TIME SERIES ANALYSIS, FORECASTING, AND CLIMATE CHANGE DETECTION: AMMAN-ZARQA BASIN CASE STUDY

By
Ahmad G. Alhyasat

Supervisor
Dr. Adnan Al-Salihi

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COMMITIEE DECISION

This Thesis/Dissertation (Time Series Analysis, Forecasting, and Climate Change Detection: Amman-Zarqa Basin Case Study) was Successfully Defended and Approved on 15/05/2008.

<u>**Examination Committee**</u>	<u>**Signature**</u>
Dr. Adnan Hmodi Al Salihi, (Supervisor) Assoc. Prof. of Water Resources and Hydraulic Structures	Al Salihi
Dr. Nabil Abd Al Hameed El Khairy, (Member) Assist. Prof. of Hydraulics	Khair
Dr. Manar Khaled Fayyad, (Member) Prof. of Inorganic and Analytical Chemistry/Water Quality	M.K. Fayyad
Dr. Rakad Ayed Ta'any, (Member) Assist. Prof. of Water Resources Management (Al Balqa' Applied University)	....

DEDICATION

To The Invisible Community of those who Strive For Knowledge, Beauty, and Justice.

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LIST OF ABBREVIATIONS

ACF: Autocorrelation Function

AIC: Akaike's Information Criterion

AR: Autoregressive

ARMA: Autoregressive Moving Average

ARIMA: Autoregressive Integrated Moving Average

ASL: Above Sea Level

BGR: Federal Institute for Geosciences and Natural Resources/Germany

BIC: Schwarz's Bayesian Criterion

BL: Broken Line

DEM: Digital Elevation Model

ENSO: El Nino-Southern Oscillation

FGN: Fractional Gaussian Noise

IDF: Intensity Duration Frequency

IQR: Inter Quantile Range

JMD: Jordan Meteorological Department

MA: Moving Average

MAD: Mean Absolute Deviation

MAPE: Mean Absolute Percentage Error

MCM: Million Cubic Meters

MEnv: Ministry of Environment

MSD: Mean Standard Deviation

MVA: Missing Value Analysis

MWI: Ministry of Water and Irrigation

NAO: North Atlantic Oscillation

PACF: Partial Autocorrelation Function

PCA: Principal Component Analysis

PGE: Palestinian Grid East

PGN: Palestinian Grid North

RLWR: Robust Locally Weighted Regression

RV: Residual Variance

SES: Single Exponential Smoothing

UNDP: United Nations Development Program

UNFCCC: United Nations Framework Convention on Climate Change

WAJ: Jordan Water Authority

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ABSTRACT

This research presents a methodology framework of analysis, modelling, and forecasting of key hydrologic and meteorological variables in Amman-Zarqa Basin. Analysed variables include rainfall, runoff, baseflow, temperature, and relative humidity at various time scales. Furthermore, storm-clusters in Amman-Zarqa Basin are identified and their total rainfall per storm-cluster is obtained.

Preliminary analysis such as missing values, outliers, and double-mass curve are applied before the more formal time series analysis. Time series analysis includes the application of trend analysis methods, smoothing models, decomposition models, and Autoregressive Integrated Moving Average Models (ARIMA). The best model for each class is obtained and fits and forecasts are provided.

Implications of climate change of phenomena such as trend direction and significance using the Mann-Kendall test, extreme events, and rainy season shifting are investigated. It is found that storm-cluster rainfall show a significant decreasing trends while mean minimum temperature shows significant increasing trends. There is no evidence to support the likelihood of extreme events and rainy season shifting, this implies that such phenomena are unlikely or simply couldn’t be detected using the available records.

CHAPTER (1): INTRODUCTION

1.1 Prologue

Jordan is located about 80 kilometres (Air distance) east of the Mediterranean Sea. The area of land mass is approximately 88,778 km^2, while area of water bodies is approximately 482 km^2 that includes the Dead Sea and the Gulf of Aqaba. Altitude ranges from less than -400 m (below mean sea level) at the surface of the Dead Sea up to the 1750 m of Jebel Rum (MEnv, 2006). Land forms can be classified into mountainous areas, deserts, and rift valleys.

The climate varies from dry sub-humid Mediterranean in the northwest of the country with rainfall of about 630 mm to desert conditions with less than 50 mm over distance of only 100 km. This climatic variety is reflected in rainfall patterns across the country where rainfall decreases from north to south, west to east and from higher to lower altitudes.

Jordan is classified among few countries of the world with limited water resources and it is one of the lowest on a per capita basis. The available water resources per capita are falling as a result of population growth and are projected to fall from less than 160 m^3 /capita/year (2006) to about 90 m^3/capita/year (2025) according to report out of MEnv and UNDP, this is putting Jordan in the category of an absolute water shortage. The scarcity of water in Jordan is the single most important constrains to the country growth and development because water is not only considered a factor for food production but a very crucial factor of health, survival and social and economical development. Water resources consist mainly of surface and ground water, with reclaimed wastewater being used at an increasing scale for irrigation (MEnv/UNDP, 2006).

Surface water resources of Jordan are distributed among 15 major basins that drain into the Dead Sea, Red Sea, or into desert mudflats. Surface water resources vary considerably between seasons and years. The long term average annual base flow is about 328 MCM and flood flow of about 334 MCM giving a total average surface flow of about 662 MCM per year. Of these renewable surface water resources, an estimated 560 MCM are useable or can be economically developed (MEnv, 2006)

Considering the semi-arid climate of Jordan and thus the high dependence on rainfall, Jordan will be on top of the chart of climate change phenomena consequences. As a response, Jordan ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 and Kyoto Protocol in 2003, and has committed to a global effort in combating climate change phenomena.

Climate change talk or discussion is evident in governmental reports. The following two statements from the Environmental Profile of Jordan (MEnv, 2006) indicate the early steps toward coupling policy and science:

1. Due to urbanization, upstream uses and *climatic changes*, the base and flood flows of most of the rivers and wadis have been affected significantly.
2. Water uses vary from year to year depending on the available surface water supply which is decreasing due to upstream uses and *climatic fluctuations*.

1.2 Research Problem

The importance of the proposed research can be summarized by the following quoted statement from Yevjevich (1987): "Determinism and stochasticity constitute the two basic approaches to investigation of nature. Axioms of determinism are based on cause-effect relationships. Usually they are described by mathematical equations. Axioms of stochasticity lead to standpoints that relationships often cannot be expressed in simple or complex cause-effect mathematical form. Instead, the "effect" variables are observed and their properties are investigated by using methods of stochastic processes and mathematical statistics".

Natural phenomenon (such as precipitation depth, temperature variation, stream runoff, etc…) is either a stochastic or combined deterministic-stochastic process which is often observed in a sequential manner. When such sequence is observed with respect to time, it can be referred to as a time series. The structure of a typical time series consists of one or more of the following components: (1) trend, (2) periodicity, and (3) stochasticity. The detection of all components is one of the tasks of the proposed research.

Generally, time series analysis and modelling can be used for building mathematical models in order to: (1) generate synthetic records, (2) determine the likelihood of extreme events, (3) forecast events, (4) detect trends and shifts in records, and (5) fill in missing data and extend records. Time series analysis is of undeniable importance in hydrology and water resources engineering. It can be used in the following: (1) planning and management of water resources, (2) defining the long-term operating policies of reservoirs, and (3) setting rules for cropping patterns in agricultural areas. Several studies have used time series analysis to track climate change and to provide models to predict the changes in natural processes as shown in chapter (3) literature review.

Jordan is located in an arid to semi-arid region with limited water resources. Global issues such as climate change will have the most drastic impact in the future. This requires a database and information sources, which are crucial tools for planning and decision making processes. The climate change phenomena will affect the future of water resources in Jordan but to what extent such change is detectable using the available data records? The answer to this question is another task of the research. The proposed research aims to analyse climate-related time series data out of existing monitoring network to one of the most important surface water basins in Jordan as a case study.

The analysis of time series data will include the use of different types of time series models to perform forecast and to detect long-term climatic changes, and then the different competing models performance will be assessed according to a number of accuracy measures and model selection criteria such as Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD), Mean Standard Deviation (MSD), Akaike's Information Criterion (AIC), and Schwarz's Bayesian Criterion (BIC).

The research considers Amman – Zarqa basin as a case study, which is one of the largest and important surface water basins in Jordan. The basin's main water course is the Zarqa River which is the largest tributary of the lower Jordan River. King Talal dam is situated at the lowest reaches of Zarqa River before the Jordan River, which is the second largest reservoir in Jordan. King Talal dam has an important role in irrigation water supply to Jordan valley during the dry season. The dam can reach 17,000 ha of farm land and supports the livelihood of 120,000 people living in the Jordan valley.

King Talal dam impacts the socio-economics of the Jordan valley in particular and Jordan in general.

The analysed time series data could be the key records for the surface water resources in the basin. The data records consist of the following: (1) Rainfall data of 8 rainfall stations in the basin, (2) Climatological data (such as, temperature and relative humidity) from two weather stations available inside the basin, and (3) Streamflow measurements at the basin. The above data is the main elements in conducting any water budget analysis or rainfall–runoff relationship.

At the end of the research the answer for the following questions could be defined: (1) what is the best forecasting model within its class for the given time series data? And (2) is there any indication to climate change phenomena? The last question couldn't be answered correctly due to the short record period.

1.3 Research Methodology

The following is a brief on the methods and analyses applied in research:

1. Missing Value Analysis (MVA): MVA is an important constant step in any time series analysis research, since having gaps in data is inevitable in most data collection agencies. Correlation and regression techniques are used to estimate and fill in missing values.

2. Double Mass Curve: The double mass curve analysis is used to adjust for inconsistencies in rainfall data; this step will remove any systematic errors in rainfall measurements.

3. Runoff Events Storm-Cluster Analysis: Significant storm-clusters are identified for each rainfall station based on runoff hydrograph. After the identification and separation of events, storm-cluster rainfall and runoff event totals are obtained for the stations used in research. This step will provide a time series at a finer time scale that is free of the larger time scale damping effects.

4. Outlier Analysis: The outlier analysis will remove any foreign data points that will hinder statistical methods efficiency. This step allows for better results and inferences since it will create a more representative sample.

5. Time Series Definition: At this point all time series are defined at various time scales (events, monthly, water year, and calendar year). This step prepares the time series for the more formal time series analysis.

6. Data Pool Correlation Analysis: Correlation matrices of time series data at all time scales are obtained, this will help us to understand how variables are related to each other.

7. Linear Regression: Regression models are considered as casual forecasting methods, simple and multiple linear regression models are developed in research.

8. Trend Analysis: Four types of trend models are fitted to time series data, namely: Linear, Exponential Growth, Quadratic, and S-Curve. Trend models give poor data fits and are used to identify time series direction, increasing or decreasing.

Furthermore, Mann-Kendall test for trend detection and significance is applied to all time series data.

9. Smoothing Models: Two types of smoothing models are used to fit time series data and provide forecasts, namely: Moving Average (MA) which smoothes the time series data by averaging consecutive values and Single Exponential Smoothing (SES) which smoothes the time series data by using computed exponentially weighted averages.

10. Decomposition Models: Decomposition models are used to provide fits and forecasts for data that exhibits seasonal behaviour such as monthly data.

11. Autoregressive Integrated Moving Average Models (ARIMA): The ARIMA models exploit the correlation structure of a time series, the first step is to obtain the autocorrelation function (ACF) and the partial autocorrelation function (PACF) plots. Now studying the ACF and PACF will provide some guidelines to specify model terms, which are the Autoregressive (AR) and Moving Average (MA) terms. Sometimes the ACF plot indicates that the time series require differencing, that is to remove any trend or seasonal effects. For possible identification errors, several tentative models are identified and their parameters are estimated. Studying the residual ACF and PACF plots along with calculating certain statistical model selection criteria (AIC, BIC, and model standard error) will determine which model is best to describe the time series. Non-seasonal and seasonal ARIMA models are fitted to time series data.

Four commercial software packages are used in analysis, namely: (1) Microsoft Excel to organize and prepare time series data export into other packages, (2) SPSS V13 and Minitab V14 for time series analysis and modelling, and (3) AutoCAD 2005 for study area map preparation.

1.4 Thesis Outline

The Thesis is composed of the following chapters:

1. Chapter (1): Introduction: Introduces the reader into research problem and methodology. The chapter set the framework for the thesis.

2. Chapter (2): Data and Study Area: Presents description of the study area in terms of geology, topography and climate. The chapter also presents time series data in terms of stations information, data description, and preliminary data analysis.

3. Chapter (3): Literature Review: Presents literature on time series, time series analysis tools, time series modelling and forecasting, and time series vs. climate change.

4. Chapter (4): Theory, Modelling, and Forecasting: Presents the theoretical foundation of all analyses and models used in research, furthermore the chapter includes examples of modelling and analyses.

5. Chapter (5): Analysis of Results: Presents results in a condensed form, discussion, and examples of modelling and analyses methodologies.

6. Chapter (6): Conclusions and Recommendations: Presents concluded statements based on results analysis and recommendations for further research.

CHAPTER (2): DATA AND STUDY AREA

2.1 Introduction

Data is a must for describing any hydrologic system, such data could be; precipitation, streamflow, evaporation, soil moisture, sediment transport, transpiration, water quality, temperature, and other variables (Viessman and Lewis, 1996). Data on hydrologic and meteorological variables are fundamental to modelling and forecasting protocols. Data can be found in the databases and publications of governmental agencies, research institutes, and universities. Data collection and analysis are procedures that require verification and discussion.

Most data collection services establish monitoring networks for the recording, collection, and management of data. Design of such networks depends on the purpose and use of the network and to some extent on the region to be monitored. Monitoring networks help to overcome the inherent variability of hydrologic and meteorological variables in space and time. Networks are essential for every basin. The variability that was found during the research could be partly due to networks to some considerable extent. Generally, the network stations are equipped with equipments starting with simple devices that require the daily attendance of personnel to sophisticated ones that can obtain, record, and transmit data to a workstation. Occasionally, remote sensing and aerial photos are used to collect data.

According to Yevjevich (1972), there are four types of hydrologic data that describe the hydrologic phenomena:

1. Historic or chronological data or observations of processes in time and the results are time series. A majority of present-day hydrologic data belongs to this type. Rainfall data observed in time at a given location is an example of this type.
2. Field data observations along lines, or surveys across areas and space of hydrologic phenomena. A substantial part of hydrologic data may be of this type. Sediment characteristics along a river bed are an example of this type.
3. Laboratory and field experimental data similar to those from hydraulic experiments.
4. Simultaneous measurements of two or more random variables in order to establish a relationship among these variables for the purpose of transferring statistical information among variables. Stage and flow measurements at a stream to establish a rating curve could be a good example of this type.

In the context of data quality, a distinction has to be made between true, virgin, and observed values of any hydrologic variable (Yevjevich, 1972). True values are never realized due to the inevitable errors of observation. Virgin values are those produced by the unchanged conditions of the environment. Such data are not influenced by unpredictable natural or man-made significant changes in the hydrologic environment. Observed data are those available through various surveys and recordings and usually published by the hydrologic service.

Observed data could have errors in each of the four phases of (1) sensing, (2) transmitting, (3) recording, and (4) processing. Processed data will usually contain errors that are either random or systematic. When systematic errors are present in the data, the data becomes inconsistent. Data affected by environmental changes, either natural or man-made, becomes non-homogenous. The concepts of randomness, inconsistency, and non-homogeneity must be accounted for in any hydrologic analysis, if reliability of statistical information is sought. This chapter deals with verification and approval of the collected data from the defined agencies.

The research considers Amman-Zarqa basin as a study area and makes an attempt to analyse, forecast, and possibly explain changes in time series data obtained from various monitoring stations in the basin of different hydrologic and meteorological variables. In Jordan, two governmental agencies monitor hydrologic and meteorological variables in Amman-Zarqa basin, namely, the Ministry of Water and Irrigation (MWI) and Jordan Meteorological Department (JMD). The MWI monitors a larger number of stations in the basin of variables related to different hydrologic phenomena.

2.2 Study Area

2.2.1 Study Area Description

Amman-Zarqa basin is considered one of the most important surface water basins in Jordan. King Talal reservoir is located within the basin and the Zarqa River is the second largest river in Jordan after Yarmouk River. The basin hosts more than 50% of Jordan population, and 80% of the industries and solid waste disposal sites (OPTIMA, 2006).

Amman-Zarqa basin lies within the Palestine Grid Coordinates, East from 212 to 320, and North from 141 to 220. Its boundaries are: Sweileh, Kitta, Wadi Sir, and Na'ur hills in the west, Mafraq and the Syrian borders in the north, Western Azraq basin in the east, and Sahab and Muwaqqar villages in the south (MWI, 1989). The basin is identified as number 14 in Figure 2.1; the basin extends from the Syrian territories in the east to Jordan River in the west.

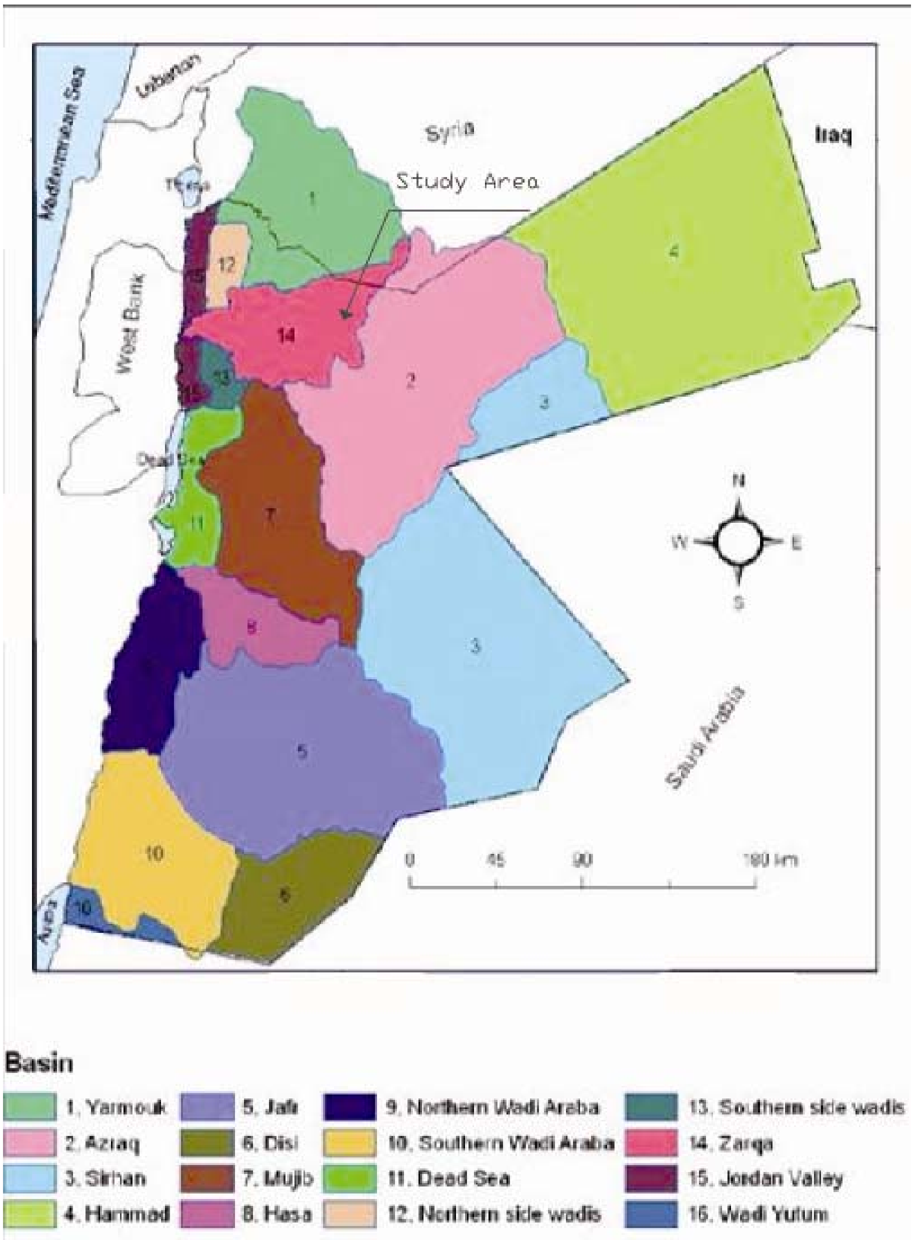

Figure 2.1: Surface Water Basins in Jordan, and Study Area Basin. (Adapted from MEnv, 2006).

The longest axis of the basin from the north-northeast to south-southwest direction is about 116 km, and the longest perpendicular axis is about 67 km (MWI, 1989). Amman-Zarqa River drains an area of 4,120 km^2 at Deir Alla into King Talal Dam and Jordan River. About 95% of its area is within Jordan and about 5% is in Syria. About 2.72 million people (according to 2004 census) are living in the basin and represent more than 50% of the total population in Jordan. The main populated centres are the cities of Amman, Zarqa, Jerash and Russeifeh.

The basin is divided mainly into two sub-basins, Seil Al-Zarqa and Wadi Dhuliel. Seil Al-Zarqa drains the most populated mountainous areas in the west, and Wadi Dhuliel drains the arid flat land area in the east including the north-eastern desert area. The two sub-basins are separated by two big faults uplifting the area between them (MWI, 1989). Brief geological description is presented in the next section.

The streamflow of the Zarqa River is impounded by King Talal Dam of an elevation of 120 m and a capacity of 75 MCM. The catchment area behind the dam is about 3,760 km^2 producing an average runoff of about 60 MCM (OPTIMA, 2006). A great deal of water at King Talal Dam is reclaimed treated wastewater from Samra wastewater treatment plant and other newly constructed plants which serve Amman and Zarqa areas.

2.2.2 Geology

The Amman-Zarqa basin is located on the north edge of the Pre-Cambrian shield of crystalline complex. The basin is made up of Mesozoic and Cainozoic formations. Extensive masses of basalt are present within the area of Wadi Dhuleil

(ENERGOPROJEKT, 1971). All outcropping formations are of Cretaceous age except for wadi-fill deposits which are of Quaternary to Recent age. The outcropping formations in the study area belong to Balqa, Ajloun, and Kurnub groups. The deep formations are of Zarqa group, which has a thickness up to 1000 m (MWI, 1989).

There are three major faults in the study area; two are in the vicinity of Wadi Dhuleil and one in Wadi Sirhan (ENERGOPROJEKT, 1971). The faulting in the study area is in two directions (MWI, 1989):

1. Southwest-Northeast.
2. Northwest-Southeast.

Soil depth in Amman-Zarqa basin is a function of slope where deep colluvial soils have been accumulated in the valleys and lower slopes. The upper slopes are affected by soil erosion and degradation, leaving behind shallow and stony soil. Both types of soil erosion are causing serious problem threatening the storage capacity of King Talal Reservoir (OPTIMA, 2006).

2.2.3 Topography

Topography of the Amman-Zarqa basin changes from west to east where hilly areas comprise a large part of the western and surrounding areas along the boundary of the basin. Altitudes gradually decrease towards the centre of the basin and towards the outlet of the catchment to Jordan Valley near Deir Alla in the west. From the centre the altitudes increase towards the northeast into Syria where the highest point of the basin is 1570 m in Jabel El-Arab located at the north of Salkhad. The lowest point of the basin is about 140 m below sea level near Deir Alla (MWI, 1989). The Digital Elevation Model (DEM) of the study area is presented in Figure 2.2.

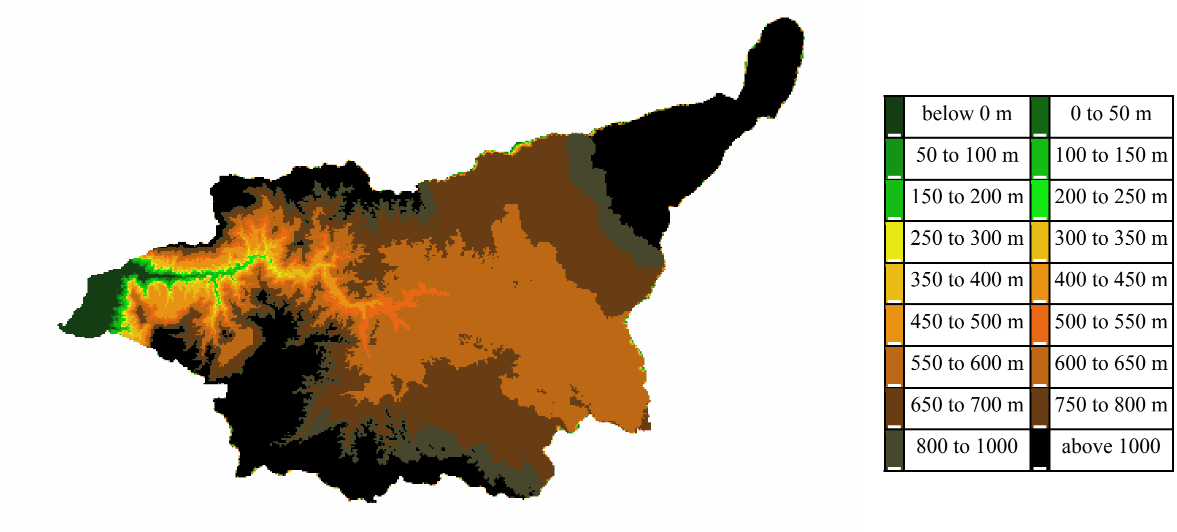

Figure 2.2: Digital Elevation Model (DEM) of Amman-Zarqa Basin. (Adapted from www.ess.co.at/OPTIMA/CASES/JO/zarqa/.html).

The general slope of the whole catchment is relatively high although the central and eastern parts are almost flat. Slopes generally don't exceed 15 % where most of the values are well below 5 %. However, slopes in the western catchment and some Wadi sides are quite high (MWI, 1989).

Topography of the basin affects to a large extent meteorological variables such as rainfall due to the orographic effect and temperature due to elevation change and wind velocity. Evaporation in the basin is affected by elevation, water vapour, soil moisture, and vegetation (MWI, 1989).

2.2.4 Climate

The basin represents a transitional area between the semi arid highlands in the North West to the arid desert in the South East (OPTIMA, 2006 and MWI, 1989). This transition is reflected in a variation in climate, land-use, natural habitat, and population.

Amman-Zarqa basin is dominated by the Mediterranean climate, which is characterized by high temperature dry season for the period from May to September and a wet season of lower temperature in the remaining months. Occasional snow storms and moderate frost nights occur during the wet season (MWI, 1989).

Cyclonic rainfall is the major type of rainfall over large areas of Amman-Zarqa basin during the colder months of the season. Orographic rainfall can occur in the west mountainous areas while thunderstorms are typical of the south-eastern desert areas (MWI, 1989).

The annual rainfall depth ranges from more than 500 mm in the north western part to less than 100 mm in the eastern part with an average precipitation of 280 mm/year. The rain occurs mainly from November till March with occasional thunder storms on October and April (OPTIMA, 2006). Sometimes, rainfall can occur even in May from a couple to few millimetres. Figure 2.3 shows rainfall isohyetal map of Jordan and the West Bank to have an idea of rainfall variation in Amman-Zarqa basin from west to east.

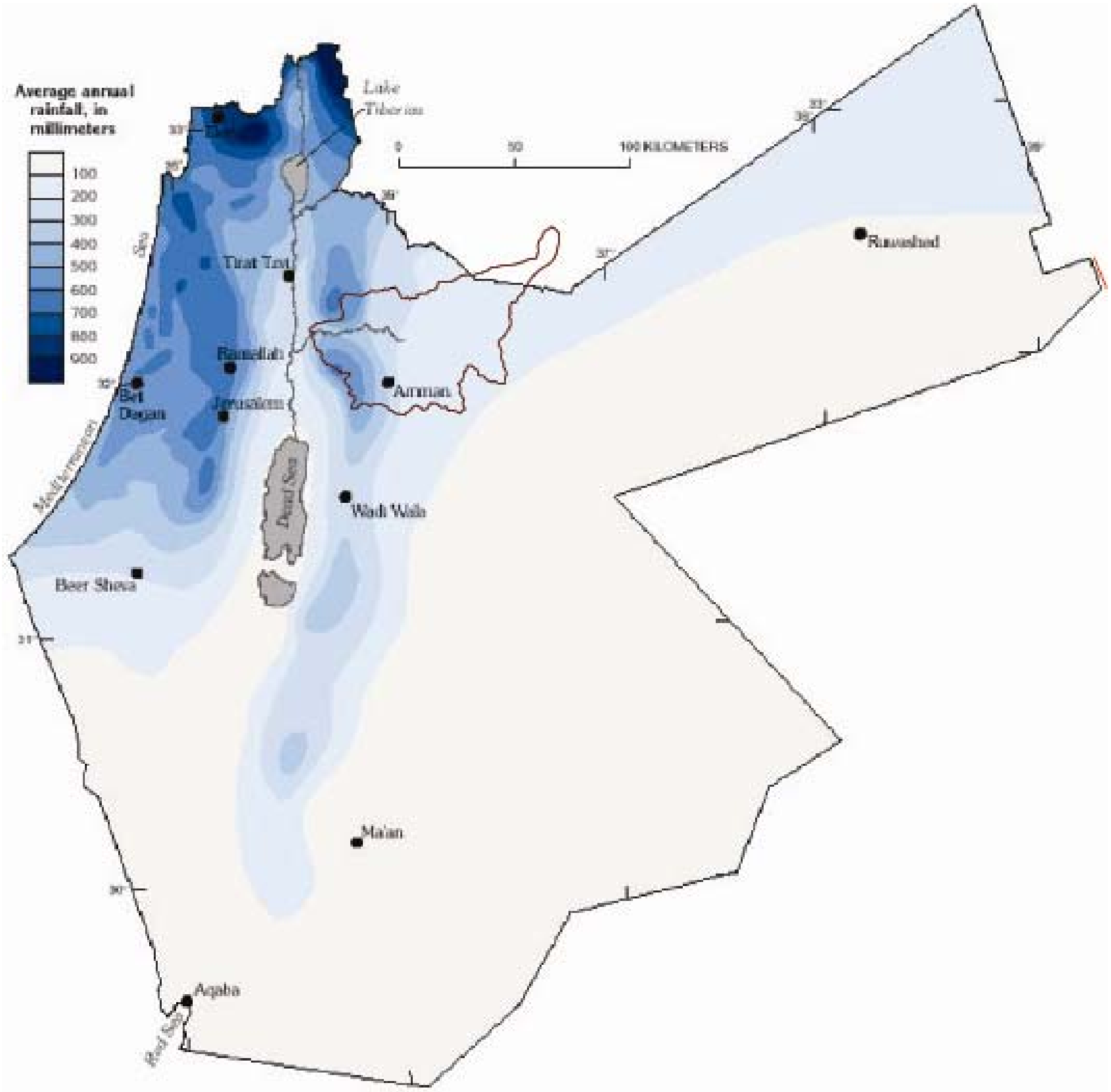

Figure 2.3: Rainfall Isohyetal Map of Jordan and West Bank. (Adapted from www.exact-me.org/overview/index.htm).

2.2.5 Industry and Agriculture

The main industrial activities in the basin are: Al-Hussein thermal power plant, the oil refinery, textile industries, paper processing, leather production, food industries, distilleries, drugs and chemical industries, intermediate petrochemicals, engineering industries, and Phosphate mining industries. These activities are considered the main source of pollution to the surface and groundwater besides their high water consumption (OPTIMA, 2006).

Agriculture is scattered with the basin from rain-fed orchards, olive and field crops to irrigated agriculture on the river banks and the Jordan valley. Private Irrigated area using groundwater as a source of irrigation water can be found in scattered places in the middle and the eastern part of the basin.

2.2.6 Problems in Study Area

During the last 20 years, Amman-Zarqa Basin has undergone enormous land use changes. Expansion of towns, reduction of grazing and fertile agricultural land, and industrial development are among the issues that reflect land use change (OPTIMA, 2006).

Water scarcity and increased demand, water usage priorities, water pollution, desertification and the reduction of agricultural lands are the problems facing Amman-Zarqa basin.

Time series analysis of the available data records can define the relations between the different hydrologic and metrological variables in the basin to facilitate a better understanding of basin problems, especially when it's expected that these problems will be aggravated by climate change.

2.3 Data

The data used in this research can be grouped into hydrologic and meteorological data. Hydrologic data comprised of rainfall and streamflow records while meteorological data comprised of temperature and relative humidity records. The data is collected from the Ministry of Water and Irrigation (MWI) as well as Jordan Meteorological Department (JMD). Figure 2.4 shows the study area and hydro-meteorological stations. Table 2.1 illustrates station ID, coordinates, and elevation of the stations used in research.

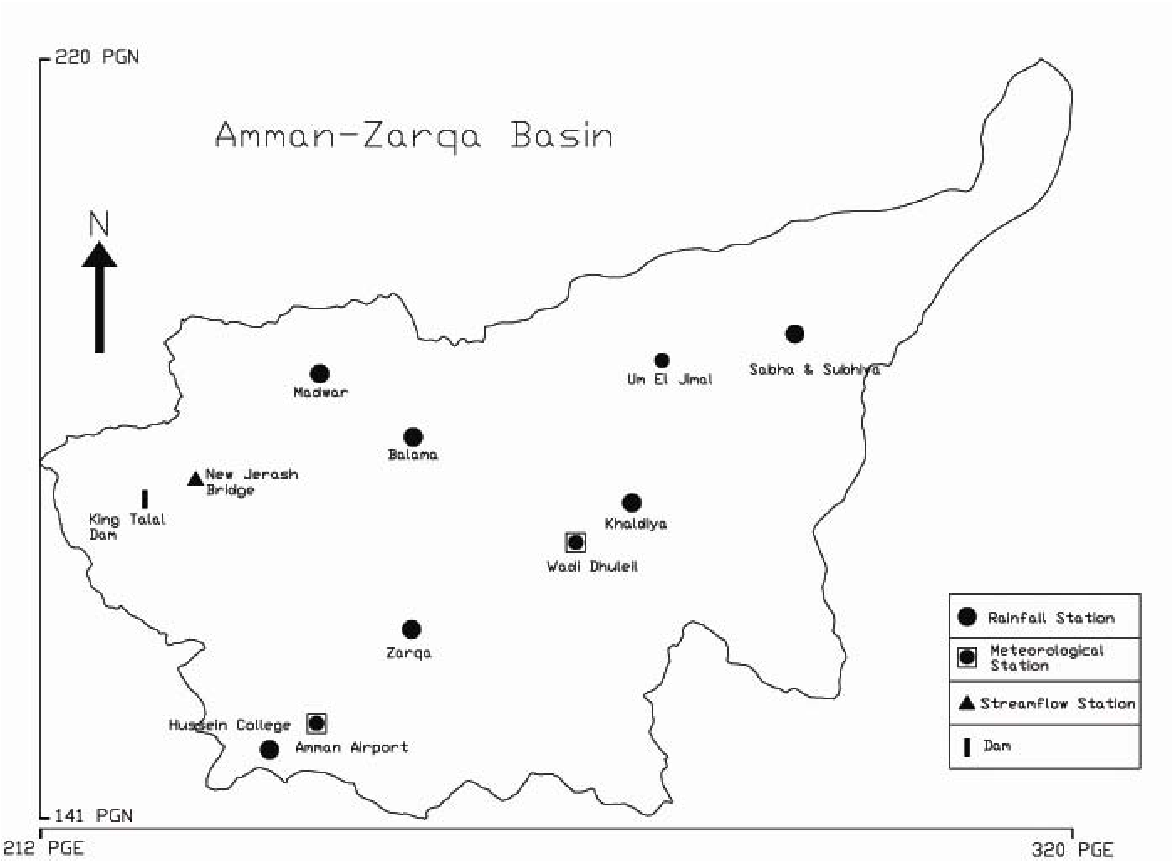

Figure 2.4: Hydrologic and Meteorological Stations in Study Area

Table 2.1: Station ID, Coordinates, and Elevation of the Hydro-meteorological Stations Used in Research.

Station	Station ID	Coordinates		Elevation (m, ASL)
		PGN	PGE	
Amman Airport (Rainfall and Meteorological)	AL0019	153.8	243.5	790
Balama (Rainfall)	AL0003	182.8	252.7	695
Hussein College (Rainfall)	AL0022	152.0	238.2	834
Khaldiya (Rainfall)	AL0048	177.0	276.0	630
Madwar (Rainfall)	AL0002	188.5	244.0	760
Sabha & Subhiya (Rainfall)	AL0058	194.0	291.8	850
Um El Jimal (Rainfall)	AL0059	190.4	276.8	650
Zarqa (Rainfall)	AL0015	163.8	253.0	610
Wadi Dhuleil (Meteorological)	AL0055	173.5	270.75	580
New Jerash Bridge (Streamflow)	AL0060	178.75	230.75	300

The Ministry of Water and Irrigation rainfall monitoring network in Amman-Zarqa basin consists of about 41 rainfall gauges (WAJ-BGR, 1995). There are more than 10 adjacent and Syrian rainfall stations distributed around the basin (MWI, 1989). Jordan Meteorological Department manages and operates 6 stations inside Amman-Zarqa basin, namely: Jordan University, Sweileh, Amman Airport, Roman Amphitheatre, Wadi Dhuleil, and Zarqa.

Hydrologic Data

Hydrologic data is comprised of rainfall and streamflow records. The rainfall records are analysed out of eight rainfall stations. The records are of daily time scale and extend between Jan-1969 to April-2006.

Rainfall records used in this research belong to different stations with varying spatial characteristics across Amman-Zarqa Basin. Processing of rainfall data requires extensive work like missing value analysis, checking the data for consistency, and computing the monthly and annual totals out of daily data records.

The first observation of rainfall inside Amman-Zarqa basin and in fact in Jordan begun at the old Amman Airport station in the water year 1922/23, since then the basin has witnessed the opening and closing of many rainfall stations. The first rainfall recorder installed in the basin was at Wadi Es-Sir yard station in 1962 (MWI, 1989).

Some rainfall stations in the basin have been shifted to other locations while others suffer from discontinuity. This can be regarded to construction needs, the unserious commitment of personnel, station tampering by curious people, lack of maintenance of stations, and change of recording mechanism. This kind of un-documented events can impart the ability to deduce useful findings in hydrologic research. Therefore, double-mass curve analysis is used to check such incidents and events in rainfall data records as discussed later on.

Filling in the missing data is an essential step in the beginning of any hydrological research or study to avoid incorrect data and to obtain reliable results and findings. The process starts with organizing the eight daily rainfall records and to prepare them for analysis. The method of recording in the Ministry of Water and Irrigation consists of just entering into the database the dates on which rainfall occurs along with daily rainfall totals with no regard to chronological order. Given a station daily record, it will not show if the non-recorded date is one of no-rainfall or just missing.

The missing value analysis consisted of the following tasks: (1) Calculation of rainfall long-term averages before any missing values estimation, (2) Comparison with rainfall long-term averages published by the Ministry of Water and Irrigation (WAJ-BGR, 1995), (3) Careful assessment of missing values within data records, and (4) Use of correlation and regression techniques to estimate missing values.

It was found that Balama, Khaldiya, Sabha and Subhiya, Um El Jimal, and Zarqa stations all suffer from missing values. Correlation and regression techniques have been used to estimate and fill in missing values. Tables 2.2 and 2.3, show the long-term average comparison before and after missing value analysis and the correlation matrix between rainfall stations, respectively. Figure 2.5 shows the scatter plots of the five stations which suffer from missing values against their respective estimator stations. Estimator stations are selected based on the highest correlation coefficient with respect to missing values stations and hydro-meteorological similarity. Three rainfall records show about 7 % difference in long-term average, which is assumed as acceptable error due to the difficulty in estimating the true missing values.

Table 2.2: Annual Rainfall Long-Term Average Comparison

Station	Before MVA*	After MVA	(WAJ-BGR, 1995)	Percent Deviation After MVA
Amman Airport	257.1	257.1	276.6	-7.0
Balama	203.6	211.7	210.2	0.7
Hussein College	410.4	410.4	382.3	7.3
Khaldiya	126.9	141.7	147.4	-3.8
Madwar	224.2	224.2	215.1	4.2
Sabha & Subhiya	111.4	137.6	145.0	-5.1
Um El Jimal	119.5	127.4	137.1	-7.1
Zarqa	111.4	132.5	136.0	-2.6

***MVA = Missing Value Analysis**

Table 2.3: Correlation Matrix of Rainfall Records Used in Research

	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
Amman Airport	1.000	0.501	0.633	0.505	0.399	0.336	0.484	0.678
Balama	0.501	1.000	0.497	0.532	0.555	0.342	0.402	0.518
Hussein College	0.633	0.497	1.000	0.412	0.448	0.266	0.372	0.472
Khaldiya	0.505	0.532	0.412	1.000	0.499	0.419	0.568	0.568
Madwar	0.399	0.555	0.448	0.499	1.000	0.440	0.367	0.444
Sabha & Subhiya	0.336	0.342	0.266	0.419	0.440	1.000	0.447	0.309
Um El Jimal	0.484	0.402	0.372	0.568	0.367	0.447	1.000	0.510
Zarqa	0.678	0.518	0.472	0.568	0.444	0.309	0.510	1.000

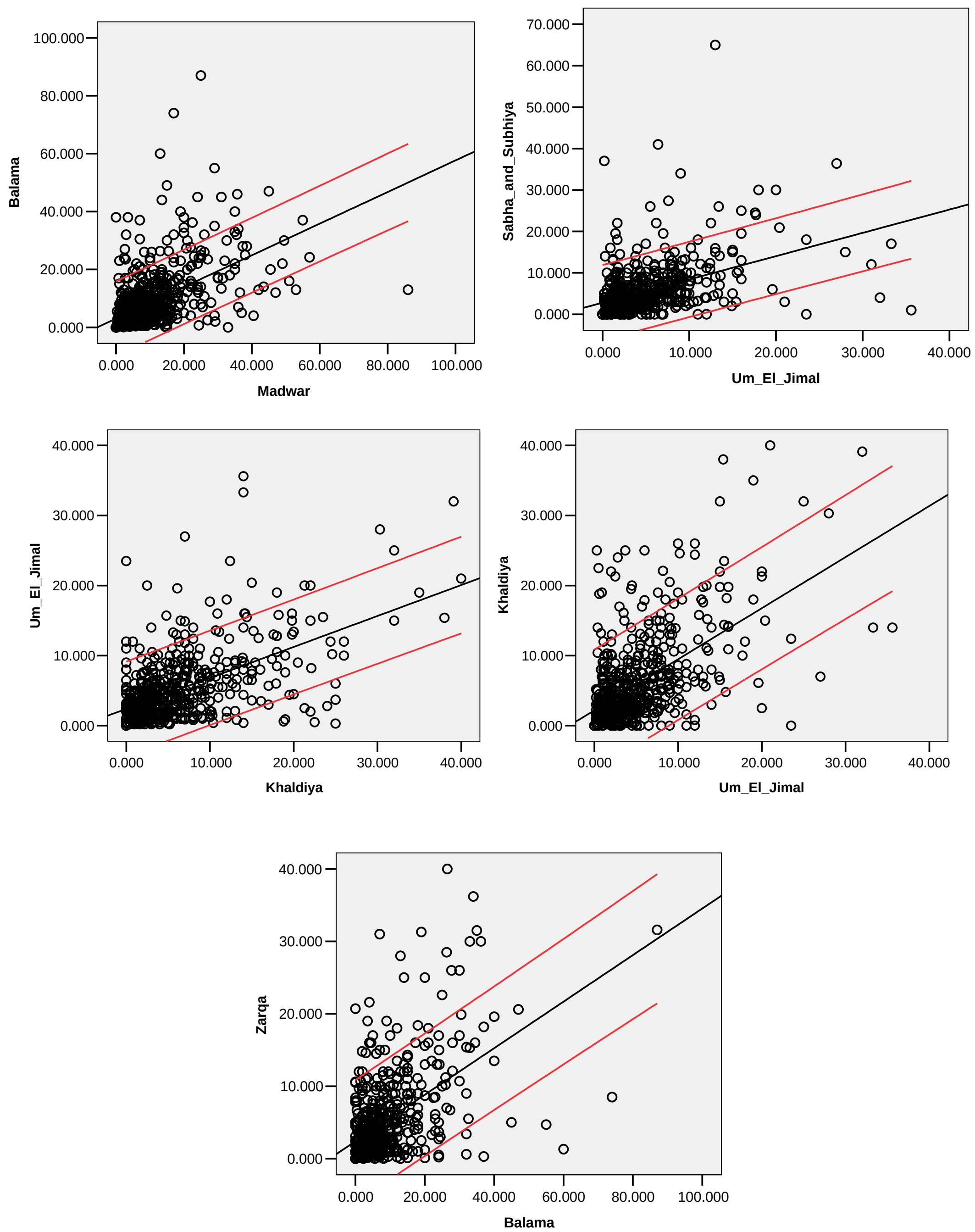

Figure 2.5: Scatter Plots of Rainfall Stations for Missing Value Analysis with 95% Confidence Interval

A consistent rainfall record is one where the characteristics of the record have not changed with time. An inconsistent rainfall record may develop through time as a result of changes in observation, changes in gauge exposure, or changes in land use that make it impractical to maintain the gauge at the old location. Where inconsistency is evident, an adjustment is necessary. Adjusting for gauge consistency involves estimation of the adjustment factor

Double-mass curve analysis is the method that is used to check for an inconsistency of the records. A double-mass curve is a graph of the cumulative rainfall of interest versus the cumulative rainfall of the gauges in the region that have been subjected to similar hydro-metrological setting. The rainfall record is consistent for constant slope of the double-mass curve. A change in the slope of the double-mass curve would suggest an external factor has imparted a change in the rainfall record and thus inconsistency. Adjustment of an inconsistent record requires the rainfall values to be changed so that the multiple slopes of the double-mass curve are changed to a single slope line.

Madwar and Sabha and Subhiya rainfall records showed inconsistent records and required adjustment. The remaining rainfall records were consistent. Figure 2.6 shows the consistent double-mass curve of Amman Airport station, while Figure 2.7 and Figure 2.8 show an inconsistent double-mass curve of Madwar station and the corresponding adjusted double-mass curve, respectively.

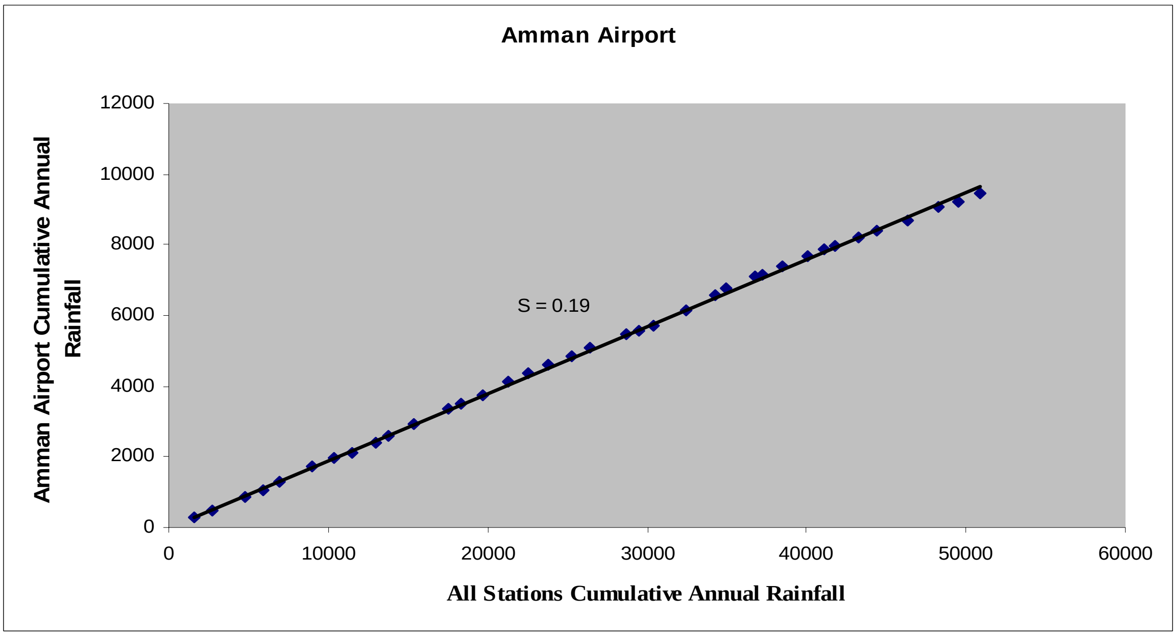

Figure 2.6: Double-Mass Curve of Amman Airport Station Showing a Consistent Record.

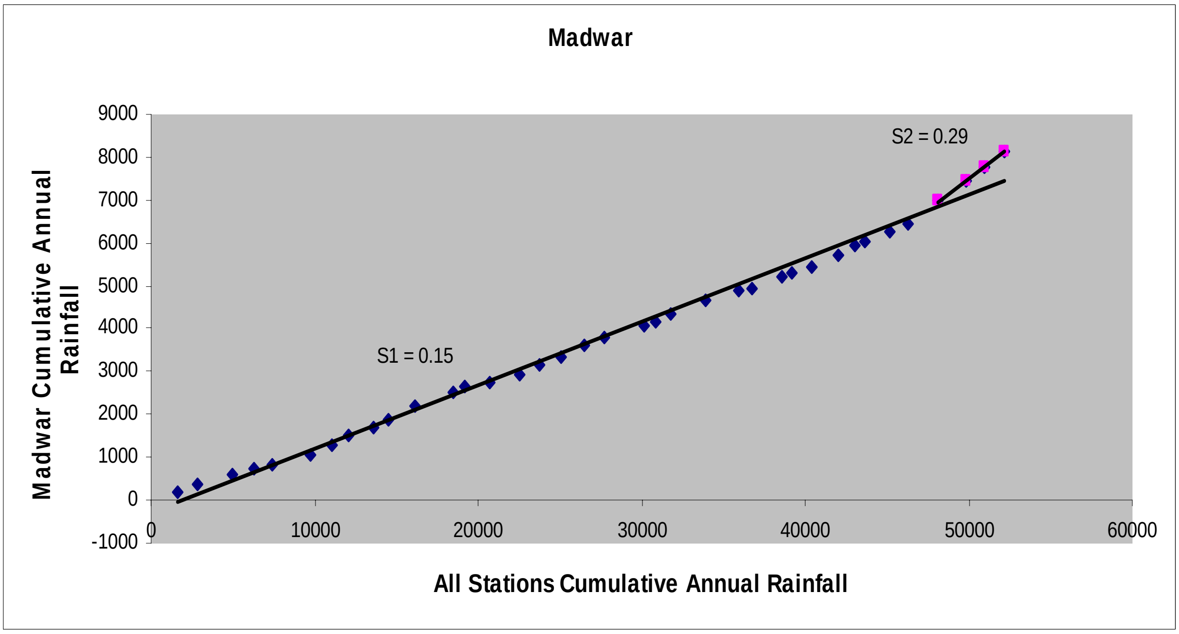

Figure 2.7: Double-Mass Curve of Madwar Station Showing an Inconsistent Record.

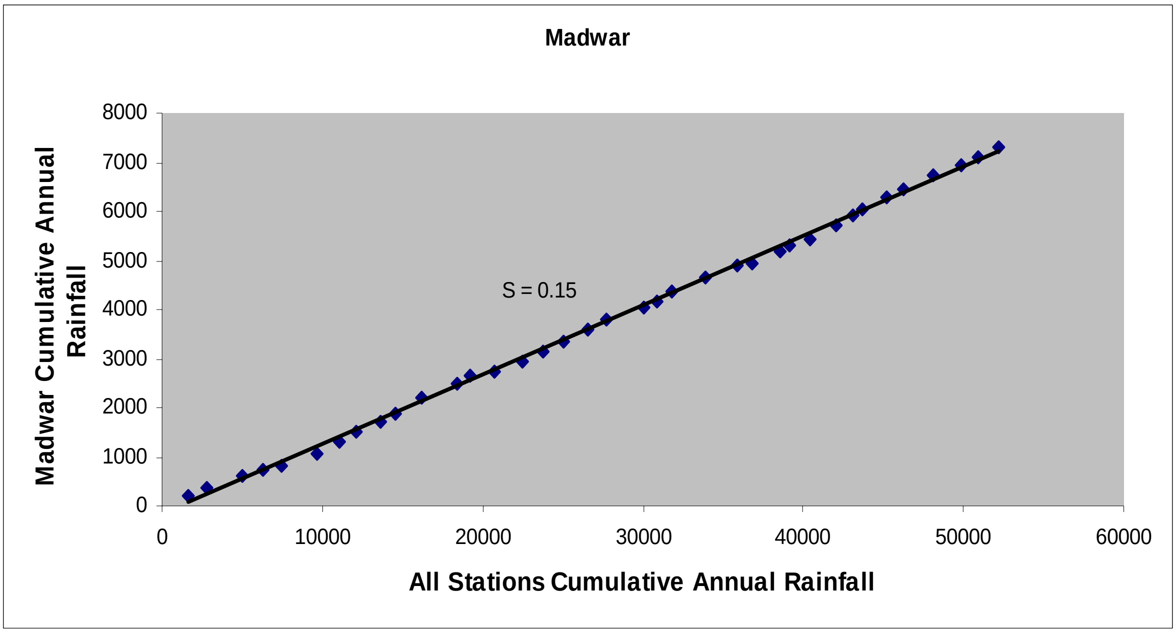

Figure 2.8: Double-Mass Curve of Madwar Station after Adjustment.

Streamflow at given location on a water course is represented by a hydrograph. This continuous graph displays the properties of a streamflow with respect to time, normally obtained by means of a continuous recorder that shows stage (depth) versus time (stage hydrograph), and is then transformed into a discharge hydrograph by application of a rating curve (Viessman and Lewis, 1996).

Streamflow data collection in Amman-Zarqa basin started with float measurements in 1938. The current meter was used for the first time in 1949. The first water level recorder was established in Deir Alla at the outlet of the basin in 1953. Following that streamflow recording stations were established at different sites of the basin, namely, Old Jerash Bridge, Sukhna, Ain Ghazal, Wadi Dhuleil, Wadi Muruj, Um Al-Dananeer, Slehi, New Jerash Bridge, Wadi Abdoon, and Qa'Khanna (MWI, 1989).

The discontinuity of streamflow data in most of the stations in the basin is due to unavailable resources to maintain the station, poor station siting, inadequate flash-floods protection, poor experience of the staff, and station tampering by curious people.

In the water year 1968/69 New Jerash Bridge station was established upstream of the Old Jerash Bridge station. This station is the most important one in Amman-Zarqa basin (MWI, 1989). The flow at this station represents 90% of the basin and provides a good measuring site of the inflow toward King Talal Dam which is located a few kilometres downstream. New Jerash Bridge station has the longest and most continuous record among other stations in the basin.

The streamflow at the New Jerash Bridge station is composed of storm direct runoff and baseflow. The baseflow consists mainly of municipal and industrial effluents discharge into Zarqa River in addition to some springs flow. The storm direct runoff will be expressed as runoff depth over the catchment area at New Jerash Bridge station. Runoff variation depends on amount of rainfall, rainfall intensity, and distribution of rainfall across the rainy season among many other factors. The streamflow data of New Jerash Bridge Station will be used in the research. The data is continuous and extends from (1-Jan-1970) to (30-Sep-2005).

The New Jerash Bridge station had been relocated about 50 meters downstream due to inability to measure flow after the scouring caused by road making long the Wadi (MWI, 1989).

Meteorological Data

The meteorological data is comprised of mean temperature and relative humidity records. The data records are complete and don't require missing value analysis. The mean temperature will be calculated by summing maximum and minimum temperatures and dividing by two. Tables 2.4 and 2.5 illustrate the meteorological data used in research at two stations which are serviced by the Jordan Meteorological Department.

Table 2.4: Temperature (ºC) Data at Two Stations.

Station	**Time Scale**	**Record**
Amman Airport	Monthly	(Jan – 1923) - (Dec – 2006)
Wadi Dhuleil	Monthly	(Jan - 1968) - (Dec - 2004)

Table 2.5: Relative Humidity (%) Data at Two Stations.

Station	**Time Scale**	**Record**
Amman Airport	Monthly	(Jan-1966)-(Dec-2006)
Wadi Dhuleil	Monthly	(Jan-1977)-(Dec-2006)

It should be noted here that Wadi Dhuleil station is an agro-meteorological station and it's located between long trees. The data of this station could show systematic change due to surrounding environment effects, the research will take that into account.

2.4 Time Series Definition

Rainfall, runoff, baseflow, temperature, and relative humidity time series at different time scales (water year or calendar year, and monthly) are defined for analysis. Significant or runoff-producing storm-clusters are identified considering the selected rainfall stations in the study area. Identification is based on the daily flood flow hydrograph at the New Jerash Bridge streamflow station. The storm-cluster is defined as the event that is accompanying a runoff-event (Flood flow hydrograph) and is separated from a past storm-cluster by a minimum 2-day of no rainfall in all of the eight rainfall stations used in the research. Table 2.6, Figure 2.9, and Figure 2.10 show an example of storm-cluster analysis. After the identification of all storm-clusters in the period of record, storm-cluster total rainfall is obtained for each rainfall station. Furthermore, runoff-event totals are obtained for the New Jerash Bridge station.

Table 2.6: Example of Storm-Cluster in Amman Zarqa Basin.

Date	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha and Subhiya	Um El Jimal	Zarqa	New Jerash Bridge
	Rainfall (mm)								Runoff (mm)
8-Feb-76	1.4	1.0	1.7		15.0			1.9	
9-Feb-76	10.6	7.3	18.2	4.2	12.0	10.0	3.6	4.4	0.16
10-Feb-76	4.7	2.2	14.0	1.6	8.0	3.6	2.2	2.4	0.73
11-Feb-76	0.3	1.2	1.8		4.0			2.0	0.95
12-Feb-76					2.0				0.26
13-Feb-76									0.1
14-Feb-76									0.05

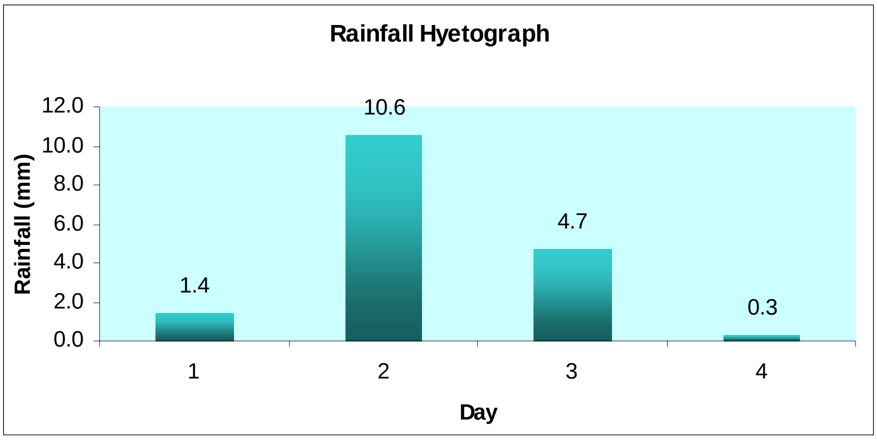

Figure 2.9: Rainfall Hyetograph at Amman Airport Station (8-Feb to 14 Feb, 1976).

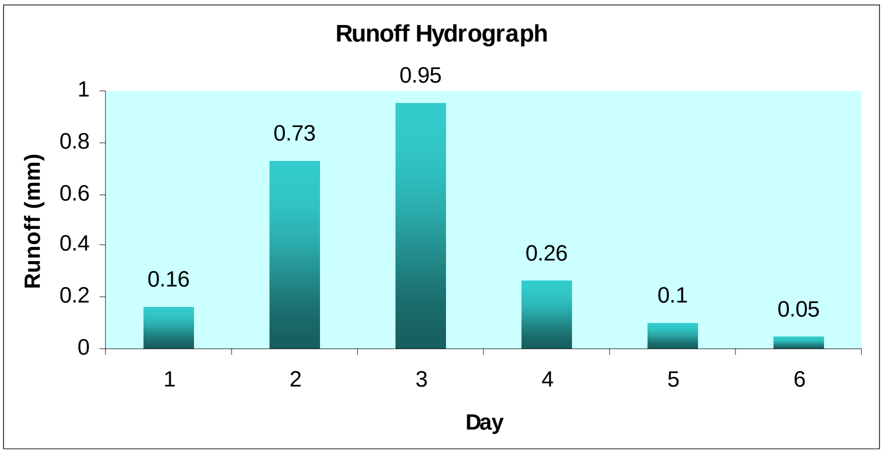

Figure 2.10: Runoff Hydrograph at New Jerash Bridge Station (8-Feb to 14 Feb, 1976).

Outlier analysis and adjustment is performed for all records. Box plots are developed for all time series used in the research to identify outlier data points; Figure 2.11 shows the box plot of water year rainfall at all rainfall stations. Outlier analysis removes any data points that are sample-foreign and that may compromise analysis results and findings.

In outlier analysis, the star points in Figure 2.11 is considered as an outlier since its out of three Inter Quantile Range (IQR), as indicated for Hussein College and Khaldiya Stations.

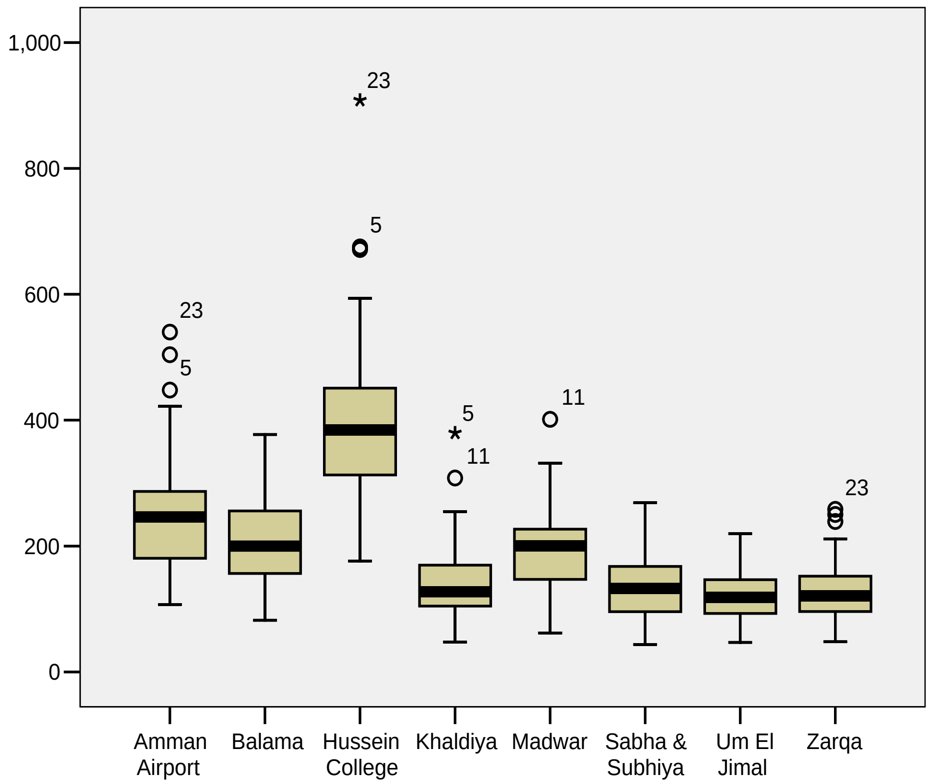

Figure 2.11: Box Plot of Water Year Rainfall to Introduce Outliers.

The data introduced in this chapter are analysed through this research. Time series analysis will be discussed in the following chapters after discussing similar researches in the next chapter.

CHAPTER (3): LITERATURE REVIEW

3.1 Introduction

Hydrologic environments are those parts of earth in which particular hydrologic phenomena of the water cycle occur; an example would be oceans and continental solid. Examples of hydrologic phenomena (processes) are precipitation, evaporation, runoff, ground-water levels, sediment transport, lake levels, snow and ice accumulation and melt, water quality properties, properties of porous environments, river basin geomorphologic forms, and many more (Yevjevich, 1972). This section explains some of the parameters, which are used in the research.

Hydrologic variables describe the hydrologic phenomena and can be classified into basic and derived. A basic variable would be rainfall intensity on a rain gage chart for a given storm and the derived variable is the accumulated daily rainfall. Hydrologic statistical parameters describe the probability distributions and stochastic processes of the hydrologic variables, such as, mean, median, variance, coefficient of variation, skewness coefficient, serial correlation coefficients, and others.

Natural hydrologic processes are either stochastic or combined stochastic-deterministic processes. Deterministic processes with a negligible stochastic component can be realized under controlled conditions. A stochastic process is a process in which the outcome X can't be predicted with certainty and X is called a random variable. On the other hand, a deterministic process is one in which the outcome X can be predicted with certainty and X is called a deterministic variable (Salas et al. 1980).

Relationships between variables can be classified into: First, pure deterministic relationship where the effect-variable is related to a limited number of casual factors using a mathematical equation, the effect-variable is totally explained putting aside random measurement errors. Second, pure stochastic relationship where the effect-variable is related to an infinite number of casual factors each of them with an infinitesimally small partial effect, the effect-variable is conceived and investigated as an independent random variable since no mathematical expression is feasible for the description of the cause-effect relationship, and Third, transitional deterministic-stochastic relationship which represents most cases of cause-effect relationships in geophysical sciences, here a compromise is made where the substantial partial effects of a limited number of casual factors are taken into account in the model and the partial effects of a the large number of remaining causal factors are replaced by a random variable (Yevjevich, 1987).

The above parameters and relationships are used to discuss the related articles in the literature and through the investigation of this study.

3.2 Time Series

Time series can be defined as a sequence of numerical observations which describe an underlying process mechanism in a given system. Time series is characterized by the time orderly fashion and the existence of a dependence structure among observations, which is exploited in forecasting and control of time series behaviour (Vandaele, 1983). Time series can be expressed as X_t, where (X) refers to the random variable being observed and the subscript (t) refers to the time order of the observation, that is X_1, X_2, X_3,…..,X_n.

Time series scale can be continuous or discrete. A continuous time series scale exists at every point in time, an example would be the temperature recorded continuously at a given place. A discrete time series scale exists at equally spaced intervals of time or sometimes nearly equal. A discrete time series scale can be obtained by the instantaneous recording at the end of a specified time interval such as temperature recorded at 12:00 PM every day or by accumulating values to the end of a time interval such as accumulated rainfall in one day.

The random variable (or variable) described by the time series may be discrete or continuous. A series of 0s and 1s indicating rainless and rainy days respectively would be a discrete process with a discrete time scale. On the other hand, the amount of rainfall accumulated to the end of day would be a continuous process with a discrete time scale (Haan, 1977).

An ensemble of time series is a set of several time series measuring the same variable. A single time series is called a realization. Thus an ensemble is made up of several realizations.

The properties of a time series over a given time interval can be derived based on a single realization and are called time average properties or based on several realizations and called ensemble properties. If the time average properties and the ensemble properties are the same, the series is said to be ergodic (Haan, 1977).

A stationary time series is one in which the probability density function properties don't change with time (Haan, 1977). However, a time series is said to be stationary in the mean or first-order stationary when the expected values (means) are constant with time. Similarly when the time series is said to be stationary in the variance, the variance is constant with time. A time series is stationary with respect to the covariance when the covariance depends only on the time lag (k) and not on the position (t). A second-order stationary time series or weak stationary is the one that is stationary in the mean, variance, and covariance. The time series becomes strong stationary when other properties are constant with time (Salas et al. 1980). However a process can be stationary in regard to one property and not in regard to other.

A time series can be composed of only deterministic components, only a stochastic component, or a combination of the two. The deterministic components can be periodic, trendy, jumpy, or a combination of these. The stochastic component is superimposed on the deterministic components.

Trends are results of gradual natural and/or man-made effects, jumps are results of sharp or catastrophic change in the hydrologic environment such as large forest fires, and periodicities are results of astronomical cycles and periodic behaviours tied to the system.

Objectives of time series analysis (Vandaele, 1983):

1. To obtain a concise description of the features of a particular time series process.
2. To construct a model to explain the time series behaviour in terms of other variables and to relate the observations to some structural rule of behaviour.
3. To forecast the behaviour of the time series in the future based upon knowledge of the past.

4. To control the process generating the time series by establishing polices that intervene only when the process deviates form a target by a prescribed amount (Intervention Analysis).

Research on hydrologic time series aimed at studying the main statistical characteristics, providing physical justification to some stochastic models, developing new and/or alternative models, improving the estimates of model parameters, developing new or improving existing modelling procedures, improving tests of goodness of fit, developing procedures on dealing with model and parameter uncertainties and studying the sensitivity of models and model parameters in applied hydrology (Salas et al. 1980).

3.3 Analysis Tools

Time series analysis tools refer to theories, concepts, and statistical methods applied in time series analysis and modelling procedures. Examples of time series analysis tools would be: Correlation analysis, spectral analysis, hypothesis testing and significance, noise filtration, frequency analysis, wavelet and Fourier transforms, non-linear dynamics, and chaos theory.

An aspect of time series analysis that needs to be looked upon carefully is stationarity. To examine stationarity of a time series, a visual plot is often enough to convince a forecaster that the data are stationary or non-stationary. The Autocorrelation Function (ACF) will drop to zero after the second or third time lag for a stationary time series while it may continue to be significantly different from zero for several time periods in case of non-stationarity (Makridakis et al. 1983). In general correlation coefficients (r_K) for non-stationary data will be relatively large and positive until the lag (k) gets big enough so that random error component begin to dominate the autocorrelation, an example would an existence of a trend component in time series. Significant partial autocorrelation coefficients will support the non-stationarity conclusion. Cordery et al. (2006) were motivated by how two apparently stationary time series produce a non-stationary one, a rainfall series when correlated with southern oscillation index series the correlation sample was highly non-stationary suggesting that one or two of the contributing series were non-stationary even at low levels. They were concerned over the implications a stationarity has over water resources modelling, time series analysis, and climate change. In their paper they applied seven standard tests of stationarity to annual, seasonal, monthly, and daily rainfall and southern oscillation index series. The standard tests were: student t, F test, normal score, Mann Whitney, rank variation, Smirnov, and chi square. They used two sampling approaches namely, by halves and progressive windows. When they used the halves sampling approach, most of the series were shown to be fairly stationary. However with progressive windows, they found that some of the series were stationary but most of them were non-stationary in more than one of the tests sometimes at high levels of significance.

Time series can be viewed as a dynamic system and can be described by a phase-space diagram; the phase-space diagram can be constructed and predicted by the time delay embedding method. The correlation dimension, the largest Lyapunov exponent, and K_2 entropy are mathematical tools used to diagnose the chaotic behaviour of the phase-space diagram describing the time series. Jayawardena and Lai (1994) employed the theory of non-linear dynamic systems in time series analysis to make non-linear predictions and to diagnose chaos using some daily streamflow and rainfall data in

Hong Kong. It was found that the time series data used exhibit some chaotic behaviour and the data series could be better modelled by the time delay embedding method than by the traditional Autoregressive Moving Average (ARMA) approach.

Natural physical fields over a given region can be expressed as a matrix of time series, an example would be a mean monthly streamflow records for a number of stations distributed uniformly in a given region, which would be a streamflow natural field. One way to understand the temporal and spatial variability of such fields is the principle component analysis (PCA). PCA can be used to construct low-frequency regional-scale anomaly fields or maps of a given hydrological or climatological variable. Maps or fields will show above-normal, normal, and below-normal occurrences of the variable. Kalayci and Kahya (2006) employed PCA to a network of 78 streamflow stations uniformly distributed across Turkey. The monthly streamflow data were logarithmically-transformed and seasonally-adjusted prior to analysis. It was found that regional variations of streamflow can be captured by a relatively small number of basic anomaly maps, 12 anomaly maps or 12 principal components that account for 80% of the total variance of the entire streamflow data set. Furthermore, significant correlations were found between large-scale atmospheric circulation patterns such as North Atlantic and southern Oscillations and the principal components.

Spectral Analysis of time series can be thought of as an exploratory data analysis tool. Spectral analysis theory is based on the classical Fourier analysis and the most fundamental spectral problem is the estimation of the spectral density function. Spectral analysis can provide an intuitive frequency-based description of time series and indicate interesting features such as long memory, presence of high frequency, and cyclical behaviour. McLeod and Hipel (1995) used two spectral density estimation methods, the periodogram smoothing and the AR-AIC-Bayes filter autoregressive method to provide estimation of the univariate spectral density function of long time series of annual streamflow, water levels, mud varves, and tree rings. Both methods showed that there is a high spectral mass near zero which supports the long-memory hypothesis. Comparisons of the estimated spectral densities with those for the best-fitting ARMA models indicate that the time series used can be satisfactorily modelled by a low order ARMA model.

Memory or persistence is a useful feature of time series that describes the serial dependence structure. Distinction has to be made between long-term and short-term memory, this can be done by judging the rate at which the autocorrelation function decreases with the number of lags. Rao and Bhattacharya (1999) analyzed time series data of streamflow, maximum streamflow, temperature, and precipitation in the mid-eastern USA at monthly and annual scales by testing two null hypotheses. The first null hypothesis: there is only short-term memory in the series, the second hypothesis: the time series is independent. The original and modified versions of the rescaled range statistics were used to test the null hypotheses. Data were standardized; autocorrelation and spectrum plots were prepared for each time series. It was found that the time series used are independent and that only short-memory is present in monthly time series, however no conclusion was drawn regarding annual series due to small sample sizes.

The correlation coefficient is used to measure the degree of linear association between pairs of random variables. Correlation analysis is evident in most hydrologic time series analysis studies and literature. Xu et al. (2004) employed correlation analysis to identify any relationship between precipitation and El Nino-Southern Oscillation (ENSO) in the south-east Asia and the pacific region in order to facilitate the possibility of providing precipitation forecasts. Monthly precipitation data from 30 basins were used in analysis, the study area was divided into three zones corresponding to climatic behaviour. Cross-spectral and coherence analysis was used to examine the correlation relationships between the random variables; the main benefit was to provide confirmation of correlation analysis and to identify any linear relationship that could have been easily overlooked. Clear correlation between ENSO and precipitation in most basins of the study area was identified, furthermore precipitation associated with warm ENSO events tend to be below normal with a larger range of variation and those associated with cold ENSO events tend to be above normal with smaller range of variation. In the coherence analysis, cycles of 6 to 12 months periods were revealed from analysis.

3.4 Modelling and Forecasting

Time series modelling is a process which can be simple or complex depending on the characteristics of the sample series, on the type of model to use, and on the selected techniques of modelling such as parameter estimation and goodness-of-fit (Salas et al. 1980).

The early studies of Hazen in 1914 and Sudler in 1927 showed the feasibility of using statistics and probability theory in analyzing river flow sequences. Hurst in 1951 reported studies of long records of river flows and other geophysical time series after investigating the Nile River for the Aswan Dam project. Hurst studies introduced concepts that affected hydrological and the geophysical time series analysis. Barnes in

1954 introduced the idea of synthetic generation of streamflow data using tables of normal random variables thus extending the early empirical work of Hazen and Sudler. It was not until the beginning of the 1960s that the formal development of stochastic modelling started with the introduction and application of autoregressive models for annual and seasonal streamflows. Several stochastic models have been proposed in the past for modelling hydrologic time series. They are: autoregressive models (AR), fractional Gaussian noise models (FGN), autoregressive moving average models (ARMA), broken-line models (BL), shot-noise models, model of intermittent processes, disaggregation models, Markov mixture models, ARMA-Markov models, and general mixture models (Salas et al. 1980).

Time series models can be classified according to the number of variables included in the model into univariate and multiple time series models. A univariate time series model use only current and past data of one variable. A fundamental assumption of the univariate model is that other factors influencing the subject time series are not expected to change sufficiently as to introduce a new pattern in the subject time series (Vandaele, 1983).

Models in hydrology can be also classified broadly into deterministic and stochastic models. Some models have deterministic and stochastic components built in them. Many hydrologic analyses combine deterministic and stochastic models together. Deterministic models are those which use some form of a law (governing mechanism) to relate variables together, most often require more than one input; an example would be a rainfall - runoff model (Haan, 1977). Stochastic models are probabilistic and require that statistical parameters to be estimated from historical records. Stochastic models generate data in the statistical sense to infer information about the data population, such information are helpful in calculating risk probabilities and in studying water resources systems behaviour such reservoir operation.

Time series modelling has mainly two uses in hydrology and water resources: (1) for generation of synthetic hydrologic time series, and (2) for forecasting future hydrologic series (Salas et al. 1980).

There are two major approaches to forecasting (Makridakis, et al. 1983): Explanatory (or casual) and time series. The two approaches are complementary and intended for different types of applications. They are based on different philosophical premises. Explanatory forecasting assumes that any change in the system's inputs will affect the output of the system in a predictable way given that a constant cause-effect relationship exists. The system can be anything, a basin, a river reach, or a lake. Time series forecasting treats the system as a black box and makes no attempt to discover the factors affecting its behaviour, the system is simply viewed as unknown generating process. There are two main reasons for wanting to treat the system as a black box, first the system may not be fully understood and even if its, it's extremely difficult to express the relationships governing its behaviour. Second, the main concern may be to forecast what will happen and not to know why it happens. Time series forecasting approach exploits the memory or the persistence aspect of the system, as so time series models require no special inputs, the only inputs would be past values of the system output.

The critical task of the time series analyst is to separate the pattern from the error component so that the former can be modelled and subsequently forecasted. The following is a selected literature on time series modelling and forecasting:

Tung et al. (2006) proposed a stochastic model to generate hourly rainstorm events. The model application and performance evaluation were based on hourly rainfall data of Hong Kong Observatory from 1884 to 1990. Historical rainfall data were used to determine the distributional properties of rainstorm characteristics necessary for model development. Statistical analysis of historical rainstorm data showed a strong positive correlation between storm duration and rainfall depth, and weak correlation between inter-event time with storm duration and rainfall depth. The best-fit distribution for storm duration and rainfall depth was the two-parameter lognormal distribution while for inter-event time best-fit distribution was two-parameter gamma distribution. The model was composed of three major components: (1) generation of the number of rainstorm events, (2) generation of rainstorm depth, duration, and inter-event time for each event, and (3) generation of rainstorm pattern for each event. Rainstorm events were defined based on dry-time, event rainfall amount, and hourly rainfall amount into 1,690 rainstorm event. The study focused on rainstorm events that could produce significant runoff events. Historical rainstorm events were divided into dry- and wet-periods and modelled accordingly, the reason behind is that statistical properties of rainstorm characteristics differ significantly between seasons. The number of rainstorm events over a specified period was modelled based on Poisson distribution which is commonly adopted to describe annual occurrence of hydrologic events. The Monte Carlo simulation method was used to simulate multivariate non-normal correlated random variates of rainfall depth, storm duration, and inter-event time. The procedure utilized information on marginal distributions and correlations of the variates along with statistical transformations. To generate the temporal pattern of a rainstorm event, a non-dimensionalization procedure of rainfall mass curve of a rainstorm event was used to remove the effects of rainstorm duration and rainfall depth and characterize the rainstorm event solely on temporal variation. Statistical cluster analysis was further used to categorize rainstorm patterns into distinct types, six rainstorm events were identified. Simulation of a rainstorm event pattern was done based on two steps: (1) to generate rainstorm pattern type using the multinomial distribution along with a contingency table that incorporates the effects of storm duration and rainstorm depth, and (2) to generate the rainfall hyetograph ordinates using log-ratio transformation and Monte Carlo simulation with Johnson distribution. It has been shown that the proposed model was capable of preserving the essential statistical features of rainstorm characteristics and annual maximum rainfall. Furthermore the proposed model showed the potential of improving the accuracy of Intensity-Duration-Frequency (IDF) curves based on short rainfall records.

Pekarova and Pekar (2006) analyzed the mean annual runoff at seven stations, in particular Turnu station, along the Danube River in Europe. The Turnu station is located in a rocky profile and provides an excellent record since 1840, the maximum and minimum annual discharges were 8265 and 3471 m^3/s respectively. Time series data of Turnu was tested for homogeneity and then filtered by Hodrick-Prescott filter, wet and dry periods are easy to identify in filtered data. The analysis of the Turnu data shows that the wettest decade was 1910–19, and the driest decade was 1857–66, when the maximum and minimum runoffs were observed respectively. A weak negative correlation was found between mean annual runoff and surface temperature and two driest periods in the record occurred at different temperature conditions. Possible existence of a long-term trend was tested and the null hypothesis: (the series fluctuates along its constant mean) is not rejected at 0.05 significant level. Spectral analysis by the combined periodogram method revealed 29–31, 20–21, 14, 5, 4.2, 3.64, and 2.4 year periods. Finally a model consisting of a harmonic deterministic component and an autoregressive component was built and predictions were made for 20 years ahead. After removing the harmonic component, logarithms of the residuals were taken and Box and Jenkins methodology was used to identify the appropriate ARIMA model part. Adjusted coefficient of determination (R^2), sum of squared residuals, and Akaike information criterion were the accuracy measures used to judge the model adequacy. The ARIMA model innovations or shocks were verified to satisfy the Gaussian noise condition that is being independent and identically distributed. According to the model results, the dry period around 1990 in the Danube basin should be followed by a wet period peaking at around year 2005 and 2010. For the Danube at Turnu, the year 2006 should be the wettest.

Mohan and Vedula (1995) proposed a multiplicative seasonal ARIMA model to forecast natural inflows into a reservoir system in Karnataka State, South of India. Historic monthly data of inflows for a period of 52 years were used in the study. The first 25 years data were used for model development and the remaining 27 years were used for validating the performance of the model. Box and Jenkins methodology of ARIMA models development was used in the study. The methodology consists of the following stages: (1) identification of model structure, (2) parameters estimation using the maximum likelihood or minimum least squares methods, (3) validation of the selected model using diagnostic checking tools, and (4) forecasting using the best model. Logarithmic transformation of monthly inflow data was carried out and examination of ACF and partial autocorrelation functions (PACF) helped to identify the proposed model structure. Eight model structures were considered for further analysis to allow for possible identification errors. Parameters of the selected models were estimated using the maximum likelihood method. The best model structure was selected based on three criteria, namely: (1) Residual Variance (RV) criterion, (2) Akaike's information criterion (AIC), and (3) Posterior probability criterion. In addition, the best model had to fulfill the principal of parsimony. Overfitting and randomness check of residuals were used in the diagnostic checking stage to validate the selected model for forecasting. In this study, it was found that the fitted ARIMA model has the ability to preserve both the short and long memory in the inflow time series and that ARMIA models family is adequate for forecasting the natural flows. It was shown that parameter uncertainty is minimal and frequent updating of model parameters isn't necessary for forecasting.

Burlando et al. (1993) developed a real-time short-term ARMA forecasting model of rainfall; the model can generate forecasts at 1 hr and 2 hr lead times. Rainfall data from two stations, Denver and Morrison, in Colorado (USA), and the storm event in November 1987 of 16 rain gages located in the Arno River basin of Central Italy were used in model development. Several stroms were extracted from each month from the 36 years Denver record and the 26 Morrison record to represent various types of storm events. Since ARMA model is valid only for stationary processes with normal marginal distribution, the rainfall data are grouped by month or season; thus the model was applied separately for data of a given month or a given season. Accordingly, model parameters such as autoregressive and moving average coefficients were determined from precipitation data pertaining to a given month or season only. For skewed data, the Box-Cox transformation was used to transform the original data into normally distributed data. Based on literature, ARMA (2, 2) model was selected as the appropriate model form in the study. Considering the intermittent natures of rainfall process, two approaches for parameter estimation were used, the continuous approach and the event-based approach. In the continuous approach, all the precipitation events which occurred in a given month or season were considered for parameter estimation, once including zero recorded rainfall and the other including non-zero rainfall. However model performance based on the continuous approach was poor and unable to forecast future rainfall trends well, especially during summer convective storms, unless the trend persisted for several hours. Moreover the model showed a tendency to underestimate rainfall. In the event-based approach, each storm event regardless of the month or season was considered separately for parameter estimation using an iterative adaptive framework. In both approaches the least squares method was used for parameter estimation. The model with the event-based approach reproduced well fluctuations in rainfall intensity in terms of trends and transitions from decreasing to increasing rainfall. Furthermore the model showed fairly good agreement between observed and forecast cumulative rainfall. In order to account for model efficiency with event-based approach a comparison was made between the forecast of the average rainfall in a given area and the average forecast of a number of rainfall stations in the same area is carried out. For that purpose the storm event in November 1987 of 16 rain gages located in the Arno River basin of Central Italy was analyzed and modelled. Comparison of the rainfall intensities forecast by the two procedures indicates that forecasts of the average rainfall intensity are closer to the observed values than those obtained by averaging forecast values for each station. It was shown that the event-based approach for parameter estimation of ARMA (2, 2) is suitable for practical purposes.

3.5 Time Series Analysis Vs. Climate Change

Climate in a narrow sense is usually defined as the "average weather", or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (www.grida.no/climate/ipcc_tar/wg1/). See Figure 3.1.

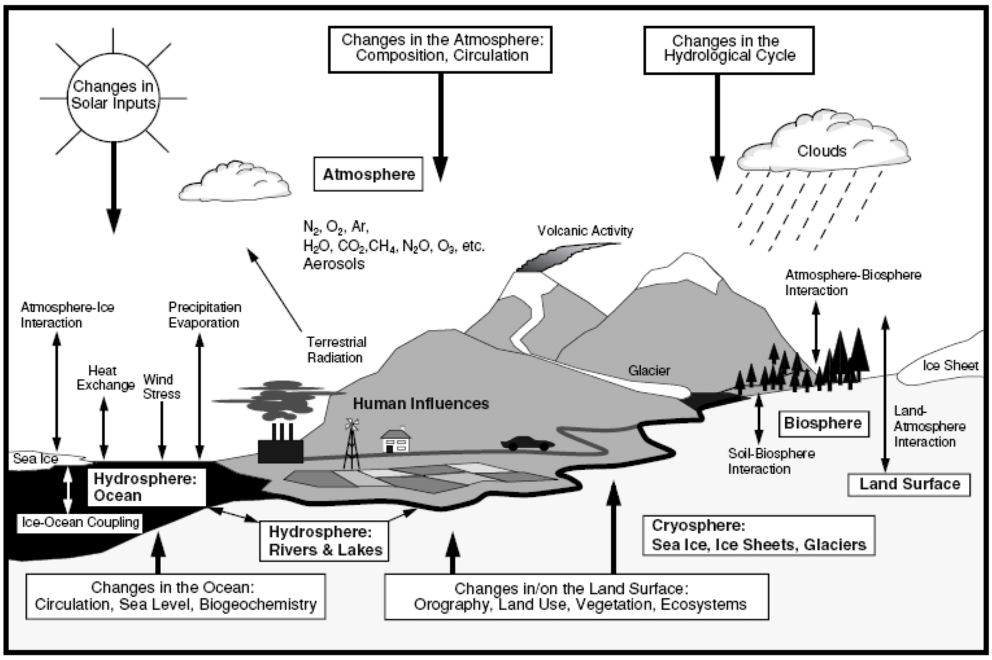

Figure 3.1: A Depiction of the Climate System and the Associated Changes.

Evidence of climate change can be quantified using instrumental observations, satellite measurements, historical records, dating, and proxy measurements such as tree rings, ice cores, ocean sediments, pollen records, and boreholes (Burroughs, 2001).

Time series analysis is a useful tool to detect and quantify climate change; the following is a selected literature on time series analysis in climate change studies:

Andreo, et al. (2006) analyzed climatic and hydrologic time series in the south of the Iberian Peninsula using spectral and correlation analyses and continuous wavelet transforms. The most complete historical series available of real data spanning to more than a hundred years have been used in the study. Time series data obtained form gauging stations in the southern Iberian Peninsula include: precipitation data at the stations of San Fernando (127 years) and Gibraltar (166 years), temperature data at the station of San Fernando (117 years), and the outflow of El Tempul spring (133 years). The aim of the study was to determine whether there are periodicities associated with climatic cycles or oscillations and whether there are any long-term trends that might be related to climatic changes. The two methodologies of time series analysis used in the study were the spectral and correlation analyses and the continuous Morlet wavelet analysis. Correlation and spectral analysis were first applied in surface water hydrology mainly for forecasting, completion of data, and parameters estimation of stochastic models. Correlation and spectral analyses deal with time series in two domains, the time domain and the frequency domain, and the approach can be simple or cross-correlated. In this study correlation and spectral analyses have been carried out at two levels: the short-term analysis (lag of 1 month) and the long-term analysis (lag of 10 months). The second method of analysis is the continuous Morlet wavelet analysis; the continuous wavelet transform provides a time-scale discrimination of the signal into sub-processes and establishes a clear distinction between random fluctuations and periodic regions. Unlike correlation and spectral analyses, the wavelet transforms lead to more precise results by detecting the distribution of periodic variability during time rather than average periodicities in time series. Wavelet transforms have been applied in the fields of hydrology and meteorology. Results of analysis indicated that a short-term periodicity of 6 months and long-term periodicities of 5 and 2.5 years exist in rainfall data at San Fernando and Gibraltar stations, which could be attributed to the North Atlantic Oscillation (NAO) influence. No long-term trends were detected in the precipitation pattern in the south of Iberian Peninsula.

Yu et al. (2006) studied variations and trends of long-term rainfall series on various time scales in Taiwan. The 80 years of historical records from 33 stations across Taiwan were used in the study. The Water Resource Bureau divides Taiwan into four regions – northern, eastern, central and southern Taiwan. Precipitation time series were analyzed using cumulative deviation test, Mann -Whitney - Pettitt statistic, and Kruskal - Wallis test. The cumulative deviation and the Mann - Whitney - Pettitt reveal the statistical significance change point, while the Kruskal - Wallis tests whether a significant difference exists between two samples separated by the change point. The change points of all precipitation records which are mostly around 1960. Kruskal - Wallis tests indicated that annual precipitation series for most stations differ markedly between the two periods separated by the change point, furthermore most stations in northern and eastern Taiwan show increasing annual precipitation and most stations in central and southern Taiwan show falling annual precipitation. The means and standard deviations changes before and after the change points were analyzed. Changes in the means and standard deviations of the monthly precipitation in Northern Taiwan were positive indicating an increasing trend, most changes in the means and standard deviations of the monthly precipitations in central and southern Taiwan are negative, revealing a decreasing monthly precipitation trend. However, the changes in the means and standard deviations of monthly precipitation in eastern Taiwan were inconsistent with each others. In Taiwan there are three precipitation seasons, Mei-rain, Typhoon, and the dry season. It was found that the mean precipitations in the typhoon season at most stations increase in northern Taiwan and decrease in central and southern Taiwan. The decrease at most stations in Southern Taiwan are statistically significant. The mean precipitations in the dry season at most stations in northern and eastern Taiwan increase and in central and southern Taiwan decrease. The declines at most stations in central Taiwan are statistically significant. The mean precipitation at most stations in the Mei-rain season increases in Northern and Eastern Taiwan, and declines in Central and Southern Taiwan. However, these changes are not statistically significant.

Kothyari et al. (1997) investigated changes of rainfall and temperature regimes in the Ganga Basin in Northern India for possible climate change effects. Rainfall (1901 to 1989) and temperature (1950 to 1989) time series data from three stations in the middle and upper parts of Ganga Basin were analyzed, namely: total yearly monsoon rainfall, total number of rainy days, and annual maximum temperature. The study objectives were to identify significant trends in the data and to estimate changes in frequency quantiles. Methods of analysis included the 10-year moving average to remove periodicity, the robust locally weighted regression (RLWR) for smoothing and to guard against outliers, Mann-Kendall test for trend significance, homogeneity test to confirm the presence of any trend, and an empirical frequency analysis. The 10-year moving average and the RLWR smoothing methods were used to visually-identify any trends present in data and to indicate periods of rise and decline in the data series. Decreasing trends were indicated for the total rainfall and the rainy days time series and increasing trends were indicated for the annual maximum temperature time series. The change point was identified to be around 1955 to 1965. Compared to the 10-year moving average method, smoothing by RLWR resulted in a more clear depiction of the trend present in the data. The Mann–Kendall test confirmed, at 95 % significant level, a decreasing trend in rainfall and an increasing trend in temperature. An empirical frequency analysis of the rainfall data was performed to quantify the changes in rainfall quantiles during the period of record, the first set consisted of data up to the period 1964, and the second set had the data for the period 1965 onwards. For the two data sets, the data were ranked in order of magnitude and their plotting positions were determined using the Weibull formula. Frequencies for both data sets were computed and plotted, a marked decrease in rainfall depth and number of rainy days at all frequencies levels was indicated.

Kite (1989) hypothesized a simple model of time series consisting of trend, periodic, autoregressive and random residual components. The study aimed to examine the fit of such model to climate-related time series and to provide physical explanation for the presence of time series components. Kite in his paper argued that meteorological data suffer from several disadvantages; such as meteorological data are only representative of small areas, they are highly susceptible to external influences, and they are generally have large fluctuations. On the other hand, hydrological time series such as river flow and lake levels measure aerially integrated effects and are more highly damped. For example random components in precipitation time series are transformed into autoregressive components in river flow time series because of the storage effects of river basins. Flow data of several Canadian rivers and levels of lakes in North America and Africa were used in the study. Although both lakes considered in the study are regulated, they can be considered natural due to their size. Linear additive model consisting of periodic, trend, and stochastic components was proposed as a time series model. The periodic component of time series was detected and removed using Shuster's periodgram. The trend component was modelled and removed using a polynomial regression. The stochastic component was assumed to be represented by the autoregressive Markov model. Spectral analysis is used to display the different components of a time series and examine the results of removal of these components. Time series components found in all lake levels data have reasonable physical explanations which could be related to other climate change phenomena and are not related to "greenhouse effect" climatic change. For example the long term trend found in Lake Superior levels is due to climate change related to uplifting after the last ice age. Apparent periodicity in the levels of Great Salt Lake is within the range of normal fluctuations. The sudden rise in Lake Victoria levels is related to unmeasured increase of precipitation over the lake, further more the lake had undergone several sharp rises and drops during the historical record and such sudden change is not likely to be of "greenhouse effect" climatic change. The analysis of river flow data showed a decreasing importance of periodic component in favor of the stochastic residual component moving geographically from west to east. This observation reflected the change of runoff source form glaciers to rainfall. There were no significant linear trends in river flow time series. Kite didn't find any statistical components in the analyzed time series data that could be attributed to "greenhouse effect" climatic change. Small sample size, insensitive data, or unsuitable techniques as discussed by Kite could have contributed to this conclusion.

CHAPTER (4): THEORY, MODELLING, AND FORECASTING

4.1 Introduction

This chapter provides the theoretical foundation of the research work; it contains descriptions of the used models and forecasting methodologies, the related equations and parameters, and examples of data modelling and analysis. Model equations and expressions are presented in Boxes with reference.

As it is pointed out in literature review, forecasting is an important use of modelling. According to Makridakis et al. (1983), forecasting can be explanatory or casual forecasting or time series forecasting. Example of explanatory forecasting models would be regression techniques and of time series forecasting models would be trend models, smoothing techniques, decomposition, and ARIMA modelling. Box 4.1 and 4.2 illustrate the difference in mathematical terms.

Box 4.1: Functional Form (Pattern) of an Explanatory Forecasting.

$$X = f(X_1, X_2, X_3, \ldots)$$

Where;

X = System's output.

X_1, X_2, X_3 = System's inputs.

Box 4.2: Functional Form (Pattern) of a Time Series Forecasting.

$$X_t = f(X_{t-1}, X_{t-2}, X_{t-3}, \ldots)$$

Where;

X_t = System's output, new values.

$X_{t-1}, X_{t-2}, X_{t-3}$ = System's inputs (old values of X_t).

There will be always a variation in the system output that will not be accounted for by inputs variations. So, to adjust for this inadequacy a random component has to be added to the forecasting model, see Box 4.3 for illustration.

Box 4.3: Forecasting Model with Random Error Component.

$$X = f(X_1, X_2, X_3, ..., u)$$
$$X_t = f(X_{t-1}, X_{t-2}, X_{t-3}, ..., u_t)$$

Where;
u, u_t = Random error component.
Other variables as defined previously.

In order to keep in line with the notation used in the expression of models; Box 4.4 illustrates forecasting notation. Useful descriptive statistics such as univariate statistics, bivariate statistics, and single time series lagged on it self statistics are given in Boxes 4.5, 4.6, and 4.7, respectively.

Box 4.4: Forecasting Notation.

$1,2,3,.....,t-2,t-1,t,t+1,t+2,t+3,.....,t+m$ = Index, rank, or time order.

$X_1, X_2, X_3, ..., X_{t-2}, X_{t-1}, X_t$ = Observed values.

$F_{t+1}, F_{t+2}, F_{t+3}, ..., F_{t+m}$ = Forecasted values.

$F_1, F_2, F_3, ..., F_{t-2}, F_{t-1}, F_t$ = Forecasted values at known observed values.

$e_1, e_2, e_3, ..., e_{t-2}, e_{t-1}, e_t$ = Errors.

Where;
$e_i = X_i - F_i$

Box 4.5: Univariate Statistics

Mean

$$\overline{X} = \frac{1}{n}\sum X_i$$

Mean Absolute Deviation

$$MAD = \frac{1}{n}\sum \left| X_i - \overline{X} \right|$$

Sum of Squared Deviations

$$SS = \sum \left(X_i - \overline{X} \right)^2$$

Mean Squared Deviation

$$MSD = \frac{1}{n}\sum \left(X_i - \overline{X} \right)^2$$

Variance

$$S^2 = \frac{1}{n-1}\sum \left(X_i - \overline{X} \right)^2$$

Root Mean Square

$$RMS = \sqrt{\frac{1}{n}\sum \left(X_i - \overline{X} \right)^2}$$

Standard Deviation

$$S = \sqrt{\frac{1}{n-1}\sum \left(X_i - \overline{X} \right)^2}$$

Skewness

$$Skew = \frac{\frac{1}{n-1}\sum \left(X_i - \overline{X} \right)^3}{S^3}$$

Where;

X_i = Sample data points,

All summations are over the index (i) from (1) to (n).

Box 4.6: Bivariate Statistics.

Covariance

$$Cov_{XY} = \frac{1}{n-1}\sum\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)$$

Correlation Coefficient

$$r = \frac{Cov_{XY}}{S_x S_Y} = \frac{\sum\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)}{\sqrt{\sum\left(X_i - \overline{X}\right)^2}\sqrt{\sum\left(Y_i - \overline{Y}\right)^2}}$$

Where;

X and Y = Random variables.

n = Number of paired data.

Box 4.7: Single Time Series Lagged on Itself Statistics.

Autocovariance

$$Auto-Cov(k) = \frac{1}{n-k-1}\sum_{t=k+1}^{n}\left(X_t - \overline{X}\right)\left(X_{t-k} - \overline{X}\right)$$

Autocorrelation

$$Auto-r(k) = \frac{\sum_{t=k+1}^{n}\left(X_t - \overline{X}\right)\left(X_{t-k} - \overline{X}\right)}{\sum_{t=1}^{n}\left(X_t - \overline{X}\right)^2}$$

Accuracy measures help to show how suitable a forecasting method is for a given data set. In most forecasting applications, accuracy is the criterion for selecting a forecasting method. Box 4.8 illustrates the accuracy measures used in the research.

Box 4.8: Accuracy Measures

Mean Absolute Percentage Error

$$MAPE = \frac{1}{n}\sum\left|PE_i\right|$$

$$PE_i = \left(\frac{X_t - F_t}{X_t}\right)*100$$

Mean Absolute Deviation

$$MAD = \frac{1}{n}\sum\left|e_i\right|$$

Mean Squared Deviation

$$MSD = \frac{1}{n}\sum e_i^2$$

All summations are over the index (i) from (1) to (n).

Goodness-of-fit refers to how well a forecasting model is able to reproduce the data that is already known. To the consumer of forecasts, it is the accuracy of the future forecasts that is matters, however to the modeller; it is the goodness-of-fit of the model to the known facts that is most important.

4.2 Linear Regression Models

Regression techniques are referred to as explanatory or casual approaches to forecasting. The regression involves discovering and measuring the relationship form between dependant and independent variables. Such relationship can be used in forecasting. Regression models allow forecast to be expressed as a function of a certain number of variables so that a better understanding of the situation can be achieved. Regression models allow experimentation with different combinations of inputs to study their effect on forecast.

In regression models development, the forecaster will choose dependant and independent variables to include in the analysis. The forecaster has to be aware of the physical relevance of his/her choice.

4.2.1 Simple Linear Regression

The simple regression refers to any regression of a single (Y) measure (dependant variable) on a single (X) measure (independent variable). The general situation will involve a sample of (n) paired data, see Box 4.9 for illustration.

Box 4.9: Simple Linear Regression.

Sample points
$\{X_i, Y_i\}$ For $i = 1,2,3,\ldots,n$

Regression model in theory
$Y = \alpha + \beta X + \varepsilon$

Where;
Y = Dependant variable.
α, β = fixed (unknown) parameters.
X = Independent variable that is assumed to be measured without error.
ε = Random variable that is normally distributed around zero with variance (σ_ε^2).

Regression model in practice
$Y_i = a + bX_i + e_i$ For $i = 1,2,3,\ldots,n$

Where;
Y_i = Dependant variable.
a, b = Estimates of (α) and (β) and are both random variables.
X_i = Independent variable that is unlikely to be measured without error.
e_i = Estimated error that is a random variable.

Once the data is plotted and a linear relationship between (Y) and (X) is considered, the statistical problem will be to arrive at the best fitting line through the plotted data.

A number of regression procedures are available to estimate model parameters but one of the most used methods of estimation in the classical statistics is the least squares method, which is developed by Gauss in 1800s. The reader is referred to Walpole and Myers (1978) for a complete treatment of the subject. Figure 4.1 shows a simple linear regression model and scatter plot of runoff events at New Jerash Bridge and storm-clusters at Khaldiya, examination of the model indicates that a storm-cluster with a rainfall amount higher than 1.04 mm is required to produce runoff events.

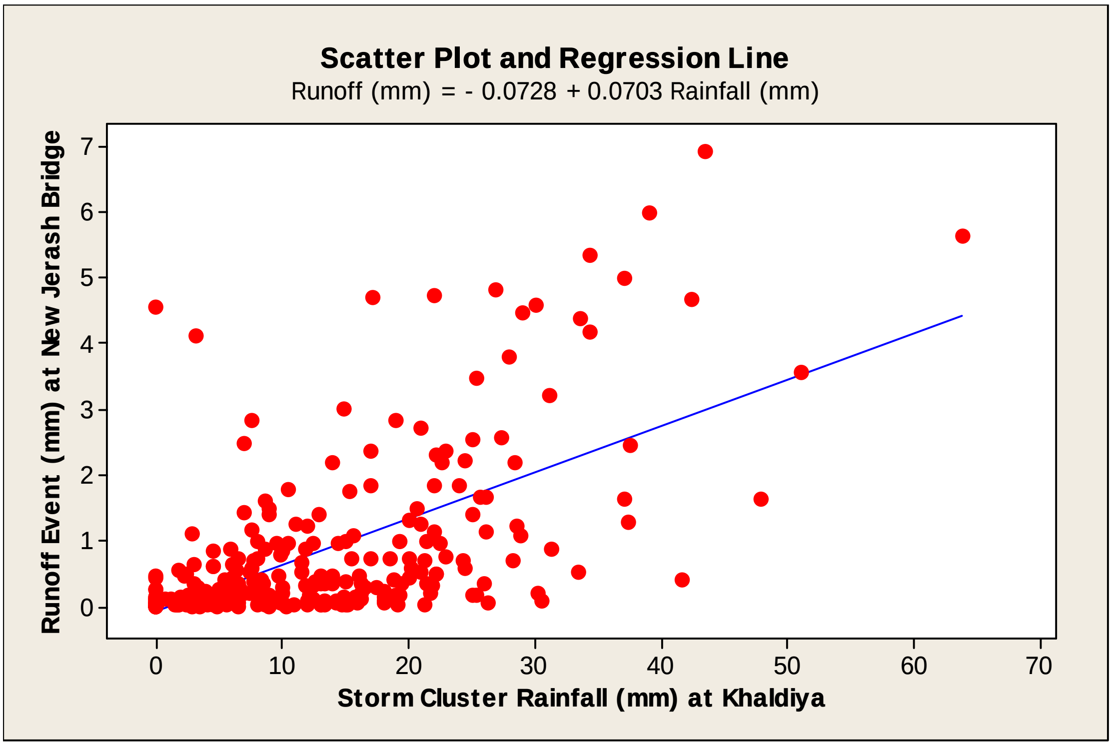

Figure 4.1: Scatter Plot and Regression Line of runoff events at New Jerash Bridge and Storm-Clusters at Khaldiya.

It often occurs that two variables are related to each other, even though its might incorrect to say that one variable is the cause of the other. In such a case a relationship can be stated by computing the correlation coefficient.

The correlation coefficient plays an important role in many multivariate data analysis. It's a relative measure of linear association between two variables and can vary from (0) (lack of correlation) to (± 1) (perfect correlation).When the correlation coefficient is greater than (0), the two variables are said to be positively correlated, and when it's less than (0), they are said to be negatively correlated. There are several computational approaches to calculate the correlation coefficient. One of these is reported in Box 4.6.

Intuitively, the correlation coefficient can be interpreted in two ways: (1) as the direction of relationship between two variables – meaning do they tend to increase and decrease together (positively related), one increases while the other increases (negatively related), or move their separate way (not correlated); and (2) as the strength of the association – meaning as the correlation coefficient moves away from zero, the two variables are more strongly associated. Table 4.1 illustrates the correlation matrix of storm-clusters; the average correlation coefficient of storm-clusters with runoff events at New Jerash Bridge is equal to 0.696. The relatively high magnitude of correlation coefficients indicates a successful storm-cluster separation process.

Table 4.1: Correlation Matrix of Storm-Clusters in Amman-Zarqa Basin at Respective Stations.

	Amman Airport	**Balama**	**Hussein College**	**Khaldiya**	**Madwar**	**Sabha and Subhiya**	**Um El Jimal**	**Zarqa**
Amman Airport	1.000	0.744	0.908	0.747	0.735	0.643	0.778	0.856
Balama	0.744	1.000	0.731	0.661	0.738	0.609	0.698	0.714
Hussein College	0.908	0.731	1.000	0.695	0.733	0.622	0.730	0.804
Khaldiya	0.747	0.661	0.695	1.000	0.665	0.608	0.846	0.809
Madwar	0.735	0.738	0.733	0.665	1.000	0.671	0.708	0.715
Sabha & Subhiya	0.643	0.609	0.622	0.608	0.671	1.000	0.731	0.597
Um El Jimal	0.778	0.698	0.730	0.846	0.708	0.731	1.000	0.795
Zarqa	0.856	0.714	0.804	0.809	0.715	0.597	0.795	1.000

The correlation coefficient is widely used in statistical analyses and can be a very useful statistic. However there are certain cautions the forecaster needs to be aware of when using such a statistic. First the correlation is a measure of linear association; the two variables can still be strongly related to each other in a non-linear way and yet they score a very low measure of the correlation coefficient. Second the sample size should approach $n = 50$ if reasonably stable correlations are sought.

The linear regression fit will be better if there exists a strong correlation and hence a strong linear relationship between the two variables, thus it's seen that regression and correlation are intimately connected. Another relationship between regression and correlation can be expressed as in Box 4.10.

Box 4.10: Relationship between Regression and Correlation.

$$b = r_{XY} \frac{S_Y}{S_X}$$

Where;

Items as previously defined.

Thus the slope of the regression line is the correlation between (Y) and (X) multiplied by the ratio ($\frac{S_Y}{S_X}$).

The coefficient of determination is a statistic describing the relation between the sample (Y_i) and the estimated (using the regression equation) ($\hat{Y}_i$). It's the squared correlation between (Y_i) and ($\hat{Y}_i$).The coefficient of determination can be expressed as in Box 4.11.

Box 4.11: Coefficient of Determination.

$$R^2 = \text{Explained variance of } (Y) \text{ / Total variance of } (Y) \quad = \frac{\sum\left(\hat{Y}_i - \bar{Y}\right)^2}{\sum\left(Y_i - \bar{Y}\right)^2} = r^2_{Y\hat{Y}} = r^2_{XY}$$

In the case of simple linear regression (r^2_{XY}) equals ($r^2_{Y\hat{Y}}$) and thus the coefficient of determination (R^2). When the explained variance approaches the total variance as indicated in Box 4.11, the linear relationship becomes more and more perfect. For example the coefficient of determination (R^2) of regression model in Figure 4.1 equals 37.5 %, meaning that the model is capable to explain 37.5 % of the total variation in runoff events at New Jerash Bridge Station.

4.2.2 Multiple Linear Regression

The case of simple linear regression is merely a special case of the more general, the multiple linear regression as illustrated by Box 4.12. Figure 4.2 shows a 3D scatter plot and multiple linear regression model in which the monthly rainfall at Hussein College station is expressed as a function of monthly mean temperature and relative humidity at Amman Airport station. The coefficient of determination (R^2) equals 53.8 %.

Box 4.12: Multiple Linear Regression.

Multiple linear regression model in theory

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \varepsilon$$

Where;

Y = Dependant variable.

$\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ = Fixed (unknown) parameters.

$X_0, X_1, X_2, \ldots, X_k$ = Independent variables that is assumed to be measured without error.

ε = Random variable that is normally distributed around zero with variance (σ_ε^2).

Multiple linear regression model in practice

$$Y_i = b_0 + b_1 X_{1i} + b_2 X_{2i} + \ldots + b_k X_{ki} + e_i \quad \text{for } i = 1,2,3,\ldots,n$$

Where;

Y_i = Dependant variable.

$b_0, b_1, b_2, \ldots, b_k$ = Estimates of $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ and are all random variables with a joint normal distribution.

$X_0, X_1, X_2, \ldots, X_k$ = Independent variables those are unlikely to be measured without error.

e_i = Estimated error that is a random variable.

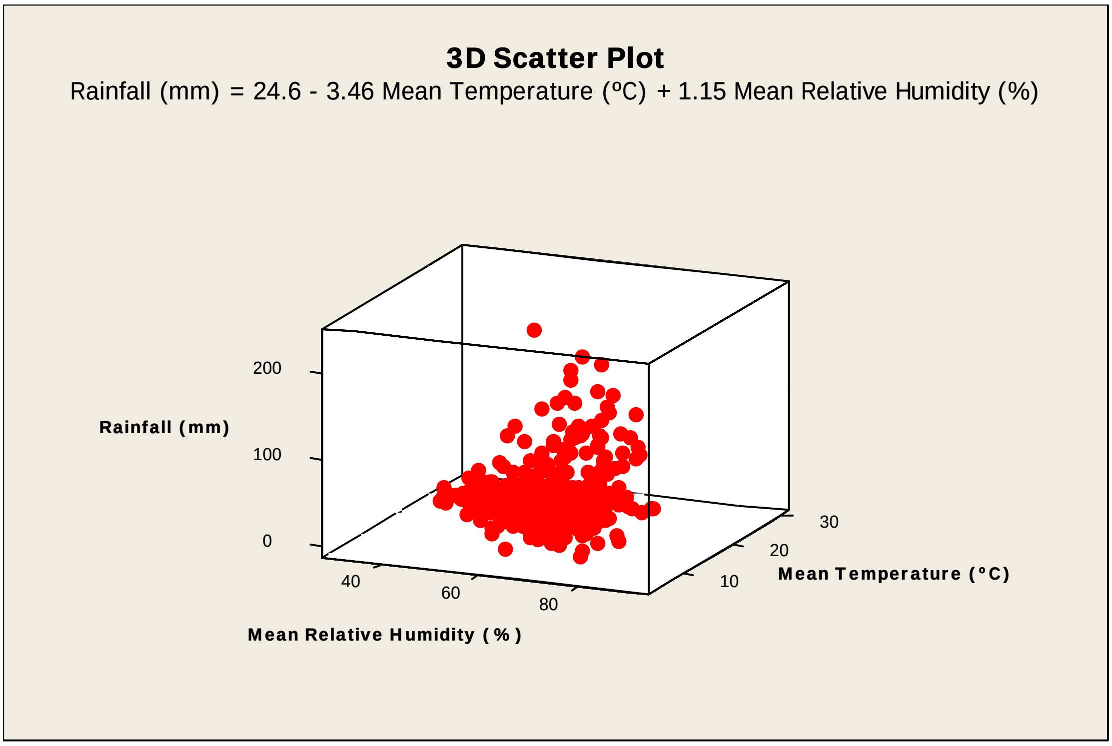

Figure 4.2: 3D Scatter Plot of Hussein College Monthly Rainfall as a Function of Monthly Mean Temperature and Relative Humidity at Amman Airport.

4.3 Trend Analysis

4.3.1 Trend Models

Trend model reflects the gradual change in time series direction, four types of trend models are fitted to all time series. Box 4.13 illustrates the mathematical expressions of the trend models used in research.

Box 4.13: Trend models.

Linear trend model:

$$Y_t = \beta_\circ + \beta_1 t + e_t$$

Quadratic trend model:

$$Y_t = \beta_\circ + \beta_1 t + \beta_2 t^2 + e_t$$

Exponential growth trend model:

$$Y_t = \beta_\circ \beta_1^t + e_t$$

S-curve trend model:

$$Y_t = \frac{10^a}{\beta_\circ + \beta_1 \beta_2^{t-1}}$$

Where;

β = Model Parameter.

Figures 4.3, 4.4, 4.5, and 4.6 show the different trend models when applied to some of research time series data.

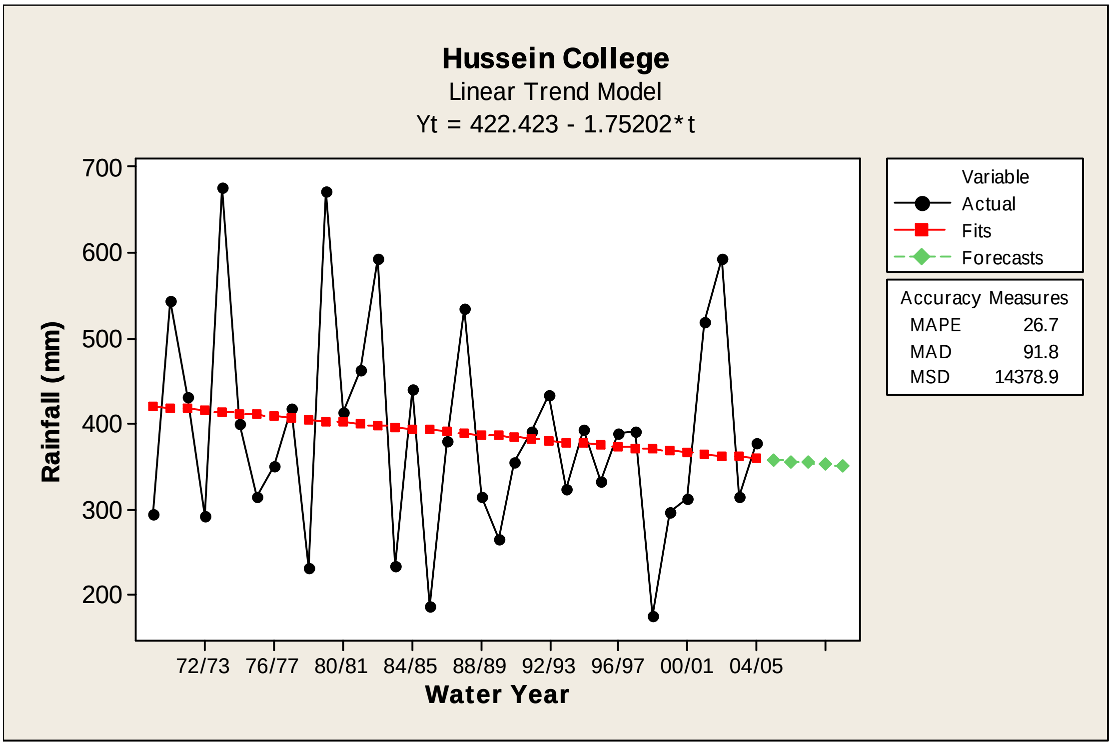

Figure 4.3: Water Year Rainfall Linear Trend Model of Hussein College.

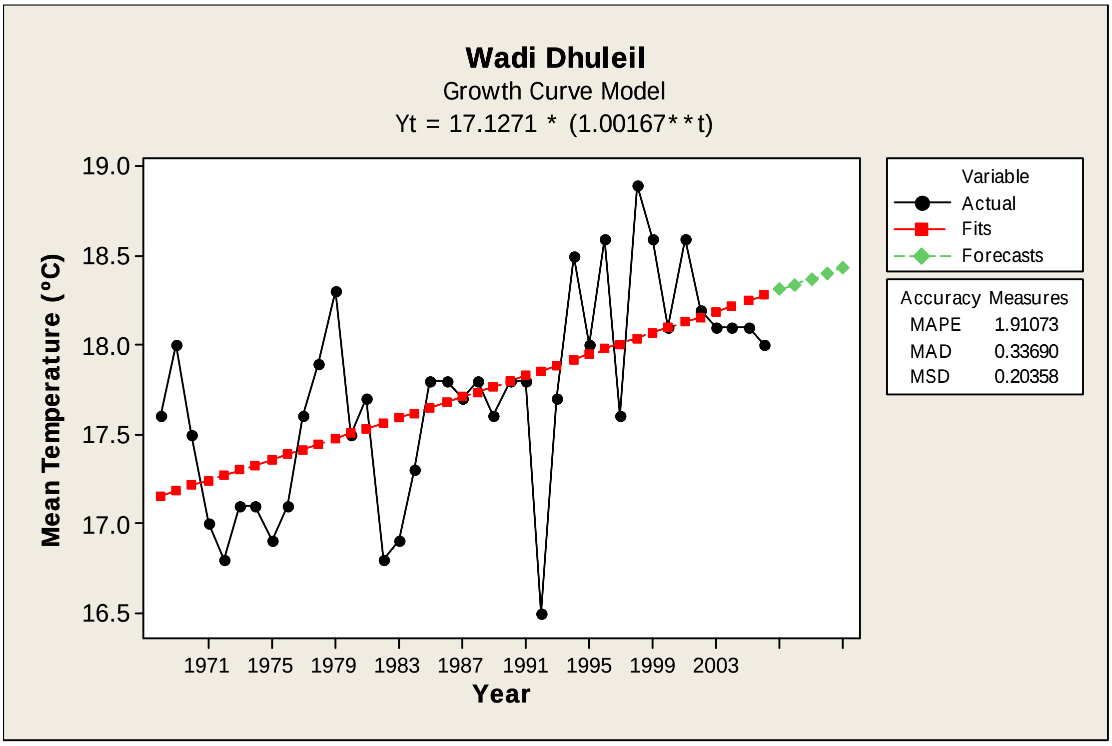

Figure 4.4: Calendar Year Mean Temperature Growth Curve Model of Wadi Dhuleil.

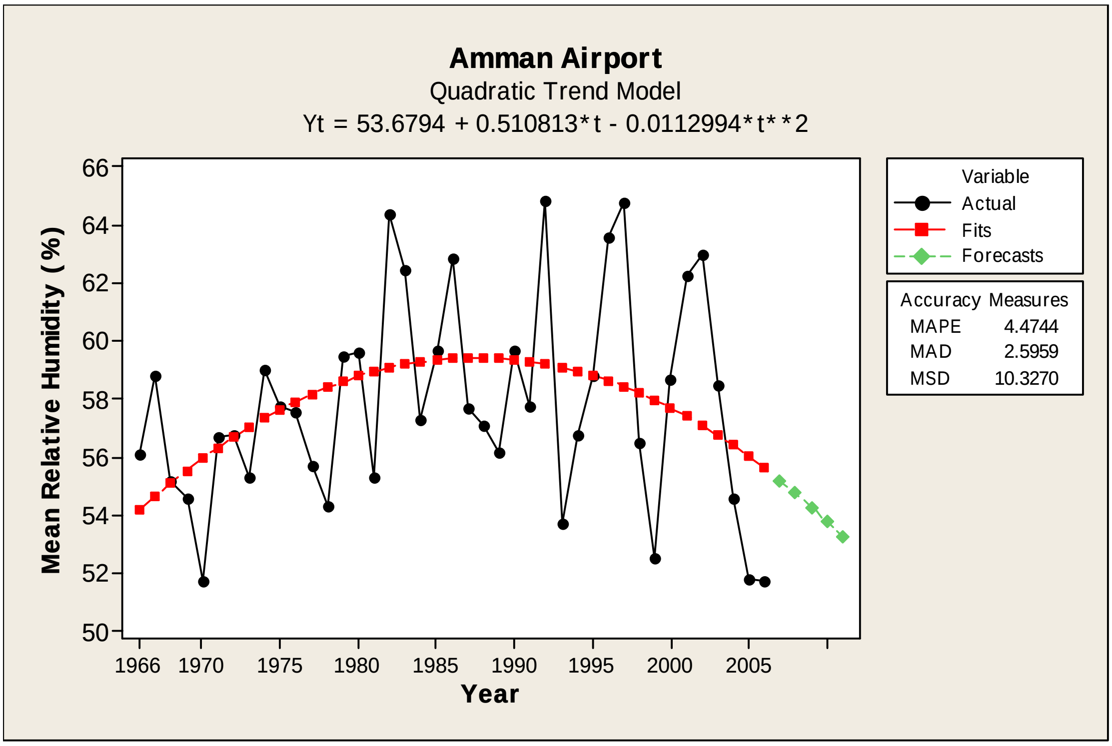

Figure 4.5: Calendar Year Mean Relative Humidity Quadratic Trend Model of Amman Airport.

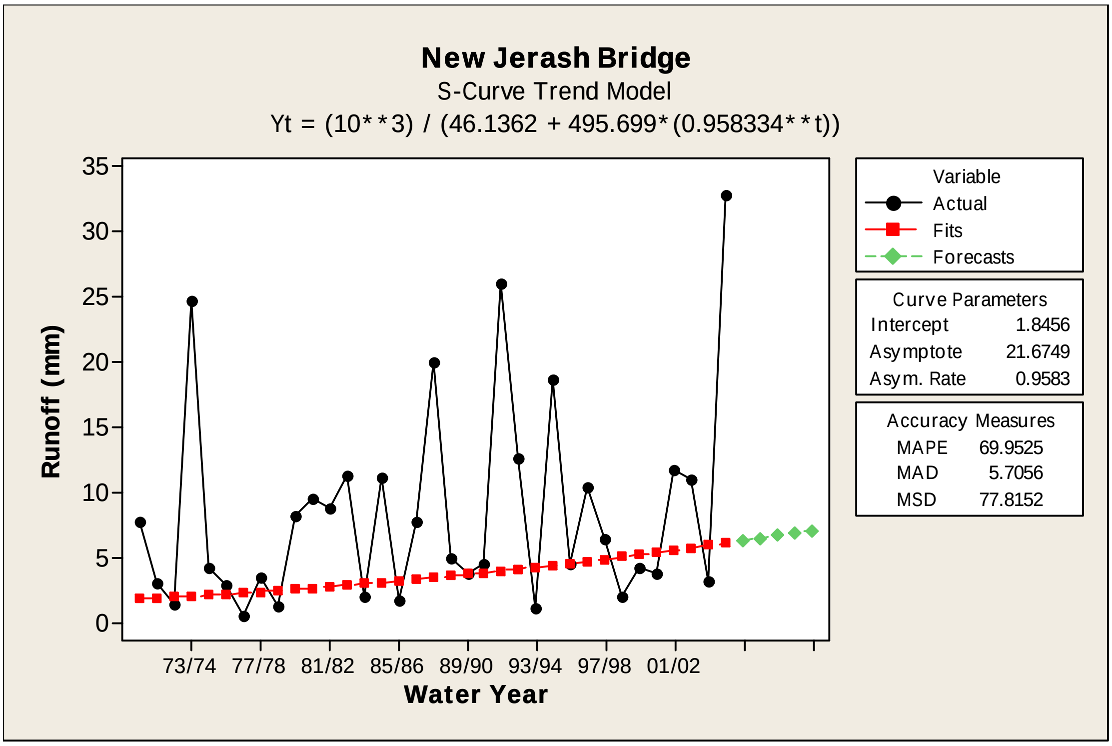

Figure 4.6: Water Year Runoff S-Curve Trend Model of New Jerash Bridge.

4.3.2 Mann-Kendall Test

Mann-Kendall test is used for trend detection and assessment of trend significance. Box 4.14 illustrates the Mann-Kendall test Statistics.

Box 4.14: Mann-Kendall Test Statistics

$$S = \sum_{K=1}^{N-1}\sum_{K=j+1}^{N} Sgn(y_j - y_K)$$

$$Sgn(y_j - y_K) = 1 \quad if \quad (y_j - y_K) > 0,$$
$$Sgn(y_j - y_K) = 0 \quad if \quad (y_j - y_K) = 0,$$
$$Sgn(y_j - y_K) = -1 \quad if \quad (y_j - y_K) < 0.$$

$$Z = \frac{S-1}{Var(S)^{1/2}} \quad if \quad S > 0,$$
$$Z = 0 \quad if \quad S = 0,$$
$$Z = \frac{S+1}{Var(S)^{1/2}} \quad if \quad S < 0.$$

Where;
S = Test Statistic.
y = Time Series Data.
Z = Z Statistic (Standard normal variate).
$Var(S)$ = Mann-Kendall Statistic Variance.

The null hypothesis states that the time series data are independent and identically distributed, that there is no trend in data and the distribution of (S) is symmetrical and normal. The alternative hypothesis of the two-sided test states that there is a trend in data, where a positive value of (S) or (Z) indicate an upward trend and a negative value indicate a downward trend. The statistic (Z) value and its probability is then compared with the chosen level of significance.

4.4 Smoothing Models

4.4.1 Moving Average Models

The mean of a given set of data as a forecasting approach for the next period provides satisfactory results given that the time series data exhibits random behaviour with no trend or seasonal pattern. As the mean includes more data points as it moves in the future, it becomes more stable as indicated in elementary statistical theory. To modify the influence of past data on the future forecast, the moving average can be used where different mean is calculated based on a given number of data points. The moving average will not handle trend or seasonality very well, although it can perform better than the total mean. Box 4.15 and 4.16 illustrate the moving average model in two mathematical ways.

Box 4.15: Moving average model.

$$F_{t+1} = \frac{X_1 + X_2 + X_3 + ... + X_n}{n} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

$$F_{t+2} = \frac{X_2 + X_3 + X_4 + ... + X_n + X_{n+1}}{n} = \frac{1}{n}\sum_{i=2}^{n+1} X_i$$

And so on.

Where;
Symbols as defined in the forecasting notation Box 4.4.

The moving average system will be referred to as MA(n), where (n) represents the number of data points included at each calculation step.

Box 4.16: An alternative form of a moving average model.

$$F_{t+2} = F_{t+1} + \frac{1}{n}\left(X_{t+1} - X_1\right)$$

As can be seen in Box 4.16, the current forecast (F_{t+2}) is only an adjustment of the previous one (F_{t+1}) by $\frac{1}{n}(X_{t+1} - X_1)$, and so on. Clearly if (N) is big the adjustment is so small and thus an MA(big) system greatly smoothes time series and pays a little attention to data fluctuation.

The moving average system will smooth out time series seasonality, for example an MA(4) system will smooth out seasonal effects effectively of a time series exhibiting quarterly data pattern. In the context of time series decomposition, the moving average system is used as centred moving average rather than a forecast in order to examine the component of a time series. Figures 4.7, 4.8, and 4.9 show different length moving average models applied to research time series data.

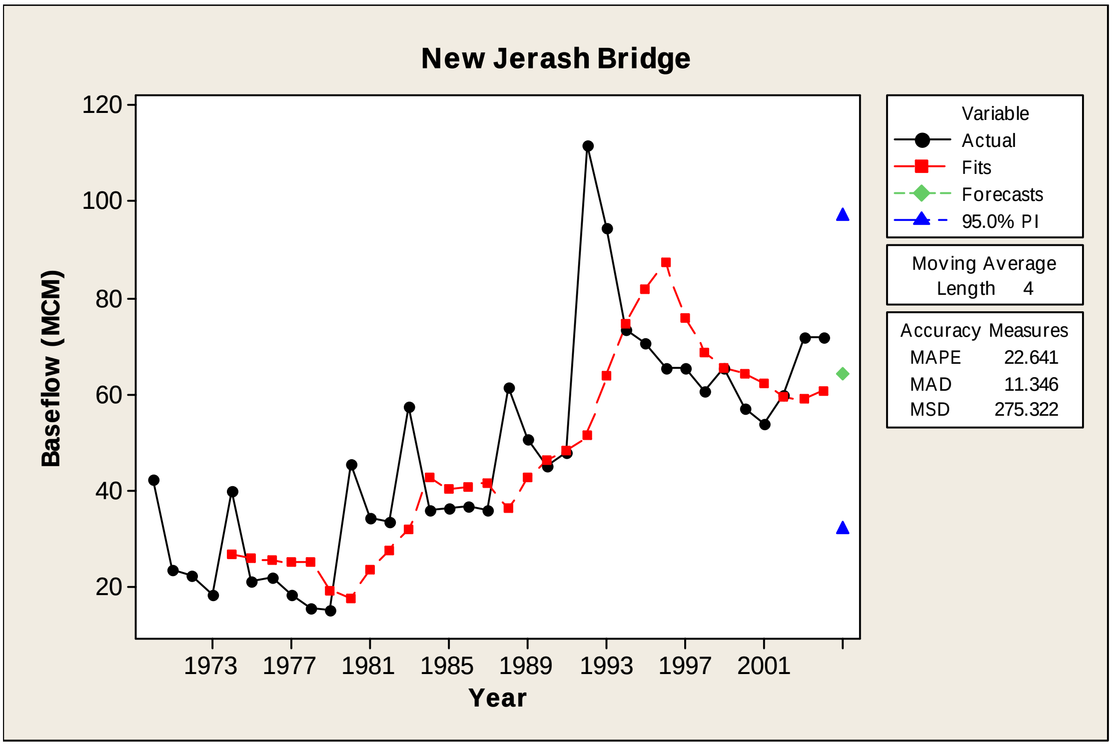

Figure 4.7: An MA(4) Model Applied to Calendar Year Baseflow Time Series at New Jerash Bridge.

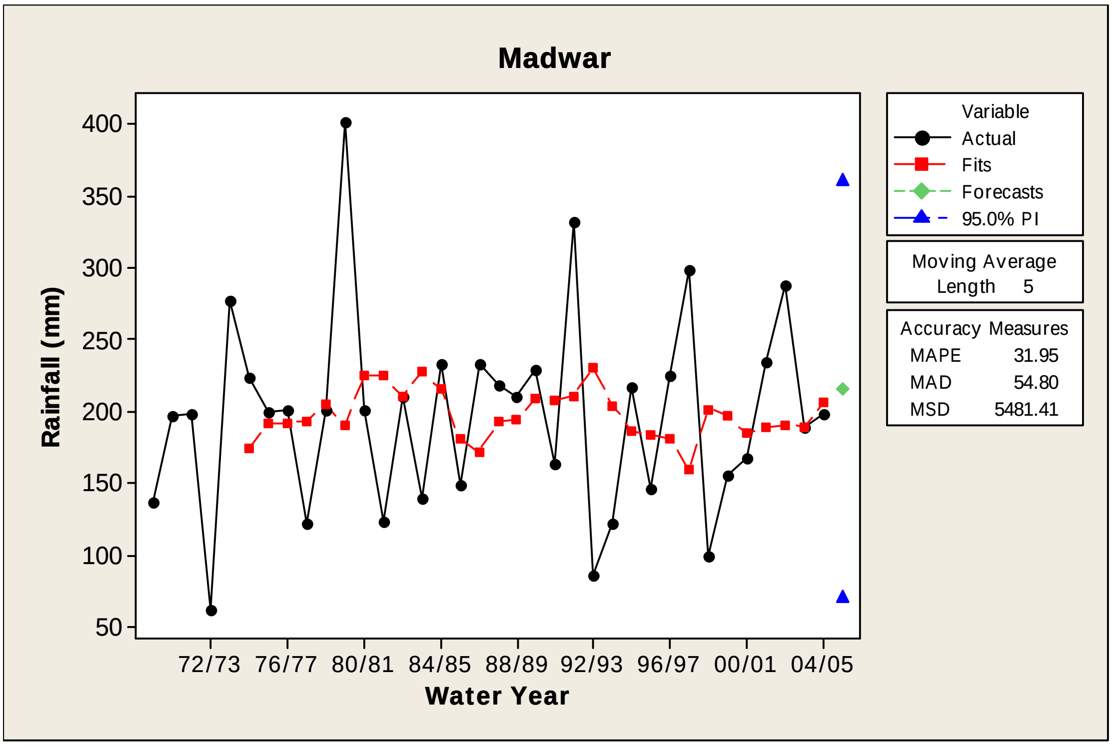

Figure 4.8: An MA(5) Model Applied to Water Year Rainfall Time Series at Madwar.

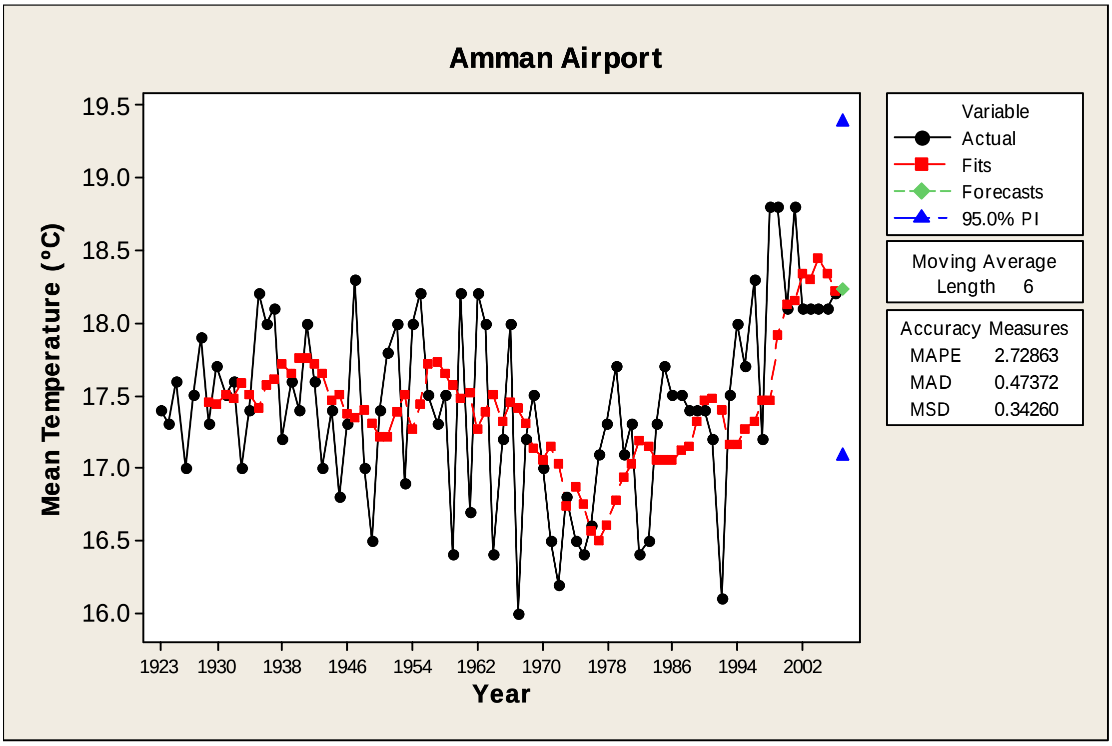

Figure 4.9: An MA(6) Model Applied to Calendar Year Mean Temperature Time Series at Amman Airport.

4.4.2 Single Exponential Smoothing Models

Single exponential smoothing (SES) is among the forecasting approaches intended for immediate or short-term ranges. The single exponential smoothing system is illustrated in Box 4.17.

Box 4.17: Single Exponential Smoothing.

$$F_{t+1} = \alpha X_t + (1-\alpha)F_t$$
$$F_{t+1} = \alpha X_t + (1-\alpha)[\alpha X_{t-1} + (1-\alpha)F_{t-1}]$$
$$F_{t+1} = \alpha X_t + \alpha(1-\alpha)X_{t-1} + (1-\alpha)^2 F_{t-1}$$

And so on.

Where;
α = model parameter and assumes a value in (0,1).

The model requires a single parameter to be specified and the weights ($\alpha, \alpha(1-\alpha), (1-\alpha)^2, \ldots$) applied to data points decrease exponentially, hence the name, single exponential smoothing. The first equation in Box 4.17 can be expressed alternatively as in Box 4.18.

Box 4.18: Alternative Form of Exponential Smoothing Model.

$$F_{t+1} = F_t + \alpha(X_t - F_t)$$
$$F_{t+1} = F_t + \alpha e_t$$

It can be seen that the current forecast (F_{t+1}) is simply an adjustment of the previous forecast (F_t) by (αe_t). In this form, one can see the effect of parameter value on the adjustment.

Given that single exponential smoothing use an adjustment to generate forecasts, the system will trail any trend in the time series by self-adjusting process that automatically corrects for the error, which is to adjust the next forecast for some percentage of the most recent error. Figures 4.10, 4.11, 4.12, 4.13, and 4.14 show a set of single exponential smoothing models with different (α) values applied to research time series data, it can be seen how the degree of smoothing changes as (α) value increases.

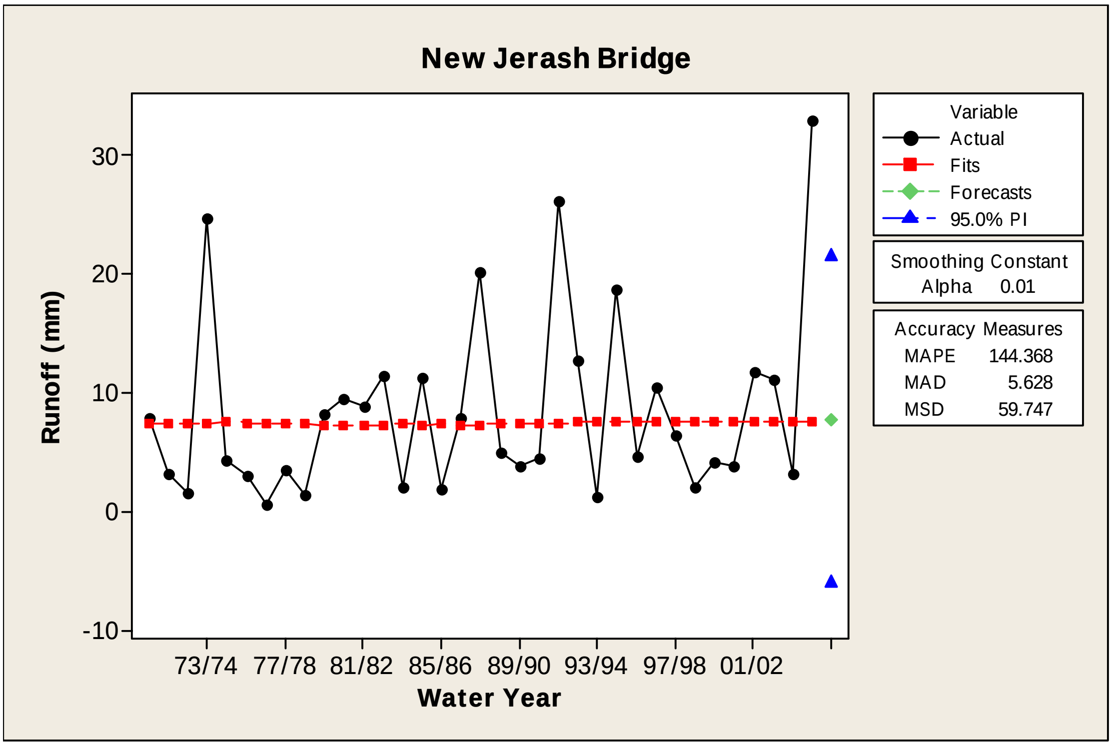

Figure 4.10: An SES Model with $\alpha = 0.01$ of Water Year Runoff at New Jerash Bridge.

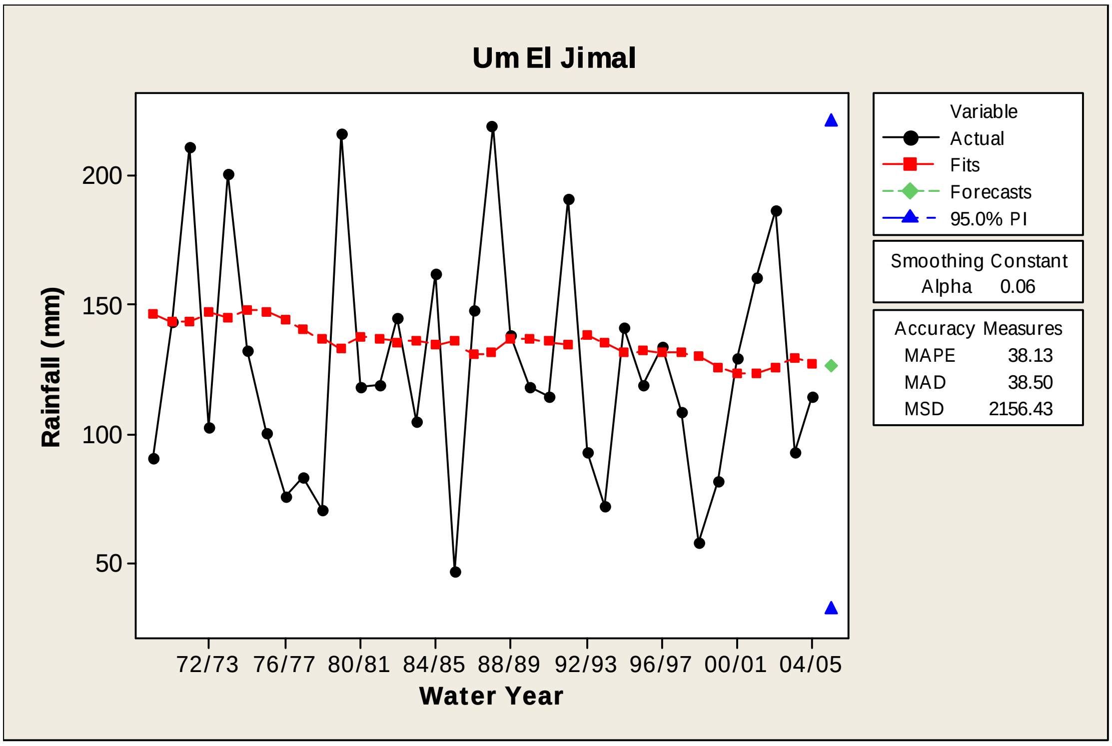

Figure 4.11: An SES Model with $\alpha = 0.06$ of Water Year Rainfall at Um El Jimal.

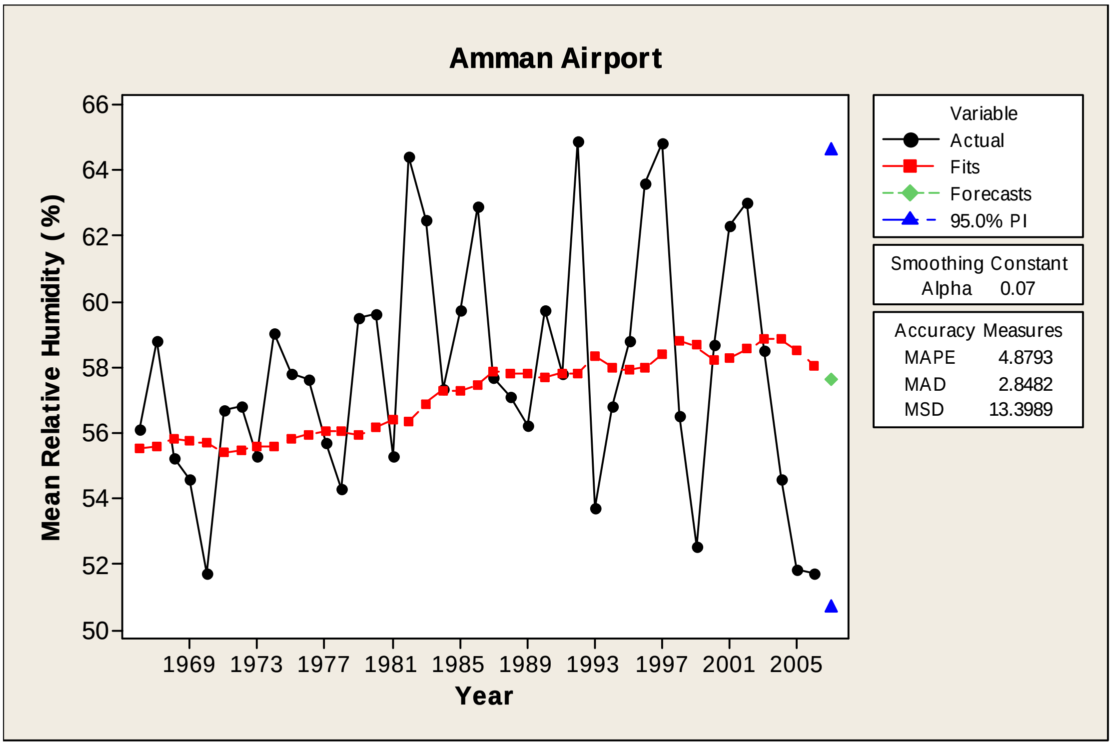

Figure 4.12: An SES Model with $\alpha = 0.07$ of Calendar Year Mean Relative Humidity at Amman Airport.

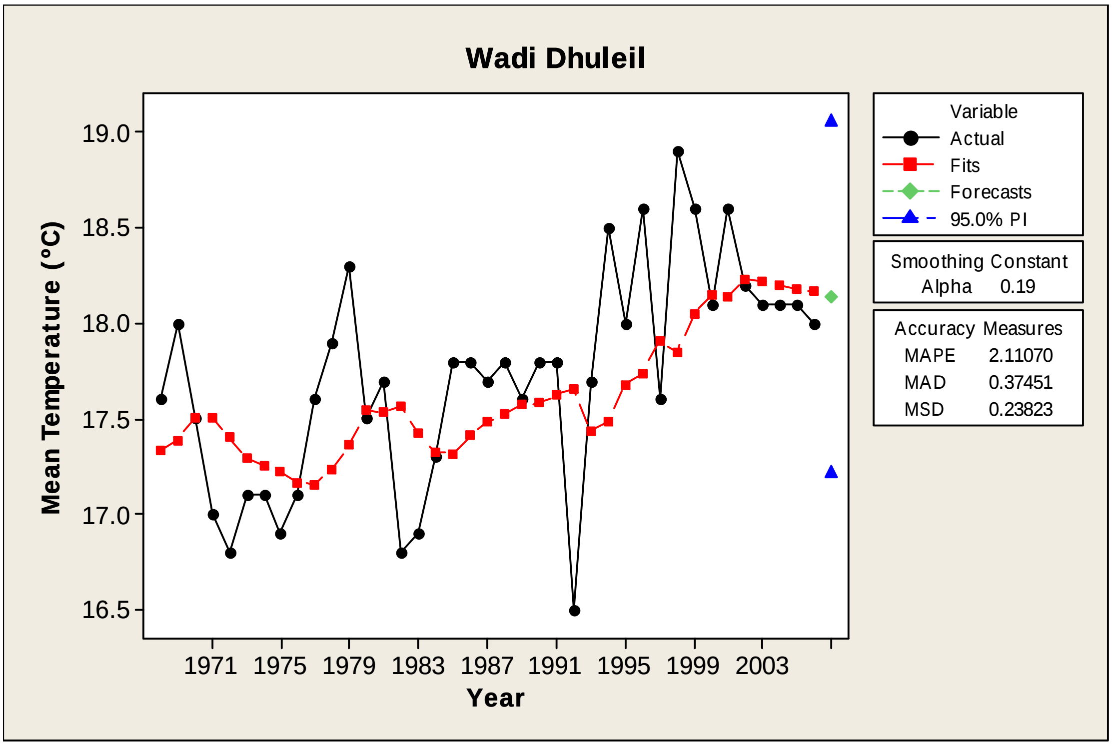

Figure 4.13: An SES Model with $\alpha = 0.19$ of Calendar Year Mean Temperature at Wadi Dhuleil.

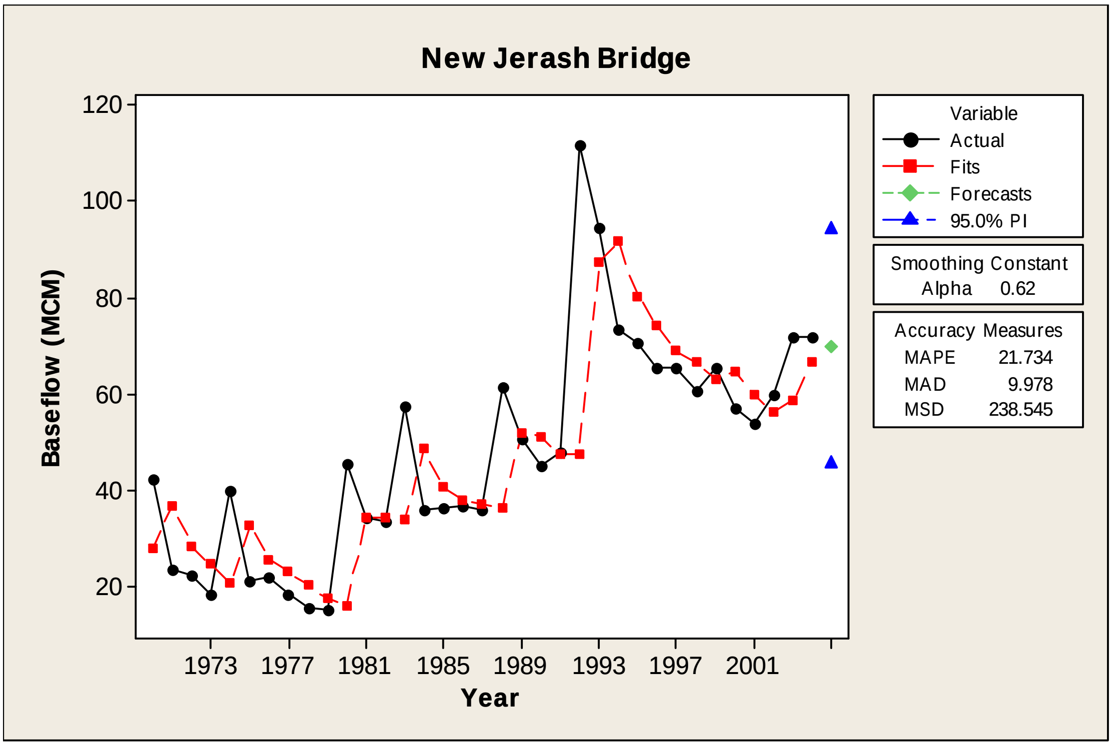

Figure 4.14: An SES Model with $\alpha = 0.62$ of Calendar Year Baseflow at New Jerash Bridge.

4.5 Decomposition Models

Smoothing methods discussed earlier, such as moving average and single exponential smoothing, are based on the concept that when an underlying pattern exists in data, that pattern can be distinguished from randomness by smoothing past data values. And as such, smoothing methods make no attempt to identify individual components of the underlying pattern. Such a breakdown can provide an improved accuracy in forecasting and aid in better understanding the behaviour of the series, and here decomposition methods come.

Decomposition methods usually try to identify components of the underlying pattern of the time series such as trend and seasonal factors. The trend reflects the long term behaviour of the data and can be increasing, decreasing, or unchanged. Seasonality in time series reflects the up and downs in the pattern due to seasonal factors and repeats itself over fixed intervals such as years, months, and so on.

Decomposition can be expressed in words as follows: (see Box 4.19 for a mathematical representation of decomposition model):

Data = Pattern + Error

= f (Trend, Seasonality) + Error

Box 4.19: The general mathematical representation of the decomposition approach:

$X_t = f(I_t, T_t, E_t)$

X_t = Time series value at period (t).
I_t = Seasonal component at period (t).
T_t = Trend component at period (t).
E_t = Random component at period (t).

Additive model
$X_t = I_t + T_t + E_t$

Multiplicative model
$X_t = I_t \times T_t \times E_t$

The process of decomposition consists of the following steps:

1. Compute a moving average whose length (N) is equal to the length of seasonality. The purpose of this step is to eliminate seasonality and randomness.
2. Separate the (N) period moving average from the original data to obtain trend.
3. Isolate the seasonal factors by averaging them for each of the periods making up the complete length of seasonality.
4. Identify the appropriate form of the trend (linear, exponential, S-curve, etc.) and calculate its value at each period.

5. Separate the seasonality and trend from the original series to isolate the remaining randomness.

Moving average is used in the context of time series decomposition to remove seasonality and randomness, and as such it represents the backbone of decomposition approach. Selecting the appropriate length moving average is an important task in decomposition methods. The longer the length of the moving average increases the likelihood that randomness will be eliminated. Figures 4.15, 4.16, 4.17, and 4.18 show decomposition models with different variations, applied to monthly rainfall at Zarqa station.

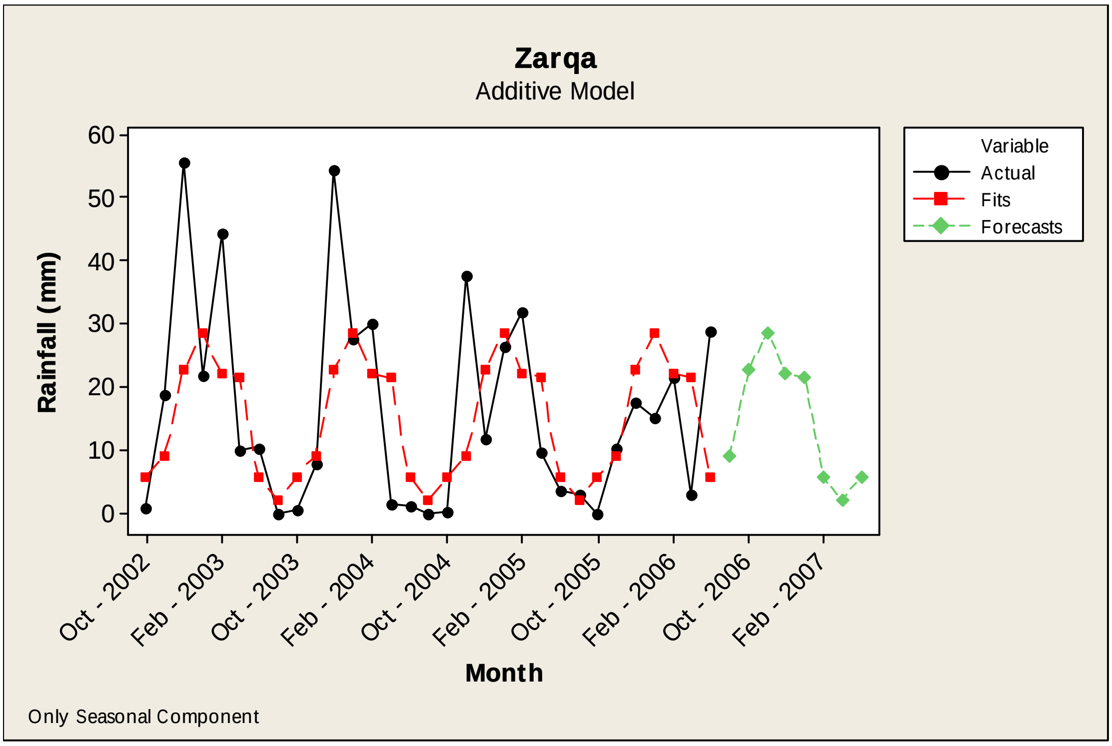

Figure 4.15: Additive Decomposition Model with Only Seasonal Component Applied to Monthly Rainfall at Zarqa.

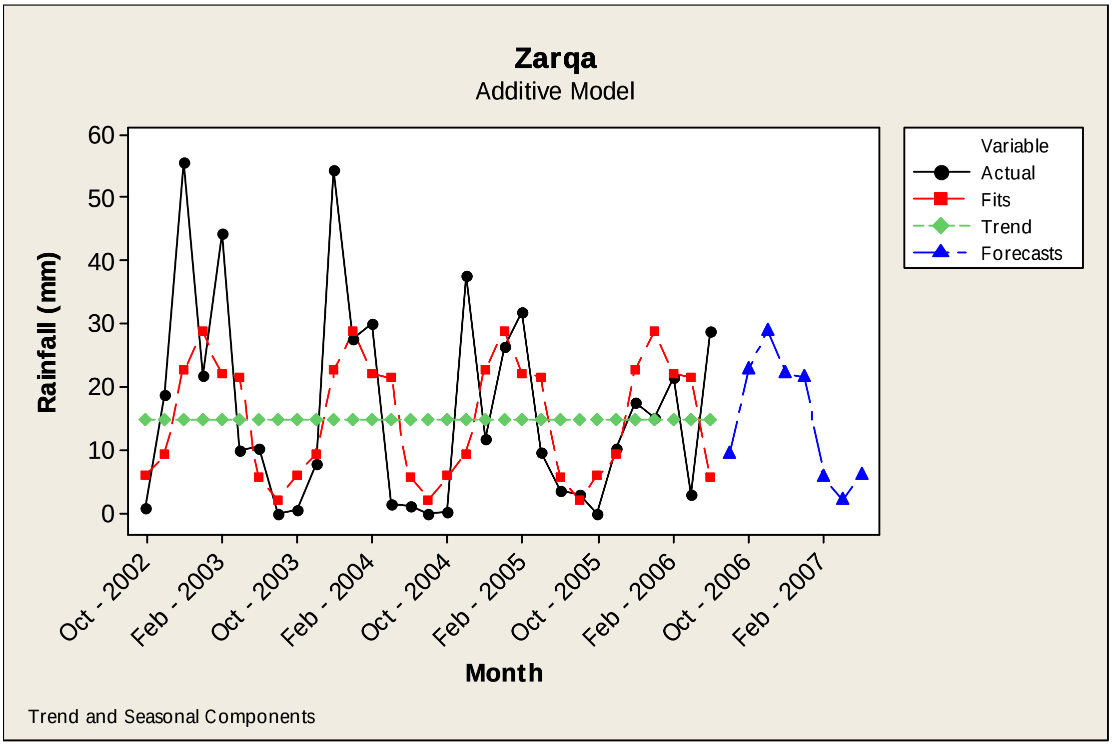

Figure 4.16: Additive Decomposition Model with Trend and Seasonal Components Applied to Monthly Rainfall at Zarqa.

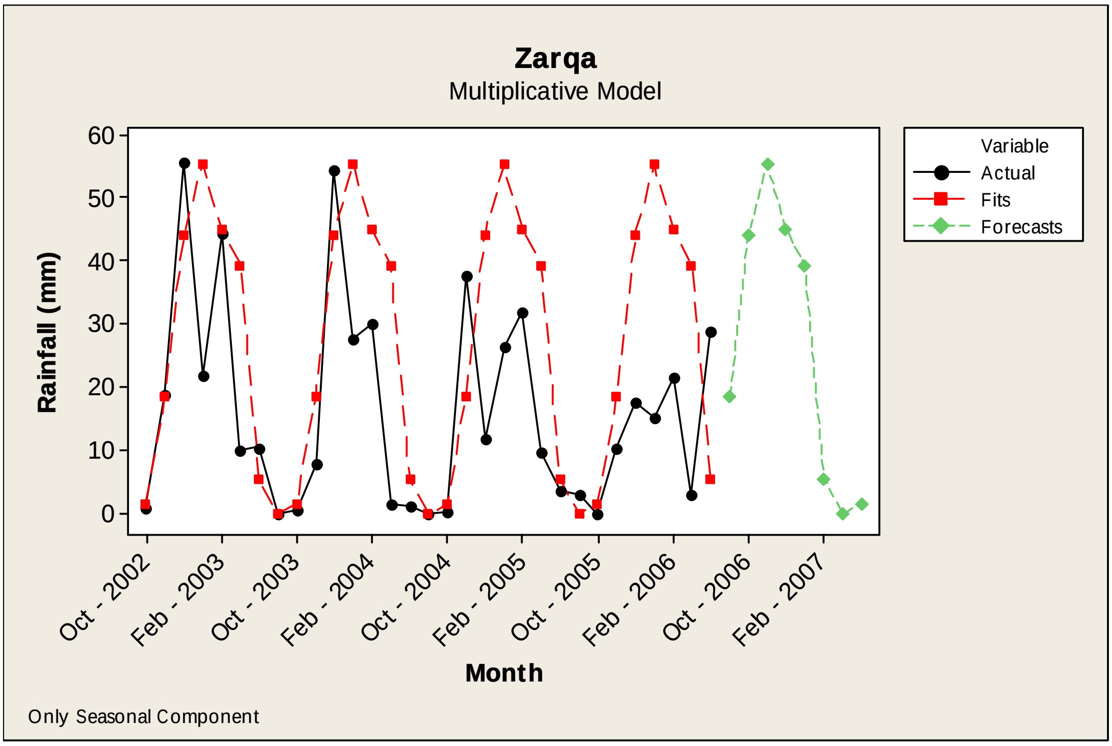

Figure 4.17: Multiplicative Decomposition Model with Only Seasonal Component Applied to Monthly Rainfall at Zarqa.

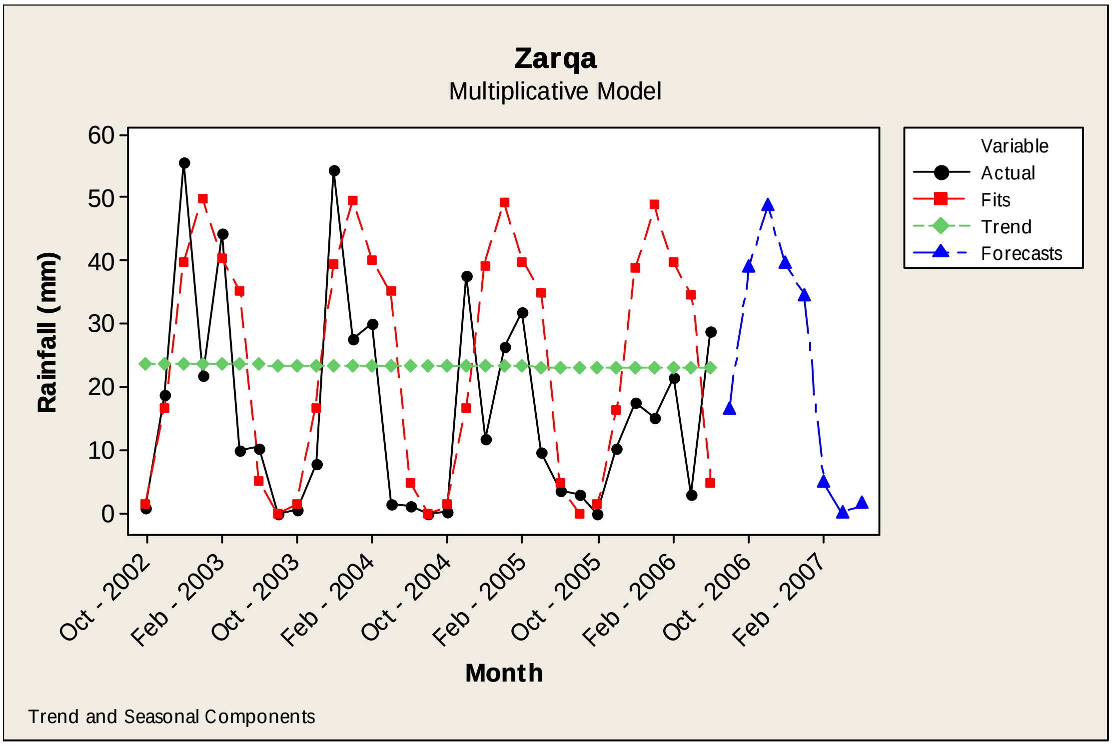

Figure 4.18: Multiplicative Decomposition Model with Trend and Seasonal Components Applied to Monthly Rainfall at Zarqa.

4.6 ARIMA Models

4.6.1 Description

The essence of ARIMA models is similar to smoothing and decomposition methods in that forecasts are based on historical time-series analysis; however the statistical theory behind ARIMA models is much well-developed. In order to use ARIMA models, substantial analysis of historical time series must be performed; appropriate model forms must be identified and applied for forecasting. ARIMA models development follows some general guidelines in addition to experience combined with trial and error approach.

4.6.2 Analysis Tools

Methodological tools for analyzing time series data in the process of ARIMA models development:

1. Plot of time series data.
2. Autocorrelation function (ACF): The ACF indicate the dependence structure of a time series by introducing correlation coefficients at a number of lags.
3. Partial autocorrelation function (PACF): The PACF indicate the degree of association between (X_t) and (X_{t-k}) when the effects of other time lags $(1,2,3,...,k-1)$ are partialled out. The partial autocorrelation coefficient of order (m) is defined as the last autoregressive coefficient of an AR(m) model. The development of a PACF plot involves the solution of a set of equations.

4.6.3 Backshift Operator and Differencing

The backshift operator is a useful notational device used to describe ARIMA model structures and the method of differencing. The backshift operator can be expressed as in Box 4.20.

Box 4.20: Backshift Operator

$BX_t = X_{t-1}$

Generally;

$B^n X_t = X_{t-n}$

Where;

B = Backshift operator.
X_t = Time series.
n = An integer indicating back-shifting.

The purpose of taking differences is to achieve stationarity and if it takes a d th-order difference to achieve stationarity, the d th-order difference will be expressed as in Box 4.21.

Box 4.21: The d th-order difference.

d th-order difference = $(1-B)^d X_t$
Where;
B = Backshift operator.
X_t = Time series.

In practice it's seldom necessary to go beyond the 1st and 2nd difference.

4.6.4 ARIMA Processes Expressions and Signatures

Box 4.22: An ARIMA (0, 0, 0) process or random model

$X_t = \mu + e_t$
Where;
X_t = Time series.
μ = Mean value.
e_t = Error term.

Box 4.23: An ARIMA (0, d, 0) process

$(1-B)^d X_t = e_t$
Where;
d = Order of differencing.

Box 4.24: An ARIMA (0, 1, 0) process can be expressed as follows:

$(1-B)X_t = e_t$
Or
$X_t - X_{t-1} = e_t$
$W_t = e_t$
Where;
$W_t = X_t - X_{t-1}$, a stationary random process.

A pure ARIMA (0, 1, 0) process will have theoretically zero autocorrelations and partial autocorrelations.

Box 4.25: An ARIMA (p, 0, 0) process or AR(p) can be expressed as follows:

$$X_t = \mu' + \phi_1 X_{t-1} + \phi_2 X_{t-2} + \ldots + \phi_p X_{t-p} + e_t$$

$$\mu' = \mu - \phi_1 \mu - \phi_2 \mu - \ldots - \phi_p \mu$$

Where;

μ' = Constant term.

ϕ_i = Autoregressive parameters.

Box 4.26: An ARIMA (1, 0, 0) process or AR(1)

$$X_t = \mu' + \phi_1 X_{t-1} + e_t$$

$$X_t - \phi_1 X_{t-1} = \mu' + e_t$$

$$(1 - \phi_1 B) X_t = \mu' + e_t$$

A pure AR(1) process will have an exponentially decaying autocorrelations and a single significant partial.

Box 4.27: An ARIMA (2, 0, 0) process or AR(2)

$$X_t = \mu' + \phi_1 X_{t-1} + \phi_2 X_{t-2} + e_t$$

$$X_t - \phi_1 X_{t-1} - \phi_2 X_{t-2} = \mu' + e_t$$

$$(1 - \phi_1 B - \phi_2 B^2) X_t = \mu' + e_t$$

A pure AR(2) process will have a damped sine wave decaying autocorrelations and exactly two significant partials.

Box 4.28: An ARIMA (0, 0, q) process or MA(q) can be expressed as follows:

$$X_t = \mu + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \ldots - \theta_q e_{t-q}$$

Where;

θ_i = Moving average parameters.

Box 4.29: An ARIMA (0, 0, 1) process or MA(1) can be expressed as follows:

$$X_t = \mu + (1 - \theta_1 B)e_t$$

A pure MA(1) process with positive (θ_1) will have one negative significant autocorrelation and the partials decay exponentially and all are negative. A pure MA(1) process with negative (θ_1) will have one positive significant autocorrelation and the partials decay exponentially with alternating sign.

Box 4.30: An ARIMA (0, 0, 2) process or MA(2)

$$X_t = \mu + (1 - \theta_1 B - \theta_2 B^2)e_t$$

A pure MA(2) process will have a two significant autocorrelations and partials will decay in a damped sine wave manner. Which is the opposite of a pure AR(2) process.

Box 4.31: An ARIMA (1, 0, 1) or ARMA (1,1) process

$$X_t = \mu' + \phi_1 X_{t-1} + e_t - \theta_1 e_{t-1}$$
$$(1 - \phi_1 B)X_t = \mu' + (1 - \theta_1 B)e_t$$

Where;

$(1 - \phi_1 B)X_t$ = AR(1) term.
$(1 - \theta_1 B)e_t$ = MA(1) term.

A Pure ARMA (1,1) will have autocorrelations and partials both decay exponentially with partials alternating in sign.

Box 4.32: An ARIMA (1, 1, 1) process

$$X_t = (1 + \phi_1)X_{t-1} - \phi_1 X_{t-2} + \mu' + e_t - \theta_1 e_{t-1}$$
$$(X_t - X_{t-1}) = \phi_1 (X_t - X_{t-1}) + \mu' + e_t - \theta_1 e_{t-1}$$
$$(1 - B)(1 - \phi_1 B)X_t = \mu' + (1 - \theta_1 B)e_t$$

Where;
$(1 - B)$= First difference.
$(1 - \phi_1 B)X_t$ = AR(1) term.
$(1 - \theta_1 B)e_t$ = MA(1) term.

The general ARIMA (p, q, d) model yields a tremendous variety of patterns in autocorrelations and partials that it's unwise to state rules for identifying ARIMA models. However, AR(1), MA(1), AR(2), MA(2) models do provide some identifying features that will help the forecaster zero in on a particular ARIMA model identification. It should be noted that several different models might yield the same quality forecasts so the process of identification is not as difficult as it might seem. The more noise in the data the more difficulty one will have in identifying an underlying ARIMA model. However, in practice it's seldom necessary to deal with values of p, d, or q that are other than 0, 1, or 2, and the model with the least number of parameters is to be preferred.

4.6.5 Seasonal ARIMA Models

ARIMA models can be extended to include seasonal aspects. In the same way consecutive data points may exhibit AR or and MA signatures, so data separated by seasonal length such as a month. Furthermore, seasonal differencing can be used to damp the magnitude of the correlation structure in the time series at specific lags of ACF. Box 4.33 illustrates the general notation of a seasonal ARIMA model.

Box 4.33: The General Notation of a Seasonal ARIMA Model.

$$ARIMA(p,d,q)(P,D,Q)^{S}$$

Where;

(p,d,q) = Non Seasonal ARIMA Part or Conventional.
(P,D,Q) = Seasonal ARIMA Part.
s = Number of Periods per Season.

4.6.6 Identification

Identification is the process by which an appropriate ARIMA model is identified with respect to the order of differencing, AR terms, and MA terms. Following is some guidelines on how to systematically specify model terms:

1. If the series has a positive autocorrelations out to a high number of lags and/or exhibits a distinctive pattern, then it probably needs a higher order of differencing.
2. If the lag-1 autocorrelation is zero or negative, or the autocorrelations are all small and patternless, then the series doesn't need a higher order of differencing.
3. Differencing will drive the positive lag-1 autocorrelation into zero or negative value. If the lag-1 autocorrelation is -0.5 or more negative and/or there is an excessive changes in sign from one autocorrelation to the other, then the series is probably over-differenced.
4. If the PACF of the differenced series displays a sharp cut-off and/or the lag-1 autocorrelation is positive, then the series is exhibiting an AR signature. The lag at which the PACF cuts-off is the number of the AR terms.
5. If the ACF of the differenced series displays a sharp cut-off and/or the lag-1 autocorrelation is negative, then the series is exhibiting an MA signature. The lag at which the ACF cuts-off is the number of the MA terms.

ARIMA models are identified based on the above-mentioned rules and considering the examples of basic ARIMA models signatures.

4.6.7 Parameter Estimation

AR and MA parameters of the identified ARIMA model have to be estimated, there are fundamentally two ways of doing this:

1. Trial and error where you examine different values and then you choose values that minimize the sum of squared residuals.
2. Iterative approach using a software package.

4.6.8 Diagnostic Checking

Diagnostic checking is the process by which the modeller verifies that identified and parameter estimated model is adequate. There are basically two ways of doing so:

1. Studying the ACF and PACF of the residuals. Adequate model will produce residuals that have neither significant autocorrelations nor partials.
2. Calculating certain Statistical Model Selection Criterions such as: Model standard error (Standard Deviation of the Error), Akaike's Information Criterion (AIC), and Schwarz's Bayesian Criterion (BIC). See Box 4.34 for illustration.

Box 4.34: AIC and BIC Statistical Criterions

$$AIC = 2k + n[\ln(2\pi RSS / n) + 1]$$

$$BIC = n \ln(RSS / n) + k \ln(n)$$

Where;
k = Number of Parameters in the Statistical Model.
RSS = Residual Sum of Squares.
n = Number of Data Points.

Figure 4.19 shows an ARIMA (0,1,1) model of calendar year mean temperature at Amman Airport station.

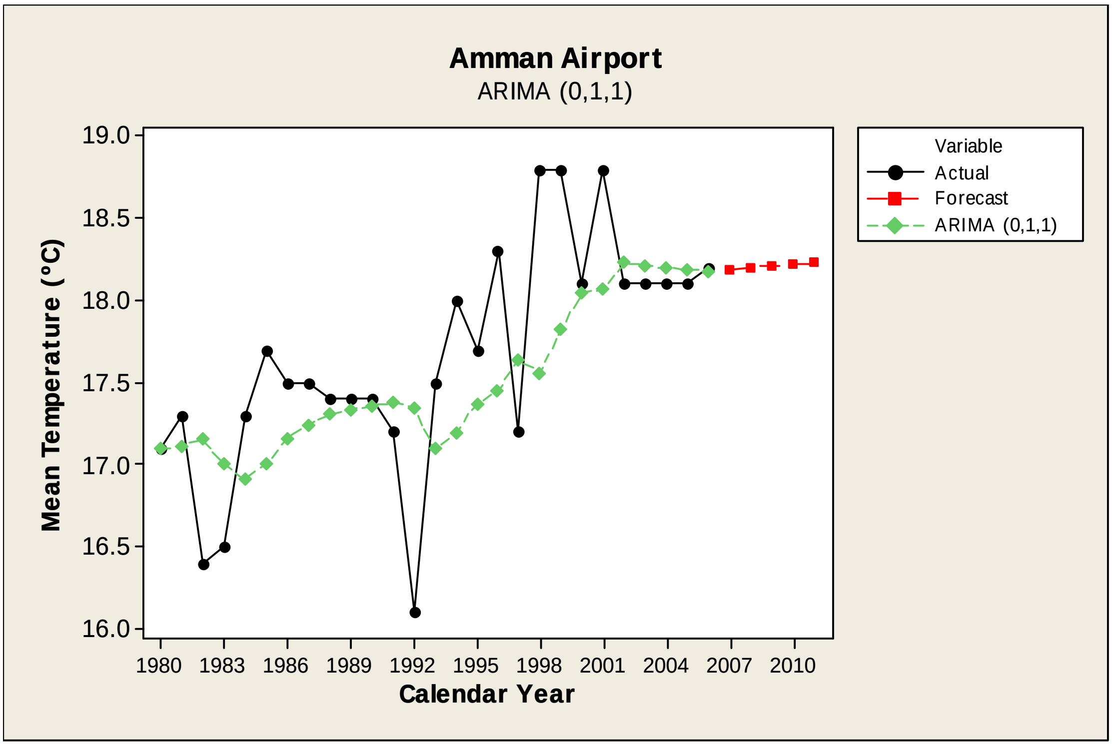

Figure 4.19: ARIMA (0,1,1) Model of Calendar Year Mean Temperature at Amman Airport.

CHAPTER (5): RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents analysis and modelling results in a condensed form. For each class of models there will be a discussion on the quality of results and an example on how to arrive at the best fit model. Furthermore, an example of model fits and forecast will be provided.

The research utilized: (1) 8 rainfall stations distributed uniformly across the basin, (2) 2 meteorological stations namely Amman Airport which represents the situation in western hilly areas and Wadi Dhuleil which represents the situation in the eastern arid areas, (3) 1 streamflow station in the west near the outlet of the basin and covering the catchment area of all rainfall stations used in research.

5.2 Linear Regression Models

Regression models are referred to as explanatory or casual forecasting models. Simple linear regression models are developed in research, in which the runoff is the dependant variable and rainfall is the independent variable. Furthermore, multiple regression models are developed, in which the monthly rainfall is the dependant variable and monthly mean temperature and relative humidity are the independent variables.

5.2.1 Simple Linear Regression

Simple linear regression models that are developed include (1) Runoff-events at New Jerash Bridge Station vs. Storm-cluster rainfall at Khaldiya rainfall station, (2) Monthly runoff at New Jerash Bridge Station vs. Monthly rainfall at Amman Airport

Station, and (3) Water year runoff at New Jerash Bridge Station vs. Water year rainfall at Amman Airport Station. Selection of variables was based on the highest value of correlation coefficient. Figure 5.1 shows the simple linear regression between the monthly runoff at New Jerash Bridge and the monthly rainfall at Amman Airport.

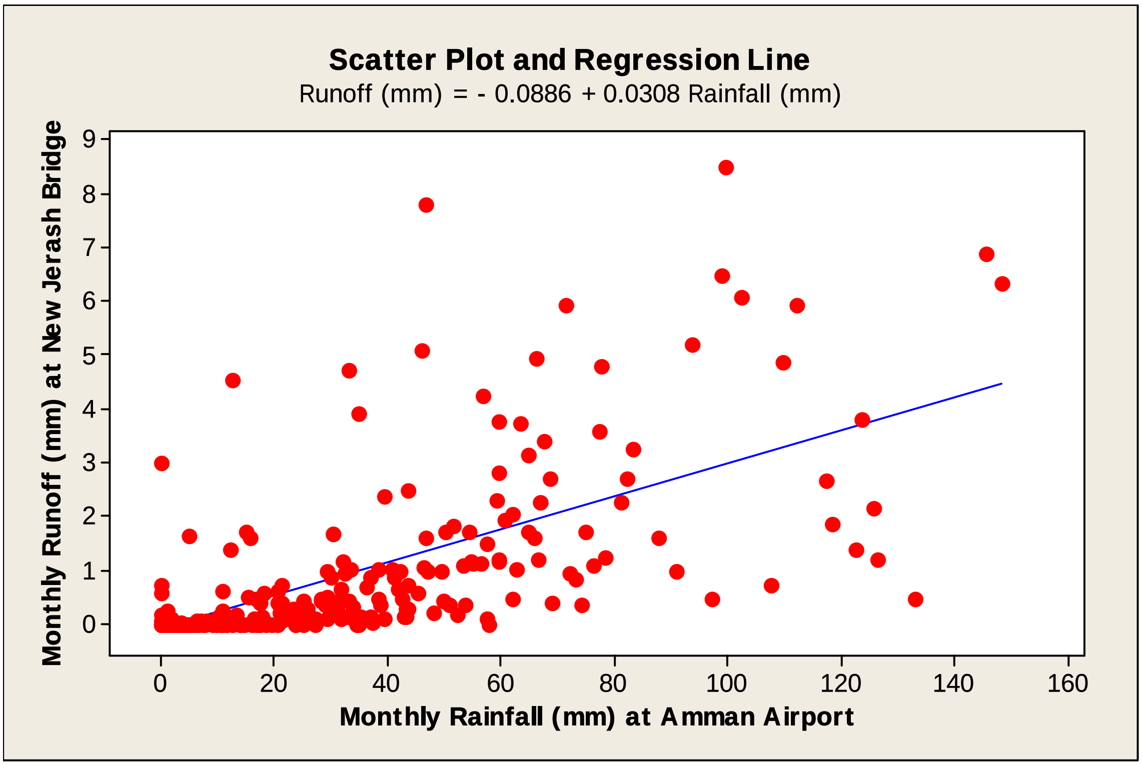

Figure 5.1: Simple Linear Regression Model of Monthly Runoff at New Jerash Bridge vs. Monthly Rainfall at Amman Airport.

Simple linear regression models developed are able to explain 37.5 %, 44.5 %, and 42.8 % of runoff variation at runoff event, monthly, and water year time scales, respectively.

5.2.2 Multiple Linear Regression Models

Multiple linear regression models are developed where the monthly rainfall is the dependant variable and the monthly mean temperature and relative humidity as the independent variables. Three rainfall stations are selected for modelling, namely: (1) Hussein College Station which represents the western hilly areas in Amman-Zarqa Basin, (2) Balama Station which represents the middle transitional zone between the hilly areas and the flat arid areas in the east of Amman-Zarqa Basin, and (3) Um El Jimal Station which represents the eastern arid areas of Amman-Zarqa Basin. Furthermore, this selection is reinforced by the value of correlation coefficient between the above mentioned stations and the two meteorological stations, Amman Airport and Wadi Dhuleil. Table 5.1 shows the R-square values of the respective models.

Table 5.1: R-Square Values (%) of Multiple Linear Regression Models of Monthly Rainfall as a Function of Monthly Mean Temperature and Relative Humidity.

Meteorological/Rainfall	**Hussein College**	**Balama**	**Um El Jimal**
Amman Airport	53.8	51.6	54.4
Wadi Dhuleil	55.3	52.3	54.3

It can be seen from Table 5.1 that the monthly mean temperature and relative humidity are able to explain at least 50 % of monthly rainfall variation at the selected stations. Figure 5.2 shows the 3D scatter plot and the multiple regression model of monthly rainfall at Hussein College and the monthly mean temperature and relative humidity at Wadi Dhuleil.

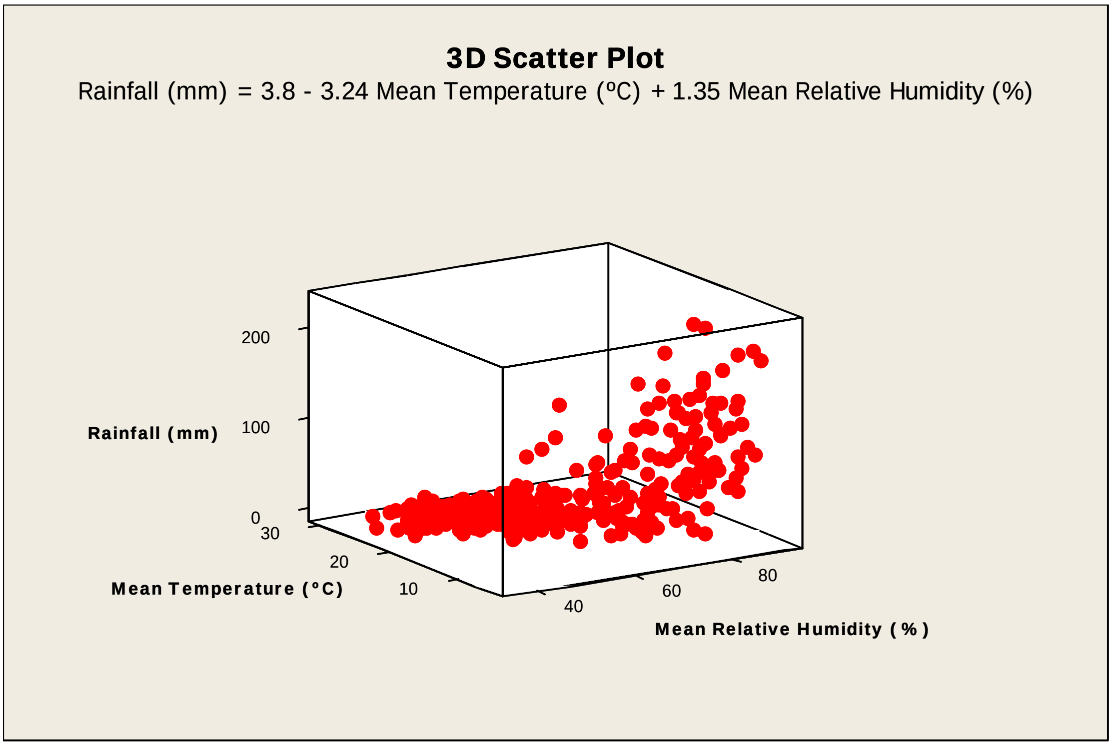

Figure 5.2: 3D Scatter Plot of Monthly Rainfall at Hussein College and the Monthly Mean Temperature and Relative Humidity at Wadi Dhuleil.

As can be seen from the model coefficients in Figure 5.2, the rainfall is inversely proportional with temperature and directly proportional with relative humidity.

5.3 Trend Analysis

5.3.1 Trend Modelling

Trend modelling is more about reflecting the direction of time series as time evolves more than merely arriving at a best fit model and providing forecasts. Four types of trend models are used to model time series data namely: linear, exponential growth, quadratic and S-curve trend models. All of these models have a mono-direction, either increasing or decreasing, except the quadratic model which has local direction changes, for this particular model the final tail direction will be considered in results.

The best fit model is selected based on the accuracy measures (MAPE, MAD, and MSD) comparison across the different models. Figure 5.3 shows accuracy measures values plotted against trend models types.

Figure 5.3: Accuracy Measures Values versus Trend Model Classes for Calendar Year Mean Temperature at Wadi Dhuleil.

Examination of Figure 5.3 gives that the best fit model of calendar year mean temperature at Wadi Dhuleil is the exponential growth model. Figure 5.4 shows the model plot and Figure 5.5 shows the residual plots, it can be seen that residuals are approximately normally distributed and by looking at the residuals versus fitted values plot, it can be seen that trend models provide poor fit.

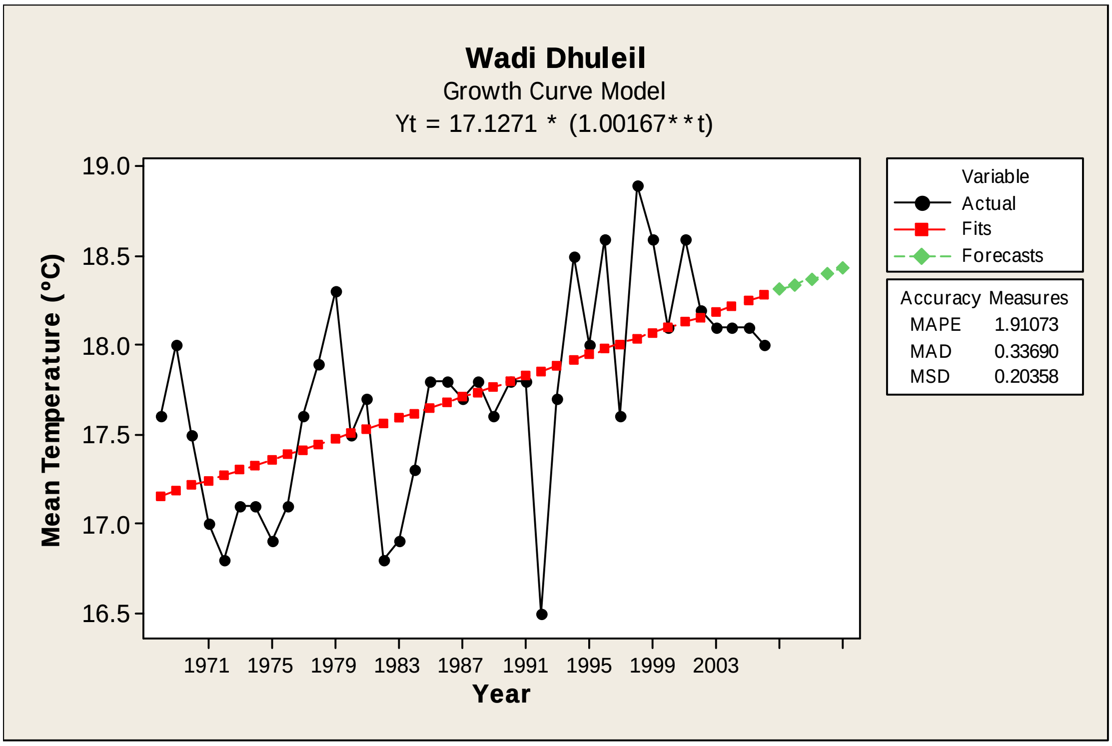

Figure 5.4: Exponential Growth Model of Calendar Year Mean Temperature at Wadi Dhuleil.

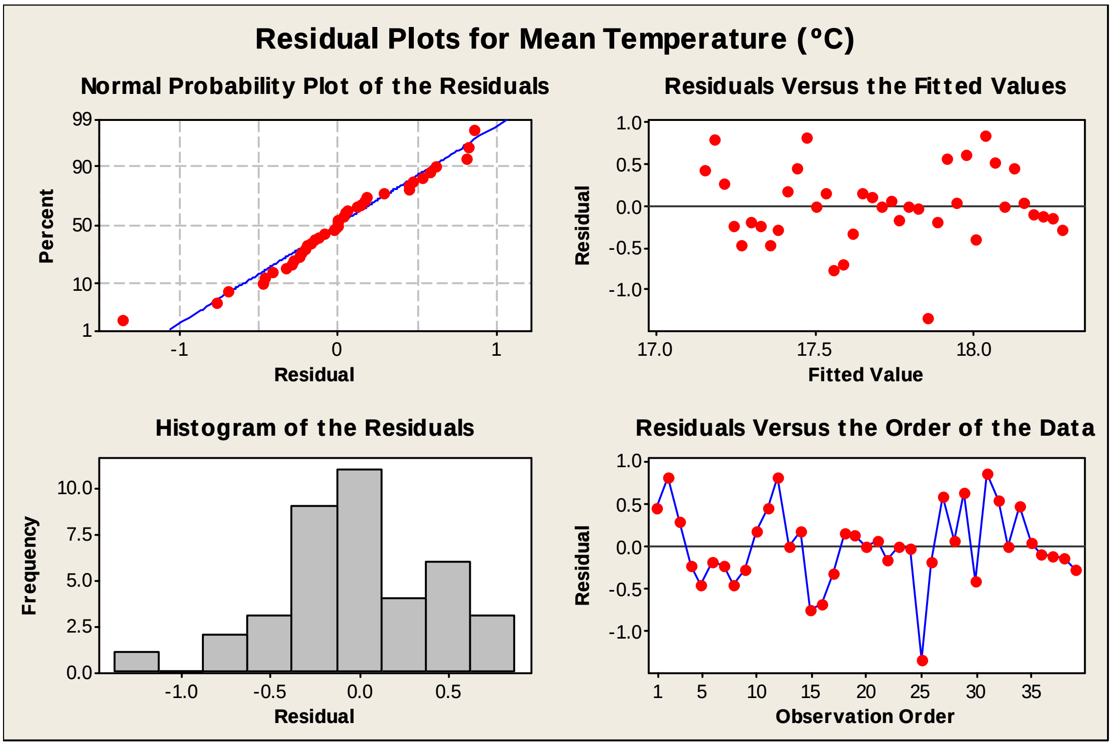

Figure 5.5: Exponential Growth Trend Model Residual Plots for Calendar Year Mean Temperature at Wadi Dhuleil.

5.3.2 Best Fit Trend Model and Direction

Table 5.2 illustrates the best fit trend model and the direction of each model for rainfall time series at all time scales. The best fit model is highlighted by shaded cell corresponding to the respective station at the specified time scale (Water year, monthly, and storm-cluster), wherever there is no shade, any model will perform equally well.

The direction of trend is specified by + to indicate an increasing trend and - to indicate a decreasing trend. For example, the best fit model for Madwar Station at the water year time scale is the quadratic trend model and the direction is specified by -, that is the model indicates a decreasing trend. The "No Fit" phrase in Table 5.2 indicates that the respective model couldn't be fit to data.

Table 5.2: Trend Models of Rainfall Time Series.

Water Year				
Station	**Linear**	**Exponential Growth**	**Quadratic**	**S-curve**
Amman Airport	-	-	-	-
Balama	-	-	+	No Fit
Hussein College	-	-	+	-
Khaldiya	+	+	-	No Fit
Madwar	+	+	-	+
Sabha & Subhiya	-	-	+	-
Um El Jimal	-	-	-	No Fit
Zarqa	-	+	-	No Fit
Monthly				
Station	**Linear**	**Exponential Growth**	**Quadratic**	**S-curve**
Amman Airport	-	No Fit	+	No Fit
Balama	-	No Fit	+	No Fit
Hussein College	-	No Fit	+	No Fit
Khaldiya	-	No Fit	-	-
Madwar	+	No Fit	+	-
Sabha & Subhiya	-	No Fit	+	-
Um El Jimal	-	No Fit	+	No Fit
Zarqa	+	No Fit	+	No Fit
Storm-Cluster				
Station	**Linear**	**Exponential Growth**	**Quadratic**	**S-curve**
Amman Airport	-	-	-	+
Balama	-	-	-	No Fit
Hussein College	-	-	-	No Fit
Khaldiya	-	-	-	-
Madwar	-	-	-	-
Sabha & Subhiya	-	-	+	-
Um El Jimal	-	-	-	No Fit
Zarqa	-	-	-	No Fit

It can be seen that trend models of rainfall time series at the water year and monthly time scales doesn't provide consistent results in terms of trend direction, even for the same rainfall station and across different trend models. For example, at the monthly time scale of Madwar station, the linear trend model is showing an increasing trend whereas the S-curve model is showing a decreasing one. Furthermore, the exponential growth trend model of Um El Jimal station, which is the best fit model, is showing a decreasing direction at the water year time scale whereas the quadratic trend model, which is the best fit model, of the same station is showing an increasing trend at the monthly time scale.

A possible explanation of the disparity in the trend models directions at the water year and monthly time scales is that trend model can be thought of as a time varying mean of the time series and as indicated in elementary statistics the mean will be more stable as more points are included in its calculation. This is not the case with respect to water year time scale due to low number of points. At the monthly time scale, seasonality component effects will mask the ability of the trend model to capture the direction of the trend component in time series, since any trend fitting procedure will minimize the residuals as much as possible.

The time series of storm-cluster rainfall are of sufficient length and free of seasonality effects to some extent. As it can be seen in Table 5.2, more consistent results in terms of trend direction and most of rainfall stations are showing a decreasing trend across the different types of trend models. Figure 5.6 shows an exponential growth model at Hussein College Station showing a decreasing trend in storm-cluster rainfall.

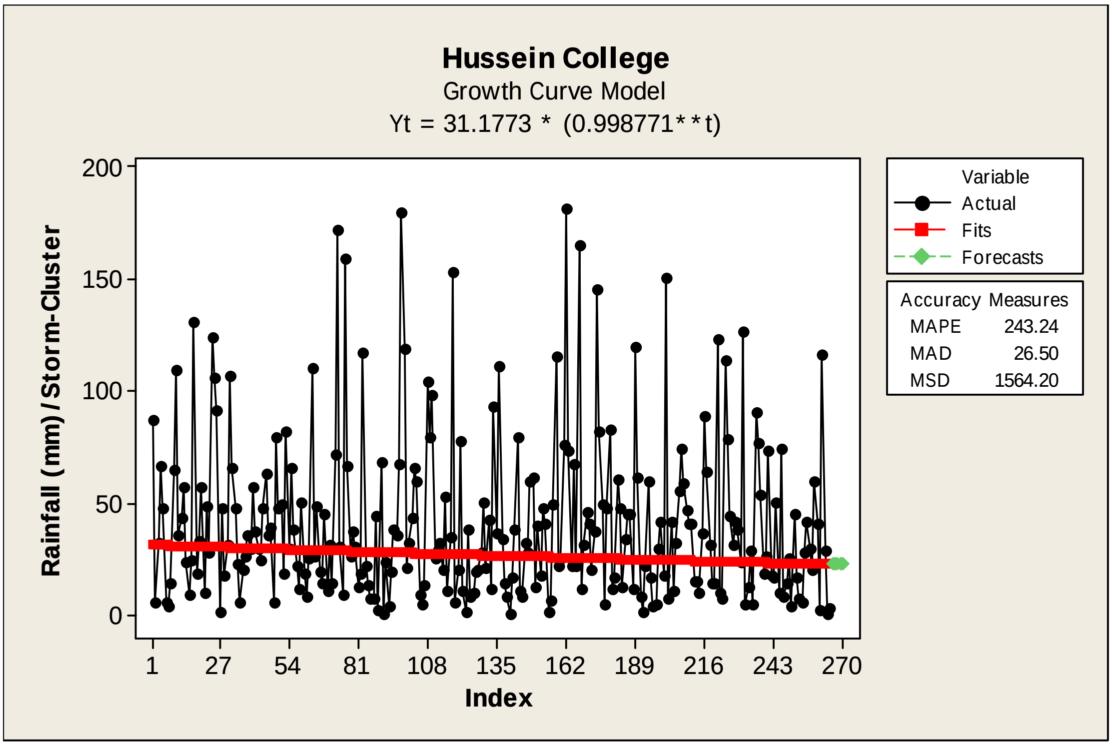

Figure 5.6: Exponential Growth Trend Model of Storm-Cluster Rainfall at Hussein College.

It should be noted here that any trend modelling is merely a fitting procedure that have an indirect implications of climate change. Table 5.3 illustrates the best fit trend models and directions of runoff and baseflow time series at New Jerash Bridge station.

Table 5.3: Trend Models of Runoff and Baseflow Time Series.

Runoff				
	Linear	**Exponential Growth**	**Quadratic**	**S-curve**
Water Year	+	+	+	+
Monthly	+	No Fit	-	+
Runoff-Event	-	+	-	+
BaseFlow				
	Linear	**Exponential Growth**	**Quadratic**	**S-curve**
Calendar Year	+	+	+	+

As it can be seen from Table 5.3, trend directions aren't consistent for runoff time series at water year, monthly, and runoff-event scales. Possible explanation of such disparity is that the New Jerash Bridge Station was relocated 50 m downstream due to inability to measure flow after the scouring caused by road making along the Wadi (MWI, 1989). Other possible explanations include errors in flood and baseflow separation process or measurement site scouring and poor rating curve calibration.

Table 5.3 illustrates an increasing trend in the baseflow time series, such increase can be attributed to increased wastewater discharge into Zarqa River from wastewater treatment plants. Figure 5.7 shows the S-curve model at New Jerash Bridge, the best fit, showing an increasing trend in calendar year baseflow.

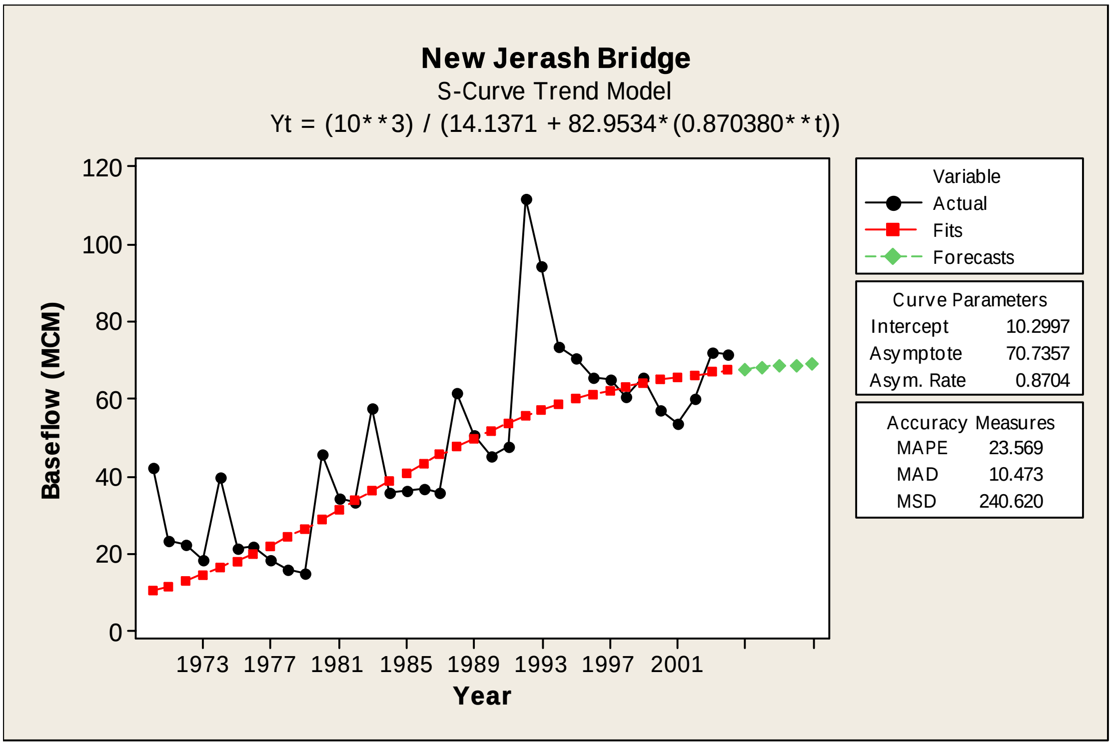

Figure 5.7: S-Curve Trend Model of Calendar Year Baseflow at New Jerash Bridge.

Table 5.4 illustrates the best fit trend models and directions of mean temperature time series at Amman Airport and Wadi Dhuleil stations. As can be seen from the table, all trend models are showing an increasing trend in the mean temperature in both stations and at different time scales. Figure 5.8 shows a quadratic model at Amman Airport, the best fit, showing an increasing trend in monthly mean temperature.

Table 5.4: Trend Models of Temperature Time Series.

Calendar Year				
Station	**Linear**	**Exponential Growth**	**Quadratic**	**S-curve**
Amman Airport	+	+	+	No Fit
Wadi Dhuleil	+	+	+	+
Monthly				
Station	**Linear**	**Exponential Growth**	**Quadratic**	**S-curve**
Amman Airport	+	+	+	No Fit
Wadi Dhuleil	+	+	+	No Fit

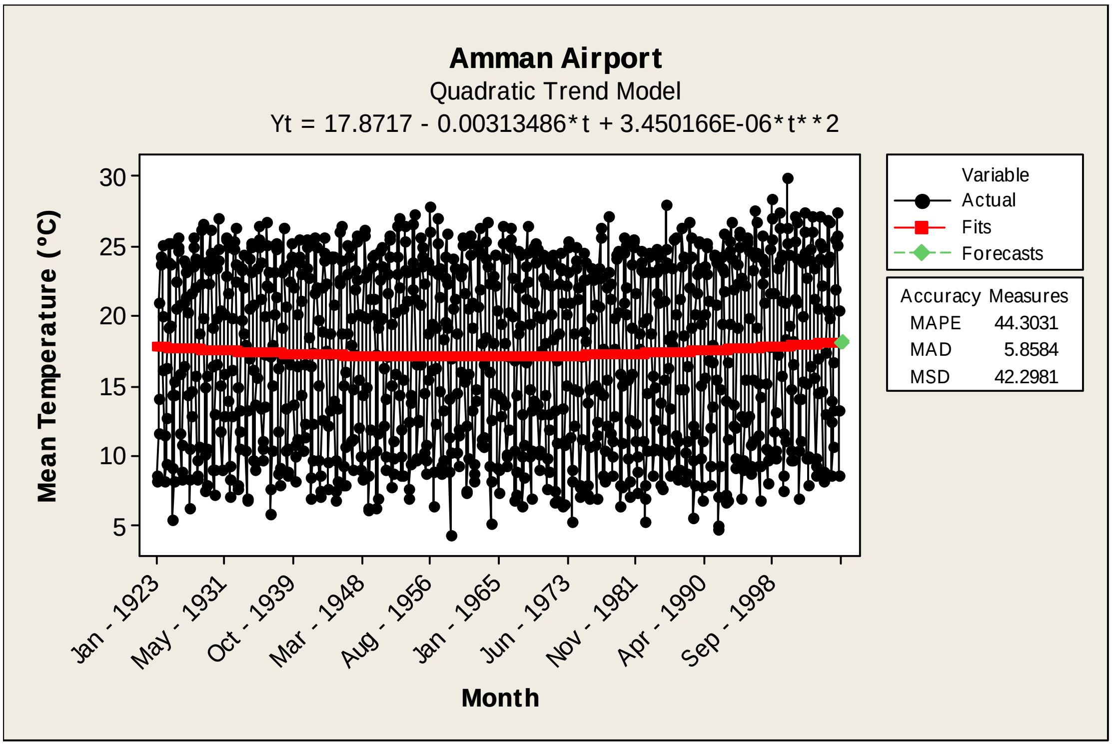

Figure 5.8: Quadratic Trend Model of Monthly Mean Temperature at Amman Airport.

Table 5.5 illustrates the best fit trend models and directions of mean relative humidity time series at Amman Airport and Wadi Dhuleil stations. At Amman Airport station, the best fit trend model is showing a decreasing trend in the mean relative humidity at the calendar year and monthly time scales; however, other models are showing an increasing trend. At Wadi Dhuleil all trend models are showing an increase in the mean relative humidity. Figure 5.9 shows quadratic model at Wadi Dhuleil, the best fit, showing an increasing trend in monthly mean relative humidity.

Table 5.5: Trend Models of Relative Humidity Time Series.

Calendar Year				
Station	**Linear**	**Exponential Growth**	**Quadratic**	**S-curve**
Amman Airport	+	+	-	No Fit
Wadi Dhuleil	+	+	+	+
Monthly				
Station	**Linear**	**Exponential Growth**	**Quadratic**	**S-curve**
Amman Airport	+	+	-	No Fit
Wadi Dhuleil	+	+	+	+

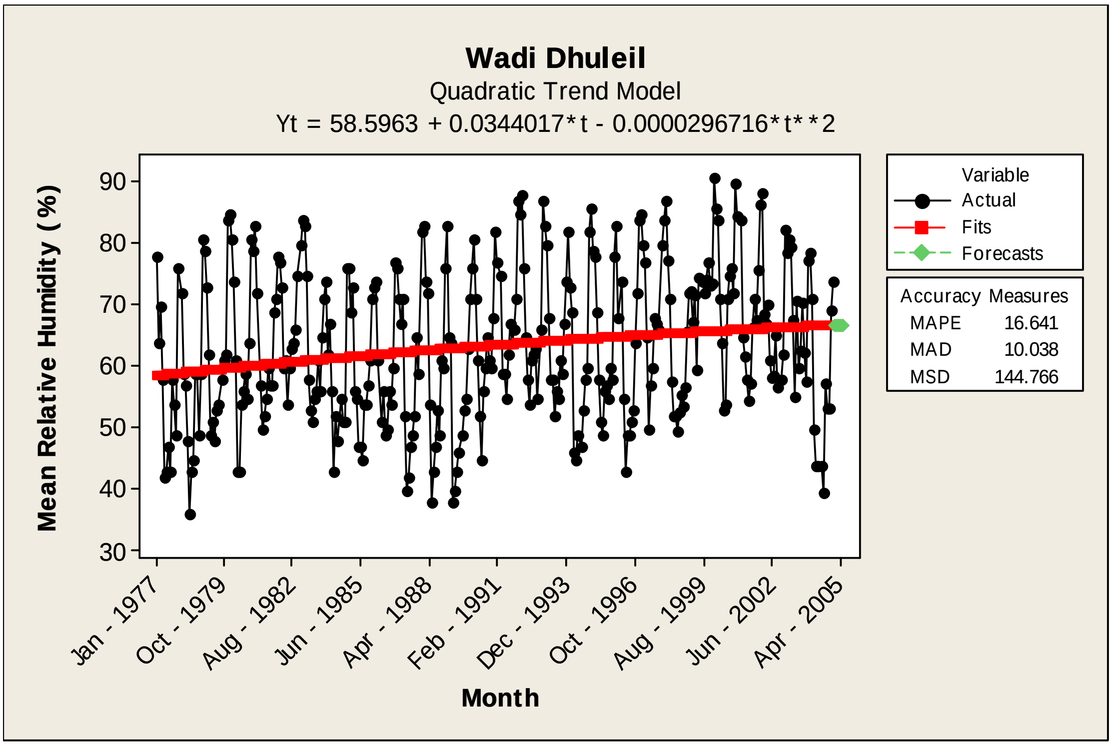

Figure 5.9: Quadratic Trend Model of Monthly Mean Relative Humidity at Wadi Dhuleil.

5.3.3 Rainfall Extreme Events

Table 5.6 presents linear trend models slope coefficients of storm-cluster rainfall, rainy days per storm-cluster, and rainfall intensity (mm/day) time series. Slope coefficients can be thought of as change rates, and as such one can see that the change rates in storm-cluster time series is much more than those of rainy days and thus intensity. According to Table 5.6 there is no evidence of extreme events occurrence in future although this doesn't rule out such phenomenon since it might be in its early stages and couldn't be detected using the available records. Table 5.7 shows storm-cluster rainfall, rainy days per storm-cluster, and rainfall intensity (mm/day) time series arranged in a descending order.

Table 5.6: Storm-Cluster Rainfall, Rainy Days, and Rainfall Intensity Change Rates.

Station	Storm-Cluster Rainfall	Rainy Days/Storm-Cluster	Intensity
Amman Airport	-0.016	0.0007	-0.01
Balama	-0.031	-0.0007	-0.012
Hussein College	-0.027	-0.0005	-0.004
Khaldiya	-0.017	-0.0011	-0.007
Madwar	-0.027	-0.0006	-0.012
Sabha and Subhiya	-0.009	-0.0011	-0.006
Um El Jimal	-0.006	-0.0014	-0.001
Zarqa	-0.011	-0.0008	-0.004

Table 5.7: Change Rates of Storm-Clusters, Rainy Days, and Intensity in a Descending Order.

Station	Storm Cluster	Station	Rainy Days/Storm-Cluster	Station	Intensity
Um El Jimal	-0.006	Amman Airport	0.0007	Um El Jimal	-0.001
Sabha and Subhiya	-0.009	Hussein College	-0.0005	Hussein College	-0.004
Zarqa	-0.011	Madwar	-0.0006	Zarqa	-0.004
Amman Airport	-0.016	Balama	-0.0007	Sabha and Subhiya	-0.006
Khaldiya	-0.017	Zarqa	-0.0008	Khaldiya	-0.007
Hussein College	-0.027	Khaldiya	-0.0011	Amman Airport	-0.010
Madwar	-0.027	Sabha and Subhiya	-0.0011	Balama	-0.012
Balama	-0.031	Um El Jimal	-0.0014	Madwar	-0.012

5.3.4 Rainy Season Shifting

Table 5.8 illustrates the linear trend models slope coefficients or change rates of rainfall-month time series as per rainfall station. It can be seen that positive change rates are observed for the months December and January whereas a negative change rate is observed for March and April for all rainfall stations. Such observations indicate that any shifting in the rainy season isn't perceived and may be more time is needed to quantify and detect such change. Furthermore, it was found that there is no shifting in the center of gravity of storm-clusters distribution in Amman-Zarqa basin as could be expected for a shifting rainy season, see Table 5.9.

Table 5.8: Slope Coefficients of Linear Trend Models of Rainfall-Month Time Series.

Month	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
Oct	-0.13	-0.076	0.045	-0.08	-0.055	-0.039	-0.0092	-0.027
Nov	0.032	-0.042	-0.18	0.18	-0.027	-0.0081	-0.033	0.11
Dec	**0.17**	**0.036**	**0.44**	**0.22**	**0.67**	**0.27**	**0.15**	**0.44**
Jan	**0.37**	**0.23**	**0.57**	**0.42**	**0.87**	**0.08**	**0.23**	**0.34**
Feb	0.36	0.13	0.053	-0.058	0.66	-0.31	-0.0052	-0.096
Mar	**-0.52**	**-0.89**	**-0.65**	**-0.56**	**-0.85**	**-0.46**	**-0.41**	**-0.5**
Apr	**-0.16**	**-0.12**	**-0.093**	**-0.18**	**-0.087**	**-0.11**	**-0.092**	**-0.013**
May	0.0099	0.016	0.057	0.048	0.039	-0.044	0.014	0.042

Table 5.9: Storm-Clusters Distribution in Amman-Zarqa Basin Since the Water Year 70/71.

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
70/71			1	3		1	1		6
71/72			2	1	1	1	1		6
72/73		1		1	2	1			5
73/74		2	1	2	1	2			8
74/75		1	1		4	2	1		9
75/76		1		1	2	2			6
76/77		1	1	1	1	1	1		6
77/78	1	1	2	1	2	2			9
78/79			1	2	1	1			5
79/80	2	2	4	3	3	1	1		16
80/81			2	1	2	1	1		7
81/82					2	4	1	1	8
82/83	1	2		4	1	2		1	11
83/84		1		2	1	2			6
84/85	1		2		3	1			7
85/86			1	1	3		1		6
86/87	1	2	1	1	2	1			8
87/88	2		4	3	3	2	1		15
88/89	1		3	3	1	1			9
89/90				3	2	2	1		8
90/91	1			3	1	2			7
91/92			2		1				3
92/93		1	3	1	1				6
93/94	1			3		2			6
94/95		2	1		2				5
95/96				3	1	2			6
96/97		2	1	3	1	1			8
97/98	2	1	2	4	2	2			13
98/99				2	2				4
99/00				3	1	2			6
00/01	2		2	1	1	1		1	8
01/02			2	3	1	2	1		9
02/03			3	2	4	3			12
03/04			4	4	3	1	1		13
04/05		3	1	2	2	1	1	1	11
Average	**<1**	**<1**	**1 - 2**	**~2**	**~2**	**1 - 2**	**<1**	**<1**	**8**

The last row in Table 5.9 represents the long-term average of the number of storm-clusters in any given month (Considering zero values). In a way; it can be considered as some sort of forecast. For example, it's expected to have at best two significant or runoff producing storm-clusters in January and eight storm-clusters in any given water year.

5.3.5 Mann-Kendall Test

Trend models fitting give an indirect insight into the existence of trends in data. For a more formal detection and confidence, a more specialised approach is recommended such as the Mann-Kendall test for trend detection and significance.

A positive Z-Statistic value indicates an upward trend whereas a negative Z-Statistic value indicates a downward trend. The P-values are the standard normal distribution probabilities from left to right. The P-values are used to determine if the Z-Statistic values are falling in the rejection regions of the null hypothesis H_o: No Trend in Data.

Table 5.10 presents the Mann-Kendall statistics of rainfall time series. Storm-cluster rainfall at Balama, Khaldiya, Madwar, and Sabha & Subhiya is showing a significant downward trend at 0.05 level, while at Zarqa the downward trend is significant at 0.1 level. In other stations such as Amman Airport and Hussein College the storm-cluster rainfall is showing a very close proximity to the 0.1 significance level. However at the monthly and water year time scales, the trends are weak and with no significance.

Table 5.10: Rainfall Time Series Mann-Kendall Statistics.

Station	Storm-Cluster		Monthly		Water Year	
	Z-Statistic	P-Value	Z-Statistic	P-Value	Z-Statistic	P-Value
Amman Airport	-1.143	0.126	-0.456	0.324	-0.586	0.279
Balama	-2.624*	0.004	-0.621	0.267	-0.286	0.387
Hussein College	-1.265	0.103	-0.308	0.379	-0.790	0.215
Khaldiya	-2.278*	0.011	0.020	0.508	0.245	0.597
Madwar	-2.002*	0.023	0.701	0.758	0.845	0.801
Sabha and Subhiya	-1.675*	0.047	-1.079	0.140	-0.913	0.181
Um El Jimal	-0.888	0.187	-0.855	0.196	-0.354	0.362
Zarqa	-1.366**	0.086	0.435	0.668	0.545	0.707

* = Significant at ($\alpha/2 = 0.05$).
** = Significant at ($\alpha/2 = 0.1$).

Table 5.11 presents Mann-Kendall statistics of runoff and baseflow time series, as can be seen from the table runoff time series are showing upward trends, while a very significant upward trend exists for calendar year baseflow.

Table 5.11: Runoff and Baseflow Time Series Mann-Kendall Statistics.

Time Scale	Z-Statistic	P-Value
Runoff Events	0.845	0.801
Monthly Runoff	0.603	0.727
Water Year Runoff	1.350**	0.911
Calendar Year Baseflow	4.559*	0.999

* = Significant at ($\alpha/2 = 0.05$).
** = Significant at ($\alpha/2 = 0.1$).

Table 5.12 presents the Mann-Kendall statistics of temperature and relative humidity, as can be seen from the table temperature and relative humidity time series are showing upward trends for Amman Airport and Wadi Dhuleil Stations, where the trends are more significant at Wadi Dhuleil.

Table 5.12: Temperature and Relative Humidity Time Series Mann-Kendall Statistics.

Time Scale	Temperature (ºC)			
	Amman Airport		Wadi Dhuleil	
	Z-Statistic	P-Value	Z-Statistic	P-Value
Monthly	1.142	0.771	1.615**	0.947
Calendar Year	1.046	0.852	3.971*	0.999
Time Scale	**Relative Humidity (%)**			
	Amman Airport		**Wadi Dhuleil**	
	Z-Statistic	**P-Value**	**Z-Statistic**	**P-Value**
Monthly	0.956	0.830	3.488*	0.999
Calendar Year	0.921	0.822	2.292*	0.989

* = Significant at ($\alpha/2 = 0.05$).
** = Significant at ($\alpha/2 = 0.1$).

Table 5.13 presents Mann-Kendall statistics of mean maximum and minimum month-temperature at Amman Airport station, as can be seen from the table minimum month-temperature is showing a significant upward trend mostly in dry months. This observation has an important implications regarding temperature variation within the day. Furthermore nearly downward trends, sometimes significant as would be for November, are observed in wet months. This could imply a tendency toward warmer summers and colder winters. These two Phenomena, temperature variation and warmer summers and colder winters, are worth-while to investigate on a regional scale.

Table 5.13: Month-Temperature Time Series Mann-Kendall Statistics.

Mean Max Month-Temp			Mean Min Month-Temp		
Month	Z-Statistic	P-Value	Month	Z-Statistic	P-Value
Jan	0.549	0.708	Jan	0.638	0.738
Feb	0.363	0.642	Feb	0.507	0.694
Mar	-0.873	0.191	Mar	0.994	0.840
Apr	0.058	0.523	Apr	2.424*	0.992
May	-0.576	0.282	May	2.149*	0.984
Jun	-0.569	0.285	Jun	4.864*	0.999
Jul	0.653	0.743	Jul	4.329*	0.999
Aug	-0.688	0.246	Aug	3.305*	0.999
Sep	-0.808	0.210	Sep	3.329*	0.999
Oct	-1.504**	0.066	Oct	2.054*	0.980
Nov	-2.300*	0.011	Nov	-1.581**	0.057
Dec	-1.047	0.147	Dec	-0.367	0.357

* = Significant at ($\alpha/2 = 0.05$).
** = Significant at ($\alpha/2 = 0.1$).

5.4 Smoothing Models

Smoothing models includes the moving average (MA) and the single exponential smoothing (SES) models. Smoothing models are applied to calendar and water year time series.

5.4.1 Moving Average Models

To find the best fit MA model length, different MA lengths should be tried and then to observe accuracy measures values change. As an illustration, Figure 5.10 shows the accuracy measures values plotted against different MA lengths for the calendar year mean relative humidity at Amman Airport Station.

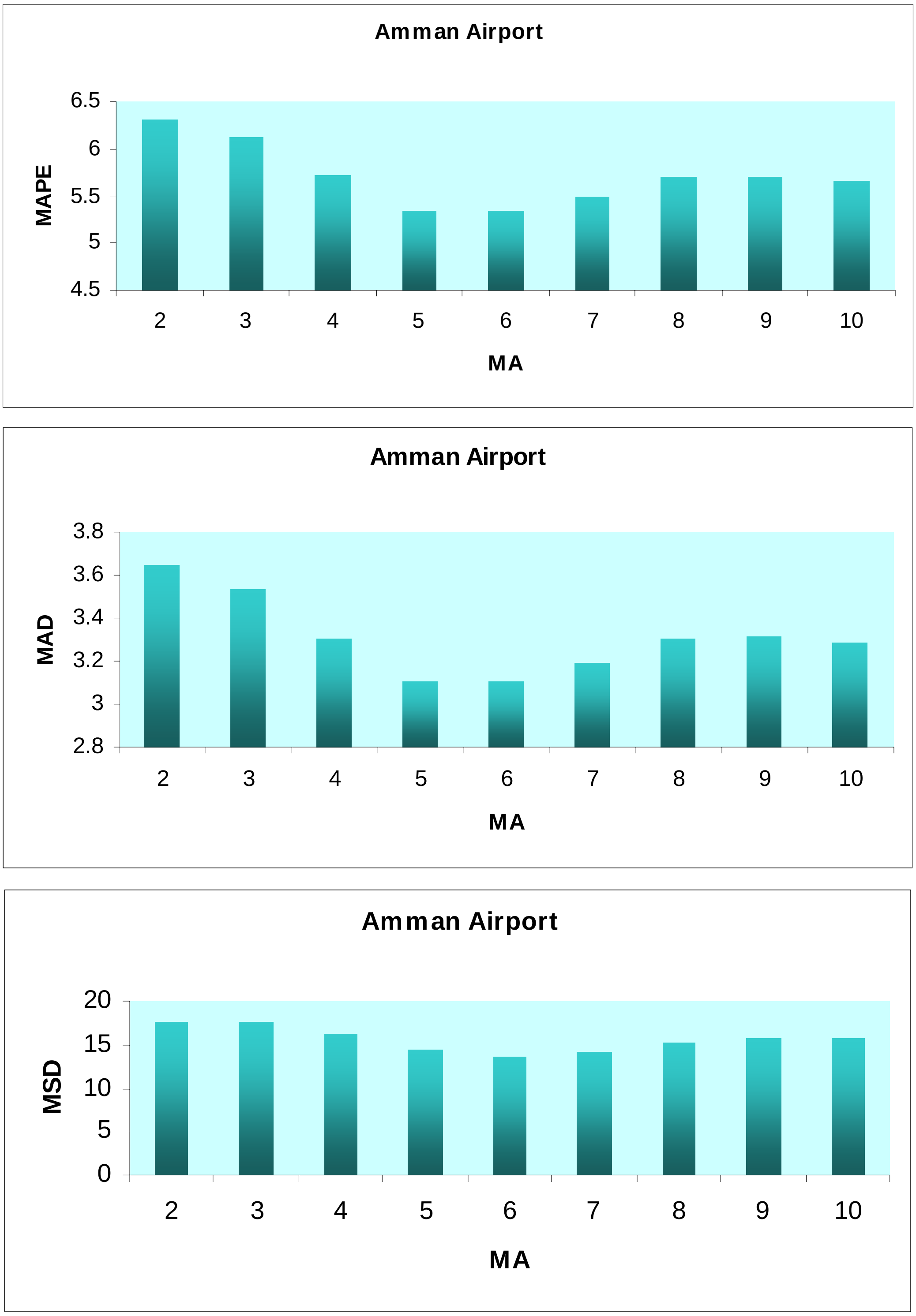

Figure 5.10: Accuracy Measures Values versus MA Lengths for Calendar Year Mean Relative Humidity at Amman Airport.

It can be seen from Figure 5.10 that the best MA length of the calendar year mean relative humidity at Amman Airport is 6. Figure 5.11 shows the MA (6) model plot and Figure 5.12 shows the residual plots.

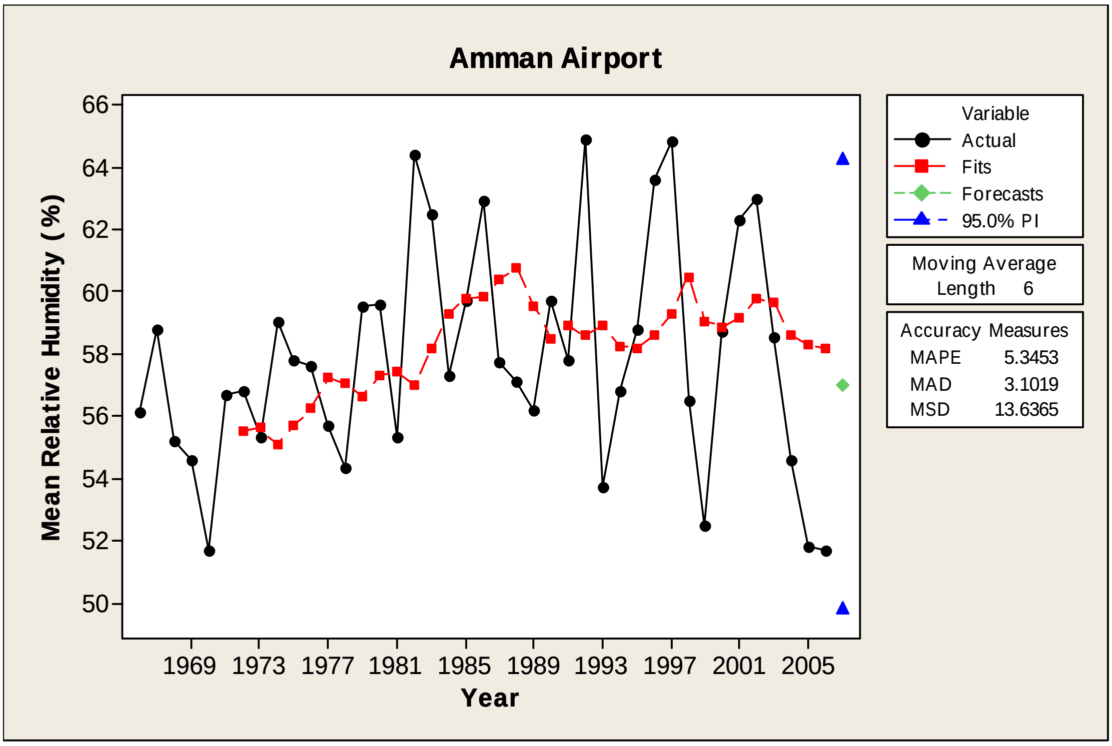

Figure 5.11: MA (6) Model of the Calendar Year Mean Relative Humidity at Amman Airport.

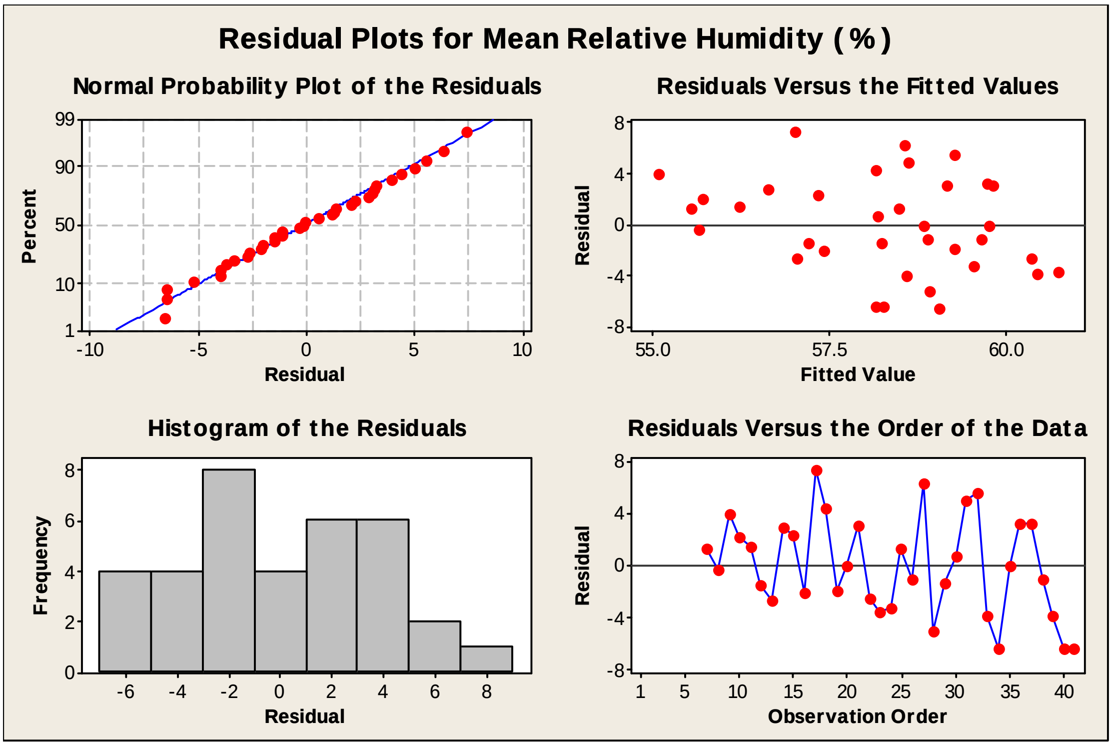

Figure 5.12: Residual Plots of the MA (6) Model of the Calendar Year Mean Relative Humidity at Amman Airport.

Table 5.14 presents the corresponding best MA lengths of the calendar and water year time series as per respective station. Table 5.15 presents MA models fits and forecasts (Bold) of the calendar year mean temperature and relative humidity.

Table 5.14: Best-Fit MA Lengths of Calendar and Water Year Time Series.

Rainfall		**Runoff**		**Temperature**	
Station	**MA**	**Station**	**MA**	**Station**	**MA**
Amman Airport	5	New Jerash Bridge	7	Amman Airport	6
Balama	5	**Baseflow**		Wadi Dhuleil	3
Hussein College	5	**Station**	**MA**	**Relative Humidity**	
Khaldiya	8	New Jerash Bridge	4	**Station**	**MA**
Madwar	5			Amman Airport	6
Sabha and Subhiya	4			Wadi Dhuleil	9
Um El Jimal	5				
Zarqa	3				

Table 5.15: Best MA Model Fits and Forecasts of Calendar Year Mean Temperature and Relative Humidity at Respective Stations.

Year	**Mean Temperature (ºC)**				**Mean Relative Humidity (%)**			
	Amman Airport		**Wadi Dhuleil**		**Amman Airport**		**Wadi Dhuleil**	
	Actual	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**
1986	17.5	17.1	17.8	17.3	62.9	59.8	61.4	60.9
1987	17.5	17.1	17.7	17.6	57.7	60.4	58.1	61.4
1988	17.4	17.2	17.8	17.8	57.1	60.8	59.2	61.7
1989	17.4	17.3	17.6	17.8	56.2	59.5	55.8	61.5
1990	17.4	17.5	17.8	17.7	59.7	58.5	63	60.7
1991	17.2	17.5	17.8	17.7	57.8	58.9	68.7	60.6
1992	16.1	17.4	16.5	17.7	64.9	58.6	68.3	60.8
1993	17.5	17.2	17.7	17.4	53.7	58.9	64.3	61.2
1994	18	17.2	18.5	17.3	56.8	58.2	62.5	61.8
1995	17.7	17.3	18	17.6	58.8	58.2	62.3	62.4
1996	18.3	17.3	18.6	18.1	63.6	58.6	62.1	62.5
1997	17.2	17.5	17.6	18.4	64.8	59.3	69.9	62.9
1998	18.8	17.5	18.9	18.1	56.5	60.4	61	64.1
1999	18.8	17.9	18.6	18.4	52.5	59.0	71.9	64.7
2000	18.1	18.1	18.1	18.4	58.7	58.8	73.9	65.7
2001	18.8	18.2	18.6	18.5	62.3	59.2	69.4	66.2
2002	18.1	18.3	18.2	18.4	63	59.7	66.4	66.4
2003	18.1	18.3	18.1	18.3	58.5	59.6	68.6	66.6
2004	18.1	18.5	18.1	18.3	54.6	58.6	56.5	67.3
2005	18.1	18.3	18.1	18.1	51.8	58.3		**66.6**
2006	18.2	18.2	18	18.1	51.7	58.2		
2007		**18.2**		**18.1**		**57.0**		

5.4.2 Single Exponential Smoothing

To find the best fit SES model, an accurate value of the smoothing constant alpha (α) has to be specified. As an illustration, Figure 5.13 shows accuracy measures values plotted against the smoothing constant alpha in the range of (0,1) for water year rainfall at Balama rainfall station as a preliminary step.

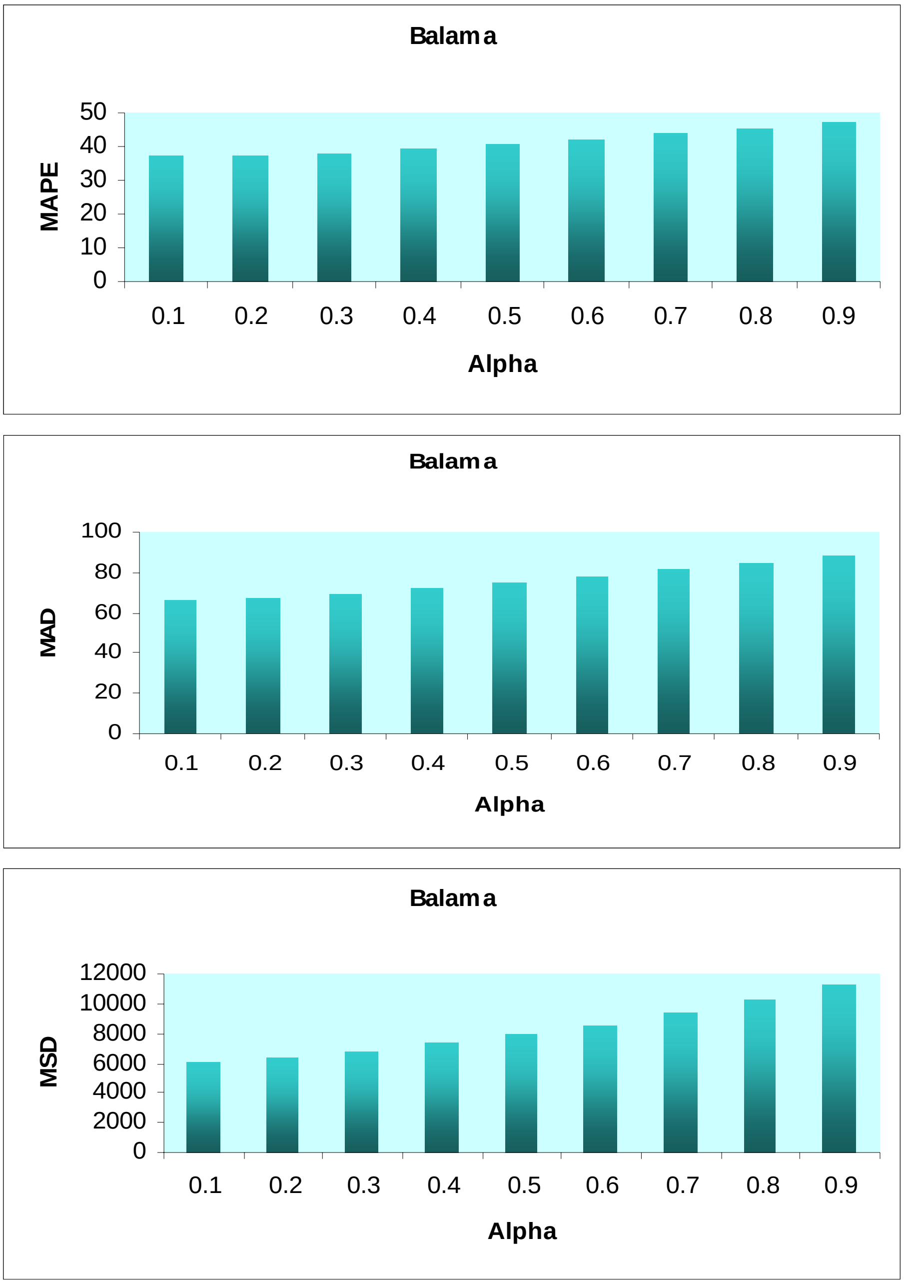

Figure 5.13: Alpha Values versus Accuracy Measures of Water Year Rainfall at Balama.

Inspection of Figure 5.13 indicates that the best fit alpha value lies somewhere around 0.1. Figure 5.14 shows accuracy measures values plotted against another set of alpha values in the range of (0.0, 0.2).

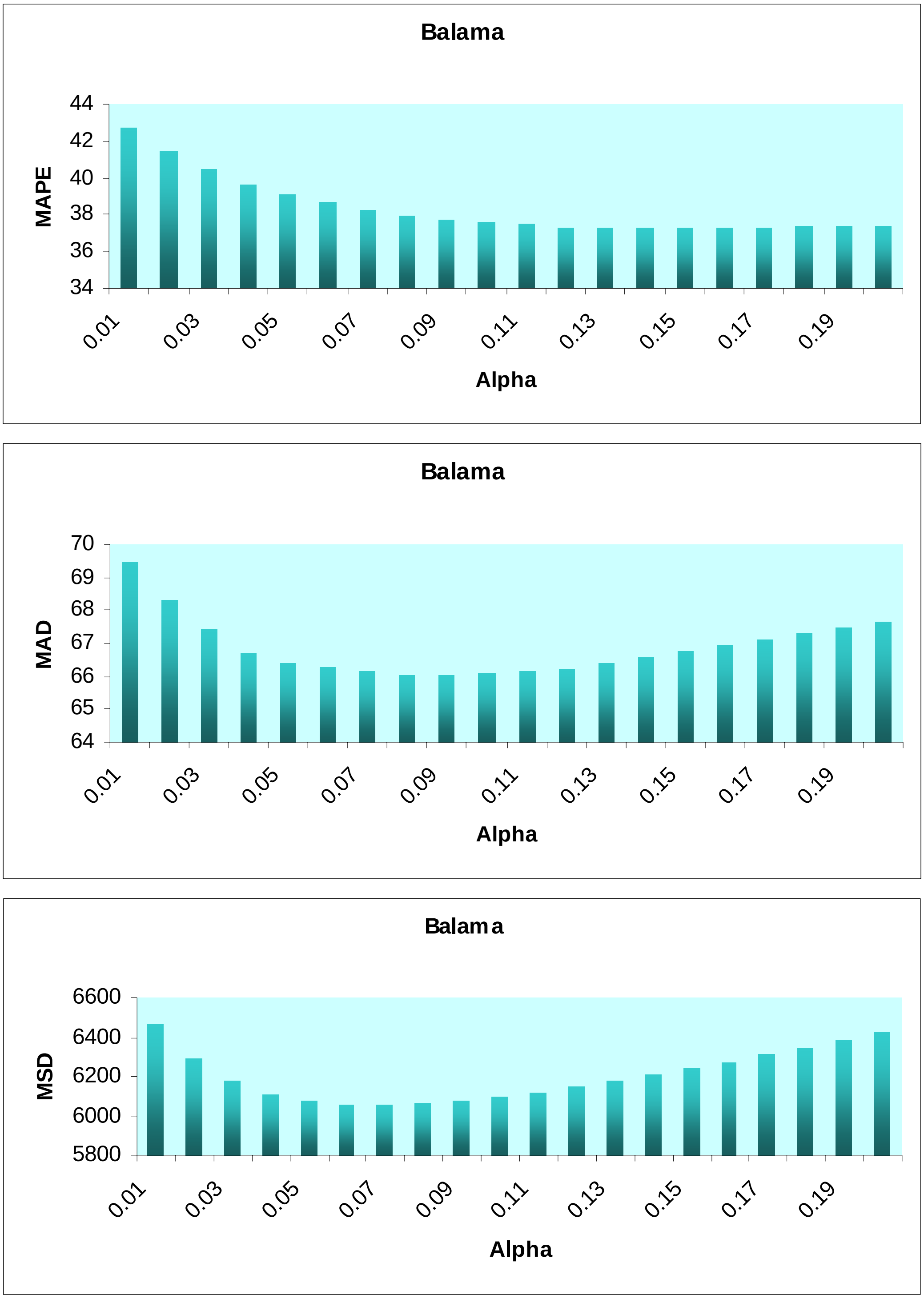

Figure 5.14: A New Set of Alpha Values versus Accuracy Measures of Water Year Rainfall at Balama.

Examination of MAPE curve in Figure 5.14 doesn't provide a hint on the best fit alpha value, while at the same time MAD and MSD curves have a minimum alpha trough in their plots at 0.09 and 0.07 respectively. It can be seen from the MAPE curve that alpha value of 0.09 scores less than alpha value 0.07, so the best fit alpha value of water year rainfall at Balama would be 0.09. Figure 5.15 shows the 0.09 alpha SES model for the water year rainfall at Balama station, Figure 5.16 shows the residuals plots.

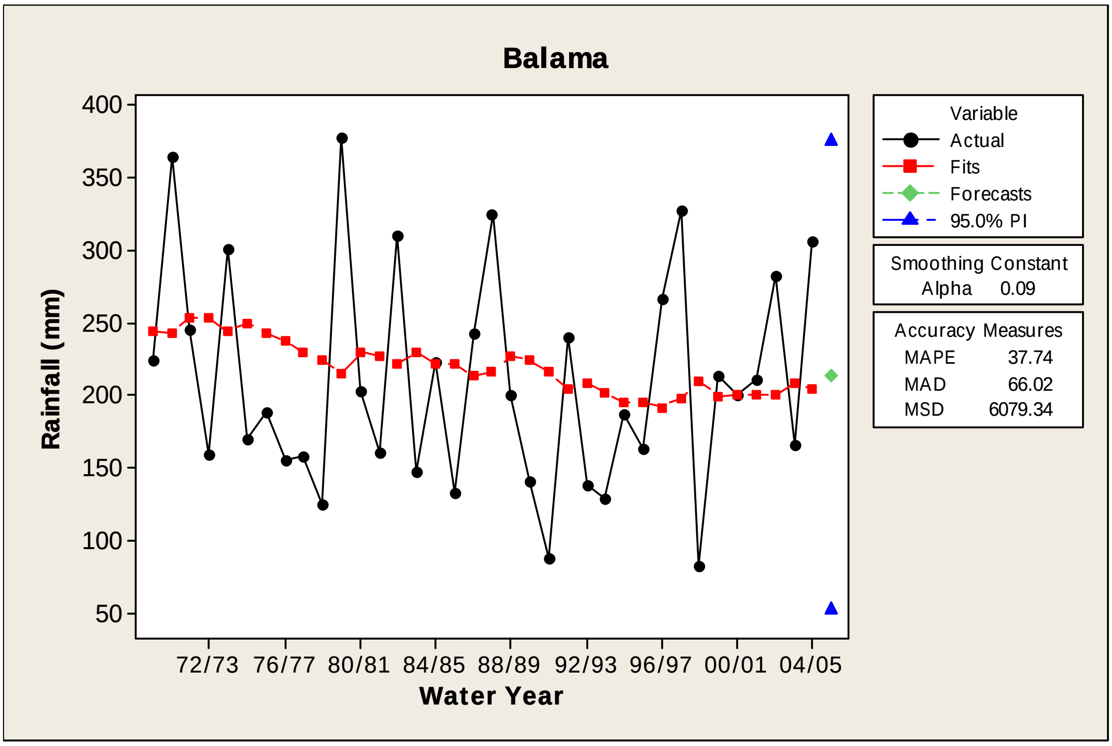

Figure 5.15: An SES Model (Alpha = 0.09) of Water Year Rainfall at Balama.

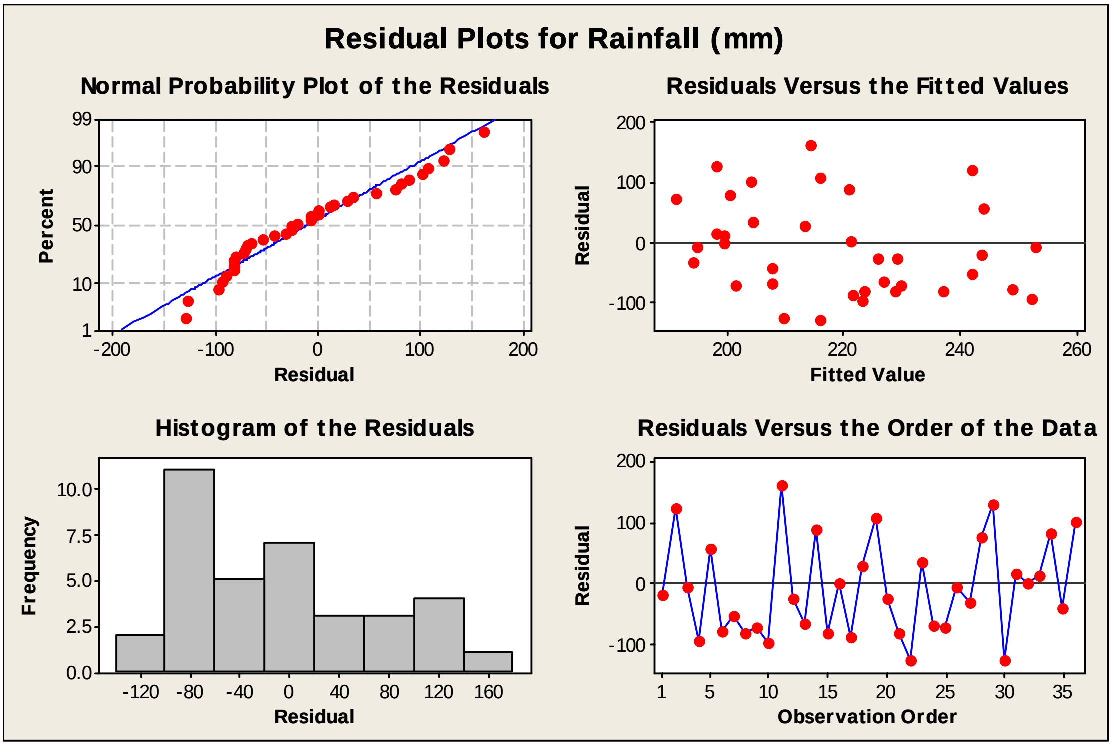

Figure 5.16: Residual Plots of the Water Year Rainfall SES Model (Alpha = 0.09) at Balama.

Table 5.16 shows the SES model best fit alpha values for the calendar and water year time series. Alpha values ranges in (0,1), where values closer to 1 indicate a dependence structure in the time series or deterministic component and the forecast is influenced by closer past value. The opposite is true for alpha values closer to 0 on the other end that indicate randomness.

Table 5.16: SES Best Fit Alpha Values of the Calendar and Water Year Time Series.

Rainfall		**Runoff**		**Temperature**	
Station	**Alpha**	**Station**	**Alpha**	**Station**	**Alpha**
Amman Airport	0.03	New Jerash Bridge	0.01	Amman Airport	0.25
Balama	0.09	**Baseflow**		Wadi Dhuleil	0.19
Hussein College	0.09	**Station**	**Alpha**	**Relative Humidity**	
Khaldiya	0.01	New Jerash Bridge	0.62	**Station**	**Alpha**
Madwar	0.01			Amman Airport	0.07
Sabha and Subhiya	0.12			Wadi Dhuleil	0.15
Um El Jimal	0.05				
Zarqa	0.01				

Table 5.17 presents fits and forecasts (Bold) of the best fit SES model for the water year rainfall and runoff.

Table 5.17: Best SES Model Forecasts and Fits of the Water Year Rainfall and Runoff at Respective Stations.

	Amman Airport		**Balama**		**Hussein College**		**Khaldiya**		**Madwar**		**Sabha and Subhiya**		**Um El Jimal**		**Zarqa**		**New Jerash Bridge**	
85/86	109.0	275.6	132.3	221.5	186.9	427.8	60.4	126.5	148.9	184.2	63.6	147.4	46.9	137.1	84.7	132.1	1.8	7.3
86/87	264.2	270.6	242.9	213.5	380.2	406.1	169.4	125.8	233.4	183.9	185.0	137.3	148.2	132.6	172.7	131.6	7.8	7.3
87/88	359.3	270.4	324.0	216.1	534.1	403.8	254.8	126.2	217.9	184.4	199.9	143.0	219.7	133.4	250.1	132.0	20.1	7.3
88/89	243.7	273.1	200.0	225.8	313.9	415.5	157.6	127.5	210.6	184.7	150.8	149.9	138.0	137.7	149.8	133.2	5.0	7.4
89/90	156.2	272.2	140.6	223.5	265.0	406.4	110.4	127.8	229.1	185.0	170.8	150.0	117.9	137.7	130.3	133.4	3.8	7.4
90/91	197.9	268.7	87.4	216.0	355.0	393.6	94.8	127.7	162.6	185.4	228.2	152.5	114.7	136.7	88.1	133.3	4.5	7.3
91/92	539.9	266.6	239.5	204.5	390.0	390.2	245.4	127.3	331.7	185.2	131.8	161.6	191.4	135.6	258.2	132.9	26.1	7.3
92/93	256.8	274.8	138.0	207.6	433.1	390.1	108.4	128.5	86.0	186.6	87.0	158.0	92.9	138.4	97.9	134.1	12.7	7.5
93/94	160.5	274.2	128.6	201.3	324.6	394.0	65.4	128.3	121.7	185.6	86.5	149.5	72.2	136.1	107.7	133.8	1.2	7.5
94/95	278.8	270.8	186.8	194.8	392.7	387.8	170.0	127.7	216.5	185.0	133.3	141.9	141.0	132.9	146.3	133.5	18.7	7.5
95/96	178.2	271.1	162.5	194.1	332.2	388.2	129.3	128.1	145.5	185.3	81.2	140.9	118.6	133.3	96.1	133.6	4.6	7.6
96/97	268.7	268.3	266.2	191.2	388.5	383.2	151.7	128.1	224.4	184.9	129.4	133.7	133.5	132.6	123.9	133.3	10.4	7.6
97/98	258.6	268.3	326.7	198.0	390.5	383.6	173.5	128.4	298.5	185.3	111.7	133.2	108.2	132.6	143.9	133.2	6.4	7.6
98/99	107.2	268.0	82.0	209.6	176.2	384.3	47.6	128.8	98.5	186.4	43.8	130.6	57.7	131.4	48.0	133.3	2.0	7.6
99/00	172.1	263.2	213.5	198.1	296.5	365.5	97.6	128.0	154.7	185.6	75.5	120.2	81.7	127.7	122.6	132.4	4.2	7.5
00/01	176.5	260.4	199.7	199.5	311.9	359.3	107.8	127.7	167.5	185.2	115.4	114.8	129.4	125.4	100.6	132.3	3.8	7.5
01/02	277.7	257.9	210.8	199.5	518.0	355.1	131.0	127.5	234.0	185.1	160.0	114.9	160.5	125.6	157.0	132.0	11.8	7.5
02/03	377.9	258.5	281.8	200.5	592.7	369.7	175.1	127.5	287.8	185.6	199.1	120.3	186.4	127.4	162.5	132.3	11.1	7.5
03/04	183.2	262.1	165.3	207.8	315.1	389.8	139.7	128.0	188.4	186.6	139.2	129.8	92.9	130.3	123.6	132.6	3.2	7.5
04/05	262.7	259.7	305.5	204.0	378.4	383.1	117.8	128.1	197.6	186.6	162.9	130.9	114.8	128.5	125.0	132.5	32.9	7.5
05/06		**259.8**		**213.1**		**382.6**		**128.0**		**186.7**		**134.7**		**127.8**		**132.4**		**7.7**

5.5 Decomposition Models

Decomposition models are applied to monthly time series of rainfall, runoff, temperature and relative humidity. Seasonal multiplicative and additive models with or without trend component are used in analysis, it is found that for all time series seasonal additive decomposition model with trend components is suitable and performed best with all the monthly time series. Figure 5.17 shows how the seasonal additive model with trend component of the monthly mean temperature at Amman Airport gives minimum accuracy measures values.

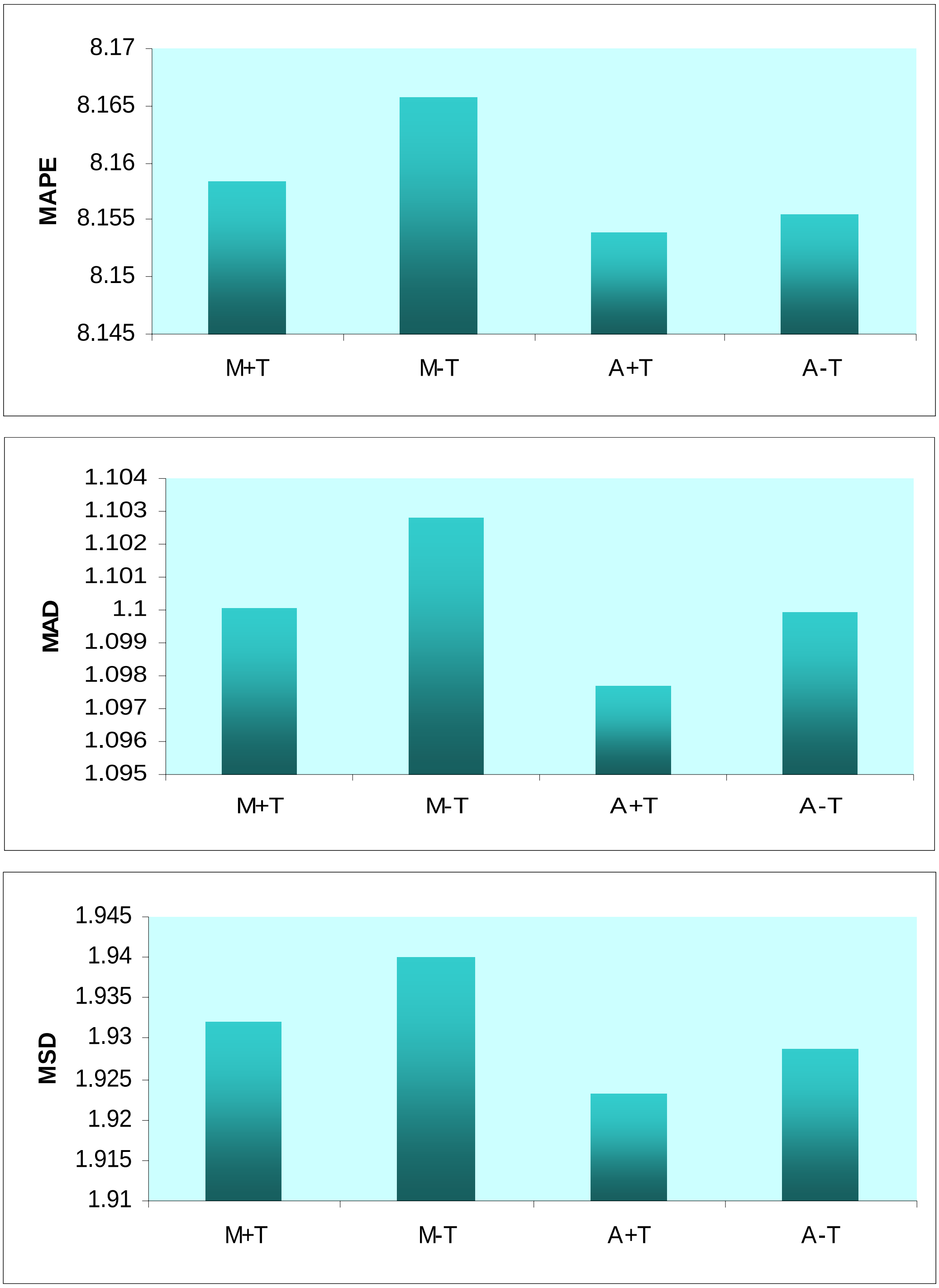

Figure 5.17: Accuracy Measures versus the Type of Decomposition Model of Monthly Mean Temperature at Amman Airport. (Where; M = Multiplicative, A = Additive, and T = Trend Component).

It's clear from Figure 5.17 that the best model to describe the monthly mean temperature at Amman Airport would be an additive model with trend component, see Figure 5.18.

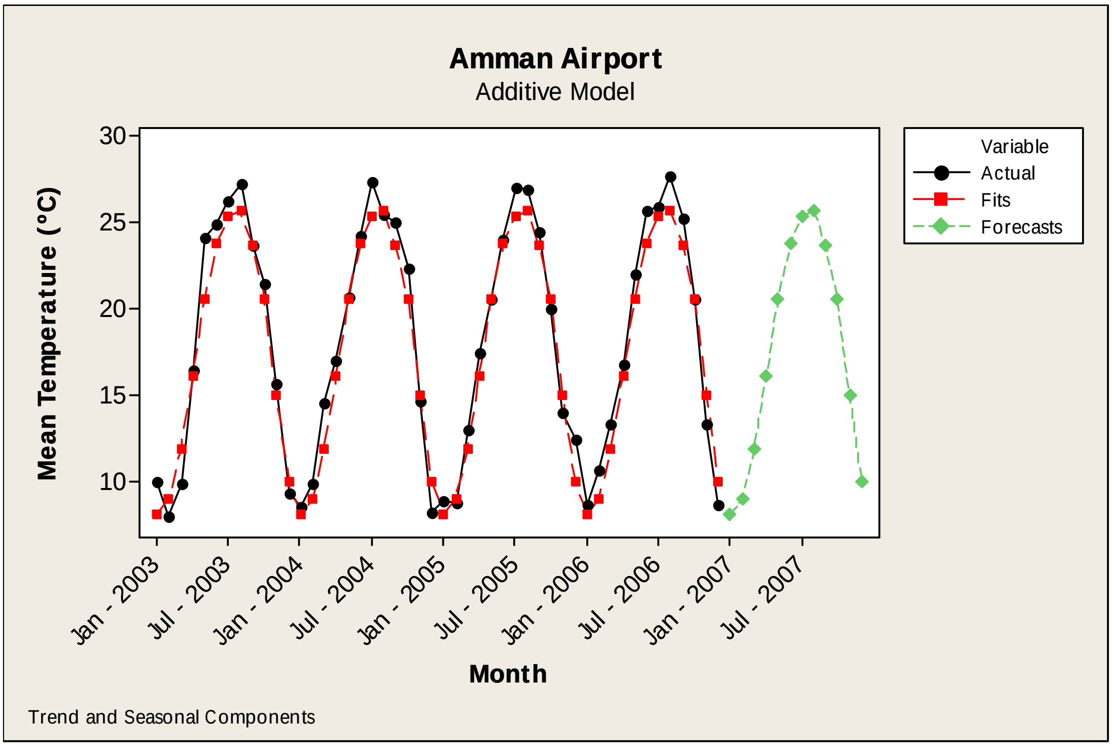

Figure 5.18: A Seasonal Additive Decomposition Model with Trend Component of Monthly Mean Temperature at Amman Airport.

Table 5.18 presents fits and forecasts (Bold) of the monthly rainfall using the seasonal additive model with trend component.

Table 5.18: Fits and Forecasts of a Whole Season (Oct to May) of Monthly Rainfall and Runoff at Respective Stations.

	Amman Airport		**Balama**		**Hussein College**		**Khaldiya**		**Madwar**		**Sabha and Subhiya**		**Um El Jimal**		**Zarqa**		**New Jerash Bridge**	
	Actual	Fit	Actual	Fit	Actual	Fit	Actual	Fit	Actual	Fit	Actual	Fit	Actual	Fit	Actual	Fit	Actual	Fit
Oct-03	0.3	9.2	0	4.7	0	14.3	0	5.3	0	8.7	0	3.0	0	3.8	0.7	6.4	0	0.6
Nov-03	6.5	19.4	4.5	14.6	12	34.5	29	12.8	10.3	16.1	6.5	10.9	13	13.7	8	9.8	0	0.8
Dec-03	72.2	31.6	54.5	26.5	95.1	64.4	34.1	19.9	61.6	27.9	72.6	21.7	43.4	23.8	54.3	23.2	0.954	1.0
Jan-04	59.5	53.1	35.5	44.7	117	83.8	23.3	29.8	60.4	42.2	34	28.5	14	25.3	27.8	29.5	1.158	1.5
Feb-04	32.6	47.5	63	44.7	72	78.0	41.1	26.8	43.9	46.6	18	26.3	15	21.7	30	22.8	0.947	1.2
Mar-04	1.8	41.9	3	39.6	11	72.4	4	23.0	6.1	31.7	5.9	22.3	1.5	20.9	1.6	22.4	0.102	1.3
Apr-04	8	10.8	4.8	8.8	6	15.8	4.1	7.4	6.1	11.6	2.1	4.3	3	6.8	1.2	6.0	0.04	0.6
May-04	2.3	5.0	0	2.2	2	11.6	4.1	3.0	0	7.0	0	0.2	3	2.1	0	2.8	0	0.5
Oct-04	1.4	9.1	5.4	4.7	2.5	14.3	0	5.2	2.6	8.8	0	2.9	0	3.8	0.3	6.5	0	0.6
Nov-04	64.7	19.3	47.9	14.6	99.5	34.6	36.2	12.7	34.2	16.2	42.7	10.8	27.2	13.7	37.8	9.8	3.162	0.8
Dec-04	16.7	31.5	23.5	26.5	24	64.4	9.7	19.8	14.3	28.0	19.5	21.6	10.5	23.8	12	23.3	0.46	1.0
Jan-05	65	53.0	72.9	44.7	101	83.9	22.3	29.8	45	42.3	35.7	28.4	24	25.3	26.5	29.5	1.696	1.5
Feb-05	83.4	47.4	113.9	44.6	118.2	78.1	31.2	26.7	82.5	46.7	39.2	26.3	39	21.7	32	22.8	3.237	1.2
Mar-05	25.2	41.8	24.5	39.6	29	72.5	8.3	23.0	10.5	31.8	8.5	22.2	6.2	20.9	9.8	22.5	0.41	1.3
Apr-05	2.7	10.7	8.6	8.7	1.2	15.9	6.5	7.4	3.1	11.7	11.6	4.2	4.9	6.8	3.6	6.0	0.013	0.6
May-05	3.6	4.9	8.8	2.1	3	11.6	3.6	2.9	5.6	7.1	5.8	0.1	3	2.1	3	2.8	0.021	0.5
Oct-05		**9.0**		**4.6**		**14.3**		**5.2**		**8.9**		**2.8**		**3.8**		**6.5**		**0.6**
Nov-05		**19.2**		**14.5**		**34.6**		**12.7**		**16.3**		**10.7**		**13.7**		**9.9**		**0.8**
Dec-05		**31.4**		**26.4**		**64.5**		**19.8**		**28.1**		**21.5**		**23.8**		**23.3**		**1.0**
Jan-06		**52.9**		**44.6**		**83.9**		**29.8**		**42.4**		**28.3**		**25.3**		**29.6**		**1.5**
Feb-06		**47.3**		**44.6**		**78.1**		**26.7**		**46.8**		**26.2**		**21.7**		**22.8**		**1.2**
Mar-06		**41.7**		**39.6**		**72.5**		**22.9**		**31.9**		**22.1**		**20.9**		**22.5**		**1.3**
Apr-06		**10.6**		**8.7**		**15.9**		**7.4**		**11.8**		**4.1**		**6.8**		**6.1**		**0.6**
May-06		**4.8**		**2.1**		**11.7**		**2.9**		**7.2**		**0.0**		**2.1**		**2.9**		**0.5**

5.6 ARIMA Models

ARIMA models exploits the correlation properties of a time series in model building, ARIMA modelling uses differencing to remove significant autocorrelations and thus non-stationarity and adjusts by adding AR and/or MA terms for the remaining correlation pattern.

5.6.1 Research Time Series Autocorrelation Structure

Time series autocorrelation dependence structure is embedded in the ACF and PACF plots of the time series. ACF and PACF plots will respond and change when the original time series is subjected to differencing or transformation as will be shown later on. The present section will illustrate a sample of research time series autocorrelation structures based on their ACF plots.

The Water year rainfall, storm-cluster rainfall, water year runoff, and runoff events time series exhibits a weak autocorrelation patterns, the thing that will make the identification of a tentative ARIMA model less than straight forward approach. Figure 5.19 shows the ACF plot of the water year rainfall at Hussein College Station.

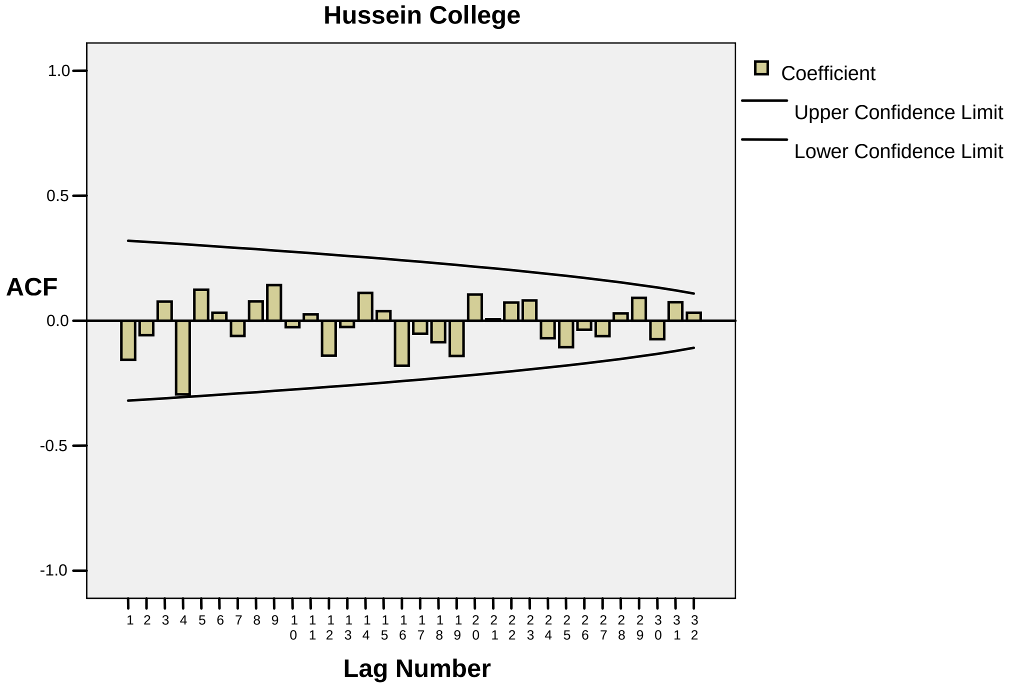

Figure 5.19: ACF Plot of Water Year Rainfall at Hussein College.

As can be seen from Figure 5.19, the ACF coefficients are quite random and within confidence limits, that is no significant autocorrelations exist. This can be attributed to the fact that the water year rainfall time series are quite short, 36 data points are used to develop the ACF plot.

The storm-cluster rainfall and runoff event time series also exhibits a weak autocorrelation pattern, this however somehow indicate that the existing trends detected in the time series are not due to autocorrelation pattern in the data. Figure 5.20 shows the ACF plot of storm-cluster rainfall at Um El Jimal Station.

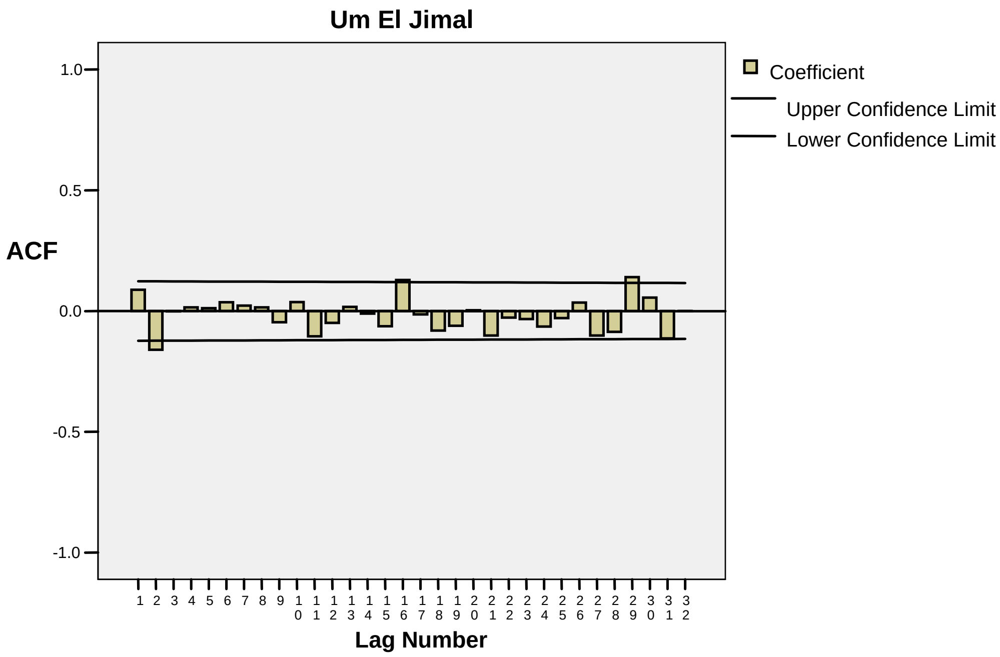

Figure 5.20: ACF Plot of Storm-Cluster Rainfall at Um El Jimal Rainfall.

The monthly data of rainfall, temperature, and relative humidity provide the strongest autocorrelation pattern and thus such pattern will be handled by seasonal ARIMA models. Figure 5.21 shows the ACF plot of monthly mean temperature at Amman Airport Station.

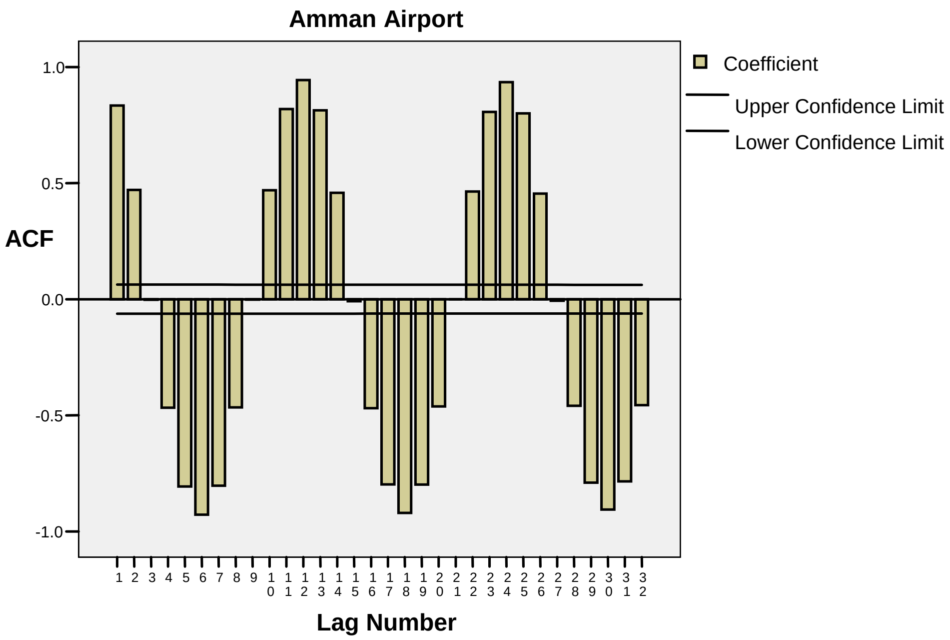

Figure 5.21: ACF Plot of Monthly Mean Temperature at Amman Airport.

Calendar year temperature, relative humidity, and baseflow give an intermediate strength ACF, Figure 5.22 shows the ACF plot of calendar year baseflow at New Jerash Bridge Station.

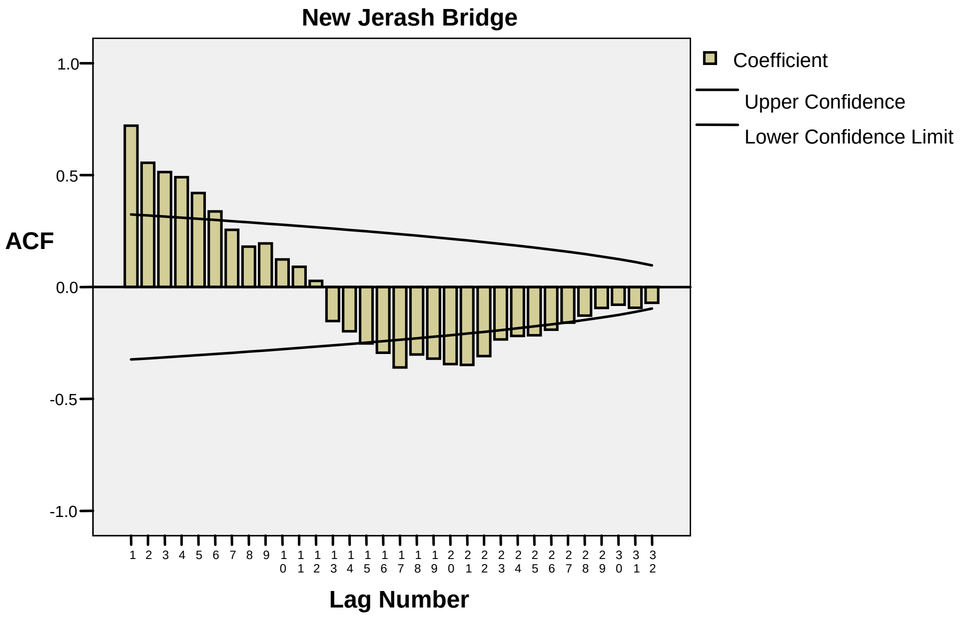

Figure 5.22: ACF Plot of Calendar Year Baseflow at New Jerash Bridge.

5.6.2 Non-Seasonal ARIMA Models

Non-seasonal ARIMA models or simply ARIMA models are applied to all time series except at monthly time scale, monthly time series are better modelled by seasonal ARIMA.

ARIMA modelling process begins with a plot of the time series, Figure 5.23 shows the time series plot of storm-cluster rainfall at Amman Airport Station. As can be seen from the figure, the series is quite stationary (no profound trend) and no apparent seasonality; this will be confirmed in the ACF and PACF plots later on. Another observation is that the time series exhibits a non-stable variance across successive periods and thus a skewed distribution. This observation applies also to all other storm-cluster time series. As such a transformation is necessary to stabilize the variance to obtain more accurate models; natural-log transformation is used in analysis.

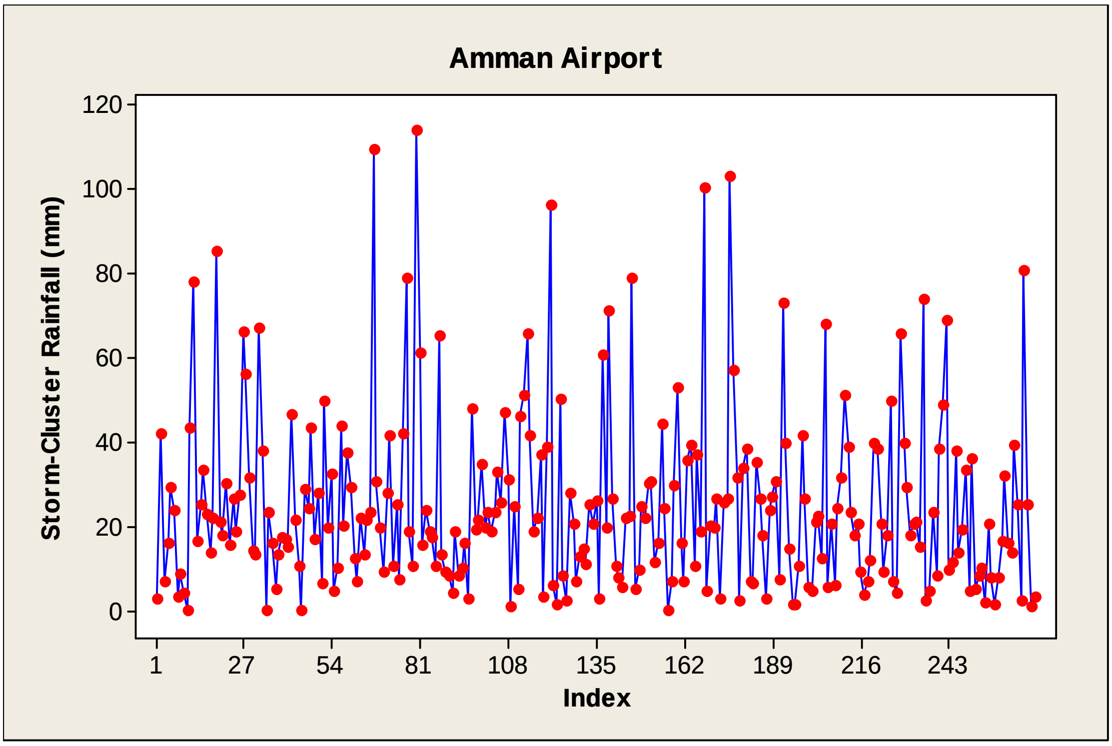

Figure 5.23: Time Series Plot of Storm-Cluster Rainfall at Amman Airport.

Figure 5.24 and Figure 5.25 show the ACF and PACF plots of the natural-log transformed storm-cluster rainfall time series, respectively. At this point, inspection of the ACF and PACF plots doesn't provide a clear picture of the underlying governing process.

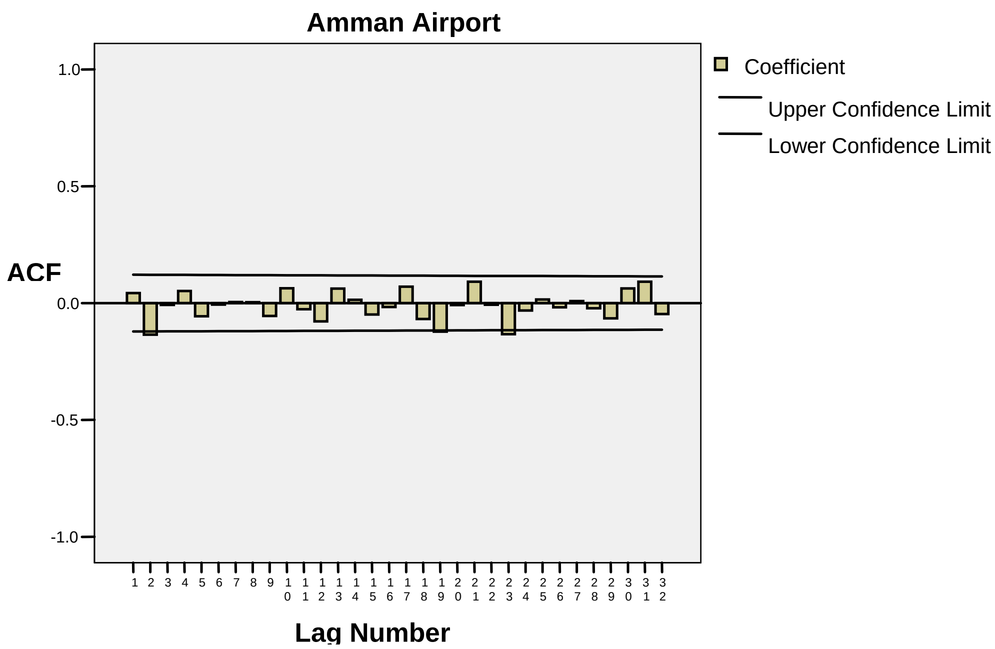

Figure 5.24: ACF Plot of the Natural-Log Transformed Storm-Cluster Rainfall Time Series.

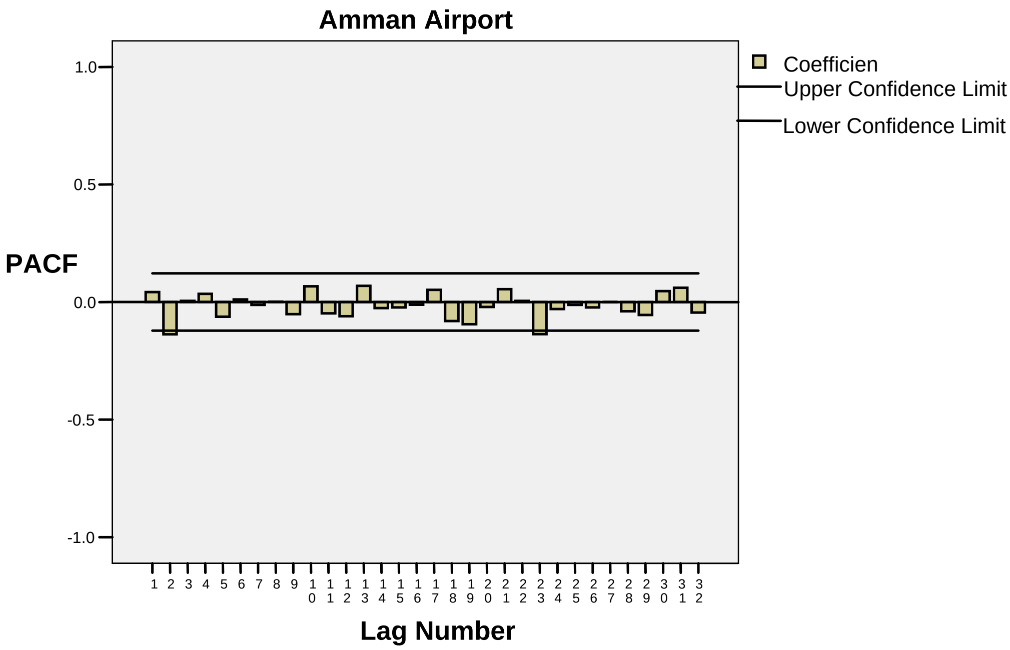

Figure 5.25: PACF Plot of Natural-Log Transformed Storm-Cluster Rainfall Time Series.

Figure 5.26 and Figure 5.27 show the ACF and PACF plots of the first difference of the natural-log transformed storm-cluster rainfall time series.

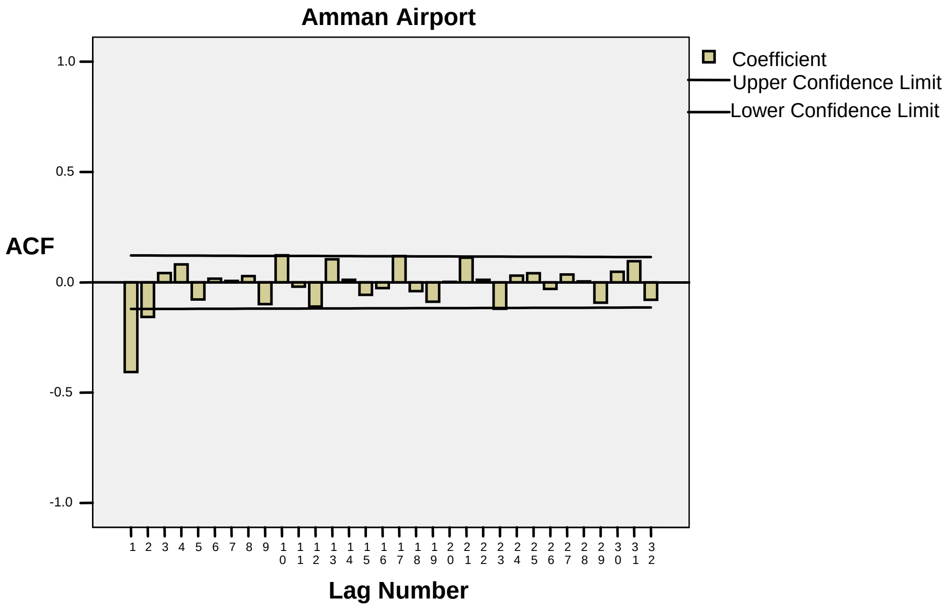

Figure 5.26: ACF Plot of the 1st Difference of the Natural-Log Transformed Storm-Cluster Rainfall Time Series.

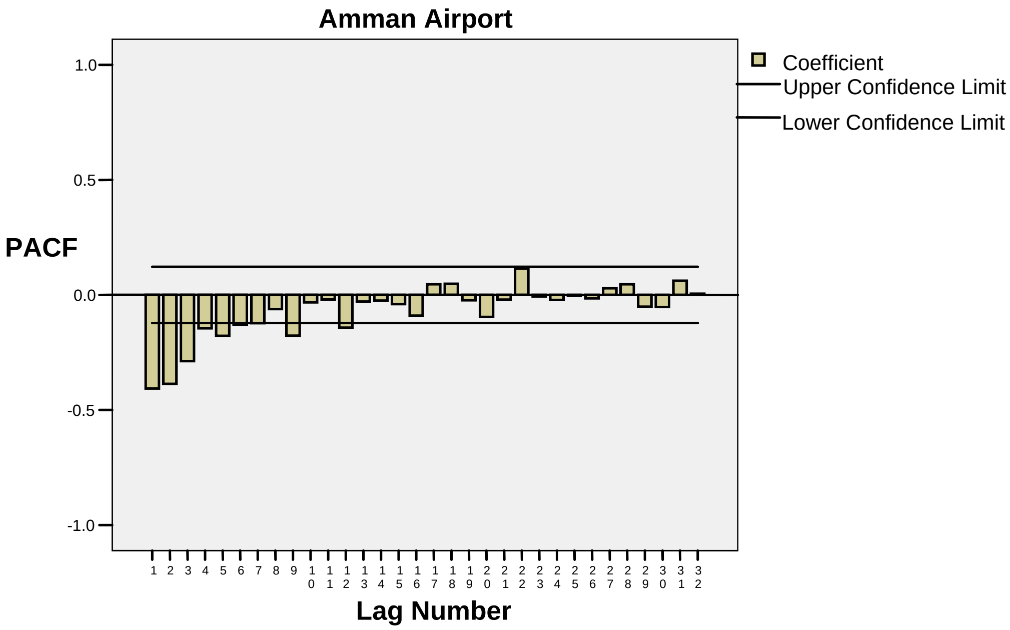

Figure 5.27: PACF Plot of the 1st Difference Natural-Log Transformed Storm-Cluster Rainfall Time Series.

Inspection of Figures 5.26 and 5.27 indicate an MA (1) signature, which is a significant negative autocorrelation coefficient in the ACF and a negative exponential decay in the PACF, so an ARIMA (0,1, 1) is identified as a first tentative model.

Figures 5.28 and 5.29 show respectively the ACF and PACF plots of the 2nd difference natural-log transformed storm-cluster rainfall time series, as can be seen from the figures the natural-log transferred storm-cluster rainfall time series is over-differenced at this point. Signs of over-differencing include alternate excessive changes in sign from coefficient to coefficient in the ACF plot, furthermore the 1st ACF and PACF coefficients are driven more into negative (more than - 0.5).

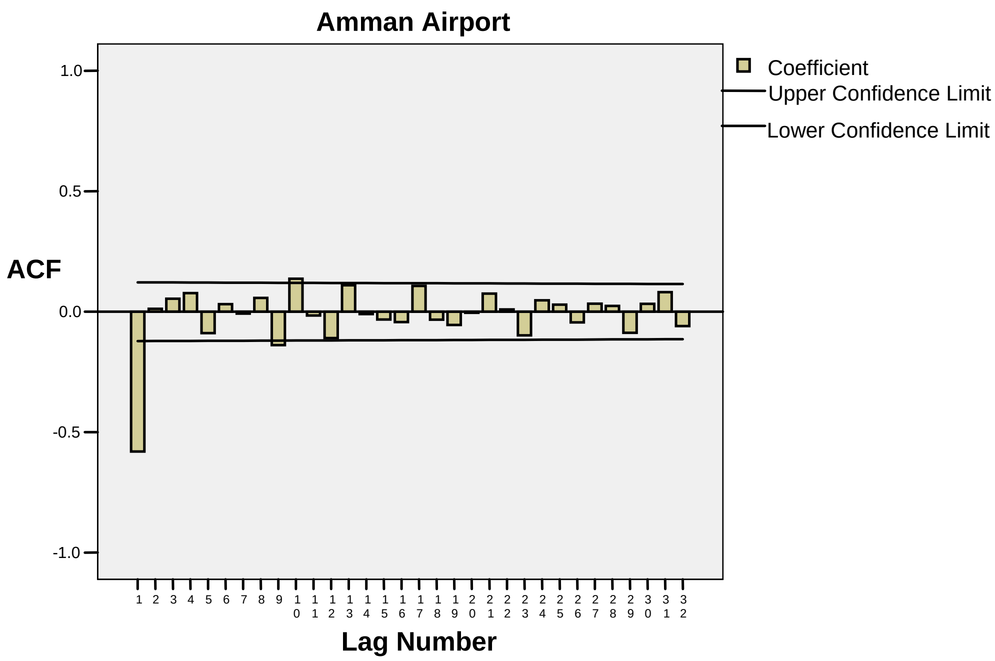

Figure 5.28: ACF Plot of the 2nd Difference Natural-Log Transformed Storm-Cluster Rainfall Time Series.

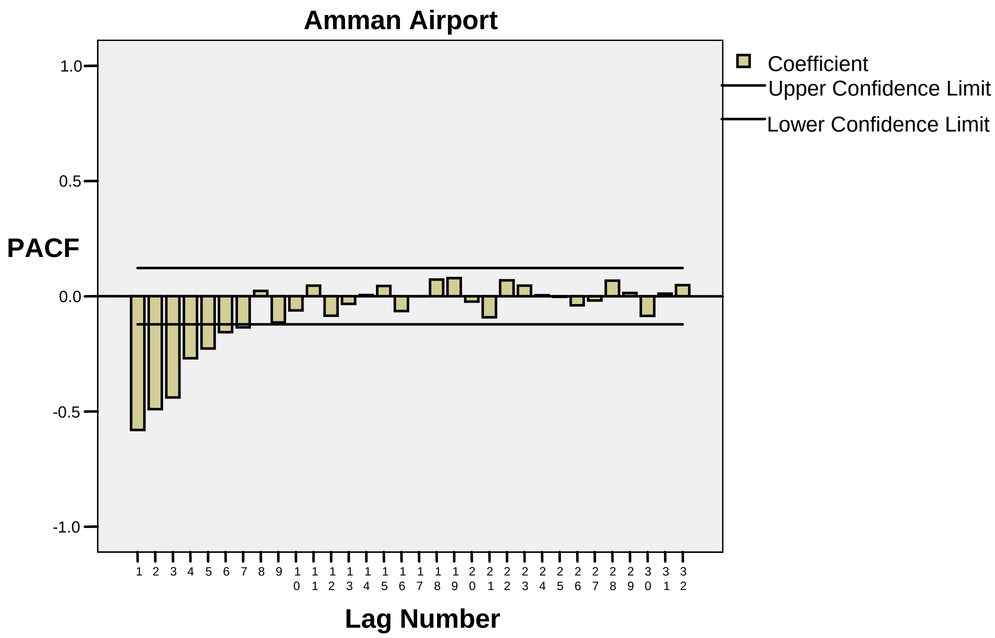

Figure 5.29: PACF Plot of 2nd Difference Natural-Log Transformed Storm-Cluster Rainfall Time Series.

one tentative model of the transformed storm-cluster time series, namely: ARIMA (0, 1, 1) is identified, to allow for possible identification errors Table 5.19 shows residual diagnostics of a number of possible neighbouring models with and without natural-log transformation of the original series, where shaded cells indicate minimum values. It can be seen from Table 5.19 how considerably the natural-log transformation reduces residual diagnostics.

Table 5.19: Residual Diagnostics of Storm-Cluster Rainfall Time Series ARIMA Models at Amman Airport.

ARIMA	No Transformation			Natural-Log Transformation		
	AIC	BIC	Model Std.Error	AIC	BIC	Model Std.Error
(0,0,1)	2404.142	2411.332	21.031	796.365	803.555	1.0592
(0,0,2)	2401.751	2412.535	20.897	793.829	804.613	1.0522
(1,0,0)	2404.312	2411.501	21.037	796.554	803.743	1.0596
(1,0,1)	2406.340	2417.124	21.077	796.857	807.641	1.0582
(1,0,2)	2403.406	2417.784	20.923	795.727	810.106	1.0540
(2,0,0)	2401.420	2412.204	20.884	793.287	804.071	1.0511
(2,0,1)	2403.324	2417.703	20.919	795.295	809.674	1.0531
(2,0,2)	2405.324	2423.297	20.958	793.062	811.036	1.0459
(0,1,1)	2401.563	2408.745	21.065	964.646	968.237	1.4606
(0,1,2)	2415.681	2426.454	21.658	799.738	806.920	1.0608
(1,1,1)	2404.521	2415.294	21.219	813.243	824.016	1.0875
(1,1,2)	2404.294	2418.657	21.123	917.505	924.687	1.3347
(2,1,1)	2402.390	2416.754	21.103	812.450	823.222	1.0918
(2,1,2)	2402.930	2420.885	21.001	802.309	816.673	1.0624
(0,1,0)	2568.031	2571.622	29.087	875.759	886.532	1.2316
(1,1,0)	2521.190	2528.372	26.594	798.054	812.417	1.0533
(2,1,0)	2483.200	2493.973	24.715	802.080	820.034	1.0597

Inspection of Table 5.19 indicates that an ARIMA (2, 0, 2) can adequately fit the natural-log transformed storm-cluster rainfall at Amman Airport station. This is confirmed by the ACF and PACF plots of residuals which are random and small as seen in Figures 5.30 and 5.31.

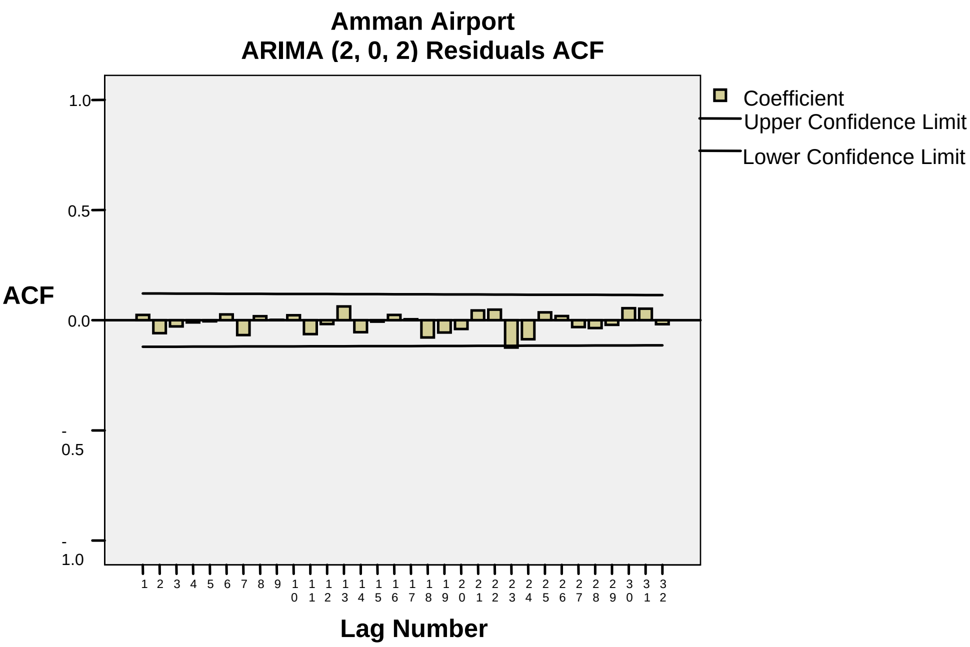

Figure 5.30: Residuals ACF Plot of ARIMA (2, 0, 2) Model of Storm-Cluster Rainfall at Amman Airport.

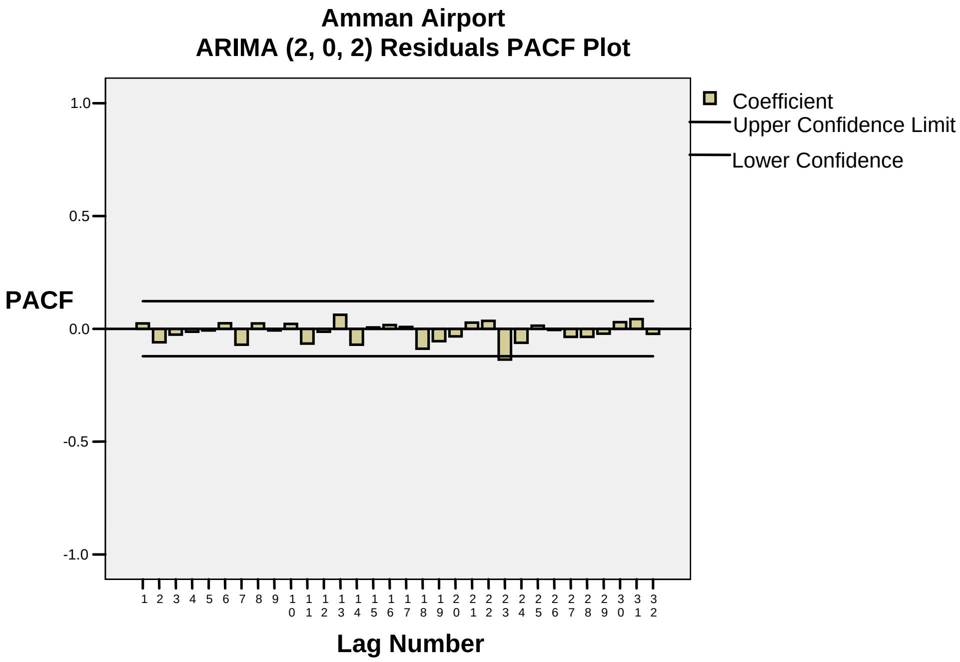

Figure 5.31: Residuals PACF Plot of ARIMA (2, 0, 2) Model of Storm-Cluster Rainfall at Amman Airport.

Figure 5.32 shows the ARIMA (2, 0, 2) model plot after back-transformation of storm-cluster rainfall at Amman Airport, Figure 5.33 shows the residual plots which are approximately normal and indicate a very good fit.

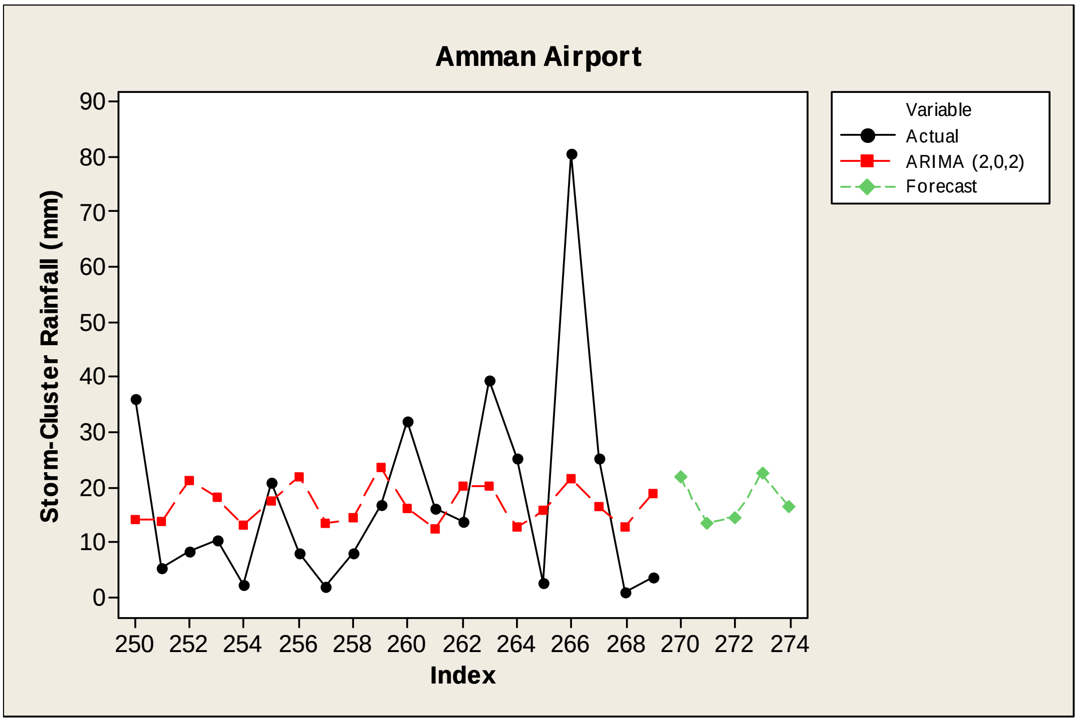

Figure 5.32: ARIMA (2, 0, 2) Model of Storm-Cluster Rainfall at Amman Airport (Back-transformed).

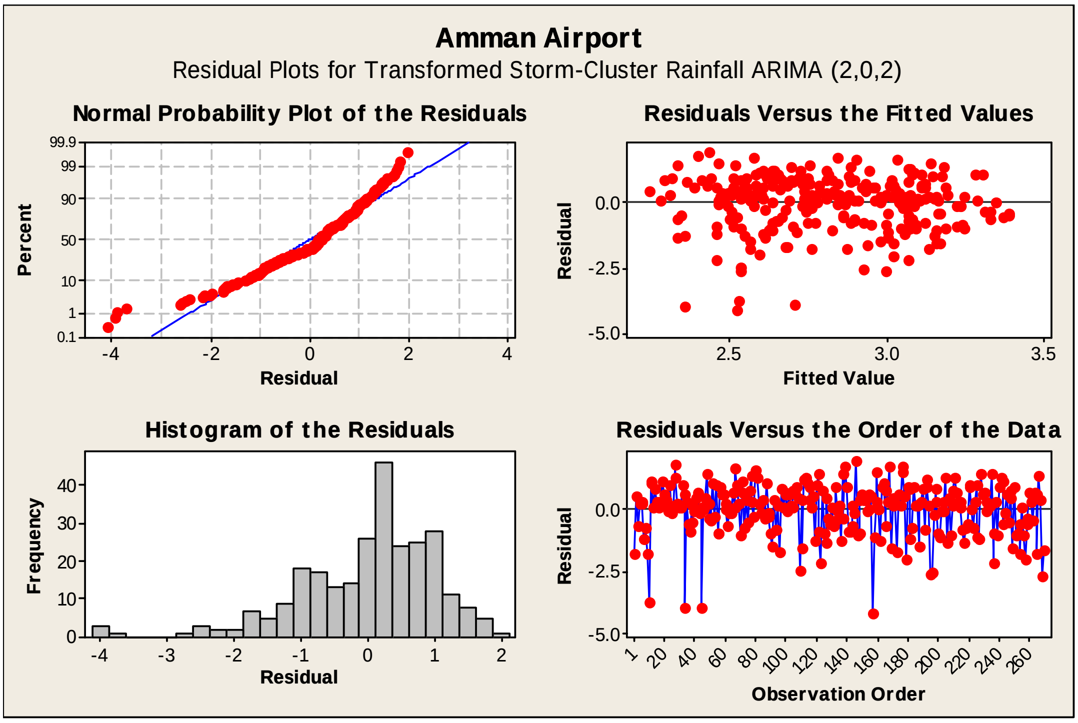

Figure 5.33: Residual Plots of ARIMA (2, 0, 2) of Transformed Storm-Cluster Rainfall at Amman Airport.

Table 5.20 illustrates best-fit ARIMA models of the different time series. Table 5.21 illustrates fits and forecasts (Bold) of the storm-cluster rainfall, it should be noted here that natural-log transformation is applied to all storm-cluster rainfall and Table 5.21 provide model fits and forecast (Bold) after back-transformation, the last 20 storm-cluster rainfall are presented in the table.

Table 5.20: Best-Fit ARIMA Models of the Different Time Series as Per Respective Station.

Station/Time Scale	**Water Year**	**Storm-Cluster**	**Storm-Cluster (Trans)**	
Amman Airport	(1,0,2)	(2,0,0)	**(2,0,2)**	
Balama	(1,0,1)	(0,1,1)	**(0,1,1)**	
Hussein College	(2,0,1)	(2,0,0)	**(0,0,1)**	
Khaldiya	(2,0,2)	(2,0,0)	**(2,1,2)**	
Madwar	(0,0,2)	(0,0,2)	**(1,0,1)**	
Sabha and Subhiya	(0,1,1)	(0,1,1)	**(0,0,1)**	
Um El Jimal	(2,0,1)	(0,0,2)	**(1,0,1)**	
Zarqa	(1,0,1)	(1,0,2)	**(2,1,2)**	
Station/Time Scale	**Calendar Year Temperature**	**Calendar Year Relative Humidity**		
Amman Airport	(0,1,1)	(0,0,1)		
Wadi Dhuleil	(1,1,1)	(1,1,1)		
Station/Time Scale	**Water Year Runoff**	**Runoff Events**	**Runoff Events (Trans)**	**Calendar Year Baseflow**
New Jerash Bridge	(2,0,1)	**(0,0,2)**	(2,0,2)	(0,1,1)

Table 5.21: Best-Fit ARIMA Model Fits and Forecasts of Storm-Cluster Rainfall as Per Respective Stations.

Amman Airport		**Balama**		**Hussein College**		**Khaldiya**		**Madwar**		**Sabha and Subhiya**		**Um El Jimal**		**Zarqa**	
Actual	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**
36.0	11.9	25.0	11.8	74.5	24.0	6.6	8.0	39.0	11.2	47.9	10.3	14.0	7.4	18.0	7.5
5.2	16.3	1.0	11.8	8.0	29.4	11.5	7.5	6.1	19.5	2.1	9.9	2.0	7.2	26.1	7.0
8.3	21.7	17.5	11.7	14.5	23.4	2.7	8.8	15.3	10.1	26.9	11.0	9.0	7.8	0.7	6.2
10.2	15.0	4.0	11.7	25.0	25.3	11.8	7.2	16.3	18.2	5.2	10.1	2.0	7.8	20.8	6.9
2.2	14.1	14.0	11.6	4.0	26.4	7.4	10.3	4.1	12.3	1.8	10.7	4.0	8.4	7.0	10.9
20.8	19.4	23.0	11.6	45.0	22.2	16.6	8.1	10.7	13.2	12.3	11.0	9.0	8.7	8.5	5.9
7.8	19.5	23.5	11.6	17.0	28.3	22.2	9.0	7.1	14.4	1.6	10.4	5.0	8.7	19.0	7.8
1.8	12.9	14.5	11.6	7.0	25.2	5.9	8.3	6.1	12.8	3.5	11.1	1.5	8.9	0.5	7.0
8.0	16.2	3.0	11.6	6.0	23.5	4.0	6.7	4.1	13.6	5.9	10.8	3.0	9.7	1.6	7.1
16.6	23.0	3.3	11.5	27.5	23.3	4.1	7.9	12.8	12.3	2.1	10.6	9.0	10.3	1.2	12.4
31.9	14.7	16.6	11.4	42.0	26.9	5.9	8.7	14.3	15.6	13.4	11.0	14.7	10.2	9.8	9.3
16.2	13.7	20.9	11.4	30.0	27.6	25.7	9.1	7.1	13.4	25.4	10.4	3.5	10.0	22.0	9.3
13.7	20.6	10.4	11.4	20.0	26.7	4.6	10.0	12.8	13.4	3.9	10.1	9.5	10.4	11.0	6.3
39.6	17.7	19.2	11.4	60.0	25.8	9.7	6.6	24.6	14.6	19.5	10.7	15.0	10.4	17.5	6.0
25.4	13.8	37.4	11.4	41.0	28.6	12.4	8.8	20.4	15.2	21.7	10.2	9.0	10.1	9.0	6.7
2.7	17.3	35.4	11.4	1.8	27.4	9.9	8.4	0.2	14.4	14.0	10.2	1.0	10.1	1.0	6.3
80.7	18.1	2.8	11.4	116.2	20.5	31.2	7.8	82.3	7.6	39.2	10.3	38.0	11.2	31.0	7.7
25.2	17.4	24.5	11.4	29.0	31.1	8.3	8.9	10.5	28.5	8.5	10.0	6.2	10.4	9.8	9.4
0.9	14.5	3.7	11.4	0.2	26.3	6.5	6.6	1.0	8.4	10.2	10.5	3.9	10.6	2.1	5.3
3.6	15.7	8.8	11.3	3.0	16.8	3.6	7.6	5.6	13.9	5.8	10.4	3.0	11.0	3.0	7.5
	21.1		**11.3**		**22.5**		**7.7**		**12.6**		**10.6**		**11.6**		**9.0**

5.6.3 Seasonal ARIMA Models

Seasonal ARIMA models are applied to monthly rainfall, runoff, mean temperature, and mean relative humidity. The first step in seasonal ARIMA model building is to find the seasonal ACF and PACF plots. Figures 5.34 and 5.35 show the seasonal ACF and PACF plots of monthly mean temperature at Amman Airport Station.

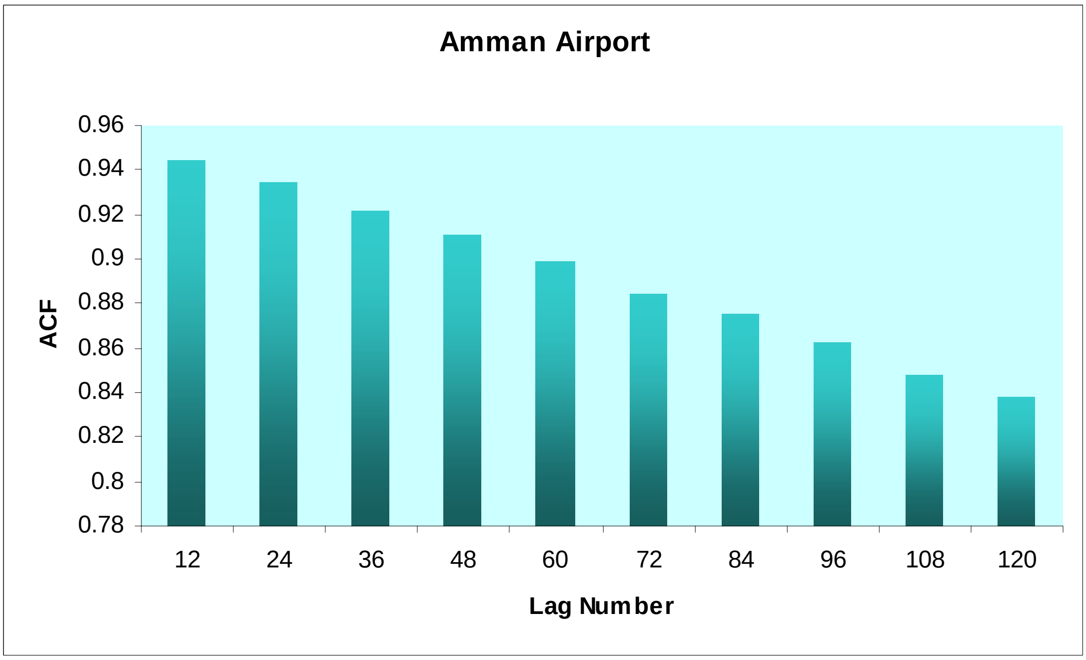

Figure 5.34: Seasonal ACF Plot of Monthly Mean Temperature at Amman Airport.

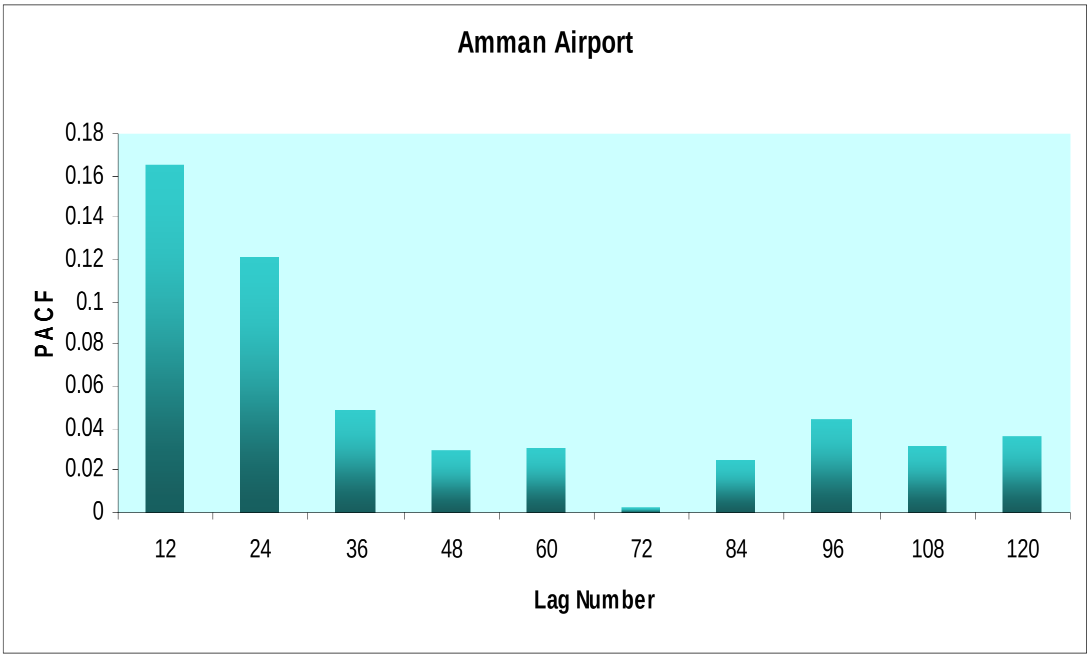

Figure 5.35: Seasonal PACF Plot of Monthly Mean Temperature at Amman Airport.

Inspection of Figures 5.34 and 5.35 indicate that differencing of 12 lags (Equivalent to 1st seasonal difference) is required to remove seasonal effects. Figures 5.36 and 5.37 show the seasonal ACF and PACF respectively of the 12th difference monthly mean temperature at Amman Airport Station.

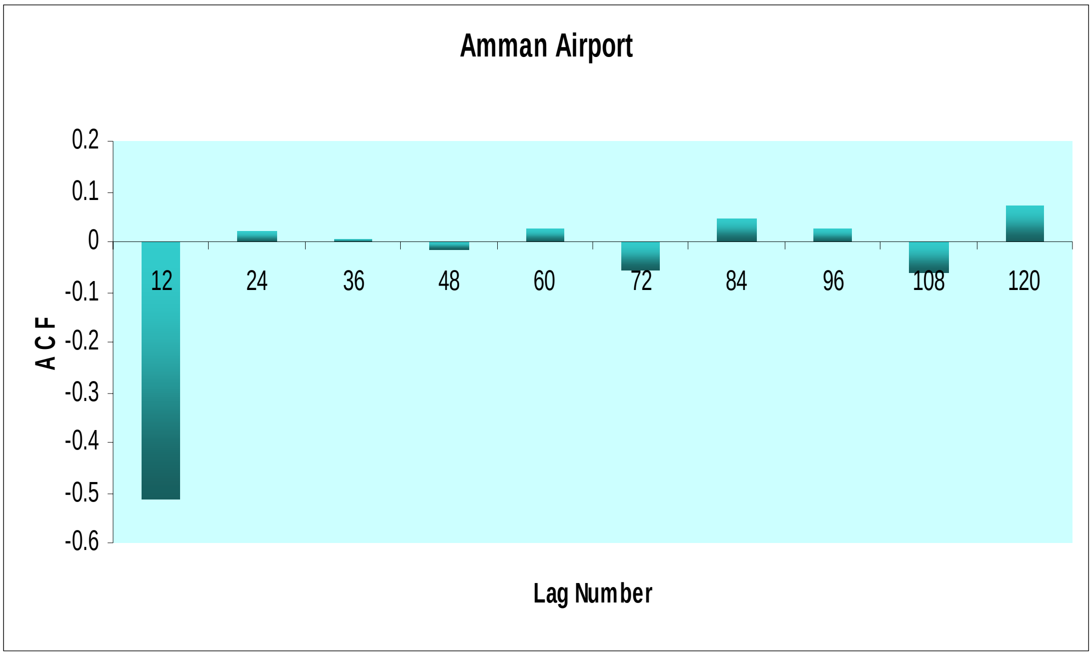

Figure 5.36: Seasonal ACF Plot of the 12th Difference Monthly Mean Temperature at Amman Airport.

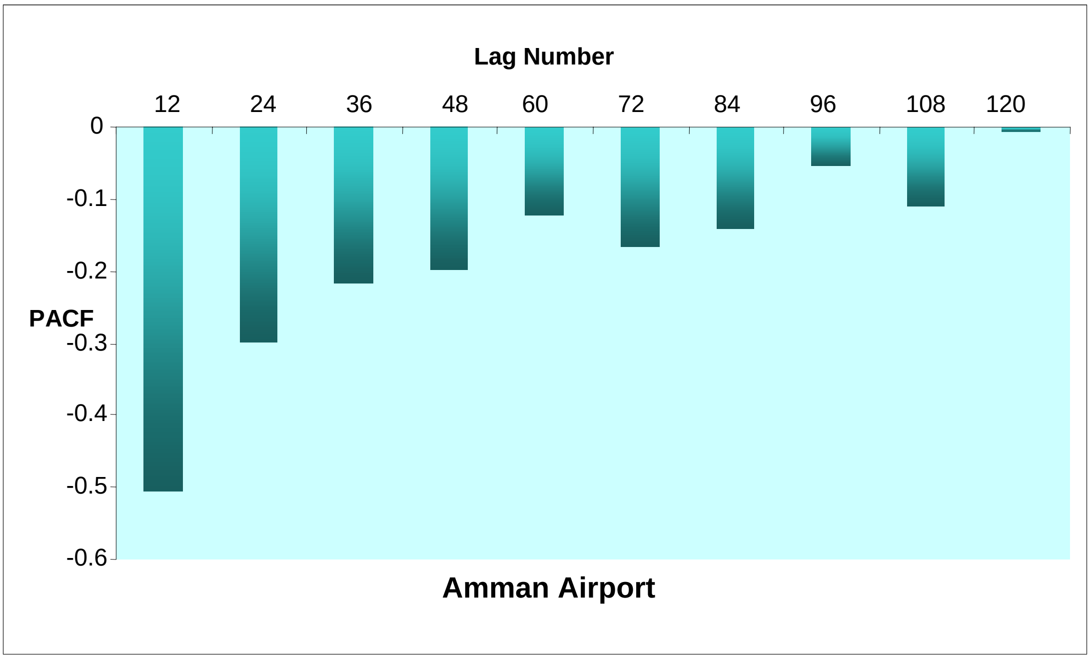

Figure 5.37: Seasonal PACF Plot of the 12th Difference Monthly Mean Temperature at Amman Airport.

Inspection of Figures 5.36 and 5.37 indicate that a seasonal MA (1) process can be used to adjust for the remaining seasonal autocorrelation. In fact, an ARIMA (p, d, q) (0, 1, 1)^S is adequate to describe all of the monthly data used here in this research, and the remaining task would be to find the non-seasonal ARIMA terms in the model. This task appears to be difficult as the seasonal effects are dominant in the ACF and PACF plots, recall Figure 5.21. However, a number of candidate models are identified and then diagnostic residuals will solve the problem. Table 5.22 illustrates the residuals diagnostics of monthly mean temperature candidate seasonal ARIMA models.

Table 5.22: Residual Diagnostics of Monthly Mean Temperature Seasonal ARIMA Models.

ARIMA (p,d,q) (P,Q,D)^S	**AIC**	**BIC**	**Model Std.Error**
(0,0,1) (0,1,1)^{12}	3459.373	3474.085	1.3537
(0,0,2) (0,1,1)^{12}	3458.941	3478.556	1.3521
(1,0,0) (0,1,1)^{12}	3454.956	3469.667	1.3495
(1,0,1) (0,1,1)^{12}	3454.712	3474.327	1.3475
(1,0,2) (0,1,1)^{12}	3435.037	3459.555	1.3308
(2,0,0) (0,1,1)^{12}	3456.703	3476.318	1.3499
(2,0,1) (0,1,1)^{12}	3435.850	3460.369	1.3314
(2,0,2) (0,1,1)^{12}	3438.601	3468.024	1.3335
(0,1,0) (0,1,1)^{12}	3896.529	3906.335	1.6765
(0,1,1) (0,1,1)^{12}	3560.297	3575.005	1.4350
(0,1,2) (0,1,1)^{12}	3516.189	3535.800	1.4018
(1,1,0) (0,1,1)^{12}	3821.388	3836.097	1.6377
(1,1,1) (0,1,1)^{12}	3515.178	3534.789	1.4009
(1,1,2) (0,1,1)^{12}	3441.353	3465.867	1.3323
(2,1,0) (0,1,1)^{12}	3706.682	3726.293	1.5450
(2,1,1) (0,1,1)^{12}	3518.520	3543.034	1.4027
(2,1,2) (0,1,1)^{12}	3442.950	3472.367	1.3325

It can be seen from Table 5.22 that an ARIMA (1, 0, 2) (0, 1, 1)^{12} is an adequate model to describe the mean monthly temperature at Amman Airport, this is confirmed by the residuals ACF and PACF plots, see Figures 5.38 and 5.39.

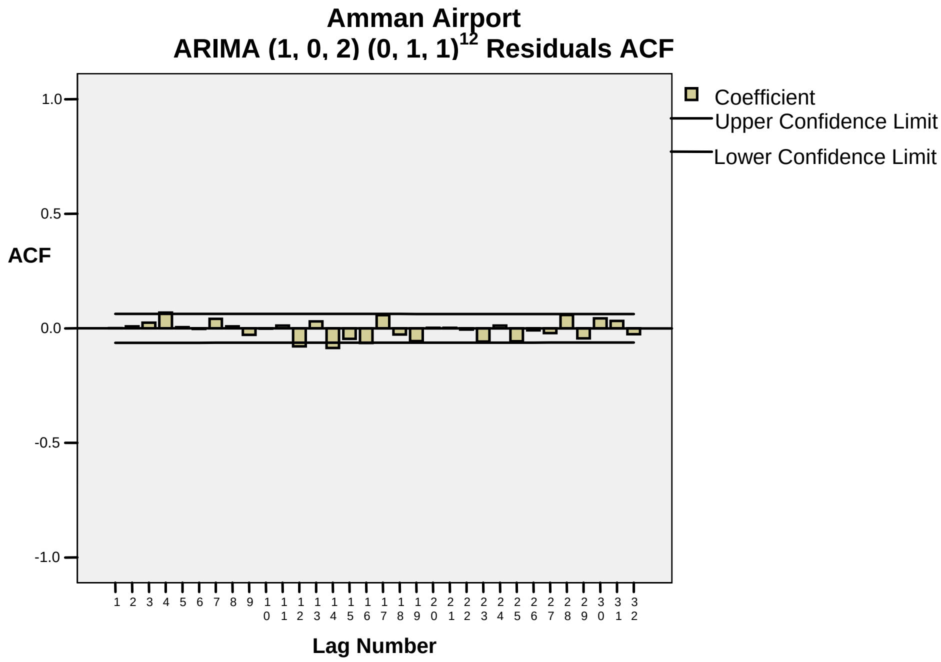

Figure 5.38: Residuals ACF Plot of ARIMA (1, 0, 2) $(0, 1, 1)^{12}$ Model of Monthly Mean Temperature at Amman Airport.

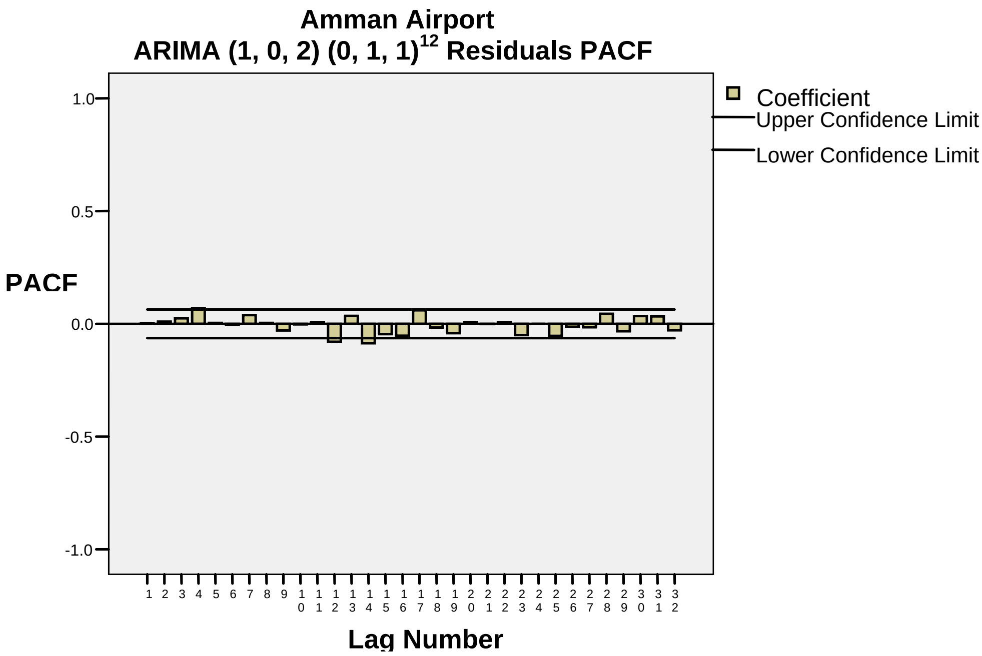

Figure 5.39: Residuals PACF Plot of ARIMA (1, 0, 2) $(0, 1, 1)^{12}$ Model of Monthly Mean Temperature at Amman Airport.

Figure 5.40 show ARIMA (1, 0, 2) (0, 1, 1)^{12} model of monthly mean temperature along forecasts and Figure 5.41 show residual plots. Residual plots show that residuals follow a normal distribution fairly very well and indicate a very good fit.

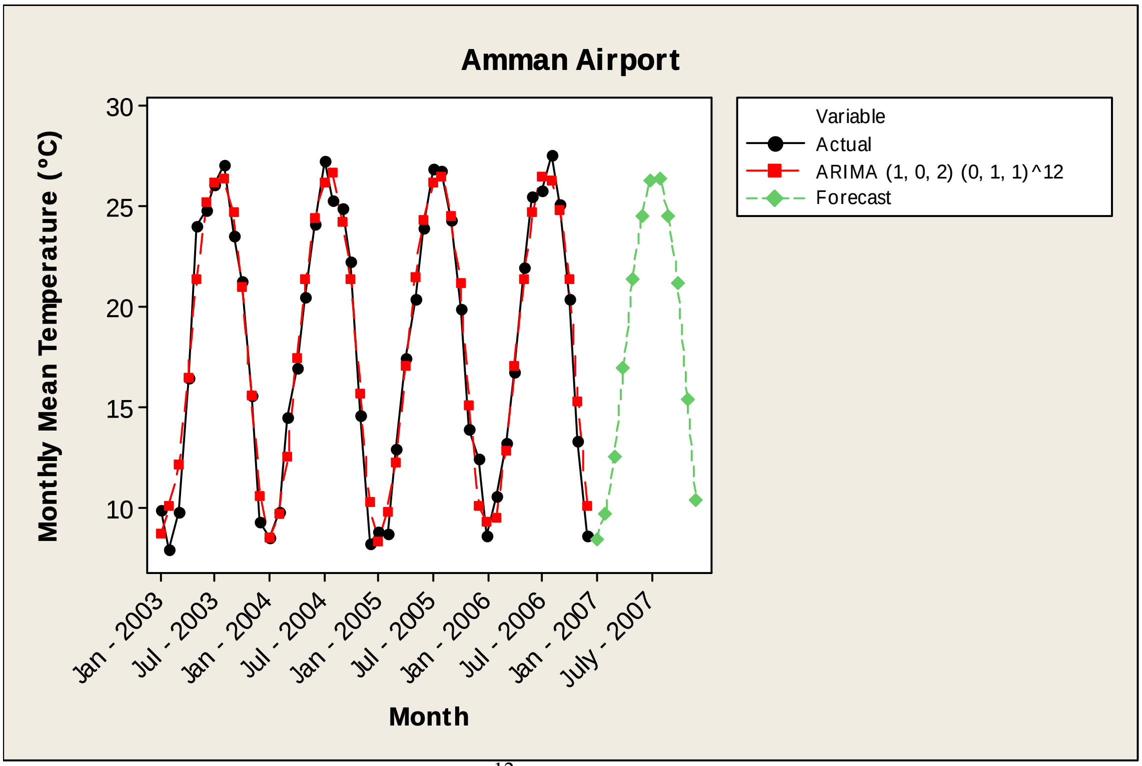

Figure 5.40: ARIMA (1, 0, 2) (0, 1, 1)^{12} Model of Monthly Mean Temperature at Amman Airport.

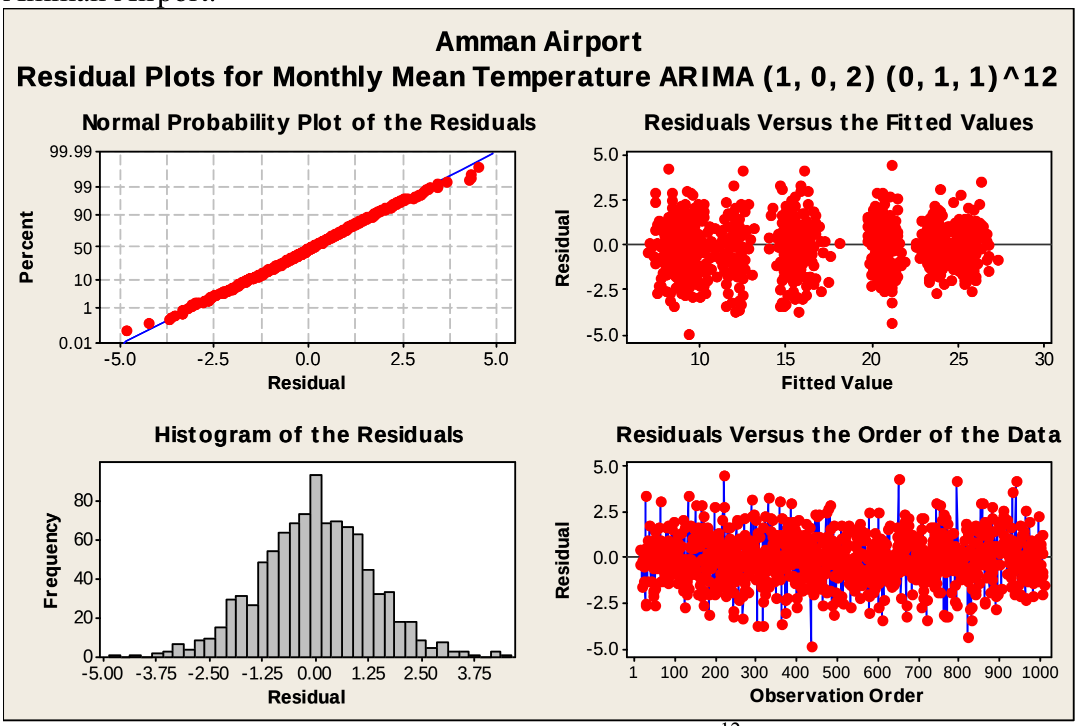

Figure 5.41: Residual Plots of ARIMA (1, 0, 2) (0, 1, 1)^{12} Model of Monthly Mean Temperature at Amman Airport.

Table 5.23 illustrates the best-fit seasonal ARIMA models, Table 5.24 illustrates sample fits and forecasts of monthly mean temperature and relative humidity, and Table 5.25 illustrates sample fits and forecasts of monthly rainfall and runoff.

Table 5.23: Best-Fit Seasonal ARIMA Models of the Different Time Series as Per Respective Station.

Rainfall		**Temperature**	
Station	**ARIMA (p,d,q) (P,Q,D)^{S}**	**Station**	**ARIMA (p,d,q) (P,Q,D)^{S}**
Amman Airport	$(1,0,1)\ (0,1,1)^{8}$	Amman Airport	$(1,0,2)\ (0,1,1)^{12}$
Balama	$(0,0,2)\ (0,1,1)^{8}$	Wadi Dhuleil	$(2,0,2)\ (0,1,1)^{12}$
Hussein College	$(1,0,1)\ (0,1,1)^{8}$	**Relative Humidity**	
Khaldiya	$(0,0,2)\ (0,1,1)^{8}$	**Station**	**ARIMA (p,d,q) (P,Q,D)^{S}**
Madwar	$(0,0,2)\ (0,1,1)^{8}$	Amman Airport	$(1,0,1)\ (0,1,1)^{12}$
Sabha and Subhiya	$(2,0,2)\ (0,1,1)^{8}$	Wadi Dhuleil	$(2,0,1)\ (0,1,1)^{12}$
Um El Jimal	$(2,0,0)\ (0,1,1)^{8}$		
Zarqa	$(0,0,2)\ (0,1,1)^{8}$		
New Jerash Bridge (Runoff)	$(2,0,1)\ (0,1,1)^{8}$		

Table 5.24: Best-Fit Seasonal ARIMA Fits and Forecasts of Monthly Mean Temperature and Relative Humidity as Per Respective Station.

	Temperature (°C)				**Relative Humidity (%)**				
	Amman Airport		**Wadi Dhuleil**		**Amman Airport**		**Wadi Dhuliel**		
Month	**Actual**	**Fit**	**Actual**	**Fit**	**Actual**	**Fit**	**Month**	**Actual**	**Fit**
Jan-06	8.7	9.3	8.8	8.7	67.8	66.8	Jan-04	78.8	80.2
Feb-06	10.7	9.6	10.6	9.6	61.5	65.1	Feb-04	71	75.3
Mar-06	13.3	12.9	13.4	13.2	54.2	58.4	Mar-04	49.8	69.0
Apr-06	16.8	17.2	17.3	17.7	55.5	45.4	Apr-04	43.9	51.1
May-06	22	21.4	22.2	22.0	39.4	40.6	May-04	43.8	42.5
Jun-06	25.6	24.8	25.8	25.0	35.1	40.5	Jun-04	43.8	46.5
Jul-06	25.9	26.6	26	27.1	42.7	41.4	Jul-04	39.5	48.3
Aug-06	27.6	26.3	27.7	26.7	40.7	47.5	Aug-04	57.3	50.9
Sep-06	25.2	24.9	25.2	25.2	48.5	49.5	Sep-04	53.3	57.2
Oct-06	20.5	21.4	20.1	20.9	65.1	51.6	Oct-04	53.4	56.9
Nov-06	13.4	15.4	12.1	14.4	53.2	63.2	Nov-04	69.4	61.6
Dec-06	8.7	10.1	6.9	9.3	56.9	70.3	Dec-04	73.9	78.4
Jan-07		**8.5**		**7.9**		**68.3**	Jan-05		**78.9**
Feb-07		**9.8**		**9.5**		**66.0**	Feb-05		**74.5**
Mar-07		**12.6**		**12.8**		**60.1**	Mar-05		**68.9**
Apr-07		**17.0**		**17.4**		**48.7**	Apr-05		**58.8**
May-07		**21.5**		**21.9**		**40.3**	May-05		**52.2**
Jun-07		**24.6**		**24.8**		**40.4**	Jun-05		**53.9**
Jul-07		**26.3**		**26.7**		**43.1**	Jul-05		**55.2**
Aug-07		**26.4**		**26.8**		**48.3**	Aug-05		**61.1**
Sep-07		**24.6**		**24.9**		**52.3**	Sep-05		**62.8**
Oct-07		**21.2**		**20.7**		**55.0**	Oct-05		**63.2**
Nov-07		**15.4**		**14.3**		**61.6**	Nov-05		**69.0**
Dec-07		**10.5**		**9.6**		**71.5**	Dec-05		**81.1**

Table 5.25: Best-Fit Seasonal ARIMA Fits and Forecasts of Monthly Rainfall and Runoff (New Jerash Bridge) as Per Respective Station.

	Amman Airport		Balama		Hussein College		Khaldiya		Madwar		Sabha and Subhiya		Um El Jimal		Zarqa		New Jerash Bridge	
	Actual	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**	**Actual**	**Fits**
Oct-03	0.3	5.1	0	3.2	0	7.9	0	3.5	0	5.0	0	3.5	0	2.7	0.7	6.3	0.000	0.338
Nov-03	6.5	20.9	4.5	15.5	12	32.6	29	15.1	10.3	18.5	6.5	11.7	13	13.7	8	14.3	0.000	0.418
Dec-03	72.2	41.0	54.5	34.6	95.1	74.4	34.1	21.3	61.6	36.9	72.6	19.7	43.4	22.1	54.3	24.4	0.954	1.584
Jan-04	59.5	54.2	35.5	43.5	117	91.2	23.3	32.2	60.4	46.3	34	31.6	14	27.0	27.8	28.7	1.158	1.465
Feb-04	32.6	46.8	63	45.8	72	83.0	41.1	29.3	43.9	45.2	18	25.2	15	28.2	30	25.8	0.947	1.238
Mar-04	1.8	38.4	3	33.0	11	68.4	4	21.1	6.1	31.4	5.9	20.7	1.5	19.3	1.6	19.2	0.102	1.132
Apr-04	8	10.5	4.8	8.3	6	13.8	4.1	6.4	6.1	7.8	2.1	3.3	3	4.8	1.2	5.3	0.040	0.233
May-04	2.3	0.0	0	0.0	2	3.3	4.1	0.0	0	0.2	0	0.0	3	0.0	0	0.0	0.000	0.124
Oct-04	1.4	5.0	5.4	2.6	2.5	7.8	0	3.7	2.6	5.8	0	0.0	0	2.5	0.3	5.4	0.000	0.338
Nov-04	64.7	20.0	47.9	15.4	99.5	31.7	36.2	16.3	34.2	18.5	42.7	9.2	27.2	14.0	37.8	14.1	3.162	0.409
Dec-04	16.7	41.1	23.5	33.5	24	71.2	9.7	21.6	14.3	39.4	19.5	24.7	10.5	22.8	12	26.8	0.460	1.775
Jan-05	65	56.3	72.9	49.7	101	97.0	22.3	33.2	45	47.3	35.7	30.6	24	29.0	26.5	30.5	1.696	1.492
Feb-05	83.4	44.8	113.9	41.4	118.2	81.7	31.2	27.5	82.5	40.1	39.2	24.5	39	23.4	32	21.9	3.237	1.249
Mar-05	25.2	36.3	24.5	31.6	29	64.2	8.3	20.4	10.5	30.6	8.5	22.0	6.2	18.7	9.8	18.2	0.410	1.266
Apr-05	2.7	10.0	8.6	13.1	1.2	13.3	6.5	5.4	3.1	11.9	11.6	6.1	4.9	7.3	3.6	5.9	0.013	0.295
May-05	3.6	0.1	8.8	0.0	3	3.6	3.6	0.0	5.6	0.3	5.8	1.3	3	0.0	3	0.7	0.021	0.123
Oct-05		**4.5**		**2.1**		**7.4**		**3.9**		**5.3**		**3.8**		**2.6**		**5.3**		**0.333**
Nov-05		**22.0**		**17.8**		**34.2**		**16.9**		**20.0**		**14.8**		**14.6**		**15.7**		**0.527**
Dec-05		**40.8**		**34.6**		**72.5**		**22.0**		**37.9**		**24.9**		**22.8**		**25.9**		**1.572**
Jan-06		**55.5**		**46.7**		**93.8**		**30.5**		**46.9**		**30.9**		**26.9**		**28.5**		**1.522**
Feb-06		**47.3**		**47.1**		**84.7**		**28.4**		**44.6**		**24.3**		**25.5**		**23.9**		**1.339**
Mar-06		**36.0**		**33.0**		**63.9**		**21.0**		**28.3**		**18.3**		**18.8**		**17.9**		**1.111**
Apr-06		**9.1**		**4.7**		**10.8**		**4.7**		**8.7**		**4.1**		**5.2**		**5.1**		**0.300**
May-06		**0.3**		**0.5**		**3.8**		**0.9**		**2.8**		**0.0**		**1.2**		**1.7**		**0.163**

CHAPTER (6): CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Simple linear regression models developed (Rainfall vs. runoff) are able to explain 37.5 %, 44.5 %, and 42.8 % of runoff variation at runoff event, monthly, and water year time scales, respectively. Multiple linear regression models developed are able to explain at least 50 % of monthly rainfall variation when regressed on monthly temperature and relative humidity.

Trend modelling of rainfall time series at water year and monthly time scales show inconsistent results in terms of trend direction. This is due to small sample size in the case of water year and seasonal effects in the case of monthly rainfall. Trend modelling of storm-cluster rainfall time series show a consistent decreasing trend in all rainfall stations and across different trend models. Storm-cluster rainfall time series are of sufficient length (Example, 265 data points for Hussein College), free of seasonal effects, and don't possess a profound autocorrelation structure, autocorrelation can be responsible of existing trends in data. Furthermore, the storm-cluster time series is free of damping effects that could be present when dealing with water year, monthly, and even daily time scales. Mann-Kendall test indicates that storm-cluster rainfall exhibit a significant downward trend for all stations, the test also indicates that monthly and water year rainfall exhibit a weak with no significance trends.

Trend modelling of runoff time series give inconsistent results in terms of direction, this may be attributed to the fact that New Jerash Bridge Station had been relocated about 50 meters downstream and thus more Wadis contribute to the measured runoff.. Flood-baseflow separation systematic errors or measurement site scouring and poor rating curve calibration may have also contributed to these findings. Trend modelling of calendar year baseflow time series show an increasing trend, this is attributed to increased wastewater effluent discharge into Zarqa River. Mann-Kendall test indicates that runoff time series at all time scales exhibit upward trend while the calendar year baseflow exhibit a highly significant upward trend.

Trend modelling of temperature time series show an increasing trend at monthly and calendar year time scales for Amman Airport and Wadi Dhuleil Stations. Trend modelling of relative humidity time series at Amman Airport Station show an increasing trend for all models except for the quadratic model (Best fit). However, the quadratic trend model responds to the direction of the most recent data points. Trend modelling of relative humidity at Wadi Dhuleil shows an increasing trend at monthly and calendar year time scales and across different trend models. Mann-Kendall test indicates that monthly and calendar year temperature and relative humidity at Amman Airport and Wadi Dhuleil exhibit an upward trend, where the trends are highly significant at Wadi Dhuleil. Furthermore, Mann-Kendall test indicates significant upward trend in mean minimum month-temperature at Amman Airport in the dry months, this have important implications on daily temperature variation.

An attempt was made to identify the tendency toward rainfall extreme events. Studying the slope coefficients or change rates of linear trend models of storm-clusters, rainy days per storm-cluster and rainfall intensity indicate that there is no tendency toward extreme events in the future. The phenomenon might be unlikely or simply in its early stages and couldn't be detected using the available records.

Rainy season shifting is investigated by studying the change rates of rainfall-month time series linear trend models and the long-term rainy season distribution of storm-clusters. It's found that there is no apparent shifting in the rainy season. The phenomenon might be unlikely or simply in its early stages and couldn't be detected using the available records.

Moving average (MA) models are applied to calendar and water year time series. The best Moving average length for rainfall is found to be around 5 although an MA length of 8 is found suitable for Khaldiya Station. The best MA length for runoff is 7 and 4 for baseflow. The best MA length for temperature and relative humidity at Amman Airport is the same, as 6. The best MA length for temperature and relative humidity at Wadi Dhuleil is the quite different, as 3 for temperature and as 9 for relative humidity.

Single exponential smoothing (SES) models are applied to calendar and water year time series. Alpha values for rainfall are all below 0.1 except for Sabha and Subhiya Station at 0.12. Alpha value for runoff is quite similar to rainfall and it's at 0.01. The picture is quite different with baseflow with an alpha value of 0.62. Alpha values of 0.25 and 0.07 are obtained for temperature and relative humidity at Amman Airport while alpha values of 0.19 and 0.15 are obtained for temperature and relative humidity at Wadi Dhuleil, respectively. Based on alpha values, water year rainfall and runoff time series are random, calendar year temperature and relative humidity time series comes next with less randomness and temperature being less than relative humidity, calendar year baseflow times series show quite deterministic behaviour where recent values depend on past values.

Seasonal decomposition models are applied to monthly data. It is found that a seasonal decomposition model with a trend component performed best with all data time series.

Based on autocorrelation functions (ACF) plots, it's found that water year rainfall, water year runoff, storm-clusters, and runoff events have a weak autocorrelation structure. Calendar year temperature, relative humidity, and baseflow come next with a moderate strength autocorrelation structure. Monthly time series of rainfall, runoff, temperature, and relative humidity have high strength autocorrelation pattern.

Variance fluctuation is observed in storm-cluster rainfall time series, a natural-log transformation of storm-cluster rainfall time series allows a better quality Autoregressive Integrated Moving Average (ARIMA) models to be developed. The seasonal ARIMA models will handle very well the high strength autocorrelation structure in monthly data.

The seasonal ARIMA models of monthly rainfall at Sabha and Subhiya $(2,0,2)(0,1,1)^8$ and Um El Jimal $(2,0,0)(0,1,1)^8$ rainfall stations are similar to the seasonal ARIMA model of monthly runoff at New Jerash Bridge $(2,0,1)(0,1,1)^8$ in terms of AR Processes. Both rainfall stations are representative of relatively large sub-catchments in the north-eastern part of Amman-Zarqa Basin, and possess a high effectiveness percentage of Amman-Zarqa Thiessen Network.

6.2 Recommendations

In the research area of climate change and time series analysis, it is recommended that any quantification of impact on the hydrological cycle and in particular rainfall process to use a finer scale time series. Examples of phenomena that could be investigated are trend direction, extreme events, and shifting in the rainy season.

It is strongly recommended that efficient databases to be developed and to allow the unlimited sharing of data and resources. Only the right data and team work can alleviate such a problem, the “climate change

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APPENDIX (1): DATA

Storm-Cluster Rainfall (mm)								
Index	**Amman Airport**	**Balama**	**Hussein College**	**Khaldiya**	**Madwar**	**Sabha & Subhiya**	**Um El Jimal**	**Zarqa**
1	3.0	1.4	87.1	2.2	34.6	3.1	1.0	2.1
2	42.1	46.0	5.2	14.3	3.7	32.4	13.1	19.9
3	7.2	4.5	32.4	9.0	9.2	15.0	8.3	5.0
4	16.0	18.4	66.1	8.0	28.8	10.6	5.0	9.8
5	29.2	45.0	47.2	14.0	20.0	11.1	5.7	14.2
6	24.1	45.6	5.6	22.9	7.0	19.1	20.4	14.6
7	3.5	7.7	3.5	15.8	8.6	22.0	4.8	8.0
8	8.7	9.0	14.5	21.4	8.9	5.5	12.5	7.5
9	4.2	17.5	64.4	4.5	4.5	8.5	6.5	2.0
10	0.3	10.4	109.6	11.9	18.2	14.0	8.7	9.3
11	43.5	53.8	35.5	43.4	77.7	25.7	17.6	50.0
12	78.2	48.4	43.0	21.0	34.0	5.5	38.5	36.0
13	16.5	11.6	56.8	3.2	9.6	16.9	23.1	2.9
14	25.2	43.4	23.8	13.0	16.0	22.3	1.1	8.0
15	33.6	30.0	8.8	21.3	41.9	12.0	10.6	21.2
16	22.9	7.7	24.5	20.0	12.0	20.9	14.9	25.5
17	14.0	26.3	130.4	41.6	6.0	24.5	10.3	4.8
18	21.9	31.0	18.1	19.5	17.5	2.0	23.0	28.5
19	85.3	21.6	32.8	18.0	39.7	27.2	22.9	29.1
20	21.3	15.0	56.9	9.0	15.6	4.0	26.4	4.8
21	17.9	46.6	10.0	25.4	28.3	12.0	8.4	15.4
22	30.2	26.0	48.7	10.5	30.0	37.2	4.6	11.4
23	15.9	28.5	27.5	16.0	86.0	20.0	24.7	10.2
24	26.7	16.5	123.5	9.8	52.6	14.0	8.8	11.3
25	18.8	24.6	105.5	10.9	34.7	28.8	8.1	13.0
26	27.7	46.3	91.6	24.5	9.1	12.2	3.6	25.7
27	66.3	29.0	1.0	37.4	25.5	5.5	10.3	17.5
28	56.1	10.0	47.4	6.1	35.7	34.5	44.6	5.4
29	31.7	7.0	18.0	8.5	20.4	34.0	16.3	4.3
30	14.2	37.7	31.6	18.1	2.3	7.4	2.2	22.4
31	13.6	51.0	107.0	8.7	8.5	12.0	11.7	22.9
32	67.3	21.0	66.0	8.2	11.5	16.4	7.8	11.3
33	38.2	28.3	47.4	5.8	13.4	9.4	9.0	14.1
34	0.2	11.8	22.7	26.2	41.0	1.2	19.5	7.7
35	23.6	16.0	5.5	27.4	23.5	6.5	37.2	7.8
36	16.0	11.7	20.5	4.2	61.5	13.6	3.8	10.7
37	5.1	28.5	25.8	6.3	22.5	8.4	3.7	18.8
38	13.4	48.0	35.7	16.3	45.0	45.0	16.6	23.3
39	17.6	21.0	29.9	14.9	30.0	7.6	6.6	9.7
40	17.0	20.0	57.0	19.3	15.4	17.9	4.4	10.9
41	15.4	22.6	37.6	4.8	29.9	14.0	5.7	13.4
42	46.6	17.0	29.2	20.0	24.3	20.2	5.7	9.7
43	21.8	42.5	24.3	3.6	20.0	6.5	19.3	22.7
44	10.5	14.2	47.5	22.1	11.3	7.0	18.6	8.6
45	0.3	18.7	62.8	13.4	11.5	4.1	3.6	10.4
46	28.7	54.9	35.7	8.7	3.5	20.8	4.1	29.1
47	24.3	15.5	38.8	2.9	6.0	12.9	12.1	7.6
48	43.5	10.0	5.5	15.6	62.1	9.4	13.2	5.4

Storm-Cluster Rainfall (mm) (Cont.)

Index	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
49	17.0	39.0	79.3	13.1	16.0	3.6	15.3	21.3
50	28.2	25.0	47.5	6.0	15.0	15.9	2.5	12.8
51	6.4	8.0	49.6	12.2	38.0	17.1	7.8	4.7
52	49.8	8.3	18.7	21.3	42.8	7.1	2.5	6.3
53	19.8	29.5	82.2	5.0	18.4	11.2	19.6	17.6
54	32.5	16.0	29.6	9.0	6.7	16.2	11.6	10.8
55	4.9	8.0	66.0	7.0	17.2	6.1	6.6	4.7
56	10.2	7.0	37.8	12.0	54.9	43.0	1.8	4.3
57	43.8	8.0	22.3	52.0	52.0	18.0	12.6	4.7
58	20.1	54.7	12.0	22.0	21.0	4.0	16.0	25.9
59	37.4	25.6	50.0	7.0	27.0	16.7	6.6	13.0
60	29.2	19.0	18.1	19.0	16.2	10.0	9.7	10.5
61	12.5	33.0	8.0	17.0	37.7	8.5	15.5	15.9
62	7.1	22.0	25.4	14.0	19.8	8.0	5.0	10.1
63	21.9	24.0	109.8	13.0	10.5	14.0	14.0	15.5
64	13.4	24.0	25.8	15.0	53.8	8.0	46.7	14.0
65	21.6	7.5	48.7	4.5	39.7	24.0	17.7	4.5
66	23.6	45.0	19.5	22.5	13.9	35.3	2.5	26.7
67	109.6	66.4	14.0	42.4	5.7	14.0	19.5	39.7
68	30.9	17.0	45.2	25.0	50.0	8.0	13.3	8.2
69	19.9	8.0	10.4	13.0	54.0	39.0	14.0	6.2
70	9.2	47.5	31.5	37.5	13.8	10.2	7.3	53.5
71	27.9	25.4	14.2	34.3	25.4	2.5	8.5	48.4
72	41.5	20.0	71.6	7.0	8.0	12.7	3.9	2.0
73	10.6	24.0	171.6	6.1	18.5	7.5	17.4	16.2
74	25.2	21.3	30.7	21.7	2.0	10.4	26.6	9.3
75	7.7	29.3	9.4	15.0	27.5	8.3	11.4	7.3
76	41.9	2.1	158.7	28.8	14.0	12.3	5.6	0.1
77	78.8	65.0	66.8	5.6	3.0	3.2	17.5	25.9
78	19.0	10.5	25.9	2.4	16.0	15.5	42.1	4.9
79	10.6	8.8	37.1	4.5	2.0	7.0	1.6	4.2
80	113.9	16.1	30.6	2.6	1.0	13.9	3.8	2.4
81	61.1	4.8	12.6	5.6	2.0	16.9	17.2	1.1
82	15.5	1.2	18.9	14.8	6.0	5.4	9.3	11.6
83	23.8	15.0	116.8	19.0	16.0	18.3	18.6	14.3
84	18.7	3.0	22.0	12.0	4.0	6.4	4.0	10.7
85	17.4	7.6	13.6	18.0	9.1	9.7	1.1	9.2
86	10.7	15.1	7.0	4.0	5.4	7.0	3.8	11.5
87	65.4	8.0	7.1	5.0	2.3	46.3	3.7	4.2
88	13.4	37.6	44.1	11.0	9.5	26.8	0.6	21.0
89	9.4	5.5	1.9	28.0	81.0	7.1	15.0	13.0
90	8.5	10.2	68.2	37.0	56.0	11.4	15.5	19.3
91	4.4	30.0	0.5	18.0	14.0	14.0	7.2	45.9
92	18.8	89.5	23.9	26.0	43.0	4.2	13.3	30.6
93	8.4	75.5	4.1	17.5	2.0	14.5	7.6	9.7
94	10.2	9.0	19.6	24.3	24.0	7.7	9.8	6.4
95	16.2	30.0	37.8	33.4	17.1	26.5	5.8	20.2
96	2.8	24.0	35.5	22.6	49.5	20.8	2.2	6.3
97	48.1	43.2	67.0	10.0	57.0	7.2	27.4	29.1
98	19.5	42.3	179.3	4.5	45.1	8.5	17.4	24.3

Storm-Cluster Rainfall (mm) (Cont.)

Index	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
99	21.4	0.5	118.6	22.0	13.3	18.0	6.7	1.5
100	34.9	13.7	21.4	15.3	27.5	19.3	12.8	13.0
101	20.0	4.0	32.0	7.5	16.0	20.0	13.9	33.5
102	23.6	44.5	43.7	31.3	30.5	18.5	4.8	45.0
103	19.0	38.0	65.2	10.0	5.9	7.6	19.5	22.0
104	23.5	55.1	59.5	9.0	11.5	11.0	9.0	2.0
105	33.0	13.1	9.0	12.5	85.6	14.9	19.3	13.0
106	25.8	13.8	5.0	8.0	7.9	7.0	29.9	17.0
107	47.3	11.5	13.7	1.8	22.0	16.6	8.5	2.0
108	31.2	26.5	104.6	6.5	41.5	2.5	12.0	4.0
109	1.1	39.5	79.3	63.8	7.5	21.0	7.5	26.4
110	25.0	4.0	97.9	13.9	1.5	8.5	21.0	4.4
111	5.0	6.1	25.7	2.4	16.5	19.6	14.7	2.5
112	46.2	7.0	28.9	22.0	4.8	10.5	26.0	22.6
113	51.3	89.0	32.4	3.5	1.4	12.5	31.5	5.0
114	65.6	8.5	20.3	2.9	16.6	5.8	16.2	2.3
115	41.6	16.0	53.0	30.6	8.7	7.5	4.1	13.5
116	19.0	45.8	10.5	17.1	15.8	15.5	9.0	16.6
117	22.0	6.5	35.0	15.2	33.5	3.6	14.5	6.2
118	37.0	2.0	152.7	2.6	17.2	11.0	5.4	17.0
119	3.6	24.8	5.5	3.1	19.5	12.0	16.0	0.9
120	38.8	6.0	20.0	16.2	46.0	26.6	14.0	6.0
121	96.4	5.0	77.7	21.0	2.5	1.1	0.1	9.2
122	6.0	11.8	10.8	26.1	17.5	5.0	22.0	19.9
123	1.4	7.5	1.0	1.6	2.5	16.5	3.2	15.1
124	50.3	14.7	38.2	54.6	1.5	19.5	2.0	1.0
125	8.4	26.1	7.8	2.5	14.7	1.0	2.0	38.7
126	2.7	14.5	9.9	30.0	9.0	5.0	6.0	10.0
127	28.2	42.6	19.2	28.2	12.1	7.0	6.4	11.0
128	20.6	2.0	20.3	8.7	7.2	7.0	11.0	8.9
129	7.0	52.0	28.2	6.2	7.5	7.5	28.6	5.9
130	13.0	13.1	49.8	19.2	19.0	29.0	36.0	14.3
131	14.9	76.0	21.3	30.3	14.0	19.0	2.0	6.8
132	11.3	14.5	42.8	51.1	59.0	12.3	35.0	57.0
133	25.3	16.2	11.5	4.8	24.0	2.1	7.0	6.0
134	20.9	2.7	93.4	6.5	14.0	5.0	18.5	3.6
135	26.2	12.0	36.3	10.0	8.0	10.0	18.5	20.9
136	3.0	6.0	111.1	5.4	23.0	22.0	10.0	8.6
137	60.8	8.0	33.5	3.0	11.5	5.3	10.5	14.0
138	19.8	7.0	14.5	11.5	21.0	35.5	13.6	11.2
139	71.3	9.0	8.5	12.0	17.2	8.1	20.4	1.3
140	26.7	10.5	0.2	8.0	47.8	3.6	39.8	15.5
141	10.7	11.5	17.0	2.0	9.5	44.5	3.2	14.8
142	7.8	32.0	38.0	5.2	3.5	10.5	4.6	1.7
143	5.6	25.4	79.6	9.0	28.2	26.8	6.2	11.5
144	22.1	3.0	10.5	14.0	64.0	55.4	8.5	20.7
145	22.4	6.0	8.0	13.3	70.2	10.0	12.5	12.4
146	79.1	8.0	32.5	6.4	7.5	8.5	19.2	10.3
147	5.0	8.0	28.1	20.7	6.5	15.0	10.2	14.0
148	9.9	8.5	60.0	9.0	12.5	7.0	12.4	19.0

Storm-Cluster Rainfall (mm) (Cont.)

Index	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
149	24.8	10.0	61.0	5.0	2.0	35.5	2.5	8.0
150	22.0	14.3	12.5	17.0	37.3	9.0	6.4	0.3
151	30.2	3.0	39.5	57.4	9.0	7.5	0.5	16.9
152	30.5	12.0	18.0	49.8	9.0	5.0	12.0	45.4
153	11.4	3.7	47.2	22.9	27.5	8.0	3.7	24.6
154	16.0	30.0	41.0	3.2	11.5	9.5	14.5	3.4
155	44.4	19.3	1.7	12.9	8.0	22.5	16.6	12.2
156	24.2	67.6	6.5	5.4	43.5	46.0	6.4	7.6
157	0.2	8.5	49.1	33.5	56.5	16.0	3.0	29.3
158	7.1	6.1	115.0	2.4	24.0	10.0	32.6	13.0
159	30.0	9.5	21.5	4.0	35.0	18.0	39.6	14.6
160	52.9	7.2	25.5	9.5	11.0	14.5	9.5	11.1
161	16.3	1.0	75.8	12.6	24.8	14.5	7.0	15.1
162	6.9	4.0	181.4	6.2	24.0	3.0	12.2	9.7
163	35.6	11.5	73.5	3.3	4.5	17.0	1.5	7.7
164	39.6	42.0	22.2	39.1	27.0	21.0	37.2	28.4
165	10.6	3.0	67.2	47.2	25.2	9.0	3.9	54.8
166	37.3	20.0	21.8	29.0	4.9	8.0	6.3	28.7
167	18.9	17.5	164.7	7.8	2.0	14.0	5.4	7.9
168	100.2	61.6	12.0	12.4	14.0	11.0	4.5	2.7
169	4.7	26.0	31.0	16.1	34.0	5.0	4.9	17.7
170	20.3	35.5	46.0	26.1	15.0	2.0	9.9	28.0
171	19.9	6.0	41.0	1.2	7.0	29.8	34.0	1.2
172	26.5	28.0	20.0	0.2	62.0	12.3	39.1	1.0
173	2.8	14.0	37.2	24.0	19.4	12.0	15.5	14.5
174	25.5	3.5	145.0	18.8	4.0	1.6	10.6	9.5
175	26.6	45.5	82.0	14.3	2.0	17.1	23.9	26.0
176	103.2	35.0	49.5	2.8	9.0	22.2	19.6	15.5
177	57.2	14.5	5.0	14.0	45.0	10.0	10.8	9.0
178	31.7	24.0	47.3	25.1	68.2	7.0	2.0	26.0
179	2.7	21.5	82.6	25.3	21.0	2.5	4.1	1.0
180	34.0	39.4	12.0	1.5	13.5	8.5	21.4	14.1
181	38.6	30.0	17.0	21.0	25.0	1.1	17.1	17.5
182	7.0	5.0	60.3	7.5	30.0	14.3	9.0	5.3
183	6.7	58.2	48.0	5.9	1.5	9.4	7.0	9.7
184	35.3	18.5	12.5	10.3	44.3	16.2	6.6	9.0
185	26.8	4.0	34.0	1.6	17.0	2.5	21.4	0.4
186	18.1	1.0	45.0	3.6	33.5	6.6	18.1	28.4
187	2.9	2.0	45.0	24.4	11.0	6.6	3.1	19.5
188	23.7	9.0	12.0	20.1	6.0	5.6	13.3	5.5
189	27.3	47.0	120.0	10.1	39.5	26.0	9.0	3.6
190	30.8	52.0	61.0	14.7	46.0	15.9	4.0	6.8
191	7.3	6.2	8.0	7.6	30.2	6.5	1.5	17.1
192	72.9	21.0	1.0	10.0	12.5	5.0	16.2	0.8
193	40.0	24.0	21.5	37.0	8.0	4.0	22.5	23.3
194	15.0	15.5	60.0	15.1	12.0	1.0	7.2	1.8
195	1.5	7.5	17.0	16.2	2.0	15.0	7.1	10.0
196	1.5	18.0	3.5	0.7	19.0	23.5	3.9	2.0
197	10.5	18.0	4.5	7.4	45.0	32.4	11.0	10.0
198	41.8	10.5	30.0	9.5	42.5	2.0	1.0	16.0

Storm-Cluster Rainfall (mm) (Cont.)								
Index	**Amman Airport**	**Balama**	**Hussein College**	**Khaldiya**	**Madwar**	**Sabha & Subhiya**	**Um El Jimal**	**Zarqa**
199	26.7	11.0	41.3	6.5	14.0	4.0	17.0	17.4
200	5.7	29.0	17.5	28.5	4.8	5.0	11.3	11.5
201	4.9	16.5	150.3	18.5	3.5	21.5	18.5	24.1
202	21.1	62.0	7.7	4.5	67.3	9.0	1.7	11.2
203	22.7	54.5	42.0	17.0	6.0	3.0	10.7	18.0
204	12.5	17.0	11.0	3.3	1.0	39.5	7.8	2.5
205	68.1	22.0	32.0	6.3	46.1	27.5	11.8	12.0
206	5.5	5.5	55.0	1.7	30.8	10.5	24.2	0.5
207	20.5	15.0	74.0	8.0	16.3	10.0	11.0	7.2
208	6.1	3.0	58.7	47.8	5.1	18.5	6.4	27.9
209	24.2	24.0	46.5	19.3	23.5	9.0	5.7	18.7
210	31.6	56.0	41.0	4.2	13.4	7.9	3.1	12.5
211	51.0	42.0	40.5	5.0	10.2	30.9	12.0	4.5
212	39.1	13.8	14.7	4.1	76.4	11.7	3.0	7.6
213	23.6	5.6	15.0	34.4	18.4	5.6	10.5	36.0
214	18.1	7.0	9.5	2.8	4.8	15.8	22.0	3.0
215	20.7	35.0	36.5	1.8	16.3	4.2	22.0	2.0
216	9.2	4.0	88.6	25.0	3.7	10.6	8.0	34.0
217	3.8	1.5	63.6	22.2	31.5	19.2	10.0	21.7
218	7.1	46.5	31.0	10.5	32.7	34.5	1.2	20.0
219	12.1	50.5	14.0	20.2	28.7	11.3	29.0	5.8
220	39.7	15.0	14.0	7.7	3.8	12.7	7.0	18.7
221	38.4	10.0	123.0	3.0	10.2	5.6	6.0	4.0
222	20.6	30.0	10.3	26.9	22.2	16.9	30.0	9.0
223	9.4	5.0	7.6	13.0	9.8	47.9	31.0	43.0
224	18.1	19.0	113.5	3.5	14.3	2.1	16.0	0.5
225	49.7	33.0	78.8	14.4	32.9	26.9	8.0	2.0
226	7.0	7.0	44.0	1.8	4.6	5.2	16.0	20.0
227	4.2	4.0	31.5	21.9	39.0	1.8	11.0	3.0
228	65.7	24.5	41.2	15.5	6.1	12.3	8.2	9.0
229	39.9	10.0	37.8	28.4	15.3	1.6	29.0	13.0
230	29.2	17.0	24.0	1.8	16.3	3.5	9.0	19.5
231	17.9	20.0	126.9	2.4	4.1	5.9	3.0	3.0
232	20.5	83.8	5.0	21.4	10.7	2.1	18.6	6.0
233	21.1	4.0	12.8	13.3	7.1	13.4	2.0	9.5
234	15.2	5.0	28.4	6.6	6.1	25.4	10.0	18.0
235	73.8	22.0	5.0	11.5	4.1	3.9	22.0	26.1
236	2.5	14.5	90.1	2.7	12.8	19.5	24.0	0.7
237	4.9	14.0	76.5	11.8	14.3	21.7	2.0	20.8
238	23.3	25.0	54.0	7.4	7.1	14.0	11.0	7.0
239	8.3	1.0	18.4	16.6	12.8	39.2	18.0	8.5
240	38.4	17.5	26.0	22.2	24.6	8.5	12.4	19.0
241	48.9	4.0	73.5	5.9	20.4	10.2	15.0	0.5
242	68.9	14.0	17.5	4.0	0.2	5.8	14.0	1.6
243	9.7	23.0	17.0	4.1	82.3		2.0	1.2
244	11.4	23.5	50.6	5.9	10.5		9.0	9.8
245	38.0	14.5	10.0	25.7	1.0		2.0	22.0
246	13.9	3.0	74.5	4.6	5.6		4.0	11.0
247	19.4	3.3	8.0	9.7			9.0	17.5
248	33.6	16.6	14.5	12.4			5.0	9.0

Storm-Cluster Rainfall (mm) (Cont.)

Index	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
249	4.8	20.9	25.0	9.9			1.5	1.0
250	36.0	10.4	4.0	31.2			3.0	31.0
251	5.2	19.2	45.0	8.3			9.0	9.8
252	8.3	37.4	17.0	6.5			14.7	2.1
253	10.2	35.4	7.0	3.6			3.5	3.0
254	2.2	2.8	6.0				9.5	
255	20.8	24.5	27.5				15.0	
256	7.8	3.7	42.0				9.0	
257	1.8	8.8	30.0				1.0	
258	8.0		20.0				38.0	
259	16.6		60.0				6.2	
260	31.9		41.0				3.9	
261	16.2		1.8				3.0	
262	13.7		116.2					
263	39.6		29.0					
264	25.4		0.2					
265	2.7		3.0					
266	80.7							
267	25.2							
268	0.9							
269	3.6							

Monthly Rainfall (mm)

Month	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
Jan - 1969	73.6	92.9	147.1	18.8	67.1	40.4	54.0	52.2
Feb - 1969	17.4	14.9	34.5	6.5	10.7	8.2	10.0	9.6
Mar - 1969	144.3	85.8	237.0	52.2	97.0	77.1	59.7	56.1
Apr - 1969	16.9	12.5	16.3	3.2	8.3	2.8	6.9	4.7
May - 1969	0.0	0.0	0.0	0.0	0.0	11.3	1.8	0.0
Oct - 1969	18.2	17.0	12.6	18.2	9.2	18.3	12.6	13.3
Nov - 1969	13.1	13.0	13.2	15.4	9.6	17.6	11.6	9.1
Dec - 1969	10.5	11.3	14.4	6.6	0.0	9.2	3.0	11.0
Jan - 1970	45.5	47.4	87.1	21.5	35.6	41.9	16.6	23.0
Feb - 1970	24.8	30.4	40.7	17.0	15.5	25.6	13.3	19.2
Mar - 1970	53.5	91.7	113.3	39.8	48.8	35.1	26.5	30.7
Apr - 1970	10.5	13.4	13.5	13.0	18.2	12.1	7.1	7.2
May - 1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1970	1.5	0.0	3.9	0.0	0.0	0.0	0.0	0.0
Nov - 1970	5.2	5.5	10.2	0.0	7.0	0.0	6.1	0.0
Dec - 1970	37.4	53.9	73.2	14.4	33.2	13.5	25.3	7.3
Jan - 1971	18.4	40.9	41.2	43.7	26.8	41.0	32.3	21.0
Feb - 1971	34.7	42.4	66.0	7.4	21.1	34.0	17.3	13.0
Mar - 1971	51.1	58.2	80.3	11.9	25.9	14.0	19.4	10.7
Apr - 1971	145.6	6.6	13.9	46.8	82.2	62.0	42.8	55.0
May - 1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov - 1971	13.9	18.0	24.4	0.0	22.0	20.0	21.8	10.3

Monthly Rainfall (mm)(Cont.)								
Month	**Amman Airport**	**Balama**	**Hussein College**	**Khaldiya**	**Madwar**	**Sabha & Subhiya**	**Um El Jimal**	**Zarqa**
Dec - 1971	122.5	80.7	181.1	37.2	69.4	70.6	50.1	52.8
Jan - 1972	32.7	11.7	51.7	6.4	20.0	44.0	29.0	11.0
Feb - 1972	53.7	72.4	80.0	25.7	53.4	51.5	36.4	36.2
Mar - 1972	38.5	50.0	48.4	30.4	16.7	35.3	33.5	28.5
Apr - 1972	43.7	12.7	32.8	21.3	17.0	44.3	39.5	9.2
May - 1972	6.6	0.0	12.2	0.0	0.0	3.1	1.0	0.0
Oct - 1972	0.0	0.0	0.2	0.0	0.0	0.0	1.1	0.0
Nov - 1972	31.1	33.0	40.7	0.0	4.6	26.5	24.8	34.6
Dec - 1972	6.0	0.4	8.3	0.0	0.0	0.0	0.6	0.5
Jan - 1973	107.5	52.6	149.8	20.0	17.5	0.0	31.9	29.4
Feb - 1973	17.9	15.0	33.1	0.0	0.0	2.0	8.3	20.2
Mar - 1973	31.4	49.6	58.7	41.6	39.7	27.2	25.4	11.4
Apr - 1973	1.2	7.9	1.1	5.8	0.0	0.0	7.2	0.0
May - 1973	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0
Oct - 1973	0.4	0.0	0.0	0.0	0.0	0.0	2.0	5.5
Nov - 1973	49.9	54.5	75.3	39.0	43.9	16.0	19.1	21.5
Dec - 1973	31.7	27.0	41.8	16.0	5.5	2.0	6.4	1.8
Jan - 1974	54.5	48.1	89.3	29.5	47.6	44.2	27.2	28.2
Feb - 1974	98.9	65.3	152.4	85.3	47.9	67.0	56.1	28.4
Mar - 1974	12.3	10.0	20.2	5.9	25.6	26.0	8.6	8.4
Apr - 1974	19.5	14.0	30.6	8.0	14.5	0.0	10.3	12.2
May - 1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov - 1974	34.1	0.0	49.6	17.5	0.0	31.4	12.0	0.0
Dec - 1974	24.7	20.0	41.4	20.9	9.1	22.4	15.6	10.9
Jan - 1975	17.5	4.3	28.5	12.6	28.4	16.6	6.8	7.8
Feb - 1975	125.7	99.7	216.1	84.0	43.9	27.7	26.3	52.7
Mar - 1975	33.2	45.3	58.8	22.9	16.3	22.9	19.1	22.3
Apr - 1975	5.1	0.0	5.5	12.3	8.5	14.9	7.8	0.0
May - 1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov - 1975	21.3	11.8	33.6	0.0	12.5	3.7	11.8	7.7
Dec - 1975	23.7	32.6	45.8	14.8	14.9	22.8	17.5	20.4
Jan - 1976	29.2	18.2	46.1	8.2	14.9	10.5	5.7	10.2
Feb - 1976	42.9	50.8	78.9	42.7	65.0	33.2	32.1	36.7
Mar - 1976	68.6	69.0	96.0	31.6	84.0	45.0	22.2	33.0
Apr - 1976	9.3	5.5	14.7	10.5	8.5	10.0	10.9	6.7
May - 1976	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0
Oct - 1976	1.1	5.0	2.9	0.0	2.7	8.0	0.0	5.0
Nov - 1976	10.5	20.0	29.2	6.3	45.0	7.6	4.1	10.9
Dec - 1976	1.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
Jan - 1977	43.4	38.1	99.4	35.0	51.5	37.6	26.7	24.0
Feb - 1977	24.3	17.0	47.5	14.9	15.4	14.0	13.2	9.7
Mar - 1977	52.5	47.5	79.3	24.7	42.8	27.0	18.3	26.2
Apr - 1977	57.6	27.7	90.5	19.1	43.5	21.4	13.7	18.5
May - 1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1977	28.2	19.8	38.8	27.9	25.5	10.2	9.0	12.3
Nov - 1977	6.4	0.0	5.5	3.6	0.0	4.1	2.5	0.0
Dec - 1977	73.3	63.4	136.1	40.9	11.3	39.2	35.6	35.4
Jan - 1978	41.3	15.5	62.0	18.1	11.5	20.6	12.6	7.6

Monthly Rainfall (mm)(Cont.)

Month	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
Feb - 1978	27.2	19.2	50.2	8.9	12.0	10.9	5.5	10.6
Mar - 1978	66.7	40.0	113.6	23.3	62.1	24.6	18.2	23.3
Apr - 1978	5.5	0.0	12.3	0.0	0.0	0.0	0.0	0.0
May - 1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1978	1.9	4.8	2.1	0.0	0.0	4.0	3.4	3.4
Nov - 1978	1.4	0.0	2.6	0.0	0.0	3.2	3.0	0.0
Dec - 1978	42.6	34.0	80.3	15.9	66.0	24.8	20.7	19.4
Jan - 1979	42.0	16.3	60.9	23.2	31.0	18.3	16.8	11.0
Feb - 1979	7.1	29.5	12.0	21.3	38.0	18.4	15.7	17.6
Mar - 1979	35.3	40.5	71.5	9.6	58.1	7.1	5.4	23.5
Apr - 1979	0.6	0.0	3.1	0.0	8.1	3.2	5.7	0.0
May - 1979	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1979	35.0	15.0	26.1	16.0	25.1	0.0	0.0	8.9
Nov - 1979	133.2	62.7	135.2	68.0	72.8	43.0	60.7	30.6
Dec - 1979	87.9	77.6	108.0	65.0	100.0	48.7	53.0	39.4
Jan - 1980	77.3	70.0	87.1	42.0	73.7	30.5	29.8	39.5
Feb - 1980	76.4	82.0	163.2	37.5	80.6	41.8	31.0	51.9
Mar - 1980	77.8	56.9	132.9	60.3	40.4	49.5	35.8	29.8
Apr - 1980	16.2	13.0	18.6	19.2	8.6	9.2	5.8	11.2
May - 1980	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1980	2.0	0.0	0.0	1.9	0.0	0.0	0.7	0.0
Nov - 1980	7.3	7.0	7.9	2.0	2.5	4.0	1.6	2.7
Dec - 1980	46.7	72.9	225.5	79.9	104.0	24.5	65.6	22.5
Jan - 1981	48.2	25.5	83.8	15.5	21.8	16.6	5.8	22.1
Feb - 1981	37.0	61.4	54.4	45.2	52.1	21.1	26.3	15.9
Mar - 1981	20.5	28.8	22.7	20.1	16.5	5.3	13.9	8.8
Apr - 1981	11.1	7.6	19.1	1.0	4.0	3.0	4.6	2.9
May - 1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov - 1981	23.9	15.8	50.4	12.3	29.1	11.5	14.0	12.4
Dec - 1981	0.8	2.2	4.4	2.0	5.6	0.0	1.1	0.0
Jan - 1982	57.9	46.0	67.7	43.9	14.3	18.2	28.6	39.5
Feb - 1982	56.4	46.5	153.7	27.5	48.0	26.0	32.7	21.6
Mar - 1982	43.3	30.9	115.8	18.1	23.0	15.5	9.2	20.2
Apr - 1982	12.6	16.0	2.3	7.2	1.0	15.5	16.7	15.1
May - 1982	0.0	3.0	68.2	14.8	2.0	7.0	16.4	10.7
Oct - 1982	10.2	7.6	1.4	0.0	6.0	24.2	16.0	9.2
Nov - 1982	23.6	23.1	30.5	31.0	20.0	27.9	22.1	15.7
Dec - 1982	18.6	14.1	31.6	14.0	2.5	26.4	10.6	12.0
Jan - 1983	118.6	81.7	203.2	35.0	26.3	46.6	18.4	50.7
Feb - 1983	59.6	97.5	181.3	36.0	84.4	69.1	39.2	62.1
Mar - 1983	46.1	84.5	142.0	37.0	71.0	33.9	24.1	40.3
Apr - 1983	3.1	1.0	3.5	0.0	0.0	7.7	0.9	0.6
May - 1983	1.2	0.0	0.0	18.5	0.0	16.6	13.5	3.1
Oct - 1983	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov - 1983	23.8	0.0	37.0	0.0	0.0	14.0	13.9	0.0
Dec - 1983	3.7	0.0	2.7	0.0	0.0	5.2	1.4	0.0
Jan - 1984	62.0	30.0	119.6	26.0	0.0	21.7	30.3	26.6
Feb - 1984	25.8	24.0	59.5	17.5	0.0	7.7	9.0	6.3
Mar - 1984	78.5	85.5	14.0	58.2	30.9	49.4	49.2	53.4

Monthly Rainfall (mm)(Cont.)								
Month	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
Apr - 1984	6.4	7.6	0.0	0.0	8.3	0.0	1.0	0.0
May - 1984	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1984	15.5	7.0	15.0	32.2	16.8	10.0	8.5	3.3
Nov - 1984	15.1	15.3	22.9	7.8	4.7	18.0	32.2	9.5
Dec - 1984	30.5	19.7	65.7	14.5	41.1	21.0	19.5	0.0
Jan - 1985	25.3	40.0	12.2	5.2	32.3	12.8	11.5	0.0
Feb - 1985	148.4	114.6	88.5	44.8	43.9	37.3	55.2	26.7
Mar - 1985	42.3	13.1	27.7	31.3	0.0	20.0	31.5	0.0
Apr - 1985	2.4	6.6	12.2	1.0	3.5	1.0	2.3	0.0
May - 1985	0.0	6.0	1.1	0.0	1.5	0.0	1.0	0.0
Oct - 1985	0.0	5.5	1.2	2.0	5.8	0.0	0.0	3.0
Nov - 1985	5.1	4.2	7.0	2.1	7.0	2.8	0.6	0.0
Dec - 1985	27.3	13.8	35.3	11.4	18.9	27.3	18.7	34.1
Jan - 1986	0.0	19.5	34.6	12.0	31.3	7.6	4.1	2.0
Feb - 1986	62.6	70.0	83.8	20.5	46.5	25.9	23.5	32.0
Mar - 1986	6.2	4.0	11.5	2.2	8.0	0.0	0.0	2.8
Apr - 1986	0.0	7.3	3.4	6.3	6.9	0.0	0.0	4.8
May - 1986	7.8	8.0	10.1	3.9	24.5	0.0	0.0	6.0
Oct - 1986	38.8	7.0	35.0	6.5	11.5	7.0	5.4	26.4
Nov - 1986	102.3	94.5	157.6	75.9	93.5	14.3	14.4	74.8
Dec - 1986	20.9	25.0	59.6	10.2	33.5	13.1	6.8	8.5
Jan - 1987	46.4	61.8	57.6	24.4	44.2	27.0	11.4	27.4
Feb - 1987	16.4	23.0	20.3	9.0	20.8	16.0	6.9	11.2
Mar - 1987	39.4	31.6	50.1	43.4	29.9	35.6	32.2	24.4
Apr - 1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May - 1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1987	33.2	11.0	26.9	22.5	21.6	10.5	5.2	32.6
Nov - 1987	4.0	5.0	5.0	5.7	5.5	1.2	7.5	2.0
Dec - 1987	69.2	62.1	123.1	40.7	77.1	41.3	29.9	34.3
Jan - 1988	50.1	63.6	76.1	49.9	41.7	78.6	27.2	36.0
Feb - 1988	126.3	48.5	201.3	80.1	64.5	20.0	52.5	26.7
Mar - 1988	63.4	37.7	88.2	43.9	5.5	36.7	39.5	35.6
Apr - 1988	13.1	7.5	13.5	12.0	2.0	11.6	14.5	6.2
May - 1988	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1988	8.0	13.3	6.4	0.5	5.0	0.0	2.9	6.0
Nov - 1988	14.6	7.7	24.5	10.8	16.6	3.5	12.8	5.3
Dec - 1988	123.6	119.0	134.6	25.2	38.0	24.5	22.8	78.1
Jan - 1989	43.7	32.5	55.8	29.8	30.8	23.5	22.4	32.9
Feb - 1989	22.0	12.5	28.1	5.9	19.0	7.0	10.1	12.1
Mar - 1989	31.8	15.0	64.5	10.0	19.0	21.3	16.0	15.4
Apr - 1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May - 1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1989	0.0	0.0	0.5	0.0	0.0	0.0	3.9	0.0
Nov - 1989	0.0	15.3	17.2	19.1	33.0	24.5	8.3	11.8
Dec - 1989	13.9	13.3	18.8	13.9	26.9	19.0	22.5	22.3
Jan - 1990	0.0	70.6	115.0	24.5	83.2	49.5	31.1	29.8
Feb - 1990	55.2	16.9	1.9	22.0	30.5	34.3	25.6	20.4
Mar - 1990	65.9	19.0	77.6	17.9	39.0	21.5	19.5	34.8
Apr - 1990	21.2	5.5	34.0	13.0	16.5	22.0	7.0	11.2
May - 1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Monthly Rainfall (mm)(Cont.)								
Month	**Amman Airport**	**Balama**	**Hussein College**	**Khaldiya**	**Madwar**	**Sabha & Subhiya**	**Um El Jimal**	**Zarqa**
Oct - 1990	1.8	0.0	5.0	5.0	2.0	1.5	2.5	0.0
Nov - 1990	3.7	5.5	8.5	1.5	9.4	14.2	6.0	5.4
Dec - 1990	2.5	0.0	2.5	0.0	0.0	0.0	2.8	0.3
Jan - 1991	90.9	24.3	121.8	42.1	55.3	29.9	51.5	43.2
Feb - 1991	47.2	18.9	105.8	22.7	45.2	49.1	12.4	17.1
Mar - 1991	43.5	35.7	103.4	23.5	32.7	48.6	37.3	18.3
Apr - 1991	6.2	3.0	4.6	0.0	18.0	0.0	0.0	3.6
May - 1991	2.1	0.0	3.4	0.0	0.0	0.0	2.2	0.2
Oct - 1991	4.7	2.6	16.4	4.1	1.0	14.6	2.7	1.1
Nov - 1991	35.0	5.0	57.5	12.8	11.2	9.0	11.8	14.0
Dec - 1991	46.7	33.5	69.5	25.2	38.0	17.5	68.6	71.8
Jan - 1992	112.1	11.8	102.5	49.6	81.5	43.2	36.1	40.9
Feb - 1992	59.6	65.8	88.5	85.0	90.0	42.5	63.1	26.7
Mar - 1992	15.7	7.0	28.6	4.5	10.0	5.0	8.6	13.6
Apr - 1992	0.0	0.0	3.5	0.0	0.0	0.0	0.0	1.3
May - 1992	6.0	0.0	3.5	0.0	0.0	0.0	0.5	0.7
Oct - 1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov - 1992	39.6	8.5	73.5	24.9	7.5	10.0	9.5	26.8
Dec - 1992	71.5	27.9	119.2	26.6	32.0	33.5	22.7	25.6
Jan - 1993	67.5	86.0	120.7	22.8	26.8	25.0	24.7	18.2
Feb - 1993	49.5	12.5	79.7	15.0	10.5	10.5	17.4	14.7
Mar - 1993	17.1	0.1	26.6	11.8	2.2	4.0	14.6	9.0
Apr - 1993	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May - 1993	11.6	3.0	13.4	7.3	7.0	4.0	4.0	3.6
Oct - 1993	0.0	1.0	12.0	2.0	0.0	2.0	2.4	13.5
Nov - 1993	22.1	4.1	32.6	0.4	0.0	6.0	3.0	6.2
Dec - 1993	16.8	4.0	20.0	2.5	7.7	6.0	2.4	9.0
Jan - 1994	74.3	74.5	147.4	41.2	56.5	38.5	32.7	50.2
Feb - 1994	17.6	19.0	44.5	9.3	31.0	12.5	15.1	7.3
Mar - 1994	29.0	26.0	66.8	10.0	26.5	20.5	16.6	21.5
Apr - 1994	0.7	0.0	1.3	0.0	0.0	1.0	0.0	0.0
May - 1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1994	12.6	0.5	8.9	8.9	9.0	2.3	2.0	10.6
Nov - 1994	97.3	58.5	129.7	72.5	88.5	54.0	63.2	69.1
Dec - 1994	99.5	62.6	146.0	47.2	52.0	35.0	29.2	50.4
Jan - 1995	1.7	0.2	5.0	1.2	4.0	0.0	0.0	1.6
Feb - 1995	36.2	41.5	55.5	26.2	46.0	28.0	39.6	10.8
Mar - 1995	27.3	19.5	39.6	12.7	11.5	12.5	7.0	3.3
Apr - 1995	4.2	4.0	8.0	1.3	5.5	1.5	0.0	0.5
May - 1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov - 1995	1.8	14.0	31.0	11.9	16.5	4.0	9.7	3.5
Dec - 1995	0.0	5.5	18.5	10.2	8.5	7.2	14.7	11.0
Jan - 1996	81.3	54.0	141.9	59.8	58.8	29.0	46.5	48.4
Feb - 1996	18.4	3.5	17.0	0.2	4.5	3.0	6.2	6.0
Mar - 1996	66.9	82.5	113.3	43.2	53.7	38.0	40.1	24.7
Apr - 1996	9.8	3.0	10.5	4.0	3.5	0.0	1.4	2.5
May - 1996	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1996	0.7	3.9	7.7	3.1	5.6	5.9	6.5	1.5
Nov - 1996	32.1	38.5	12.5	17.1	6.9	18.2	16.0	26.5

Monthly Rainfall (mm)(Cont.)

Month	Amman Airport	Balama	Hussein College	Khaldiya	Madwar	Sabha & Subhiya	Um El Jimal	Zarqa
Dec - 1996	28.2	22.5	35.8	18.0	18.5	23.0	16.1	15.5
Jan - 1997	66.1	75.9	104.0	67.9	58.5	21.8	53.5	38.0
Feb - 1997	82.4	74.4	140.0	28.6	85.5	37.8	20.0	18.1
Mar - 1997	54.8	49.5	86.0	16.5	47.4	18.3	17.6	22.3
Apr - 1997	3.6	1.5	2.0	0.5	2.0	0.5	1.6	0.0
May - 1997	0.8	0.0	0.5	0.0	0.0	4.0	2.3	2.0
Oct - 1997	16.5	5.0	8.0	16.2	6.0	13.6	5.5	15.0
Nov - 1997	10.7	8.5	17.0	8.5	10.0	23.1	21.7	17.8
Dec - 1997	59.4	61.0	90.5	30.7	57.2	22.2	22.5	30.5
Jan - 1998	60.8	103.2	58.0	52.5	47.6	19.5	18.2	36.3
Feb - 1998	34.0	15.5	51.3	10.0	30.0	8.5	11.0	17.2
Mar - 1998	75.0	40.1	165.7	54.1	63.8	24.8	29.3	25.8
Apr - 1998	1.9	3.0	0.0	1.5	3.8	0.0	0.0	1.3
May - 1998	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1998	0.4	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Nov - 1998	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec - 1998	3.6	0.0	2.8	0.0	0.0	3.4	1.5	1.5
Jan - 1999	29.2	28.5	54.0	16.9	44.5	18.7	20.2	12.0
Feb - 1999	57.7	47.0	89.0	22.0	51.5	16.7	25.2	29.0
Mar - 1999	11.7	0.0	25.9	4.7	0.0	3.9	7.4	4.0
Apr - 1999	3.9	6.5	4.0	4.0	2.5	1.0	3.5	1.5
May - 1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov - 1999	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec - 1999	3.3	7.0	8.5	1.1	8.0	3.5	5.4	1.5
Jan - 2000	117.4	48.1	185.3	69.3	114.2	57.5	56.8	28.2
Feb - 2000	20.8	18.0	46.5	6.1	13.5	6.5	8.5	18.7
Mar - 2000	30.1	30.5	56.2	21.1	19.0	8.0	11.0	21.6
Apr - 2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May - 2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 2000	10.9	18.0	24.5	8.0	14.0	5.0	15.0	12.5
Nov - 2000	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec - 2000	51.8	80.0	125.1	55.8	64.0	38.5	34.5	35.1
Jan - 2001	40.7	42.0	66.6	19.3	42.5	32.4	22.0	19.7
Feb - 2001	37.0	42.6	62.2	13.4	35.7	15.5	36.7	17.5
Mar - 2001	9.6	5.6	16.0	5.7	4.8	4.0	10.0	4.7
Apr - 2001	11.0	7.5	3.5	4.1	4.5	20.0	11.2	4.5
May - 2001	13.3	4.0	14.0	1.5	2.0	0.0	0.0	6.6
Oct - 2001	1.2	0.0	2.5	0.3	4.0	0.0	0.0	3.5
Nov - 2001	20.6	19.5	22.1	19.5	32.1	17.5	13.5	17.6
Dec - 2001	56.7	32.0	133.9	23.1	59.0	23.5	29.0	29.0
Jan - 2002	109.8	98.5	199.9	49.0	77.9	70.0	67.0	57.7
Feb - 2002	29.3	15.0	44.1	10.5	16.3	10.5	16.0	20.0
Mar - 2002	38.4	40.0	72.7	20.2	28.6	28.5	24.0	24.5
Apr - 2002	21.2	5.0	39.8	7.7	15.6	9.5	11.0	4.2
May - 2002	0.5	0.8	3.0	0.7	0.6	0.5	0.0	0.5
Oct - 2002	3.0	1.0	7.2	2.0	0.3	1.5	0.0	1.0
Nov - 2002	16.3	25.0	17.5	19.1	14.1	18.3	21.8	19.0
Dec - 2002	93.9	61.5	166.1	42.9	112.0	51.3	48.2	55.5
Jan - 2003	33.6	28.5	44.7	17.9	21.2	21.4	21.6	22.0

Monthly Rainfall (mm)(Cont.)								
Month	**Amman Airport**	**Balama**	**Hussein College**	**Khaldiya**	**Madwar**	**Sabha & Subhiya**	**Um El Jimal**	**Zarqa**
Feb - 2003	59.6	92.8	225.6	66.8	94.8	68.5	58.0	44.5
Mar - 2003	62.0	69.0	122.4	26.4	42.6	35.3	34.0	10.0
Apr - 2003	5.3	4.0	9.2	0.0	2.9	2.8	2.8	10.5
May - 2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct - 2003	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.7
Nov - 2003	6.5	4.5	12.0	29.0	10.3	6.5	13.0	8.0
Dec - 2003	72.2	54.5	95.1	34.1	61.6	72.6	43.4	54.3
Jan - 2004	59.5	35.5	117.0	23.3	60.4	34.0	14.0	27.8
Feb - 2004	32.6	63.0	72.0	41.1	43.9	18.0	15.0	30.0
Mar - 2004	1.8	3.0	11.0	4.0	6.1	5.9	1.5	1.6
Apr - 2004	8.0	4.8	6.0	4.1	6.1	2.1	3.0	1.2
May - 2004	2.3	0.0	2.0	4.1	0.0	0.0	3.0	0.0
Oct - 2004	1.4	5.4	2.5	0.0	2.6	0.0	0.0	0.3
Nov - 2004	64.7	47.9	99.5	36.2	34.2	42.7	27.2	37.8
Dec - 2004	16.7	23.5	24.0	9.7	14.3	19.5	10.5	12.0
Jan - 2005	65.0	72.9	101.0	22.3	45.0	35.7	24.0	26.5
Feb - 2005	83.4	113.9	118.2	31.2	82.5	39.2	39.0	32.0
Mar - 2005	25.2	24.5	29.0	8.3	10.5	8.5	6.2	9.8
Apr - 2005	2.7	8.6	1.2	6.5	3.1	11.6	4.9	3.6
May - 2005	3.6	8.8	3.0	3.6	5.6	5.8	3.0	3.0
Oct - 2005	0.7	1.0	1.0	0.0	2.6	4.2	2.0	0.0
Nov - 2005	5.9	14.4	13.1	5.5	14.7	9.4	10.5	10.2
Dec - 2005	41.2	20.1	82.5	23.3	32.3	22.6	16.1	17.5
Jan - 2006	24.9	35.5	47.6	20.8	89.5	11.3	19.5	15.3
Feb - 2006	52.5	56.2	82.3	36.8	87.0	25.8	23.5	21.7
Mar - 2006	8.1	6.8	16.0	1.2	15.0	0.0	0.5	3.1
Apr - 2006	55.4	26.4	92.3	14.6	42.5	28.7	13.2	28.8

Water Year Rainfall (mm)								
Water Year	**Amman Airport**	**Balama**	**Hussein College**	**Khaldiya**	**Madwar**	**Sabha & Subhiya**	**Um El Jimal**	**Zarqa**
69/70	176.1	224.2	294.8	131.4	136.9	159.8	90.7	113.7
70/71	293.9	364.3	543.4	124.2	196.2	164.5	143.2	107
71/72	311.6	245.5	430.6	121	198.5	268.8	211.3	148
72/73	195.1	158.5	291.9	67.4	61.8	55.7	102.7	96.1
73/74	447.9	301.2	675.3	135.2	276.4	155.2	200.4	238.9
74/75	240.3	169.3	399.9	170.2	223.4	197.5	132.2	93.6
75/76	195	187.9	315.1	107.8	199.8	131.6	100.2	114.6
76/77	190.4	155.3	350.2	100	200.9	115.6	76	94.3
77/78	248.6	157.9	418.5	122.6	122.4	109.6	83.4	89.1
78/79	134.2	125.1	232.5	70	201.2	79	70.7	74.8
79/80	504	377.2	671.1	308	401.2	222.7	216.1	211.4
80/81	301.1	203.2	413.4	165.6	200.9	155.5	118.5	154.7
81/82	194.9	160.4	462.5	125.8	123	93.7	118.7	119.5
82/83	422	309.5	593.5	171.5	210.2	252.3	144.8	193.7
83/84	200.2	147.1	232.8	101.7	139.8	98	104.8	86.3
84/85	279.5	222.3	439.4	136.8	232.5	120.1	161.7	104.3
85/86	109	132.3	186.9	60.4	148.9	63.6	46.9	84.7
86/87	264.2	242.9	380.2	169.4	233.4	185	148.2	172.7
87/88	359.3	324	534.1	254.8	217.9	199.9	219.7	250.1
88/89	243.7	200	313.9	157.6	210.6	150.8	138	149.8
89/90	156.2	140.6	265	110.4	229.1	170.8	117.9	130.3
90/91	197.9	87.4	355	94.8	162.6	228.2	114.7	88.1
91/92	539.9	239.5	390	245.4	331.7	131.8	191.4	258.2
92/93	256.8	138	433.1	108.4	86	87	92.9	97.9
93/94	160.5	128.6	324.6	65.4	121.7	86.5	72.2	107.7
94/95	278.8	186.8	392.7	170	216.5	133.3	141	146.3
95/96	178.2	162.5	332.2	129.3	145.5	81.2	118.6	96.1
96/97	268.7	266.2	388.5	151.7	224.4	129.4	133.5	123.9
97/98	258.6	326.7	390.5	173.5	298.5	111.7	108.2	143.9
98/99	107.2	82	176.2	47.6	98.5	43.8	57.7	48
99/00	172.1	213.5	296.5	97.6	154.7	75.5	81.7	122.6
00/01	176.5	199.7	311.9	107.8	167.5	115.4	129.4	100.6
01/02	277.7	210.8	518	131	234	160	160.5	157
02/03	377.9	281.8	592.7	175.1	287.8	199.1	186.4	162.5
03/04	183.2	165.3	315.1	139.7	188.4	139.2	92.9	123.6
04/05	262.7	305.5	378.4	117.8	197.6	162.9	114.8	125

Runoff Events (mm) at New Jerash Bridge

Index	Runoff	Index	Runoff	Index	Runoff	Index	Runoff	Index	Runoff	Index	Runoff
1	0.482	51	0.083	101	0.256	151	3.577	201	0.066	251	0.488
2	0.096	52	0.446	102	1.251	152	0.016	202	0.012	252	1.009
3	0.010	53	0.054	103	3.785	153	0.050	203	0.087	253	0.089
4	0.025	54	0.486	104	4.983	154	0.215	204	0.087	254	0.256
5	0.353	55	0.350	105	0.104	155	0.234	205	2.220	255	0.542
6	0.753	56	0.877	106	0.237	156	0.658	206	1.316	256	0.067
7	0.006	57	0.014	107	0.013	157	0.671	207	0.037	257	0.887
8	0.159	58	0.069	108	0.106	158	0.021	208	0.031	258	0.060
9	0.357	59	1.070	109	0.356	159	0.022	209	0.574	259	0.210
10	0.058	60	0.142	110	0.283	160	0.982	210	0.294	260	0.288
11	0.336	61	0.465	111	0.712	161	0.146	211	0.059	261	0.046
12	6.910	62	0.456	112	0.518	162	0.108	212	1.634	262	0.499
13	1.254	63	0.174	113	2.186	163	1.507	213	0.026	263	0.113
14	0.125	64	0.042	114	0.846	164	0.388	214	0.359	264	0.102
15	0.130	65	0.101	115	0.846	165	0.017	215	0.127	265	0.040
16	0.360	66	1.414	116	1.855	166	0.019	216	0.537	266	0.891
17	0.470	67	2.498	117	1.756	167	0.341	217	0.972	267	1.656
18	0.715	68	1.230	118	2.824	168	1.496	218	0.724	268	0.615
19	0.264	69	4.742	119	0.884	169	0.113	219	1.216	269	0.460
20	0.722	70	1.425	120	0.071	170	0.145	220	0.741	270	0.966
21	0.064	71	2.844	121	0.167	171	2.354	221	0.611	271	0.798
22	0.060	72	1.854	122	0.110	172	2.378	222	0.746	272	0.010
23	0.419	73	2.201	123	0.729	173	4.125	223	0.122	273	3.227
24	0.343	74	0.370	124	0.158	174	1.405	224	0.572	274	0.410
25	0.084	75	1.004	125	0.558	175	0.415	225	0.034	275	0.013
26	0.103	76	0.056	126	0.369	176	4.373	226	0.179	276	0.021
27	0.178	77	0.956	127	5.623	177	0.084	227	1.634		
28	6.252	78	4.680	128	0.475	178	0.237	228	0.998		
29	1.787	79	0.168	129	0.078	179	0.102	229	0.130		
30	0.115	80	0.028	130	1.143	180	0.385	230	0.073		
31	0.070	81	2.470	131	0.009	181	0.070	231	0.178		
32	0.061	82	5.359	132	0.013	182	0.288	232	4.188		
33	0.047	83	0.200	133	0.078	183	5.998	233	0.056		
34	0.601	84	0.645	134	4.711	184	4.470	234	0.026		
35	1.296	85	0.217	135	0.011	185	0.370	235	2.533		
36	0.199	86	0.398	136	0.026	186	0.312	236	2.322		
37	0.364	87	0.258	137	0.060	187	0.461	237	0.979		
38	0.059	88	1.088	138	0.076	188	1.660	238	0.430		
39	1.622	89	0.020	139	0.216	189	0.127	239	0.577		
40	0.043	90	0.048	140	0.531	190	0.076	240	0.698		
41	0.089	91	0.048	141	1.145	191	1.856	241	0.354		
42	0.063	92	0.020	142	0.025	192	0.416	242	4.816		
43	0.073	93	0.153	143	0.176	193	0.053	243	0.032		
44	2.561	94	4.550	144	4.589	194	1.119	244	0.023		
45	0.147	95	3.007	145	0.713	195	0.438	245	0.981		
46	0.032	96	0.132	146	0.048	196	1.414	246	0.092		
47	0.004	97	0.173	147	0.070	197	3.486	247	0.320		
48	0.117	98	0.095	148	0.018	198	0.035	248	0.730		
49	0.144	99	0.162	149	0.048	199	2.712	249	2.192		
50	0.165	100	0.203	150	0.200	200	1.168	250	0.039		

Monthly Runoff (mm) at New Jerash Bridge

Year/Month	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
1970	0.579	0.035	1.105	0.000	0.000	0.000	0.000	0.006
1971	0.574	0.000	0.336	6.910	0.000	0.000	0.000	1.378
1972	0.130	0.360	0.470	0.715	0.000	0.000	0.264	0.000
1973	0.728	0.118	0.419	0.000	0.000	0.000	0.428	0.103
1974	1.696	6.504	1.398	0.000	0.000	0.000	0.070	0.061
1975	0.000	2.144	0.423	1.622	0.000	0.043	0.043	0.000
1976	0.089	0.136	2.708	0.000	0.000	0.000	0.032	0.004
1977	0.117	0.173	0.165	0.083	0.000	0.446	0.054	0.836
1978	0.877	0.084	1.212	0.000	0.000	0.000	0.000	0.465
1979	0.647	0.042	0.129	0.000	0.000	3.911	0.466	1.588
1980	3.576	1.078	4.782	0.028	0.000	0.000	0.000	7.829
1981	0.200	0.863	0.398	0.258	0.000	0.000	0.000	0.000
1982	0.000	1.107	0.269	4.550	3.007	0.132	0.268	0.000
1983	1.873	3.785	5.087	0.000	0.237	0.000	0.013	0.000
1984	0.463	0.283	1.230	0.000	0.000	0.491	1.695	1.692
1985	0.000	6.360	0.959	0.000	0.000	0.000	0.000	0.071
1986	0.167	0.996	0.000	0.558	0.000	0.369	6.102	0.217
1987	1.036	0.022	0.078	0.023	0.000	4.722	0.000	0.378
1988	1.701	1.194	3.742	0.070	0.000	0.018	0.000	3.824
1989	0.281	0.234	0.658	0.000	0.000	0.000	0.000	0.000
1990	0.714	1.128	1.615	0.388	0.000	0.017	0.000	0.000
1991	0.993	0.976	2.499	0.000	0.000	0.000	0.000	1.588
1992	5.946	1.194	1.618	0.000	0.000	0.000	2.378	5.945
1993	3.403	0.969	0.000	0.000	0.000	0.000	0.084	0.000
1994	0.340	0.385	0.358	0.000	0.000	0.000	0.466	8.492
1995	0.000	0.682	0.000	0.000	0.000	0.000	0.000	0.000
1996	2.247	0.076	2.272	0.000	0.000	0.000	1.171	0.438
1997	4.934	2.712	1.168	0.000	0.000	0.078	0.087	2.307
1998	1.930	0.321	1.719	0.000	0.000	0.000	0.000	0.000
1999	0.486	1.509	0.000	0.000	0.000	0.000	0.000	0.000
2000	2.681	0.611	0.868	0.000	0.000	0.606	0.000	1.813
2001	0.998	0.130	0.073	0.000	0.178	0.000	0.000	4.244
2002	4.882	0.979	0.996	0.708	0.000	0.000	0.000	5.202
2003	1.003	2.814	2.056	0.000	0.000	0.000	0.000	0.954
2004	1.158	0.947	0.102	0.040	0.000	0.000	3.162	0.460
2005	1.696	3.237	0.410	0.013	0.021			

Water Year Runoff (mm) and Calendar Year Baseflow (MCM) at New Jerash Bridge			
Water Year	Runoff	Year	Baseflow
69/70	1.7	1970	42.2
70/71	7.8	1971	23.3
71/72	3.1	1972	22.2
72/73	1.5	1973	18.1
73/74	24.7	1974	39.7
74/75	4.3	1975	21.2
75/76	3.0	1976	21.7
76/77	0.6	1977	18.3
77/78	3.5	1978	15.6
78/79	1.3	1979	14.9
79/80	8.2	1980	45.5
80/81	9.5	1981	34.2
81/82	8.9	1982	33.3
82/83	11.4	1983	57.5
83/84	2.0	1984	35.7
84/85	11.2	1985	36.2
85/86	1.8	1986	36.5
86/87	7.8	1987	35.7
87/88	20.1	1988	61.5
88/89	5.0	1989	50.4
89/90	3.8	1990	45.1
90/91	4.5	1991	47.7
91/92	26.1	1992	111.5
92/93	12.7	1993	94.3
93/94	1.2	1994	73.2
94/95	18.7	1995	70.4
95/96	4.6	1996	65.5
96/97	10.4	1997	65.2
97/98	6.4	1998	60.6
98/99	2.0	1999	65.4
99/00	4.2	2000	57.1
00/01	3.8	2001	53.6
01/02	11.8	2002	59.8
02/03	11.1	2003	71.7
03/04	3.2	2004	71.5
04/05	32.9		

Mean Maximum Temperature (ºC) at Amman Airport												
Year/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1923	12.7	12.7	17.5	20.8	28.1	32.4	31.0	30.6	33.1	26.2	22.1	15.6
1924	12.0	13.3	18.0	23.3	26.0	30.5	32.0	31.9	30.8	25.2	19.2	13.6
1925	9.7	13.8	21.8	20.7	28.3	29.3	32.1	32.7	32.4	27.2	20.8	16.2
1926	11.7	12.9	15.4	23.5	28.4	31.8	30.5	30.2	28.8	27.4	20.4	15.1
1927	13.0	9.8	19.2	20.8	30.0	30.7	32.4	32.1	31.7	29.1	21.3	15.2
1928	13.2	12.1	16.9	26.6	30.0	31.7	33.2	33.7	31.4	27.1	21.1	14.9
1929	12.1	11.9	16.3	22.9	30.2	30.7	30.8	33.3	31.8	26.1	22.3	13.1
1930	11.7	13.6	19.6	23.5	27.8	30.9	31.7	34.6	31.6	27.5	21.0	16.7
1931	13.3	13.9	18.9	22.6	28.1	30.1	32.5	32.7	32.5	28.8	19.3	13.2
1932	11.1	14.4	19.5	23.1	27.4	32.3	32.6	34.1	31.5	29.8	20.9	13.3
1933	11.6	15.7	17.4	19.5	26.9	30.7	30.4	31.6	29.1	25.4	24.8	15.4
1934	11.0	11.8	20.6	24.3	27.7	31.4	32.1	32.5	30.2	27.7	22.6	13.9
1935	13.4	13.8	19.9	22.7	31.5	33.3	32.2	34.3	31.0	27.9	18.5	16.1
1936	14.7	15.3	19.5	23.9	26.8	29.2	31.7	33.4	28.9	30.4	22.6	11.6
1937	9.7	15.5	21.9	24.7	26.9	30.3	31.4	31.8	32.6	27.8	21.4	17.5
1938	12.4	12.1	13.7	23.5	26.0	30.4	33.2	33.8	30.4	27.9	18.3	15.4
1939	13.7	12.7	15.3	23.3	31.7	29.9	31.6	30.9	30.9	29.1	18.6	15.6
1940	12.1	14.8	16.7	22.6	27.5	31.3	31.9	31.2	30.2	27.6	19.6	14.9
1941	15.1	18.2	16.1	23.1	33.7	30.8	31.8	32.3	29.3	25.2	22.3	12.0
1942	10.8	14.7	17.3	23.9	28.8	32.9	31.2	31.8	29.0	25.2	20.1	14.2
1943	11.2	11.2	13.2	18.4	25.9	29.6	31.1	32.4	31.5	28.7	23.8	17.3
1944	11.4	14.6	19.7	23.9	25.0	31.4	30.7	31.1	31.7	27.8	17.8	13.2
1945	11.3	10.6	13.3	19.7	29.2	29.7	33.2	33.6	31.2	25.0	20.8	14.0
1946	11.9	11.9	15.6	22.6	24.2	29.6	31.8	31.5	31.1	26.3	24.3	15.6
1947	12.8	16.6	20.8	24.4	28.7	30.3	32.2	32.5	29.4	26.7	20.6	16.6
1948	14.2	12.8	12.4	20.1	26.7	29.5	32.9	32.3	30.3	26.5	20.1	12.1
1949	10.4	9.7	14.2	17.1	27.9	31.3	31.1	31.3	28.0	27.2	23.7	13.9
1950	9.5	11.4	16.8	26.2	26.1	29.7	31.2	32.0	30.5	26.1	22.4	17.5
1951	14.4	14.9	20.3	23.7	28.6	30.1	32.5	33.1	31.1	25.5	20.8	11.1
1952	13.2	14.3	15.8	22.3	27.5	30.3	30.9	33.2	34.6	29.2	19.9	17.3
1953	13.4	14.7	12.8	21.8	27.7	30.4	33.1	32.1	30.5	27.9	17.2	11.1
1954	11.8	13.8	20.1	20.3	29.7	31.2	33.9	34.3	30.1	28.3	20.4	14.0
1955	15.4	18.2	18.8	23.1	27.6	33.3	31.9	31.6	30.8	29.8	19.4	14.0
1956	13.3	15.7	14.7	21.6	26.1	31.6	33.1	35.2	30.4	26.5	21.2	13.5
1957	11.0	13.7	16.4	21.6	26.6	30.4	33.1	35.2	31.3	28.7	20.4	14.6
1958	12.9	16.0	20.7	26.0	27.5	30.4	32.2	34.0	30.0	26.4	20.8	17.9
1959	14.3	8.8	16.0	24.6	28.6	31.6	30.3	31.5	28.8	25.9	20.9	16.1
1960	14.6	17.9	18.4	23.1	31.0	30.7	32.8	33.5	31.5	29.7	21.2	17.9
1961	12.3	12.0	15.9	23.9	28.8	32.4	32.9	33.3	28.7	27.5	19.6	14.2
1962	13.5	13.3	21.3	22.0	28.9	33.2	33.2	34.2	33.5	29.3	25.3	16.1
1963	17.2	16.9	16.9	23.7	26.0	32.5	32.6	34.4	32.9	29.8	22.5	14.2
1964	9.9	13.2	18.8	21.6	26.4	30.8	32.5	32.6	30.7	29.9	20.8	14.7
1965	11.8	15.1	20.3	21.3	27.9	33.7	33.3	34.9	32.6	25.3	20.6	15.7
1966	15.4	16.6	19.3	25.3	28.9	33.7	33.6	35.1	31.0	27.7	23.7	15.2
1967	11.9	12.6	14.6	21.7	26.9	30.5	32.0	31.3	28.9	25.8	18.0	14.3
1968	10.3	13.5	16	23	28.1	30.4	33.6	31.1	29.3	25.2	20.2	14
1969	10.4	15.4	18.7	19.7	27.8	31.5	30.4	32.5	31.7	26.4	20.3	16.2
1970	14.2	16.2	18.7	24.9	27.6	30.3	30.7	31.1	29.2	25.3	20.5	12.5
1971	15.2	13.8	18.2	18.7	27.6	29.2	30.5	30.9	31.4	25.7	18.9	11.2
1972	11.5	12	16.4	23.6	25.9	29.3	30.1	31.6	31.2	28.6	19.6	12.1

Mean Maximum Temperature (ºC) at Amman Airport (Cont.)												
Year/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1973	12.2	17	16.9	21.9	27.4	29.5	32.3	32.3	31	28.5	16.8	14.3
1974	8.9	13.1	17.7	21.4	27.1	30.9	31.7	30.8	29.2	28.9	20.9	12.9
1975	12.4	12.6	17.8	24.6	26.3	29.5	31.7	30.6	29.7	26	20.1	12.6
1976	12.4	11.8	16.7	21.2	27	30.2	30.2	29.9	29.4	27.5	21.4	16.5
1977	11.3	18.5	17	20.8	28	30.5	32.5	34	29.9	23.7	20.8	12.6
1978	13.1	15.9	18	23	29.7	30.5	34.5	30.6	29.4	28.6	17.6	14.7
1979	13.7	17	18.7	24.8	26.6	31.1	31.3	31.9	31.7	26.8	21.5	11.5
1980	10.3	11.5	16.2	21.5	28.7	31.5	32.1	31.5	28.9	26.2	21.2	14.2
1981	10.8	12.2	17.6	21.8	25.5	30.1	31.6	31.8	31.8	28.3	17.3	16.4
1982	13.4	11.2	14.5	23.8	24.8	29.6	29.9	30.8	29.5	25.4	15.7	12
1983	8.7	10.6	15.2	20	26.2	29.7	30.9	30.6	29.7	24.6	21.1	15.4
1984	12.7	16.1	17.6	20.6	28.2	29.5	30.9	29.4	31.3	27	18.4	12.4
1985	15	11.8	17.8	21.6	27.6	30.4	31.1	35	30.5	24	22	14.5
1986	13.2	15.3	19	24.8	24	29.6	32.1	32	32.2	25.8	15.6	12.6
1987	13.6	16.3	13.8	21.2	28.7	30.4	32.9	32.9	30.9	24	21	13.4
1988	11.6	12.7	15.5	22.6	29	30.6	33	31.7	31	24.6	17.3	13.7
1989	9.6	12.8	16.9	27.4	28.6	29.9	31.9	31.8	30.3	25.3	20.1	14.7
1990	10.5	11.6	16.5	21.6	26.9	30.3	31.2	31.3	29.7	27.4	22.5	17.2
1991	12.0	13.8	18.5	24.1	26.5	30.6	30.4	30.5	30.4	26.7	21.0	10.5
1992	8.1	8.1	14.0	21.1	25.7	29.5	30.6	32.3	29.5	28.7	18.8	10.6
1993	11.3	11.2	16.6	23.2	25.6	31.4	31.7	33.1	30.8	28	18.6	17.3
1994	13.8	13.4	17.2	26	29.1	30.3	30.5	32.4	32.1	28.7	16.6	10.9
1995	13.5	14.3	18	22	29	31.9	31.2	32.3	31	26.1	18.1	14.1
1996	12.7	15.5	15.6	21.8	30.1	31	33.6	33.1	31.1	24.9	20.2	16
1997	13.9	11.4	13.8	20.4	29.1	30.6	31.8	29.7	29.5	27.2	20.4	14.9
1998	11.6	14.2	15.4	24.3	28.3	31.3	33.4	35.2	31.6	28.3	23.9	16.3
1999	14.6	15.6	18.6	23.5	30	29.9	32.1	33.7	30.7	26.8	21.2	17.1
2000	11.3	13.3	16.3	24.6	27.5	31.7	36.3	32.5	30.3	24.7	20.3	14.4
2001	14.3	13.9	22.6	24.6	27.7	32.0	33.1	32.9	30.2	26.5	19.3	14.4
2002	10.7	16.5	19.3	20.8	26.4	30.5	33.3	31.9	31.1	28.8	20.5	13.4
2003	14.1	11.3	14.0	22.2	30.5	30.7	31.9	33.3	29.6	27.5	20.9	13.2
2004	12.4	14.7	20.3	23.3	27.3	30.3	33.4	31.4	31.9	28.4	19.4	13.0
2005	13.2	12.9	18.5	23.4	26.9	30.3	32.6	32.8	30.1	25.9	19.2	17.8
2006	13.0	15.7	19.1	22.4	28.6	31.9	31.5	33.6	31.6	25.8	18.7	13.6

Mean Minimum Temperature (ºC) at Amman Airport												
Year/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1923	3.9	4.6	5.8	7.3	14.0	16.2	17.8	16.9	17.3	13.9	10.2	7.3
1924	4.6	5.6	7.6	9.5	12.5	17.2	18.5	18.6	16.8	13.5	9.6	4.8
1925	1.2	2.6	8.9	8.2	13.1	15.8	17.8	18.8	17.2	14.6	10.9	7.2
1926	5.1	4.9	6.3	9.4	13.5	16.4	17.1	16.1	14.1	13.3	8.6	6.1
1927	3.8	2.7	6.6	8.6	13.6	16.6	18.9	18.0	16.6	15.2	10.3	4.2
1928	4.1	4.6	4.5	11.1	14.8	16.2	19.3	19.6	16.4	12.6	8.8	5.4
1929	3.0	3.8	4.9	8.6	14.6	16.0	17.4	19.3	17.6	12.4	10.6	5.0
1930	2.8	4.6	6.3	9.8	12.1	16.1	18.0	19.5	16.5	13.4	9.3	6.9
1931	4.6	4.1	6.8	9.3	12.3	15.8	18.6	18.6	17.6	14.6	8.6	3.6
1932	3.3	4.1	6.3	9.2	12.4	17.4	18.4	18.6	16.1	15.4	9.1	2.6
1933	3.7	5.4	6.1	7.2	12.6	16.3	16.3	17.3	15.1	12.1	11.1	5.3
1934	2.9	2.0	6.1	9.8	13.6	16.9	17.9	18.2	16.2	14.0	9.9	5.4
1935	4.6	5.3	7.6	8.6	15.4	17.8	17.9	18.8	16.8	14.6	8.4	6.1
1936	4.8	5.9	7.6	10.7	13.4	15.4	18.6	20.1	15.2	16.0	11.8	3.8
1937	2.0	5.2	8.3	11.3	13.6	16.1	18.9	17.9	18.2	15.1	11.3	6.1
1938	5.1	3.8	4.6	10.4	12.6	16.1	19.7	19.2	16.5	13.7	8.6	5.6
1939	3.6	5.0	5.8	9.9	15.8	15.3	19.1	17.7	17.3	15.3	8.8	6.1
1940	4.5	5.3	5.9	10.3	12.8	16.6	19.2	17.5	16.0	14.7	9.1	6.1
1941	5.8	6.6	6.6	10.0	17.4	16.4	18.2	18.2	16.3	11.9	10.6	5.0
1942	3.1	4.8	7.5	11.0	14.6	18.4	18.8	18.1	15.2	14.4	10.1	5.4
1943	3.8	2.9	3.9	6.9	12.1	14.6	18.1	19.2	16.7	16.3	11.4	7.1
1944	3.9	4.6	6.8	10.6	12.6	16.9	18.1	17.5	16.8	14.0	10.2	6.2
1945	3.8	2.9	3.0	7.2	15.6	15.7	18.9	19.6	17.0	12.5	9.6	4.8
1946	3.8	3.8	5.7	9.6	13.3	16.5	18.5	18.6	17.7	13.7	11.7	6.7
1947	5.2	5.9	8.7	10.4	15.2	16.5	18.8	19.2	16.0	13.8	10.6	7.6
1948	5.8	5.3	4.4	8.7	13.5	16.2	19.6	19.4	16.3	13.4	9.9	5.2
1949	2.2	2.6	6.1	6.9	14.8	16.0	17.4	17.7	14.6	13.3	10.8	6.8
1950	3.1	2.6	6.5	12.1	13.4	15.7	18.3	18.0	16.8	13.9	10.4	6.8
1951	3.8	5.2	8.1	10.6	14.8	16.1	18.7	18.7	17.6	13.4	9.4	4.4
1952	4.3	5.5	6.4	9.7	13.2	15.8	17.7	20.0	19.5	15.2	8.9	6.4
1953	4.0	5.5	4.6	9.3	13.6	16.4	20.1	18.8	15.9	14.5	7.7	2.9
1954	3.6	5.1	7.6	8.5	14.2	16.7	19.5	20.4	16.3	14.3	12.8	5.8
1955	4.2	6.7	6.3	10.1	14.1	18.2	18.2	16.9	16.6	14.9	9.8	6.5
1956	4.3	5.9	4.9	9.3	11.4	16.4	19.1	20.8	16.4	12.6	11.3	4.2
1957	1.8	4.0	8.4	11.2	11.8	15.7	17.7	19.0	15.9	14.2	8.9	4.0
1958	4.6	3.3	6.1	11.0	11.8	15.4	16.5	17.9	14.7	12.2	7.4	4.9
1959	3.5	-0.1	4.5	9.3	12.8	16.8	16.7	15.6	13.8	11.6	8.2	4.4
1960	3.9	5.0	5.4	9.0	15.0	15.9	17.5	17.8	15.5	13.6	9.6	6.7
1961	2.7	2.7	3.9	7.9	12.6	16.6	17.8	18.4	13.4	11.0	6.9	4.8
1962	4.0	3.1	6.6	7.6	12.6	16.5	17.1	18.6	15.9	14.7	11.0	5.7
1963	5.3	5.8	4.5	9.5	11.2	15.9	18.3	19.1	14.4	15.2	9.6	4.3
1964	0.5	3.2	6.4	7.5	9.8	15.2	16.4	16.3	13.8	11.1	7.9	3.7
1965	3.0	3.0	5.4	7.1	11.2	16.8	17.3	18.2	15.7	11.1	6.8	4.4
1966	3.1	3.8	4.7	9.1	11.8	16.2	17.6	17.9	14.7	12.5	10.0	5.6
1967	1.8	2.0	3.1	7.1	10.7	13.9	17.5	17.6	15.5	13.0	8.1	5.6
1968	2.7	3.5	5.7	10.5	14.6	16.9	19.5	18.0	15.8	14.0	9.6	6.2
1969	3.5	5.3	8.1	8.3	14.4	18.7	17.5	18.3	18.1	13.7	7.3	4.8
1970	4.0	4.2	7.2	10.3	12.2	15.5	17.7	17.9	15.6	11.1	8.4	2.9
1971	4.5	4.0	5.5	7.2	12.9	15.4	17.0	18.0	16.4	11.2	7.7	3.7
1972	1.8	1.8	5.5	10.1	11.6	15.6	16.7	17.6	15.8	13.4	7.4	0.6

Mean Minimum Temperature (ºC) at Amman Airport (Cont.)												
Year/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1973	1.0	4.7	5.4	8.2	13.1	15.0	18.6	17.6	15.6	13.4	6.0	3.7
1974	1.9	3.2	6.7	8.4	10.7	16.3	18.4	17.3	15.0	13.6	8.5	3.0
1975	2.0	3.0	4.7	9.8	11.6	15.8	17.7	17.2	15.6	10.5	7.7	3.1
1976	2.2	2.1	4.6	8.3	13.0	15.4	16.9	16.8	15.9	14.2	8.9	5.3
1977	2.6	6.4	5.9	8.6	13.6	16.4	18.9	18.7	15.7	11.6	8.1	4.7
1978	3.4	4.8	6.3	8.1	14.5	16.1	19.8	15.7	15.6	14.0	5.7	5.5
1979	3.7	5.4	7.0	10.6	13.3	17.2	17.6	17.6	17.3	14.0	10.5	4.2
1980	2.5	4.0	5.7	8.7	13.5	17.9	19.5	18.9	15.3	14.2	10.0	5.5
1981	3.3	4.4	7.7	10.0	12.8	17.5	19.3	19.3	18.1	15.0	7.5	5.9
1982	4.3	3.6	5.5	11.7	12.8	17.2	18.1	18.7	17.0	14.0	6.6	3.9
1983	1.9	3.4	5.5	9.1	13.7	16.9	18.5	18.1	16.9	12.9	10.5	5.6
1984	4.7	5.1	7.8	9.3	15.1	17.1	18.8	17.7	17.3	14.9	9.4	3.3
1985	5.8	3.6	6.1	9.6	14.7	16.7	18.6	21.1	17.4	12.7	10.8	5.8
1986	4.0	5.7	7.9	12.5	12.0	17.4	19.0	19.1	19.4	14.5	7.6	4.2
1987	4.3	6.1	4.4	8.6	13.9	16.9	20.1	19.9	17.7	13.3	8.8	7.1
1988	4.7	4.8	6.6	10.3	15.1	17.8	20.5	19.7	17.8	13.7	7.1	5.7
1989	1.5	3.0	6.5	13.1	14.8	16.3	18.8	19.1	16.8	13.8	10.1	5.1
1990	3.3	4.0	5.9	9.8	13.7	17.0	19.6	18.8	16.5	15.0	11.3	6.9
1991	3.8	4.7	8.7	11.8	7.0	17.9	18.6	18.5	17.6	15.1	10.0	3.9
1992	1.4	2.0	4.6	8.7	13.4	17.4	18.0	19.6	17.0	15.1	9.1	3.9
1993	2.0	2.6	6.0	10.3	13.5	18.2	19.3	20.5	17.5	15.9	8.8	7.2
1994	5.9	4.9	6.9	12.5	15.9	17.3	19.6	20.0	19.6	16.9	9.2	3.1
1995	4.5	5.2	7.0	8.9	15.6	19.0	19.3	19.3	18.6	13.9	7.7	4.7
1996	4.9	6.1	6.8	9.1	16.7	17.7	21.7	20.4	18.3	13.7	10.4	7.2
1997	4.9	2.1	5.0	8.2	15.9	17.8	19.9	18.3	16.8	15.0	10.2	6.3
1998	4.5	5.3	5.6	11.5	15.2	18.4	20.8	21.8	19.5	15.0	11.9	7.2
1999	5.2	5.3	7.8	11.1	16.9	18.2	20.7	21.3	18.2	15.5	10.4	6.2
2000	3.6	4.0	6.0	12.2	14.4	18.9	23.6	20.4	18.7	14.0	9.4	6.6
2001	5.0	5.5	10.7	11.9	15.0	18.9	21.4	20.7	18.2	15.5	9.1	6.6
2002	3.3	5.9	8.8	10.0	13.7	17.2	21.7	20.4	18.2	16.7	10.0	6.3
2003	5.8	4.6	5.7	10.7	17.6	19.1	20.5	21.0	17.6	15.3	10.5	5.6
2004	4.7	5.1	8.9	10.6	13.8	18.1	21.2	19.4	18.0	16.2	9.9	3.5
2005	4.6	4.6	7.5	11.5	14.1	17.7	21.3	20.9	18.6	14.0	8.7	7.2
2006	4.3	5.7	7.5	11.2	15.3	19.2	20.2	21.6	18.7	15.1	8.1	3.8

Mean Maximum Temperature (ºC) at Wadi Dhuleil												
Year/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1968	11.9	15.2	18.4	25.5	30.3	32.8	36.1	33.9	32.2	27.9	21.7	16
1969	11.7	17.5	21	23.2	29.8	34.3	33.2	35.3	34	28.1	21.2	17.5
1970	15	17.6	20.8	27.3	30.2	33	33.2	34	31.8	26.8	22.5	13.4
1971	15.6	15.5	20	20.9	30.2	31.6	32.8	33	33.8	27.3	20.4	12.4
1972	12.2	13.1	18.3	25.6	28.1	31.7	32.6	34.3	33.4	30.3	20.8	13.4
1973	13.4	18.4	19.3	23.7	29.5	32	34.8	34.8	33.4	30.1	18.2	15.3
1974	10.4	14.2	19.5	23.7	29.7	33.8	34.9	33.6	31.8	30.8	22.4	14.1
1975	13.7	14.1	19.8	26.8	28.8	32.3	34.5	33.3	32.2	27.8	21.2	13.7
1976	14	13.3	18.4	23.4	29.2	33	33	33	32	29.2	22.4	17.8
1977	12.7	20.4	19.2	23.4	30.6	33.2	35.5	36.7	32.7	25.7	22.3	14
1978	14.6	17.7	20.5	25.7	32.1	32.9	36.9	33.6	32	30.3	18.8	16.1
1979	15.1	18.5	20.8	26.6	29.4	33.8	34.3	34.9	34.2	28.8	22.8	13.1
1980	11.8	13.7	18.3	24.6	31.5	35	35.2	34.7	32.1	28.9	23	15.5
1981	13	14.6	20.5	24.8	28.5	33	35	35.2	34.6	30.4	19.1	17.8
1982	14.8	12.9	17.2	26.3	27.8	32.6	32.8	34.1	32.5	27.6	17.2	13.2
1983	10.4	12.6	17.6	23.2	29.3	33	34.8	33.9	32.6	26.7	23	16.6
1984	14.8	18.1	19.8	23.7	31.1	32.7	33.8	32.7	34.1	28.9	20	14
1985	16.2	13.7	19.4	24.7	30.5	33.4	34.4	38	33.2	26.5	23.6	15.9
1986	14.7	17.1	21.4	27	26.7	32.8	35.6	35.6	35.3	28.3	17.2	14.6
1987	15.2	18.6	15.7	24.1	31.5	33.7	36.1	36.1	33.9	26.2	22.2	15.3
1988	13.3	14.7	17.6	24.9	31.6	33.5	36.6	35.3	34.2	27.3	19.2	14.7
1989	10.4	14.7	19.5	30.4	31.8	33.4	35.5	35.6	33.5	27.9	21.5	16
1990	12.2	13.9	18.8	24.8	29.9	33.9	35.3	35	33	29.1	23.9	18.4
1991	13.2	15.3	20.8	26.7	29.8	34.2	33.8	33.6	32.9	28.7	22.8	12
1992	9.8	10.3	16.1	23.9	28.9	32.8	34.1	35.7	32.3	31	20.5	11.9
1993	12.5	13.4	19.4	26.4	28.5	34.6	35.5	36.2	34.2	30.2	20.5	18.7
1994	15.3	15.5	20	28.4	32.1	33.9	33.9	36	35.2	30.5	18.4	12.3
1995	15.2	15.9	20.5	25.1	31.9	35.2	34.7	35.9	34.2	28.6	20	15.2
1996	14	17.5	18.2	24.3	33.2	34.7	37.3	37	33.9	27.2	21.8	17.9
1997	15.1	13.4	16.2	23.2	32.3	34.1	35.4	33.2	32.4	28.9	21.7	16.2
1998	13.2	16	17.6	26.6	30.9	34.7	36.7	38.5	34.3	30.3	25.8	18.1
1999	16.2	17.6	21	26.2	32.6	33.2	35.4	37	33.4	29.3	22.9	18.3
2000	13	15.4	18.5	27.1	30.4	35	39.5	35.9	32.8	26.2	21.8	15.9
2001	15.9	16.1	24.7	26.6	30.3	34.6	36.1	35.8	32.9	28.5	20.7	15.9
2002	12	17.8	21.6	23.7	29	33.1	35.9	34.6	33.6	30.4	21.7	14.8
2003	15.6	13	16.1	25.1	32.8	33.5	34.9	36.5	32.3	29.3	22.1	14.6
2004	13.8	15.9	22.7	25.5	29.8	33.2	36.4	34.4	34.3	30.2	21.2	14.2
2005	14.6	14.6	21.3	25.8	29.6	33	36.1	35.9	32.9	27.7	20.7	19
2006	14.5	16.6	21.4	24.8	31.3	35.1	34.5	36.7	33.9	27.8	20.2	14.6

Mean Minimum Temperature (ºC) at Wadi Dhuleil												
Year/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1968	1.6	3.7	4.4	9.2	13.7	15.5	17.8	16.2	14.1	11.4	7.6	4.5
1969	2.4	3.8	9.1	8.6	13.8	16.5	15.8	16.3	16.1	13.1	6	3.2
1970	3.3	3.7	6.5	10	11.5	14.2	15.6	16.1	15	9.8	7.6	0.8
1971	3.1	3.4	5	7.8	12.9	14.7	16.1	16.4	15.9	9.7	6.5	3
1972	0.7	1	4.9	10.3	11.6	14.4	15.7	16.3	15.2	12.5	6.5	-0.7
1973	-0.2	3.6	4.7	7.7	11.4	13.4	16.7	16.8	15	11.4	4.3	2.4
1974	1.6	3.4	6.8	8.3	10.7	14.8	16.4	16.1	13.2	11.7	6.8	1.2
1975	0.5	2.5	4	9.9	11	14.7	16.5	16.3	14.8	9	6	1.9
1976	0.8	2.7	4.7	8.5	13	14.6	15.8	15.6	14	11.9	6.2	3.6
1977	1.5	5	5.4	8.2	12.8	15	17.1	17.4	15.3	10.2	5.3	3.3
1978	2.5	3.5	5.8	8.3	16.1	14.8	18.4	15.1	14.5	12	3.3	3.8
1979	2.2	4.6	6.4	10	12.2	15.3	16.8	16.5	16.6	12.8	9.4	3.7
1980	1.4	3.8	5.3	8.4	12.1	14.4	17.4	16.8	13.9	11.1	7.2	4.4
1981	1.9	3.8	6.5	8.8	11.5	15	17.6	17.2	16.5	12.2	4.7	3.2
1982	2.6	2.9	4.1	10.4	12.4	14.2	16.2	16.9	15.4	11.7	4.8	1.5
1983	1.2	2.2	4.4	8.2	12.3	15.1	16.6	16.5	15.1	10	7.3	3.2
1984	2.1	2.7	6.6	8.2	12.4	14	16.3	15.3	14.7	11.6	7.7	0.7
1985	3.6	2.4	4.3	7.9	13.2	14.7	15.7	19.4	15.1	9.9	7.8	2.6
1986	1.9	3.5	6.3	10.8	10.4	15.5	16.7	17.3	17.3	13	5.9	1.9
1987	2.1	4	3.6	7.1	11.5	14.1	17.6	18	15.5	11.2	6.3	5.7
1988	3.7	4	8	9.1	13.4	15.4	18.2	17.9	15.3	11.8	4.4	3.6
1989	0	0.7	5	10	12.7	14.3	16.9	17.2	15.1	11.1	7.2	2.4
1990	1.7	2.7	5	8.2	11.6	15	16.7	16.7	15.3	12.2	8.4	4.5
1991	2.2	3	7.5	10.1	12.3	15	16.7	17.1	15.4	13.1	7.2	2.8
1992	0.5	1.9	3.2	7.1	11.7	14.3	16	17.7	14.8	11.3	6.6	2.7
1993	0.1	0.9	4	8.1	12	15.6	17	17.5	15.1	13.6	6.1	4.8
1994	4.7	3.4	5.8	10.4	13.5	15.3	16.9	17.3	18.1	15.6	8.5	2.3
1995	2.3	3.4	5.3	7.6	13.2	16.6	17.5	17.9	16.4	11.6	4.3	2.4
1996	3.5	4.6	5.8	8.1	14.7	15.3	19.5	18.1	16.1	10.8	8.2	4.9
1997	2.7	0.4	3.6	7.4	14	15.8	17.7	16.6	15.3	12.9	8.2	4.9
1998	3.2	3.5	4.9	10.1	14	15.9	18.5	19.6	17.3	11.7	8.8	4.2
1999	2.3	3.4	5.7	8.7	14.1	15.7	18.1	18.9	16	12.6	6	1.8
2000	1.6	1.8	4.2	10.3	11.8	15.7	20.4	18.7	16	11.6	6.2	4.4
2001	1.9	3	8.3	10	13	16	18.2	18.7	16.5	12.3	5.7	4.4
2002	1.8	3.3	6.7	9.4	12.1	15.7	19.3	18.3	16	14.6	6.9	4.8
2003	3.3	3.8	4.6	9	15.5	16.1	17.6	18.7	15.5	12.8	8	4.2
2004	2.9	3.3	6.7	9.1	12.5	15.7	18.2	17	15.8	13.7	8.2	0.7
2005	2.7	3.5	5.8	9.7	12.1	15.6	18.5	18.9	15.8	10.9	5.1	4
2006	3.1	4.5	5.4	9.8	13.1	16.4	17.4	18.6	16.5	12.3	4	-0.9

Mean Relative Humidity (%) at Amman Airport												
Year/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1966	72.0	73.0	64.0	48.0	40.0	36.0	46.0	48.0	58.0	58.0	56.0	74.0
1967	76.0	71.0	72.0	61.0	55.0	40.0	40.0	40.0	55.0	57.0	67.0	72.0
1968	74.0	66.0	60.0	49.0	44.0	44.0	36.0	45.0	54.0	58.0	61.0	71.0
1969	77.0	65.0	61.0	57.0	43.0	37.0	47.0	43.0	47.0	57.0	58.0	63.0
1970	70.0	65.0	56.0	43.0	36.0	37.0	43.0	41.0	53.0	48.0	59.0	69.0
1971	62.0	64.0	56.0	70.0	46.0	45.0	47.0	47.0	52.0	52.0	64.0	75.0
1972	73.0	64.0	67.0	57.0	48.0	48.0	53.0	46.0	48.0	50.0	66.0	62.0
1973	64.0	63.0	62.0	57.0	44.0	43.0	42.0	49.0	51.0	49.0	62.0	77.0
1974	84.0	75.0	73.0	61.0	46.0	42.0	40.0	52.0	51.0	47.0	64.0	73.0
1975	73.0	74.0	59.0	48.0	47.0	44.0	44.0	55.0	57.0	58.0	62.0	72.0
1976	74.0	75.0	63.0	56.0	52.0	44.0	53.0	54.0	50.0	52.0	51.0	67.0
1977	73.0	57.0	67.0	61.0	43.0	43.0	46.0	43.0	57.0	55.0	49.0	74.0
1978	68.0	62.0	66.0	56.0	34.0	41.0	38.0	52.0	57.0	47.0	54.0	77.0
1979	76.0	67.0	62.0	44.0	46.0	47.0	55.0	53.0	59.0	62.0	60.0	83.0
1980	77.0	80.0	71.0	64.0	42.0	44.0	47.0	51.0	56.0	50.0	59.0	74.0
1981	70.0	76.0	63.0	52.0	45.0	44.0	46.0	47.0	45.0	48.0	63.0	64.0
1982	70.0	72.0	70.0	52.0	57.0	49.0	60.0	57.0	63.0	64.0	76.0	83.0
1983	85.0	82.0	73.0	63.0	53.0	46.0	50.0	54.0	57.0	55.0	63.0	69.0
1984	76.0	59.0	67.0	61.0	39.0	43.0	46.0	54.0	46.0	48.0	75.0	73.0
1985	70.0	78.0	60.0	57.0	48.0	44.0	44.0	54.0	56.0	65.0	66.0	74.0
1986	78.0	77.0	66.0	50.0	57.0	50.0	46.0	53.0	55.0	66.0	78.0	79.0
1987	76.0	72.0	75.0	55.0	38.0	38.0	42.0	48.0	53.0	62.0	56.0	77.0
1988	82.0	73.0	74.0	50.0	35.0	41.0	44.0	45.0	46.0	63.0	58.0	74.0
1989	77.0	59.0	63.0	35.0	38.0	44.0	48.0	50.0	57.0	59.0	70.0	74.0
1990	73.0	76.0	59.0	48.0	43.0	41.0	43.0	58.0	73.0	65.0	62.0	75.0
1991	87.0	83.0	82.0	63.0	61.0	59.0	67.0	74.0	70.0	71.0	76.0	91.0
1992	83.0	88.0	70.0	62.0	53.0	46.0	57.0	60.0	64.0	48.0	67.0	81.0
1993	74.0	75.0	63.0	44.0	44.0	38.0	44.0	37.0	45.0	48.0	63.0	69.0
1994	76.0	69.0	68.0	37.0	38.0	41.0	45.0	45.0	51.0	51.0	79.0	81.0
1995	75.0	76.0	60.0	48.0	36.0	42.0	57.0	60.0	51.0	61.0	57.0	82.0
1996	85.0	74.0	81.0	62.0	43.0	50.0	51.0	53.0	55.0	61.0	70.0	78.0
1997	79.0	75.0	77.0	63.0	46.0	52.0	54.0	65.0	60.0	60.0	69.0	77.0
1998	79.0	70.8	68.6	53.8	46.7	47.1	42.5	44.0	54.8	52.1	57.1	61.8
1999	67.0	65.5	51.6	44.2	37.4	50.8	47.5	49.8	52.8	56.7	52.0	54.2
2000	73.0	70.0	66.0	49.0	41.0	38.0	33.0	56.0	61.0	70.0	62.0	85.0
2001	76.6	79.7	56.9	51.9	49.6	43.7	47.9	60.3	69.1	64.9	70.0	77.0
2002	80.3	64.9	62.7	65.3	56.1	56.3	50.9	57.1	54.9	57.2	65.7	84.9
2003	74.5	80.1	77.2	57.2	31.7	38.7	46.3	46.9	52.0	54.7	62.9	79.6
2004	80.3	75.7	63.2	48.4	41.3	42.6	33.6	45.4	46.1	47.6	63.3	67.3
2005	68.0	73.0	59.3	46.0	42.8	39.4	38.6	44.7	47.1	50.4	57.0	54.8
2006	67.8	61.5	54.2	55.5	39.4	35.1	42.7	40.7	48.5	65.1	53.2	56.9

Mean Relative Humidity (%) at Wadi Dhuleil												
Year/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1977	78	64	70	58	42	43	47	43	58	54	49	76
1978	72	59	57	48	36	43	45	59	59	49	59	81
1979	79	73	62	49	51	48	53	54	58	61	62	84
1980	85	81	74	61	43	43	54	56	59	55	64	81
1981	79	83	72	57	50	52	55	60	57	57	69	71
1982	78	77	73	60	61	54	60	63	64	66	75	80
1983	84	83	75	58	53	51	55	56	61	56	65	71
1984	74	62	67	56	43	52	48	55	51	51	76	76
1985	69	73	56	55	47	47	45	54	54	57	61	71
1986	73	74	61	51	56	49	50	56	54	60	77	76
1987	71	67	71	52	40	42	47	49	52	65	59	82
1988	83	74	72	54	38	43	47	53	49	61	60	76
1989	83	65	64	38	40	43	46	49	53	55	63	71
1990	76	81	71	61	52	45	56	60	65	61	60	68
1991	82	77	75	59	59	55	62	67	64	66	71	87
1992	85	88	76	65	58	54	61	62	63	55	66	87
1993	83	80	68	58	58	52	56	55	61	59	67	74
1994	82	73	69	46	45	49	47	53	58	60	82	86
1995	79	78	69	58	51	49	56	57	55	60	58	78
1996	83	68	74	55	43	49	49	51	53	64	72	84
1997	85	80	77	65	50	57	60	68	67	66	80	84
1998	87.1	77.4	71.3	57.7	52	52.2	49.5	52.8	55.6	53.5	56.6	65.7
1999	72	72.5	67.3	71.7	59.5	74.7	74.1	72.2	74.2	77.2	73.3	73.7
2000	91	86	84	71	64	53	54	71	75	76	72	90
2001	84.6	84	64.9	61.9	58.1	54.5	57.4	66.3	71	67.8	75.9	86.5
2002	88.5	68.6	67	70.3	61.1	58.4	58.6	65.2	56.9	57.9	62.1	82.5
2003	78.6	81	79.7	67.6	55.2	70.9	59.8	62.6	70.4	62.4	57.8	77.5
2004	78.8	71	49.8	43.9	43.8	43.8	39.5	57.3	53.3	53.4	69.4	73.9

تحليل السلاسل الزمنية، و التنبؤ، و تتبع التغير المناخي: حوض عمان-الزرقاء حالة دراسية

اعداد
أحمد غالب الحياصات

المشرف
الأستاذ الدكتور عدنان حمودي الصالحي

الملخص

يقدم البحث منهجية للتحليل و عمل النماذج الرياضية و التنبؤ لعدد من المتغيرات الهيدرولوجية و الطقس في حوض عمان-الزرقاء المائي. المتغيرات الرياضية تشمل بيانات للامطار و التدفق و درجة الحرارة و الرطوبة النسبية. هذا بالاضافة الى انه تم تحديد المنخفضات الجوية في حوض عمان-الزرقاء و تم الحصول على كمية الامطار لكل منخفض جوي.

تم تحليل البيانات - كمرحلة ابتدائيه- من حيث البيانات المفقودة و البيانات غير الممثلة للعينة و المنحنى التراكمي للامطار. تحليل السلاسل الزمنية يشمل نماذج Trend و Smoothing و Decomposition و ARIMA. تم الحصول على افضل نموذج من كل نوع و ايجاد قيم هذا النموذج و التنبؤ.

تم تحليل الظواهر الطبيعية و التي لها دلائل غير مباشرة على التغير المناخي، هذه الظواهر تشمل اتجاه Trend و الاحداث غير العادية و التغير في الموسم المطري. لقد اظهرت النتائج وجود نقصان تدريجي ذي اهمية احصائية في كمية امطار المنخفضات الجوية و ازدياد تدريجي ذي اهمية احصائية في درجة الحرارة الصغرى. لم يتوفر دليل لوجود امكانية للاحداث غير العادية او التغير في الموسم المطري، هذا يدل على ان هذه الظواهر اما غير ممكنة او ان البحث لم يتمكن من تتبعها بسبب محدودية البيانات.