \le 1, \tag{6.1}$$

and summation of probability on N events should add to one as

$$\sum_{i}^{N} P(E_i) = 1, \tag{6.2}$$

For instance, when a coin is tossed, probability of head $P(H) = 0.5$, and probability of tail is $P(T) = 0.5$. Hence a coin tossed once a year, it will have head or tail in 2 years, since 1/0.5 = 2 years, which is called the return period T_r, and it can be written as follows:

$$T_r = \frac{1}{P}, \tag{6.3}$$

Where, P is the probability of the occurrence. In general, the return period is an average value, not an actual value of the period of the occurrences. A storm that has been exceeded on the average once in 10 years has a probability of exceedence in any year 1/10 or 0.1. In other words, storm that exceeds 1 year on 10 years has probability of 0.1 x100 % = 10 % of being exceeded any year. This probability does not mean that every 10 years a storm will occur. The probability of a storm will not occur in any year can be written as follows:

$$\bar{P} = (1 - P) = (1 - \frac{1}{T_r}), \tag{6.4}$$

The probability that the storm will not occur in n successive years may be written

$$(\bar{P})^n = (1 - P)^n = (1 - \frac{1}{T_r})^n, \tag{6.5}$$

On the other hand, the probability of the occurrence at least once in n years can be expressed as,

$$R = 1 - (\bar{P})^n = 1 - (1 - P)^n = 1 - (1 - \frac{1}{T_r})^n , \tag{6.6}$$

Where, R is called risk, and it may be used for designing any water project, especially in calculation of drainage systems. Based on Eq. (6.1) various return period probabilities are given in Table 6.1.

Table 6.1: Return period for various probability and life of the project Singh 1993.

Risk or Prob.%	Project life in years 10	15	20	30	40	50	60	75
	Return periods in years							
10	95.41	142.87	190.32	288.1	380.1	475.06	593.7	712.32
15	62.03	92.8	123.56	186.9	246.62	308.16	385.1	461.98
20	45.32	67.72	90.13	149.8	179.75	224.57	280.58	336..6
25	35.26	52.64	70.02	105.8	139.54	174.3	217.75	261..2
30	28.54	42.56	56.57	93.9	112.64	140.68	175.73	210.77
35	23.72	35.32	46.93	77.8	93.35	116.57	145.73	174.6
40	20.08	29.87	39.65	65.7	78.80	98.38	122.85	147.32
45	17.23	25.59	33.96	51.18	67.41	84.14	105..04	125.95
50	14.93	22.14	24.36	44.2	58.21	72.64	90..66	108.7

This table explains the relations among the probability or risk and the return period. For example, from Table 6.1, there is 30 % chance that an event of return period 28.54 years will exceed or equal during the next 10 years. In other words, if there is probability or risk of 30 % of an event to occur in successive 10 years then its return period is 28.54 years.

Taking an example from Shoubak station Table 6.4, rainfall intensity is 49.8 mm per one hour which is highest recorded during 15 years. What is the risk or probability to have the same storm or any exceeding one? The probability of this storm is

$$P = \frac{1}{T} = \frac{1}{15} = 0.066$$

The probability that this storm will not occur at all is from Eq. (6.4):

$$\bar{P} = (1 - P),$$

The probability that this storm will not occur in successive five years, can be obtained from Eq. (6.5

$$(\bar{P})^n = (1 - P)^n = (1 - \frac{1}{T_r})^n,$$

The probability of the occurrence at least once can be calculated from Eq. (6.6) as

$$R = 1 - (\bar{P})^n = 1 - (1 - P)^n = 1 - (1 - \frac{1}{T_r})^n,$$

or numerically as

$$0.066=1-(1-\frac{1}{T_r})^5, \Rightarrow \quad T_r = 73.7 \text{ years.}$$

This means that, this event has returned period or (recuurence interval) of 73.7 years and with the probability of 6.6 %, it will exceed this number or equal after five years.

6.3 Extremes and the concept of intensity, duration and frequency

6.3.1 Definitions

Rainfall intensity is the amount of rainfall per unit time, e.g., 50 mm/hr, so that it is different from rainfall amount. Rainfall duration is a period of time during which a continous rainfall of specific intensity takes place, e.g., 20 mm/hr lasts for 15 minutes.

Rainfall frequency is the recurrence of an event, e.g., rainfall of 20 mm/hr intensity, 15 minutes duration has frequency once every 3 years.

In hydrological studies, it is important to determine the probability of an event being equal or exceeding in any year. Let us give the following example. Theoretically, suppose that we have a series of measurements say 30 rainfalls data, where the data are arranged in ascending order with 1 for the smallest value, n for the highest. The probability of each one is $P_1 \doteq 1/30$ = 0.033, and for number 8, $P_8 = 8/30 = 0.26$, for rank 30; $P_{30} = 30/30 = 1$.

This is theoretically correct, if the number of data is N and the rank is m, then the probability in general $P = m/N$. For example, the probability of having higher value than rank 8 can be expressed

$$\bar{P} = 1 - 0.26 = 0.74,$$

and for rank 30,

$$\bar{P} = 1 - 1 = 0,$$

As mentioned before, this is theoretically correct, but practically we never have zero probability to have higher values than the recoded maximum. Naturally there is always probability than what have been recorded. For this purpose, Weibull (1939), proposed new equation for recurrence interval or sometimes called return period, this equation is widely used as follows:

$$P = \frac{m}{N+1} \tag{6.7}$$

the probability of having higher values than the number of m rank will be $(1-P)$, which is Eq. (6.4). Gumbel (1958) used the former equation in his world wide distribution for calculation the extreme values of rainfall in relation to duration and frequency. Gumbel formula can be written as follows:

$$P = 1 - e^{-e^{-y}} \tag{6.8}$$

By substituting in Eq. (6.4), this expression may be written as follows

$$\bar{P} = -e^{-e^{-y}} \tag{6.9}$$

or as

$$y = -\ln\left[\ln\frac{1}{\bar{P}}\right] \tag{6.10}$$

where, $\overline{P}$ is the probability of a given event equaled or exceeded. e is the napierian logarithms, and y is a reduced variant which has a probability function. All the distributions for calculation of extreme events in relation to duration and frequency are generalized by the following formula:

$$X = \overline{X} + K\sigma_x \tag{6.11}$$

where, X is the extreme event, $\overline{X}$ is the mean of event series, σ_x is the standard deviation of the records and K is the frequency factor, has different values according to the used distribution.

The extreme value by Gumbel may be used by substituting the value of K in Eq. (5.9) in terms of y as follows:

$$X = \overline{X} + (\frac{y - y_n}{\sigma_n})\sigma_x \tag{6.12}$$

where, y_n and σ_n are the mean and standard deviation of reduced variant y which is a function of length of the records. Tables D.1 and D.2; (Appendix D) give the mean and standard deviation for different record lengths.

6.4 Application for Jordan

Gumbel distribution for calculation the extremes of rainfall in relation to duration and frequency is used for three geographical regions in Jordan. They represent the north, central and southern areas. Irbed, Suweileh and Shoubak stations are chosen to represent these regions, respectively. The daily recorded rainfall graphics of these stations are analyzed using a digitizer. This converts the records to the rainfall intensity for the following intervals 5, 10, 20 and 30 minutes and 1, 2, 3, 6 and 24 hours Tables 6.2- 6.4 show the rainfall intensities of the stations.

On the other hand, for the purpose of calculations the extremes, the mean, standard deviation and standard return periods of the reduced variant y should be considered according to the length of the records. Its mean and standard deviation vary according to the length of the records. Besides it has constant value for each return period. Tables D.1-D.3 in the appendix D give the former values, respectively. The following example shows the way of calculating the mean of y for records.

Table 6.2: Maximum rainfall intensity (mm) in Irbed station.

Season	**Minutes**						
	20	30	60	120	180	360	1440
80/81	6.80	7.60	9.80	15.80	21.20	31.80	34.80
81/82	16.20	17.00	17.20	17.20	20.80	23.60	51.60
82/83	5.80	6.80	8.40	13.40	17.40	28.80	49.20
83/84	9.20	12.40	14.80	21.80	30.00	43.80	60.20
84/85	7.60	7.60	9.40	16.20	19.60	23.40	38.80
85/86	13.40	14.00	14.00	15.20	19.40	31.60	43.00
86/87	7.80	8.40	11.20	19.40	27.00	40.20	83.20
87/88	7.20	9.60	9.60	10.60	13.20	19.00	33.20
88/89	16.8	19.40	21.40	21.40	21.60	23.20	29.60
89/90	4.00	6.20	6.20	10.80	11.20	11.20	24.80
90/91	7.80	9.80	12.80	14.20	17.60	30.80	73.20
91/92	6.20	7.60	9.20	15.40	20.60	25.60	45.40
92/93	3.20	5.60	8.00	13.60	19.40	33.60	54.80
93/94	10.0	10.00	20.00	14	20.60	26.00	39.20
94/95	6.60	11.20	16.00	16.00	22.60	27.00	30.00
95/96	4.40	5.60	7.40	10.80	11.60	20.00	29.20
96/97	6.20	7.80	7.80	11.80	12.20	17.00	19.00
97/98	5.80	9.40	10.20	13.40	14.20	22.00	57.60
Mean	8.13	9.78	11.86	15.39	18.90	26.59	44.27
St. Dev.	3.953	3.821	4.458	3.511	5.09590	8.002	16.989

Table 6.3: Maximum rainfall intensity (mm) in Suweileh station.

Season	**Minutes**						
	20	30	60	120	80	360	1440
63/64	9.20	14.00	18.00	27.00	31.00	38.00	49.30
70/71	6.50	6.50	12.50	24	34.00	56.00	139.50
71/72	5.00	5.00	7.50	14.00	20.00	23.00	30.00
72/73	10.00	10.00	14.50	16.00	16.50	27.00	30.00
73/74	5.00	5.00	5.50	9.50	12.50	23.50	38.00
74/75	4.50	4.50	8.50	10.00	12.00	12.00	13.00
75/76	10.00	11.40	12.20	19.20	26.00	44.60	72.00
81/82	6.00	10.00	16.40	28.40	33.40	33.40	34.00
82/83	6	8	13	19	27	42	53
83/84	7	10	13	18	21	35	52
84/85	8	9	11	20	24	31	49
85/86	8	9	10	11	13	19	38
86/87	7	8	9	17	23	34	66
88/89	4	5	10	14	11	32	47
89/90	4	5	8	14	15	16	35
90/91	4	5	7	13	18	31	52
91/92	3	4	8	16	21	37	66
92/93	3	6	10	19	24	41	63
93/94	8	10	12	20	25	31	36
94/95	7	10	10	11	12	18	39
95/96	5	5	6	11	16	27	50
96/97	5	6	10	17	23	40	46
97/98	8	10	10	14	14	16	42
Mean	6.19	7.65	10.63	16.5609	20.50	30.74	49.57
St. Dev.	2.14	2.75	3.10	5.11	6.91	10.65	23.88

Table 6.4: Maximum rainfall (mm) intensity for Shoubak station.

Year	Minutes								
	5	10	20	30	60	120	180	360	1440
74	2.5	2.9	4.3	5.3	8.8	9.7	13.3	22.2	70
75	2.5	3.5	6.6	7	8.8	17.6	25.6	43.1	92.1
76	2	3.5	5.9	8.1	10.1	14.3	21.8	34.5	45.1
77	9	12	24	31	49.8	55	67	67.8	75.6
78	1.7	2.9	4.2	5.2	7.9	9.5	12.4	17.4	38.3
79	2.7	3.3	4.8	4.9	9.5	17.5	24.3	35.6	70.1
80	2.5	4.1	4.5	6.5	12	21	29	47.3	78
81	4	4.8	5.9	7.4	12.4	16.1	16.7	20.7	49.7
82	5.4	7.6	9.8	14.4	21.5	24.8	29.7	30.4	49.5
83	5.6	6.6	7.4	8.4	10.7	15.5	20.2	32.9	46
84	2.5	3	5	5.7	6.5	11.5	16	17.6	41.6
85	3.6	4.2	7.4	9.2	12.3	14.9	18.5	26.9	59.7
86	4.2	5.6	6.1	6.4	7.7	12.2	15	28	44.7
87	2	2.5	3.7	4.4	8	12.2	15.3	28.4	53
88	2.3	2.8	4.9	6.7	10.8	14.7	15.8	23.7	70.4
Mean	3.5	4.62	6.96	8.7	13.12	17.767	22.76	31.76	58.92
St.dev.	1.942	2.525	4.972	6.627	10.742	11.079	13.395	13.171	166.07

In order to calculate the mean and standard deviation of y for 10 years-record the following steps should be followed:

1. Find the probability of each year separately by applying Eq. (6.4) and (6.10), e.g. for the first year

$$\overline{P}_1 = 1-(\frac{1}{10+1}) = 0.9090,$$

2. Calculate the value of y using Eq. (6.10)

$$y_1 = -\ln\left[\ln\frac{1}{0.9090}\right] = 2.3506,$$

3. In the same way the values of y_2 to y_{10} are found. The mean value of y_1 to y_{10} is found to be 0.4952 as given in Table D.1.

4. The same procedures can be applied to find the standard deviation using the following formula:

$$\sigma_n = \sqrt{\frac{\sum y^2 - \frac{1}{N}(\sum y)^2}{N}} \qquad (6.13)$$

In order to calculate the extremes of different durations and different frequencies or return periods, Gumbel Eq. (6.12) is used Irbed station is taken as sample of calculations.

1. Find the mean and standard deviation for each period in Table 6.2.

2. The number of records is 18 years, the mean and standard deviation of y

   Corresponding to these records may be found as 0.5202 and 1.049, respectively from Tables D.1 and D.2.
3. The standard value of y corresponding to each return period may be substituted from Table D.3.
4. Using Eq. (6.12). The extremes during different intervals (duration) can be determined (see Table 6.5). The intervals in minutes are chosen as 20, 30, 60, 120, 180, 360 and 1440 minutes. On the other hand the frequencies or return periods (years) are taken as follows 2, 5, 10, 25, 50, 100, 200, 250, 500, 1000 and 2000 years.

In order to unify the values of this Table 6.5 to be in mm/hr, it is necessary to multiply the 20 and 30 minutes-columns by 3, and 2 respectively. Dividing 120, 180, 360 and 1440 minute columns by 2, 3, 6 and 24 respectively (see Table 6.6). Using the data in Table 6.6 and Figures 6.1 intensity-duration-frequency (IDF) for Irbed area can be constructed. The same procedures are applied to draw IDF figures for Shoubak and Suwielh stations. These figures are used for construction planning

Table 6.5: Maximum rainfall intensity (mm) in Irbed for a given duration and frequency.

Return Period	Minutes						
	20	30	60	120	180	360	1440
2	7.5504	9.2180	11.202	14.874	18.153	25.41	41.778
5	11.820	13.346	16.018	18.667	23.658	34.060	60.130
10	14.647	16.079	19.207	21.178	27.302	39.782	72.281
25	18.218	19.533	23.236	24.350	31.907	47.012	87.633
50	20.868	22.095	26.225	26.704	35.323	52.376	99.022
100	23.498	24.638	29.192	29.040	38.714	57.701	110.32
200	26.119	27.171	32.148	31.368	42.092	63.006	121.59
250	26.962	27.986	33.099	32.116	43.178	64.711	125.21
500	29.577	30.514	36.048	34.439	46.549	70.004	136.45
1000	32.190	33.041	38.996	36.760	49.918	75.294	147.68
2000	34.802	35.566	41.942	39.080	53.280	80.582	158.91

Table 6.6: Maximum rainfall intensity mm/hr for given duration and frequency in Irbed station.

Return Period	Minutes						
	20	30	60	120	180	360	1440
2	22.651	18.436	11.202	7.4373	6.0512	4.2361	1.7407
5	35.460	26.692	16.018	9.3335	7.8860	5.6766	2.5054
10	43.941	32.159	19.207	10.589	9.1008	6.6304	3.0117
25	54.656	39.066	23.236	12.175	10.635	7.8354	3.6513
50	62.606	44.190	26.225	13.352	11.774	8.7294	4.1259
100	70.496	49.276	29.192	14.520	12.904	9.6168	4.5970
200	78.358	54.343	32.148	15.684	14.030	10.501	5.0663
250	80.886	55.972	33.099	16.058	14.392	10.785	5.2172
500	88.731	61.029	36.048	17.219	15.516	11.667	5.6855
1000	96.570	66.082	38.996	18.380	16.639	12.549	6.1535
2000	104.40	71.133	41.942	19.540	17.762	13.430	6.6213

especially that related to water. The same procedures are followed to draw figures for Shoubak in the south and Suweileh in the central regions (see Appendix D, Tables D.4 and D.5).

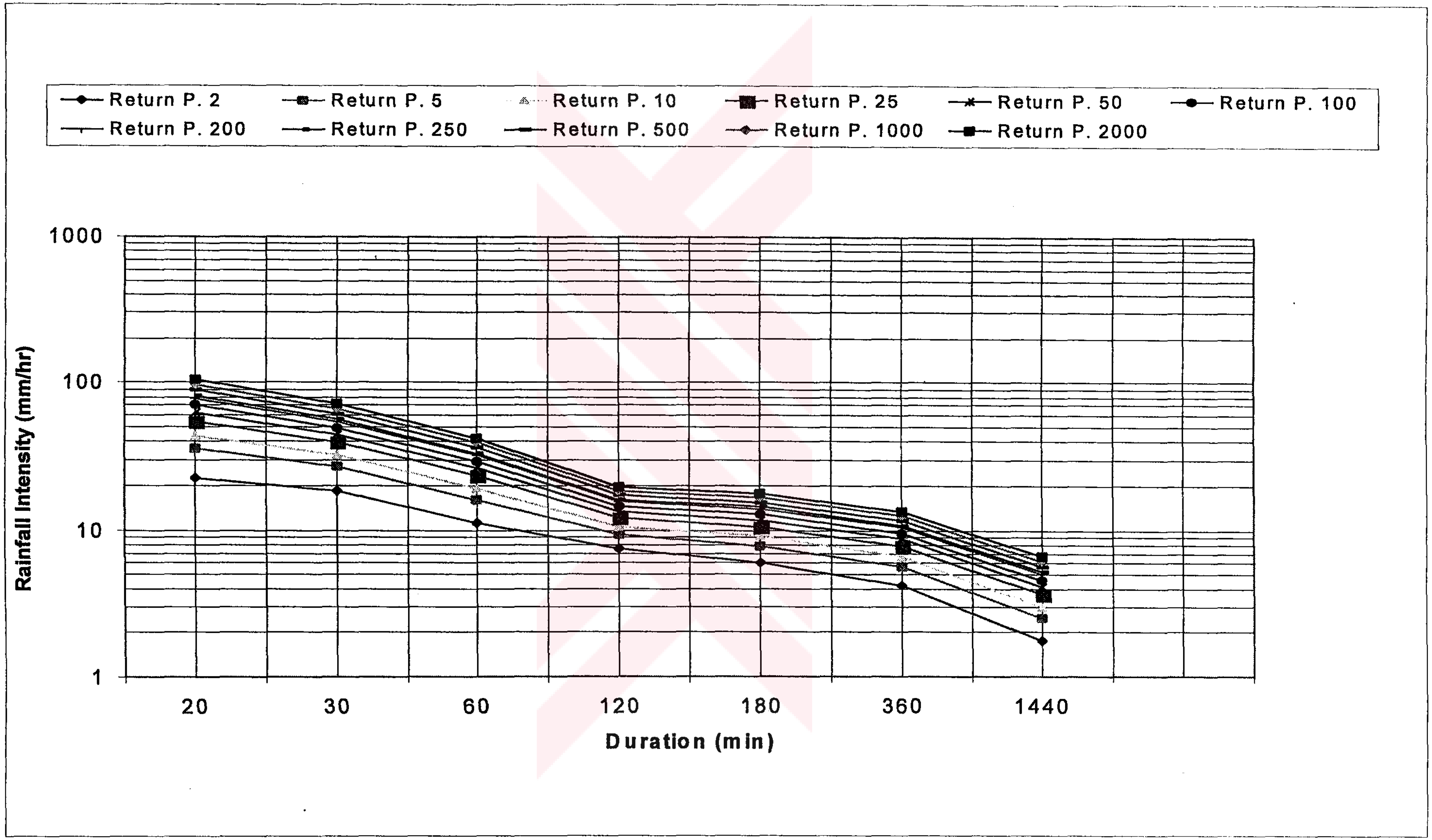

Figure 6.1: Maximum rainfall intensity-duration-frequency for Irbed area.

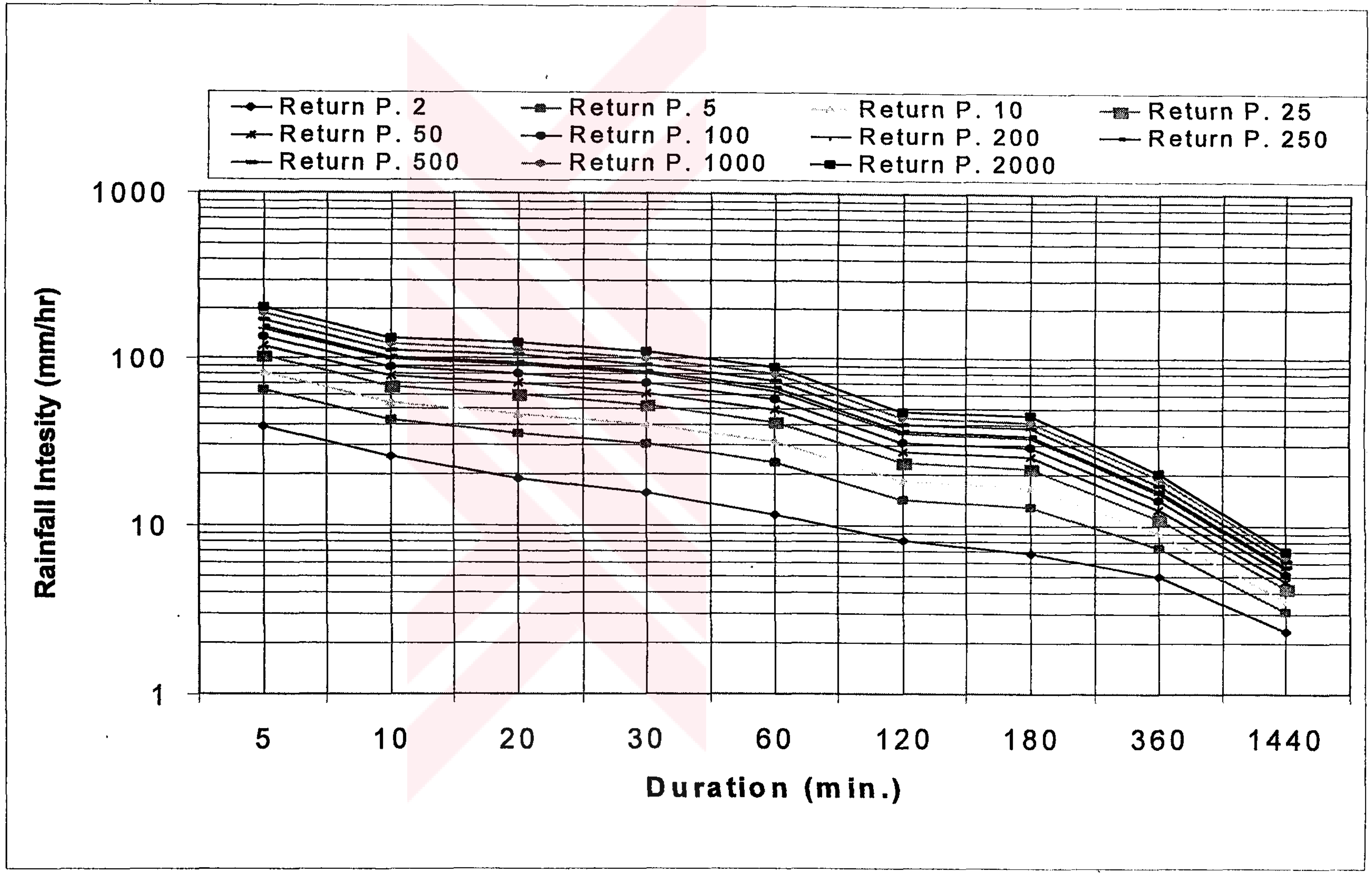

Figure 6.2: Maximum rainfall intensity-duration-frequency for Shoubak area.

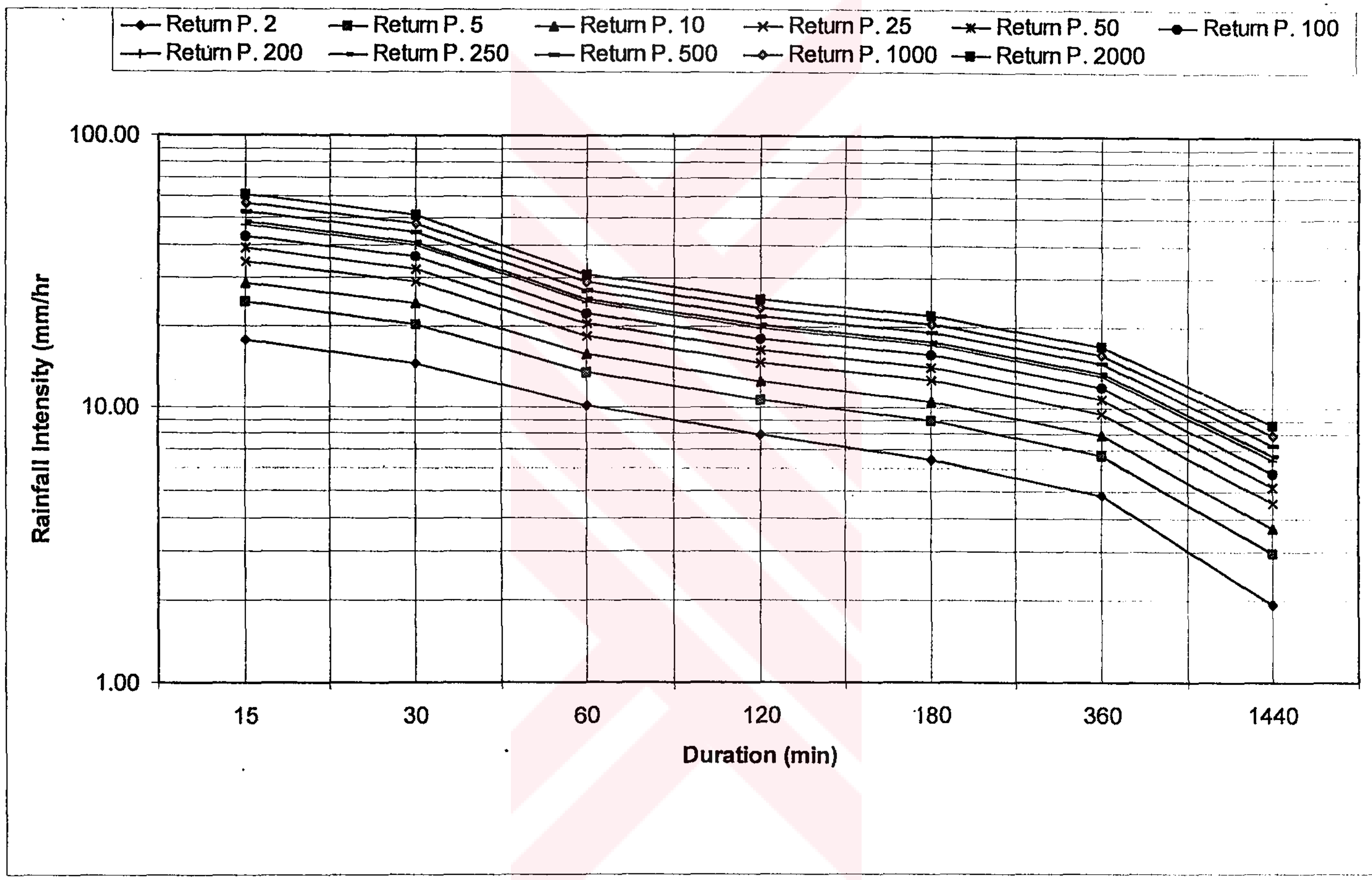

Figure 6.3: Maximum rainfall intensity-duration- frequency forSuweileh area

Chapter 7

Conclusion and Recommendations

7.1 Conclusion

The analysis of rainfall variability in Jordan, especially in the huge desertic region which represents more than 75 % of the total area are among the fundamental requirements for wide variety of human activities and water project designs. The assigned objectives of this study were, first to determine the rainfall features and to predict its magnitude in space; second, to study the environmental and climatic impacts of water resources.

The major conclusion of this study can be summarized as follows:

1. Rainfall distribution in Jordan depends on the location due to the north or west. The maximum rainfall amount does not necessarily occur at high elevation as shown in the spatial analysis.

2. Synoptically, winter storms are the fundamental rainfall regime; the convective rainfall type contributes in small percentage of total rainfall amount.

3. Semivariogram techniques show the regional dependence of Amman area rainfall which has high correlation in all direction except the desert side where there is no homogeneity and there is weak correlation in the desert side. The method is highly depicted the behavior of the rainfall around Amman area.

4. The weights or standard regional dependence function for each direction at several distances are determined which help in rainfall estimation.

5. Cross validation method is successfully used in estimation rainfall with an error not exceeds 14 %, while the desertic side shows large errors due to the weak correlation between the desert and Amman.

6. Rainfall regimes are identified using semivariograms samples.

7. The percentage of variances shows large contributions of the first harmonic, it represents 90 % of the total variances in most stations, except in the northeast.

8. The percentage of variances of the second harmonics has the high value 10 % in the northest, due to the convective type of rainfall.

9. The time of maximum rainfall is shown for all location using the harmonicanalysis, which help in identifying the type of rainfall of the region.

10. The maximum amplitudes are found in the north mountainous region such as Ras Munif station about 65 mm.

11. The amplitudes of the 1st and 2nd harmonic decrease from north to south and from west to east.

12. Jordan enjoys moderate drought except Shoubak and Madaba areas which have severe drought, the two stations represent mountain areas.

13. There are mountainous stations of 5 years drought frequency duration such as Shoubak in the southern mountains and Madaba in the central mountainous areas, these areas should be taken in cosideration in planing for water resources or agricultural projects.

14. The longest dry spell duration is 7 years in southern desert area and 6 years in one station in the central mountains.

15. The extreme events of rainfall of different part of Jordan; northern, central and southern are found for sevral durations and return periods.

16. Figures for engineering design are constructed for these areas which help in water resources projects such drainge structure of dams or highway bridges.

7.2 Recommendations

Based on the findings of this study, it is possible to make a number of recommendations for future studies, all of which are aimed to better understanding the climate and of precipitation in Jordan. These can be stated as follows.

1. The semivariogram is helpful in studying rainfall characteristics especially in the desert of Jordan, where there are lack of information about the volume of water in these areas. Applying this method for the desert areas separtaly is recommended..

2. Harmonic analysis shows superiorty in climate analysis and the periodicity of rainfall, this method must be applied to other variables for better understanding the climate of Jordan.

3. The result of drought analysis must be taken into consideration in planning for water resources or agricultural projects, e.g. Areas of the longest dry spell duration such as Jafer area and areas of highest frequency of 5 drought-years such as Shoubak area, the water resources projects in these areas should be designed to withstand of such extreme drought, especaily the goverment of Jordan is planning to constructs new dams throghout the country.

4. The quantity of single year drought intensity is useful for short-term planning, especially for irrigation and agricultural projects, so that it is valuable to determined the type of plants, because some plants cannot withstand in such exterme circumstances, such as rewashed in the northeast and Irbed in the northern area.

5. The study shows the areas of severe drought such as Madaba and Shoubak, the study recommend to pay attention to these areas in order not to have more degradation in these areas and to observe any man-made effect of these areas.

6. Mountains areas enjoy drought as much as desertic aeas, the study recommend applying other indices for better understanding this phenomenon.

7. The rainfall intensity, duration and frequency may be used for designing water resources projects.

8. The semivariogram method may be introduced to the Mining Phosphate Company to be used in excavation process. Besides that, this method may used to study the distribution of air pollution.

9. The study introduces new techniques for Jordan such as semivariogram and harmonic analysis. These techniques have never been used before in Jordan in such climatic and environmental study.

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APPENDIX A

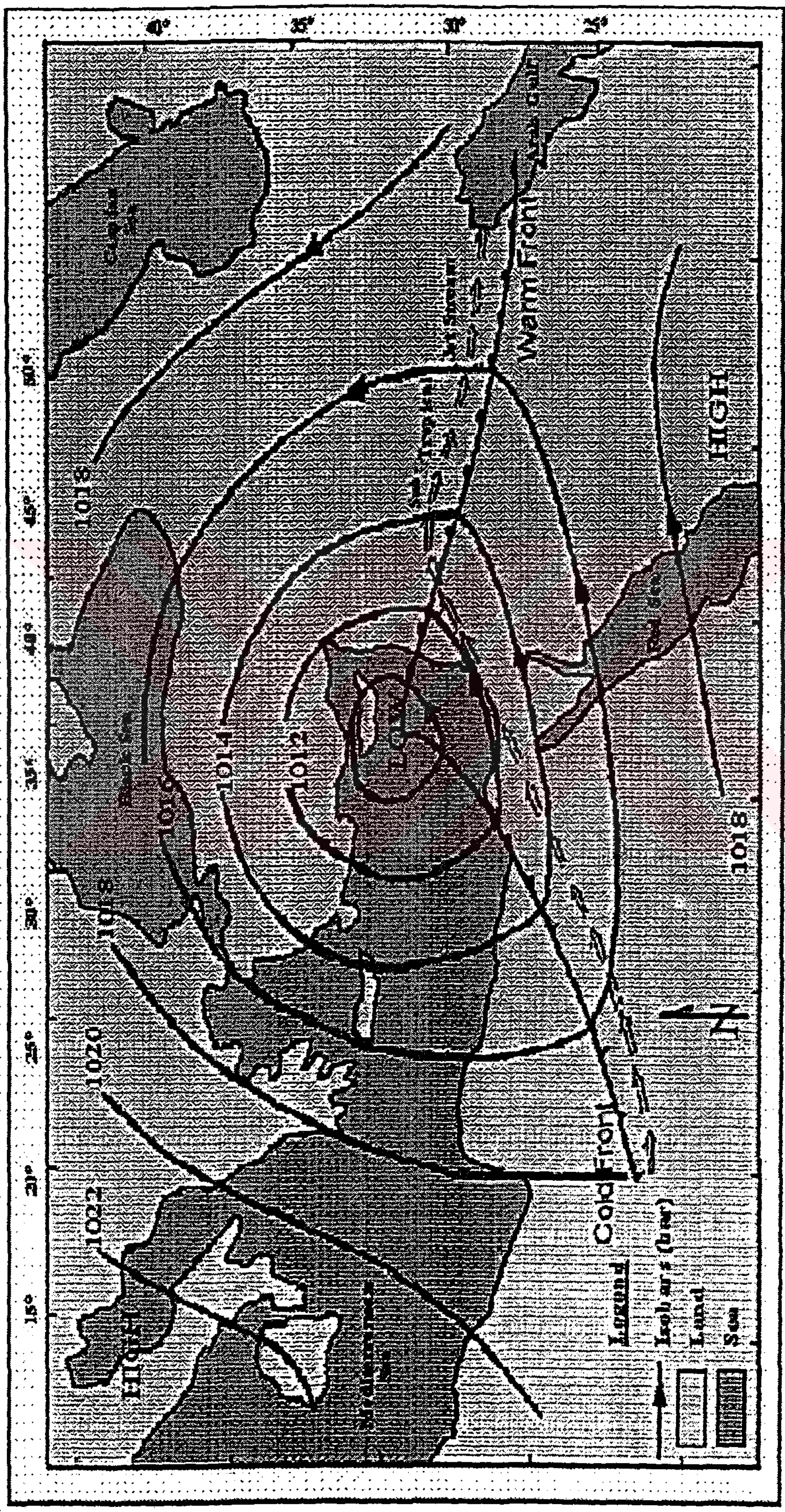

Figure A.1: Weather chart for Jan. Winter season (Source UNDP Project by AL-SHAMEL Eng.)

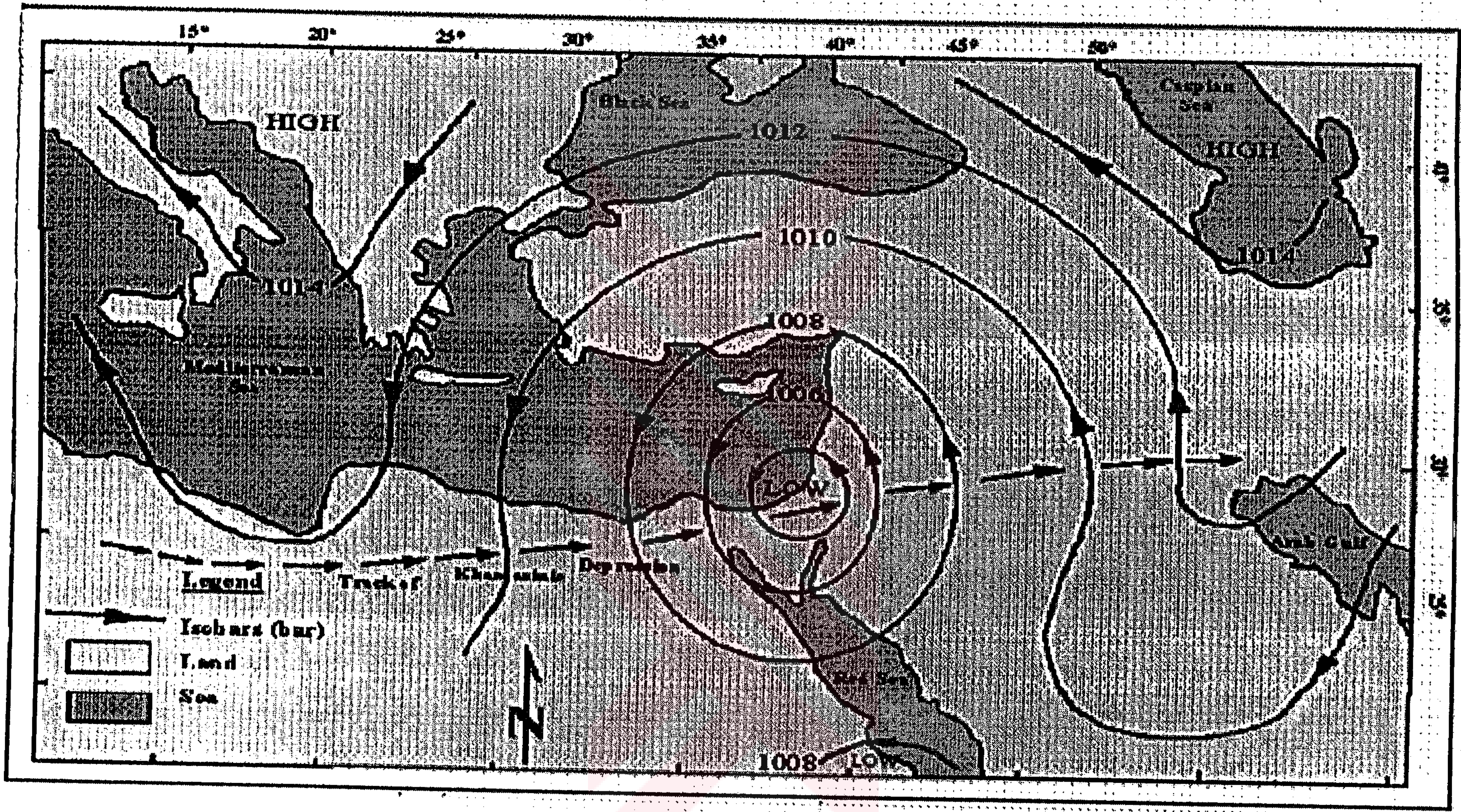

Figure A..2:Weather chart in spring season, Source: UNDP project, AL-Shamel Eng.

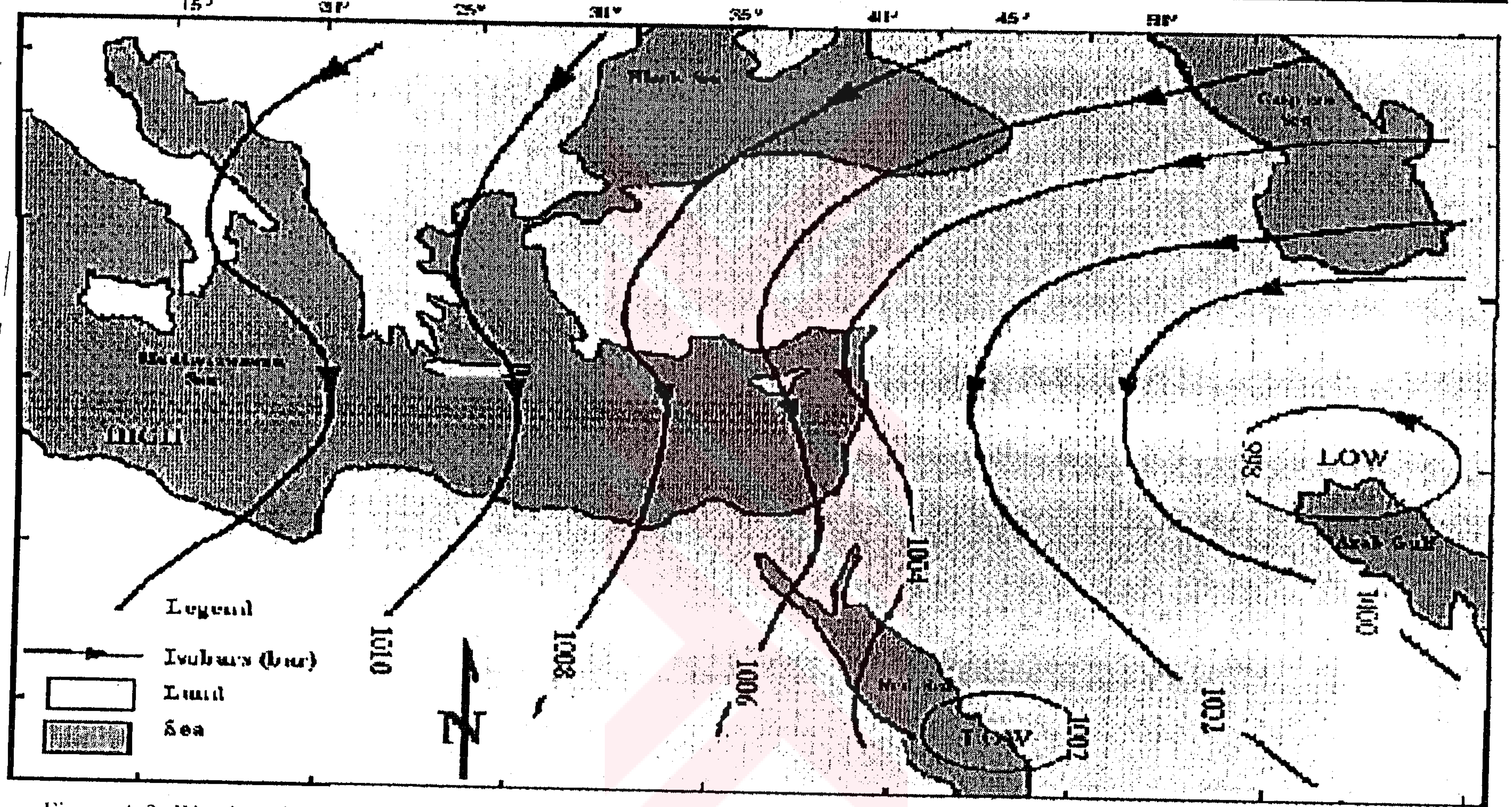

Figure A.3: Weather chart for summer season, Source : UNDP Proj. AL-Shamel Eng.

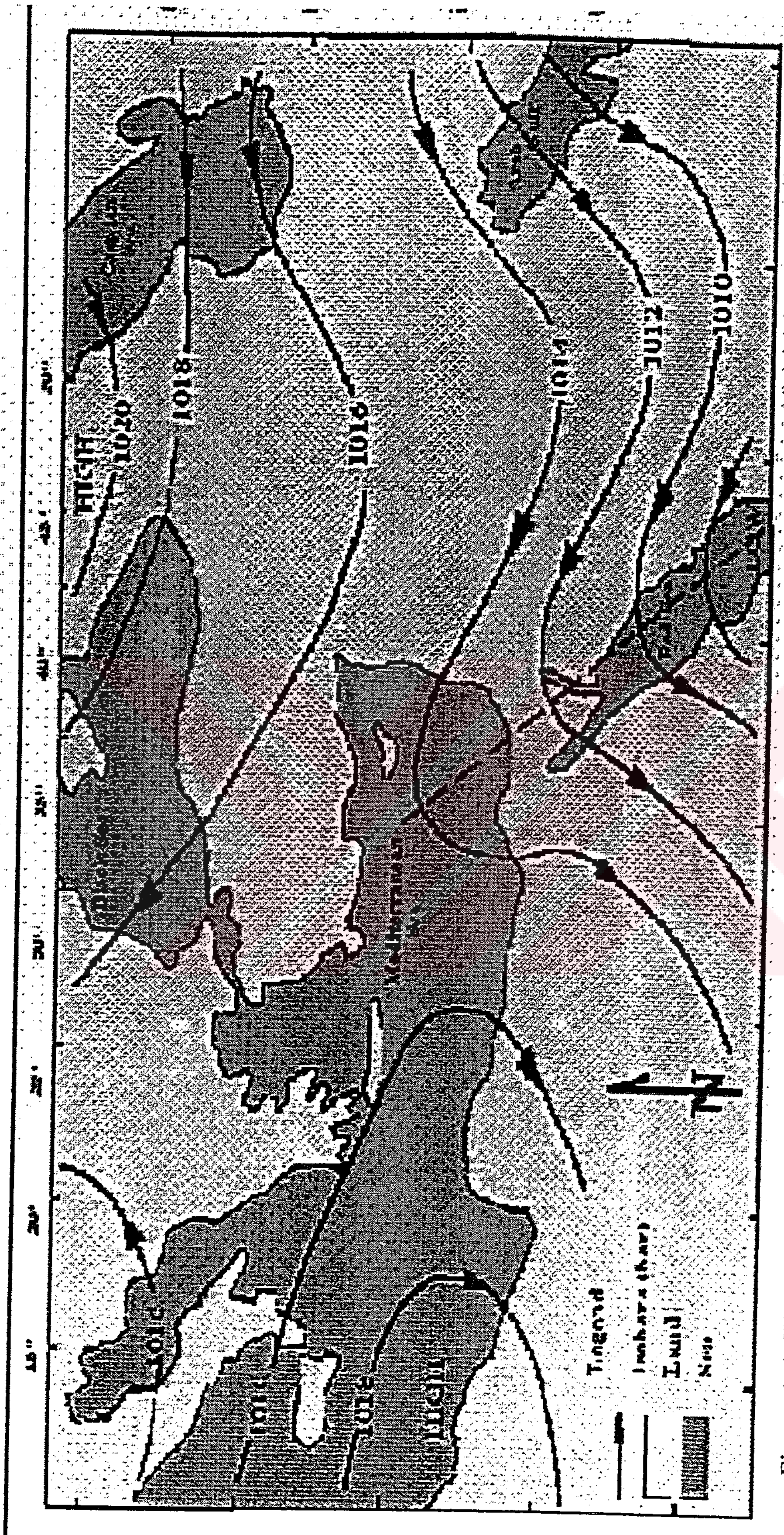

Figure A.4: Weather chart fFor autumn season,Source UNDP Proj. AL-Shamel Eng.

APPENDIX B

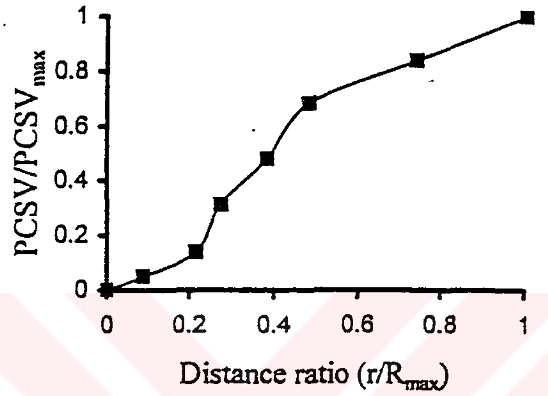

Figure B.1: PCSV of east Amman sample.

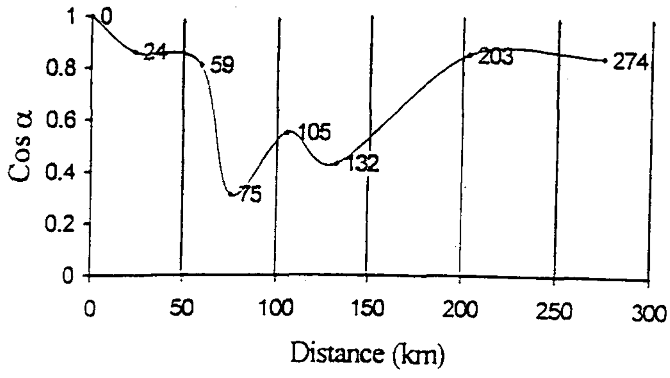

Figure B.2: Radius of influence for east Amman.
distances measured from Amman

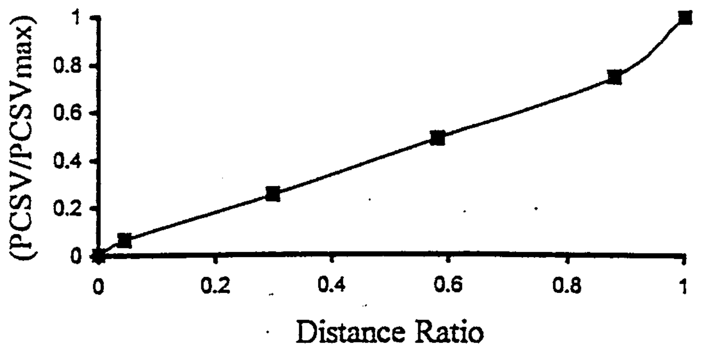

Figure B.3: PCSV of southeastren sample.

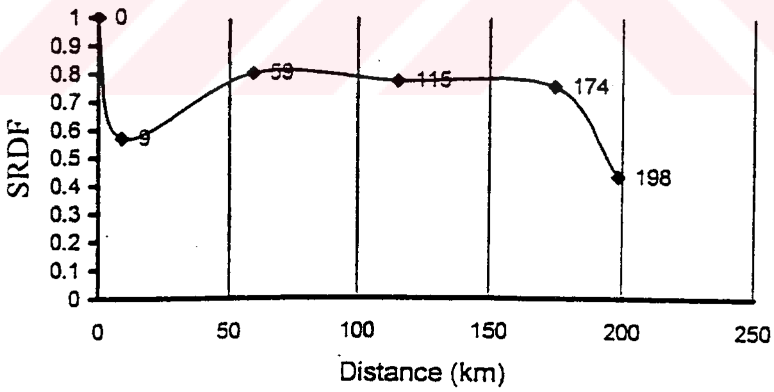

Figure B.4: Radius of influence of souththeast sample, distances measured from Amman.

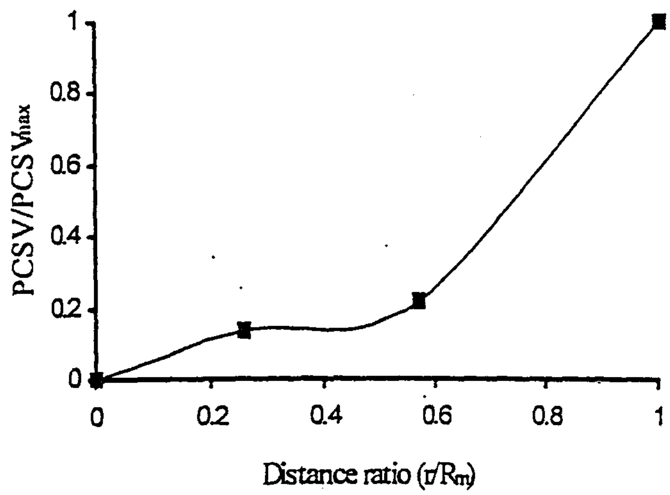

Figure B.5: PCSV of the southwest sample.

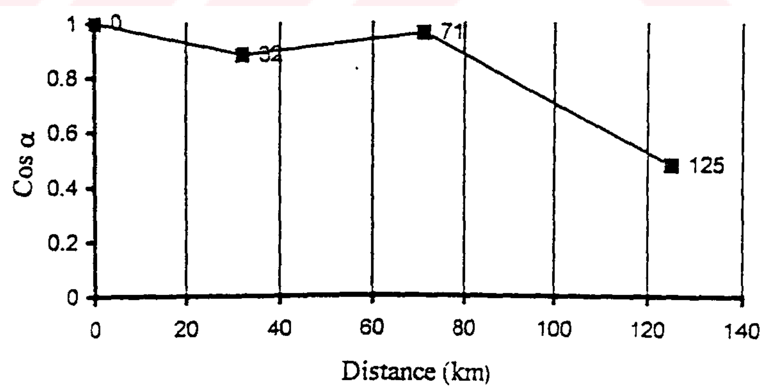

Figure B.6: Radius of influence for southwest, distances measured from Amman.

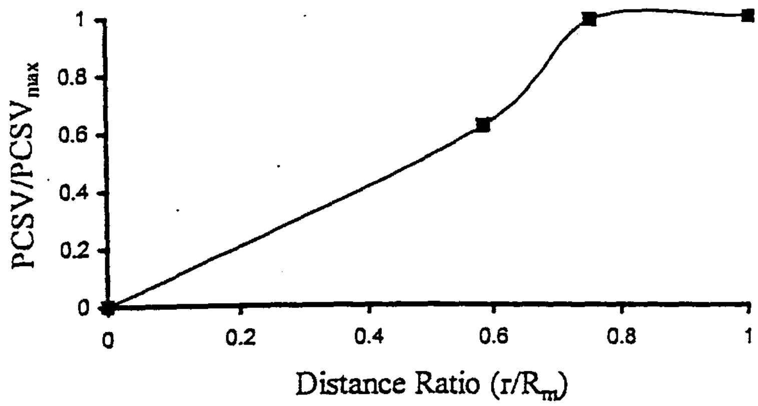

Figure B.7: PCSV of the west sample.

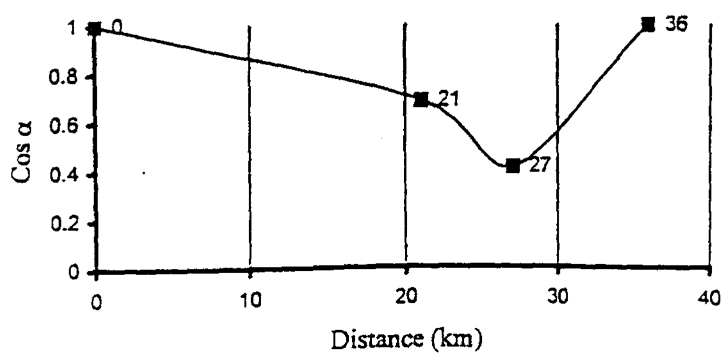

Figure B.8: Radius of influence of the west sample, distances measured from Amman.

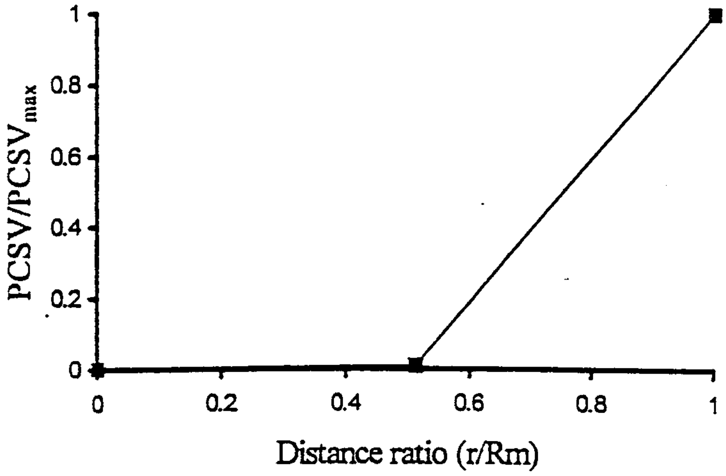

Figure B.9: PCSV sample of the northwest direction.

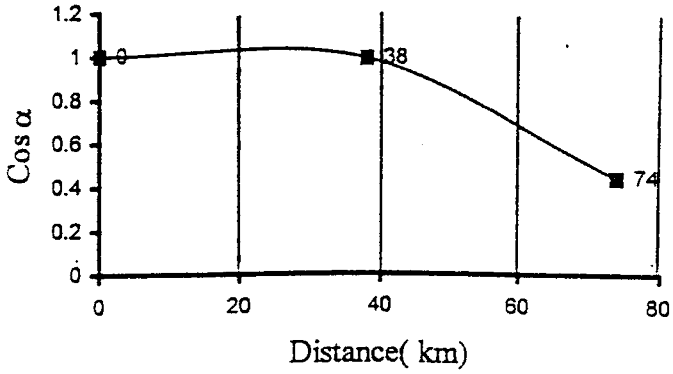

Figure B.10: The radius of influence of the northwest sample, distances measured from Amman.

APPENDIX C

Result of harmonic analysis calculations

Safawi

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	6.117	4.187	7.413	34.390	27.476	95.542	95.542
2	0.527	0.511	0.734	44.133	0.269	0.936	96.479
3	0.285	-0.858	0.904	-71.63	0.409	1.422	97.901
4	0.442	-0.675	0.807	-56.82	0.326	1.132	99.033
5	0.728	0.045	0.729	3.506	0.266	0.924	99.957
6	0.157	0	0.157	-0.001	0.012	0.043	100.000

Mafraq

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	14.969	10.626	18.357	35.370	168.482	93.496	93.496
2	0.88	3.582	3.689	76.199	6.804	3.776	97.272
3	-0.397	-1.697	1.742	-89.67	1.518	0.842	98.114
4	0.613	-0.24	0.658	-21.33	0.217	0.12	98.235
5	-0.262	1.758	1.777	-89.69	1.579	0.876	99.111
6	-1.790	0	1.790	-89.68	1.602	0.889	100.000

Rewashed

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	11.012	4.797	12.012	23.538	72.140	44.815	44.815
2	5.771	-0.963	5.851	-9.471	17.115	10.632	55.447
3	6.093	-0.788	6.144	-7.372	18.875	11.726	67.172
4	5.149	-0.484	5.172	-5.365	13.374	8.308	75.480
5	6.344	-0.145	6.346	-1.311	20.136	12.509	87.989
6	6.218	0	6.218	0	19.334	12.011	100.000

Amman

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	25.777	20.733	33.080	38.811	547.150	89.850	89.850
2	1.885	10.678	10.843	79.989	58.787	9.654	99.503
3	-0.988	-0.868	1.316	-89.68	0.865	0.142	99.645
4	0.678	-1.521	1.666	-65.96	1.387	0.228	99.873
5	-0.013	0.324	0.324	-89.71	0.052	0.009	99.882
6	-1.200	0	1.200	-89.68	0.72	0.118	100.000

Aqaba

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	2.577	1.966	3.241	37.346	5.252	84.806	84.806
2	0.413	0.035	0.415	4.791	0.086	1.389	86.195
3	0.758	-0.285	0.81	-20.59	0.328	5.299	91.493
4	0.457	0.202	0.499	23.869	0.125	2.013	93.506
5	0.55	0.084	0.556	8.674	0.155	2.500	96.006
6	0.703	0	0.703	0	0.247	3.994	100.000

Dulail

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	13.795	10.376	17.261	36.948	148.979	90.526	90.526
2	1.147	4.316	4.465	75.120	9.970	6.058	96.585
3	-0.013	-0.737	0.737	-89.54	0.271	0.165	96.750
4	0.572	0.364	0.678	32.467	0.23	0.139	96.889
5	-0.867	1.863	2.054	-89.68	2.110	1.282	98.171
6	-2.453	0	2.453	-89.68	3.009	1.829	100.000

Shobak

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	27.181	27.112	38.391	44.928	736.923	87.791	87.791
2	0.436	12.400	12.408	87.987	76.975	9.170	96.961
3	1.347	-1.332	1.894	-44.67	1.793	0.214	97.175
4	4.658	-0.221	4.663	-2.715	10.871	1.295	98.470
5	1.353	3.706	3.945	69.948	7.783	0.927	99.397
6	-3.182	0	3.182	-89.68	5.062	0.603	100.000

Irbed

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	47.717	35.401	59.415	36.571	1765.06	88.514	88.514
2	7.037	15.184	16.736	65.136	140.039	7.023	95.537
3	5.893	-3.583	6.897	-31.3	23.786	1.193	96.730
4	9.478	0.286	9.483	1.727	44.960	2.255	98.984
5	3.605	5.081	6.230	54.647	19.405	0.973	99.957
6	-1.303	0	1.303	-89.68	0.849	0.043	100.000

G. Safi

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	6.458	6.442	9.121	44.928	41.598	88.339	88.339
2	-0.135	2.361	2.365	-89.71	2.797	5.940	94.279
3	0.447	-0.985	1.082	-65.6	0.585	1.242	95.521
4	1.267	-0.667	1.431	-27.76	1.025	2.176	97.697
5	1.161	-0.057	1.162	-2.789	0.675	1.434	99.130
6	0.905	0	0.905	0	0.41	0.87	100.000

Madaba

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	38.676	27.502	47.457	35.416	1126.10	86.003	86.003
2	7.638	13.282	15.322	60.097	117.377	8.964	94.967
3	5.432	-2.992	6.201	-28.84	19.227	1.468	96.435
4	8.143	-2.125	8.416	-14.62	35.414	2.705	99.140
5	4.252	2.067	4.728	25.922	11.175	0.853	99.993
6	0.413	0	0.413	-0.002	0.085	0.007	100.000

J.Univ.

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	51.492	37.028	63.423	35.720	2011.25	86.017	86.017
2	9.463	19.335	21.527	63.922	231.708	9.910	95.927
3	5.638	-2.563	6.194	-24.44	19.181	0.82	96.747
4	10.150	-1.882	10.323	-10.5	53.283	2.279	99.026
5	5.685	3.588	6.723	32.260	22.597	0.966	99.992
6	0.598	0	0.598	-0.002	0.179	0.008	100.000

Ma'an

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	3.296	2.422	4.090	36.314	8.364	94.379	94.379
2	-0.137	0.026	0.139	-89.68	0.01	0.109	94.488
3	-0.343	-0.448	0.565	-89.67	0.159	1.799	96.287
4	-0.085	0.012	0.086	-89.68	0.004	0.042	96.329
5	0.493	0.629	0.799	51.953	0.319	3.605	99.934
6	0.108	0	0.108	-0.001	0.006	0.066	100.000

R.Munif

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	55.563	41.440	69.315	36.717	2.40226	91.342	91.342
2	6.901	17.507	18.818	68.487	177.053	6.732	98.074
3	3.227	-5.008	5.958	-57.2	17.747	0.675	98.749
4	6.594	-1.993	6.889	-16.81	23.728	0.902	99.651
5	1.806	3.286	3.750	61.214	7.030	0.267	99.918
6	-2.072	0	2.072	-89.68	2.146	0.082	100.000

D.Alla

i	a_i	b_i	A_i	Φ_i	V_i	PVAR(i)	CVR
1	27.429	19.204	33.483	34.997	560.567	91.505	91.505
2	3.658	8.079	8.868	65.642	39.320	6.419	97.924
3	1.235	-2.487	2.776	-63.58	3.854	0.629	98.553
4	1.613	-0.847	1.822	-27.71	1.659	0.271	98.824
5	-1.309	1.404	1.920	-89.68	1.843	0.301	99.125
6	-3.275	0	3.275	-89.68	5.363	0.875	100.000

APPENDIX D

Table D.1: Reduced mean $\bar{y}_n$ for N-years.

N	0	1	2	3	4	5	6	7	8	9
10	0.4952	0.4996	0.5035	0.507	0.51	0.5128	0.5157	0.518	0.5202	0.522
20	0.5236	0.5252	0.5268	0.5283	0.5296	0.5309	0.532	0.533	0.5343	0.5353
30	0.5362	0.5371	0.538	0.5388	0.5396	0.5402	0.541	0.542	0.5424	0.543
40	0.5436	0.5442	0.5448	0.5453	0.5458	0.5463	0.5468	0.5473	0.5477	0.5481
50	0.5485	0.5489	0.5493	0.5497	0.5501	0.5504	0.5508	0.5511	0.5515	0.5518

Table D.2: Standard deviation σ_n of the reduced variant for N-years

N	0	1	2	3	4	5	6	7	8	9
10	0.949	0.967	0.983	0.997	1.009	1.020	1.031	1.04	1.04 9	1.056
20	1.062	1.069	1.075	1.081	1.086	1.091	1.096	1.1	1.104	1.108
30	1.112	1.115	1.119	1.122	1.125	1.128	1.131	1.133	1.136	1.138
40	1.141	1.143	1.145	1.148	1.149	1.151	1.153	1.155	1.157	1.159
50	1.160	1.162	1.163	1.165	1.166	1.168	1.169	1.170	1.172	1.173

Table D.3: Reduced variant of Standard return periods.

Standard return period	Probability	y
2	0.5	0.36651292
5	0.8	1.49993999
10	0.9	2.25036733
25	0.96	3.19853426
50	0.98	3.90193866
100	0.99	4.60014923
200	0.995	5.29581214
250	0.996	5.51945758
500	0.998	6.21360726
1000	0.999	6.90725507
2000	0.9995	7.6006524

Table D.4: Maximum Rainfall Intensity. Duration and Frequency for Shoubak.

Return Period	Minutes								
	5	10	20	30	60	120	180	360	1440
2	38.66	25.55	18.74	15.51	11.58	8.09	6.81	4.98	2.36
5	64.66	42.38	35.31	30.23	23.51	14.24	12.8	7.42	3.1
10	81.66	53.52	46.27	39.98	31.41	18.31	16.77	9.03	3.59
25	103.35	67.6	60.13	52.29	41.39	23.46	21.78	11.07	4.22
50	119.42	78.04	70.41	61.43	48.79	27.28	25.5	12.58	4.68
100	135.37	88.41	80.62	70.49	56.14	31.07	29.18	14.09	5.14
200	151.26	98.74	90.78	79.53	63.46	34.84	32.86	15.58	5.59
250	156.36	102.06	94.05	82.43	65.82	36.06	34.04	16.06	5.74
500	172.22	112.37	104.2	91.45	73.12	39.83	37.71	17.56	6.2
1000	188.07	122.66	114.33	100.4	80.42	43.59	41.38	19.05	6.65
2000	203.9	132.96	124.46	109.4	87.72	47.35	45.03	20.53	7.1

Table D.5: Maximum Rainfall Intensity. Duration and Frequency for Suweileh.

Return Period	Minutes						
	15	30	60	120	180	360	1440
2	17.62	14.47	10.17	7.9	6.49	4.86	1.92
5	24.38	20.28	13.44	10.59	8.92	6.73	2.97
10	28.85	24.12	15.6	12.38	10.53	7.97	3.66
25	34.51	28.97	18.33	14.63	12.56	9.53	4.54
50	38.71	32.58	20.36	16.3	14.07	10.7	5.19
100	42.87	36.15	22.37	17.96	15.57	11.85	5.83
200	47.02	39.71	24.38	19.62	17.06	13	6.48
250	48.35	40.86	25.02	20.15	17.54	13.37	6.68
500	52.49	44.41	27.03	21.8	19.02	14.51	7.33
1000	56.63	47.96	29.03	23.45	20.51	15.66	7.97
2000	60.77	51.51	31.02	25.1	22	16.8	8.61

C.V.

Qassem Yahya TARAWNEH was born in Amman in 1961. He finished his secondary school from Al-karak in 1980. He got a scholarship to study meteorology in the Meteorological Department at King Abdulaziz University, Saudi Arabia and he graduated from there in 1985. He started his M.Sc. degree in 1985 in Meteorological Engineering Department at Istanbul Technical University, and he graduated in Fall 1988. He completed his military service in 1990.

He started his job in Meteorological Department of Jordan in the same year working as a weather forecaster, and part time instructor of meteorology at Balqa University, Queen Noor College. He was instructor of meteorology in the Royal Jordanian Airforce. He attended several training courses in weather analysis and forecasting, rainfall enhancement and radar meteorology in Italy. In 1999, he received a Ph.D scholarship from the Turkish Government to study in the Meteorological Eng. Dept. at Istanbul Technical University. He is married and has three children.